

Urbanization of Irrigated Land and Water Transfers

A USCID Water Management Conference

Scottsdale, Arizona
May 28-31, 2008



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The U.S. society for irrigation and drainage professionals

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Preface

The papers included in these Proceedings were presented during the **USCID Conference on Urbanization of Irrigated Land and Water Transfers**, held May 28-31, 2008, in Scottsdale, Arizona. An accompanying book presents abstracts of each paper.

Urbanization is a fact of life for many irrigation districts. Some have been impacted for many years; others are just beginning to face the challenge. As a result, irrigation districts faced with encroaching urbanization are learning to change the way they do business.

The Conference also focused on **water transfers**, an issue related to urbanization, but also an issue affecting water districts seeking to augment their water supplies in the face of increasing competition. The Conference brought together water resource professionals with experience and interest in both **technical and policy issues** regarding urbanization and water transfers.

Papers presented during concurrent technical sessions addressed the following topics: **Policy and Water Transfers; Managing Urbanization; and Infrastructure and Technology**, as well as half-day case study sessions on the **Salt River Project** in the Phoenix area and the **Imperial Irrigation District in southern California**. Papers presented during the opening and closing plenary sessions and a Poster Session are also included in the Proceedings.

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

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

Robert S. Gooch

Salt River Project
Phoenix, Arizona

Conference Chairman

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URBANIZATION — FRIEND OR FOE? NORTHERN WATER’S EXPERIENCE

Don Carlson, P.E.¹

ABSTRACT

The Northern Front Range of Colorado has experienced a significant transformation from an agricultural economy and landscape to an ever-increasing urbanized population.

One challenge we face is the expectation by our municipal and domestic water providers for better water quality. Water treatment facilities are highly regulated and therefore required to meet higher and higher drinking water standards for their customers. Changes in reservoir or delivery system water quality can have significant economic consequences and potential health risks. Farmers and irrigators traditionally have had lower expectations, within reason, and are generally more concerned with the quantity of water available to them each year.

The Colorado-Big Thompson Project was primarily designed to deliver water to farmers on a seasonal basis to support irrigated agriculture. Necessary operation and maintenance activities were scheduled for completion during the off-season. However, municipal and domestic water providers are expected to deliver water 365 days a year, 24 hours each day. Redundancy and reliability are more important than ever before.

Thirdly, farmers have a need to grow the best crop possible each year. Once committed to a crop, fall contracts, bank loans, and tractor payments, it takes a certain amount of rainfall and irrigation water to make it happen. Their city cousins are always looking ahead one or more years. They need to have “water in the bank” because next year could be the first year of the next drought. They will conserve this year to save for next year.

The fourth challenge in our urbanizing region is the permanent transfer of agricultural water to urban uses. Many farmers have relied on their water assets to support investments in their business or to support their retirement years. When a municipality purchases these water rights or water allotment contracts, they are there to stay. While our agricultural heritage may be slowly disappearing, these transfers have presented opportunities.

Our challenge has been to take advantage of these opportunities as we serve our new constituency.

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INTRODUCTION AND BACKGROUND

History of District

The Northern Colorado Water Conservancy District (Northern Water) originally began in 1933 as the “Grand Lake Committee,” a group of Greeley, Colorado farmers and businessmen that were experiencing the 1930’s “Triple D’s” - drought, depression, and debt. They were pursuing an unheard of idea to transport water from the Colorado River, west of the Colorado continental divide to the South Platte River Basin in northeast Colorado. The agricultural economy of the north front range of Colorado had been thriving because of the extensive development of many irrigation reservoirs and ditch companies. By that time, many of these companies had already been operating and supplying irrigation water to farmers for over 50 years.

The Grand Lake Committee took a step to formalize itself by becoming the Northern Colorado Water Users Association, patterned somewhat after other water user associations that were each comprised of several ditch and reservoir companies located within the various river basins tributary to the South Platte River. They approached the U. S. Bureau of Reclamation with their dream of bringing water over from the west slope to supplement their existing supplies and returning to the days of having an adequate water supply that they enjoyed in the 1920’s before the drought years. Reclamation eventually agreed and began their work.

The United States government required there to be a local agency or organization to contract with the federal government to repay the government for a portion of the project costs. The 1937 Colorado Water Conservancy Act provided for the establishment of water conservancy districts and for taxing authority to raise revenue for these repayment contracts and obligations. The Northern Colorado Water Conservancy District was formed by court order in 1937 and the repayment contract with the United States was signed in 1938. These farmers and citizens agreed to tax themselves by a vote ratio of 17 to 1, even during those difficult times.

Project Description

The Colorado-Big Thompson Project was designed to collect 310,000 acre-feet of water from the upper Colorado River Basin on the west slope of the continental divide in Colorado and deliver that water as a supplemental supply to irrigated farmland in Boulder, Larimer, and Weld Counties on the east slope. The return flows from the first use of that water was to be made available to downstream irrigators on the South Platte River from Greeley, Colorado all the way to the Nebraska state line.

The Project has nearly one million acre-feet of storage capacity in 12 reservoirs, approximately 100 miles of canals, tunnels, pipelines, and six hydroelectric plants. Today it supplies supplemental water for 700,000 acres of irrigated farmland, served by 120 ditch and irrigation companies, and for over 750,000 people living in 32 cities and towns north of the Denver metro region.

Design and construction began in 1938 and took nearly 20 years to complete. The Colorado-Big Thompson Project began full operations in 1959. 310,000 acre-foot units of allotment contracts were made available to farmers, irrigation companies, and local communities. Although over 85% of the units were owned by agriculture, 95% of the water was delivered for irrigation purposes during those initial years.

Changes in Ownership

Although farmers and irrigation companies originally owned the vast majority of allotment contracts, some were allotted to several small cities and towns with the District. During the 1960's rural domestic water districts formed to serve higher quality drinking water to rural residents and their water treatment plants were strategically located below two C-BT Project reservoirs. They began purchasing allotment contracts from the farmers whom they served. As the rural areas became more urbanized and as the towns and cities grew, the C-BT contact ownership began to change. In 1997, the ownership reached 50% agriculture and 50% municipal/industrial/domestic. Today it stands at 36% agriculture and 64% municipal/industrial/domestic.

WATER QUALITY CHALLENGES

Beneficial Uses

The water quality regulatory program in Colorado recognizes water supply, aquatic life, recreation, and irrigation as beneficial uses that must be protected. Project reservoirs in the west slope collection system are primarily used for recreation and aquatic life (i.e., fishing) and the east slope reservoirs supply water for drinking water and irrigation. One of the west slope reservoirs, Shadow Mountain Reservoir, has a surface area of 1,300 acres and a mean depth of only 10 feet. Over the years, Shadow Mountain has experienced aquatic weed growth and algae blooms. These problems affect the recreational amenities the lake offers to tourists and residents.

These same nutrient-related problems have affected at least one east slope reservoir in the past and have resulted in taste and odor issues for the local water utility.

Water Quality Monitoring

The District began water quality monitoring activities over 30 years ago and now staffs a department and program team to monitor water quality throughout the entire system.

We are particularly interested in the many NPDES water transfer cases making their way through the court system throughout the country. The C-BT Project is based on transferring water from one basin to another, so we collect water quality information on all reservoirs, canals, and receiving streams throughout our system.

Nutrient Studies

As algae and aquatic weed problems have occurred over the years, everyone seems to be an expert and points a finger at this cause or that one. We initiated a long-term nutrient study to more accurately assess the current situation and then focus in on specific issues and problems. Our O&M staff is experimenting with grass carp and non-toxic chemicals to control algal growth in our canals. Shadow Mountain Reservoir was drained in an attempt to control aquatic weeds by freezing them. We are evaluating multi-level reservoir outlet structures to minimize adverse impacts to water treatment facilities. Our water resource engineers work closely with local governments as they develop watershed protection plans.

DELIVERY CHALLENGES**Seasonal vs. Annual**

The C-BT Project was primarily designed to provide a supplemental water supply to farmers in northeastern Colorado. Therefore, the water delivery season was during crop irrigation months. Scheduling operation and maintenance activities was not a problem.

As our District has become more and more urbanized, seasonal deliveries have become annual deliveries – 365 days a year and 24 hours each day. Scheduling windows of time for maintenance and repairs has become a major challenge, especially as the project facilities age.

Emergency repairs can have immediate effects on municipal water providers, whereas irrigators are usually much more flexible.

Southern Water Supply Pipeline

This concern has come to the forefront during recent years for our Southern Water Supply Project. The District constructed a raw water delivery pipeline system, with pump stations, during the 1990's to deliver water from Carter Lake Reservoir to several growing communities in the southern and eastern regions of our District. The single outlet structure from the reservoir was 50 years old and nearing the end of its useful life. The pipeline and existing canal delivery system serves over 300,000 residents, along with thousand of acres of productive irrigated farmland.

Carter Lake Outlet Project

For these reasons, the District undertook the development of a second redundant outlet structure from the reservoir that would serve the same delivery systems. A \$10 million 110-ft. tall multi-level outlet tower, 800-ft. long tunnel lined with a 6-ft. pipe, 350-ft. long penstock leading to a flow control valve, and provisions for a small hydroelectric plant have been constructed. A strong and productive partnership with the U.S. Bureau of

Reclamation has made this project a success. We can now accommodate maintenance activities and emergencies.

DROUGHT SUPPLY CHALLENGES

Regional Supply and Quota

Since the C-BT Project is a supplemental water supply project, the District has the responsibility to allocate water to all of its users. This allocation is accomplished through a "quota" system. If the lands within district boundaries are low in moisture and need additional water supplies, our Board of Directors could issue a 100% quota. For each acre-foot unit allotment they own, they would receive a full acre-foot of water. In other years when east slope supplies are above average, a 50% quota may be authorized and each acre-foot unit would result in a delivery of one-half an acre-foot of water. The average quota has been 70%.

Weather patterns and water supply conditions can vary over the 1.6 million acres within District boundaries. C-BT water is often leased by one allottee that has more than adequate supplies to another water user within the District. These seasonal transfers add tremendous flexibility and stretch the water supplies every year.

This allocation and seasonal transfer system encourages cooperation among all water users, especially cities and farmers. Cities are always looking ahead to next year to make sure their supplies will be adequate. Farmers, while interested in future years, are far more interested in the year at hand. If their crop does not yield, financial consequences could be severe, and next year does not matter. The District is pursuing a major project that will build on these relationships, while providing a new supply for several growing towns and domestic water providers.

Northern Integrated Supply Project

Several small, but rapidly growing, towns and water districts within our District are searching for additional water supplies to meet their current and future needs. Rather than pursue their own solutions, they have joined together to find a regional answer to their problem. The District formed a Water Activity Enterprise on their behalf and is coordinating the planning, permitting, design, and construction of a new project. This estimated \$400 million project consists of two reservoirs (180,000 and 40,000 acre-feet), two large pump stations, many miles of underground pipelines, and a major highway relocation. It will yield 40,000 acre-feet of new supplies for these participants.

The project is dependent on a water exchange with two major irrigation companies. The project will deliver South Platte River water to them in exchange for their C-BT Project water. That C-BT water can be delivered to project participants anywhere within District boundaries.

This project will insure the annual yield that farmer under these two irrigation companies need. Participant cities and water district benefit by the new supply, but more importantly, a reservoir that will help them with their multi-year water supply planning and storage.

PERMANENT TRANSFER CHALLENGES

Change Allotment Contracts

Although there were only seven communities that obtained approximately 10% of the original allotment contracts for C-BT Project water, today over thirty towns and cities, along with more than a dozen domestic water districts, own contracts. Cities, towns, water districts, and industries own nearly 200,000 acre-foot units of C-BT water. These permanent transfers have taken place during the past 50 years and will likely continue.

The cost per acre-foot unit has risen from \$1.50 to \$10,000, peaking at over \$15,000 a few years ago. These are private party transfers that the District Board of Directors approves. The District has no financial interest in the transfer of units itself; however, when the original \$1.50 contracts are transferred to new owners, they are “open-rated.” That means that the new holders of the contracts will pay to the District an “open-rated” annual assessment. Over the past 50 years, assessment revenue to the District has increased from approximately \$465,000 to over \$5 million in 2007.

Other Revenue

The two other main sources of revenue for our District are a one-mil tax levy and charges for services. Every owner of real property within District boundaries pay a one-mil tax to the District for benefits received from the Project. In 2007 that amounted to a little over \$13 million. The assessed valuation due to urbanization has grown tremendously over the years.

The District’s employees provide professional services to its Municipal Subdistrict that owns and operates the Windy Gap Project. Services are also provided to four different “water activity enterprises” that are the financial organizations for four different pipeline and reservoir projects. These services generate over \$5 million each year for the District.

Revenue Implications

These revenue sources are primarily from our urban constituents. They are pursuing the new projects and are paying the higher annual assessments. They also include the industries, universities, health care facilities, high tech companies, and businesses that have the highest assessed valuations and therefore pay the lion’s share of taxes to the District. Tax revenue to the District has doubled since 1998.

Although less than five percent of the total revenue that supports the District’s \$70 million FY2008 budget comes from agriculture, irrigated agriculture remains a vital part

of the region's economy. The C-BT Project still provides supplemental water for the same 700,000 acres of irrigated farmland as it did 50 years ago. In 2003, the estimated market value of agriculture products produced in the counties that are within the District was \$2 billion.

SUMMARY AND CONCLUSIONS

The Northern Colorado Water Conservancy District has transformed from an agricultural economy in 1937 when the Colorado-Big Thompson Project began, to a very diverse and growing economy and population in 2008. While some fondly remember those days when agriculture was king and the cities and towns were small, the urbanization of northern Colorado has brought greater financial stability. These changes present unique challenges. At the same time, though, these changes will provide the means to allow us to operate and maintain the C-BT Project so generations that follow will always benefit from the Project as we do today.

FROM GROWING CROPS TO GROWING CITIES: SRP'S TRANSITION FROM AG TO URBAN

Shelly C. Dudley¹

ABSTRACT

This presentation will visually show, through the use of historic and contemporary photographs, that reclamation was a cornerstone of growth in the West: providing a stable water supply for crops, transforming the desert to the farmlands, and now farmlands to the development of cities businesses and communities; developing power, to operate the irrigation pumps, light the homes, and now power our industries. SRP, as one of the first multi-purpose reclamation projects authorized by the federal government, provided irrigation water to the settlers of the Salt River Valley at the beginning of the twentieth century. Now, over one hundred years later, SRP continues that tradition and is still delivering water to its shareholders and customers, but now in an urban setting.

INTRODUCTION AND BACKGROUND

Within a year of the passage of the National Reclamation Act in 1902, the Secretary of the Interior authorized the Salt River Project as one of the first federal reclamation projects. Reclamation Service engineers constructed Theodore Roosevelt and Granite Reef Diversion dams, purchased existing irrigation systems, and built additional canals to deliver water to 150,000 acres for the Salt River Project. Within three decades and after the construction of additional dams, power facilities and groundwater pumps, SRP provided irrigation water to approximately 238,000 acres.

Over one hundred years later, the Salt River Valley is the major population center of Arizona, made possible by the water storage and delivery system of the Salt River Project. Phoenix is the seat of Maricopa County, the state capitol of Arizona, and now the 5th largest city in the United States with a population of 3,700,000. SRP is the third largest public power provider in the nation. Salt River Project still provides water to its member lands, but today, less than 24,000 acres are still being farmed. Much of the Project's stored and developed water now passes through municipal water treatment plants and is delivered to residential, commercial and industrial enterprises.

Shortly after Jack Swilling's arrival in the Salt River Valley in the late 1860s, he and other farmers started digging canals, using the prehistoric structures left by the Hohokam as the foundation for their work.² By 1870, there were 700 people living in the Valley and over 7,000 acres irrigated. Pioneers, farmers, miners and entrepreneurs flocked to central Arizona when they heard of the fertile soil and healthy climate. With the construction of the railroad, Arizona citrus could be shipped East prior to the West Coast

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² Jack Swilling was an explorer, prospector, Confederate soldier, entrepreneur, and farmer who constructed the first modern irrigation canal in the Salt River Valley.

harvest, since the fruit ripened before the California orchards (see Image 1). Exotic fruits were grown beyond the staple crops of grain, cotton and alfalfa. At the beginning of the new century, the U.S. Census tallied over 20,000 people within Maricopa County and the acreage farmed within the Valley totaled more than 130,000.



Image 1. Oranges grown in the Arizona sun.

Farmers on both sides of the Salt River expanded the irrigation systems so much that when the rains did not fall, the river stopped flowing and not enough water could be diverted into the various canal headings. Private enterprise could not raise the capital necessary to construct a large storage reservoir up on the Salt River. Early surveyors had already found the ideal location, but money was not available to build a dam. In the midst of a drought in central Arizona, the national irrigation movement was hard at work attempting to get a federal reclamation bill passed through Congress. Benjamin Fowler, chairman of the Maricopa County Water Storage Committee, had been in Washington D.C. at various times since 1900, lobbying for passage of the Reclamation Act. Fowler and reclamation lobbyist George Maxwell aided Francis Newlands in his congressional fight for a reclamation act. At his Washington residence, Maxwell gathered government officials, including Gifford Pinchot and Frederick Newell, to discuss the national irrigation movement and possibly a Salt River Valley reclamation project. Pinchot and Maxwell were good friends with Vice-President Theodore Roosevelt, a strong supporter of the reclamation and conservation movements. Following the ascendancy of Roosevelt to the office of the President, the reclamation measure passed Congress and the Secretary of the Interior was authorized to choose the first projects from a list supplied by Newell.³

NATIONAL RECLAMATION AND SRP

After the passage of the National Reclamation Act on June 17, 1902, the Secretary of Interior authorized the Salt River Project and the construction of Theodore Roosevelt Dam by the U.S. Reclamation Service. The Project allowed for the storage of water on the Salt River to be used when normal flow was not available. Valley landowners

³Smith, "Campaign for Water in Central Arizona," 127-147. Benjamin A. Fowler to E. A. Hitchcock, November 20, 1900. National Archives, Washington, D.C. RG 48, LANDS & R.R. DIV., RECL., S.R.P.

organized the Salt River Valley Water Users' Association (Association) in February 1903, to facilitate the repayment of the construction costs and to later operate and maintain the Project. The Association opened up membership to those who owned land within the boundaries set by the Articles of Incorporation; within five months farmers signed up more than 142,000 acres. By the end of the 1920s, approximately 238,000 acres joined the Project.

The drought that started in 1898 ended in 1905 following a torrential down pour that sent water rushing down the Salt River, delaying construction of Roosevelt Dam and washing out all the small diversion dams in the Valley. Local farmers approached the U.S. Reclamation Service engineers for assistance. The government purchased the northside canals in April 1906, paying over \$300,000 for the Arizona, Grand, Maricopa, Salt River Valley and Crosscut canals. The federal engineers also constructed Granite Reef Diversion Dam (see Image 2) which diverted water to both sides of the river.

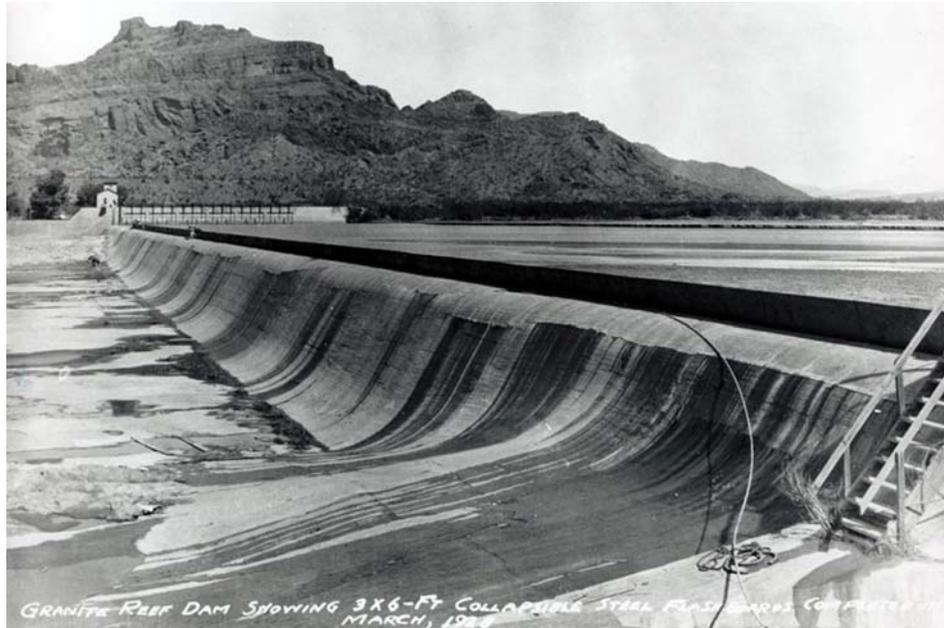


Image 2. Granite Reef Diversion Dam.

Because some lands did not immediately join the Salt River Project, a combination of local farmers and government crews constructed additional canals on the south side of the river. Later, the Reclamation Service embarked on a program to acquire private laterals; by 1915 almost sixty miles of laterals and ditches had been acquired and rebuilt.⁴

Following completion of Roosevelt Dam in 1911 and the settling of financial accounts, the Association assumed operational control of the Salt River Project in 1917, although title to the dams and irrigation works remained with the United States (see Image 3). Shareholders farmed over 181,000 acres of land and with World War I in progress, additional acreage was irrigated to over 205,000 acres by the fall of 1918. With

⁴U.S. Reclamation Service. *Fourteenth Annual Report 1914-1915*. GPO, 1915 p. 50

continuous irrigation, portions of the Valley soon experienced water logging from the rising groundwater table. The Association amended its Articles of Incorporation in 1919 and embarked on a program of constructing over 300 miles of drains and installing pumping plants.⁵



Image 3. Roosevelt Dam spilling.

As the wartime economy grew, so did the population of Maricopa County, rising in 1920 to 90,000 from 34,500 people in 1910. In the second half of 1920, the booming financial conditions came to a dead stop, and prices of agricultural goods plummeted to below pre-war levels. Valley farmers were especially desperate because they had planted cotton in record amounts, not anticipating the market bottoming out at the end of war. Expecting cotton prices of \$1.50 per pound, SRP farmers planted 146,000 acres of cotton in 1920 (see image 4). Enthusiasm was so high that alfalfa lands were plowed up and dairy cattle slaughtered to make more room for cotton. When the price of cotton dropped to 28 cents a pound—half the cost of production—only those farmers who could afford to hold their crop in hopes of better prices survived. It was estimated that the loss on agricultural produce in 1920, amounting to more than \$12 million, was more than the cost of constructing Roosevelt Dam and the Valley canals. It is interesting to note, however, that although the amount of cotton grown in 1921 was less than half cropped the year before, the Valley farmers only decreased the total number of acres irrigated by only 2,000.⁶

⁵SRP *Annual History* 1920-1921, p 62.

⁶Michael Kotlanger, S.J., “An Overview of Economic Development in Phoenix in the 1920s,” in *Phoenix in the Twentieth Century: Essays in Community History*, edited by G. Wesley Johnson, Jr. University of Oklahoma Press, 1993.



Image 4. Cotton picking in the Salt River Valley.

While the depression of the 1930s was more moderate in the Valley than other parts of the nation, farm prices did drop and the Arizona copper industry was at one of its lowest points. For the Salt River Project, this meant shareholders had difficulty paying assessments and power revenues were reduced. Farmers irrigated almost half the acreage in alfalfa, grain or pasturage with a total number of acres being cropped within the Salt River Project reaching 208,546. By the middle of the decade, farmers were irrigating more than 228,000 acres, not including fallow, urban irrigation or water to townsite lands (see Image 5). Prices also had risen on almost all the crops being grown.⁷



Image 5. Irrigating the fields.

Although the farmers were still able to sell their produce, the scarcity of funds limited the amount of maintenance work done on the SRP irrigation system. Following the election of Franklin D. Roosevelt and his programs of finding work for the unemployed, the Civilian Conservation Corps (CCC) came to the Salt River Valley in the fall of 1935.

⁷SRP *Annual History* 1930-1931; SRP *Annual History* 1934-35.

Utilizing the services of this federal agency, the Association had the men construct headgates, line canals, and help repair damages to the irrigation structures throughout the Project. The CCC crews repaired the canals on both sides of the river when floods broke through the irrigation structures. Operation and maintenance of the SRP irrigation system was reaching a critical point in 1938. A large number of ditch structures had been constructed of redwood lumber during the early years of the Project and these features were reaching their end of useful life when CCC crews replaced practically all these structures with concrete (see Image 6). The CCC also worked on modifying the ditch and lateral capacities due to the increase in specialty crops, such as lettuce, concentrated in particular areas. The original lateral system was designed for diversified cropping, which permitted delivery of water through a normal rotation. The special crops often required simultaneous demands for water service within the same contiguous areas.⁸ The CCC work on the Project was discontinued because of the trade union complaints charging the corps members were doing the skilled work of the union laborers. Before its departure, the CCC completed over 700 projects at SRP.



Image 6. CCC work done on SRP lateral in 1938.

By the time Europe was engulfed in war in 1940, the irrigated acreage remained at approximately 214,000 acres, but farmers were double cropping almost that same amount of acres. Previously, acreage that supported at least two crops rose from 10,000 acres in 1920, to 60,000 acres in 1930 and then 177,000 acres in 1935. Once America became involved in World War II, central Arizona felt the impact of the war time production. Military bases opened in the Valley, the Arizona copper mines operated at full capacity and agricultural prices rose. After the war was over, many of the military personnel who were stationed in the Valley returned and the spectacular economic expansion broke all past projections for growth in central Arizona. The population of Maricopa County rose to over 330,000 in 1950, but cultivated acreage remained relatively the same.⁹

⁸SRP, *Annual History*, Irrigation Division, 1938, 2.

⁹SRP *Annual History* 1930-31; 1934-35; 1940.

URBAN LANDSCAPE

Although agricultural land slowly was becoming residential subdivisions and shopping centers, SRP still needed to maintain its irrigations in an evolving urban setting. Because of the lack of workers and materials, minimal improvements were made to the irrigation system in the 1940s. In 1949, the U.S. Congress passed legislation, the Rehabilitation and Betterment Act, which loaned funds to federal reclamation projects to improve both power and water infrastructure. During the first fifty years of the Salt River Project, the design of the irrigation distribution system focused on delivering water with little seepage loss and limited expense; losses of water in unlined dirt ditches were unwanted, but the cost to line them with concrete was prohibitive for the Association. The turnout structures were meant to be functional, not beautiful. That attitude changed after the war. Long time residents frowned at the unsightly turn-out structures which stood above-ground in their neighborhoods, but they realized the necessity for the delivery of subdivision and irrigation water in the area (see Image 7). The newer citizens were unaware of the connection of the water, distribution system and their land.



Image 7. SRP employee cleaning a lateral.

In 1952, the City of Phoenix and the Salt River Project signed a twenty-five year domestic water agreement which allowed the city, as an agent for the landowners, to receive all the water no longer being irrigated from the SRP system, within the city limits for distribution to those lands. Phoenix assumed responsibility for collecting and paying delinquent and future assessments on these lands. As Phoenix grew and the annexed lands within the Association boundaries were transformed into residential subdivisions and businesses, the city gained access to the same amount of water those lands would have received if they had remained farms. Water treatment plants were constructed next to the canals (see Image 8).



Image 8. Val Vista Water Treatment Plant, South Canal.

The domestic water agreement also opened the way for SRP water to be delivered to cities through canals, and the first Phoenix canal water treatment plant opened on the Arizona Canal in 1952. The contract increased the supply available to cities, and it provided the Salt River Project with a way to manage the urbanization of its area by providing water to the new residents who were coming to live on the former farmlands. Furthermore, the contract became a model for other agreements with local municipalities. In time, the cities of Scottsdale, Tempe, Mesa, Chandler, Gilbert, and Peoria all signed similar domestic water contracts.

While SRP had always worked to improve their irrigation structures, it was not until the mid 1960s when they started “dressing up” the exposed portion of a structure to give it a decorative appearance. The Project placed a new emphasis on beauty (community styling); its engineers aided this beautification effort by designing “more picturesque” structures.¹⁰ In 1964 SRP employees started laying flagstones and other types of inlay into the concrete slabs (see Image 9). An average structure used approximately 1.5 tons of stone and SRP termed this “hydro-styled” to make it pleasing to the eye.¹¹

¹⁰“A More Beautiful Valley . . .” *The Current News*, August 1965, 8.

¹¹“Designed for Beauty,” *The Current News*, August 1965, 12-13.



Image 9. Community styling irrigation structure.

These structures had the appearance of blending into the surrounding area. When SRP needed to replace an irrigation turnout, employees installed one of the new community designed structures, attempting to make it “fit into a neighborhood” with its shape and pattern. Plans could call for flagstone, brickwork, redwood veneer or new types of precast designs. As new subdivisions or commercial enterprises took over farm land, SRP worked with the developers and supplied the builders with specifications and plans for the new structures.¹² Road and building construction required most of the laterals and ditches to be relocated and piped (see Image 10).



Image 10. Cast in place pipe being manufactured as open laterals are placed underground.

During the first half of the century, farm and ranch children usually did not have the luxury of going to the city to cool off in the municipal pools during the hot summer months. Instead many just had to cross the field to one the Project's laterals and swim with the neighborhood children. Today, SRP strongly discourages this activity for health and safety reasons.

¹²“A More Beautiful Valley,” *The Current News*, August 1965, 9.

In the mid-1960s, SRP changed its view of the irrigation system as only a means to deliver water. As the urban area increased in proximity to SRP's canals and laterals, the need to provide for recreational and multi-use activities along the canals became more apparent. The Project cooperated with the local Valley Beautiful committee by planting trees and landscaping along the banks of the waterways. With encouragement from local communities, neighborhoods, and cities, SRP and the Bureau of Reclamation signed agreements that would permit the use of canal and lateral rights of way for parks and trails, but swimming was still not allowed (see Image 11). Employees trimmed trees and removed weeds along the banks of the canals, laterals and ditches.



Image 11. Jogging along a SRP canal.

From 1965 to the present, agricultural acreage within SRP has decreased from 145,000 acres to less than 24,000 being cropped (see Chart 1).

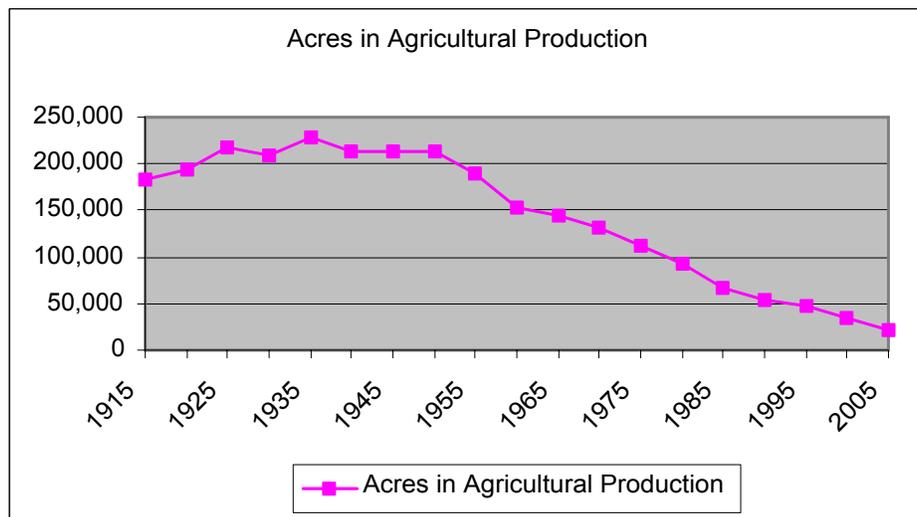


Chart 1

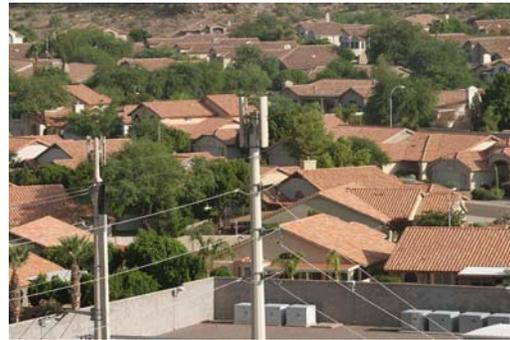
SRP is still delivering water to shareholder land, but instead of having a zanjero open a head gate, the water is diverted at one of the municipal water treatment plants located on

the SRP canal system, including the newest one, on Arizona Canal Lateral 19 for its Glendale Oasis Water Campus. The plant will furnish a new source of potable water with state-of-the-art technology.

SRP continues to deliver water to the residents of the Valley. Over the past one hundred years, SRP provided a stable water supply for crops, transforming the desert to the farmlands, and now farmlands to the development of cities businesses and communities; developing power, to operate the irrigation pumps, light the homes, and now power our industries.



Tempe irrigated fields, 1903



Residential subdivisions, 2005

MANAGING A WATER DELIVERY SYSTEM IN AN URBAN ENVIRONMENT: COMPETITION AND COMPATIBILITY

Steve B. Doncaster¹

ABSTRACT

The purpose of this paper is to illustrate just some of the many legal and institutional challenges faced by a canal operator in coping with the dramatic pace of urbanization of the metropolitan area served by a canal system originally constructed across primarily agricultural terrain. These challenges pale in comparison to the actual day to day challenges faced by those who operate and maintain the canal system “in the field”, which are beyond the scope of the paper. Still, the ones addressed herein have very real and far reaching consequences for many operators of water delivery systems known as federal reclamation projects, throughout the western United States.

INTRODUCTION

Prior to 1902, the United States government assumed that its objective of “settling” the western United States could and would be accomplished through its encouragement of private initiatives, pursuant to “homestead” laws. With the Reclamation Act of 1902 (Act), Congress signaled the federal government’s resolve to “reclaim” arid lands in the west by committing federal funds on a massive scale to construct dams and reservoirs on major rivers to facilitate irrigation of lands by the homesteaders. These became known as “reclamation projects”, and one of the very first of these was the Salt River Reclamation Project in central Arizona. This was not a “free ride” for the private landowners who benefited from the irrigation water, as they were expected to repay the federal government for the cost of constructing the reclamation project facilities. In addition, the Act contemplated the transfer to these same beneficiaries of the responsibility of operating and managing the facilities following repayment. In central Arizona, it was the Salt River Valley Water Users’ Association (SRVWUA) that formally assumed the responsibility to operate and manage the reclamation project through contract with the United States.

More than one hundred (100) years after assuming managerial control of a vast system of water distribution and drainage canals and laterals designed primarily for agricultural irrigation, the SRVWUA, commonly known as the Salt River Project (SRP) today, operates this same system on landscape that would be unrecognizable to those who constructed the system. Though, in many ways, the duties SRP performs in managing the canal system have changed little over the years, the public perception of, and expectations regarding, the canals, has changed dramatically. As well, the political and regulatory picture has become much more complex.

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This paper discusses some of the challenges SRP faces today in its continuing responsibilities for delivering water through a canal system that has been engulfed by urbanization. It begins in the late 19th century, with a discussion of the history of the construction of the canal system. Shortly thereafter, both the United States' government and the Salt River Project entered the picture, contributing to the dramatic transformation of the arid lands of the Territory of Arizona into farmland and later, cities. The paper discusses the nature of the land rights that underlay the canals, and the myriad rules that have been developed to govern the use of these lands by often competing users. Finally, the paper outlines the measures SRP has implemented to accommodate competing uses of the property, while preserving its ability to fulfill the responsibilities it assumed 100 years ago, and has never relinquished.

THE CANALS

Most of the canals SRP manages today were constructed over land in the public domain by private canal companies in the late 19th century. The land remained in the ownership of the United States government, but the canal companies acquired rights to construct the canals through the operation of several federal statutes, like the following:

“The right of way through the public lands and reservations of the United States is hereby granted to any canal ditch company, irrigation or drainage district formed for the purpose of irrigation or drainage, and duly organized under the laws of any state or Territory....” 43 U.S.C.A. Section 946 [so called “1891 Act”].

The precise nature of the land right acquired through the statutes has been debated by state and federal agencies and courts ever since. Much of the debate has focused on Congress' choice of the words “right of way” in the statutes. Federal and state courts have alternately interpreted such words as denoting an easement or a “limited fee” property interest. The concept of a “limited fee” is explained in various court cases [notably, *Kern River Co. v. United States*, 257 U.S. 147 (1921)] as a perpetual right to use the property for the purpose mentioned in the statute, here a canal, limited by an implied condition of reverter in the event the property is no longer used for that stated purpose. Nonetheless, the statutes intended to authorize those with vested rights to water to construct conveyance systems to enable them to put the water to beneficial use for mining, agricultural and other purposes.

Sometime following the construction of the canals, the land on which they were constructed was patented to those settling the lands of the arid west. The patents purported to convey all of the interest of the United States' government to those lands, but usually contained reservations of interest like the following:

“...; subject to any vested and accrued water rights,...and rights to ditches and reservoirs used in connection with such water rights, as may be recognized and acknowledged...; but excepting, nevertheless, and reserving unto the United States, rights of way over, across and through

said lands for canals and ditches constructed, or to be constructed, by its authority, all in a manner prescribed and directed by...Congress....”

Successors in interest to some of these patentees would much later turn out to be “competitors” of SRP over the use and control of canal property, discussed more herein. Disputes over these properties are complicated even further by actions taken by the United States government in pursuit of federal reclamation policy implemented by the Reclamation Act of 1902 [32 Stat. 388, 43 U.S.C. 391] and subsequent acts.

In the late decades of the 19th century, Congress sought to accomplish the reclamation of the west by promoting private efforts at homesteading and irrigating the land. It soon became clear however, that large scale reclamation could only be accomplished with massive water projects comprised of dams and canal systems. The Reclamation Act of 1902 authorized the Secretary of Interior (Secretary) to withdraw and acquire lands for dams, reservoirs and canals in order to facilitate the reclamation of arid lands throughout the western United States. Pursuant to this authority, the United States acquired the canals from the canal companies that constructed them, in order to incorporate them into what would become the Salt River Reclamation Project in 1903. It is at least arguable that, upon conveyance from the canal company to the United States of all of its interest in the canal property, that the United States then and thereafter owned the canal property in fee simple absolute, given the merger of the canal company interest, a “limited fee”, with the reversionary interest held by the United States. Henceforth, no person had any claim of right to the canals absent a grant of such a right by the United States.

Though the United States has retained possessory interest in the canal property to this day, it was authorized to, and did, transfer responsibility for management and operation of the canals, as a part of the entirety of the Salt River Reclamation Project, to a water users’ association, known today as the Salt River Project². From the date of the formation of the Salt River Valley Water Users’ Association (Association) in 1903, until September 6, 1917, the United States Reclamation Service continued to operate the reclamation project. On that date in 1917, the United States executed an agreement with the Association that would “...turn over and vest in the...Association, the care, operation and maintenance of the irrigation works known as the Salt River Project...and all property of whatsoever kind, real, personal or mixed, appurtenant to or constructed or otherwise acquired to be used in connection with the said Salt River Project...”.

Among the responsibilities assumed by the Salt River Project in its contract with the United States is the task of regulating the use of canal property, and protecting and preserving the interest of the United States therein. The paramount use of this property remains the delivery and distribution of water to end users, ranging from farms and orchards to churches, schools and homes for urban irrigation, to shopping malls, restaurants and office buildings via city water treatment plants, for drinking and other

² References in this paper to the “Salt River Project” are to two distinct legal entities, one the Salt River Valley Water Users’ Association, and the other, the Salt River Project Agricultural Improvement and Power District, a political subdivision of the state of Arizona. These two entities are, by contract, in effect jointly responsible for operating and maintaining the Salt River Reclamation Project today.

“domestic” purposes. Increasingly however, the canal property is used for recreation, city beautification efforts, utility corridors and even restaurant patios, with the consent of Salt River Project and the United States; and for vehicular ingress and egress, mail delivery, refuse pick up, dumping and even fencing and other structural improvements, often with the consent of neither Salt River Project nor the United States.

THE 21ST CENTURY RULES OF CANAL USE

Federal Rules

As mentioned above, the United States government remains the owner of the canal property, thus it retains the ultimate authority to govern its use. Contracts between the Salt River Project and the United States delegate to Salt River Project certain limited power to permit uses other than its own; that is, for the delivery and distribution of water. In 1964 for example, Salt River Project and the United States executed an agreement that provides, among other things, that “...the United States hereby consents to the use, [for Public Recreational Activities]...of the [canals], by the public...in accordance with the provisions of a permit to be issued by the [Salt River Project]...”. Pursuant to this agreement, Salt River Project has issued such permits to most major municipalities within the Salt River Reclamation Project to provide for public recreational opportunities on canal property. Importantly, neither the United States nor Salt River Project allows swimming or otherwise entering the water of the canals for recreational purposes. The recreation contemplated by the 1964 agreement and the permits issued pursuant thereto, contemplate uses of canal banks for walking, running, bicycling and horseback riding.

At all times, public access to and use of canal property is governed by federal law, most notably federal regulations promulgated by the United States Bureau of Reclamation “...to maintain law and order and protect persons and property within Reclamation projects and on Reclamation facilities, lands, and waterbodies.” [43 CFR 423.1] Original authority for the Secretary to promulgate such rules of public use is found in the Reclamation Recreation Management Act of 1992, [16 U.S.C. 460l-31 et seq]:

“The Secretary, acting through the Commissioner of Reclamation, shall promulgate such regulations as the Secretary determines to be necessary...to ensure the protection, comfort and well being of the public...with respect to the use of Reclamation lands...” [16 U.S.C. 460l-33. (2) (B)].

These regulations were vastly expanded in April, 2006 pursuant to 43 U.S.C. 373b.(a) (Public Law 107-69), passed in November, 2001, emphasizing the importance of security for reclamation facilities. Among other things, these regulations now provide:

“If a non-Federal entity has assumed responsibility for operating, maintaining or managing Reclamation facilities, lands or waterbodies through a contract or other written agreement, public conduct in and on those Reclamation facilities, lands and waterbodies will be regulated by

this part 423 as well as any regulations established by the entity, the terms of the entity's contract with Reclamation, and applicable Federal, state, and local law." [43 CFR 423.3 (c)].

Here, in one fell swoop, the United States declares that all those who use the canals of the Salt River Reclamation Project are subject simultaneously to these specific regulations, other federal law, the laws of the state, county or city within which the canals are situated and the rules set by the contractual agent of the United States, the Salt River Project. The regulations go on to expressly proscribe specific activities like swimming in canals, being "disorderly", possessing a firearm at Reclamation facilities like dams and power plants or possessing substances governed by the Controlled Substance Act, 21 U.S.C. 812, while on Reclamation facilities or land. Otherwise, these regulations for the most part defer to states, municipalities and entities like Salt River Project to set the rules.

State and Local Rules

Any activity that violates a law of the state, county or municipality within which the canals are situated, may be prosecuted by those jurisdictions as if the activity had occurred anywhere else within the jurisdiction. The federal nature of reclamation property does not affect this otherwise elementary principle of law enforcement, and Salt River Project rarely encounters any issues related to this fundamental exercise of governmental police powers.

The Arizona law regarding criminal trespass can be similarly enforced on the canal property, however, like in most states, a necessary precondition to a violation of this state statute is notice by either the United States or Salt River Project that entry onto the property is prohibited. As discussed further below, neither the United States nor Salt River Project implements such a general prohibition. This decision not to post the canal property "no trespassing" has two interesting side effects, peculiar to Arizona. One is with respect to the regulation of fishing from the canal water. While an owner of private land in Arizona may prohibit hunting, fishing or trapping on their land, state and federal land may not be so posted without express approval from the Arizona Game and Fish Commission. This is primarily because wildlife within the state is considered a state natural resource subject to exclusive state jurisdiction and regulation, unless on private land. A second important consequence of the decision not to generally deny entry to the public derives from a state statute that confers immunity upon Salt River Project from liability for injury to those who so enter; provided that Salt River Project has granted permission expressly or impliedly (not posting to the contrary) for such persons to recreate on the property without paying an admission fee. This immunity is far from ironclad, but it, and other Arizona law, together significantly diminish the exposure Salt River Project would otherwise have with public access to the property.

Salt River Project Rules

As mentioned above, both the United States and Salt River Project consider the canal property to be open for public recreational use, with exceptions. Salt River Project posts

the canals with signs expressly prohibiting “water activities” and use by motor vehicles other than by permit from Salt River Project. Beyond this, the implication is that the public may use the canal property for any other lawful purpose. Still, Salt River Project must ensure that its own operational prerogatives are preserved, that public recreational access is not otherwise impeded and that this United States government property is protected from unlawful encroachments.

One of the ways Salt River Project accomplishes this is through the issuance of licenses for non public recreational, but otherwise compatible, uses of the canal property. For example, municipalities through which the canals traverse, are increasingly viewing the canals as an amenity for their residents. Some are essentially converting them into linear parks, complete with paved multi-use recreational trails, landscaping, benches and lighting. In order to maintain control over these developments, manage the potential effects on Salt River Project operations, shift liability and recover costs, Salt River Project requires the municipality to enter into a “canal multiple use” license agreement. These licenses must meet minimum criteria established by Salt River Project’s governing bodies. Among these are, insurance mandates, indemnification provisions, commitments to preserve public access, obligations to reimburse for incremental costs to operate and maintain the improved canal property, unconditional revocation privilege for both parties and occasionally use fees.

Once licensed, the related improvements to the canal property can be effectively managed by Salt River Project, with little impact to canal operations. Other uses Salt River Project routinely licenses include underground utility and road and bridge crossings. Though all of these uses complicate canal operations, prohibiting them would have a much more substantial adverse effect on urban development. The more troublesome uses of canal property are those that are unlicensed and unauthorized. Some of these are a knowing and blatant disregard of the interests of the United States and Salt River Project. Others, given the somewhat complex nature of the land rights, discussed herein, are unknowing encroachments. In either case, Salt River Project has a contractual obligation to manage the canal system in a way that minimizes these unauthorized uses. Unfortunately, this sometimes involves litigation.

CONCLUSION

In simpler times, the canals could be largely ignored by all those other than the operators thereof. They served a limited, albeit critical, purpose: the distribution of water throughout a mostly undeveloped landscape, for the irrigation of otherwise useless land. Today, the canals still serve this critical function, but can no longer be ignored in the context of urbanization. They are alternately viewed as an amenity or a nuisance, but they cannot be ignored. Salt River Project strives to facilitate an amicable assimilation of the canal system into the fabric of cities, while preserving its fundamental role in providing critical sustenance to city dwellers. It will not likely get much easier in the future.

TRANSFORMATION OF WATER ACCOUNTING FOR IRRIGATION TO DOMESTIC USE

Michael M. Ference¹
Kim K. Hunt²
Sally K. Moore³

ABSTRACT

In 1967, accounting for 87% of the water deliveries to the Salt River Project (SRP) irrigation users was merely a water order tracking process. Water orders, rather than deliveries, were monitored and limited to account entitlements. Accounting for types of water to member land within the Federal Reclamation Project included *no-charge* spill water, *normal flow*, *stored* and *developed* water, and *pump right*.

Population growth and urbanization of the Salt River Valley created a need for SRP and 10 valley cities to negotiate Water Delivery and Use Agreements. These Agreements between SRP and the Cities changed the previous role of accounting for agricultural deliveries from water orders to actual water delivered. In 2006, water deliveries to municipal treatment plants increased to 68% of SRP's total deliveries. Rather than monitoring water orders, accounting has progressed to metering, categorizing, calculating losses, debiting use to a variety of entitlements, and totaling transportation and leasing fees.

Legislation tends to follow on the heels of urbanization. State regulations coupled with new groundwater conservation programs, the need for water exchanges, and the introduction of new water types, now require technology, computer systems, and analysis to track water use and entitlements and to prepare daily and monthly accounting reports for 10 valley cities.

Since SRP and the Cities are water providers, accounting applications and reports are now designed to be the foundation for filing annual reports with the Arizona Department of Water Resources and the Bureau of Reclamation.

INTRODUCTION AND BACKGROUND

What Is SRP

SRP is comprised of the Salt River Valley Water Users' Association and the Salt River Project Agricultural Improvement and Power District. The Association operates and

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maintains the water delivery system which provides an average of 1 million acre-feet of water each year for agricultural, municipal and industrial users within a 250,000-acre service area in Maricopa County. SRP operates seven reservoirs, six of which store and regulate the surface water supplied by the Salt and Verde rivers and their tributaries. SRP also operates 255 deep well pumps within the Association's boundaries located in the Salt River Valley.

As water is needed, releases are made from Bartlett Dam (constructed 1935-1939) on the Verde River and Stewart Mountain Dam (c.1928-1930) on the Salt River. The regulated water converges about 3.5 miles upstream of Granite Reef Diversion Dam (c.1906-1908). At Granite Reef, the water is released into SRP's two main canals, the Arizona (c.1883) on the north and the South Canal (c.1906-1908) on the south of the Salt River. Groundwater wells typically supplement the surface water.

Why Account for Water

The Association's "Articles of Incorporation" state in Article IV, Section 1, that the holders of shares are entitled to an adequate supply of water for beneficial uses. Article XII, Section 8 reinforces that the landowner having paid assessments and water charges, is entitled to receive the water which the land is entitled to use. Water accounting ensures that eligible land receives adequate water without exceeding entitlement.

After describing the exterior reclamation boundaries of the Salt River Reservoir District, Article IV, Section 3 provides that no water will ever be sold, distributed or delivered outside the boundaries or to land within having no entitlement except for lawful exchanges. Water accounting is essential in ensuring that water is repaid to the Association in equal and fair amounts under a lawful exchange.

Since SRP is a large water provider that interacts with Federal, State and Municipal agencies, water accounting becomes a practical source for various reports required by Governments. Participants in water conservation programs and projects also have a need for water distribution and financial reporting. Water accounting is the building block for these reports.

The Early Years

Publications from the era of 1951 to 1960 reported types of water accounts (e.g. regular, subdivision, townsite, no water run, less than minimum and over minimum use) and number of accounts and area. Also reported, were water orders for free water service, *normal flow*, *stored* and *developed*, and *pump right*. All reported data was assembled by canal and lateral.

In 1958, water accounting employees monitored 99,971 accounts (Salt River Valley Water Users' Association, Irrigation Department 1958). They contained canal, lateral, gate serving the land and the total acres assigned to the account. Every November, the Association's Board of Governors declared the allocation for the following year. The

acres multiplied by the allocation (typically 3.0 acre-feet per acre) determined the entitlement for each account. Payment of assessment entitled the user to a minimum service of 2.0 acre-feet of *stored* water per acre. If allotted by the Governors, additional water comprised of *stored* and/or *developed* (groundwater) could be ordered. Some, but not all, accounts had additional right to *normal flow* (entitlement judged and decreed by Judge Edward Kent, March 1, 1910) and *pump right* water from financial participation in well drilling programs.

The accounting and reporting process consisted of a customer providing an account number and placing a water order. Entitlement balances and payments were regularly updated on the accounts so the water order and entitlement balance could be compared to avoid overdrafts. Each day, the orders were summed by lateral and the laterals were summed by canal to determine the required surface water and groundwater supplies for the next day. Monthly and annual accounting reports were created from this process.

WATER ACCOUNTING SHIFTS WITH LAND USE

Prior to the 60's

As seen in the following graphs, agriculture dominated the land and water use prior to and during the 1960's.

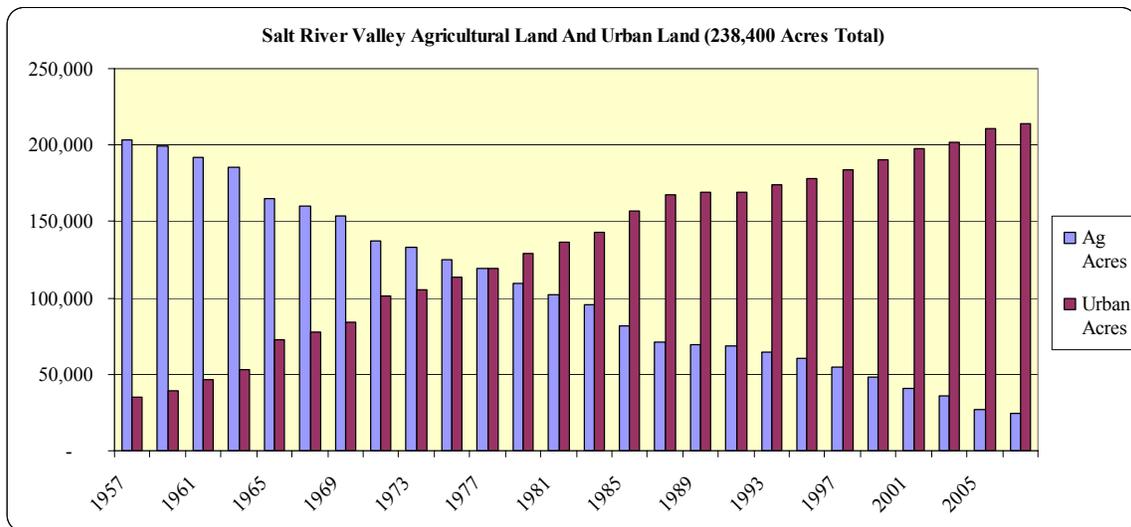


Figure 1. Transformation of Acreage from Agricultural to Urban

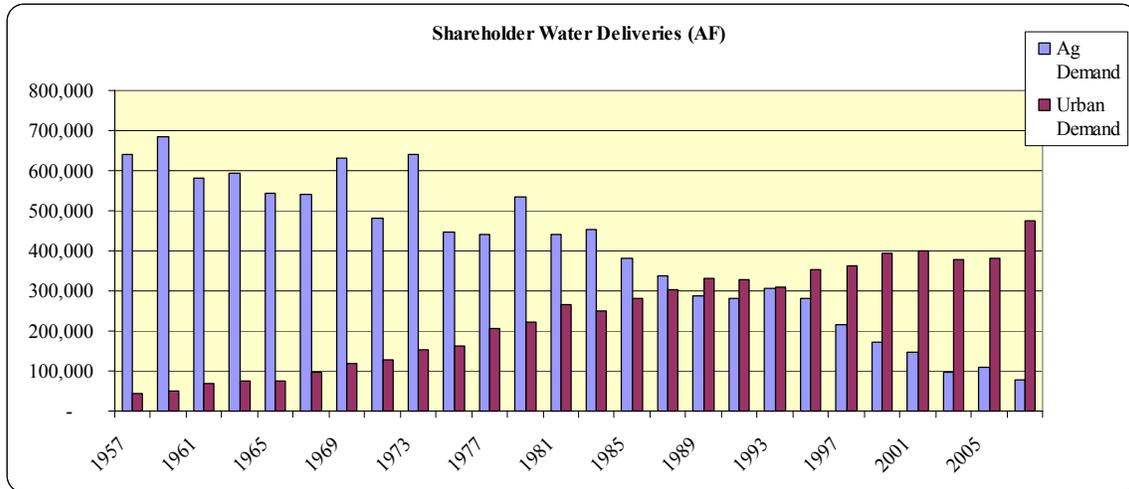


Figure 2. Transformation of Water Deliveries from Agricultural to Domestic

Following World War II, ex-servicemen who trained in the valley returned with their families, friends and relatives to settle. This put new pressures on city services. Between 1946 and 1956, Maricopa County's population increased from 250,000 to 510,000 people (Teeple and Lynch 1983).

In 1952, 59 new subdivisions containing 3,700 homes were developed. As more and more farmland was transformed to subdivisions, the water entitlements were needed for domestic purposes. The City of Phoenix signed the first Domestic Water Agreement with SRP. The City agreed to pay the water assessments on the urbanized land in exchange for the water entitlement belonging to the land. This 1952 agreement served as a model for other developing towns within SRP's service area (Teeple and Lynch 1983).

After the 60's

During the 1970's, the change from agricultural acres to urban acres occurred at a rate of 4,000 to 7,000 acres a year. As of 1983, about 95,000 acres remained in agriculture (Juetten and Ference 1984). In 2006, about 24,100 acres or 10% of the land was classified as agriculture.

As valley cities grew, subdivisions and industrial parks replaced farmland and yards replaced crops as water users. This shift dictated changes in water use and accounting systems, practices and procedures.

WATER ACCOUNTING MERGES WITH TECHNOLOGY

Drivers for Change

The reasons for developing new systems and procedures for water accounting are:

- A. Transformation from agricultural to urban domestic use
- B. Cities need for water on non eligible land under a lawful exchange
- C. Rules, standards and practices stated in various agreements with the Cities

- D. Cities obtaining water supplies and exchange credits other than groundwater
 - 1. Colorado River Water (CAP)
 - 2. Reuse of effluent water for exchange credits
 - 3. Excess water stored in new conservation space funded by Cities
 - a. Adding gates to Horseshoe Dam to store more water
 - b. Raising Roosevelt Dam to a higher storage elevation
 - 4. Recharging water in underground storage projects for recovery by wells
 - a. Granite Reef Underground Storage Project
 - b. New River-Agua Fria Underground Storage Project
 - 5. Credits from groundwater saved in Groundwater Storage Facilities
- E. Need for more accuracy and detail to reduce unaccounted for water losses
- F. Foundation for SRP's monthly reporting and billing to Cities
- G. Meet annual reporting requirements of the Groundwater Management Act

Tools for Change

Facing the challenges of transitioning from water order accounting to metering, categorizing, calculating losses, debiting use to a variety of entitlements, and totaling transportation and leasing fees, SRP has developed technical and modern tools.

While installing numerous weirs and flow meters to measure deliveries and pumping throughout the distribution system, SRP installed the Supervisory Control And Data Acquisition System. SCADA is a computer system adapted to SRP's operations which provides centralized access for monitoring and controlling remote sites. These sites collect data, actuate gates, operate well pumps and monitor water quality.

WATER II and Water Tracking And Accounts Processing (WTAP) are SRP owned and developed computer systems to track water orders, water entitlements and money transactions on land accounts receiving direct deliveries via canals, laterals, and gates. Even though these systems retain the concept of water accounting by tracking water orders, exchange accounts have been included. These exchange accounts use metered deliveries rather than water orders to track exchange credits and debits.

The Water Contract Accounting System (WCAS) is an SRP owned and developed computer system to track deliveries primarily to municipal water treatment plants. After combining SRP's delivery data with water reports from the Cities, the system's programming determines where water is used and accounts for the types of supply sources.

Water Contract Accounting 101

In Municipal water treatment and distribution systems, SRP supplies are commingled with City supplies. SRP supplies are typically *normal flow* of the Salt and Verde Rivers, reservoir water allocated by the Board of Governors as *stored* water, groundwater allocated by the Board as *developed* water, *pump right* water, and *no-charge* surface water when storms and runoff cause river or drain releases. City supplies are typically

groundwater pumped from wells located on non eligible land, CAP water, excess surface water stored in new conservation space added to the Salt and Verde reservoirs (NCS), and recovery of water stored in underground storage projects. All supplies are input into WCAS. The two major accounting concerns are 1) non eligible land water deliveries and exchange credits and debits, 2) eligible land water deliveries and remaining entitlement balances.

Non Eligible Land Exchange Accounting. As observed in figure 3, if City supplies (col. 4) are less than metered deliveries (col. 3) to non eligible land an exchange debit occurs (col. 5). This situation occurs when City supplies are insufficient to meet non eligible demand and SRP supplies are delivered to compensate.

If City supplies are greater than metered deliveries to non eligible land an exchange credit (col. 7) is accrued. This occurs when SRP supplies are insufficient to meet eligible land demand and City supplies are delivered to compensate.

As stated in the Water Delivery and Use Agreements, the goal over the course of a calendar year is to net the debits and credits to zero. Credits and debits can also occur when a City delivers *city water* directly to eligible land (credit) or when SRP delivers SRP water directly to non eligible land (debit). As mentioned above, these credits and debits are stored on exchange accounts in WATER II and WTAP and linked to WCAS to complete the exchange accounting (see col.14).

Report 1.0 - Off-Project Use, Supply, and Balance

(Quantities in Acre-Feet)

Page 1

Off Project and Remaining Non Member Use and Supply

	1	2	3	4	5	6	7
		OP	OP/NM	Off		OP/NM	
	Non Mem	Dom	Dom	Project	OP/NM	No	Remaining
<u>Month</u>	<u>Dom Debit</u>	<u>Debit</u>	<u>Debit</u>	<u>Supply</u>	<u>Debit</u>	<u>Charge</u>	<u>OP/NM</u>
						<u>Adjust</u>	<u>Debit/CR</u>
Jan-07	1,553.74	8,154.70	9,708.44	10,203.11	0.00	0.00	-494.67
Feb-07	1,459.19	7,092.61	8,551.80	8,214.95	336.85	0.00	336.85
Mar-07	1,687.45	9,530.91	11,218.36	11,218.81	0.00	0.00	-0.45
Apr-07	1,874.43	10,621.09	12,495.52	11,336.39	1,159.13	0.00	1,159.13
May-07	2,293.83	13,379.51	15,673.34	13,530.69	2,142.65	0.00	2,142.65
Jun-07	2,753.07	15,403.24	18,156.31	15,142.39	3,013.92	0.00	3,013.92
Jul-07	2,915.58	16,206.67	19,122.25	15,826.37	3,295.88	25.68	3,270.20
Aug-07	3,112.33	14,038.71	17,151.04	14,932.70	2,218.34	91.98	2,126.36
Sep-07	2,300.76	14,728.27	17,029.03	14,945.30	2,083.73	0.00	2,083.73
Total AF	19,950.38	109,155.71	129,106.09	115,350.71	14,250.50	117.66	13,637.72

Figure 3. Non Eligible Land Accounting Spreadsheet (1 of 2)

Report 1.0 - Off-Project Use, Supply, and Balance

(Quantities in Acre-Feet)

	8	9	10	11	12	13	Page 2 14
<u>Month</u>	<u>Remaining Non Mem Turf Debit</u>	<u>Off Project Turf Use</u>	<u>Previous Month Debit</u>	<u>Total YTD Remaining Debit</u>	<u>Remaining OP/NM Credit</u>	<u>Net Exchange Wtr Credit</u>	<u>Net CY Remaining Debit/CR</u>
Jan-07	34.63	10.13	1,000.00	1,044.76	494.67	0.00	550.09
Feb-07	54.52	20.24	550.09	961.70	0.00	0.00	961.70
Mar-07	75.28	23.50	961.70	1,060.48	0.44	60.04	1,000.00
Apr-07	108.24	41.19	1,000.00	2,308.56	0.00	1,308.56	1,000.00
May-07	128.78	49.87	1,000.00	3,321.30	0.00	2,321.30	1,000.00
Jun-07	125.82	68.80	1,000.00	4,208.54	0.00	3,208.54	1,000.00
Jul-07	140.36	52.43	1,000.00	4,462.99	0.00	3,462.99	1,000.00
Aug-07	122.36	54.39	1,000.00	3,303.11	0.00	2,303.11	1,000.00
Sep-07	144.09	43.20	1,000.00	3,271.02	0.00	2,271.02	1,000.00
Total AF	934.08	363.75			495.11	1,711.08	

Figure 3. Non Eligible Land Accounting Spreadsheet (2 of 2)

Eligible Land Accounting. After accounting for the supplies and deliveries to non eligible land, the next task is to account for the water to eligible land. As observed in figure 4, the metered SRP deliveries to City water treatment plants (col. 1) for eligible land are calculated. Eligible land charged deliveries are then added to recovered Salt & Verde water (MSR) from City owned wells (col. 2) and groundwater from SRP owned wells (col. 3) all of which are located on eligible land. These metered pumping amounts are introduced into the City distribution system but are not included in the treatment plant deliveries. WCAS calculates the total deliveries charged to eligible land (col. 8) by subtracting any *no-charge* water (col. 5), adding treatment plant cut back charges (col. 6) and adding deliveries to eligible land from City water sources (col. 7).

Water II provides account numbers, a city identifier, total acres and acres of “A” lands with priority dates (Kent 1910) for each inactive account the City has paid assessments for use of the entitlements. This data is necessary to establish the types of water entitlements accessible to WCAS.

To calculate *normal flow*, which is the first layer of entitlement for the City, WCAS queries the Trott table (matrix developed by Frank P.Trott for Judge Kent comparing incremental flows of Salt and Verde Rivers to amount of “A” land acres that can be irrigated) and daily river flow tables stored in WTAP and accumulates the “A” lands with priority dates from WATERII. Entitlement is compared to charged deliveries to member land and the lesser amount becomes the *normal flow* delivery (col. 9). This use is subtracted from total charged deliveries to calculate the second layer of entitlement which is *stored water* (col. 10). The third layer is *developed water* (col. 11) followed by *pump right* (col. 12).

Monthly beginning balances for *stored water* and *developed water* are calculated by multiplying the total acres in the City account by the current water allocation set by the

Board of Governors. Each month the *stored* water balance is reduced by the quantity of charged water remaining after *normal flow* was deducted until the balance is depleted (col.10).

If *developed* water is allocated, remaining charged deliveries after depleting *stored* water entitlement are then deducted from *developed* entitlement (col. 11). Otherwise, remaining charges are deducted from *pump right* entitlement (col. 12) available in WATERII.

Report 5.0 - On Project Accounting

(Quantities in Acre-Feet)

	1	2	3	4	5	6	7	8
	WTP	MSR	SRP	Total	No	Cutback	City	Total
<u>Month</u>	<u>Deliveries</u>	<u>GRUSP</u>	<u>Wells</u>	<u>Deliveries</u>	<u>Charge</u>	<u>Water</u>	<u>Water</u>	<u>Charged</u>
		<u>Delivery</u>	<u>to City</u>		<u>Water</u>		<u>Charged</u>	<u>Charged</u>
			<u>(GW)</u>					
Jan-07	9,824.42	0.00	0.00	9,824.42	0.00	0.00	494.67	10,319.09
Feb-07	9,285.59	0.00	0.00	9,285.59	0.00	0.00	0.00	9,285.59
Mar-07	12,076.72	0.00	0.00	12,076.72	120.71	0.00	0.44	11,956.45
Apr-07	12,983.20	0.00	0.00	12,983.20	0.00	0.00	0.00	12,983.20
May-07	16,290.06	0.00	0.00	16,290.06	0.00	0.00	0.00	16,290.06
Jun-07	17,775.28	0.00	0.00	17,775.28	0.00	0.00	0.00	17,775.28
Jul-07	18,800.34	0.00	0.00	18,800.34	146.44	0.00	0.00	18,653.90
Aug-07	17,541.21	0.00	0.00	17,541.21	727.32	40.07	0.00	16,853.96
Sep-07	15,826.14	0.00	0.00	15,826.14	0.00	0.00	0.00	15,826.14
Total AF	130,402.96	0.00	0.00	130,402.96	994.47	40.07	495.11	129,943.67

	9	10	11	12	13	14	15
	Normal	Stored	Developed	Pump	Stored	Developed	Pump
<u>Month</u>	<u>Flow</u>	<u>Water</u>	<u>Water</u>	<u>Right</u>	<u>Water</u>	<u>Water</u>	<u>Right</u>
	<u>Use</u>	<u>Use</u>	<u>Use</u>	<u>Use</u>	<u>Balance</u>	<u>Balance</u>	<u>Balance</u>
Jan-07	3,141.23	7,177.86	0.00	0.00	188,078.17	45,814.01	59,070.38
Feb-07	4,292.02	4,993.57	0.00	0.00	183,341.76	45,878.30	59,195.08
Mar-07	6,389.68	5,566.77	0.00	0.00	177,717.51	45,863.93	59,181.08
Apr-07	5,404.16	7,579.04	0.00	0.00	170,194.63	45,877.97	59,192.11
May-07	3,921.88	12,368.18	0.00	0.00	157,148.93	45,708.59	58,703.06
Jun-07	2,205.03	15,570.25	0.00	0.00	141,734.08	45,747.44	58,765.25
Jul-07	3,786.87	14,867.03	0.00	0.00	126,528.89	45,662.90	58,441.95
Aug-07	8,536.22	8,317.74	0.00	0.00	118,084.67	45,631.28	58,369.55
Sep-07	3,880.25	11,945.89	0.00	0.00	105,021.22	45,351.89	57,864.05
Total AF	41,557.34	88,386.33	0.00	0.00			

Figure 4. Eligible Land Accounting Spreadsheet

Monthly water accounting reports for January are processed and distributed to the Cities between the 15th and 25th of February and repeated each new month.

OTHER BENEFITS OF WATER ACCOUNTING

Monthly Reports

Monthly water accounting reports provide SRP and the Cities the ability to monitor more accurately and with more detail the supply and demand for eligible and non eligible land. Operational issues and water planning can be adjusted from observed trends.

SRP collects millions of dollars in revenues from the Cities. Water accounting reports provide detailed information to prepare accurate billings. Cities can use these same reports to validate appropriate billings.

Annual Reports

The Arizona Groundwater Management Act established the Arizona Department of Water Resources (ADWR) to enforce regulations and establish rules, procedures and reporting. SRP and the Cities are designated as water providers and are required to file annual reports for surface and ground water deliveries, recovery programs, exchange certificates, groundwater storage facilities and more. Currently, a \$2.75 withdrawal fee per acre foot of groundwater pumped is collected at the time of filing.

Water accounting reports produced by WCAS provide both accuracy and detail for completing both SRP's and Cities' reports and withdrawal fee payment required by ADWR.

SUMMARY

Urbanization coupled with legislation has caused SRP to design and implement computer programs and systems that accurately and with more detail account for water supply and demand for domestic users. If water supplies were color coded and layered in distribution systems and berms constructed between eligible and non eligible lands, water accounting might be less complex. Since the 1960's water accounting has evolved from tracking water orders to metering, categorizing, calculating losses, debiting use to a variety of entitlements, and invoicing fees such as water transportation and facility leasing.

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WATER RESOURCES MANAGEMENT AT THE SALT RIVER PROJECT

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Timothy E. Skarupa³
Charles. E. Ester⁴
Jon A. Skindlov⁵

ABSTRACT

The Salt River Water Users' Association, generally known as Salt River Project (SRP), was created to assure an adequate water supply for its shareholders in the Salt River Valley in the early 1900s. The straight forward job of storing inflows and meeting demand from a single reservoir system soon became more complex as the population of the Valley swelled, additional reservoirs were added to the system, alternative supplies of water were developed, and hydro power generation became a financial consideration in reservoir operations. Nevertheless, the primary operational objective continues to be the conjunctive management of multiple sources of water to ensure an adequate carry over supply of water for SRP's shareholders.

This objective has traditionally been accomplished by managing the reservoir system as if each time the reservoirs fill to capacity is the beginning of an extended drought comparable to the worst historical drought in recorded history. Over the past 20 years, however, several subtle yet significant events have taken place which raise concerns regarding SRP's traditional method of water management.

Changes in demand patterns, an ongoing drought rivaling the historical drought of record, studies suggesting even more severe droughts have occurred in pre-historic times and the specter of a changing climate due to global warming all suggest that a business as usual approach to water management may no longer be appropriate.

In this paper, the authors will describe how the reservoir operations planning process changed as SRP service area transitioned from mainly agricultural water use to mainly urban water use. In addition, the authors will include some preliminary results on how the water resources planning process may need to change to deal with a prolonged drought.

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INTRODUCTION AND BACKGROUND

The Salt River Water Users' Association, generally known as Salt River Project (SRP), was created to assure an adequate water supply for its, at that time mainly agricultural, shareholders in the Salt River Valley in the early 1900s. SRP, is a collective name used to refer to two separate entities: the Salt River Project Agricultural Improvement and Power District, a political subdivision of the state of Arizona, and the Salt River Valley Water Users' Association, a private company that serves as an electrical utility and water provider for the Phoenix metropolitan area. Operating under the umbrella name, SRP, it is one of the primary public utility companies in Arizona. (For a history of the SRP and the two entities it comprises, please refer to <http://www.srpnet.com/about/history/timeline.aspx>.)

As the Salt River Valley has urbanized, SRP has transitioned from providing water to agricultural customers to now providing water to primarily municipal customers and urban turf irrigators.

Salt and Verde Rivers Watershed

The Salt & Verde rivers' watershed is about 13,000 square miles in Central Arizona, with the Salt River watershed slightly larger than the Verde River watershed (see Figure 1)..



Figure 1. Salt & Verde Rivers' Watershed

Precipitation on the watershed is both seasonal and variable from year to year, creating the need for reservoir storage to even out this variability. Most of the water stored in the reservoirs comes from snowmelt.

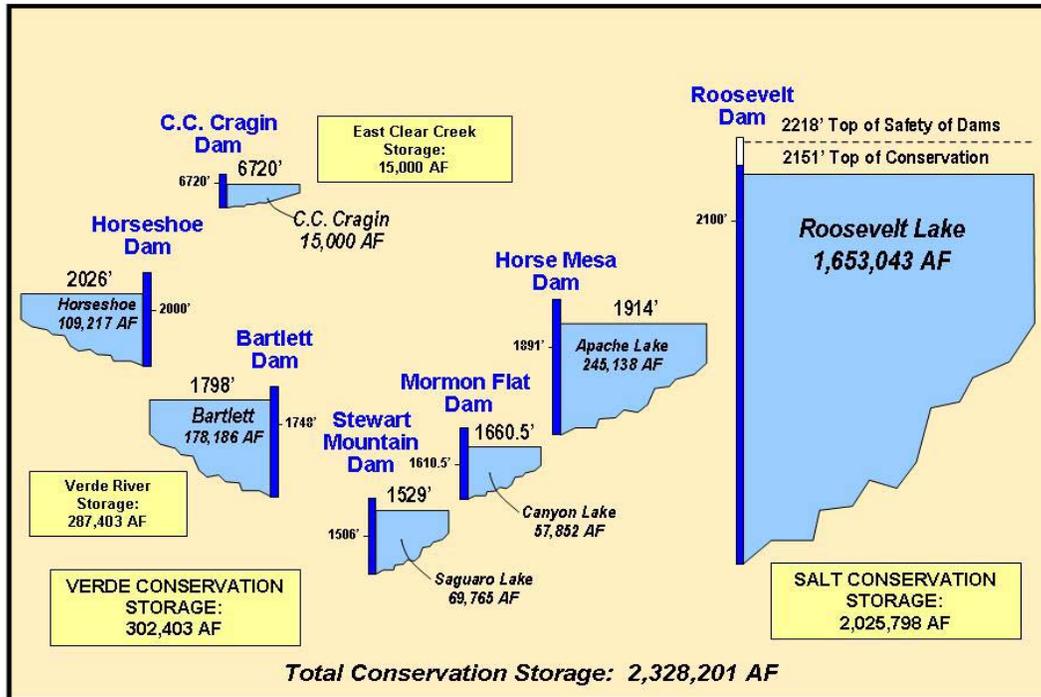


Figure 2. Salt River Project Reservoir System

Reservoir System

SRP operates four dams on the Salt River (Roosevelt, Horse Mesa, Mormon Flat and Stewart Mountain) and two dams on the Verde River (Horseshoe and Bartlett), see Figure 2. A number of years ago, SRP bought Blue Ridge Reservoir (renamed C.C. Cragin) from Phelps Dodge Corporation. The reservoir is on the Little Colorado River watershed, but water stored in the reservoir is pumped into the East Verde River, which discharges into the Verde River.

The dams were constructed for water conservation. The goal of water management is to optimize water storage in the reservoirs. The Salt River Reservoir System has the most storage capacity and the capability to produce hydroelectric power. The Verde River Reservoir System has about 13% of the combined reservoir system storage capacity. Releases from Bartlett and Stewart Mountain dams combine in the Salt River just upstream from Granite Reef Diversion Dam. At this dam, water is diverted in the SRP canal transmission system, to the north in the Arizona Canal and to the south in the South Canal. The Central Arizona Project canal crosses the Salt River bed in the vicinity of Granite Reef Diversion Dam. Just downstream of that crossing, CAP can make deliveries to the SRP canal system via a turnout.

Well System

SRP owns 248 groundwater wells in its water service area which are operated as another 'reservoir'. With the change from agricultural to urban land use, many wells became disconnected from the canal and lateral system. However, if located conveniently, those wells are connected directly to City water distribution systems. The annual pumping capacity is estimated between 325,000 and 340,000 Acre-Feet (AF). This is about one-third of the annual water demand. Minimum pumping required to reach parts of the distribution system that cannot be served by gravity flow is between 50,000 and 75,000 AF/year.

Other Resources

SRP has a water exchange agreement with the Central Arizona Project (CAP) through which it can receive Colorado River water at the heads of the Arizona and South canals (just downstream of the Granite Reef Diversion Dam). This arrangement gives SRP an additional source of surface water. The exchange agreement allows for SRP to receive Colorado River water if the resource is available (certain legal conditions need to be satisfied). Then, SRP can pay CAP back by delivering its shareholders' water to CAP customers on SRP canals (cities with a CAP allocation). Or SRP can buy CAP water under certain conditions with no obligation of delivering shareholders' water to CAP customers.

PROJECT RESERVOIR OPERATIONS PLANNING PROCESS

SRP annually sets water allocations for shareholders. It conjunctively operates the surface and groundwater resources to achieve the normal allocation of 3 AF/acre. Water allocations consist of part surface water and part groundwater. A reduction or increase in allocation is used in the management of SRP's water supply to affect demand. The water allocation is set so as to assure an adequate carryover supply of stored surface water in the reservoir system. This process is accomplished through a relatively simple process utilizing a Storage Planning Diagram (SPD). The original SPD was developed in the 1980s and was nicknamed the Mexican flag (Figure 3). The diagram gives the relation between total reservoir storage, groundwater pumping production as a percentage of demand, and water allocation. The SPD and the critical process it guides has remained unchanged for more than 30 years.

Given current reservoir conditions and projected runoff and demand, SRP makes a Project Reservoir Operations Plan (PROP) with short-to-medium term planning horizon (6 months to one and a half years). The PROP provides the monthly quantities of surface water releases, groundwater pumping, and CAP water (if available and used for the plan to achieve water management goals). The source of surface water, Salt River, Verde River and/or CAP water, is included for each month of the year.

The PROP is regularly updated (up to two times per year if reservoir conditions change) in coordination with three other operating groups (in power and water group).

The reservoirs are operated given the following priorities:

1. Safety and integrity of the dams
2. Maintain storage to meet delivery obligation
3. Optimize water storage in the reservoir system for SRP shareholder use
4. Maintain adequate carry-over storage
5. Conjunctively manage groundwater pumping, given storage, projected runoff and demand
6. Maximize hydrogeneration
7. Operate to permit maintenance

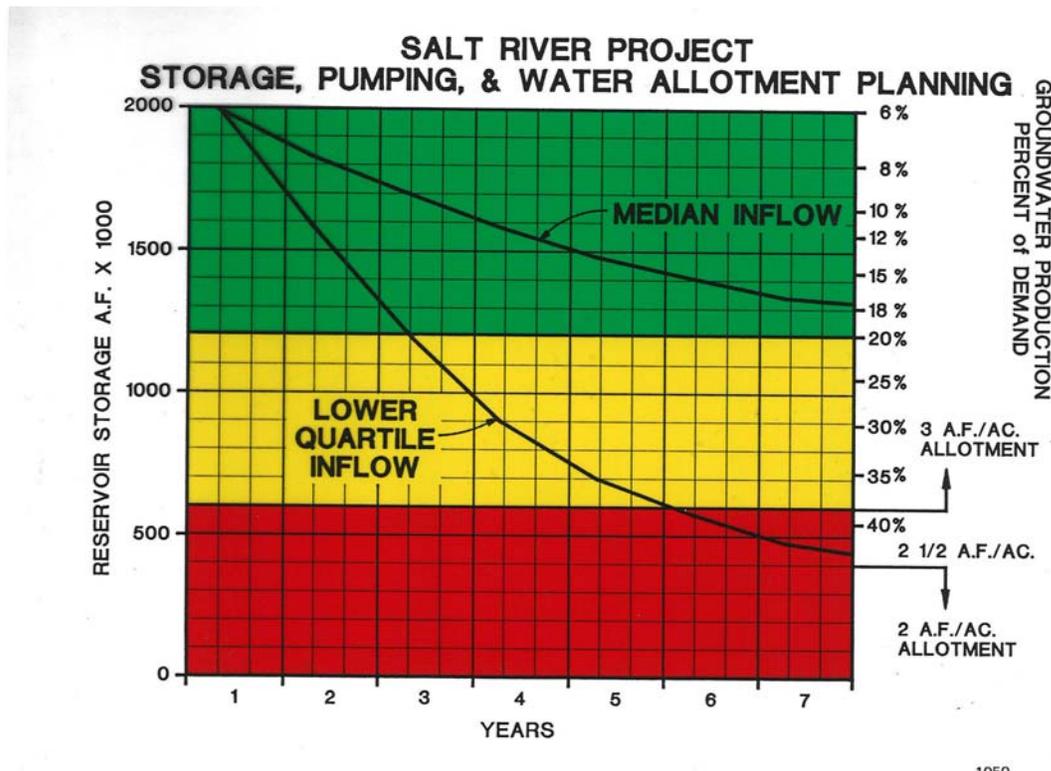


Figure 3. Storage Planning Diagram ('Mexican Flag')

Following is a description of the project planning process in the 1980s and 1990s.

Reservoir Storage Planning in the 1980s

In the beginning 1980s, the following procedure was used to arrive at a project reservoir operations plan, PROP. Consulting the SPD and reservoir storage, a groundwater pumping goal was determined. Monthly quantities of pumping were determined from 10-year mean monthly pumping. Then, the water order was determined, looking at the following variables: mean 10-year demand, agriculture irrigation constraints, cropping patterns, conservation programs, cities' use, and canal operational constraints. Once the total demand was determined, the surface water demand could be calculated by subtracting the groundwater pumping amount. The PROP maximizes hydro-generation

while meeting the annual water demand. This is accomplished by using the majority of the surface water demand from the Salt system during the warmer months (May-Sep) when both water and power demands are highest. During the winter months (Oct-Apr), Salt releases are minimal and the bulk of the surface water demand is released from the Verde River reservoir system. Because the two reservoirs on the Verde River have a maximum storage of only 13% of the combined Salt-Verde reservoir system storage capacity, the planning process must ensure that sufficient water is used from the Verde system each year to prevent spilling water the next spring. Hence, the following criteria were used to achieve those goals: a) the Verde system should have at least 100,000 AF of storage on May 1st each year to adequately supplement Salt releases during the summer; b) there should be 100,000 AF of available space in the Verde system by December 1st, so as to contain the upper quartile Verde runoff during the winter and spring; and, c) the probabilities of filling and spilling each system during the runoff period should be as near as equal as reasonable possible on December 1st each year. To meet the latter criterion, it may be necessary to adjust and shift the release amounts from one system to the other. This was achieved by doing a number of iterations.

Reservoir Storage Planning in the Mid 1990s

In the mid 1990s, the reservoir planning process started to incorporate more probabilistic factors, such as winter weather forecasts, La Nina or El Nino predictions and other factors deemed important. In Figure 4, the factors taken into consideration to prepare a PROP are shown.

The PROP planning process was programmed into a spreadsheet. The SPD was changed to reflect reservoir storage fluctuations throughout the year and include the flow record of the then longest known drought record in the historic record (1898-1904). See Figure 5. Reservoir storage, while operating in accordance with the SPD guidelines, is shown for median inflows and for the drought of record. The diagram was developed by assuming that each time the reservoirs fill to capacity is the onset of a new drought comparable to the 1898-1904 drought of record. Note that on this diagram, groundwater pumping is shown as a level of pumping in thousands of AF instead of a percentage of demand as in Figure 3. As reservoir storage declines during the 7-year period, groundwater pumping is gradually increased to maximum capacity and water allocations are reduced. For any given year, total stored water relates to a recommended water allocation and groundwater pumping goal. By adhering to the SPD guidelines, SRP would be guaranteed to weather the worst drought in the historical record without running out of surface water.

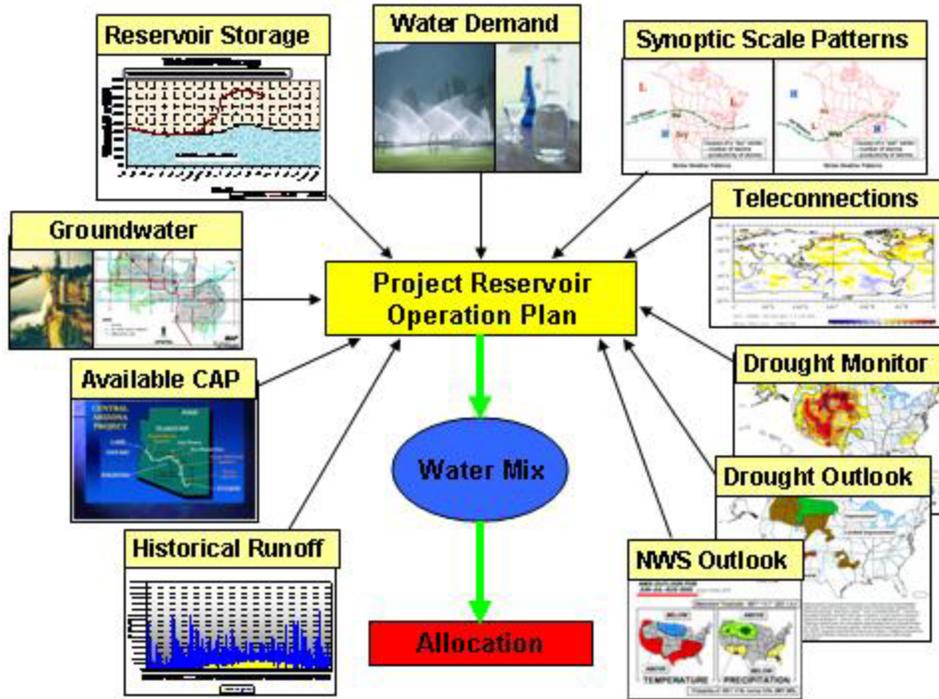


Figure 4. Project Reservoir Operations Planning Process

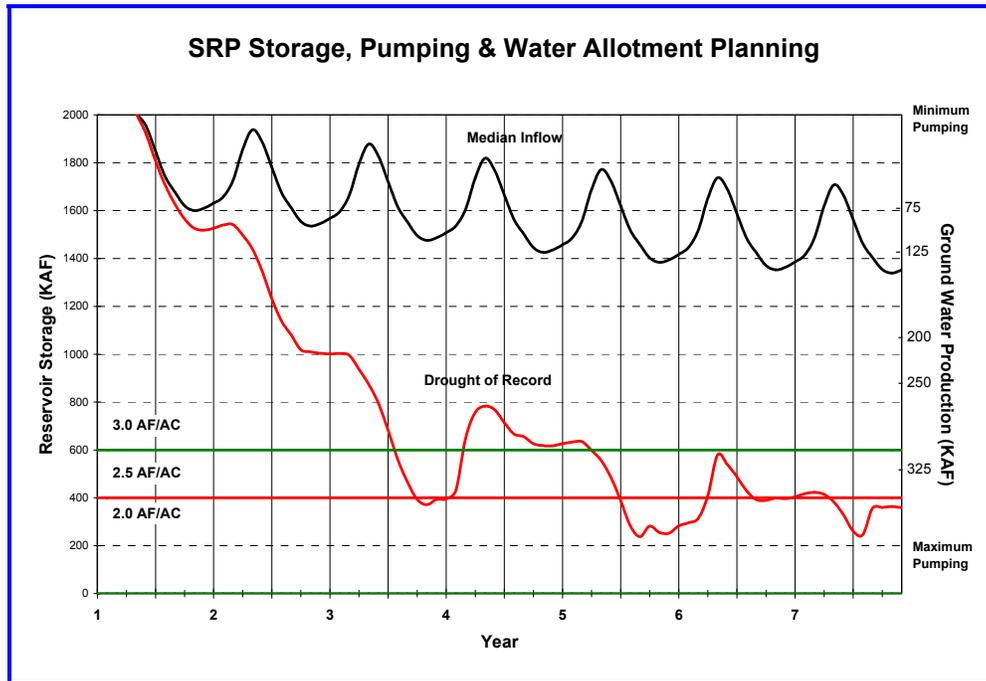


Figure 5. Storage Planning Diagram - Mid 1990s

This planning process was used satisfactorily during the 1990s and early 2000s.

WHAT MADE SRP REVIEW ITS WATER SUPPLY PLANNING PROCESS?

Until the current drought, which started in 1996, the longest drought affecting the Salt-Verde watershed had been the seven years, mentioned previously, from 1898-1904. In Figure 6, the total annual inflow (Salt plus Tonto plus Verde) for the period 1889-2007 is shown, and the droughts in the beginning of the 20th century and end of the century droughts can easily distinguished from the record.

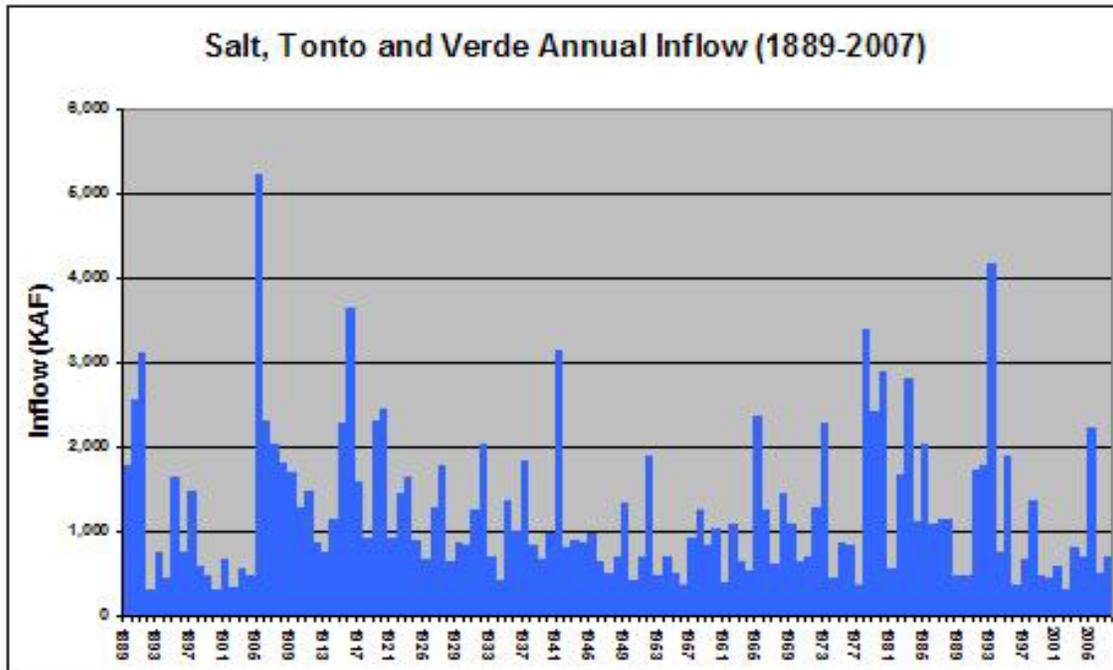


Figure 6. Total Annual Inflow for 1889 – 2007

If a drought persists, with groundwater pumping at maximum levels and reservoir storage continuing to decrease, the only remaining option is to reduce allocations. Since 1925, annual allocations have been less than 3 AF/AC for two consecutive years five times. Since 1920, allocations have been reduced to 2 AF/AC for two consecutive years only twice: 1947-48 and 2003-04.

Since 1998, SRP has borrowed or purchased 515,000 AF of water from CAP to keep more carry-over storage in the reservoirs. SRP has no annual CAP allocation but excess Colorado River water was available for purchase during those years.

If not for the excess Colorado River water purchased via CAP, Roosevelt Reservoir would have been close to empty in 2002. Since the mid-1990s, the availability of Colorado River water (via CAP) has made it possible for SRP to maintain normal allocations, until 2003-04.

As agricultural lands have become urbanized, SRP has observed no appreciable decrease in demand when allocations have been reduced to 2.5 AF/acre from the full allocation of

3.0 AF/acre. After the years with reduced allocation, it took several years for the demand to come back to the level before the reduction in allocation. Several different explanations can be given for that, but none of them have been fully analyzed. It is possible that the ‘Water Use It Wisely’ campaign started in the beginning of the 21st century is working; it is possible that cities having bought and scheduled CAP water deliveries, could not make use of the normal allocation in 2005 (after the reservoirs filled), or most cities’ water use is generally less than the normal allocation, or the users kept on conserving water because the message to the public still was that ‘one wet year does not end the drought’. To understand the reason for the decrease in demand, it will be necessary to conduct a separate study analyzing the trends in demands in the Phoenix Valley. From a water supplier view point though, it became important to look how SRP could change the water supply planning principles to maintain carry-over storage for the longest sustained drought over the watershed and maintain its goal of managing shareholders’ water resources in an environmentally prudent manner to sustain life and economic growth in the Phoenix Valley.

To more fully assess SRP’s vulnerability to a prolonged drought, a new application was developed for long-term drought analysis. The PROP spreadsheet, developed in the 1990s, was modified in 2006 to model the system water balance for an eleven year period to assess the impact of the eleven year tree-ring drought. This was not enough for the long-term (over 20 years) analysis of the system. The spreadsheet was extended to allow for analysis of projected monthly data for a period up to 50 years. Methods for inputting inflow series, demand and pumping curves were enhanced. The method for inputting an inflow series was modified to allow for multiple inflow series to be analyzed within the same spreadsheet. The new spreadsheet is the Long-Term Drought Planning Model (LTDPM).

The LTDPM provides a tool to analyze the effect of long-term droughts on the SRP Reservoir System using current operational guidelines. The severity of any drought simulated in the inflow series can be seen graphically using the model. The historical medians based on the 1914-2006 inflow record were the basis for the analysis.

REVIEW OF PREVIOUS ANALYSES

Historical Data and Statistics

Mean daily flow data of good quality are available for the Salt and Verde rivers and Tonto Creek for the period 1913-present. Monthly mean flow data for the Salt and Verde rivers of lesser quality are available from approximately 1889-1913 with some gaps in the record. An analysis of historical data from 1914-2006 yields a combined (Salt + Tonto + Verde) average annual flow of 1,660 cfs and an annual median flow of 1,236 cfs. The earlier data indicates that the 7-year period from 1898-1904 was the most severe drought in recorded history with an approximate average annual flow of 61% of the historical median. The “historical” record is the record of inflows which was actually recorded and published. “Pre-historic” refers to the period before the historical record began.

Tree-ring Research

In 2005, the Laboratory of Tree-Ring Research at the University of Arizona issued the final report for an SRP sponsored research project with the primary purpose to assess the likelihood of simultaneous drought on both the Upper Colorado and Salt/Verde watersheds. The study also provided an extended reconstruction of river flows on the Salt and Verde rivers, dating back to around 1200 A.D. The study showed that severe drought on either the Colorado River watershed was likely to coincide with severe drought Salt/Verde rivers' watershed. In addition, the tree-ring record for the Salt/Verde watersheds showed extended periods of drought more severe than anything observed in the historical record.

SRP Vulnerability to Droughts in the Tree-Ring Record

In 2006, SRP completed an evaluation of its vulnerability to extended drought periods in the pre-historic tree-ring record. A severe 11-year drought period identified in the tree-ring record was selected for the drought vulnerability analysis. This drought, dating from 1575-1585, had an average annual flow of 70% of the historic median, based on reconstructed river flows from the tree-ring record. Longer droughts were identified from the reconstructed flows; however these extended periods contained at least one wet year sufficient to refill the reservoirs to capacity. Similarly, more severe droughts were apparent for shorter durations, but not long enough to threaten the reservoirs going dry. In analyzing the 11-year drought, it was assumed that coincident drought was occurring on the Colorado River and that Colorado River water would not be available to supplement SRP's usual sources of supply. It was also assumed that demand would follow recent historical trends for a given annual water allocation and that maximum groundwater pumping would remain unchanged from recent levels of about 325,000 AF/year. A preliminary analysis indicated that SRP would be unable to manage the 11-year drought without drawing the reservoirs down to an unacceptable level by the end of the period. However, by altering the guidelines of the SPD, the drought became manageable, specifically, when the option of a reduction in allocation to 2.5AF/acre was eliminated. Groundwater pumping guidelines on the SPD were adjusted to initiate pumping sooner in the extended drawdown period. Through iterations on the allocation and pumping guidelines, the SPD was modified to the point at which SRP could now manage the 11-year drought contained in the tree-ring record. The modified SPD is shown below, Figure 7.

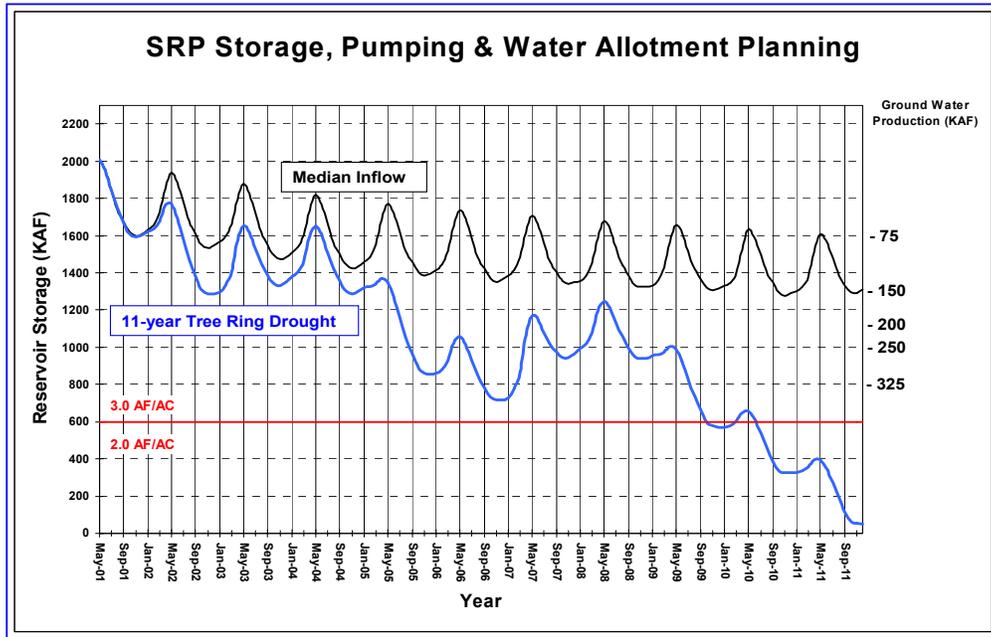


Figure 7. SRP’s New Storage Planning Diagram

The decisions to reduce allocation and to determine the amount of pumping were automated in the new spreadsheet based on the end-of-year total system storage, incorporating the guidelines developed for the new SPD. Total system storage was generated by using a simple water balance method of inflow and release from the Salt and Verde reservoirs systems calculated month-to-month. The LTDPM allows the user to efficiently compare multiple inflow scenarios have on the water supply by saving the results to a summary page. Results are graphed automatically. A table showing the end-of-year storage, allocation, and pumping volume is also automatically generated.

VULNERABILITY TO LONG-TERM DROUGHT

The science and understanding of climate change processes is constantly evolving and the projected implications for any given region are subject to change. Therefore, rather than trying to assess a moving target, a more general analysis of SRP’s vulnerability to sustained drought is appropriate.

To accomplish this analysis, a broad range of drought scenarios were created. It was assumed that annual reservoir inflows are reduced to a constant percentage of historical annual median inflows for a period of 50 consecutive years. While this approach fails to simulate natural variability in stream flow, it represents a systematic and objective way of assessing the effects of long-term drought on reservoir storage.

In addition to the assumed persistent annual inflows at a fixed percentage of historical median, it was assumed that no additional source of water would be available to

supplement SRP's water resources and SRP continued to operate, throughout the drought in accordance with the newly developed SPD.

Increasingly severe droughts, based on simulated perpetual inflows at a fixed percentage of the historical median, were analyzed to determine how much reduction of inflow would be required to eventually empty the reservoirs. An example of the model's graphical output is shown in Figure 8 for a scenario of median inflows over a 50-year period. The analysis shows that SRP could perpetually operate, under current guidelines, without experiencing a significant drawdown in reservoir storage. (The right axes in the figure show the required level of groundwater pumping in 1,000s of acre-feet.)

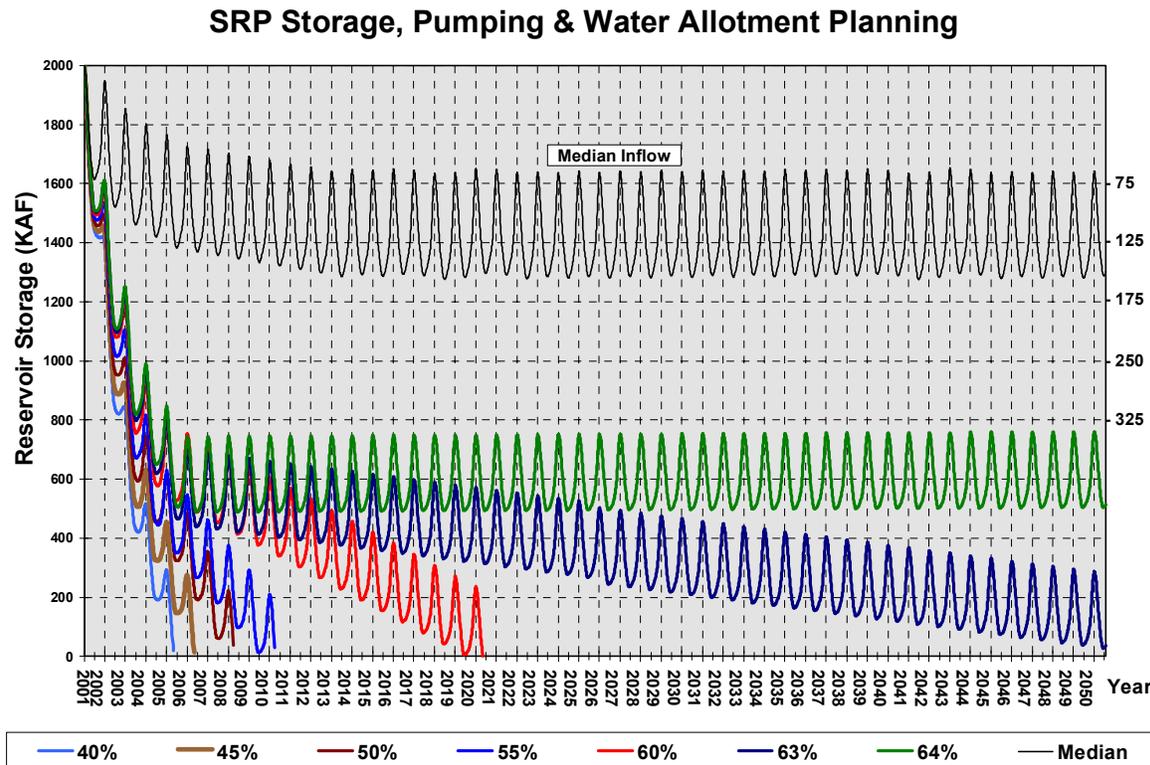


Figure 8. Simulated Reservoir Storage for a Range of Perpetually Reduced Inflows (as a percent of historical median)

In Figure 9, the historical median inflow and the various percentages of the median inflow used in the analysis are presented.

A key finding of this analysis is that a prolonged period of average annual inflows at 64% of the historical median inflow can be managed indefinitely using current management procedures without the reservoirs going completely dry. However, a further slight reduction in inflow to a prolonged period of average annual inflows at 63% of median will result in the eventual depletion of all stored surface water in slightly more than 50 years. As annual inflows are further reduced below the 63% of median threshold, the

time required for the reservoir system to go dry is reduced as well. Figure 8 shows total reservoir system storage over time for a range of sustained reduced inflow scenarios.

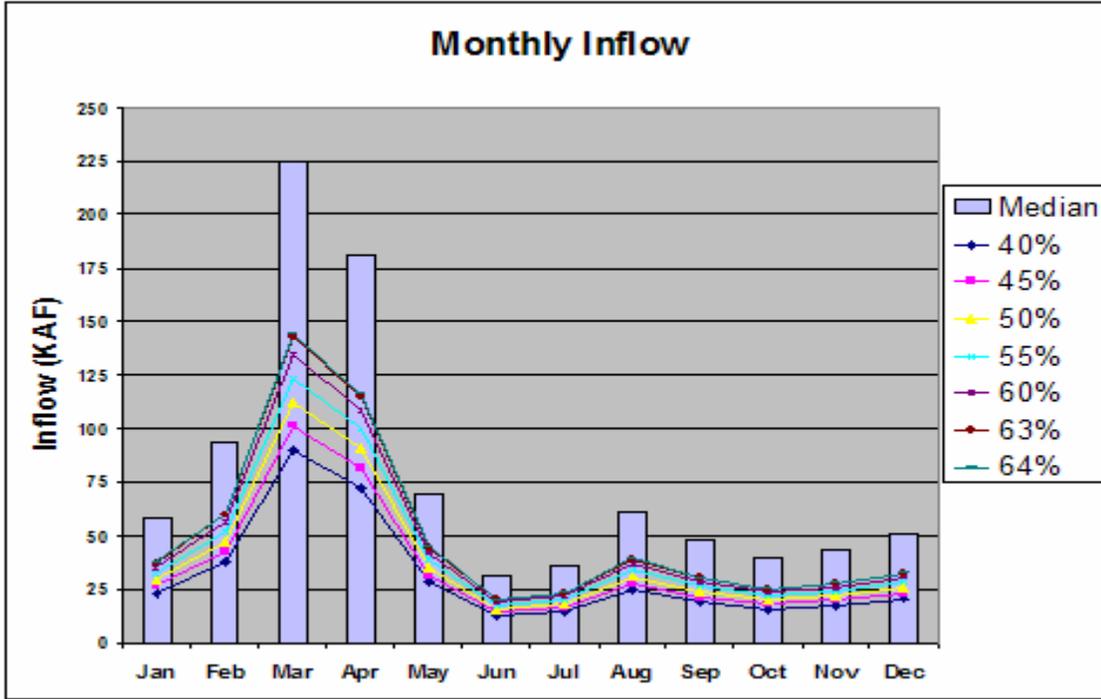


Figure 9. Historical Monthly Median Inflow and the Various Percentages of the Median Inflow Used in the Analysis

The relationship between sustained below median annual inflow, as a percent of historical median, and the time required emptying the reservoir system is shown in Table 1 below.

Table 1. Percent of Median Inflow vs. Years to Reservoir Dry Up

Percent of Median Inflow	Years to Reservoir Dry Up
64	INDEFINITE
63	50+
60	19.5
55	9.3
50	7.3
48	6.4
45	5.4
40	4.4

EFFECTS OF REDUCED RUNOFF

To assess the effects of a potential reduction in future runoff into the reservoir system, a range of fixed percentage of historical average or median flows were evaluated. While there are an infinite number of ways to achieve, for example, a 10% reduction in long-term median flow, the most straight forward approach is to simply apply the 10% reduction to each year. This has the added advantage of achieving both a 10% reduction in the long-term median as well as a 10% reduction in the long-term average flow, while still maintaining the natural variability of the runoff record. What this method does not simulate is a change in variability which might accompany the reduction in flow.

Historical Record

Published estimates of annual flow dating back to 1890 were used to extend the high-quality historical record beginning in 1913. These estimates were used in order to include the 1898-1904 drought in the analysis. Annual flows for each river system were reduced by 10, 15, 20, and 30%.

In no case would a 10% reduction in flow result in a drought period severe enough to deplete the surface water supply.

Likewise, a 15% reduction in flow did not produce any periods which would completely empty the reservoirs, however, two periods in the historical record came very close to depleting the surface water supply: A four-year period from 1999-2002 was reduced to an average annual flow of 43% of median, and the seven-year drought of record from 1898-1904 was reduced to an average annual flow of 51% of median.

A 20% reduction in flow resulted in two periods which met or exceeded the thresholds required to deplete the surface water supply. The seven-year 1898-1904 drought would have been reduced to an average annual flow of 48% of historical median, depleting the surface water supply by the end of the drought. The nine-year 1996-2004 drought would have been reduced to an average annual flow of 55% of historical median, also depleting the surface water supply.

A 30% reduction in flow did not produce any additional historical periods resulting in a depletion of the surface water supply. The two drought periods identified above, however, were significantly more severe and the surface water supply was depleted much earlier in the drought period.

Tree-Ring Record

A similar analysis was applied to the 800-year reconstructed flow record derived from the tree-ring analysis. The results were remarkably similar to those found using the historical record, lending some confidence to the results.

A 10% reduction in flow did not produce any drought periods capable of depleting the surface water supply.

A 15% reduction in flow resulted in one critical period. The seven-year period from 1579-1585 had an average annual flow of 50% of median. In addition, three additional periods came very close to meeting the criteria: 1214-1217 at 43% of median, 1666-1670 at 48% of median, and 1818-1823 at 51% of median.

A 20 % reduction in flow identified the same drought periods found with the 15 % reduction, but the drought periods were more severe.

In combining the historical and reconstructed flow records from tree-ring research, several severe drought periods have been identified (see Table 2). For example, given the 1214-1217 inflow series, reduced by 20%, it will take 4 years to deplete the surface water supply. The reduced inflow series is 40% of the median inflow. As can be concluded from the data presented in the table, even a modest long-term reduction in flow would result in reservoir depleting conditions.

Table 2: Severe Droughts Capable of Depleting Surface Water Supply with the Noted Reduction in Flow

Period	Source	Duration (yrs)	Flow Reduction	Average Annual % of Median
1214-1217	Tree-ring	4	20%	40%
1579-1585	Tree-ring	7	15%	50%
1666-1670	Tree-ring	5	20%	45%
1817-1823	Tree-ring	6	20%	48%
1898-1904	Historical	7	20%	48%
1999-2002	Historical	4	20%	40%

CONCLUSIONS

Analysis of historical and tree-ring-based reconstructed inflow records has shown that a 10% reduction in long-term flows would not produce a drought severe enough to deplete SRP’s surface water supply, using current operating criteria. A 15% reduction in flows, however, would have resulted in at least one period capable of emptying the reservoirs and precluding SRP from meeting its minimum water delivery obligations. A 20% reduction in flow would result in six historic or pre-historic periods of critical severity over an 800-year period with durations ranging from four to seven years.

A review of the most recent climate-change assessments and projections suggests that runoff from the Salt and Verde Watersheds could be reduced by 20-50% within the next 50 years.

If the climate-change projections have the slightest chance of occurrence then SRP could be faced with an unprecedented water management crisis in the not to distant future.

PRICING RECLAMATION PROJECT IRRIGATION WATER APPLIED TO SMALL TRACTS — A UTAH CASE STUDY

Wayne Pullan¹

ABSTRACT

Agricultural land is being developed—carved into suburban lots—throughout the West. Agricultural irrigation systems are being converted into secondary irrigations systems which deliver untreated water for the irrigation of suburban landscaping. As a result, Bureau of Reclamation (Reclamation) project irrigation water is increasingly being applied to suburban tracts. Under Reclamation law, repayment of water development costs drives water rates. Users of project municipal and industrial (M&I) water repay the costs allocated to M&I uses over 40 to 50 years with interest. Irrigation users are not required to pay interest and in many cases only repay an amount equivalent to the “ability to pay.” The result is a substantial differential between the per-acre-foot price of M&I water (\$300) and irrigation water (\$5). This price differential creates an incentive to avoid officially changing the classification of use from irrigation to M&I.

The price differential raises the question whether there is some intermediate price—a non-commercial irrigation rate that would be appropriate for water applied to the irrigation of landscaping on suburban tracts. Reclamation law and policy provides some flexibility in the pricing of non-irrigation water, e.g. the application of water for miscellaneous purposes under the 1920 Act and water supply contracts under the 1939 Act.

One approach to the pricing of irrigation water for suburban tracts is to calculate the net benefit of irrigation water applied to a suburban lot, to use that amount as an indication of the landowner’s maximum willingness to pay, and to use that amount in establishing a rate for non-commercial irrigation water. This approach is based on the value of landscaping as a component of the value of a home. Wasatch County, Utah, provides a case study for such a calculation. This net benefit of landscaping approach can yield a defensible intermediate price—between the extremes of the project M&I rate and the subsidized irrigation rate. It does, however, have several drawbacks including its sensitivity to basic assumptions about landscaping costs and the contribution of landscaping to home value.

THE LEGAL AND POLICY ENVIRONMENT FOR CONVERSION

Reclamation Law and Conversion

It is beyond the scope of this paper to offer more than a brief (accurate but without great detail) sketch of Reclamation law and policy regarding the rate water users pay for

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irrigation and M&I water. The following is intended to be sufficient for our discussion.

When the Newlands Act was enacted in 1902, Congress did not anticipate the use of Reclamation project water for any use other than agricultural irrigation. As time passed, Congress made temporizing accommodations for some uses other than for the irrigation of farmland. The Townsites Act of 1906, for example, offers project water for town sites laid out as part of Reclamation projects. The 1920 Act authorized the sale of excess project water for miscellaneous purposes—if a strict set of provisions were met.

It was not until the enactment of the 1939 Act that M&I use was recognized as a project purpose. Under the 1939 Act, M&I water from Reclamation projects can be offered under a repayment contract or under a water service contract. The M&I water provided under a repayment contract is priced at the full cost of the development of the project water—repayment of capital costs and interest accrued during construction—with interest.

Since 1902, irrigators were required to repay the cost of the development of the project irrigation water but without interest during construction or repayment interest. The 1939 Act introduced another benefit for project irrigators: the irrigators' obligation to repay project capital costs could be limited to their "ability-to-pay", provided other project beneficiaries (generally power or M&I users) were available to pay the remainder of the irrigation obligation.

Reclamation Policy on Conversions

The 1939 Act created an incentive to be eligible for irrigation water by creating a substantial difference between the rate paid for irrigation water and the rate paid for M&I water delivered from the same project. For example, Bonneville Unit irrigation water delivered to Wasatch County is priced at the irrigators' ability to pay--\$3.10 per acre-foot. Bonneville Unit M&I water delivered in Wasatch County is priced at in excess of \$200 per acre-foot. Because of the difference in price, it was important to define clearly who was eligible to receive the subsidy.

The recent history of Reclamation policy with respect to the pricing of irrigation and M&I water begins with the 1982 Letter. The 1982 Letter was an attempt to set a workable definition about which lands were eligible to receive project irrigation water. The 1982 Letter concluded irrigation water could only be used to support commercial agricultural enterprises. It defined a commercial enterprise by tract size. Under the 1982 letter, tracts over ten acres were eligible to receive project irrigation water. Tracts under two acres were not. Tracts between two and ten acres may be eligible but the operator was required to show evidence that the enterprise was grossing \$5,000 annually.

In 1994, Reclamation came under scrutiny by the Department of the Interior's Inspector General for allowing the unchecked "unauthorized use" of irrigation water. In other words, Reclamation was criticized for failing to monitor the use of irrigation water, allowing it to be applied to small tracts and failing to collect the additional revenue. In response, Reclamation went so far as to publish draft regulations regarding unauthorized

use. The regulations were never finalized.

The issue of irrigation of small tracts continued to simmer until January 2001. Reclamation was updating its documents for implementing the Department of the Interior's "Principles Governing Voluntary Water Transactions That Involve or Affect Facilities Owned or Operated by the Department of the Interior". In the update to Reclamation's policy manual, it uses a footnote (Footnote 6) to sweep away the small tract/unauthorized use issue. Footnote 6 of WTR P02, Voluntary Transfers of Project Water, states:

"Accordingly, when a project contractor or end user is itself the one who continues to use untreated, raw project water which is converted from the irrigation of commercial crops to the irrigation of other vegetation (including but not limited to lawns and ornamental shrubbery used in residential and commercial landscaping; gardens, golf courses, parks, and other developed recreational facilities, commercial nurseries, and pastures for animals raised only for personal pleasure and use), then such a conversion is not a 'change in the type of use' of project water and is, therefore, not a transfer of project water subject to this policy."

Footnote 6 concluded that, as long as the irrigation water is untreated and is used to irrigate non-commercial vegetation, it would remain irrigation water under Reclamation law and policy. In other words, issues of tract size and commercial viability of an agricultural enterprise were no longer issues in the use of irrigation water. Irrigation water could be applied to small tracts and landscaping.

Footnote 6 was silent, however, on the issue of price. Would irrigation water applied to small tracts and landscaping be eligible for the irrigation subsidy? Reclamation promised that Footnote 6 would be followed by a sister policy introducing a new rate for non-commercial use of irrigation water—a rate, Reclamation hinted, that would be somewhere between the subsidized irrigation rate and the full M&I rate.

Five years into its gestation, the sister policy to Footnote 6 (the pricing policy) has not been born. As Reclamation attempted to develop its policy, its legal counsel concluded that Footnote 6 contradicted definitions of irrigation in the Reclamation Reform Act of 1982. By 2006, Reclamation had placed Footnote 6 under a cloud. It discouraged any transfers of irrigation water under Footnote 6 and indicated it would repeal the policy, but failed to provide an alternative. Today, Footnote 6 remains in place and Reclamation continues to operate within a policy vacuum.

UPPER AND LOWER LIMITS FOR A NON-COMMERCIAL IRRIGATION RATE

At the time Reclamation introduced Footnote 6, many speculated about the promised pricing policy and what approach Reclamation might take in arriving at an intermediate rate—a non-commercial irrigation rate for water applied to the landscaping of residences,

commercial properties, gardens, golf courses, and parks. This paper presents one foray into the development of a non-commercial irrigation rate. To frame the discussion of non-commercial irrigation rates, it is helpful to review the two rates that bookend the non-commercial irrigation rate—the M&I rate and the commercial irrigation rate (as shaped by Reclamation law and policy).

M&I Rate

Determining rates for project water provided by Reclamation projects begins with the allocation of project costs among project purposes. There are a few viable approaches, each having strengths, weaknesses, and biases. In the Central Utah Project Completion Act (P.L. 102-575), for example, Congress mandated the application of a Use of Facilities method in allocating Central Utah Project (CUP) Bonneville Unit costs. In general, cost allocation produces: the proportion of project costs that is subject to repayment including both construction costs and interest during construction; the portion of project costs subject to repayment on M&I terms; and the amount subject to repayment on irrigation terms.

After the cost allocation produces an amount for M&I repayment, Reclamation divides the amount by the average number of acre-feet to be delivered—arriving at a per-acre-foot amount to be repaid. Reclamation amortizes this amount over the repayment period using the project interest rate which is usually a rate set when the project is first authorized and funding is appropriated. For the Bonneville Unit of the CUP, the rate is 3.222 percent. The repayment period is over forty years; however, the Water Supply Act of 1958 offers a ten-year deferral of repayment, creating in effect an opportunity for 50-year repayment.

The result of the amortization is the per-acre-foot repayment rate for M&I water. The rate is not subsidized except to the extent that the project interest rate may be lower than comparable commercial interest rates. The estimated price for M&I water developed by the final phase of the Bonneville Unit (based on a 40-year amortization) is \$301.29.

Commercial Irrigation Rate

In developing the commercial irrigation rate, Reclamation develops an allocation of project costs to irrigation. The allocation to irrigation does not include interest during construction. Interest during construction allocated to irrigation is a non-reimbursable cost and is not subject to repayment. It is absorbed by the United States and is the first element of irrigation water subsidization.

After determining the amount of irrigation costs subject to repayment, Reclamation estimates agriculture's ability to pay. The method for determining ability to pay begins with studies of agriculture in the regions served by the project. Based upon those studies, Reclamation models a typical farming/ranching operation. It then estimates the expected annual revenue for operating the model enterprise as well as all expected costs (including returns to the operator and his or her family). This calculation yields the profit of the

operation or the ability to pay. When this excess of revenues over costs is divided among the project water required by the operation, the result is agriculture's ability-to-pay per acre-foot. In projects authorized under the 1939 Act, the rate that commercial irrigators pay for project irrigation water may be limited to this amount.

To be certain, these ability-to-pay rates are low. In the Bonneville Unit of the CUP, the rate for irrigation water delivered to Duchesne County, mostly for cow-calf operations is \$1.90. The rate for Utah County and its fruit orchards is \$5.60. These Bonneville Unit rates are based on calculations that are decades old. In the intervening years, agriculture has not become more profitable. Today, ability-to-pay studies routinely result in abilities-to-pay of less than zero. (At this point in the discussion, the reader should insert his or her own joke about the profitability or unprofitability of farming and ranching.)

Under Reclamation law, the difference between the full per-acre-foot rate for irrigation water and the ability-to-pay rate is repaid by power users. The power users' share can be substantial. The Bonneville Unit allocates a total of over \$299 million to irrigation. Of that amount, the obligation of power users is \$282.6 million.

For small tracts, the ability to pay approach is inappropriate. First, Reclamation has rightly determined that small tracts are not commercial operations. They are not business enterprises. As a result, any rate calculation based on revenues and costs is a kind of non sequitur. Notions of profit do not apply. Second, we can speculate about what policy objectives drove Congress to create a subsidy to water applied to commercial agriculture. These objectives justified the limiting of the rate for irrigation water and the transfer of these costs to power users. We can safely assume that Congress probably did not anticipate that the subsidy would apply to orthodontists who run a couple of horses on the back two acres of their ranchettes or to high-tech types who are raising a prize crop of Kentucky bluegrass on quarter-acre lots.

These two rates (commercial irrigation and M&I) set the limits of any attempt to quantify a defensible non-commercial irrigation rate. The upper limit is the M&I rate at approximately \$300 per acre-foot. The absolute lower end is the subsidized irrigation rate at some amount less than \$10 per acre-foot; however, political realities would require, in practice, any non-commercial irrigation rate to be substantially higher than the irrigation rate. In deference to those practical realities, the approach described here uses an arbitrary lower limit of \$100 per acre-foot.

ONE APPROACH TO A NON-COMMERCIAL RATE: WILLINGNESS TO PAY

In 2005, the Central Utah Water Conservancy District (the entity responsible for repayment and for operation and maintenance associated with the Bonneville Unit) was first making inquiries about applying Bonneville Unit irrigation water to small tracts in Utah's Wasatch and Summit Counties. There were questions about whether to simply convert the water to M&I use or to use Footnote 6. In those deliberations, the eventual rate to be imposed by the promised Footnote 6 sister policy was a key question.

In this milieu, my colleagues and I began thinking about how a viable and defensible non-commercial rate could be developed. In the approach described below, I worked closely with Karl Stock who at that time was the contracts and repayment specialist and economist for Reclamation's Provo Area Office.

Theoretically, there could be a wide range of approaches to developing a non-commercial irrigation rate. The approach described here began with a question: what is the value of irrigation water applied to non-commercial tracts? One answer to this question is this: non-commercial irrigation water makes possible the development and maintenance of landscaping. If this is the case, landowners should be willing to pay up to the net value added to the property by landscaping. The approach then is to determine the value added to a small tract by each acre-foot of irrigation water applied to landscaping; this amount would represent the landowner's maximum willingness to pay.

The following are assumptions and data points used in developing a willingness to pay approach for Wasatch County in 2005 and 2006. I have not attempted to index to 2008 any of the costs or update any assumptions.

Typical Small Tract

Lot Size. We assumed a lot size of one-half acre with ten percent of the lot being covered by hardscape (and not requiring any irrigation water).

Irrigation Water Requirement. We assumed an irrigation water requirement of three acre-feet per acre annually. The 0.45 acres of landscaped area would require 1.35 acre-feet of irrigation water each year.

Median Home Price. Using the Consumer Price Index, we indexed the median home price for Wasatch County—resulting in a median home value of \$212,253.

Value Derived from Landscaping

Reliable data about the proportion of the value of a suburban home that can be attributed to landscaping were scarce. Most of what was available was self-serving, sponsored by associations of landscapers, nurseries, and realtors. The results varied widely. The lowest percentage was 11 percent. One percentage repeated often in several sources was 17 percent. A Utah realtor and member of the Utah County Property Tax Appeals Board estimated 25 percent. For our analysis, we used 11 percent. At 11 percent, landscaping accounted for \$23,348 of the median home's value. To annualize this amount, we amortized it at 6.0 percent over 30 years, resulting in an annualized value of \$1,696.

Costs Associated with Developing and Maintaining Landscaping

Capital Costs. Based on our experience in landscaping a new half-acre lot, we assumed the total cost of purchasing and installing sprinklers, preparing the soil, planting lawn, and planting trees, shrubs, and flowers at \$7,000. To annualize this amount, we amortized

it at 6.0 percent over 30 years, resulting in an annualized cost of landscaping installation of \$509.

Operation and Maintenance Costs. In the analysis, annual O&M costs included labor, capital, materials, and operating costs associated with: annual replanting and replacement of lawn, trees, shrubs, and flowers; fertilizer, pesticide, and aeration; mowing, gardening, and pruning; and maintenance of the irrigation system. The total annual O&M costs in the analysis were \$1,020.

Net Benefit – Maximum Willingness to Pay

The difference between total annualized costs and annualized value was \$167. When distributed across the 1.35 acre-foot irrigation water requirement, the result was \$124 per acre-foot. It is important to remember that the result is a theoretical upper limit to the average suburban landowner's willingness to pay. Table 1 summarizes the assumptions and the result.

Table 1. Non-Commercial Irrigation Rate – Wasatch County, Utah

Item	Acres	Acre-Feet	Total Costs	Annualized Costs
Typical Small Tract				
Lot Size (Acres):	0.50			
Hardscape (10% of Acreage):	0.05			
Irrigable Acreage:	0.45			
Duty (Acre-Feet/Acre)		3.00		
Irrigation Water Requirement:		1.35		
Median Home Price (Jan 2000)			\$186,800	
Median Home Price (Feb 2005)			\$212,253	
Benefits				
Value of Landscaping (11%)			\$23,348	
Annualized Benefit (30 yrs @ 6%)				\$1,696
Costs				
Capital Costs			\$7,000	
Annualized Capital Costs (30 yrs @ 6%)				\$509
Annual Operation and Maintenance				\$1,020
Annual Costs Sub-Total:				\$1,529
Net Benefits (Maximum Willingness to Pay)				
Total Annualized Benefits				\$1,696
Total Annualized Costs				\$1,529
Net Benefit Per Lot				\$168
Benefit Per Acre-Foot				\$124

At first glance, the \$124 per acre-foot inspires some hope. It certainly is within the specified range--\$100 to \$300 per acre-foot annually; however, sensitivity analysis reveals that the \$124 figure is a number fraught with trouble.

FLAWS IN THE WILLINGNESS TO PAY APPROACH

One of the rewards of any economic, statistical, or numerical analysis is the satisfaction that comes when the numbers tell you something you did not know before. In the sensitivity analysis of the willingness to pay approach, that satisfaction was tempered by bad news: our assumptions had landed us (by coincidence not intelligence) at a pinnacle of optimality--\$124 per acre-foot. It became abundantly clear that the virtues of the model dropped off quickly almost as soon as the assumptions changed—regarding the value of landscaping as a percentage of home value, median home price, and O&M expenses.

Value of Landscaping

Table 2 reveals how hypersensitive the model is to assumptions about the value of landscaping as a percentage of median home value. In the table, boldface type indicates the range of percentages which result in a willingness to pay within the \$100 to \$300 per acre-foot range.

Table 2. Value of Landscaping – Sensitivity Analysis

Value of Landscaping (as a Percentage of Home Value)	Max Willingness to Pay for Irrigation Water
5%	-\$561
6%	-\$447
7%	-\$333
8%	-\$219
9%	-\$104
10%	\$10
11%	\$124
12%	\$238
13%	\$352
14%	\$467
15%	\$581
16%	\$695
17%	\$809
18%	\$924
19%	\$1,038
20%	\$1,152

As Table 2 reveals, assumptions about the value of landscaping must remain within a very narrow range in order to keep the non-commercial irrigation rate within the prescribed range. It is important to remember that many estimates of the value of landscaping were higher—in the range of 17 percent.

Median Home Price

Table 3 uses boldface type to indicate the range of median home values which result in a willingness to pay within the \$100 to \$300 per acre-foot range.

Table 3. Median Home Value – Sensitivity Analysis

Median Home Price (\$000)	Percentage Change in Median Home Price	Maximum Willingness to Pay (Irrigation Water)
\$204	96%	\$74
\$208	98%	\$99
\$212	100%	\$124
\$216	102%	\$149
\$221	104%	\$174
\$225	106%	\$199
\$229	108%	\$225
\$233	110%	\$250
\$238	112%	\$275
\$242	114%	\$300
\$246	116%	\$325
\$250	118%	\$350
\$255	120%	\$375
\$259	122%	\$400
\$263	124%	\$426
\$267	126%	\$451

Table 3 indicates that the model cannot accommodate a decline in median home value. It does accommodate increases of up to 14 percent. The years between 2005 and 2008 have taught us that annual increases and decreases beyond 14 percent are possible—revealing another inadequacy of the model.

O&M Expenses

Table 4 highlights the inverse relationship between O&M Costs and Maximum Willingness to Pay. It clearly indicates that the model can accommodate lower O&M expenses but cannot accommodate increases at all.

Table 4. O&M Expense – Sensitivity Analysis

Annual O&M Costs	Percentage Change in O&M Expenses	Maximum Willingness to Pay (Irrigation Water)
\$765	75%	313
\$790	77%	294
\$816	80%	275
\$841	82%	256
\$867	85%	238
\$892	87%	219
\$918	90%	200
\$943	92%	181
\$969	95%	162
\$994	97%	143
\$1,020	100%	124
\$1,045	102%	105
\$1,071	105%	86
\$1,096	107%	68
\$1,122	110%	49
\$1,147	112%	30

The assumptions regarding O&M costs were particularly imprecise and were probably biased toward the low end. Based on Table 4, it is clear the model cannot absorb higher O&M expenses.

RESULTS OF THE WILLINGNESS TO PAY ANALYSIS

The news is not good. The sensitivity of the model to key assumptions makes it particularly unworkable in selecting a non-commercial rate for an area in which lot sizes and home values cover a wide range. As a result, we quickly abandoned the model. Eventually, the Department of the Interior and the Central Utah Water Conservancy District elected to provide water to small tracts by converting irrigation water to M&I use.

I have to admit to some embarrassment in writing about the inadequacies of the model. It is much more gratifying to add to the store of knowledge through one's brilliance than one's unsuccessful attempts. To have one's best efforts go badly (especially when the initial results seemed quite promising) and then to volunteer to write a paper about it can inspire an existentialist crisis. In Moby Dick, Ishmael describes such feelings and offers a remedy:

“Whenever I find myself growing grim about the mouth; whenever it is a damp, drizzly November in my soul; whenever I find myself involuntarily pausing before coffin warehouses, and bringing up the rear of every funeral I meet; and especially whenever my hypos get such an upper hand of me, that it requires a strong moral principle to prevent me from deliberately stepping into the street, and methodically knocking people's hats off -- then, I account it high time to get to sea as soon as I can.”

Before I take Ishmael's advice and go off to hunt the great white whale, let me offer the following thoughts regarding the search for a non-commercial irrigation rate.

Suburbanites Are Willing to Pay the M&I Rate

There is substantial evidence that owners of small tracts are willing to pay the M&I rate.

First, the assumption regarding the value of landscaping as a proportion of home value in the model was on the low end. Higher values can reasonable be assumed and may be confirmed by additional study. At higher values of landscaping as a proportion of median home price, the willingness to pay easily exceeds the M&I rate (see Table 2).

Second, it is possible to observe willingness to pay M&I rates. Throughout the west, there are communities, similarly-situated, paying different rates for Reclamation water to irrigate small tracts. One will have converted irrigation water to M&I use and its residents will be paying M&I rates. Another will have converted surreptitiously or converted under Footnote 6 and its residents will be paying irrigation rates. The only observable difference between these communities may be a greater willingness to practice conservation among the resident of the community facing M&I rates.

Third, the difference in Reclamation rates is easily absorbed within the budget of most suburban households. If we assume that O&M charges for users of M&I and irrigation water are equivalent, the only difference in the impact on households is the difference in the rate for irrigation and M&I water. On average, most suburban homes use less than one acre-foot of project water for irrigation. The question is whether a suburban household can absorb a \$300 bill. If spread evenly over twelve months, the additional payment is \$25 per month—less than the cost of a family trip to McDonald's.

Small Tract Uses Should Not Be Subsidized

There is no compelling justification for extending the subsidy to suburbanites. It is a simple exercise to imagine what objectives motivated Congress in creating irrigation subsidies as part of the 1939 Act. All of these would be related to the viability of commercial agriculture. None of these probable objectives would apply to suburban America and the irrigation of small tracts. There is no credible objective for protecting lawn irrigators from the full cost of the water's development.

On the other hand, there are ample reasons for ensuring that suburban water users do pay the full cost of water development. Conservation is one.

Maintaining accurate price signals is another. The fact remains that irrigation subsidies are an income transfer from power users to irrigators (both commercial and non-commercial). Assuming there are adequate reasons for such a transfer on behalf of commercial irrigators, it is unclear that any policy objective is served by having West Coast power users pay the irrigation bills of Utah dentists and school teachers.

M&I Rates for Non-Commercial Agriculture Reduce Uncertainty

In administering a water project, consistency and predictability are important. Water user organizations wish to (and may be required to) treat all similarly-situated customers equally and equitably. In making planning and investment decisions, landowners and developers seek foreseeable and predictable conditions. Converting project irrigation water to M&I use before it is applied to small tracts offers consistency and predictability. In the current legal and policy environment, subsidizing rates for non-commercial agriculture does not.

Reclamation has two policy options: keep Footnote 6 or discard Footnote 6. For those who wish to subsidize non-commercial irrigation rates, both options promise unpredictable outcomes.

Keep Footnote 6 . For now, Reclamation appears to have decided to keep the Footnote 6 policy. With Footnote 6 in place, the question of pricing remains—as does the prospect for the Footnote 6-companion water rate policy bursting into being. Under this outcome, water users face an unknown future rate for project water applied to non-commercial tracts.

Discard Footnote 6. Reclamation admits that questions remain as to the legal soundness of applying subsidized irrigation water to landscaping and other non-commercial applications. If Reclamation discards it, no one can predict what the next policy will be and how it will affect rates. Under this outcome as well, water users face uncertainty and unpredictability.

Creating a New Class of Project Water

Finally, pricing non-commercial irrigation at a higher rate than commercial irrigation creates a new class of water. This new class of water may fit into irrigation water provided for miscellaneous purposes under the 1920 Act but, in the main, it would be a new class of water—a class of water unanticipated in general by Reclamation law.

CONCLUSIONS

- A willingness-to-pay approach to developing a non-commercial irrigation rate based upon the value of suburban landscaping is highly sensitive to: assumptions about the value of landscaping; median home price; and O&M expenses.
- The inadequacies of a willingness-to-pay approach to developing a non-commercial irrigation rate call into question the whole notion of a non-commercial irrigation rate.
- Owners of small tracts are willing to pay M&I rates for irrigation water. This willingness can be observed. It is also indicated by the relatively small impact of M&I rates on the household budgets of suburbanites.

- There is no apparent public policy justification for extending all or part of the federal irrigation subsidy suburban tracts.
- There are apparent public policy objectives served by ensuring that suburban water users do pay the full cost of water development. These include encouraging conservation and preserving accurate price signals.
- Reclamation's ambivalence about Footnote 6 creates an atmosphere of unpredictability and uncertainty for water user organizations, water users, and developers. In addition to uncertainty about the rate, there is uncertainty about what laws apply to non-commercial irrigation water (a new class of Reclamation project water) and about how it will be administered.

A SUBDIVISION POLICY FOR AN URBANIZING IRRIGATION DISTRICT

Steven R. Knell, P.E.¹

ABSTRACT

An ever increasing challenge for rural irrigation districts in the agriculturally rich San Joaquin Valley of California is adjusting to urbanization while maintaining an effective and efficient irrigation water delivery system. The Oakdale Irrigation District (OID) is currently facing this challenge and has developed a Subdivision/Parcel Map Development Policy that attempts to bring balance to that concern. This paper will present OID's Subdivision Policy and discuss the reasoning behind the conditions and requirements within the policy. It is the intent of this paper to provide other irrigation districts, facing similar urbanization pressures, a foundation for development of similar policies in the hopes of preserving and protecting the water delivery systems so vital to our agricultural communities.

INTRODUCTION

Oakdale Irrigation District

Oakdale Irrigation District (OID) is located in the northeastern portion of Stanislaus County and is considered the northern boundary of the fertile San Joaquin Valley. OID provides irrigation and domestic water within a service area of 72,345 acres of which approximately 55,000 acres are irrigated farmland. The OID holds a senior water right to the Stanislaus River in addition to managing 27 deep wells and 43 reclamation pumps that provide water to its agricultural customers. Principle crops in the area are irrigated pasture, almonds, walnuts, corn and rice.

Situated an hour and a half east of the San Francisco Bay Area, the Oakdale area is considered within the ideal commute range for a growing number of metropolitan workers. The Oakdale area offers much of what the urban dweller lacks within their own region; that being open space, relatively affordable housing, less crime, increased recreational opportunities and a country atmosphere. All together these amenities amount to an increasing urban inflow and a new set of challenges for an irrigation district. Primary amongst these challenges is how to continue the delivery of irrigation water while wrestling with the demands of facility impacts from a patchwork quilt of sprawling developments.

OID has developed a Subdivision/Parcel Map Development Policy (hereafter referred as Policy) that attempts at one end; to control development which has a negative impact on OID water delivery and drainage facilities and on the other end is pliable enough for developers to work with, such that planned development may enhance the expanding community areas.

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What follows first is a presentation of the Policy itself. The presentation is then followed by a general discussion of certain sections of the Policy for purposes of clarifying the intent of the OID Board of Directors in making such requirements.

SUBDIVISION/PARCEL MAP DEVELOPMENT POLICY

In accordance with the Subdivision Map Act (California Government Code Section 66410 et seq.), a Parcel Map is distinguished from a Subdivision Map by the number of parcels created and its designation when submitted by the appropriate lead agency for review. A Parcel Map can create up to 4 new parcels plus a remainder. A Parcel Map can create more than 4 parcels, and a remainder, if the parcels are 40 acres or greater in size or has a zoning designation of Commercial or Industrial. A Subdivision Map creates 5 or more parcels.

Pursuant to California Law, a parcel map is required when:

1. The land before division contains less than five (5) acres, each parcel created by the division abuts upon a maintained public street or highway and no dedication or improvements are required, or
2. Each parcel created by the division has a gross area of twenty (20) acres or more and has an approved access to a maintained public street or highway, or
3. The land consists of a parcel or parcels of land having approved access to a public street or highway which comprises part of a tract of land zoned for industrial or commercial development, and which has been approved as to street alignments and widths, or
4. Each parcel created by the division has a gross area of not less than forty (40) acres or is not less than a quarter of a quarter-section.

The following are the requirements, recommendations and considerations from the Oakdale Irrigation District (District) regarding development of subdivisions and parcel maps within the District's water service area in accord with and pursuant to the Subdivision Map Act.

Requirements-General

1. The District requires written, recorded easements for all of its facilities within the development area with the recorded instrument number noted on Parcel and Final (Subdivision) Maps.
2. The District requires that its irrigation and drainage easements be clearly identified on recorded Parcel and Final (Subdivision) Maps. Any proposed easements due to relocation requests shall also be identified.

3. The District requires that existing irrigation pipelines, canals, ditches, structures, turnouts and drains on the created parcels (both District and Private) be shown on the Parcel and Tentative Subdivision Maps for review purposes.
4. The District requires full, unencumbered access, as determined solely by the District, to both sides of its facilities and will rehabilitate, at its cost, those facilities within its control that do not meet that standard. This work shall be performed by the District after receipt of recorded easements and prior to signing the Final Map.
5. Relocation of District facilities to the benefit of the development must be coordinated and approved by the District. All costs associated with design, approval and analysis of relocations, including reasonable attorney and consultant fees, shall be at the Developer's expense.
6. The District shall require a Developer Agreement before any work can be done on District Facilities. Developer Agreements require a retainer for staff preparation time and additional related costs reasonably incurred by the District.
7. All irrigation facilities to the benefit of the development shall be built outside the District's easements and rights of way.
8. The District shall not provide water to ponds except as approved by the Board of Directors.

Requirements-Irrigation

1. The historical water delivery point for the developed property will continue to be the point of diversion for the development. No additional irrigation delivery connections will be provided as a result of development unless approved by the Board of Directors.
2. The historical water delivery volume for the developed property will not increase as a result of development. Totalizing flow meters shall be installed, at the developer's expense, to all District approved water delivery points within the development as a condition of project approval. All testing associated with verifying the flow volume shall be performed by the District at the Developer's expense.
3. The historical water delivery point and flow volumes will be determined by the District. The District may, at its sole discretion, reduce the number of historical delivery points on any development.
4. Parcels within the proposed development that will continue to irrigate shall be required to have independent water delivery systems. The independent delivery systems will be served by a cluster well or sump provided at the historical point of delivery by the developer. The District has standard plans available for this purpose.

5. The District will not serve irrigation water to created parcels that are less than 10 acres in size unless approved by the Board of Directors.
6. If parcels created by a Parcel Map or Subdivision Map choose not to irrigate, the Developer may apply to the District for a Surface Water Irrigation Service Abandonment and Quitclaim Agreement. Any Irrigation Service Abandonment Agreement is subject to approval by the District Board of Directors.
7. California Water Code requirements will be enforced on each irrigated parcel to ensure the reasonable and beneficial uses of water. Parcels or lots within developments, which have not shown a reasonable standard of care in the preparation for the receipt of irrigation water, as determined by the District, will not be permitted to irrigate or receive water.

Requirements-Drainage

1. No drainage from residential and rural subdivisions, industrial developments and commercial developments shall be allowed into District facilities. All costs incurred by the District to mitigate or resolve drainage issues shall be at the cost of the Developer, including consultant and/or attorney fees.
2. Drainage from irrigated farmland shall be compliant with the Irrigated Lands Program as administered and controlled by the Central Valley Regional Water Quality Control Board.
3. Drainage from irrigated farmland into a District canal or drain shall be by agreement only and subject to existing District drainage policy.

Requirements-Easements and Encroachments

1. Revocable License Agreements are required for any existing encroachments or proposed improvements within the current or requested District easement.
2. The District requires that its easements, rights-of-way, and fee title property be fenced to District Standards. This cost shall be borne by the Developer. Fencing shall be completed prior to approval of the Final Map. No gates nor cross fencing shall be installed or permitted within these areas without prior written authorization from the District.
3. Existing District facilities within a public road right-of-way shall be relocated into a right-of-way or easement dedicated to the District.
4. Standard Easement widths for District facilities shall be:

Main Canals	100 foot centered on canal
Canals/Drains	60 foot centered on canal/drain

Pipelines	30 foot centered on pipeline
Pipelines adjacent to roadways	20 foot
Pipelines adjacent to PUE	15 foot

Easement widths for joint projects shall meet the above minimum easement widths plus any additional easement width that may be required based on the specific project uses or as approved by the Board of Directors.

5. If an existing District facility is not centered on the property boundary between two properties, the District may require an easement width based on the distance to the centerline of the District facility.

Recommendations and Considerations

1. The developer should provide private irrigation easements for said properties to insure that existing downstream users can have access to irrigation water and can irrigate or continue to irrigate.
2. The developer should provide private drainage easements for the benefit of upstream parcels that have historically drained across newly created parcels.
3. If, upon review, the District determines that parcels created in a Parcel Map or Subdivision cannot irrigate efficiently, based on poor grading and planning, irrigation water will not be delivered until the situation is corrected to the sole satisfaction of the District.
4. “Improvement District” formation should be considered as a mechanism to ensure the responsible long-term operation and maintenance of private irrigation systems and as a means of irrigating parcels or lots developed under the ten-acre minimum.
5. The District would consider financially participating in conjunctive use reservoirs constructed to serve the irrigation needs of the development.

BASIS FOR POLICY REQUIREMENTS

The following section provides some insight and background on the basis for many of the aforementioned policy requirements. Each segment will be addressed in the order it appeared in the Policy.

Requirements-General

During the early development of irrigation districts in California, many of the canals and drains of districts were constructed solely under verbal agreements with underlying landowners who were more than cooperative to have irrigation water delivered to their lands. After so many years, the districts acquired prescriptive rights to the canal or drainage facility, but still no written easement. In today’s “modern” society, while the

importance of irrigation water to the urban dweller has mostly diminished, their desire to challenge the land holdings of the irrigation district has escalated.

Therefore, OID has made it a condition of development that the developer shall provide deeded and recorded easements for all OID facilities within the developed area. In addition, these facilities (whether ditch, pipe, turnout, check, etc.) will be clearly identified and marked on the Tentative Maps.

The loss of facility access in OID is one of the biggest impediments caused by urban development. To ensure no further loss of access occurs, OID intends to go in and reconstruct its facility within developing areas to re-establish its footprint. By doing so, with proper markers, fences, etc., not only does it become more difficult to encroach upon OID facilities, it makes illegal encroachments more visible. The old adage about “fences make good neighbors” is never truer than it is today. OID views fencing as a new expense worth the investment as a means to insure continued access.

The desire to have a pond by small ranchette owners who purchase rural acreages is problematic for OID. Most believe this is a right associated with land ownership and new urban land owners share little sympathy or understanding with the reasonable and beneficial use standards applied to water in California. Early denial of such planning efforts when caught in the planning process is the best tool to curb this practice.

Requirements-Irrigation

Much of this section of the Policy is fairly self explanatory, but the largest premise here is; OID will not accept additional new turnouts as a result of development. A 40-acre parcel broken into eight 5-acre parcels adds a net seven (7) customers to what previously was one. The increased labor demand on an irrigation district can be substantial and it is not an expense OID wishes to pass on to its existing customers.

Likewise, on issues related to billings and non-payments, shut-off events are more easily controlled and performed if each resident has their own individual shut-off valve located at a cluster well accessible by the irrigation district. This is why the OID reserves the right to dictate the location of the point of water delivery for each development.

The 10-acre limitation for receipt of water delivery is an attempt to differentiate between true agricultural usage and non-agricultural usage (i.e. ranchette water) for purposes of billing structure in the future. It is also an attempt to further limit the 1 and 2 acre parcels that seem to be appearing in the countryside from 40 acre parcel owners wishing to cash in on high land values.

As always, the OID wishes to further influence the need for good water management practices even on small acreages. As OID’s own policy dictates, if the land is not prepared for the receipt of irrigation water, it may not be delivered. This standard applies to all landowners equally.

Requirements-Drainage

Changes in the laws concerning agricultural drainage in California are putting an ever increasing demand on drainage water containment. Current policy in OID requires the agricultural discharger to have a drainage agreement from the OID before runoff water will be accepted into OID facilities.

Approximately 10 percent of OID is in San Joaquin County. The storm containment policy of that county is the 50-year storm event. The remaining 90 percent of OID within Stanislaus County has a storm containment requirement for the 25-year event. Any exceedences of these events are considered “acts of God” and beyond the control of OID should these waters enter an OID facility.

In the Central Valley of California the Regional Water Quality Control Board has put requirements on the drainage of water, both irrigation and stormwater on owners of lands outside city defined boundaries. These requirements are the responsibility of the landowner and it is OID’s intent to steer landowners to seek the compliance guidelines from the Regional Water Quality Control Board before accepting any drainage waters into its system.

Requirements-Easements and Encroachments

The Policy intent is not to permit the permanent installation of any encroachment not integral to the delivery of irrigation water. That being said, OID’s use of a Revocable License Agreement ensures this legal control.

The ability to fence an easement in California is precluded by law unless that right is waived by the underlying landowner. OID, as a condition of development, requires that the developer give up that right and give an easement to OID waiving their rights. This requirement ensures that OID’s facility footprint is established prior to the creation of multiple parcels.

Recommendations and Considerations

Beyond the easement and rights of way boundaries of the OID, OID is precluded from placing conditions or requirements on land not within its control. However, it does not preclude the OID from making recommendations or considerations to developers during the development process. This section of the Policy is an attempt to deal ahead of time with many of the post-development issues OID encounters resulting from poor planning of subdivisions and/or parcel splits. After development, unsuspecting urbanites, with preconceived premises of country living, come to the OID seeking assistance in obtaining water. Often, their premises and OID policy requirements are at odds.

The OID irrigation system was laid out to provide water to the quarter section (160 acre parcel). Upon OID meeting that requirement, all systems emanating from that point are considered private systems and the responsibility of the benefiting landowners. When

new property owners come to OID seeking water, OID informs them of the nearest point of delivery and their obligation to get the water to their lands. Often this requires crossing another parcel or parcels to accomplish that effort. This is the most common issue OID faces with new small parcel owners. As such, OID recommends that the ability to bring water to a new parcel be addressed by providing legally dedicated irrigation easements for that purpose.

As enthusiastically as the above easements are sought for irrigation, dedicated drainage easements are equally suggested. For any seasoned veteran in agriculture, the need for drainage pathways seems intuitively obvious. For the urbanite however, this is not the case. Their past world has dealt with water flowing to the front of the lot, into the street, down the gutter and into a storm drain system. In the county however, the storm drain system is above ground, and if one purchases low-land properties, one ends up seeing quite a bit of that flow across their property. This issue consumes more field staff time than any other issue faced at OID. Having defined drainage easements attached to property titles goes a long way in quelling complaints.

To address both the above issues, OID encourages the formation of “Improvement Districts” as a means to operate and maintain common irrigation and/or drainage facilities within developments. These organizations, outlined in California’s Water Code (§ 23600), provide a sense of certainty for small parcel owners that their irrigation and drainage needs will be met financially for years to come.

Landowners within rural subdivisions or small parcel owners in the country, if not retired and not farming for a living, have another job. If they are a daily commuter, they travel long distances consuming a good portion of each and every day of the week. Their need to take care of their properties then is usually relegated to weekends, including the need to irrigate.

In its intent to adjust to a changing customer base, OID is open to the development of multi-functional reservoirs within developments. OID offers to each development the opportunity to build reservoirs that serve both a function to the development and also OID. This offering is predicated on the idea that a reservoir could be constructed within the development, sufficient in size to accommodate the weekend water needs of the development. In short, irrigation water would be available Saturday and Sunday within the development.

During the Monday through Friday time period, when not in use or needed, OID could use the reservoir as an intermittent storage or delivery facility to meet its agricultural demands. However, always leaving the reservoir full come midnight on Friday. Costs for this division of use are left to be negotiated on a case by case basis.

SUMMARY

Portions of OID’s Subdivision/Parcel Map Development Policy have been in effect for a number of years. However, the recent surge in developments, subdivisions and the

parceling out of Oakdale's rural countryside has prompted OID to take a more proactive roll in protecting its' irrigation and drainage interests.

It would be futile to attempt to change the course of the community's growth. However, Oakdale is still a heavy agricultural area producing a way of life and a national product (food) that needs to be protected. The end result OID strives for in its policy is balance. A balance in the protection of an irrigation district's ability to provide for the efficient operation and maintenance of its water delivery and drainage facilities with the needs of professional well planned developments that strive to meet the quality of life needs of our growing rural community.

URBANIZATION OF IRRIGATED AGRICULTURAL LAND IN EL PASO COUNTY, TEXAS

A.W. Blair, P.E.¹
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ABSTRACT

The El Paso County Water Improvement District No. 1 (the District) is a political subdivision of the State of Texas providing irrigation and drainage of agricultural land within the Texas portion of the federal Rio Grande Reclamation Project (Project). The issues discussed in this paper regarding urbanization of District irrigable land are categorized into three general topics:

- 1) Increased demand for irrigation water for municipal use,
- 2) Increased demand for third-party use of District property and rights of ways, and
- 3) Increased operations and maintenance cost resulting from development of land adjacent to the District's facilities.

This paper summarizes the litigation that resulted from urbanization from 1949 to present, the agreements for water use between the United States, the City, and the District, and the administrative and operation methods implemented by the District to mitigate the damage to the District facilities caused by the urbanization of irrigated land.

INTRODUCTION AND BACKGROUND

The Rio Grande Project (Project) is a federal reclamation project that was authorized by Congress in 1905 and consists of 159,650 acres of irrigable land in the Rincon, Mesilla, and El Paso valleys of New Mexico and Texas (see Figure 1). The Rio Grande Project extends from the headwaters of Elephant Butte Reservoir in New Mexico to approximately 75 miles southeast of El Paso. Elephant Butte Dam was completed in 1916. The use of Project water is governed by federal reclamation law, the interstate Rio Grande Compact, and the Treaty of 1906 with the Republic of Mexico. The three irrigation districts that use Project water are the Elephant Butte Irrigation District (EBID) in New Mexico, and the El Paso County Water Improvement District No. 1 (District) and Hudspeth County Conservation and Reclamation District No. 1 (HCCRD) in Texas. EBID and the District are allocated Project water by the Bureau of Reclamation (Reclamation) and HCCRD uses Project return flow and spill water.

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At the time the Project was constructed between 1916 and 1928 the population of El Paso was less than 50,000 people. Currently, the City of El Paso (City) has a population of over 650,000 people. The City divides the District into two areas as shown in the aerial photograph in Figure 2. The northern (upper) part of the District is within the Texas portion of the Mesilla Valley, and the southern (lower) part of the District is within the El Paso Valley.

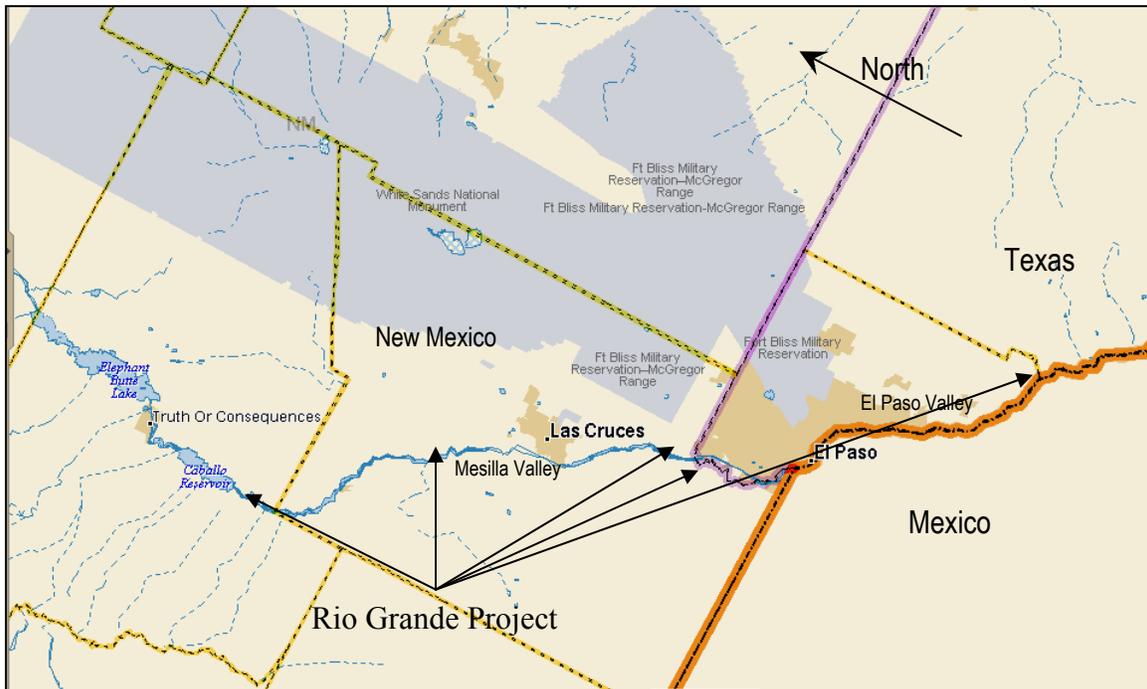


Figure 1. Rio Grande Project

Increased Municipal Demand for Project Water

During the build-out of the Project from 1916 to the late 1930's the City was invited to participate in funding a portion of the Project construction costs in return for contractual rights to Project water. During the build-out of the Project the City turned down the United States invitations, claiming the City had no need for surface water because of an inexhaustible supply of less expensive groundwater. Starting in 1941 the City of El Paso realized its need for surface water. In 1941 the City entered into a contract with the United States and the District to provide for the delivery by the United States to the City a limited supply of Project water based on the amount of irrigable land owned by the City. This contract was modified in 1944 to include land within EBID.

On November 1, 1948 the City of El Paso filed an application with the Texas Board of Water Engineers for a permit to appropriate, store, and divert 27,000 acre-feet per year of water from the Rio Grande including some of the return flow Project water used by HCCRD and EPCWID. The application was contested by the District and others and ultimately a compromise settlement resulted in 1949 in the form of a contract among the District, the City, and the United States. In the early 1950's federal litigation between the

United States, the City, and District was initiated regarding riparian rights on the Rio Grande and the fact that the City had commenced pumping water from the District's irrigation canal without the District's or the United States' approval. After several years of litigation, on August 1, 1955 Judge Dooley issued his opinion (133 F Supp. 894, United States District Court for the Western District of Texas, El Paso Division) regarding the City's claim of riparian rights to Project water and in part stated:

In any event, an analysis of the [Rio Grande] Compact shows convincingly that the water belonging to Texas is definitely committed to the service of the Rio Grande Project. This Compact is binding on Texas and the Defendant City and, for that matter, is binding on the inhabitants and citizens of Texas.

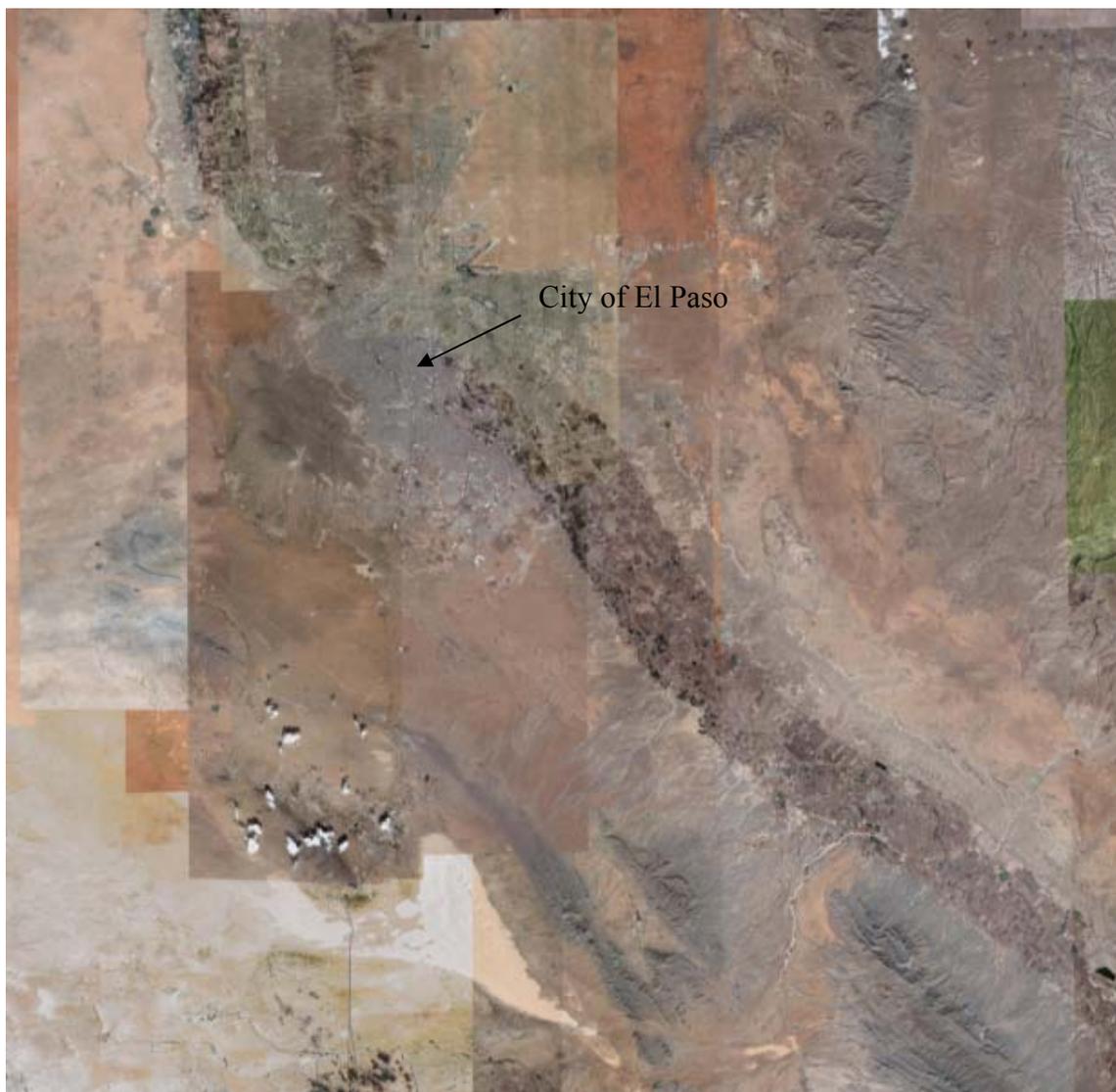


Figure 2. Aerial Photograph of the El Paso Region of the Rio Grande Project

During the 1980's the City applied for water well permits in the New Mexico portion of the Project which resulted in over ten years of contentious litigation between the City and various New Mexico entities. The litigation resulted in a settlement that required the City to conserve and make use of water resources other than groundwater located in New Mexico.

In 1961 Texas passed the Surface Water Adjudication Act which, in part, required the adjudication of all existing surface water use throughout the 31 river basins in Texas. Because of the diversity of the Rio Grande Basin, the adjudication was broken into four sections: Lower Basin, Middle Basin, Upper Basin downstream of Ft. Quitman, Texas, and Upper Basin upstream of Ft. Quitman, Texas. The El Paso area is upstream of Ft. Quitman. Because of the complexity of interests and federal laws within this section of the Rio Grande Basin it was the last basin to be adjudicated within Texas. After years of legal hearings, the final judgment was issued in early 2007, and it provided, in part, that the City could divert from the Rio Grande 11,000 acre-feet of Project water with Reclamation's approval and under the condition that the water was not needed by the District or HCCRD.

In 2000, the City filed litigation in state court against the District regarding water rights contract issues. The litigation was removed to federal court and the United States was joined as a party. The litigation was settled in 2001, in part, through a comprehensive agreement between the United States, the City, and the District that made available by contract approximately 18,000 acre-feet of water to the City salvaged as a result of canal lining and other water conservation projects.

In 2007, the City expanded its litigation efforts to include real property issues, this time claiming unfettered use without any compensation of the District's irrigation and drainage canals for pipelines, roads, and storm drains. The litigation was settled with an agreement providing for the City's water utilities to obtain, for a fee, the limited use by license for several hundred existing utility crossings of District's canals and rights-of-ways, and that the City would use the District existing license procedures for any new uses.

Currently, the City has access to approximately 70,000 to 80,000 acre-feet of Project water during years when Reclamation makes a full allocation. The three primary mechanisms by which the City has acquired the use of Project water are by: 1) lease of use rights appurtenant to irrigable land that has been subdivided into parcels less than 2 acres in size, and designated for residential or commercial use, 2) water salvaged by conservation projects, or 3) through the purchase and fallowing of irrigable land. The amount of water made available to the City as a result of canal lining projects and improvements in the District's delivery efficiency is approximately 34,000 acre-feet per year or over 40% of the City's allocation in a full allocation year.

The above contracts limit the amount of fallow land to 3,000 acres. During the first year of the ongoing drought in the Project, the City, Reclamation, and the District entered into a 4-year forbearance agreement that allowed for a limited amount of Project water to be converted from irrigation to municipal use on a year by year basis. This agreement

required the City to execute standardized contracts with irrigable land owners. The contracts provided for payments to the land owner if the land owner was willing to temporarily forebear the use of irrigation water. The agreement expired without any contracts being executed and there does not appear to be any interest by the City to renew the forbearance agreement.

INCREASED DEMAND FOR USE OF RIGHTS-OF-WAYS

The District's irrigation and drainage canals (rights-of-ways), for the most part, run parallel to the Rio Grande and portions of the Mesilla and El Paso valleys. Many parcels of land are bordered on two or more sides by District property. The demand for use of these rights of ways for roads, water, gas, petroleum, and sewer pipelines, electrical power, subdivision entrances, buried and aerial cables, and other uses has increased geometrically each decade. Currently, the District has several hundred applications for use of District property under review. The licensing process attempts to minimize the damage caused by each proposed use and provides for administrative process for approving any license and provide for enforcement by the District of any violation of the license. As an example Figure 3, shows an aerial photograph of a highway crossing the seven of the District irrigation and drainage canals.

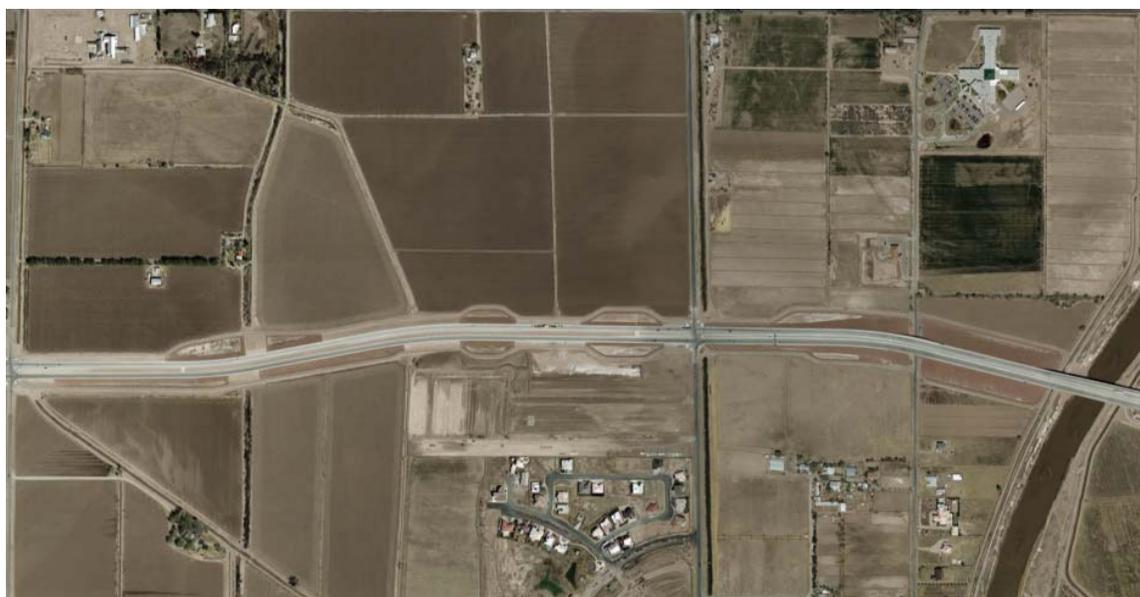


Figure 3. Aerial Photograph of Highway Crossing District Facilities

The primary problems caused by the highway crossings shown in Figure 3 include increased maintenance problems (trash and sediment accumulation) at each of the canal culverts or siphons, and increase transportation time and cost for patrolling or maintaining the canals. For example, most of the District's drainage canals are periodically maintained using large track excavators. Whereas, prior to the highway's construction, these excavators could move down the O&M road unimpeded, after the highways' construction the excavator must stop at the highway, be loaded onto a transport trailer and hauled around the highway to the other side. The transportation and

the lost productivity come at significant cost to the District. The present value of the total cost to the District for a typical highway crossing that cuts-off district thoroughfares ranges from several hundred thousand to over a million dollars.

The District prepared a “License Manual” that contains information regarding the engineering design, land surveying, and legal procedures required to obtain a license from the District to use any of the District facilities. A copy of this manual can be downloaded at EPCWID’s web site at www.epcwid1.org. All licenses must be approved by the District’s board before the applicant can use any District property.

INCREASED OPERATION AND MAINTENANCE COST DUE TO URBANIZATION

Figure 4 shows an example of the large amount of housing subdivisions that have been built on irrigable land within the District. The increase population density results in an increased amount of vandalism, trespass, encroachment, and dumping of trash. El Paso County has private trash collection for a fee. Often, even though it is illegal, trash is dumped into the District irrigation and drainage canals to avoid paying the fee and for the convenience of location. Each year the magnitude of the amount of trash increases significantly. Because of disposal fees, used tires are common items that are discarded into drainage canals. Currently, Hudspeth County provides trash collection as a service paid through property and other taxes, and as a result very little trash is disposed of in



Figure 4. Example of Urbanized and Irrigated Land within the Irrigated Portion of El Paso County

HCCRD's canals. The estimated cost to the District for trash removal ranges from three hundred to five hundred thousand dollars per year.

MITIGATION OF DAMAGES CAUSED BY URBANIZATION

The District has addressed each of the three urbanization issues by the following efforts:

Increased demand for irrigation water for municipal use.

Establishment of contracts and procedures for conversion of irrigation water appurtenant to irrigable land to municipal use after such land is subdivided for non-agricultural purposes;

- a) Continuous effort to increase the reliability and quantity of water available for both irrigation and municipal use;
- b) Establishment of a program to assist water users wishing to irrigate small (less than 2 acres) parcels of irrigable land;
- c) Strong technical and legal support regarding all water rights and property issues; and
- d) Good day-to-day communication between District water delivery and City water treatment staff.

Increased demand for third-party use of District property and rights of ways.

Establish a formal administrative process for accepting applications for use of district property and the processing of the application;

- a) Document and make public via the internet the administrative procedures required to obtain a license;
- b) Work with other government entities to establish standard license forms acceptable to all parties; and
- c) Provide digital access to District records and maps.

Increased operations and maintenance cost resulting from development.

Work with City Council and County Commissioners to pass ordinances requiring approval of subdivisions by the District prior to platting;

- a) Address urban trash issue through adoption of county wide trash collection; and
- b) Work with the County Sheriff and City Police departments, and Justice of the Peace regarding enforcement of existing laws.

SUMMARY

The urbanization of irrigable land within EPCWID has reduced the total amount of irrigated land from 69,010 acres in the late 1940's to less than 50,000 acres in 2007. Estimates of the amount of total amount land that will be irrigated in future years are uncertain, but each year irrigable land is subdivided for non-agricultural use. It is likely that even in the year 2050 there will still be a significant amount of irrigated land.

Many years of litigation and negotiation have resulted in agreements between the EPCWID, the City of El Paso, and the United States for the conversion of the use of water from irrigation to municipal purposes. The water made available to the City under these agreements was a result of either water conservation savings projects or the conversion of irrigated land to residential or municipal use.

Many irrigation districts that currently have a relatively minor amount of urbanization activity need to set in place today procedures and policy that will help the district manage its future problems.

REFERENCES

Rio Grande Reclamation Project Act, February 25, 1905, 33 Stat.814.

Convention with Mexico providing for the equitable distribution of the water of the Rio Grande, 1906, 34 Stat. 2953.

Contract among the United States, the El Paso County Water Improvement District No. 1, and the City of El Paso, 1941.

Contract among the United States, the El Paso County Water Improvement District No. 1, and the City of El Paso, 2001.

Dooley, 1955, 133 F Supp. 894, United States District Court for the Western District of Texas, El Paso Division.

SNWA'S DEVELOPMENT OF VIRGIN AND MUDDY RIVER WATER RIGHTS USING INTENTIONALLY CREATED SURPLUS

Colby N. Temple¹
Amber Cunningham²

ABSTRACT

The Southern Nevada Water Authority (SNWA) is a cooperative agency formed in 1991 to address Southern Nevada's unique water needs on a regional basis. Seeking new water to meet escalating urban demands as well as providing resources not linked to the drought stricken Colorado River, SNWA began developing what it coined “in-state water resources”. SNWA began by purchasing agricultural surface water rights along the Muddy and Virgin Rivers to convert to M&I use. Both the Muddy and Virgin River flow to Lake Mead however there was resistance to SNWA from using its existing infrastructure in Lake Mead to retrieve these water rights. In lieu of a proposed 66 mile pipeline and water treatment plant to export the water from the rivers and travel overland to SNWA’s service area, the Seven Colorado River Basin States came up with a proposal to allow prior perfected water rights and conserved water on tributaries of the Lower Colorado River to be utilized from the mainstem of the Colorado River through a mechanism called Tributary Conservation Intentionally Created Surplus. Operational guidelines adopted by the Bureau of Reclamation in December 2007 included this mechanism. The mechanism provides for leaving flows in-stream and in some cases augments river flow which will be beneficial to wildlife. Also, 5% of the total water conserved will be left in the Colorado River System enhancing the water in storage and available for future needs. Additionally leaving flows in-stream is more cost effective for the irrigation companies and SNWA. SNWA can provide more flexibility to the irrigation companies in their daily and long-term operations.

INTRODUCTION

In Nevada the Virgin and Muddy Rivers provide tributary flows to the Colorado River system at the Overton Arm of Lake Mead. Some of the water rights on the Muddy and Virgin Rivers used for agriculture were decreed and in use prior to the effective date of the Boulder Canyon Project Act. Recently SNWA has purchased and leased some of these rights.

In order to transport the acquired water rights to their service area, Clark County, Nevada including the Las Vegas Valley, SNWA proposed to build an expensive 66 mile pipeline, water treatment plant, and appurtenant facilities overland and divert their rights prior to reaching the mainstem of the Colorado River. However, on December 13, 2007, the Secretary of the Interior signed a Record of Decision for the “Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead” (Interim Guidelines). One element of the Interim Guidelines is a mechanism

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called Intentionally Created Surplus (ICS) which is designed to encourage and account for augmentation and conservation of water supplies. SNWA will use one category of this mechanism, Tributary Conservation ICS, to create credits for conveying its Muddy and Virgin River rights to Lake Mead. These credits can later be diverted by SNWA through its existing Lake Mead intakes.

BACKGROUND

The eight-year period from 2000 through 2007 was the driest eight-year period in the 100-year historical record of the Colorado River. This drought in the Colorado River Basin has reduced Colorado River system storage, while demands for Colorado River water supplies have continued to increase. The Secretary of the Interior, acting through the Bureau of Reclamation (Reclamation) proposed to adopt specific interim guidelines for Colorado River Lower Basin shortages and coordinated operations for Lake Powell and Lake Mead, particularly under low reservoir conditions.

A unique and remarkable consensus emerged in the basin among stakeholders through the course of the study effort. This consensus had a number of common themes: encourage conservation, plan for shortages, implement closer coordination of operations of Lake Powell and Lake Mead, preserve flexibility to deal with further challenges such as climate change and deepening drought, implement operational rules for a long – *but not permanent* – period in order to gain valuable operating experience, and continue to have the federal government facilitate – *but not dictate* – informed decision-making in the Basin.

Four operational elements were analyzed in the Environmental Impact Statement (EIS): discrete levels of shortage volumes associated with Lake Mead elevations, coordinated operations between Lake Powell and Lake Mead, storage and delivery of conserved water, and revision to the Interim Surplus Guidelines. The third element, storage and delivery of conserved water as implemented in the Interim Guidelines as Intentionally Created Surplus authorizes several categories of ICS.

INTENTIONALLY CREATED SURPLUS

ICS is defined in the Interim Guidelines as “a mechanism to encourage and account for augmentation and conservation of water supplies...that would minimize the likelihood and severity of potential future shortages” (2007, Record of Decision). Categories of ICS include Imported ICS, System Efficiency ICS, Tributary Conservation ICS, and Extraordinary Conservation ICS. Land fallowing, canal lining, desalination programs, system efficiency projects, and conserving water on tributaries to the Colorado River are all examples of ICS that would fall into the categories listed above.

SNWA plans to use Tributary Conservation ICS for its Muddy and Virgin River water rights. Tributary Conservation ICS may be created by a contractor by purchasing

documented water rights on the Colorado River system tributaries within a Contractor's³ state if there is documentation that the water rights have been used for a significant period of years and that the water rights were perfected prior to June 25, 1929 (the effective date of the Boulder Canyon Project Act).

The pre-Boulder Canyon Project Act water rights SNWA acquired on the Virgin and Muddy Rivers will be retired from their current use (primarily agriculture) and the water secured by SNWA through this process would flow into Lake Mead for delivery for municipal and industrial purposes during shortage or ICS surplus years. For any contractor creating ICS, "there shall be a one-time deduction of five percent (5%) from the amount of ICS in the year of its creation. This system assessment shall result in additional system water in storage in Lake Mead." (Record of Decision 2007) Tributary Conservation ICS credits that are not used in the year they are created and stay in the system are automatically converted to a different category of ICS, Extraordinary Conservation ICS (EC ICS) and subject to annual evaporation losses.

The maximum amount of EC ICS credits that can be created during any year, the maximum cumulative amount of EC ICS credits that can be available at any one time, and the maximum amount of EC ICS credits that may be recovered in any one year under the proposed action are presented in Table 1.

If flood control releases occur, EC ICS credits would be reduced on a pro-rata basis among all holders until no credits remain. The remaining credits could then be used during any year with "normal" operating conditions when an ICS surplus condition has been declared. During shortage conditions EC ICS credits can not be used. For the purposes of calendar year determinations of surplus, normal, and shortage conditions, EC ICS credits would be considered system water – helping avoid shortages in the Lower Basin.

³Contractor is defined in the Record of Decision as an entity holding an entitlement to Mainstream water under (a) the Consolidated Decree, (b) a water delivery contract with the United States through the Secretary, or (c) a reservation of water by the Secretary, whether the entitlement is obtained under (a), (b), or (c) before or after the adoption of these Guidelines.

Table 1. Extraordinary Conservation Intentionally Created Surplus
Limitations of Extraordinary Conservation ICS

Entity	Maximum Annual EC ICS Creation (kaf)	Maximum Cumulative EC ICS (kaf)	Maximum Annual EC ICS Delivery (kaf)
Arizona	100	300	300
California	400	1,500	400
Nevada	125	300	300
Total¹	625	2,100	1,000

1 It is anticipated that the ICS mechanism will be implemented to allow a maximum cumulative amount of ICS that would be available at any one time of up to 2.1 maf.

SNWA, and others wishing to create any of the four categories of ICS will be required to submit a plan to the Secretary demonstrating how all requirements of the guidelines will be met (Section 3B.1, Interim Guidelines) This plan must include the following at a minimum:

- Project description, including what extraordinary measures will be taken to conserve or import water;
- Term of the activity;
- Estimate of the amount of water that will be conserved or imported;
- Proposed methodology for verification of the amount of water conserved or imported; and
- Documentation regarding any state or federal permits or other regulatory approvals that have already been obtained by the Contractor or that need to be obtained prior to creation of ICS.

In addition, SNWA will also be required to submit for the Secretary's review and verification, appropriate information, as determined by the Secretary, contained in a Certification Report, to demonstrate the amount of ICS created and that the method of creation was consistent with the SNWA's approved ICS plan.

HYDROLOGY OF THE MUDDY AND VIRGIN RIVER

Lower Virgin River

The Virgin River occupies a 6,000 square mile watershed situated between the Colorado Plateau, the Great Basin, and the Mojave Desert, within the states of Nevada, Arizona, and Utah (see Figure 1). The Virgin River is tributary to the Colorado River and discharges to Lake Mead approximately 60 miles upstream of Hoover Dam. The river begins in Washington County, Utah, at an elevation of approximately 10,000 feet above mean sea level (AMSL), some 150 miles from its mouth.



Figure 1. Virgin River

Flows in the Virgin River are principally influenced by snowmelt in the mountains in southwestern Utah and flooding from summer monsoonal storms. The Littlefield gage is located upstream of the Bunkerville and Mesquite Irrigation Companies. Gage flows are highly variable as seen in Table 2. A maximum discharge of 36,500 cubic feet per second (cfs) was recorded in 2005 and a minimum daily flow of 40 cfs was recorded in 1966. Currently, there is no operational gage below the Bunkerville and Mesquite diversions and their respective agricultural return flows. However, the Halfway Wash Gage was operated from 1977 to 1983 and in 1985. The gage record for this site was reconstructed by Bache et al. in 2006 and shows an annual average flow of 144,800 afy. This is approximately 30,000 afy lower than the flow at the Littlefield Gage.

Muddy River

The Muddy River watershed is located in Nevada, immediately northeast of the Las Vegas Valley. The Muddy River discharges to Lake Mead approximately 60 miles upstream of Hoover Dam. Before the construction of Hoover Dam and the subsequent flooding of the Colorado and Virgin River Valleys, the Muddy River discharged to the Virgin River, upstream of the confluence of the Virgin and Colorado Rivers.

The highest point in the watershed is Hayford Peak at elevation 9,912 ft AMSL in the Desert National Wildlife Refuge, north of the Las Vegas Valley. The headwaters of the Muddy River's longest tributary are in Lincoln County, at an elevation of approximately 7,300 ft AMSL near the Utah border, nearly 100 miles upstream of Lake Mead. The watershed includes the Pahrnagat Valley near Alamo. The Pahrnagat Wash flows through the Pahrnagat Valley and southward into Coyote Spring Valley, where it joins the Muddy River. The Muddy River continues to the southeast, passing through Arrow Canyon, before it heads southeast, emerging into the Moapa Valley. In its lower reach, the Muddy River passes the towns of Moapa, Glendale (at Interstate-15), Logandale, Glassand, and Overton before discharging to Lake Mead. Glendale is located about 4 miles upstream of the existing Bowman Reservoir, a 4,000 acre-feet surface storage reservoir. Several washes contribute flow to the River along its course, the largest of which is Lower Meadow Valley Wash. Lower Meadow Valley Wash joins the river near the intersection of the river and Interstate-15 in Glendale.

Irrigated agriculture is practiced along the flood plain of the lower Muddy River near Moapa and further downstream between Logandale and Overton.

Unlike the Virgin River, which gains the majority of its flow from snow melt and rainfall events, a substantial portion of the Muddy River flows are from spring discharges in the Warm Springs area northwest of Moapa. Because of this, the Muddy River has a more stable base flow and has less variance in annual discharge; however, floods from the Pahrnagat River or Lower Meadow Valley Wash can cause large spikes in river flow. The United States Geological Survey (USGS) maintains a series of gaging stations on the Muddy River shown in Figure 2. Table 3 summarizes data of three USGS gaging station located along the river.

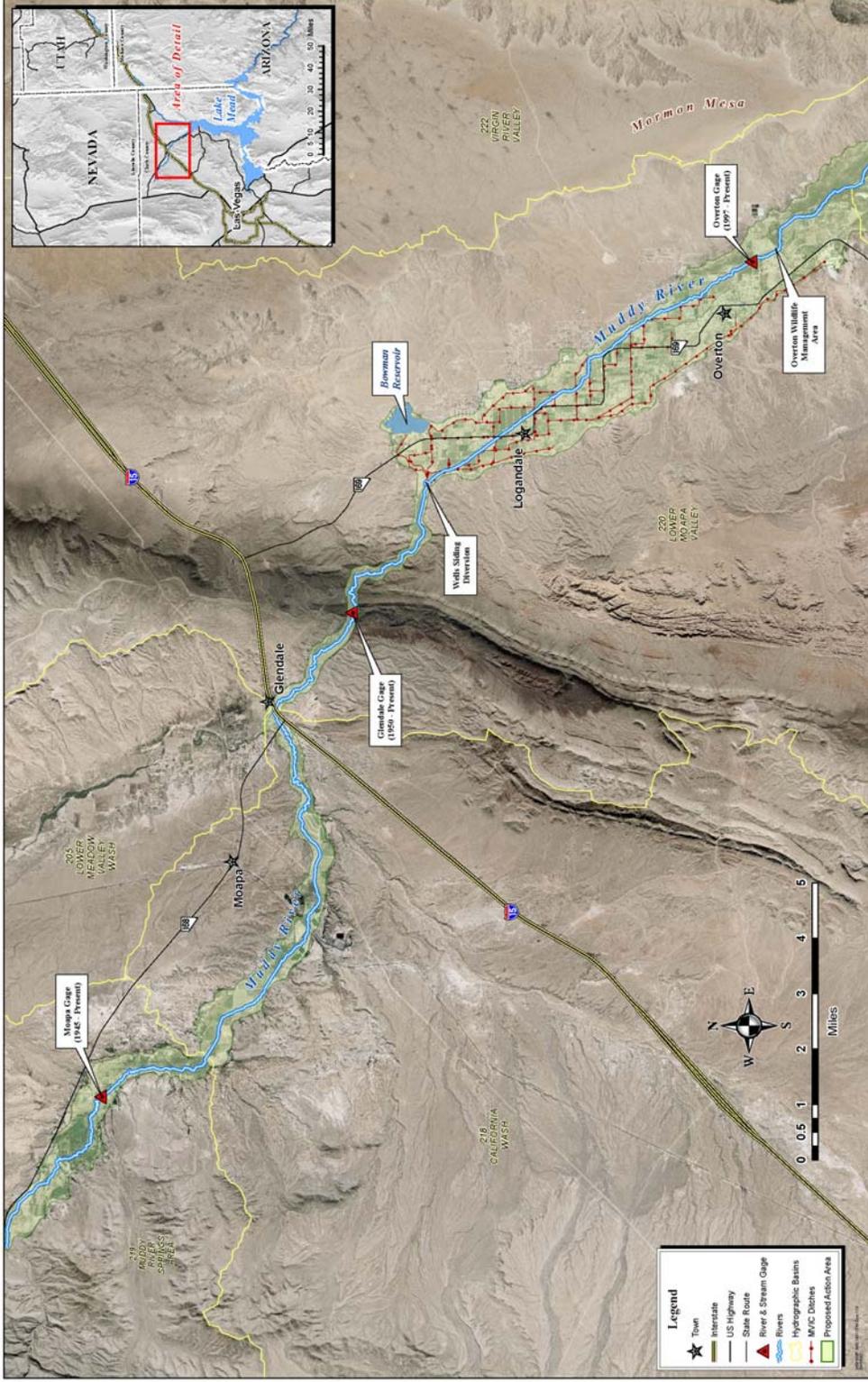


Figure 2. Muddy River

Table 2.
USGS Gage Record on Virgin River

USGS ID	Common Name	Period of Record	Virgin River												Annual
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
9415000	Littlerfield	1930-2006	9,470	11,426	13,713	15,988	17,829	22,260	24,161	26,380	8,688	6,641	10,638	8,926	176,422
			38,372	32,849	76,682	143,094	129,413	110,995	82,420	132,948	66,591	23,429	60,017	43,858	
			2005	1947	1967	2005	1980	1995	1969	2005	1983	1932	1932	1939	
			3,284	6,010	6,826	6,641	5,989	5,251	3,666	3,068	2,785	3,173	3,062	3,172	
			1965	1991	1964	1964	2002	1977	1934	1990	1964	1965	2002	1964	

Table 3.
USGS Gage Records on Muddy River

USGS ID	Common Name	Period of Record	Muddy River												Annual
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
9416000	Moapa	1913-2006	2,423	2,476	2,638	2,687	2,438	2,650	2,452	2,515	2,291	2,349	2,411	2,386	29,727
			3,806	3,666	3,376	3,407	3,255	3,290	3,118	2,982	2,743	3,474	3,757	5,427	
			1973	1961	1960	1960	1914	1958	1965	1958	1957	1984	1990	1967	
			1,396	1,601	1,722	1,759	1,683	1,753	1,845	1,968	1,750	1,765	1,679	1,506	
			2004	2002	2002	2004	1997	2005	2003	2006	2004	2004	1995	2003	
9419000	Glendale	1950-2006	2,275	2,636	2,779	3,241	2,971	3,210	2,517	2,324	1,988	2,017	2,454	2,428	30,886
			3,751	12,437	5,989	22,998	12,775	14,574	5,951	2,952	3,011	3,167	8,363	13,390	
			1973	1961	2005	2005	1993	1983	1969	1991	1965	1961	1981	1998	
			1,464	1,773	1,882	1,906	1,777	1,814	1,631	1,734	1,404	1,433	1,482	1,464	
			1997	1996	1997	2004	1997	1989	1989	1997	1997	1990	2001	1996	
9419507	Overton	1998-2004	965	905	658	547	794	996	899	689	483	603	581	1,113	9,254
			1,457	1,262	1,088	756	1,833	1,537	1,214	1,039	821	1,304	1,138	3,344	
			1999	2000	1999	2000	1998	2000	1998	1999	1999	1998	2000	1998	
			595	470	489	439	349	627	514	536	350	313	362	436	
			2002	2002	2002	2004	2004	2003	2002	2003	2004	2004	2004	2001	

The Muddy River is generally divided into two portions when addressing surface water rights, the area above Wells Siding Diversion (Upper Muddy River) and the area below (Lower Muddy River). The Muddy River decree allocated between 4,000 and 5,000 afy to users upstream of the Wells Siding Diversion (Upper Muddy River) and the entire remaining flow of the river at the Wells Siding Diversion to the Muddy Valley Irrigation Company (MVIC). SNWA's current ownership on the Upper Muddy River is limited to a 1,000 afy lease from the Church of Jesus Christ of Latter Day Saints (LDS Church). This water was historically used primarily upstream of the Moapa Gage, but some of the leased water currently flows in the river channel. In recent years, the lands along the Upper Muddy River have been used for livestock, not active farming, resulting in a lower water use than what was historically used and decreed.

In the Lower Muddy River, the surface flows are measured at the Overton Gage which averages approximately 9,000 afy. The Overton Gage is very near the top of full pool elevation in Lake Mead (1,229 ft-AMSL). Therefore, this gage is believed to reflect surface water flows reaching Lake Mead. While there have been no studies confirming irrigation system losses to the alluvium, it is believed that there is water bypassing the Overton gage as underflow from irrigation system losses.

WATER RIGHTS

The Virgin River was decreed by the Nevada Supreme Court in 1927. The decree allocated 17,785 acre-feet per year (afy) to the Bunkerville and Mesquite Irrigation Companies. SNWA currently owns shares in the Bunkerville Irrigation Company representing approximately 3,700 afy of surface water rights.

On the Muddy River, water rights were decreed in 1920 and that decree allocated the entire flow of the Muddy River. On the Lower Muddy River, the entire flow of the river is diverted by the MVIC for agricultural use. SNWA currently owns shares in the MVIC representing approximately 7,000 afy of surface water rights and leases approximately 1,000 afy from the LDS Church. The LDS Church lease is for a term of 20 years, with the option to renew the lease for an additional 20 years.

SNWA'S TRIBUTARY CONSERVATION ICS PROJECT

The SNWA has been purchasing pre-Boulder Canyon Project Act (BCPA) water rights on the Virgin and Muddy Rivers since 1997, in an effort to reduce SNWA's dependence on the Colorado River and develop additional water supplies for Southern Nevada. Water rights historically used for agriculture along these rivers are being voluntarily sold or leased to willing buyers, including buyers not associated with SNWA. Sometimes the water rights are leased back for agricultural use with a provision that at the end of the lease term, the water rights will be retired and allowed to return to the river system. SNWA's purchase and retirement of pre-BCPA water rights will allow for assured flows within the entire Muddy River and the portion of the Virgin River below the Mesquite and Bunkerville Irrigation Companies by using flows that were historically consumptively used off channel by agriculture for the creation of Tributary Conservation ICS.

SNWA anticipates acquiring a total of approximately 30,000 afy of pre-BCPA water rights from entities with rights on the Virgin and Muddy Rivers. Approximately one-third of this amount is expected to come from the Virgin River and two-thirds from the Muddy River.

As of July 1, 2007, SNWA has acquired water rights from Virgin and Muddy River sources that will yield an average annual water supply of approximately 11,700 afy. The anticipated method of conveying these water supplies through the Virgin and Muddy Rivers to the Overton Arm of Lake Mead is described in Table 4 below. It is anticipated that the additional water supplies to be secured by SNWA (the remainder of the 30,000 afy) will be conveyed through the Virgin and Muddy Rivers, via the Overton Arm to Lake Mead through a similar process. SNWA will pursue acquiring water rights on both the Upper Muddy River and on the Lower Muddy River from MVIC; however it is much more likely that the remaining acquisitions on the Muddy River will be from MVIC shareholders. It is unknown at this time from exactly which sources on the Virgin River SNWA will acquire these additional water supplies.

Table 4. Example of Conveyance of Tributary Conservation ICS from Virgin and Muddy Rivers to Lake Mead

River	Irrigation Company/Water Right Holder	SNWA's current ownership/leases (approximate values in afy) ^a	SNWA's potential range of acquisitions (approximate values in afy) ^b	SNWA's total future potential ownership/leases (approximate values in afy) ^c	Method of Conveyance
Virgin	Mesquite Irrigation Company	0	0-3,000	Up to 3,000	Remain in river at historic point of diversion
Virgin	Bunkerville Irrigation Company	3,700	4,300 - 6,300	Up to 10,000	Diverted at the historic point of diversion and flow through irrigation company ditches before returning to the river further downstream
Muddy	MVIC	7,000	8,500 - 12,000	Up to 20,000	Diverted at the historic point of diversion and flow through irrigation company ditches before returning to the river further downstream
Muddy	LDS Church Lease	1,000	0 – 1,000	Up to 2,000	Remain in river at the historic point of diversion
Muddy	Other Users	0	0 – 2,500	Up to 2,500	Remain in river at the historic point of diversion

a – Based on conveyance of 11,700 afy water supply secured as of June 1, 2007

b – Based on future potential conveyance of additional 18,300 afy water supply

c - In aggregate supplies will not exceed 30,000 afy however, it is difficult to predict how much water will be purchased from the separate right holder

The retired agricultural water rights will be conveyed to Lake Mead via the Overton Arm in one of two fashions. The water will be diverted from the river through its historic point of diversion, flow through irrigation company ditches, and return to the mainstem of the river further downstream if the flow is necessary in the irrigation company ditches to avoid impacts to the irrigation company's operations or wildlife, such as southwestern willow flycatcher and other bird species that may rely on agricultural returns to support their habitat. This is the proposed operation for waters thus far acquired in the Bunkerville Irrigation Company and MVIC. Alternatively, if the water is not associated with an irrigation company or not required for the purposes described above, it will remain in the mainstem of the river. The conveyance of SNWA's water rights can be flexible, based on the irrigation company operating requirements and wildlife needs. To accommodate these needs, the water rights may be diverted at different places or during different times of the year.

BENEFITS TO LOCAL AGRICULTURAL USERS

The ability for SNWA to create Tributary Conservation ICS will provide benefits to agricultural users on both the Muddy and Virgin Rivers. Nearly all of the agricultural users on the Muddy and Virgin Rivers use gravity-flow systems to convey water to their fields. Decreasing the amount of water in the river, or in certain main irrigation ditches, by exporting the water upstream of their historical places of use would require costly repairs due to decreased head in the irrigation ditches. By leaving the water in these rivers and allowing it to flow to Lake Mead, past all the agricultural lands, it allows the remaining agricultural users to avoid having to make costly upgrades to the system.

In addition, SNWA negotiated all sales to include provisions for the seller to lease back their water for several years to allow that user to slowly transition their lands to non-agricultural uses, sell their land, seek other land uses, etc. As a result of the slow transition, the local economy will have time to adjust and adapt to the water movement. SNWA also created agreements with major irrigation companies and rural water companies to initially limit the amount of water that could be exported from the basin to ensure that enough water remains for rural development and needs.

BENEFITS TO THE ENVIRONMENT

Prior to the adoption of the Interim Guidelines, SNWA had proposed a surface water development project to convey their water rights on the Virgin and Muddy Rivers to the Las Vegas Valley (SWD Project). This project was also designed to convey water rights SNWA was granted on the Virgin River with a priority date of 1989, and those rights are not eligible for Tributary Conservation ICS. This project would have included the following proposed project facilities:

- Virgin River diversion dam – approximately 1,300-foot long and up to 10-foot high diversion structure in the Virgin River, with an inundation area and facility site totaling approximately 124 acres
- Halfway Wash impoundment dam – approximately 4,700-foot long and 200-foot high off-stream impoundment dam in Halfway Wash, with a reservoir

surface area, dam site and area below the dam totaling approximately 1,332 acres

- Bowman Reservoir intake – an intake structure and 24-inch diameter inlet pipe into the existing Bowman Reservoir
- Pipelines – approximately 66 miles of buried water pipelines, 18, 24, 54, and 78-inches in diameter, with a 100-foot permanent right-of-way and a 100-foot temporary construction area
- Pumping stations – five pumping stations, between 2 and 12 acres in size
- Regulating tanks – three above-ground regulating tanks, less than 1 acre in size each
- Water treatment facility (WTF) – 70 acre reverse osmosis WTF
- Brine evaporation ponds – 1,400 acre brine evaporation pond site
- Buried treated water storage reservoir – a buried storage reservoir on a 20 acre site
- Power facilities – approximately 8 miles of overhead power line, between 69 and 230 kilovolt (kV), with a 100-foot wide right-of-way, and five switching stations each approximately ½ acre in size

The adoption of the Interim Guidelines, along with additional provisions in an agreement amongst the Seven Basin States, has allowed SNWA to withdraw their right-of-way application for the project described above.

The effects of SNWA creating Tributary Conservation ICS on the Muddy and Virgin Rivers were analyzed by Reclamation in their Biological Assessment (Biological Assessment 2007). The U.S. Fish and Wildlife Service (USFWS) concurred with Reclamation's findings in their Biological Opinion (Biological Opinion 2007). Additionally, SNWA agreed to:

“work cooperatively with us [USFWS] as part of the implementation of the proposed Federal action to provide for improved conditions, where possible and in coordination with necessary operations for existing irrigation companies, which can contribute to the recovery of the Virgin River listed species. This includes the commitment to explore various options and implementing any feasible options to maintain water in the main channel of the Virgin River. Exploring or implementing any such options will be in coordination with us, and other entities if appropriate, and will be conducted only if such options and associated activities are in compliance with applicable Federal laws and the laws of the State of Nevada, and within SNWA's authorities and resources approved by its governing Board.”

The Biological Opinion also stated that the proposed action:

“may affect, but is not likely to adversely affect the southwestern willow flycatcher, Yuma clapper rail, Virgin River chub, woundfin, and the candidate western yellow-billed cuckoo, as well as no effect to the Moapa dace. In addition, it was determined that there would not be adverse effects to designated critical habitat for the southwestern willow flycatcher, Virgin River chub, and woundfin.”

SNWA's ability to create Tributary Conservation ICS, when compared to their SWD Project will leave more water in the natural river system to flow to Lake Mead.

CONCLUSIONS

In conclusion, Tributary Conservation ICS, will allow SNWA to develop its Muddy and Virgin water rights in a more cost effective and environmentally friendly manner. ICS also allows flexibility to the Virgin and Muddy River irrigators and irrigation companies thus reducing negative impacts to their operations.

The ICS mechanism is a unique accomplishment for the Colorado River. It provides water users in the Lower Basin with more flexibility to manage their water supplies and meet future water demands.

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WATER LEASES AND LIMITED IRRIGATION: OPPORTUNITIES AND CHALLENGES FOR COLORADO'S SOUTH PLATTE BASIN¹

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ABSTRACT

Burgeoning populations are increasing municipal water demand in the West, a phenomenon that is changing rural and urban economies. Agricultural water is a preferred source for meeting growing demands, but transfers often require formerly irrigated land to be fallowed, removing a key industry from rural regional economies. It is no surprise that large-scale transfers are greeted with highly-charged, emotionally contentious debates. One alternative to 'buy and dry' strategies is gaining interest. The alternative allows farmers to lease a portion of their water portfolio to cities. Leased water is generated as farmers fallow their land on a rotational basis or reduce the consumptive use of their cropping operations by limiting irrigation. Examples of limited irrigation strategies include timing irrigations during vegetative growth and adopting innovative crop rotations. Importantly, the limited irrigation cropland remains in production so that rural economies suffer reduced impacts vis a vis buy and dry activity. But will farmers adopt limited irrigation strategies if water lease markets materialize? The objectives of this research are to examine producers' potential for adoption of limited irrigations strategies and their perceptions of lease arrangements. Potential adoption is gauged from a producer survey of South Platte River Basin farmers in Colorado, a basin experiencing significant population growth in the midst of significant agriculture production. The results of this indicate that more than 60% of the respondents are willing to lease garnering between 50,000 and 60,000 acre feet of potential water supplies.

INTRODUCTION AND BACKGROUND

Water reallocation from agricultural to municipal use is expected in the West as populations increase dramatically (Colorado Water Conservation Board, 2004). It is no surprise that large-scale transfers are greeted with highly-charged, emotionally contentious debates. While individual buyer and seller presumably benefit from the transaction, stakeholders believe that rural economies are at risk.

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Thorvaldson and Pritchett (2006) document irrigated agriculture's economic activity in the four river basins listed in Table 1. Notable is the South Platte, which expects to fallow as many as 266,000 (twenty-two percent) of its irrigated acres in the next twenty-five years. An irrigated acre generates significant economic activity in the basin, so potential losses are substantial in sparsely populated rural areas with few other alternatives. Impacts include the direct loss of crop sales, the lost revenues to agribusinesses that supply irrigated farms, and the wages spent by affected employees.

Table 1. Economic activity generated by irrigated agriculture^a

Basin	Population Increase by 2020 (%)	Additional Annual Water Demand (AF)	Forecasted Fallowing of Irrigated Acres	Economic Activity \$/ac
Arkansas	55%	98,000	23,000 to 72,000	\$428
Rio Grande	35%	43,000	60,000 to 100,000	\$1,235
South Platte	65%	409,700	133,000 to 266,000	\$690

^aPopulation, water demand and lost irrigated acres drawn from the Colorado Water Conservation Board, Statewide Water Supply Initiative (2004). Thorvaldson and Pritchett (2006) provide economic activity estimates.

Negative local impacts and associated publicity are incentive enough to find alternatives to standard "buy and dry" practices that fallow large swaths of formerly irrigated farmland. Some stakeholders are arguing that leases in lieu of "buy and dry" transfers may avoid these negative externalities. Rotational fallowing and limited irrigation are two alternatives being explored³. Both involve agricultural water right holders signing leases with cities rather than selling water rights. Leasing of this type is rare in Colorado⁴, and it is uncertain if leasing markets will evolve. Following the example of Michelson and Young (1993), necessary conditions for water lease markets include a critical mass of willing leasers and water right holders so that both are reasonably assured of a mutually beneficial transaction; that the gains from leasing exceed its transactions costs; and that leasing contracts can be written, monitored, and enforced effectively.

This article's objective is to focus on agricultural water right holders. Specifically, the objectives of this research are to examine i) if farmers are willing to sign leases if suitably compensated; ii) what remuneration is needed for a farmer to enter into a lease agreement; iii) how much water the farmer will release when compensated; and iv) what characteristics are shared by farmers willing to lease.

The research approach is to gather stated preferences from South Platte basin farmers. Research results are particularly useful for policy makers who may need to alter existing institutions so that the transactions costs of leases do not outweigh the potential gains

³With rotational fallowing, a large group of agricultural water right holders sign a long term lease agreement with a municipality, but then shift fallowed acres from one farm to the next annually to spread lost economic activity over a greater landscape. Limited irrigation decreases a crop's consumptive use without fallowing, and the water savings are leased.

⁴Leasing agricultural water to farmers is standard practice in Colorado, and municipal water suppliers do frequently lease out of basin water to farmers. These leases do not require legal oversight, but the leases described in this section would require approval.

from trade. The results are also of interest to farmers and municipal water providers that are actively engaged in developing water leasing alternatives.

METHODS

A questionnaire was designed and, prior to mailing, was reviewed by an advisory committee of farmers, field extension personnel, university extension specialists, water conservancy district employees, and municipal water provider representatives. Recommendations from these experts were incorporated into the questionnaire. The questionnaire's two main sections are i) farmer and farm operation characteristics, including irrigation water source, the prevailing crop rotation, and financial demographics; and ii) attitudes about leasing arrangements, including willingness to participate, compensation, and contract provisions.

The questionnaire was mailed to South Platte basin farmers who reported more than fifty irrigated acres in the 2002 Census of Agriculture. Mailing began during the first week of September 2007 using procedures outlined by Dillman (2007) with a postcard reminder mailed ten days later, and a second survey mailing twenty-one days after the initial mailing. Of the 1,731 successful mailings, 329 (or 19%) were returned and could be used in the analysis. A copy of the survey instrument is available from the authors upon request.

RESULTS

Leasing Attitudes

A leasing market's success or failure will have much to do with farmers' attitudes about leasing. Attitudinal surveys are often scored using a Likert scale, which generates data in the form of ordinal, or ordered, responses. Probably the most common example, and the one used here, is the extent of agreement with a view: *strongly disagree*, *disagree*, *neither agree nor disagree*, *agree*, and *strongly agree*.

In order to measure these perceptions, respondents were asked to signal their agreement to several statements by using the Likert scale. If a respondent strongly agreed with the statement, the response was given a 5 value, whereas agreed, neutral, disagreed and strongly disagreed responses were given values of 4, 3, 2, and 1, respectively. The average rating among survey respondents was tabulated, and the percent of those who agreed with the statement (those responding with a 5 or 4) was calculated along with the percentage that disagreed with the statement (those responding with a 1 or 2). The results to a subset of the questionnaire's leasing attitude statements are listed in Table 2.

Table 2. Respondents' attitudes about water leasing opportunities

Leasing attitude statement	Average Ranking	Percent Agree	Percent Disagree
1. I am willing to participate in a lease if paid enough.	3.55	61.1 %	18.9 %
2. I am willing to incorporate a fallow period into my crop rotation if I am compensated enough.	3.48	63.0%	19.0%
3. I am willing to reduce my farm's consumptive water use, either by irrigating less or planting less water using crops, in order to fulfill conditions of a lease.	3.19	49.0%	29.0%
4. I am willing to lease my senior water rights and keep junior water rights if suitably compensated.	3.08	35.0%	25.0%
5. I am willing to negotiate directly with a municipality to establish a water lease.	3.21	47.5 %	29.1 %
6. I plan to sell water rights within the next 5 years.	2.07	6.6 %	63.3 %

As indicated in table 2, sixty-one percent of respondents indicate that they would be willing to sign a lease arrangement if suitably compensated, a value that stands a test of internal validity when juxtaposed against similar questions occurring later in the survey. Rotational fallowing is acceptable to 63% of respondents as indicated by statement 2 in table 2. Limited irrigation strategies are less popular (statement 3), perhaps because little is known about the financial ramifications of the strategy. Likewise, statement 4 indicates that respondents are reluctant to lease senior water rights and retain junior water rights. Less than half of all respondents are willing to negotiate directly with a municipality to lease water, perhaps leaving negotiations to their existing ditch companies, mutual associations, or another institution that may evolve in the future. Perhaps even more interesting, fewer than seven percent of respondents expect to sell their water rights within five years. If water sales were more likely, the chance of successful water leasing arrangements between farmers and water providers would be less likely.

Based on these stated preferences, respondents have a favorable view of the impact that leases will have for farmers and rural communities. Many respondents are willing to sign leases if suitably compensated. In the next section, attention is focused on those survey respondents who were willing to lease or indicated a price at which they were willing to lease water⁵.

Respondents Willing to Lease: Characteristics, Prices, and Fallowed Land

Identifying characteristics of potential lessors will identify willingness to participate at a basin level. Consequently, the unobserved continuous measure "willingness to participate

⁵In one survey section, respondents were asked to indicate if they were willing to enter into a water lease if compensated enough, and in a later section respondents were asked to indicate how much they must be compensated to forgo irrigation for one year. If respondents agreed or strongly agreed with the former, or indicated a lease amount to the latter, then their responses tabulated as potential lessees.

in a lease agreement" is specified to be a linear function of explanatory variables, plus an error term. The following explanatory variables are included in this study:

1. Demographic and socioeconomic characteristics of the farmer
2. Characteristics of the farm.
3. Opinions of water leases and agriculture.

Table 3 displays the results of the ordered logit results from regressing willingness to lease on farm and farmer characteristics. Variables that have a statistically significant negative impact on willingness to lease include debt ratio, which may indicate a more urgent need to sell water rights; percent groundwater use, high levels of which preclude one from leasing water; and proximity to urban centers, which implies increased pressure for urban development and thus increased chances of selling the water rights. Variables that have a statistically significant positive effect on willingness to lease include number of irrigated acres, which may indicate the amount of water available for lease; concern for rural communities; and willingness to work with municipalities and other organizations, which is necessary to establish a lease agreement.

Table 3. Ordered logit results from regressing willingness to lease on farm and farmer characteristics.

Explanatory Variable	Coefficient	Standard Error	z-Statistic	Probability
Age	0.13	0.21	0.64	0.52
Second job	-0.10	0.19	-0.52	0.61
Debt ratio	-0.40	0.22	-1.81	0.07
Education level	-0.02	0.06	-0.36	0.72
Groundwater use	-0.01	0.00	-3.16	0.00
Plans to upgrade irrigation system	0.05	0.22	0.24	0.82
Plans to sell water	0.13	0.40	0.33	0.74
Proximity to urban center	-0.89	0.23	-3.89	0.00
Irrigated acres	0.00	0.00	1.93	0.05
Concern for rural communities	0.49	0.22	2.24	0.03
Willingness to work with municipalities	0.39	0.08	4.55	0.00
Willingness to work with other organizations	0.38	0.10	3.69	0.00
LR statistic (12 df)	80.39	LR index (Pseudo-R2)		0.220661
Probability(LR stat)	3.48E-12			

Pricing Water Leases

The price at which farmers are willing to lease water is important. As noted previously, a necessary condition for leasing to occur is that the gains from leasing, calculated as the price difference between the willingness to accept on the part of water right holders and

the willingness to pay of water providers, must exceed the transactions costs⁶ of executing the lease else a leasing agreement will not be reached.

In an open-ended question, respondents were asked to indicate the *minimum* price they must be paid in order to forgo irrigation for one year as part of a leasing arrangement – an example of rotational fallowing. These responses were collected in the histogram shown in Figure 1, which measures pricing intervals as column bars whose labels refer to the intervals' uppermost bound. The proportions of respondents that fall within the interval are measured on the vertical axis. As an example, the proportion of respondents indicating a payment in the range of \$50 per acre to \$225 per acre is measured as 23%.

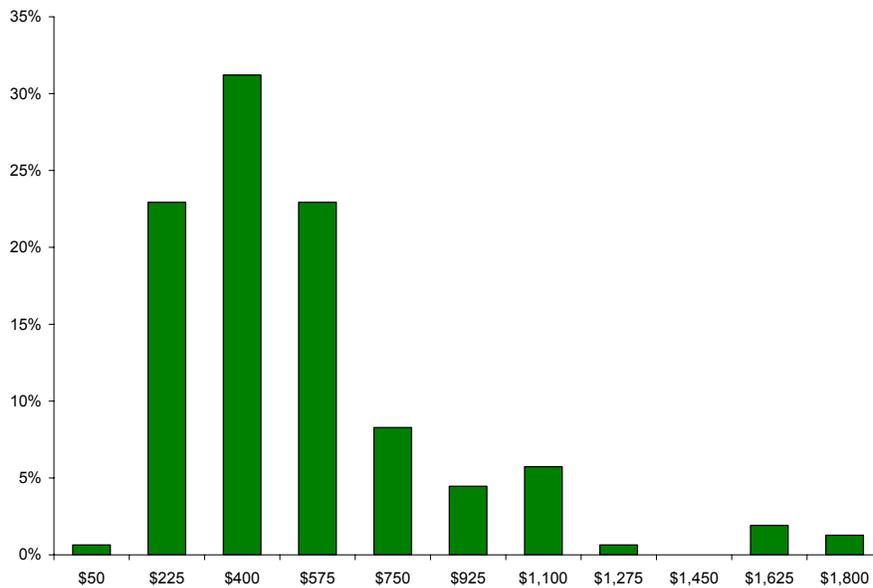


Figure 1. The minimum lease payments respondents seek for forgoing one year's irrigation (\$/ac).

The vast majority (seventy-seven percent) of responses populate an interval between \$225 per acre and \$575 per acre. A market analogy can be found for the lower end of this interval – at the time the survey was received, cash rent for irrigated cropland averaged \$300 per acre with dryland alternatives netting less than \$50 dollars per acre. The opportunity cost of forgoing irrigating cropping can be considered the difference between irrigated and dryland cash rents plus the cost of weed management and irrigation equipment maintenance. If this opportunity cost is \$300 per acre and two acre feet of water may be leased, then the opportunity cost is valued at \$150 per acre foot. It follows then that the present value of a long term lease, assuming a 5% average rate of return, is \$3,000 per acre foot. Recent sales of water bought and sold for agricultural use in the South Platte Basin have traded in the range of \$3,000 per acre foot (Water Colorado).

⁶ Transactions costs include, but are not limited to, the costs of collecting, conveying and treating water, legal costs, financing costs of paying the lease, risk premium associated inadequate supplies during drought, and the costs to maintain fallowed farmland.

However, a number of respondents indicated a minimum lease payment of more than \$1,000 per acre as is indicated in Figure 1. Following the calculations outlined in the previous paragraph, the imputed value of water in this case is \$10,000 per acre foot or more. Interestingly, this value is representative of recent water sales of agricultural water bound for municipal use (Water Colorado). Perhaps, then, these farmers are calculating a market value for their water rather than a minimum payment to forgo irrigation.

Survey respondents state a willingness to lease water and will do so at a price that is within the bounds of current water transactions. However, it remains to be determined if a sufficient amount of water is available to encourage leasing markets to evolve.

In another open-ended question, respondents were asked to indicate the *minimum* price they must be paid in order to forgo one-half of their irrigation water for one year as part of a leasing arrangement – one example of limited irrigation. These results are illustrated in Figure 2 along with the rotational fallowing results in Figure 1.

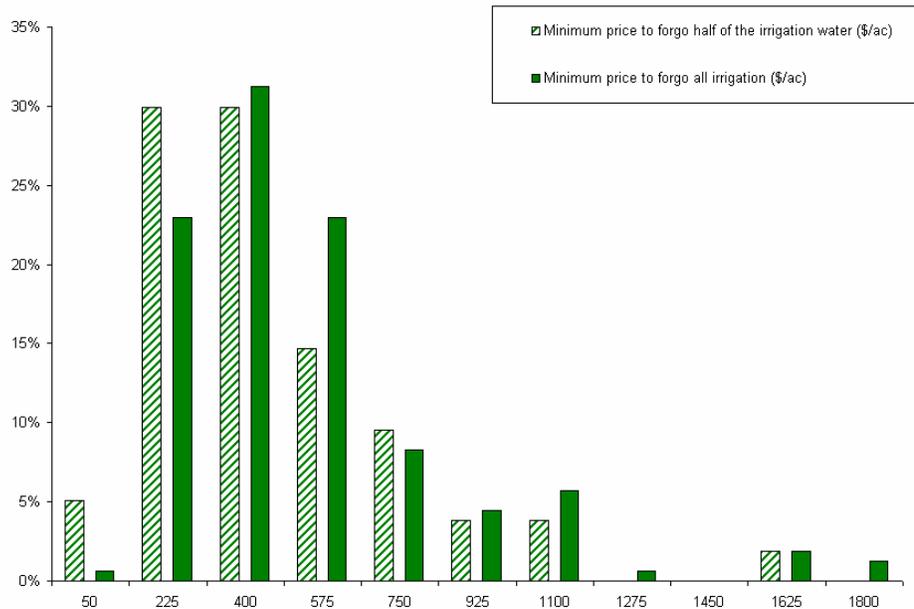


Figure 2. Respondents’ minimum payment to forgo one-half of their irrigation water and to forgo all irrigation water for one year.

Respondents’ need not be compensated as much to adopt limited irrigation when compared to rotational fallowing. However, 60% of respondents need to be compensated between \$225 and \$400 per acre.

Leased Water Quantities

In the context of rotational fallowing, respondents were asked to indicate the percent of available water that they might be willing to commit to an annual lease, the amount of land that would be fallowed as a result of a lease, and the total irrigated acres that they

held. In sum, the respondents to this question indicated they would fallow 33,352 acres that might free between 50,000 and 67,000 acre feet of water annually depending on how water courts evaluate their historical consumptive use. On average, respondents will fallow 200 acres per respondent, but a more detailed illustration of these responses is found in Figure 3.

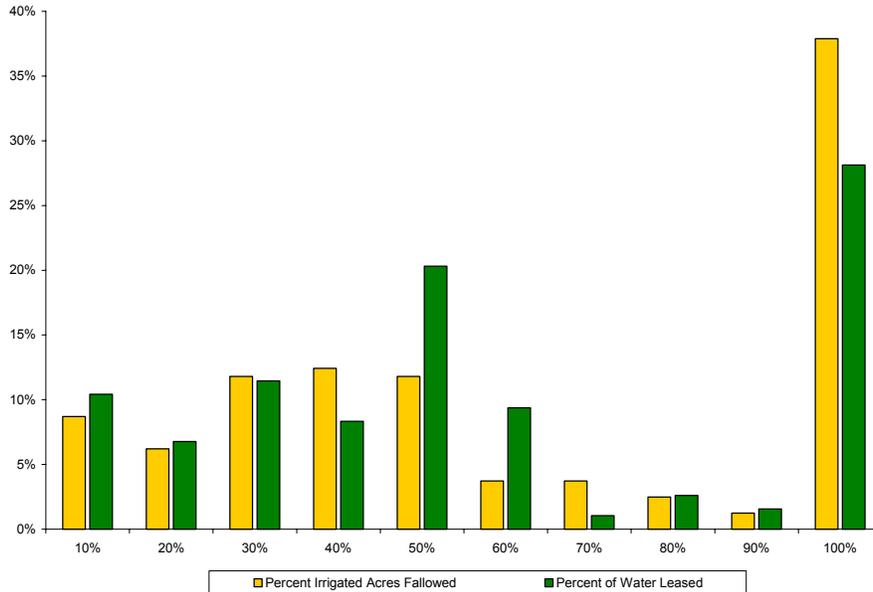


Figure 3. Respondents' percent of all irrigated acres fallowed and the percent of all water supplies committed to an annual lease.

The columns labeled on Figure 3's horizontal axis are of two types: the lightly shaded bars indicate the percent of all irrigated acres that respondents were willing to fallow in a lease, while the darker bars indicate the percent of irrigation water that might be committed to a lease. As an example, twelve percent of respondents were willing to fallow fifty percent of their irrigated acreage as part of a leasing agreement, while twenty percent of respondents were willing to commit half of their water to a lease.

In examining Figure 3, respondents tend to cluster into two groups – those that are willing to commit all of their land and water to a lease (right-hand side of the figure), and those that are willing to commit half of their holdings or less to a leasing arrangement. The latter half could be problematic in reducing transactions costs for leasing arrangements – it may simply cost more to collect, treat, and transport water from many small sources than a few large sources.

Leasing from these survey respondents may not prevent rural economies from suffering; after all, if leases fallow all of the acres on a set of clustered farms, the regional economic base may shrink just as if a 'buy and dry' transaction had occurred. Indeed, this is the impetus for designing rotational fallowing institutions that spread fallowed acres over a large geographic area.

A limitation of this section's discussion is particularly noteworthy. Water is characterized as a homogeneous commodity in the previous analysis; in reality, the prior appropriations doctrine creates a heterogeneous water product whose value varies with the seniority of its appropriation. Under the prior appropriations doctrine, those holding water rights with the earliest appropriation dates are satisfied first, and these water rights are the most valuable to municipalities. Therefore, a leasing market may prove to be too "thin" if the water made available by farmers is of relatively junior priority, and municipal water providers instead seek scarcer, senior water rights.

CONCLUSIONS AND FUTURE OPPORTUNITIES

Reallocation of water from agricultural to municipal use is inevitable given the rapid population growth of the heavily urbanized West. These water transfers are controversial largely because they may fallow large swaths of irrigated lands that are in turn a significant portion of the local rural economic base. In place of these 'buy and dry' transfers, stakeholders are interested in the opportunity to create water leasing markets to partially meet future demands.

This study focuses on the stated preferences of South Platte Basin farmers who answered a questionnaire mailed in September 2007. Analysis of the submitted questionnaires indicates that a significant amount of water may be leased at a reasonable price. Important characteristics of those willing to lease include owning a large number of irrigated acres, having concern for rural communities, and being willing to work with municipalities and other organizations to orchestrate lease agreements.

Researchers have the opportunity to perform more work before leasing markets evolve in the South Platte Basin. In particular, the willingness to pay of municipal water suppliers needs to be revealed, and the transactions costs of leasing markets needed to be examined. Transactions costs have been measured by Colby (1990) but an update is needed to determine if leasing arrangements incur the same costs as permanent water transfers. If so, then the gains from leasing may evaporate. Monitoring lease arrangements may be costly, but if monitoring does not occur, senior water rights may decrease in value. Alleged lack of enforcement precipitated the shut down of more than 440 groundwater wells in Colorado. Similar problems might limit leasing opportunities in the future.

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WATER RESOURCES PLANNING TO WATER TRANSFERS TO MODERNIZATION OF AN IRRIGATION DISTRICT — OAKDALE IRRIGATION DISTRICT CASE STUDY

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ABSTRACT

Oakdale Irrigation District (OID) was formed in 1909 and provides pre-1914 water rights to over 55,000 acres of irrigated farmland located within the northern San Joaquin Valley of California. The district's situation is similar to many irrigation districts in the Central Valley; it has an aged and often failing infrastructure which has had little investment over the years; it has an intermixed customer base of both urbanizing ranchette lands, expanding dairies and a rapid conversion to high value permanent crops; it has a demand for more flexible water deliveries and services from its customers; and has limited financial resources to meet those demands.

With that backdrop, initiated in November 2004 and completed in June 2007, OID developed a Water Resources Plan (WRP) as a strategic roadmap for addressing those issues. Today the district is moving forward with the implementation of a \$170 million capital improvement program to meet the multifaceted needs of the district. Those needs as outlined in the WRP include the protection of the District's water rights; an increase in agricultural water supply reliability during droughts; protection for the local areas surface and groundwater supplies; along with a roadmap to modernize and rebuild a century old system to meet the needs of its changing customer base. Regional water transfers are being used as the basic funding mechanism to make it all happen.

The paper will provide a background of the drivers that got the OID to begin the planning process; it will discuss how the planning process evolved; what the findings and recommendations were in the final Water Resources Plan (WRP); and finally, how those recommendations are being moved forward to implementation.

BACKGROUND

History of OID

In 1909 OID was organized under the California Irrigation District Act by a majority of landowners within the district in order to legally acquire and construct irrigation facilities and distribute irrigation water from the Stanislaus River (ref. Figure 1). In 1910 OID and the neighboring South San Joaquin Irrigation District (SSJID) purchased Stanislaus River water rights and some existing conveyance facilities from previous water companies. Both districts continued to expand their operations over the ensuing decades.

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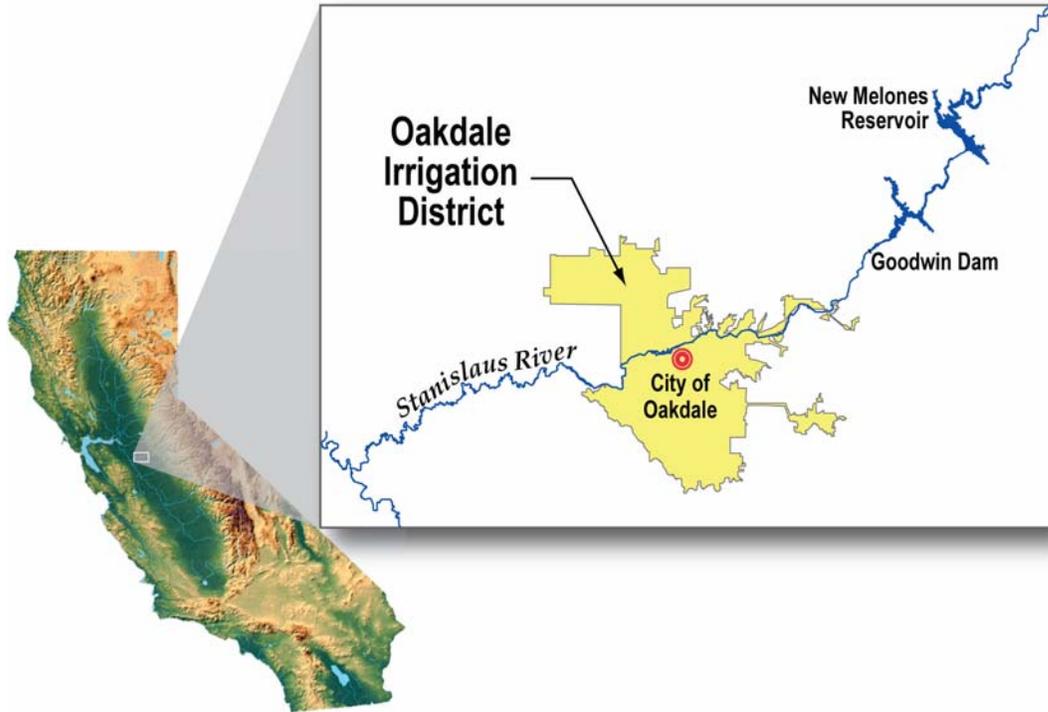


Figure 1. Location of Oakdale Irrigation District

Since their creation, OID and SSJID have constructed dams and reservoirs to regulate surface water storage and deliveries. Most dams were constructed in the 1910s and 1920s, including Goodwin Dam (1913), Rodden Dam (1915), and Melones Dam (1926), which provided 112,500 acre-feet (ac-ft) of shared capacity. To provide supplemental water storage for OID and the SSJID, the Tri-Dam Project was created in the 1940s. Sites were approved in 1948 for Donnell's Dam and Beardsley Dam on the Middle Fork of the Stanislaus River, and for Tulloch Dam above Goodwin. The two districts entered a joint agreement to carry out the proposed project and now jointly own and operate the three storage reservoirs for a combined storage capacity of 230,400 ac-ft.

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

Significant capital investment has led to a stable, plentiful water supply for the district. Over the last 50 years, the district has focused its financial resources principally on paying off these capital investments; as a result, the district has invested little in replacement, modernization, automation or rehabilitation of its existing system over the years.

Internal and External Drivers Necessitated a Change

Internal Issues. The position of the district in 2003 was not enviable. While water resources were plentiful to meet crop water needs for customers, the operational control

of that water was lacking. Principally due to a lack of modern and often failing infrastructure that inhibited the district's ability to manage the system efficiently. System failures began dominating the annual workload and budget as years of non-investment in the delivery system began to show.

On-farm water use was equally deficient in terms of efficiency. Without a good system of controls in the canals of the district, farmers experienced significant canal fluctuations which impaired their ability to efficiently manage water on their side of the farm gate. Couple the above with foothill farming practices that had for years utilized wild flooding as its principle form of irrigation, and on-farm water use efficiency was not very high.

The district was also experiencing a change in its landscape and in the customer base it served. Pasture, which dominated the area's agriculture for years, was being converted to high value tree crops like almonds and walnuts. These changes were met with demands by farmers for a different service standard for their water deliveries. Similarly, a significant amount of pasture was being converted to feed crops such as corn and oats as dairies began buying and converting pasture for their expanding operations and to meet new regulations regarding nitrogen management within their operations.

External Issues. Water quantity issues in California have always been a subject of concern but in recent years, these shortages and their repetitiveness seemed to be on the increase. While the district has three (3) water transfers to its neighbors, one 15,000 acre foot transfer to the City of Stockton via the Stockton East Water District and two (2) transfers totaling 26,000 acre feet to the Bureau of Reclamation for environmental and water quality purposes, there was pressure to do more by the City of Stockton as the transfer term of the original contract was reaching its end. Similarly, the City and County of San Francisco has always expressed an interest in discussing the future status of OID's water supply.

The recent loss of the agricultural waiver for the discharge of surface water placed another problem both on the district and its agricultural customers. Farmers were looking towards the district to help with these changing regulations and the district, not being in a financial position to do otherwise, looked at these problems as on-farm issue, not one the district should be involved in.

Needless to say, the complexity of water issues, both locally and at the state level, necessitated a rethinking of OID's current practices and priorities in order to guarantee full protection of the district's and region's water supplies into the future. The District's Board of Directors and management, recognizing this challenge, commissioned CH2M HILL in the fall of 2004 to explore the issues facing OID and develop a comprehensive plan to respond to these issues. These were the principal objectives of the Water Resources Plan (WRP).

THE WATER RESOURCES PLAN

In the development of the WRP, the OID Board of Directors developed the following five goals that they agreed key to developing water management strategies and alternatives:

- Provide long-term protection to OID's water rights
- Address federal, state, and local challenges
- Rebuild and modernize an out-of-date system to meet changing customer needs
- Develop affordable ways to finance improvements
- Involve the public in the planning process

The WRP evaluated the district's water resources, delivery system, and operations, and examined land use trends to determine how future changes in these areas will impact water supply and demand during the next two decades. The plan also provided specific, prioritized recommendations for OID facility improvements that would comply with the California Environmental Quality Act (CEQA) and accommodate available financial resources.

A recap of the WRP findings and recommendations are provided in the following paragraphs.

General Background of OID

OID is located in the northeast portion of the San Joaquin Valley, about 30 miles southeast of Stockton and 12 miles northeast of Modesto. The OID service area consists of 72,500 acres between the Sierra Nevada and the Central Valley along the San Joaquin–Stanislaus County line, surrounding the city of Oakdale and bordering the cities of Riverbank and Modesto. The district's sphere of influence (SOI), land that the district is permitted by law to annex but to which it has not yet provided service, extends 86,290 acres farther to the north and east into Calaveras County. The Stanislaus River flows from the east through the center of the district service area and SOI.

Situated near the base of the Sierra Nevada foothills, OID's topography varies from gently rolling hills to the east and south of Oakdale to nearly flat around Riverbank. Approximately 75 percent of the land within the OID service area consists of irrigated agriculture. Native vegetation and rangeland dominates the land immediately outside the OID service area to the north, south, and east.

OID experiences mild, moderately wet winters and warm, dry summers typical of the Central Valley. Average temperatures range from the mid-forties in winter to the mid-nineties in summer. Precipitation averages about 12 inches annually, over 85 percent of which occurs between November and March. Average evapotranspiration (ET) is approximately 46 inches seasonally (April through October). Climate conditions are generally uniform throughout the district.

The District Today

Currently, the district maintains over 330 miles of laterals, pipelines, and tunnels, 29 production wells, and 43 reclamation pumps to serve local customers. In general, the district's facilities, system operations, political organization, and administration have not changed significantly over the last several decades. Nearly all water supply canals were constructed more than 90 years ago. In recent years, however, the district's customers, land use, and financial resources have developed in a direction that may influence the way OID provides services and conducts business in the future. The following sidebar highlights important background facts about the district.

OAKDALE IRRIGATION DISTRICT FACTS	
Year OID was organized:	1909
Cost to OID and SSJID for existing irrigation system and water rights in 1910:	\$650,000
Total district acreage:	72,500
Total irrigated acres:	55,600
Annual diversion right:	300,000 acre feet
Diversion point:	Goodwin Dam
Maximum diversion rate from Goodwin Dam:	910 cfs
Total distance of water delivery system:	330 miles of canals (open, lined, and buried pipelines)
Number of agricultural wells:	24
Number of agricultural and domestic water accounts:	3,500
Percent of OID agricultural customers who farm parcels of 10 acres or less:	60 percent, constituting 12 percent of OID land
Percent of OID agricultural customers who farm parcels of 40 acres or more:	4 percent, constituting 60 percent of OID land

Analyses and Findings

Analyses conducted for the WRP included detailed land use modeling, water balance modeling, on-farm surveys, a comprehensive infrastructure assessment, and the development of a phased infrastructure plan to rehabilitate and modernize an out-of-date system. The integrated approach also included water right evaluations, groundwater studies, development and evaluation of program alternatives, financial analyses, environmental compliance, and public outreach. The following discussion summarizes some of the key areas of evaluation that were conducted in the study.

Land Use

OID currently serves 2,800 agricultural customers on approximately 55,600 acres of serviceable land. The district also provides water to 700 domestic accounts primarily east of the City of Oakdale. Agriculture dominates the lands in and surrounding OID, as shown in Figure 2. Within the district service area, pasture makes up approximately half of the total land use, or about 32,000 acres. The other half of the district consists of

orchards, corn and oat crops, and municipal land in relatively even proportions. Only a small percentage of the land in the district's service area consists of native vegetation. Outside the OID service area but inside the district's SOI, native vegetation dominates three-quarters of the land, or approximately 47,000 acres, as shown in Figure 3. Orchards and pasture crops make up 11 percent and 9 percent, respectively. Corn and oats make up 6 percent. Rice and urban/industrial areas make up 1 percent or less of the district SOI outside the service area.

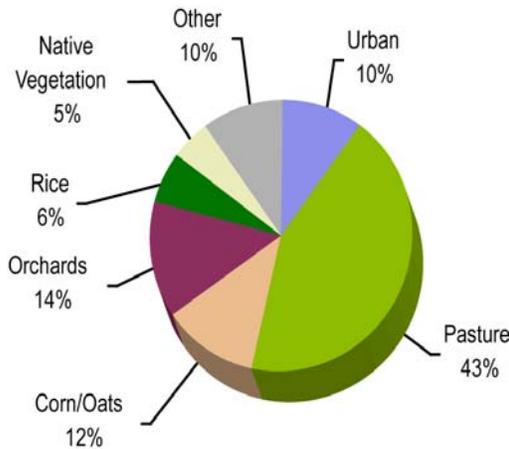


Figure 2. Land Use Distribution in OID

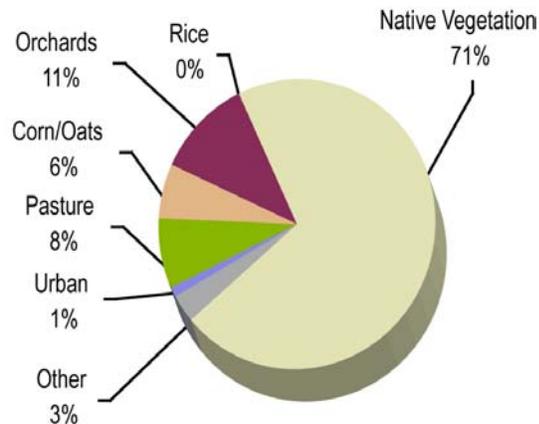


Figure 3. Land Use Distribution within OID Sphere of Influence

Land use within the OID service area has shifted in recent years, and these trends point to continued change in the future. Some agricultural land around the cities is urbanizing. The City of Oakdale is experiencing steady population growth. It is forecasted that over the next 20 years, 6,000 acres of agriculture in OID will be replaced by municipal land, resulting in fewer irrigated acres and a lower demand for OID water.

Many OID customers are also changing the types of crops they are growing. Across the region, higher-value tree crops are replacing pasture. Orchards use less water and require a more intensive, responsive level of irrigation service than is currently provided by the district. Land ownership is also changing as large parcels are subdivided, leading to increased ranchette-type development in some areas. All these factors may necessitate changes to the level of services the district can currently provide.

Of particular note is that orchard acreage outside OID's existing service boundaries has more than doubled in the past decade. This is the result of accelerated market conditions for nut crops. The irrigation water source for orchards outside OID is almost exclusively groundwater. The majority of orchard development has occurred immediately adjacent to OID's eastern boundary. This development offers significant opportunity for expansion of service by OID.

Forecasted Trends. As shown in Figures 4 and 5, forecasted land use inside and adjacent to the current OID service area is expected to continue changing substantially. While

pasture is generally projected to decrease within OID, orchards are expected to increase nearly 50 percent to approximately 15,000 acres in 2025. Nearly all these orchards are expected to implement fairly efficient irrigation systems (such as micro sprinklers), resulting in significant water savings. It is expected that most orchards (average applied water approximately 3 ac-ft per acre) will be planted on ground that was previously pasture (average applied water approximately 6 ac-ft per acre). This will result in the applied water demand being essentially cut in half. Also, the efficiency of the irrigation systems will result in other water savings, including reduced—and in many cases eliminated—tailwater production.

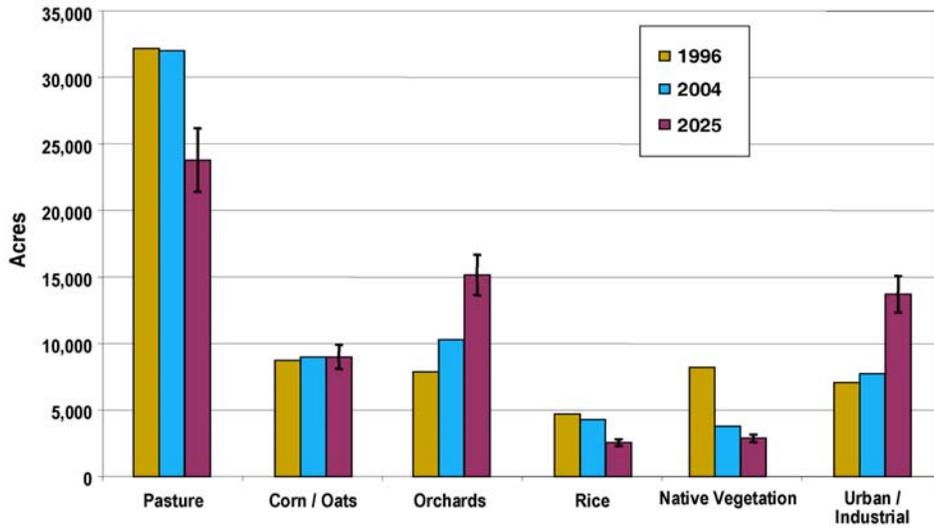


Figure 4. Historical and Forecasted Trends Inside OID Service Area

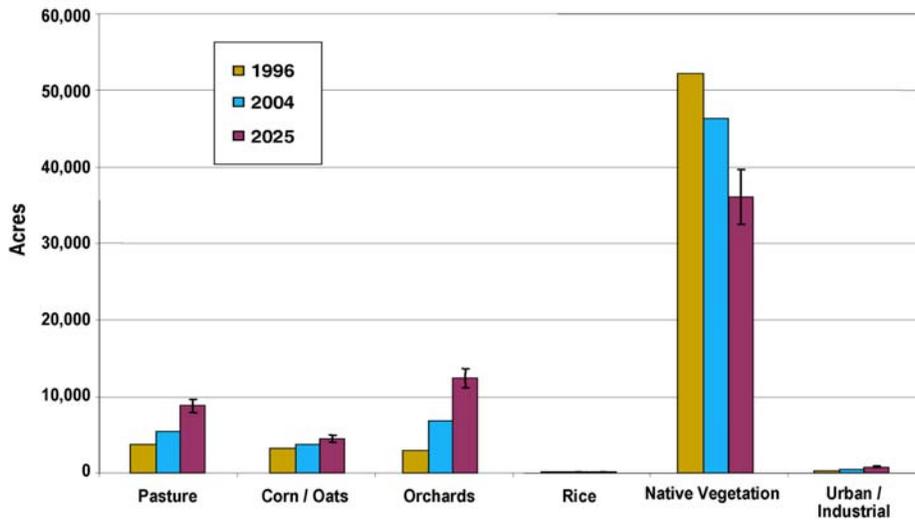


Figure 5. Historical and Forecasted Trends Outside OID Service Area

The forecasted 2015 City of Oakdale population is 29,000. Actual holding capacity of the 2015 boundary area, if completely built out, would be about 39,000. New residential growth through 2015 is forecasted to occur in all directions around the city, and will likely fill in four primary areas within the 2015 growth boundary. Accounting for additional urbanization between 2015 and 2025, 10 percent of total current OID lands, most of which is currently irrigated agriculture, will likely be lost to urbanization by 2025.

Land Use Conclusions. Historical land use and forecasted changes will significantly influence the future of OID and service to its customers. Forecasted land use is a fundamental element of the WRP and has significant influence over the suggested recommendations for the future.

Infrastructure Assessment

As part of the WRP, a detailed infrastructure assessment was conducted. Those findings concluded that major vulnerabilities existed within the OID's primary water delivery system off the Stanislaus River and that a large proportion of the system had significantly deteriorated. Additionally, changing customer needs and service conditions necessitated that OID modernize its system to provide more responsive and reliable service. The assessment performed included the following areas of OID's water delivery system:

- Joint Main Canal, North Main Canal, and South Main Canal
- Regulating reservoirs
- Primary distribution system
- Groundwater wells
- Drainwater and reclamation facilities
- Supervisory Control and Data Acquisition System (SCADA)
- OID's standards for providing irrigation service to its customers

Water Balance Modeling

To facilitate this analysis, a systemwide operational water balance model (WBM) was developed. The WBM provided a flexible analytic tool for simulating a range of long-term operating scenarios and overall WRP alternatives.

The primary water balance unit of analysis was the Lateral Service Area (LSA). Each LSA represented the portion of the OID service area supplied by a specific distribution lateral. Water supply into the LSA is provided by a combination of surface water, groundwater from wells, and reclamation pumps (drainwater). Water leaves the LSA through ET, deep percolation, tailwater spills to drains, and operational spills to drains. The drainage basin is the object in the WBM for tracking the supply, reuse, and outflow of drainwater. Each LSA overlaps one or more drainage basins, into which its tailwater and operational spills flow.

A baseline operations water balance was created to simulate the primary water components of OID's overall system under existing land use and varying hydrologic and climatic conditions. The baseline model was developed using 2004 land use information (which represents the most recent land use survey data available), irrigation efficiencies developed from an on-farm survey at OID, available outflow data from OID's boundary outflow program, and average- and drought-period climatic (ET and precipitation) records. Land use was developed using geographic information system coverage for OID's assessed parcels combined with California Department of Water Resources land use survey data. By starting with a baseline model that reasonably represents existing conditions, the model can then be used to evaluate the net impacts of key factors influencing OID's long-term water demand and supply through the 2025 planning period, such as crop shifting and changes in farm efficiency levels, annexation of new service areas, varying levels of drainwater reclamation, groundwater pumping, and distribution system improvements.

Alternative Development and Evaluation

The WRP evaluated the district's water resources, delivery system, and operations. It surveyed on-farm water use and practices and evaluated the infrastructure and modernization needs of the OID. In conjunction with this comprehensive assessment, the WRP examined land use trends to project how future land uses will impact water supply and demand over the next two decades. Lastly, the water balance efforts provided insight on projected water use and various means by which the OID may put to beneficial use water that would be generated through implementation of the WRP.

To address the expected changes in future OID customers' needs and to reasonably and beneficially use the district's water supplies, four distinct programmatic alternatives were developed and evaluated. These alternatives encompassed a range of reasonable options available to the district in response to the land use, regulatory, resources, and customer-driven issues presented in the WRP. The term *programmatic* is used to emphasize that the alternatives evaluated in the WRP are broad-based and strategic, and represent policy-level options for OID's consideration.

Evaluation Methodology. Applying some key common assumptions to all alternatives, a detailed methodology was employed to determine key water balance components for projected 2025 conditions for each programmatic alternative. Next, decisions regarding the provision of service to customers outside OID but inside the SOI (annexation) and water transfers were made for each alternative. Lastly, a Financial Model was used to analyze various strategies for viably supporting each alternative.

The four alternatives, combined with the viable financial strategies for implementation, results in a set of 13 distinct options, all of which are financially and technically feasible. Following the evaluation, a matrix summarizing each alternative was then compared to the WRP goals. From this comparison emerged the Best Apparent Alternative. The results of the water balance analysis for each programmatic alternative are summarized in Table 1.

In multiple programmatic alternatives, an initial and final level of firm and variable water transfers are identified. A firm water transfer is defined as the quantity of water provided in every year, including droughts. Variable transfers are reduced during dry years as Stanislaus River supplies to OID are curtailed. OID currently transfers water to a neighboring special district and to the federal Bureau of Reclamation. These existing transfers total 41,000 ac-ft. Of that volume, 30,000 ac-ft are firm and 11,000 ac-ft are variable. Over the course of WRP implementation, the quantities of firm and variable supplies available for transfer were forecast to increase to 50,000 ac-ft and 17,000 ac-ft, respectively. In Alternative 2, these supplies are assumed to be transferred. Alternative 4 assumes that these supplies support expansion of service into the SOI. Alternative 3 assumes that the firm quantity is transferred, and the variable quantity supports expansion of service into the SOI.

Table 1. Summary of Programmatic Alternatives and Associated

Alternative	Description	Key Components
1	Continue Present Practices	<p>The “do nothing” alternative</p> <p>Limited investing in service improvements</p> <p>Continues same level of replacement and rehabilitation</p> <p>No annexations</p> <p>Continue minimum transfers of 30,000 ac-ft up to a maximum of 41,000 ac-ft.</p>
2	Maximize Service Improvements within District Boundaries	<p>Improve service standards</p> <p>Rehabilitate and modernize system</p> <p>Provide drought protection measures with added deep wells and reclamation facilities</p> <p>No annexations</p> <p>Finance all costs through transfer of 50,000 ac-ft and additional variable transfers of 17,000 ac-ft.</p>
3	Maximize Service Improvements within District Boundaries and Moderate Expansion of Service within OID’s SOI	<p>All elements of Alternative 2 except allows annexation of 4,250 acres of expanded service in SOI to utilize 17,000 ac-ft</p> <p>Finance all costs through transfer of 50,000 ac-ft</p>
4	Maximize Expansion of Service within OID’s SOI	<p>Annexation of 16,750 acres of expanded service in SOI to utilize 67,000 ac-ft of available supplies</p> <p>Annexations would consume available water allowing for no water transfers</p>

Evaluation Results. The Financial Model analyzed various strategies for viably supporting each programmatic alternative. This analysis led to the selection of Alternative 3 as the Best Apparent Alternative. This alternative maximized improvements in the district, provided for moderate expansion into the SOI, most strongly supported all the WRP’s goals, and kept water rates at a favorable level. Following Board endorsement, Alternative 3 was termed the Proposed Program.

THE PROPOSED PROGRAM

To comply with the California Environmental Quality Act (CEQA), OID prepared a Programmatic Environmental Impact Report (PEIR) to address the potential environmental impacts resulting from the implementation of the Proposed Program. That document was concluded and certified in June 2007.

The resultant Proposed Program adopted by the OID for implementation is currently in the Implementation Phase. The major components of the adopted Proposed Program consist of the following projects and programs:

- Flow control and measurement projects
- Canal Reshaping and Rehabilitation Program
- Groundwater Well Program
- Main Canal and Tunnel Improvement Program
- Pipeline Replacement Program
- Regulating Reservoir and Woodward Reservoir Intertie
- Turnout Replacement Program
- Drainwater Reclamation Program
- Surface water outflow management projects (Reclamation Program)
- Water transfers
- Expansion into the SOI

In all, the Program components in the WRP total \$169 million in modernization, rehabilitation and replacement projects to be implemented over the next 20 year period. The principle method of funding this cost will be from revenues generated through water transfers.

FINANCING THE IMPLEMENTATION OF THE WRP

The financial support for the implementation of the WRP programs will come from water transfers. Currently the OID has 41,000 acre feet in existing transfers and will produce another 10,000 acre feet of transferable water with full implementation of the WRP over the next 20 years. With projected implementation costs for the WRP at \$169 million, and assuming 20 year financing, and 50,000 acre feet of transferred water, the return cost on transferred water is \$200 to \$250 per acre foot depending on finance terms.

Placing this on an annual basis, OID would need an average revenue stream of \$12.5 million per year for its 50,000 acre feet of transferred water to fund the rebuilding, and modernization of OID without unreasonable and preferably no water rate increases to its customers. To meet that need, the following range of transfer terms would make that possible;

- OID could find a buyer of 50,000 acre feet at \$250 per acre foot,
- OID could find a buyer of 25,000 acre feet at \$500 per acre foot,
- OID could find a buyer of 12,500 acre feet at \$1,000 per acre foot,

Water Markets

There are three water markets available to the OID in which to evaluate transfer opportunities. Each market has a different ability to pay and comes with a different set of politics.

High End Metropolitan Areas. These market areas come with a capacity to pay but the local politics of completing such transactions can be difficult for small rural irrigation districts. Water kept locally serving local needs is a mantra of concern and is not without some merit. However, the benefit in marketing in these areas is the ability to receive high returns with less water in transfer thereby, in the long run, meeting both the financial needs of the irrigation district and the needs of the local community in keeping as much water locally as is financially possible.

Local and Regional Areas. These markets are only now being exposed to the true value of water. For many years, the local and regional areas have relied on a seemingly abundant groundwater supply that is now become less than usable in the San Joaquin Valley. With the implementation of the new arsenic rule, nitrate contamination issues, salt water intrusion from years of overdraft, etc. cities in the local and regional markets are only now beginning to face avoided cost issues for their future water supplies.

Agriculture Markets. This market's capacity to pay is simple to define. Their avoided cost for water is equivalent to that which they would pay to pump groundwater. In the area east of Oakdale, where agricultural is expanding on groundwater, that current cost is approximately \$80-\$100 per acre foot of pumped water, depending on depth to water. While the market is easy to define, there is difficulty in educating locals that these markets, with a limited ability to pay, could require water rate increases to offset the lack of revenues if oversold to this market.

The End Game. The end game is to provide the maximum protection to the district's water rights. Meeting that goal may be best met by having equal participation of transferred water into each market area. Politically, this strategy may provide the broadest base support to any challenge of OID's water in the future.

OID is currently in negotiations with all parties of interest in each water market strategy and will likely conclude such discussion by the end of 2008.

CONCLUSION

The true benefit of the WRP is that it has set a course of action for the OID. It has brought focus to an irrigation district and laid a path to meet the needs of a changing agricultural industry. If implemented as planned, the WRP will have provided the following regional benefits;

- Protected the OID's water rights
- Provided enhanced customer service opportunities to constituents

- Rebuild, modernize, and expand OID's water delivery infrastructure
- Protect the future water supply needs of the local urban areas
- Keep water rates affordable through a balanced effort of water transfers (50,000 acre feet) and allowing for agricultural expansion into OID's SOI (17,000 acre feet)
- Enhances local water supplies by 30,000 ac-ft
- Substantially increases water supply reliability and meets OID service needs in a worst-case drought

HB 1437: NO NET LOSS MUNICIPAL INTERBASIN TRANSFER THROUGH AGRICULTURAL WATER CONSERVATION

Stacy Pandey¹
John McLeod²

ABSTRACT

The HB 1437 Agriculture Water Conservation Program is an innovative way to meet rising municipal demands in Williamson County, Texas, conserve river water used for irrigation, and maintain agriculture productivity. The program provides grants to implement water conservation projects on farms and in LCRA irrigation divisions through a municipal conservation surcharge.

In 1999, the Texas Legislature passed House Bill 1437 authorizing the Lower Colorado River Authority to transfer up to 25,000 acre-feet of water per year to Williamson County (through Brazos River Authority (BRA)) under certain conditions including 1) The transfer results in “no net loss” of water to the lower Colorado River basin, and 2) A conservation surcharge on the transferred water is collected from BRA customers to help pay for the conservation projects (currently 25%).

Based on BRA water demands, a 7-year plan was developed through engineering studies and public meetings to conserve approximately 3,500 ac-ft/yr of agriculture water, representing a combination of conservation projects including precision leveling and automation of canal gates in irrigation divisions.

The grant program, begun in 2006, has provided partial funding to precision level 6,275 acres of farm land. Farms that have participated in this program received a 30% cost share in addition to a 50% cost share from the EQIP³ program. To date, 4,830 acre-feet of water has been conserved from these grants. A water savings verification program is under development and will be implemented in 2008. Ongoing challenges include revised water demands, savings verification, and interaction with other water projects.

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. House Bill (HB) 1437, passed by the Texas Legislature in 1999, authorizes the Lower Colorado River Authority (LCRA)

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³ Environmental Quality Incentive Program (administered through NRCS)

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 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 August 22, 2011.

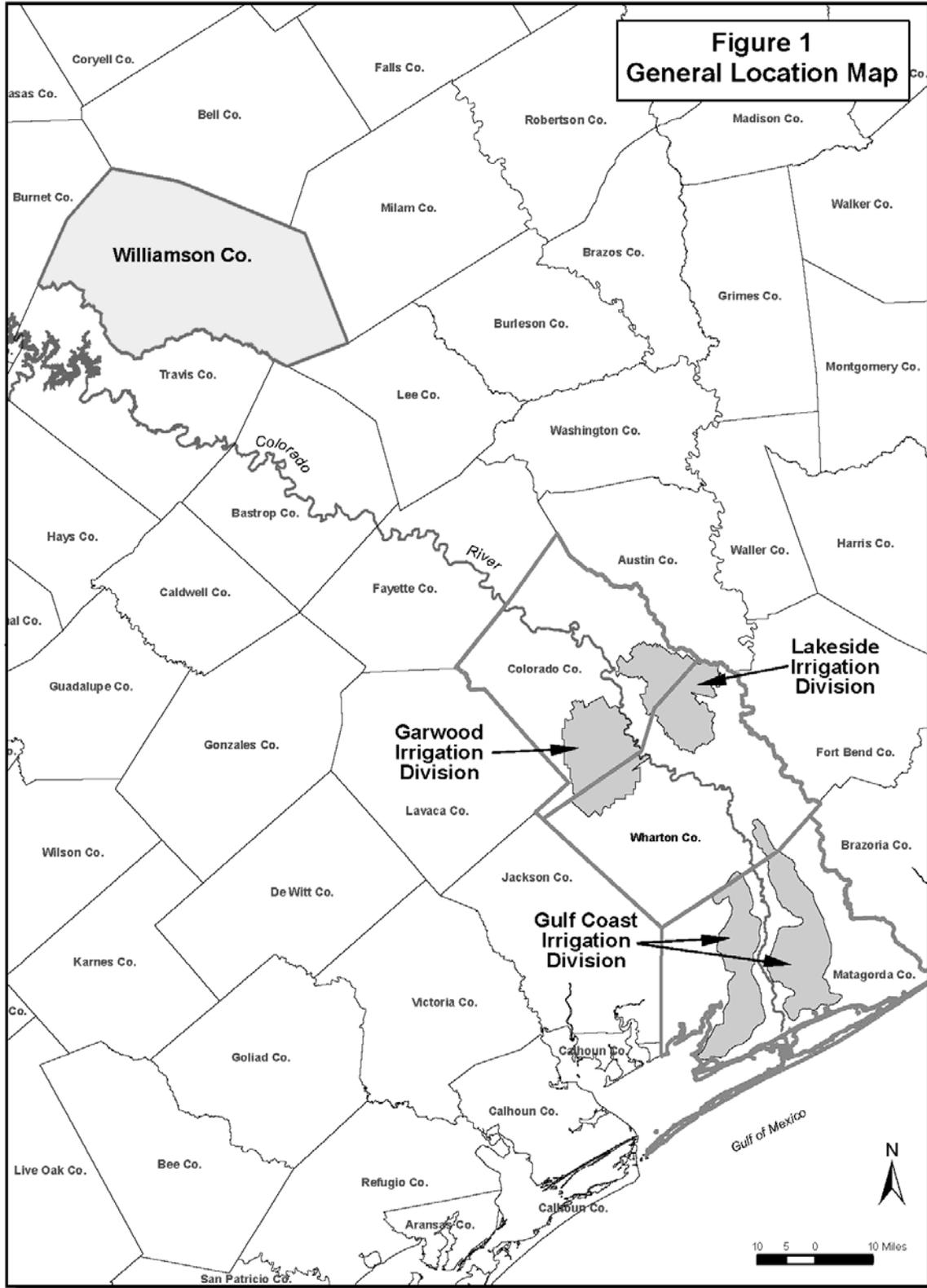
In August 2001, the Texas Natural Resource Conservation Commission issued the interbasin transfer permit to BRA to transfer up to 25,000 acre-feet of water per year to Williamson County under the conditions authorized in HB 1437. As of March 2008, no water transfers have occurred.

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, includes these important features:

- Developed a definition for “no net loss;”
- Evaluated Williamson County water demands and developed a seven-year plan to meet them through a combination of conservation projects including precision leveling 6,000 acres of farmland and rehabilitation and automation of canal gates in the LCRA irrigation divisions,
- Determined that the volume of agriculture water conserved under the planned projects satisfies projected municipal demands, meets the no net loss condition, and is eligible for interbasin transfer to Williamson County;
- Established a 25 percent conservation surcharge on the water transferred to Williamson County customers; and
- Presented additional recommendations for program implementation including policy definitions, additional engineering studies, and businesses and administrative practices.

In March 2005, the LCRA Board adopted a revised LCRA Board Policy 501, “Water Resources,” that incorporated the demands of HB 1437 Agricultural Water Conservation Program. The policy included the definition of no net loss. The HB 1437 implementation study is available at the Web site: www.hb1437.com. Figure 1 presents a general location map for the project.



No Net Loss

Four principles were identified to help define “no net loss” to comply with HB 1437:

- Clear and technically sound procedures for measuring water transferred to Williamson County and water provided to the Lower Colorado River Basin;
- Balancing over a number of years for water excess and water deficit;
- Assuring that water for transfer will be available during a critical drought; and
- Any water measurement criterion should detect water loss and provide remedial action.

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.

Transferred Water \leq Conserved Water + Developed Water + Returned Water

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.

PROGRAM OVERVIEW

The HB 1437 Agricultural Water Conservation Program is one part of the LCRA’s efforts to conserve water in agricultural uses. The program joins individual producers, local soil and water conservation districts and the U.S. Department of Agriculture’s Natural Resources Conservation Service (NRCS) in a collaborative effort to conserve water. The goals of the HB 1437 Program are to:

1. Reduce agricultural use of surface water,
2. Plan and implement conservation projects to fulfill contract obligations for HB 1437 water,
3. Provide grants from the Agricultural Water Conservation Fund to implement water conservation projects, and
4. Provide the program performance information to meet the requirements of the LCRA Board, Williamson County water customers, and the public.

Demand Projections for HB 1437 Water

The current HB1437 program plan was developed during the 2005 implementation study and included a combination of on-farm and in-division conservation improvements that balanced the projected water demands in Williamson County with the funds available in the Agricultural Water Conservation Fund. These water demand projections were developed by the Brazos River Authority and its customers, and are reviewed and updated as new information becomes available. In October, 2007 BRA presented LCRA revised demand projections for HB1437 water.

Figure 2 compares the HB1437 water demands used to developed the current HB1437 implementation plan with the updated demand projections recently provided by the BRA and their customers. The original projections provided by BRA show that about 16,000 acre-feet per year would be needed by 2020, with a steep increase in demand from 2012 to 2017. The new demand projections show that only 7,500 acre-feet per year will be needed in 2020, a near 50% reduction from the earlier projection.

The customers of the HB1437 water have changed as well. The City of Round Rock has reserved the largest percentage but does not expect to be taking water until 2014. Two entities, Chisholm Trail Sanitary Utility District (CTSUD) and the City of Georgetown have cancelled their contracts with BRA for HB1437 water. These BRA estimates are reviewed annually by LCRA staff.

Demand Projections for HB1437 Water

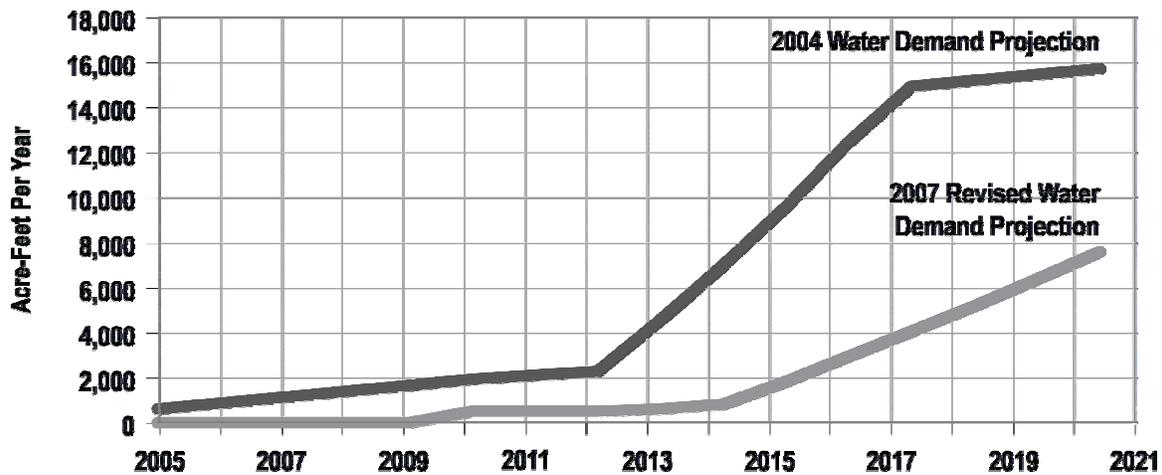


Figure 2. Water Demand Projections for HB1437 Water

Program Plan

The HB 1437 Program Plan includes a series of projects and studies to be completed during the period 2005 to 2012. The earliest cancellation date of the LCRA/BRA HB 1437 water contract is August 22, 2011, 10-years after the effective date of the

BRA/LCRA contract. The goal of this short-term program plan outlined in the HB1437 Implementation Study is to make available 3,500 acre-feet of HB 1437 water per year for transfer to Williamson County by 2009 to meet the 2004 projected demand of 2,260 acre-feet/year by 2012.

The plan, initiated in 2005, consists of three areas of activity.

- **Program and Policy** - provides the foundation of the program. Activities include development of board policy to define no net loss, expansion of program oversight by customers and the public and development of the program’s administrative processes and procedures.
- **Contract and Financing** - develops the business practices that provide financial stability and accountability to the program. These activities include development of the procedures for requesting water for transfer; acquiring assurances for program water needs beyond 2011 and debt financing agreements for construction of conservation projects.
- **Projects and Studies** - plan, construct and operate the various conservation projects. These activities include the engineering design, construction, technical studies and monitoring programs.

A summary of the HB 1437 program plan is presented in Table 1.

- **Planning Horizon:** 2005 – 2012 (plus field maintenance from 2014 through 2016)
- **HB1437 Water Available for Transfer:** 3,500 acre-feet per year.

Table 1. Conservation Projects and Program Costs

On-Farm Projects	In-Division Projects	Studies and Management
Precision level 6,000 acres of farmland	Construction of eight canal check structures in one of the LCRA irrigation divisions.	Conservation measurement and monitoring
Construction Cost - \$2.436 million (includes \$0.6 million for field maintenance)	Construction Cost - \$1.749 million	Oversight and customer communication
		Program administration
Total cost: \$5.176 million		
Funding sources: Ag Fund - \$3.9 million, EQIP - \$0.92 million, Farmer - \$0.37 million		

Program Funding

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%
- Normal Raw Water Cost: \$126/ac-ft
- Reserved Water Cost: \$63/ac-ft
- Max Available Water: 25,000 ac-ft/yr

Schedule

Under the current implementation plan for the projects, by 2009 at least 3,500 acre-feet of HB 1437 water would be conserved and available for transfer to Williamson County.

During the initial period (2005 – 2007), when only precision leveling is used, system capacity is 2,000 acre-feet per year and increases to 3,500 acre-feet per year with anticipated in-division improvements in 2008. Figure 3 shows how this implementation plan satisfies the projected water demands for HB1437 water through 2012.

Figure 3 also compares BRA's updated projection with current plans and shows a significant decrease in the rate of demand growth for HB1437 water. The decrease is relatively small through 2012 but during the period 2012 – 2017 the rate of demand increase is reduced by over 70% (2,700 acre-feet/year to 700 acre-feet/year). This demand change signals a need to update the HB1437 plan.

HB1437 Demand vs. Supply

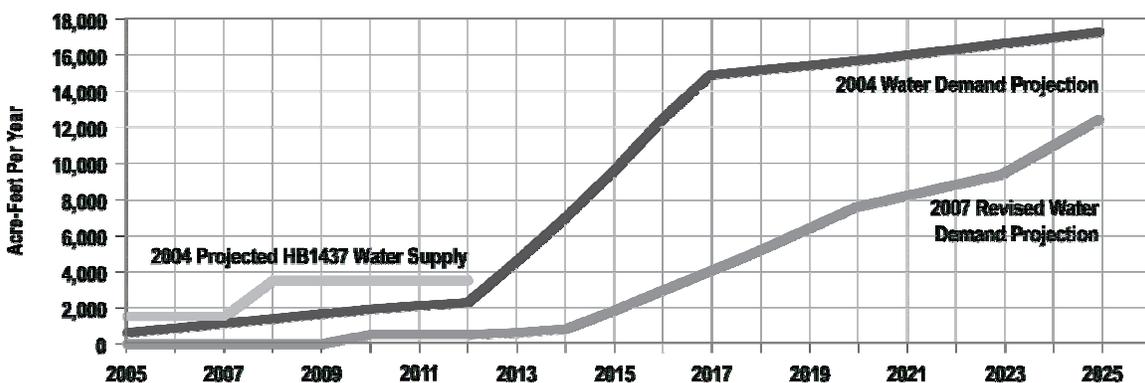


Figure 3. HB 1437 Demand vs. Supply

PROGRAM RESULTS

The program began in November 2005, when the LCRA Board approved the revised Board Policy 501. Initial efforts focused on developing the administrative and management procedures for implementing a grant program for on-farm conservation projects, and completing the interlocal agreement with the NRCS (Natural Resources Conservation Service) to integrate with their Environmental Quality Incentives Program (EQIP). This program pays 50 percent of on-farm conservation projects. The agreement was formally executed in March 2007.

In 2006, the LCRA policies necessary for program implementation were developed and adopted. These included:

- **LCRA Board adopted a revised Board Policy 501** which defined no net loss and incorporated the HB1437 water transfer requirements into LCRA policies.
- **LCRA Board authorized an interlocal agreement** with the NRCS.
- **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.

How does the Grant Program Work?

This section presents a overview of the grant program, additional details on the program are available on the program Web site: www.hb1437.com.

1. Producers submit an application to their local irrigation division office.
2. LCRA screens applications for eligibility and ranks eligible applications through a random selection lottery if demand exceeds available funds. LCRA notifies applicants of the award and signs a Cost Sharing Agreement with the applicant.
3. When the project is complete and certified by the local NRCS office, the producer submits a request for payment and is reimbursed for up to 30 percent of the cost of the approved acceptable practice based on NRCS guidelines in place at the time of contract award.
4. The LCRA reviews completed projects annually to monitor conservation success (the agreement stipulates that LCRA must be granted access to the field for inspection/measurement). The field must be in production within three years of the completion date and must be maintained to NRCS standards for the service life of the project.

On-Farm Conservation Projects

A summary of the program-funded on-farm conservation projects completed from 2006-2007 is presented in Table 2. The program shared the cost of precision leveling of 84 fields totaling 6,439 acres. The largest acreage was in the Garwood Irrigation Division,

followed by Lakeside and Gulf Coast. 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 75 acres.

Since inception, the HB 1437 Ag Fund has contributed \$486,975 out of a total cost of \$1,631,319. All of the applications submitted in 2006 and 2007 that met the first priority criteria were funded. The priority criteria can be found in the HB1437 Application Guidelines on <http://www.hb1437.com>.

Table 2. 2006-2007 Acres Leveled and Grants Awarded

Division	Fields Leveled	Acres Leveled	Total Cost	HB 1437 Share
Garwood	48	3,475	\$847,641	\$251,871
Lakeside	32	2,698	\$738,998	\$221,700
Gulf Coast	4	266	\$44,680	\$13,404
Total	84	6,439	\$1,631,319	\$486,975

Figures 4 and 5 show the locations of the leveled fields in the Garwood, Lakeside and Gulf Coast irrigation divisions. The combined acreage of HB 1437 leveled fields represents less than 2 percent of the estimated 345,230 acres historically irrigated.

In-Division Conservation Projects

There was no in-division conservation project activity during 2007. LCRA owned irrigation operations are referred to as “divisions” because they are not technically independent districts. The timing of the in-Division conservation will be re-evaluated in 2008 based on the revised water demands from BRA.

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 for 2007 was to develop a technically sound water conservation monitoring plan that could be integrated, and implemented, within the normal business practices of the LCRA irrigation divisions.

The plan for estimating water conservation factors for the HB1437 program will be based upon a statistical comparison of water use in fields leveled to EQIP standards versus water use in other non-leveled fields. The decision to analyze existing data instead of intensively studying a small number of “test” fields was based on recommendations from

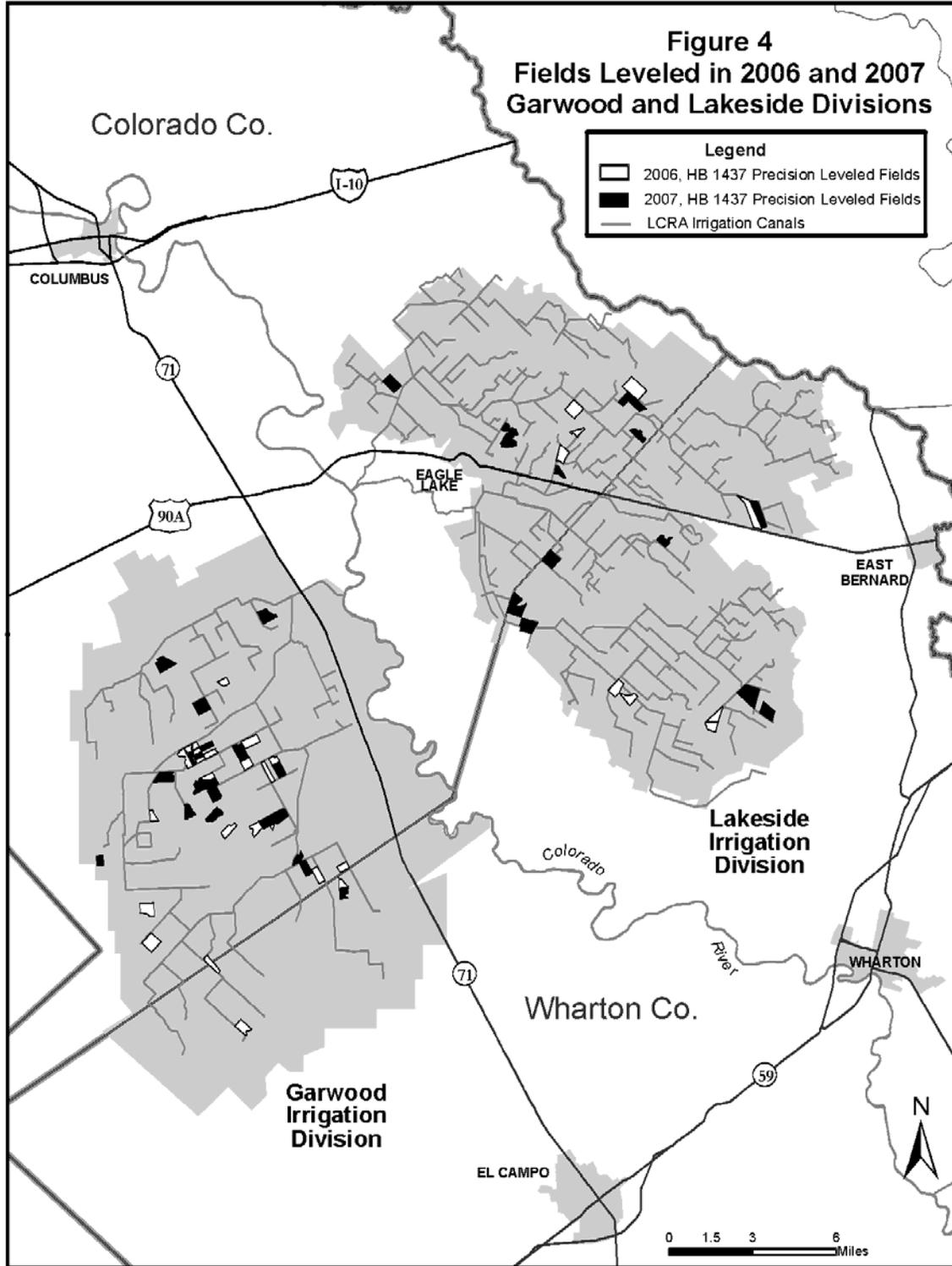
the LCRA SAWS Water Project Water Savings Verification and Monitoring Report (December 2007).

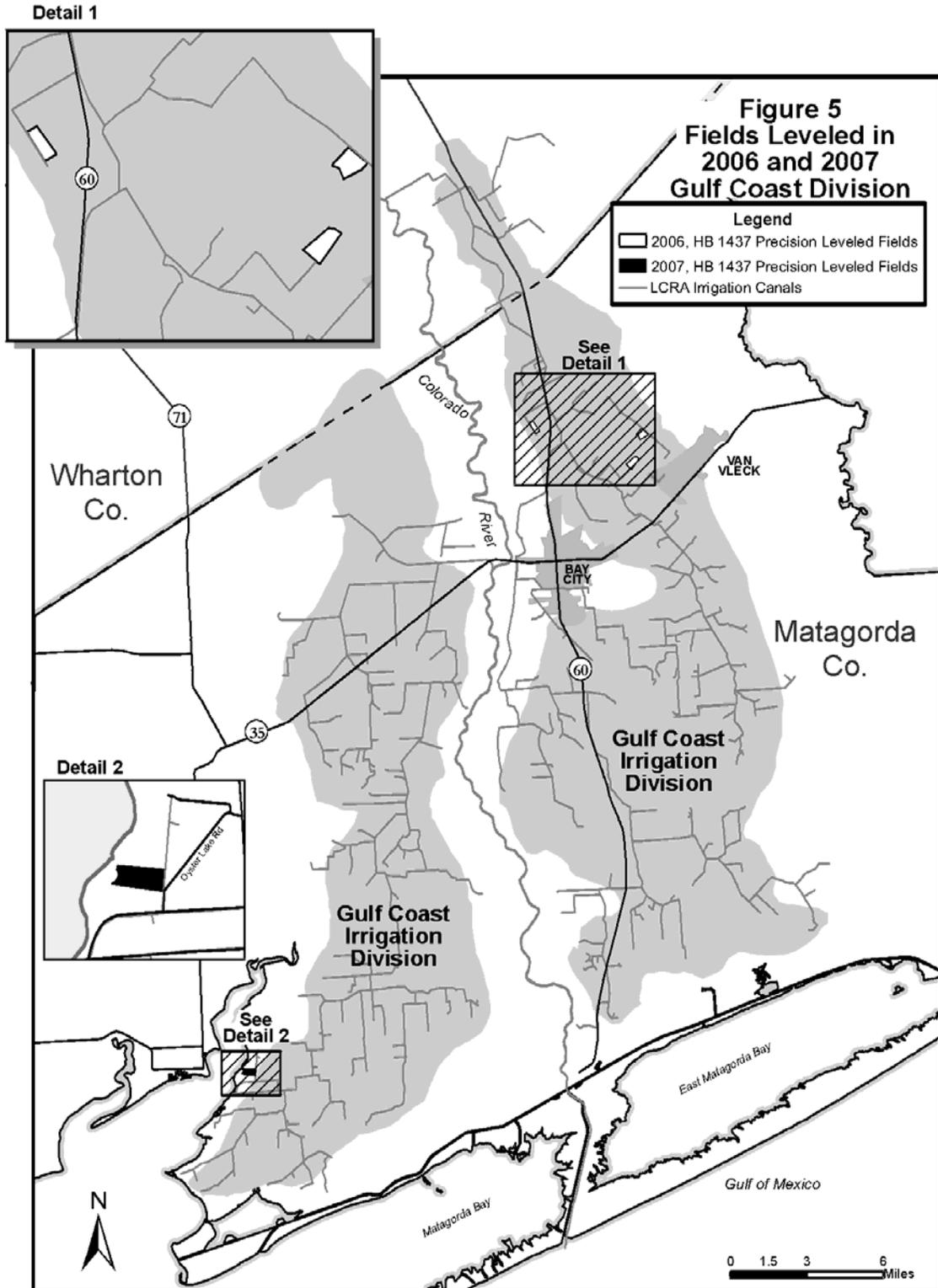
To verify this concept, staff analyzed water use data from the Lakeside Irrigation Division for 2006. Preliminary results from this analysis show that the difference in water use between the HB1437 fields and other fields closely approximates the conservation factor (0.75 ac-ft of water saved per acre leveled) currently used to estimate the supply of HB1437 water. The conservation monitoring plan calls for the development of separate conservation factors for each irrigation division.

A major challenge in implementing a HB1437 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 this division has the highest level of participation in the HB 1437 grant program (fifty-four percent of the acres leveled).

To address this condition, staff has implemented a limited water measurement program in several sections of the Garwood Irrigation Division. In 2007 staff conducted an initial test of the measurement program at 12 Garwood fields totaling 1,465 acres. Unfortunately, these measurements proved to be unreliable due to unquantifiable water use in neighboring fields and the frequency of when water measurements were taken. This issue will be addressed in 2008 (see section 5.1.3).

During 2007, staff implemented a program to develop accurate field maps. The program will digitize into a GIS layer the fields in a division and identify if it is a HB1437 field, its production status, and other water use information. All 2006 fields are mapped; mapping of 2007 fields is in progress.





Water Conserved and No Net Loss

LCRA Board Policy 501 states that no net loss occurs when the average annual volume of HB 1437 water transferred is equal to or less than the sum of the average annual volume of conserved water, returned water and developed water.

The current HB 1437 program plan relies exclusively on conserved water; production through developed water and/or returned water is not part of the short term plan, but may be added if BRA's demand for water or conservation performance estimates change.

Water Conserved. The volume of conserved water produced is calculated by multiplying the number of acres leveled times a 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 in development to refine the conserved water calculations. A leveled field must be in production to receive conservation credit; conservation credit for fallowing is not allowed. In 2006, 2,769 acres were leveled conserving an estimated 2,077 acre-feet of water. (2,769 acres x 0.75 = 2,077 acre-feet of water), and in 2007, 3,670 acres were leveled conserving an estimated 2,753 acre-feet of water (3,670 acres x 0.75 = 2,753 acre-feet of water conserved).

No Net Loss Status

Table 3 summarizes the 2005-2007 no net loss volume statistics. It shows compliance with the definition of no net loss and that 2,077 and 2,629 acre-feet of HB 1437 water was available for transfer in 2006 and 2007 respectively. Water transferred is HB1437 water transferred to Williamson County. In 2006 and 2007, 860 and 1120 acre-feet respectively was projected to be transferred. There was no HB1437 water transferred during 2006 or 2007.

Table 3. No Net Loss Summary, acre-feet

Year	Vol. Conserved	Vol. Developed	Vol. Returned	Vol. of HB 1437 Water			Net Loss
				Total Vol Available	Forecasted Demand	Actual Transferred	
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	3,000*	0*	0*		1,380		

*Planned

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 HB1437 program expenditures approved by the LCRA Board and replenished each year with the annual surcharge. In 2007, the LCRA Board approved authorization to spend \$500,000 in 2008. Figure 6 illustrates that yearly expenditures for the last two years are slightly under yearly income.

**Agriculture Fund Expenditure Calculations
Through December 2007**

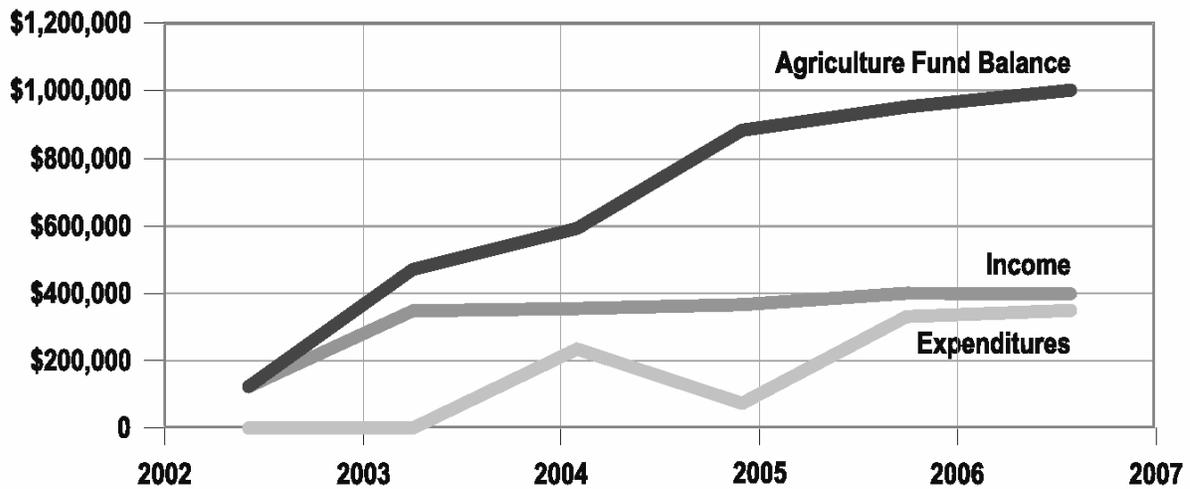


Figure 6. Agricultural Fund Income and Expenditures

PROGRAM OUTLOOK

The 2008 program consists of four areas of effort: continue the grant program and cost-share on-farm conservation projects; review and update the HB1437 implementation plan to account for new demand projections for HB1437 water; implement and refine the conservation verification program for the Garwood Division, and meet with the Agricultural Water Conservation Fund Committee.

2008 Program Activities

The program plan for 2008 consists of three components, on-farm conservation, in-division conservation and conservation monitoring and measurement.

On-farm Conservation Project. In 2008, the program will expand the 2006-2007 grant program for precision leveling projects to take advantage of existing but uncompleted EQIP contracts, as well as any new EQIP contracts. Based on discussions with local farmers, staff estimates that grant applications for as much as 5,400 acres of precision leveling projects are possible in 2008. If realized, these estimates will exceed the \$400,000 budget for grants in 2008, possibly prompting for the first time, use of the program's lottery system for awarding grants.

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. Results from the first two years of the grant program indicate that the additional 30 percent cost-share from HB 1437 encourages producers with existing EQIP contracts to complete the contracted work.

In 2005, NRCS reported that only 10 percent of the awarded EQIP contracts had been completed. This backlog of funded, but uncompleted, projects provides a reservoir of low-cost conservation projects. However, as shown in Table 4, this is changing.

The NRCS now reports that, as of September 2007, slightly more than 50 percent of the awarded EQIP contracts have been completed, and since April 2005, another 10,000 acres of EQIP contracts have been added. These changes indicate strong support for EQIP and the positive effect HB1437 is having on the implementation of water conservation projects.

Table 4. Summary of Contracted and Applied EQUIP Precision Leveling Acreage, as of September, 2007.

County	Contracted	Installed	Remaining
Colorado	17,645	8,785	8,860
Wharton	12,725	7,285	5,440
Matagorda	954	257	697
Total	31,324	16,327	14,997

Update Implementation Plan. In 2008, staff will initiate an engineering study to update the short term implementation plan and reassess the types and timing of new conservation projects. The current short-term plan includes constructing eight control-gates plus an instrumentation system in one of the irrigation divisions. This project has been delayed because of the revised water demand projections from BRA. A long term plan will also need to be developed to meet BRA water demands beyond 2012.

Conservation Monitoring and Measurement Study. Staff has reviewed on-going LCRA-SAWS water project technical studies and in particular has incorporated recommendations from the Water Savings and Monitoring Verification Report with data gathered from the HB 1437 program to design a HB1437 water conservation monitoring and measurement program for each division. This program is now underway and will continue to be refined in 2008.

Under this conservation program, a measurement study is now being implemented in the Garwood Irrigation Division, the only division where field water use is not measured. In 2008, fields watered by two entire canal reaches will be controlled by the division and farmers will have to contact LCRA to take water. This procedure is like that used in both the Lakeside and Gulf Coast Divisions. This will enable division staff to accurately measure 1,500 acres of leveled and non-leveled fields. Staff will be installing pipe walks and walk bridges to allow access to measurement boxes and to facilitate accurate measurements. The 2008 phase of this measurement project is scheduled to be completed in March 2008.

Water Contract Conditions. Long-term planning for the HB1437 program may be affected because of the 2011 cancellation provision in the LCRA-BRA water contract and the LCRA San Antonio Water System Water Project (LSWP) agreement. These limitations will become important in the next few years when high cost in-division projects are planned, when Williamson county customers begin to develop projects to deliver HB1437 water and when decisions on the future of the LSWP are made.

The LSWP agreement allows the project to use conserved water from strategies used in the HB1437 program, and provides reimbursement funds to the HB1437 Agricultural Conservation Fund. Unfortunately, the replacement of this water with new non-LSWP strategies may be more costly, and take longer to implement, than those strategies used to initially develop the HB1437 water.

In 2007, the Brushy Creek Regional Utility Authority was formed to develop a multiphase regional water supply project to deliver water from Lake Travis to the cities of Round Rock, Leander, and Cedar Park. In January, 2008 the Texas Water Development Board approved a loan of \$309,755,000 to the Brushy Creek Regional Authority to fund the project. This loan and the formation of the utility authority signals the beginning of a significant capital investment by the City of Round Rock to develop the infrastructure necessary to deliver its 21,000 ac-ft/yr share of HB1437 water. Assuming the water for the City of Round Rock will be provided under the BRA contract for HB1437 water, a long term implementation plan will require significantly more water than that provided by the existing implementation plan.

An additional consideration is the time and expense required to implement in-division conservation projects. Typically, these projects are 100 percent funded by the Ag Fund, take longer to implement than the precision leveling projects, and are not easily scalable from one year to the next. Therefore, in 2008 staff will explore with BRA its future plans for the HB 1437 water contract.

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. During 2008, staff will consult with county judges to have Ag Advisory Committee members reappointed and work with the Brazos River Authority to initiate efforts to organize and charter a Williamson County advisory committee. The 2007 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.

WATER CONVERSION IN SUMMIT AND WASATCH COUNTIES — A CASE STUDY

Wayne Pullan¹
Reed Murray²

ABSTRACT

A worldwide audience focused its attention on Summit and Wasatch Counties during the 2002 Winter Olympics. Media attention and spillover development from the Salt Lake City metropolitan area have fueled unprecedented growth in these two counties—as well as the concomitant increase in the demand for municipal and industrial (M&I) water. To meet this demand, the first conversion of irrigation water developed by the federal Central Utah Project (CUP) M&I use is being considered. The proposed conversion has potential effects on: existing agriculture; groundwater; downstream water users; downstream federal water projects; fish and wildlife; conservation measures; power generation; project repayment; and economics.

Summit and Wasatch Counties are located just east of the metropolitan area of Salt Lake City and the Wasatch Front. A permanent non-Indian settlement was established within the two county areas in 1859. Since settlement, the counties have remained largely agricultural; however, in recent years, suburban development has changed the economic bases and characters of both counties.

The counties contain three major federal reservoirs: Jordanelle (CUP), Soldier Creek (CUP), and Deer Creek (Provo River Project). Development of the CUP began in 1965. It is the largest water resources development program ever undertaken in Utah. In 2000, a portion of the CUP water was made available to provide irrigation water in Summit and Wasatch Counties. At about the same time, the Wasatch County Water Efficiency Project, a feature of the CUP, was developed to: improve the efficiency of water delivery; conserve water; restore certain stream flows; and provide water for fish and wildlife purposes.

In response to the counties' growth, the Central Utah Water Conservancy District (District), the CUP project sponsor, recently requested that CUP water authorized for irrigation use to be converted for M&I purposes. The Department of the Interior (Interior) has started the process for considering and approving conversion which will include compliance with the National Environmental Policy Act (NEPA).

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INTRODUCTION

Utah's Wasatch and Summit Counties lie to the east of Salt Lake City, roughly on the other side of the Wasatch Mountains. They are beautiful, characterized by high elevation valleys surrounded by mountains. In both winter and summer these valleys will be a few degrees cooler (or colder) than the Salt Lake Valley. Much of Wasatch County is within the Provo River drainage. The Provo River is one of the most reliable and highest quality sources of water in the state of Utah. Most of Summit County lies in the Weber River drainage but part lies in the Provo River drainage upstream from Wasatch County.

There is ample evidence of Native American use of the areas of Summit and Wasatch Counties within the Provo River drainage. The first permanent settlers were non-Indians. Mormon pioneers began to settle the Heber Valley area of Wasatch County in 1859 after a road had been completed up Provo Canyon from Provo City. Many of these early settlers were immigrants from Switzerland, attracted by the setting.

HISTORY OF WATER DEVELOPMENT

Water development in Wasatch and Summit Counties proceeded in four stages: pioneer and late-nineteenth-century irrigation; high mountain lakes construction; the Provo River Project; the Bonneville Unit of the CUP; and the Wasatch County Water Efficiency Project (WCWEP).

Pioneer and Late-Nineteenth-Century Irrigation

Settlers in the valley faced a short and dry growing season but the Provo River provided ample opportunity for irrigation. The settlers immediately began work on irrigation projects. Today, ditches and canals dating back to the early settlements continue to be used in these areas. Many of the old facilities have taken on the look of natural streams—and cannot be distinguished from natural streams by those who do not know better.

High Mountain Lakes Construction and Operation

The headwaters of the Provo River are in the Uinta Mountains east of Summit County and northeast of Wasatch County. In the early decade of the twentieth century, the headwaters provided the next opportunity for water development for irrigators. The irrigators traveled into the high Uinta Mountains, building dikes and dams to expand the storage capacity of several high mountain lakes.

Provo River Project

The next step in the water development and irrigation in the area was the construction of the Provo River Project, a Bureau of Reclamation (Reclamation) project. The Provo River Project provides a supplemental water supply for the irrigation of 48,156 acres of highly developed farmlands in Utah, Salt Lake, and Wasatch Counties. It also provides an assured domestic water supply for municipalities in Utah and Salt Lake Counties. The

key structures of the project are Deer Creek Dam and the Salt Lake Aqueduct. The dam is located on the Provo River in Wasatch County. The aqueduct runs through Utah and Salt Lake Counties. Construction on the project began in 1938 and was completed in the 1950s.

Bonneville Unit of the CUP

Congress authorized the CUP in 1956 as part of the Colorado River Storage Project Act. Of the six units (or sub-projects) under the CUP, the Bonneville Unit is the most complex, most expensive, and most productive (in terms of water supply). The Bonneville Unit provides for trans-basin diversion of project water from the Colorado River Basin to the Bonneville Basin or (in the local parlance) the Wasatch Front (the valleys immediately to the west of the Wasatch Mountains). From the early days of Bonneville Unit planning there were schemes for bringing water to Wasatch and Summit Counties.

Today, one of the key features of the Bonneville Unit is Jordanelle Reservoir. The completion of Jordanelle Reservoir made it possible for Reclamation to amend the District's repayment contract in 1997, obligating the United States to deliver irrigation water from Jordanelle Reservoir and obligating the District to repay. This amendment is referred to as Block Notice 1A. Block Notice 1A amends the Bonneville Unit repayment contract. It creates the obligation for the United States to deliver: 3,000 acre-feet of irrigation water to certain Summit and Wasatch County lands above Jordanelle Reservoir (the Francis Sub-Area); and 12,100 acre-feet irrigation water to Wasatch County lands below Jordanelle Reservoir. (Of the 12,100 acre-feet, 2,900 acre-feet is committed to the Daniels Replacement Project, leaving 9,200 acre-feet of project irrigation water—water that may be available for conversion.) At the same time, the Block Notice created the obligation for the Central Utah Water Conservancy District to pay for the irrigation water.

It is important to note that the District is a water conservancy district organized under the laws of the state of Utah, an entity with the power to levy property taxes for water development. The District signed the 1965 Bonneville Unit Repayment Contract and, hence, shoulders the responsibility for repaying the United States for reimbursable Bonneville Unit costs.

Wasatch County Water Efficiency Project

In 1992, the Central Utah Project Completion Act (CUPCA) was enacted to ensure the completion of the Bonneville Unit. One of the key CUPCA provision called for the construction of WCWEP (Figure 1). The WCWEP dramatically reduces irrigation water use by making pressurized water available for sprinkler conversions. Conveyance losses have been cut as aged canals have been lined and rehabilitated. Water conserved has been used to meet three goals: help meet CUPCA's mandated water conservation benchmarks; bolster in-stream flows in five Heber Valley streams; and replace a historic trans-basin diversion from Strawberry River.

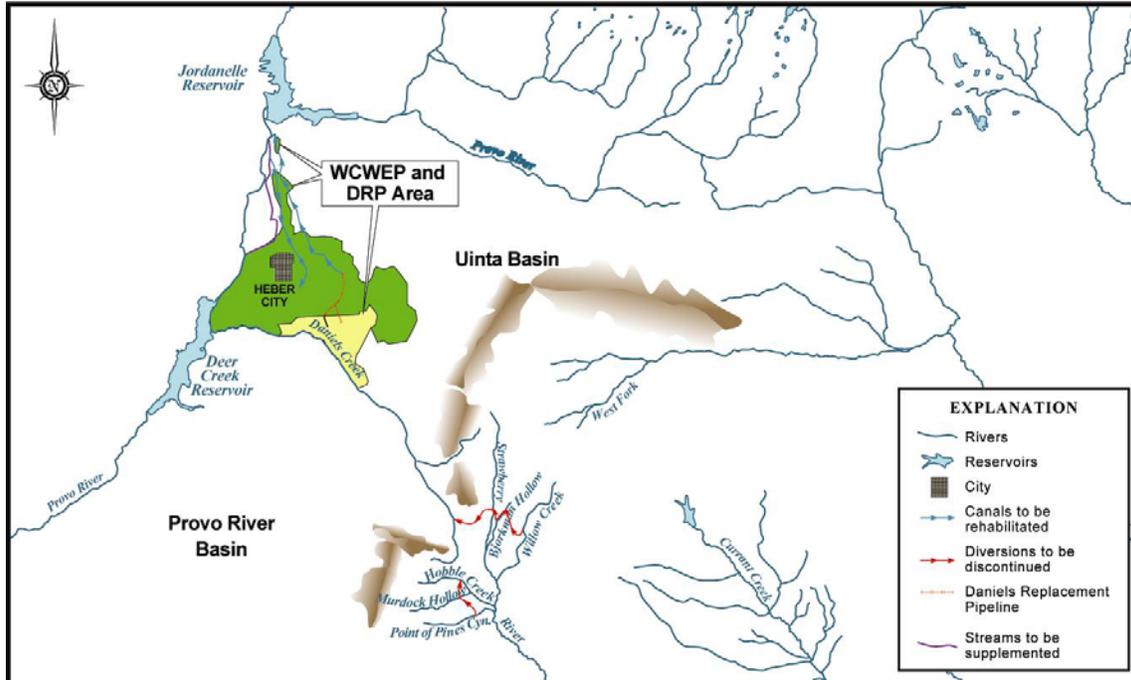


Figure 1

THE DEMAND FOR CONVERSION

A worldwide audience focused its attention on Summit and Wasatch Counties during the 2002 Winter Olympics. Media attention and spillover development from the Salt Lake City metropolitan area have fueled unprecedented growth in these two counties. The demand is likely to continue. Utah's Governor's Office of Planning and Budget (which is known for its tendency to underestimate) projects a 2.9 percent rate of population growth in Summit County through 2060. The figure for Wasatch County is 3.6 percent. By 2020, the population of Summit County is estimated to be 205 percent of its 2000 level. The increase for Wasatch County over the same period is estimated to be 234 percent.

With commercial farmland being gobbled up by horse properties, ranchettes, and suburbs, the demand for Block Notice 1A irrigation water is waning. In spite of the demand to move this water out of commercial agriculture, the ability to transfer such water to small, non-commercial tracts is hamstrung by ambiguity in Reclamation law—unless there is a possibility for conversion of project water from irrigation to M&I use.

THE LEGAL AND POLICY ENVIRONMENT FOR CONVERSION

Reclamation Law and Conversion

It is beyond the scope of this paper to offer more than a brief (accurate but without great detail) sketch of Reclamation law and policy with respect to the conversion of project water from irrigation to M&I use. The following is intended to be sufficient for our discussion.

When the Newlands Act was enacted in 1902, Congress did not anticipate the use of Reclamation project water for any use other than agricultural irrigation. As time passed, Congress made temporizing accommodations for some uses other than for the irrigation of farmland. The Townsites Act of 1906, for example, offers project water for town sites laid out as part of Reclamation Projects. The 1920 Act authorized the sale of excess project water for miscellaneous purposes—if a strict set of provisions were met.

It was not until the enactment of the 1939 Act that M&I use was recognized as a project purpose. Under the 1939 Act, M&I water from Reclamation projects can be offered under a repayment contract or under a water service contract. The M&I water provided under a repayment contract is priced at the full cost of the development of the project water—repayment of capital costs and interest accrued during construction—with interest.

Since 1902, irrigators were required to repay the cost of the development of the project irrigation water but without interest during construction or repayment interest. The 1939 Act introduced another benefit for project irrigators: the irrigators' obligation to repay project capital costs could be limited to their "ability-to-pay", provided other project beneficiaries (generally power or M&I users) were available to pay the remainder of the irrigation obligation.

The Colorado River Project Storage Act amends the 1939 Act and authorizes the Bonneville Unit of the CUP; under this authority, Bonneville Unit irrigation and M&I water is made available under the 1965 Repayment Contract between the United States and the District.

The 1965 Repayment Contract anticipated the need for conversions of Bonneville Unit irrigation water to M&I use. It acknowledges that the District may not deliver project irrigation water "for any other purpose other than agricultural purposes" without the consent of the United States. The Repayment Contract then describes the process for allocating the payments for irrigation water converted to M&I use among the two purposes. The inclusion of conversion provisions in the Repayment Contract is helpful but the conversion from irrigation to M&I requires compliance with Reclamation policy.

Reclamation Policy on Conversions

The 1939 Act created a substantial incentive to be eligible for irrigation water by creating a difference between the rate paid for irrigation water and the rate paid for M&I water in the same project. For example, Bonneville Unit irrigation water delivered to Wasatch County is priced at the irrigators' ability to pay--\$3.10 per acre-foot. Bonneville Unit M&I water delivered in Wasatch County is priced at in excess of \$200 per acre-foot. Because of the difference in price, it was important to define clearly who was eligible to receive the subsidy.

The recent history of Reclamation policy with respect to conversions begins with the 1982 Letter. The 1982 Letter was an attempt to set a workable definition about what lands were eligible to receive project irrigation water. The 1982 Letter concluded

irrigation water could only be used to support commercial agricultural enterprises. It defined a commercial enterprise by tract size. Under the 1982 letter, tracts over ten acres were eligible to receive project irrigation water. Tracts under two acres were not. Tracts between two and ten acres may be eligible but the operator was required to show evidence that the enterprise was grossing \$5,000 annually.

In 1994, the Reclamation came under scrutiny by Interior's Inspector General for allowing the unchecked "unauthorized use" of irrigation water. In other words, Reclamation was criticized for failing to monitor the use of irrigation water, allowing it to be applied to small tracts and failing to collect the additional revenue. In response, Reclamation went so far as to publish draft regulations regarding unauthorized use. The regulations were never finalized.

The issue of irrigation of small tracts continued to simmer until January 2001. Reclamation was updating its documents for implementing Interior's 1988 "Principles Governing Voluntary Water Transactions That Involve or Affect Facilities Owned or Operated by the Department of the Interior". In the update to Reclamation's policy manual, it attempted use a footnote to sweep away the small tract/unauthorized use issue. Footnote 6 of WTR P02, Voluntary Transfers of Project Water, states:

"Accordingly, when a project contractor or end user is itself the one who continues to use untreated, raw project water which is converted from the irrigation of commercial crops to the irrigation of other vegetation (including but not limited to lawns and ornamental shrubbery used in residential and commercial landscaping; gardens, golf courses, parks, and other developed recreational facilities, commercial nurseries, and pastures for animals raised only for personal pleasure and use), then such a conversion is not a 'change in the type of use' of project water and is, therefore, not a transfer of project water subject to this policy."

Footnote 6 concluded that, as long as the irrigation water is untreated and is used to irrigate non-commercial vegetation, it would remain irrigation water under Reclamation law and policy. In other words, issues of tract size and commercial viability of an agricultural enterprise were no longer issues in the use of irrigation water. Irrigation water could be applied to small tracts and landscaping.

Footnote 6 was silent, however, on the issue of price. Would irrigation water applied to small tracts and landscaping be eligible for the irrigation subsidy? Reclamation warned that Footnote 6 would be followed by a sister policy introducing a new rate for non-commercial use of irrigation water—a rate, Reclamation hinted, that would be somewhere between the subsidized irrigation rate and the full M&I rate.

Five years into its gestation, the sister policy to Footnote 6 (the pricing policy) has not been born. As Reclamation attempted to develop its policy, its legal counsel concluded that Footnote 6 contradicted definitions of irrigation in the Reclamation Reform Act of 1982. By 2006, Reclamation had placed Footnote 6 under a cloud. It discouraged any transfers of irrigation water under Footnote 6 and indicated it would repeal the policy, but

failed to provide an alternative. Today, Footnote 6 remains in place and Reclamation continues to operate within a policy vacuum. The issue of applying Bonneville Unit irrigation water to small tracts arose in the midst of this small tract policy maelstrom.

CONVERSION IN THE BONNEVILLE UNIT OF THE CUP

CUPCA and Reclamation Law and Policy

The focus of this paper now turns from Reclamation law and policy in general to the application of Reclamation law and policy in the Bonneville Unit of the CUP. At this point, it is important to address CUPCA in greater detail.

Bonneville Unit Construction proceeded slowly through the 1970s and 1980s because of the complexity of the project, the need for environmental analyses (required after enactment of NEPA in 1969), and inadequate federal funding. By the early 1990s, the slow progress prompted state and local officials to ask Congress to empower the District to complete the planning and construction of the remaining portions of the CUP, including the Bonneville Unit.

Congress responded to local concerns by enacting CUPCA on October 30, 1992. Through CUPCA, Congress provided direction for completing the CUP under a partnership among the District, the United States Department of the Interior, and the Utah Reclamation Mitigation and Conservation Commission (a federal commission created by the CUPCA). The CUPCA removed administrative responsibility for the CUP completion from Reclamation, placing it under the Office of the Secretary of the Interior. The Secretary of the Interior's local office for administering CUPCA is the CUPCA Office. To differentiate the CUPCA Office from Reclamation, it will be referred to as Interior through the remainder of the paper.

The CUPCA is an amendment to the Colorado River Storage Project Act. In administering CUPCA and the completion of the CUP, Interior is bound by Reclamation law but not necessarily bound to Reclamation's interpretation of the law. Regarding policy, Interior attempts to follow Reclamation policy but is not required to do so.

The Decision to Pursue Conversion

In 2005, the District began discussions with Interior regarding the application of irrigation water on small tracts. In both Wasatch and Summit Counties, farmers and ranchers were selling out to developers. The developers were clamoring to use the project irrigation water to irrigate the landscaping of suburban tracts and ranchettes. Irrigation companies (that were now serving secondary irrigation systems) were concerned about loss of carrying capacity in their canals and ditches—as project water moved out of the system and on to large farms elsewhere.

At that time, the District and Interior faced the following options: take no action and continue to attempt to deliver the water to large commercial agricultural tracts; pursue

application of the water to small tracts under Footnote 6; or convert the water to M&I use under the authority of the 1939 Act and the Colorado River Project Storage Act. The three options offered the following advantages and disadvantages.

Take No Action. The take no action alternative would allow the District and Interior to avoid the expense in both time and dollars of pursuing any kind of conversion, including the cost of performing environmental impact analysis under NEPA. It would allow the project irrigation water to continue to be sold for subsidized irrigation rates. The water might be transferred but it could only be applied to irrigable acreage—acreage that Reclamation had classified as irrigable in terms of soil condition, drainage, and tract size. It would harm irrigation companies serving the developing areas as the project irrigation water would inevitably move to eligible lands and away from developed lands. The result would be reduced efficiency in conveyance. No action would be, of course, a temporary solution. At some point the availability of commercial farms and ranches would dwindle to the point that project irrigation water would have insufficient irrigable lands on which to be applied.

Allow Application to Small Tracts under Footnote 6. Footnote 6 would allow the project irrigation water to continue to be applied to the same lands—as those lands were developed. In fact, Footnote 6 required that the water remain on the original tracts. It would not be a change in the use of the project water. Adequate water would remain in the canals. The water could be sold for the subsidized irrigation rate—at least until Reclamation settled on a new, higher non-commercial irrigation rate. The decision to permit irrigation of small tracts would require some level of NEPA compliance. Footnote 6 raised its own concerns. The policy seemed to be a temporary fixture. The pricing policy had not arrived, raising suspicion about Reclamation's long-term policy. If and when Reclamation settled on a non-commercial irrigation rate, the policy would essentially create a third class of water in the Bonneville Unit—irrigation, M&I, and non-commercial irrigation. None of the Bonneville Unit contracts had anticipated this new class of water. Administering the new class of water may require amendments to the earliest Bonneville Unit contracts and would certainly impose additional costs.

Convert to M&I Use. At that time (and today), Interior and the District had converted no Bonneville Unit irrigation water to M&I use. A conversion would be uncharted territory, but (unlike relying on Footnote 6) the approach was founded on clear legal and contractual authority. The conversion would require the amendment of the block notice but would likely not require amending the repayment contract (because conversions were addressed in the repayment contract). Conversion would allow the water to be transferred off lands determined to be irrigable in terms of suitability for agriculture and tract size. Generally, it would allow water to be applied to any lands within the project area regardless of tract size, Reclamation land classification, or area of previous application.

In terms of use, after conversion the water could be applied to small tracts for irrigation of landscaping, treated for culinary use, or used in industrial processes. The decision to convert would require NEPA compliance and the potential for the water to be used for new purposes would inevitably raise the interest of Bonneville Unit critics. Converted

water would sell for the full M&I rate and would not benefit from subsidies to irrigation water.

Eventually, Interior and the District elected to pursue the conversion option. They decided on conversion largely because the conversion option was a long-term solution and without some of the risks associated with Footnote 6.

Development of a Test Case

After deciding to pursue conversion, the District remained concerned about unforeseen complications and elected to pursue a test cast of just 100 acre-feet. After discussions about the expense involved and potential for allegations of ‘piece-mealing’ the NEPA compliance, the test case amount rose to 1,000 acre-feet and eventually to 3,000 acre-feet.

Eventually the 3,000 acre-feet of Block Notice 1A water for the Francis Sub-Area would become the test case (an amount that is possibly too large to be considered a test). In this area above Jordanelle Dam and Reservoir, the pressures for conversion were greater than below the dam. The conversion of the remaining project irrigation water delivered to Wasatch County below Jordanelle Dam (9,200 acre-feet) would wait and be pursued as a second step.

NEPA Compliance

The process of settling upon an approach and refining it took many months. On March 5, 2008, the District and Interior conducted a public scoping meeting to initiate the development of an Environmental Assessment (EA) on the conversion of up to 3,000 acre-feet of project irrigation water in the Francis Sub-Area—consisting of an immediate conversion of 200 acre-feet now and future conversions in 100 acre-foot increments over the next 25 years.

The scoping process, which is still underway, has identified the following project purposes for the proposed conversion:

Continue the Delivery of Bonneville Unit Water to Petitioners. Had the District and Interior elected to take no action, there would have been a potential for interrupted deliveries as irrigation water was transferred away from certain canal companies to ensure project water was only delivered to large commercial agricultural tracts. The conversion allows for project water to stay with petitioners as the underlying land is developed.

Improve Efficiency in the Application of Water. The conversion may improve efficiency in the application of water as water users face the full cost of the development of the water. Any incentive toward over-application of water created by the subsidy may be reduced. Also, the increased rate may encourage investment in avoiding waste.

Improve Efficiency in the Delivery of Water. The conversion may improve efficiency in delivery because, as large tracts have been sub-divided in recent years, project water has been removed from canals and other conveyances (because the water could no longer be provided to small tracts). As a result, there has been insufficient water in the conveyances for them to operate efficiently. The conversion will allow project water to remain in these conveyances.

Improve Efficiency in the Administration of Bonneville Unit Water. The conversion may increase administrative efficiency by eliminating the need to monitor the application of irrigation water. With project irrigation water, resources are expended to be sure that water is only applied to eligible lands. Part of this monitoring involves the filing of Reclamation Reform Act forms. After conversion, these administrative requirements disappear.

Enhance Flows in a Portion of the Provo River. Currently water is delivered from the Provo River into canal companies' private diversions. After conversion more water would remain in the Provo River because alternative delivery options would be allowed, e.g. secondary systems. These options may include leaving water in the Provo River and exchanging the rights to wells that would be pumped for municipal use. Water could be left in the stream to flow into Jordanelle Reservoir and then be pumped out of the reservoir, treated, and then delivered to municipal customers within the expanded Francis sub-area. Keeping the water in the Provo River for a longer distance would enhance the riparian zone and the aquatic ecosystem.

Assist in Maintenance of Historic Return Flows. Converting Bonneville Unit irrigation water to M&I use would assist in maintenance of historic return flows by allowing for use on small tracts of land that are currently ineligible to receive water. This action could also allow use through secondary systems which would continue to provide for historic application practices on tracts of agricultural land that have been developed into subdivisions.

The District and Interior foresee that the following resources will need to be addressed in the EA:

- water resources and water quality;
- fish and wildlife resources;
- wetlands;
- threatened or endangered species;
- visual resources;
- health, safety, air quality and noise;
- transportation and utilities;
- recreation resources;
- cultural resources;
- socioeconomics;
- land use plans and conflicts;
- Indian trust assets;

- environmental justice;
- unavoidable adverse impacts;
- cumulative impacts;
- short-term use of man's environment versus maintenance of long-term productivity; and
- irreversible and irretrievable commitment of resources.

Process for Conversion

To effect the conversion, Interior will amend Block Notice 1A, dividing it into an irrigation sub-block and M&I sub-block. The initial amendment will extract 200 acre-feet from the irrigation side of the block notice and place it in the M&I side of the block notice. That move will reduce the irrigation obligation and create an M&I obligation. As subsequent blocks of water are converted, Interior will amend the block notice similarly. The amendments will not affect the repayment period.

The District provides Block Notice 1A water to canal companies under petitions. Through these petitions, it passes its obligation to repay Interior on to the canal companies. The canal companies, in turn, pass on the obligation to share holders. After conversion, the District will be providing two very different products to petitioners and petitioners will be offering those different products to water users: first, project M&I at a high rate but with no restrictions on tract size and a wide potential area of application; and second, irrigation water at a low rate but with restrictions on tract size and place of application (lands certified irrigable by Reclamation).

In order to manage the distribution of these different types of water, the District will amend its petitions with the canal companies. Canal companies will likely be required to issue a new type of stock representing M&I water. Holders of the new stock would pay more for their water but would be able to use it without restriction.

Medium-Term and Long-Term Results of Conversion

The following appear to be the medium and long-term effect of the current conversion of Bonneville Unit irrigation water to M&I use.

Step Two: Converting Block Notice 1A Water – The successful completion of the first step (conversion of water for the Francis Sub-Area) will likely be closely followed by the second step (conversion of the Block Notice 1A water delivered below Jordanelle Dam and Reservoir).

Template for Uinta Basin Conversions – Most of the Bonneville Unit irrigation water is delivered within the Uinta Basin. Block Notice 1A is, in fact, the only permanent supply of project irrigation water delivered from the trans-basin diversion. Although the Uinta Basin is far more rural than the Wasatch Front, the recent oil boom has jump-started suburbanization of Uinta Basin towns. The successful conversion of Block Notice 1A water will serve as a template for the process of bringing about conversions that will

inevitably occur in the Uinta Basin.

Effect on Cost Allocation. By act of Congress (in CUPCA), Interior allocates the costs of the Bonneville Unit using the use of facilities method. Under this method as applied to the Bonneville Unit, each drop of water flowing through a project facility picks up its portion of the costs of that facility. Under this method, the Block Notice 1A water is the most expensive irrigation water in the system because it picks up costs from Jordanelle Dam and Reservoir. The conversion of this expensive water from irrigation to M&I will remove expenses from the allocation to irrigation. The result will likely be a reduction in the average per-acre-foot cost of irrigation water (which will be a benefit to the power users) and an increase in the per-acre-foot cost of M&I water; however the magnitude of these changes is likely to be insignificant as the changes in allocation are swamped by the large number of acre-feet across which it is distributed.

CONCLUSION

On the day the District and Interior began considering conversion of project water delivered to Wasatch and Summit Counties under Block Notice 1A, everyone would have assumed that we would be finished by now. Instead, we are only beginning the NEPA process for converting only the Summit County portion. The delay has been a disappointment to developers and a frustration to the irrigation companies, but it has resulted in a comprehensive understanding of the action, its legal basis, the political implications, and the procedure for executing it. The extra time promises to establish a knowledge base and process for proceeding with conversions in other parts of the project—as circumstances may require. Some things should not be hurried.

COLORADO'S "SUPER DITCH": CAN FARMERS COOPERATE TO MAKE LEMONADE OUT OF LEMONS?

Jay Winner¹
MaryLou Smith²

ABSTRACT

Colorado's Statewide Water Supply Initiative (SWSI) shows that the state has only enough water to meet about 70% of its needs by the year 2030, with most of the gap occurring in the front range urban areas of the state. The SWSI report forecasts that a majority of the water needed for cities will transition from agriculture, which currently uses more than 80% of the state's water. Agricultural communities are concerned what such a transition could mean to their viability. The second phase of SWSI investigated such alternatives to the traditional "buy and dry" as interruptible supply agreements, rotational fallowing leases, water banks and cropping changes.

The Lower Arkansas Valley Water Conservancy District (LAVWCD), inspired by the Palo Verde Irrigation District in California, set about to see if ditch companies in the lower Arkansas Valley might agree to form a "super ditch" whereby they would cooperatively pool part of their water to gain operational flexibility and make it available for lease to cities. By working together in a rotational fallowing scheme, they conceptualize that they will have greater bargaining power. Perhaps by converting part of their land from growing hay or corn to growing "water" they could actually benefit financially, and keep their agricultural communities viable.

Those attempting to transform the concept into reality are finding that "the devil is in the details." This paper is presented as a sociological case study in the making. The authors detail the steps Super Ditch organizers went through to determine if their scheme is feasible, as well as the hoops they are now going through to try to bring it to fruition.

BACKGROUND

LAVWCD, formed in 2002, encompasses five counties from Pueblo to the Kansas state line. While most conservancy districts were formed to *develop* water resources, the Lower Arkansas District was formed to *protect* water resources. Its mission is to insure the continued availability of water resources for long term economic viability of the Lower Arkansas Valley. What is threatening these water resources?

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Buy and Dry

Since 1950, more than 60,000 irrigated acres have been sold to municipalities—primarily Aurora, Colorado Springs, and Pueblo. 20% of one of the largest canals in the lower basin, the Fort Lyon Canal, was purchased by High Plains, now PureCycle, for transfer to the Colorado Front Range. Temporarily defeated in Colorado water court because of the state’s anti-speculation law, PureCycle is poised to move the water off the farms once they have a customer.

For several reasons, permanent transfers, frequently referred to as “buy and dry,” have historically been the preferred mechanism for municipalities to transfer water from agriculture. Owning the water allows municipalities to enjoy the appreciation of its value as an asset, but more importantly gives them certainty and control of the supply. These transfers carry a lower risk than developing new trans-basin supplies—an option which has become highly difficult in recent years given environmental and other concerns and with curtailment of federal funds for such projects.

However, despite some municipal mitigation in the form of revegetation and payment-in-lieu-of taxes to schools and other taxing districts, these “buy and dry” deals have contributed to economic difficulty, if not disaster, for the rural communities from which the water was transferred. Those irrigators selling their water enjoy immediate benefits and options for use of cash, but the community and region suffer overall economic loss.

Politically Motivated Alternatives to Buy and Dry

At this point, cities are politically motivated to seek water deals other than “buy and dry” and have begun to think in that direction. The City of Aurora, for instance, in 2004 negotiated a deal with shareholders of the Rocky Mountain High Line Canal, under the terms of which farmers would lease part of their water up to 3 out of 10 years in an “interruptible supply” arrangement to help Aurora meet demand in drought years. Farmers, many of whom could not have realistically farmed in such a dry year anyway, reaped cash benefits which kept them and their bankers happy. More than 80% of eligible farmers signed on to participate, and most of those who did not wish they had.

With the first SWSI report projecting that another 72,000 acres would likely be transferred from Arkansas Basin agriculture by 2030 (and commensurately large amounts from the state’s South Platte Basin), the state commissioned a SWSI 2 Technical Roundtable to investigate ways that water could be transferred without permanently drying up those irrigated acres. Their report, released in November 2007, details benefits and shortcomings of such alternatives to buy and dry as:

- interruptible supply agreements
- long term rotational fallowing agreements
- water banks
- reduced agricultural consumptive use without reducing return flow (through efficiencies or cropping changes)
- purchase-leaseback (a form of delayed buy and dry)

Current Investigations into Buy and Dry Alternatives

A number of efforts are currently underway in Colorado related to the issue of “ag to urban water transfers.” A committee of the Arkansas Basin Roundtable, as reported elsewhere in this conference, has brought together urbanites and agricultural folks to hammer out ways to “get it right” if water is to be transferred from agricultural to urban uses.

Colorado State University's Colorado Water Resources Research Institute is working with the Colorado Ag Water Alliance to investigate ways water can be conserved in agricultural practices to provide additional water for cities without infringing on water rights of downstream users or jeopardizing Colorado's compact with Kansas.³

The City of Parker has contracted with researchers at Colorado State University to study cropping changes such as deficit irrigation and different crops to determine if farmers can in effect add to their crop mix a new crop called “water.” A survey of farmers is being conducted to determine the willingness of farmers to lease water under a variety of circumstances.

THE SUPER DITCH

The Super Ditch is undoubtedly the most talked about alternative being investigated in Colorado for moving water from agriculture to cities without drying up agricultural lands.

What Is the Super Ditch?

The Super Ditch is not a ditch at all. Instead, it is conceptualized to be a company formed by shareholders of multiple ditch companies who would lease water to municipalities by fallowing a portion of their land in a rotating fashion. Specifically, irrigators who own shares in participating ditch companies would voluntarily offer to fallow part of their land and lease the corresponding water for other uses. Municipalities and other users would lease the water instead of purchasing it outright. The idea is for shareholders to pool their water, lease it, make money, then distribute the money to shareholders through dividends, providing an additional, predictable revenue source which farmers could use for farm improvements, debt reduction, new equipment, or capital for launching new agri-business endeavors.

LAVWCD would not be the administrator of the Super Ditch; they are only serving as the instigator to get it organized. District funds totaling close to \$600,000 have been expended for engineering and economic studies as well as legal research to determine the feasibility of the concept

³ Of particular import is that Colorado water law allows a farmer to “save” from only the CU portion of water diverted—the crop's consumptive use. For example, a farmer with 30 acres of corn to irrigate and a decree for 1000 acre feet of water cannot use any more water than a farmer with 30 acres of corn to irrigate and a decree for 100 acre feet of water. The first farmer can divert the full decree, but every drop not consumptively used he must “give back” as return flow.

Roots

Peter Nichols is one of the prime characters in the Super Ditch story. He helped conceptualize it and he is helping move it forward. Nichols is one of the authors of *Water and Growth in Colorado—A Review of Legal and Policy Issues*, published in 2001 by the Natural Resources Law Center at the University of Colorado School of Law. In this book Nichols said “moving water from the agricultural to the urban sector has the potential to solve projected municipal water shortages” but, he said, there are a host of difficult legal and policy issues to be considered, including the effect on the viability of rural communities. He proposed that temporary transfer mechanisms such as leases, dry year options and water banking might provide municipalities with drought protection while maintaining rural economies.

Now, six years later, Nichols is deep into a major experiment to see if his theory will “hold water.” Hired as special counsel to the LAVWCD, Nichols is part of the Super Ditch team made up of District personnel as well as engineering and economic consultants, actively working with farmers to work out the myriad of questions and issues which must be answered and resolved if the Super Ditch is to come to fruition.

The District began talking about alternatives to buy and dry immediately upon its 2002 formation. But others had been thinking along the same lines for some time. Bill Hancock knows the farmers and ranchers of the lower Arkansas Valley. He was lured to LAVWCD to assist with the Super Ditch effort, after 38 years working in Rocky Ford for Colorado State University Extension Service. Hancock remembers that even as far back as the mid-90’s, right after the permanent “buy and dry” sale of the Rocky Ford Ditch,⁴ extension service was trying to plant a seed for farmers to consider interruptible supply as an alternative to buy and dry.

First Steps

Identification of Potential Participating Ditches. The first concrete task LAVWCD undertook was to contract with an engineering firm to investigate how much water might potentially be available for lease and from which ditch companies. Diversion and stream flow data from sixteen ditches between Pueblo and John Martin Reservoirs was collected, and seven ditches were subsequently found to have sufficient supplies to be carried forward in engineering and economic studies. Elimination of ditches from consideration was for a variety of reasons, including negligible potential yield because of large previous transfers, limited water rights, or dedication of water as an augmentation supply. Other ditches were eliminated because of head gate issues or extreme exchange concerns.

Trip to California. “Seeing is believing” has long been a motto employed by extension service agents working with agriculturalists. Demonstration projects, models, and field trips enable farmers to get a hands-on feel for how something works. In keeping with this approach, LAVWCD organized an early 2007 trip to California so that irrigators could see for themselves a rotational fallowing arrangement undertaken by the Palo Verde

⁴ Rocky Ford Ditch should not be confused with the Rocky Ford High Line Canal discussed elsewhere.

Irrigation District (PVID) with Metropolitan Water District (MWD). Irrigators had first heard about the Palo Verde deal when Ed Smith, general manager of PVID, had spoken about it at an April, 2006 workshop funded by LAVWCD in cooperation with several lower basin ditch companies. John Wilkens-Wells, a sociologist from Colorado State University's Sociology Water Lab organized the workshop, which was titled "Innovative Approaches to Water Leasing and Canal Company Cooperation in Face of Municipal Demands for Agricultural Water Supplies."

Smith's picture of how Palo Verde farmers were improving their financial situation while supplying water to Los Angeles and other Southern California coastal communities intrigued the District—and the ditch companies. The District funded a delegation of representatives from the seven selected ditch companies to travel to California and meet with Smith and his PVID shareholders.

Delegates came back to Colorado variously "pumped up" but also aware of the considerable obstacles which stood between them and realizing a similar deal in the lower Arkansas. Unlike the Palo Verde circumstance in which there was one water right and one ditch company, the Super Ditch would be made up of seven ditch companies and many different water rights. Exemplary of the dozens of questions the delegation came back with were "how can equity be achieved when point of diversion, decree date, and yield all affect the relative value of water to be provided from various ditches?" Can ditch companies not known for having a tradition of cooperation put aside their differences to make this work? Are farmers willing to commit to a lease as long as 40 years? Are municipalities willing to commit to a lease as short as 40 years? Will the state engineer allow farmers to fallow their least productive lands? Can they get "credit" for fallowing the part of their land which has historically taken up water non-beneficially?

Forming a Steering Committee. Shortly after the California trip, the District invited delegates and other interested parties to convene to discuss the experience, and to determine if there was collective will to proceed with the Super Ditch. Despite misgivings on the part of some, there was enough enthusiasm that the District asked each of the seven ditch companies to appoint two representatives to a steering committee which would either move the concept forward or determine it was not feasible.

CONSIDERATIONS

Organization

Steering Committee meetings have provided opportunity for ditch company representatives to hear reports of further study engaged in by the engineering and economic consultants hired by LAVWCD and to discuss a variety of issues and concerns, including recommendations by legal counsel as to what legal form the Super Ditch might best take. Steering Committee members are currently meeting to make decisions about constitution of its governing board as well as preliminary bylaws and articles of incorporation which would later be adopted by the governing board. Though decisions about board constitution have not yet been made, it is clear that shareholders from

participating ditch companies will be well-represented on the Super Ditch governing board, which will be tasked with protecting the interests of the shareholders and indirectly the lower Ark valley. It will be the governing board, not LAVWCD who will make critical decisions such as whether out of basin entities will be allowed to lease water from the Super Ditch.

Forming the organization before all the pieces of the puzzle are in place has been difficult—a sort of “chicken and egg” dilemma. As one steering committee member said “We can’t work out the final details until we know who the players will be. But the players aren’t willing to commit until they know the final details.” Legal counsel has recommended an approach whereby potential shareholders can take two steps, the first to pledge willingness to participate contingent on final details, the second to actually commit. Even still, it appears that participating stakeholders don’t have to sign a particular lease, even after the organization is put together, if they don’t like the price being offered.

Ditch Company Bylaws

As a direct reaction to earlier buy and dry deals, some ditch companies have adopted clauses in their bylaws which limit the use of water to lands served directly by the ditch. This clause is frequently referred to in Colorado as “catlinization” of the bylaws, because the first ditch company to enact such a clause was the Catlin Ditch. All but two of the ditch companies being considered for the Super Ditch have this clause, which is seen to be an obstacle for shareholders’ participation in the Super Ditch. Ditch companies appear to be reticent to change their bylaws to allow their shareholders to participate in the Super Ditch until all the details are clear, yet details cannot be clear until it is known which ditch companies will allow their shareholders to participate. Again, a chicken and egg dilemma.

Laterals

Another consideration has to do with how a ditch company can ascertain that everyone on the ditch stays whole, assuming that since Super Ditch participation will be voluntary on behalf of each shareholder some shareholders may not be participating. (In fact, for planning purposes, it has been assumed that only 65-85% of shareholders would participate.) Each ditch company will still have to maintain its headgates in order to deliver water to those not participating. On the surface, this would not seem to be a problem, since each participating irrigator would be fallowing only a portion of their land at any given time. But from a practical standpoint, having enough “push” remaining in the laterals could be problematic if some laterals participate and some do not. The Rocky Mountain High Line Canal resolved this issue when they signed the interruptible supply deal with the City of Aurora by requiring that a whole lateral be either “in or out” even though that meant some folks who wanted to participate weren’t able to. Indeed, conversations with various steering committee members seems to indicate they are concerned about lack of measurement devices at the lateral level that would allow for proper measurement if even a whole lateral chooses to participate.

Storage, Transmission, Water Quality

Storage vessels to hold water from year to year and a pipeline(s) to take water at a point downstream and send it upstream are important considerations in making the Super Ditch work optimally. It is generally understood that those leasing the water would be responsible for constructing a pipeline, and in fact one potential user, Pikes Peak Regional Water Authority is already undertaking a pipeline feasibility study.

Conveyance losses/exchange factors and water quality all vary from ditch to ditch. Those shareholders low on the river have less “paper water” to contribute because of exchange factors figured due to conveyance losses. In addition, those lower on the river have lower quality water which will require more expensive treatment by municipalities. Though on the surface it would appear that their water quality should decrease their lease revenue compared to revenue from irrigators providing water from points further upstream, the point has been made that it is all those folks upstream using the water and sending it along downstream whose use has caused the water quality to worsen!

Utilizing storage will increase firm yield—and maximize revenues. Storage will also help smooth out year to year variation in demand for the water. As one steering committee member said, “With storage, you can sell wet year water in a dry year.” One of three storage options in the system is Timber Lake which holds 38,000AF and has been virtually empty the past nine years.

Which Land to Fallow?

Some steering committee members dislike the term fallowing. They point out that the terminology used should be “not irrigating.” They contend that an ideal piece of land to fulfill the “fallowing” qualifications under the Super Ditch plan may be an old hay crop you don't water—but from which you can still get a first cutting. It's not exactly fallowed; it's just not irrigated! But others bring up the issue of sub-irrigation that could be an issue with deep rooted crops like alfalfa. If you are dry land farming fallowed ground, how do you prove it isn't taking up any subsurface water? Would participants have to kill deep-rooted alfalfa?

Another question relates to whether when a participant agrees to fallow or not irrigate 25% of his land, can it be the same land every year or does he have to rotate to new ground? This brings up the wish of some to take out their worst land permanently, a practice with which the state engineer might have problems, especially if that land was not earlier consuming much water anyway. Complicating the situation is that in some cases permanently fallowing certain portions of land could improve water quality. The law does not currently give credit for this side benefit, however.

Collective Benefits

Why shouldn't individual irrigators and/or ditch companies make their own leasing arrangements with municipalities? The Rocky Mountain High Line Ditch/City of Aurora

deal referred to above is, indeed, a successful example of such. The Super Ditch model, however, allows for the possibility of greater bargaining power than if individual ditch companies are played against each other by municipalities attempting to get the best price. Another factor is that more irrigated land can be included in the arrangement when multiple ditches work together, because each ditch has some advantages to bring to the table. Some ditches have better water quality, some have more senior rights, others have most ready access to storage and piping facilities. A third advantage is the opportunity to apply economies of scale to high transaction costs for both lessor and lessee.

Benefits accruing to municipalities from a Super Ditch lease include drought protection; minimal environmental impact; high reliability, since most irrigators have senior water rights which deliver even in dry years; avoidance of capital costs; and not having to deal with the uncertainties of developing new supplies or negotiating transmountain diversions. In addition, economic reports show that municipalities can often do better financially by leasing over buying. The downside has to do with not having control of the water, not owning it as an asset, and the chance that the supplies might not be available after the initial or subsequent 40 year lease.⁵

Rural Community Viability

By annually rotating the impact across the region and across the involved ditch companies, Lower Arkansas Basin farm economy would be expected to stay more or less “as is” under the Super Ditch. Lease revenues would generate much needed financial infusions into the local agricultural economy, resulting in an overall beneficial impact. The only adverse impacts which might accrue would be to those handling farm output, such as custom harvesters and local elevators. It is generally assumed that Super Ditch leases would prompt an “averaging up” of earnings and income in the lower basin. LAVWCD economic consultants reported that “when compared to straight dry up transfers, leasing shows a \$10-\$30 million gain for the valley.” Providing anecdotal evidence, Ed Smith, manager of Palo Verde Irrigation District reports that Blythe, California, the local town impacted by their lease to MWD, “is looking much perkier these days.”

ISSUES

Dry Year Options

One issue the steering committee has wrestled with is whether pricing should be on a dry year, average year, wet year basis or whether it should be priced without such distinction. Engineering and economic consultants used the tiered approach in their investigations, based on their understanding that the three major municipalities in the basin are looking for dry year supply and would be more likely to pay a premium for it. Other potential

⁵ Bureau of Reclamation leases are typically for 40 years with an option to renew for another 40 years but they typically contain language about having to comply with endangered species situations which may have subsequently come up. This language makes them less certain than the leases being contemplated under the Super Ditch plan.

lessees, such as the Pikes Peak Regional Water Authority, currently meeting its water needs by drawing down non-renewable groundwater, would be interested in a relatively constant supply year after year. The model built for examination by the steering committee assumed that revenues would be maximized by planning on a mixed portfolio.

Sentiment among the steering committee, however, has leaned away from a tiered approach toward a “take or pay” concept. They want each irrigator to be guaranteed a minimum return year to year, regardless of what kind of year it is. These members insist that cities would be leasing the right to take delivery of the water, whether they need it that particular year or not. “My tractor lease has to get paid no matter if it’s a wet year or a dry year!” Some members, on the other hand, believe the tiered system would get them higher overall prices. Here’s a sample of the dialogue:

Herb: In California, the cities paid for the water every year whether they need it or not.

Lee: But the pricing has to take into consideration whether they need it or not. They will pay a lot more in a dry year.

Curtis: No, they are paying for an insurance policy.

Burt: It’s like fire trucks. They have to buy them and have them available whether they use them or not. A farmer’s costs don’t go down whether it’s a wet year or a dry year.

Another consideration regards how to account for water under a tiered pricing system. One member raised the question, “If the Fort Lyons ditch puts water in storage in a wet year then delivers it in a dry year, is it valued as wet year or dry year water?” Another member stated that if in a wet year a farmer could only get a small amount for his water, he would not want to commit, because he could put his land into “preventative planting” and do better.

Is the Price Right?

Another stumbling block—another of the chicken and egg dilemmas—has to do with pricing. Potential shareholders don’t want to commit to the Super Ditch concept until and unless they like the price they can expect to get for their water. But the Super Ditch concept cannot go forward and into pricing negotiations with potential lessees until the organization is formed. Some of the sentiment of farmers can be seen in these comments:

On length of lease. “If I am locked into only leasing 30% of my land and committed to a thirty year term, I would have to get big money. 30 years is too long. 5 or 10 years is all I would do.” Response from another farmer: “But you can’t expect a city to put in a pipeline without a long term commitment.”

On percent of land to be fallowed each year, fixed or variable? “Seems like in dry year folks might want to fallow all their ground—since they can’t get a crop up anyway.” Response from another farmer: “It would be hard to get folks to sign up if they don’t know more than year to year how much of their water is to be taken. How do bankers

know how much credit for collateral to give you if they don't know how much land you will be leasing year to year?" Another farmer: "The revenue amount should stay level plus inflation year after year to keep your banker happy."

On price. "It's hard to propose this whole thing to your ditch company if you don't know what the price is going to be. Farmers aren't going to do this without knowing where they are at. They want to know that each year they can only irrigate X percent of their land and every year they get a check for X amount." And another farmer: "Everybody is going to have to see a check every year to sign on. If it's not any more than I can farm for, then forget it. It has to be a premium over what we get from farming. My commitment and expenses are still there for farming. I am not here for a 1 to 1 trade. I want a 4 to 1 trade. You will have to have damned good returns to get farmers interested."

On needing more particulars. One steering committee member put it in most forthright terms. He said "Right now I wouldn't get into this for nothing. People need to have something for every year. You have to sell this to the farmers. You need to start talking money or you're going to lose your potential market."

Super Ditch organizers, realizing the chicken and egg dilemma, decided to ask the economic consultant to draw up some scenarios that would help steering committee members better understand what the possibilities might be, even though it would be impossible to guarantee any particular price.

Pulling together a number of variables to consider, the economic consultant was able to show steering committee members enough to move the organization process forward. Based on what water is selling for on various ditches, and given a proposed lease price of \$500 per acre foot in an average year and \$750 per acre foot in a dry year, it appears that a typical shareholder would come out better leasing his water through the Super Ditch than either selling it or continuing to farm. Steering committee members agreed that it is important to keep moving on the concept, even given the uncertainty of exactly what price they will get in a given lease.

CONCLUSION

U.S. Senator from Colorado, Wayne Allard, is reputed to have said several years ago, "If you can ever get the farmers in the lower Ark basin to work together, they will make a fortune." Whether or not there is a fortune at the end of the rainbow called the Super Ditch, there is definitely an opportunity worth pursuing. Various members of the steering committee have phrased it this way:

- "This is the best chance we have to get the true value of our water."
- "It's useless to talk dollars at this stage. When they realize there's no one else, the numbers will be a lot higher."
- "This is our one and only chance to get this done."
- "It's not going to be a perfect deal. Every ditch is going to have to give a little."

- “ A lot of our board members are in good shape financially so they aren't motivated to see a change. But we have to appeal to their sense of community. We all know what buy and dry does to Main Street.”
- “This thing is helping us build relationships between ditches. But it took a trip to California to kick it off.”
- “The folks in Palo Verde told us we would have to stay united or they would pick us off one by one. They were right. We have to buck up and make this work or the Front Range is going to pick us off ditch by ditch.”

Many people throughout the Arkansas Basin and for that matter all across Colorado are watching to see if Super Ditch organizers will be successful working out the details with farmers (and later with Colorado water court) in order to make what some call a pipe dream a reality. The answer to the question is seen by most to be far more sociological than technical. As Dypak Gyawali, a Nepali engineer and political economist working on water issues as part of the European Commission says, “the most critical need is not for technical solutions, but for socio-political solutions to water problems.” And those solutions, to paraphrase Delph Carpenter, prime negotiator on the 1920 Colorado River Compact, will take “time, time, time.”

TOWARD BETTER WATER TRANSFERS IN COLORADO AND CUMULATIVE COST AVOIDANCE

John Wiener¹

ABSTRACT

This paper reports one view of sound leasing and water marketing ideas, as alternatives to "buy-and-dry", transfer of agricultural irrigation water to other uses. Drought, climate change and awareness of impending urban supply issues have stimulated new public policy processes, which themselves raise concerns over the timing and pace of belated considerations of the future and public interests. Because Colorado's strict prior appropriation water law has functioned as the state's water policy and plan, examination of cumulative impacts of water transfers has been minimal. Research on "what could go wrong?" with new recommended forms of water transfer has exposed potential problems for local governments and water providers. Among these problems are post-irrigation management issues; biological impacts from cessation of agricultural water distribution and return flows; and cumulative impacts to both social and environmental conditions. The paper suggests careful cost accounting for new forms of transfer, for the short and long-term. The means of transfer should be related to constituent and customer concerns.

THE COLORADO CONTEXT

After many years of calls for improved markets for water (reviewed in Western Water Policy Review Advisory Commission 1998, Easter et al. 1998), and for improved outcomes from water transfers (reviewed in Howe 2000), rapid population growth, drought, and climate conditions have stimulated changes in Colorado – or perhaps the appearance of changes. In a series of projects seeking improved water management through increased use of climate information, finding potential uses was easy, but many obstacles appeared. Only some obstacles involve technical understanding (e.g. Hansen 2002); others were also legal and institutional. The Water Bank Pilot Program (C.R.S. 37-80.5-101 et seq.) should have supported climate-responsive water management, but did not. Next, the Drought centered on 2002 (Pielke et al. 2005) stimulated creation in 2003 of the Statewide Water Supply Initiative (SWSI) (Colorado Water Conservation Board (hereafter CWCB) 2004, 2007), but the studies did not consider climate or all impacts of water transfers. In 2005 the new Interbasin Compact Commission and Basin Roundtables were created (Colorado Department of Natural Resources 2006 and continuing). The transfer mechanisms for better outcomes now are likely those needed for future adaptive capacity for the synergistic problems of rapid population growth and worse water stress eliciting more water re-allocation, but it is unclear whether their development will be timely.

In Western prior appropriation states, cities traditionally buy supply to meet dry years, as basic risk management, and have a surplus in average and wet years (NRC 1992, CWCB

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2004. Where the land is being "developed", buyers sometimes "lease back" the water to farmers on a short term basis, but unreliability of supply may discourage modernization and investment, diminishing viability of farming and encouraging land conversion. Over-all agricultural productivity gains from seed improvement, and intensification and improvements of inputs and equipment (Fuglie et al. 2007) have helped compensate for the loss of the best farmland (Environment Colorado 2006) and effects of loss of water security, (Dobrowolski et al. 2005). Now, based on water rates in some later-developed cities in Colorado topping \$1000 per acre-foot (Woodka 2005) and with very high new tap fees (Olinger and Plunkett 2005), good farming may not be able to hold water even with ethanol from corn subsidy effects (Westcott 2007).

Historically, water transfers – changes in place, timing and kind of use of water rights – were regulated with respect for two non-party interests. First was protection of other water rights. Second was simple administration, in a time of minimal technology and small staff, resulting in use of easily observable conditions (Cech 2004). Formerly-irrigated land was dried up, not to be irrigated again; that was easily observable. Now, in a world of satellites, telemetry and remote gauging, requiring dry-up seems wrong. It prevents finding better combinations of water rights and land, a loss to all. The social impacts of large transfers have been substantial, as increasingly large areas are dried up, and agricultural yields and activity are reduced. Small towns have been "dried up" as well (Howe and Goemans 2003, Howe, et al. 1990). Insisting on the simplest contract and administration and ignoring the economic inefficiencies that result is wasteful.

Intentionally or not, law has displaced policy and planning in Colorado. The SWSI effort informal mantra was, "this is not a state plan; we won't tell you what to do..." There is no state water plan, and severe limits on normal planning in unincorporated areas, and there is no limit on growth by lack of water so far (Nichols et al. 2001). Colorado water law is not participatory; only water rights holders have standing in water court. Questions about public interest have been long delayed, and are often treated as attacks on private property rather than defense of value (observation from dozens of meetings).

Recognition of non-water rights interests has been slow and small. Some recent changes were stimulated by conflict of historically unrepresented and unsecured recreational and environmental interests versus very rapid urban growth, and quasi-agricultural rural development based on amenity and recreational values. Among these changes are modifications to the modest in-stream flow protection program (Trout Unlimited 2002, 2003), authorized to accept loans as well as donations, and making the "recreational in-channel diversion" (aimed at kayak courses as an urban attraction and amenity) a beneficial use that can support a water right (C.R.S. 37-92-102 et seq.) Environmental interests in the form of Endangered Species responses have included the Platte River Recovery Program as well as the Colorado River Recovery Program (U.S. Bureau of Reclamation 2003, 2006, and Freeman 2003). The terrestrial case of the Preble's Jumping Mouse has garnered a great deal of attention (US Fish and Wildlife Service 2007) and inflamed antagonism to the idea of limitations on individual resource use (Brook et al. 2003). Agricultural land is being converted at rapid rates (Environment Colorado 2006, Carlson 2002), with unknown environmental impacts (Baron 2002).

Despite historic federal interests in soil conservation, there is no apparent recognition of a public interest in that. The lurking issue for environmental and socio-economic problems is general disregard of cumulative impacts.

WHAT WOULD BE “BETTER”?

Externalities Internalized — From Abstract Idea to Reality?

Improvements may be achieved through different distributions and qualities of the costs, impacts, and benefits of water transfers. The recognition of non-market and public goods or public interests in a market is difficult, but political regulation is subject to change for political reasons (e.g. Nadeau and Leibowitz 2003), and may not be efficient for re-allocation (Slaughter and Wiener 2007) so many favor use of private property and markets. Water transfers that include real opportunity for participation by all affected interests would be better, including recognition of third party, local government and environmental interests. Many rural local governments have had little opportunity to consider future interests, beyond direct injury to the tax base and may need assistance. The disconnect between land use planning (if any) and water issues may aggravate the loss of agricultural jobs and population without replacement (Colorado Department of Local Affairs 2007) while amenity drives growth elsewhere (McGranahan 1999).

Meaningful representation of socio-economic interests, quality of life and future interests may depend on development of preferences and plans that could be furthered in transfer deals. Some environmental and recreational interests are being better specified by the current SWSI process of non-consumptive needs assessments, but not local and regional amenity and recreation. Adverse impacts of transfers result in part from missing interests, so procedural steps are needed as well as interest identification. If mitigation of a particular impact is impossible, other costs and benefits may be allocated.

"New" forms of leasing, water marketing and fractional sales

Three changes to traditional water law appear to meet demands and reduce adverse impacts. These ideas have been widely endorsed in the abstract (e.g. “Colorado 64 Principles” noted below, and South Platte River Task Force 2007) but little public progress has been made. The three forms needed are spot-market short-term leasing (often done through some form of “water bank”; Clifford et al. 2004), long-term agricultural fallowing/rotating crop management leasing or partnerships, for municipal or industrial “base load” needs on a predictable basis, and long-term interruptible supply contracts or partnerships for needs in unusual years, to firm supplies, or for storage (aquifer storage and drought recovery) in wet years. The Water Bank Pilot Program was authorized in 2001, (C.R.S. 37-80.5–101 et seq.) but implementation failed. Reasons included the severe drought of 2002 and frustration of potential uses by design failures (Wiener 2005, Wiener 2006 USCID Proceedings). Authority was revised and made state-wide in 2003 (and made permanent in 2007, repealing the “sunset”), but the original effort was not improved and has not yet been revived though several new projects have been announced.

Long-term or permanent transfers are different. The Colorado rotational crop management authority follows the example of the Palo Verde Irrigation District in California (CWCB 2004; Palo Verde Irrigation District 2008). The idea of distributing intermittent impacts is the same, and making the transfer financially equal to or better than farming yield. Reduced production has secondary economic impacts to input and output linkages (Howe and Goemans 2003), but they would be geographically diffused (though some regional linkages and large-area service providers may not be helped much until recapitalization stimulates recovery of production levels). Continued irrigation even with fallowing dramatically reduces changes in tax bases and impacts on almost all local government interests. Long-term financial stability would be a change for most farmers, hopefully fostering better agronomy and management. The use of long-term interruptible supply contracts distributes impacts in the same way, though the crop rotations and management should reflect higher uncertainty of water availability. In both cases, wise planning will likely involve retaining some water, rather than “dry-up”, for weed and erosion control and perhaps cover crops or habitat. The basic ideas have been rediscovered often, and carefully documented (e.g. Saliba and Brush 1987, National Research Council 1992, Michelsen and Young 1993).

The frequent objection that long-term leasing is insufficiently permanent for those who sell a tap forever can be met by re-casting the deal as a fractional sale; there would be no practical difference in the engineering and legal expenses; in the end it is all partnership in distribution of the risks, costs and benefits. Perhaps the best explanation of the lack of change is the saying, “If you are winning, you probably like the rules.”

PROGRESS OR SOMETHING ELSE, SO FAR...

Colorado’s Statewide Water Supply Initiative

Under the added stress of the 2002-centered drought, the Legislature authorized the Statewide Water Supply Initiative (SWSI), to seek a consensus for action from a common understanding (CWCB 2004, 2007). Two serious limitations remain problems. First, each water provider (municipalities, water districts, etc.) was asked to report "projects and processes" in progress or planned for supply in 2030. Needs were independently analyzed with a sophisticated treatment of per capita use by county with adjustments for each sector and conservation trends and potential. The difference in 2030 was called “the gap”. Each provider seeks supply in a private and highly competitive market, and most have strong incentives to avoid the appearance of trouble. As policy, the SWSI study took supply claims at face value, and the Basin Roundtables, convened to provide local knowledge, explicitly declined to “handicap” projects (personal observation of almost all meetings of the Arkansas Basin and South Platte Basin, Phase 1, as well as participation in three of the four Technical Roundtables of Phase 2). It was clear that some projects and processes were incompatible, and that many were optimistic.

The second severe limitation on the SWSI study was that it excluded climate change in all but miniscule ways. (This is not unique, in the author’s observation. For example, climate change was simply ignored at the annual convention of the Colorado Water Congress until “suddenly” it appeared at the 2007 meeting.) The SWSI Phase 1

(published 2004) estimates of supply were made without respect to changing seasonality of snowpack, and so forth, as were estimates of demand. In 2007, the Colorado Water Conservation Board was authorized to contract for a hydro-climatic study of future Colorado River Basin supply, stimulated by the fears of a Colorado River “Compact Call” enforcing obligations to the Lower Basin; apparently, earlier studies were without weight (e.g. Powell Consortium 1995, Gleick et al. 2000, National Research Council 2007). Meanwhile, major cities with professional staffs, the Colorado River Conservancy District and others studied potential impacts (e.g. Herrman 1992). Asymmetry of information influences outcomes in a competitive market.

Mitigation of Impacts to Areas of Origin — Not Finished

Many legislative bills requiring mitigation of transfer impacts to areas of origin failed. It has been argued that any compensation to third parties (e.g. school boards which receive diminished funds due to lower farm populations and fewer children) will reduce the price paid to sellers, injuring property rights. And, the place-specificity issue, “one size does not fit all” has been used as the perfect killing the good – there is no perfect advance prescription, so there is no prescription. The Legislature, the new Interbasin Compact Commission, and all 64 Counties have approved the “Colorado 64 Principles” for water transfers calling for impact reduction (hence the name), (HJR03-1019 is the legislative endorsement). So far, there is only a possible requirements of 30 years "transition mitigation" payment in lieu of taxes lost from transfers of water if not already purchased before the effective date of the bill (2003, C.R.S. §§ 37-92-103, -302, -304, -305).

Legislation Still Needed — The Missing Form and Information Promotion

The piece-meal approach to legislation on transfer forms is also a problem. The uses of a spot-market are shown elsewhere (in Colorado, Howe and Goemans 2003; generally, Easter et al. 1998, Clifford et al. 2004). But there seems to be limited appreciation of the value of combining the authorized long-term leases for “base load” supplies with as-yet unauthorized long-term interruptible supply contracts, or “dry-year options”. The combination supplies water at one price every year, presumably sufficient in most years. At a higher but less-often paid price, supply in dry years would be from additional or more reliable higher priority water rights from an interruptible supply contract. The combination allows acquiring water on a “pay-as-you-go” basis, avoiding costs of bonding and debt for water acquisition, and still accessing the higher reliability rights. And, it avoids the problems of revegetation and post-irrigation land management. Agriculturally, this helps keep the “best water” available for farming the best remaining soils in most years, while keeping that premium combination viable by water prices which support soil erosion prevention and fertility maintenance in years when the crop might have failed. From the every-year transfers, capitalization of better farming might result in higher yields and revenues even with less acreage. The remarkable advantages of long-term stability and planning could make a huge difference in both credit availability and uses, and development of local markets and operations such as combined livestock and farming, dairy, and specialty operations including organics and direct sales. Using the two kinds of long-term contracts could maximize the potential values for the

whole system. The well-designed interruptible supply contract would also allow “wet-year options” so that non-irrigated farming could be conducted while high water supply allows aquifer recharge and reservoir re-filling.

Information promotion to improve markets is also desirable. The conditions for a well-working market (Stiglitz 1993) are not present in Colorado. Very high transactions costs are imposed by the water court litigated adjudication process for almost every transfer. There is also a high level of oligopsony and a remarkable asymmetry in the information available to the sellers compared to the buyers. There is no requirement for price disclosure, though prices can be revealed (usually by public entities), and some public-entity “disclosures” have in fact been misinformation to keep prices low (Olinger and Plunkett 2005). The involvement of water brokers also complicates pricing and the lack of information, since another party to many transactions benefits from ignorance on the part of both sellers and buyers, often at high public expense (Olinger and Plunkett 2005). Place-specificity and unique priority makes non-uniformity of water rights unavoidable, but this can be partly alleviated by reducing costs of determining the transferable fractions of a water right. If one believes in using the prior appropriation system without planning, one might wish the market to work more effectively. Early disclosure of infrastructure plans and added state verification of costs would allow potential cooperators to reach cost-effective and fair sharing arrangements (CWCB called this “project enhancement” and described it well but without noting all potential parties).

Explanation, Outreach and Education Needs

Limited understanding of innovations is a problem. The most important progress in the Water Bank Pilot Program was overlooked -- the agreement on presumptive figures for the transferable fraction of water rights from the major ditches in the lower Arkansas Valley. That would have reduced transactions costs enormously, had the program worked, but no transaction was attempted. What was needed and has not been forthcoming is credible outreach and education about all three of the new forms of transfer. Misunderstandings have already been reported concerning the following lease idea (Woodka 2007), overlooking the fact that the State Engineer administers water rights, wherever they are assigned. Decreed leases are not subject to discontinuation on a whim, yet that was apparently a widespread concern or reason for dismissal. Simplicity is overly revered, it seems. New transfers are innovations in agriculture, calling for proven means of introduction (Wiener 2005). Demonstrations are very likely the needed step, perhaps calling for additional support such as a standardized form for leasing.

New Basin Roundtables, the Inter-basin Compact Commission and the South Platte Task Force – An Observer’s View

The Statewide Water Supply Initiative Phase 1 Report in 2004 itself sharpened the sense of urgency and competition, contrasting with public preferences for increased cooperation in water transfers, and impact mitigation. The legislature passed the Colorado Water for the 21st Century Act (C.R.S. 37-75-101 et seq; HB05-1177). This followed the SWSI use of Basin Roundtables, with wide representation of economic sectors and areas in each Basin as fora for basin-specific discussions and inquiries

(Colorado Department of Natural Resources 2006), but with greater representation for rural towns and counties regardless of population. The new Roundtables began afresh with many appointees not previously involved in SWSI, though some carried over. The Basins were tasked with refining needs assessments; these are still in progress after substantial enlargement in non-consumptive needs assessments (environment and recreation needs) for which infrastructure in decision support and information is being developed. This is an important back-door means to achieve a sort of state planning. The Basins are intended to eventually deal with each other, and can propose interbasin compacts modeled on interstate compacts, to be supervised by the Interbasin Compact Commission. So far, some basins have spent time on representatives “understanding each other”, some agency presentations for background education, and participating in limited authority to help allocate a moderate amount of funding. Meanwhile, the private competitive market continues; disclosure of deals is not required until a change decree is sought; who owns or holds options on what is not known.

There is no authority to interfere with any exercise of water rights or contracts or transfers. After two years it is also apparent that some representatives have only a reactive view of their roles, while others are active and very well informed. Roundtable committees may hold the best promise for progress, but they may also be hampered by starting afresh, and there is no guarantee of influence whenever policy is produced. It may be too late, given the unknown market and fierce but invisible competition.

The painful process of fully imposing the priority system on groundwater use in the South Platte Basin was stimulated by litigation against continuing short-term permission to pump, persisting since incomplete initial efforts to implement 1969 water law reforms. After the dramatic shut-down of hundreds of wells and substantial economic loss, followed by bitter conflict and more litigation, a Task Force was appointed to consider all alternatives (South Platte Task Force 2007). Recommendations include water marketing, and leasing; that may result in legislative action, but has not yet (March 2008).

The Efforts in Progress: The Super Ditch Project

The presentation at this Conference by Smith and Winner, will provide up-to-date description of the Super Ditch project in the Lower Arkansas Valley. Misunderstanding due to the lack of other outreach, education and clarity and public standards about what is possible is a serious problem. Seeming failure without a useful trial, as happened in the Water Bank Pilot Program, and public misunderstanding of the reasons for failure could prevent or delay a great deal of potential progress.

WHAT COULD GO WRONG WITH NEW TRANSFERS?

Suppose new transfers are tried. Are there problems worse than or different from those resulting from traditional buy-and-dry? Starting with objections and concerns raised in many interviews about the idea of leasing water, a recent project focused on seeking expert opinion to get a better view of “what can go wrong”. This part of the paper summarizes highlights from four formal workshop events and on-going discussions as well as literature reviews of the issues.

Cumulative Impact Limits as Regulatory Threats to New Transfers

There is no cumulative impact consideration in prior appropriation water law transfers. Biological impacts of water flow regulation, diversion, and distribution have been gigantic (Baron 2002, Baron et al. 1998, Strange et al. 1999), but change is only assessed fractionally and locally where it intersects with some special jurisdiction or requirement such as an Endangered Species issue (see Doremus 2001). The lands and waters involved in agriculture-to-urban transfers are private, and we have poor information on what limits may appear or may turn out to be important. (This broad statement is based on a literature review of about 230 items and synthesis project underway; Wiener forthcoming.) The regulation of water quality has been separate, and imposed by federal laws (Getches 1999). Water quality regulation has not yet been very effective on non-point source pollution, so new standards for total maximum daily loads (TMDLs) may be next (National Research Council 2001). In new law, water quality may be considered in large transfers of greater than 1000 acre-feet to distant use, but it is not yet clear how or if that will apply beyond requiring a transferor to mitigate her additions to exceedance of water quality standards (C.R.S. 37-92-305). If a TMDL were in place, this might prevent worsening of exceedance, rather than preventing transfers, but there is also protection for "vested rights of others." Does that enlarge standing? Is there now a right to water quality, as has not previously been the case? Meanwhile, salinity in the Lower Arkansas frequently hits 5000 ppm, imposing substantial costs in lost productivity and additional water treatment (Gates et al. 2006). Kansas cares. The ecological impacts from more-widely distributed and intermittent impacts may be considerably reduced; the water quality risks may be reduced by judicious choices of land to fallow.

Shift the cost and beat the limit? The costs of finally hitting a limit of some sort are potentially quite uneven and substantial. Colorado has nominally directly spent more than \$50 million on Endangered Species recovery programs, (R. Brown, Colorado Water Conservation Board, 12 November 2007, Joint Meeting, South Platte, Metro Area and Arkansas Basin Roundtables) but that does not count any of the private costs incurred, or Federal costs, or all State staff efforts (Freeman 2003). And it does not indicate costs averted by large-area multi-state plans such the Platte River Recovery Program (U.S. Bureau of Reclamation 2003). The costs will almost certainly be unevenly distributed if further transactions are prevented or must be expensively mitigated. But transactions and parties which created the problem but were under the threshold will bear no burden. Should policy always covertly favor the alert and those able to act quickly, at the expense of tax-supported remediation and costs imposed on the less-alert or less able? A minimum of adequate planning and foresight where state interests are involved seems long overdue (see National Research Council 2007, 2001).

Biological Issues Apparently Unexamined

Changes to mainstems as well as loss of pre-development conditions. Conversion of riparian and bottomland areas to agricultural use along with flow regulation and re-timing have changed vegetation communities and succession as well as fluvial processes, habitat connectivity, and conditions supporting pre-development ecologies (Baron 2002,

Bernhardt et al. 2005, Johnson and Bouzaher 1996, Johnson 1997, 2002, Katz and Shafroth 2003, Katz et al. 2005, Knopf and Samson 1997, Nadeau and Leibowitz 2003, National Research Council 2002, Strange et al. 1999). Invasives play an increasing role as the generation of cottonwood-willow established right after flow regulation is senescent and not regenerating. The ability of the riparian zones to substitute for pre-development conditions may be deteriorating rapidly. The extreme loss of wetlands, particularly in areas used for cultivated agriculture, makes this important for many species, both resident and migrant.

The Return Flow Redistribution Problem. Meanwhile, off the mainstems, the irrigation ditches and the irrigation itself have created a remarkable “hybrid ecology” (Crifasi 2002, 2005). Of 100 units of water diverted from a flow, as much as 15 to 25 units may be seeped from earthen canals into surrounding areas, and then, of the 85 to 75 units actually applied, half or more of that used in furrow irrigation may be return flow to the river, through surface tail water or drainage, near-surface flows, or deep percolation. In water transfers, the historic pattern of return flows, in volume and timing, is maintained in the river, but only in river. All of the area unintentionally watered by seepage and return flow may be dried up along with former irrigated field. Given the lack of knowledge about these private lands, the ecological consequences are unknown.

The SWSI study (Phase 1, 2004) estimated that 12 to 23% of remaining irrigated acreage on the east side of Colorado could be dried up, (not counting the many thousands of acres already dried up, including more than 50,000 acres in Crowley County alone). That estimate was based on the “gap” and an estimate if a quarter of the claimed supplies fail; it is likely optimistic. Also, the extent of acreage involved may be greater than estimated, because the acreage irrigated by increasingly junior water rights should be larger than that irrigated by more senior rights. Economic rationality suggests that lower reliability water supply would be used for supplemental irrigation on crops of lower value, and perhaps spread more widely as well as less often (data on this are poor; see Bauder and Waskom 2006). And then, there is climate change to consider, affecting reliability of water rights as well as timing of flows (e.g., National Research Council 2007).

Post-irrigation soil management and revegetation issues

The use of land which has been previously irrigated and intensively cropped for more than a century is not simple (Sutherland et al. 1992). It was often urged in SWSI discussions that farmers would simply go to dryland crops, and that this has not been regarded as a problem; that presumes profitability of dry farming which may not always be as good as in the current ethanol-subsidy boom times (Westcott 2007). A workshop on farm management issues, however, confirmed that long irrigation and intensive cultivation changes the soil physically as well as chemically, so that passive “return to nature” will not be available soon if at all. The conditions created favor undesirable weeds and invasives, unless there is substantial management which may include irrigation for a transition, soil amendment, transitional vegetation, and so forth. This suggests avoiding dry-up where possible. Worse yet, the Soil and Water Conservation Society has reported (2003) that increased intensity of precipitation (the fraction in high-force high volume events, already known to be increasing) regardless of other changes in

climate will likely have substantial adverse impact on soil erosion. So far, the costs of revegetation imposed as a requirement for dried up farmland are being treated as proprietary information, though estimates appear to be steadily rising as efforts continue. Climate change other than increased precipitation intensity may also affect revegetation and invasive plant costs, through warming-increased evapotranspiration.

Management and Cost Accounting Issues and Questions

The money. On the ditch company and irrigation side, allocation of revenues from a lease may require difficult bargaining, since ditch companies often own several water rights with different priorities, and these have different values. Irrigators have land of different quality and achieve different results, so their marginal value product from use of water differs in complicated ways. Their personal interests and situations also differ, affecting their willingness to accept different amounts. Ditch companies also differ in investments in infrastructure enabling or inhibiting individual or lateral choice in leasing or declining. Large scale projects such as the Super Ditch face all these problems as well as the coordination of activities and financial agreement across several ditches.

On the urban side, there has been no public disclosure of the basis for claims that alternatives to “buy-and-dry” cost more. The undisclosed costs of revegetation have been noted, but there are also the costs of bonding to finance water purchases. At 3.25% and two points for bond establishment costs, a typical 30 year bond adds half again to the capital cost; that could be saved if there were no debt used for water acquisition. (Moving the water may be a larger cost than buying it in many cases, and re-timing storage may also be needed, but that cost is the same regardless of the form of transfer). There is also a big saving in infrastructure if the same plumbing can be used in dry as well as normal or wet years, by stacking the interruptible supply contract on the fallowing contract..

The Permanence Problem. And, there is the assertion that if you buy the water right, you have it (as well as the appreciation in value), where if you lease it, at the end you have nothing but unmet demand. This idea depends on an unimaginative sense of the possibilities and an unlikely set of deals. No careful manager would fail to include hard-bargained arrangements for the end of the lease term, and just as cities imagine being dependent on that water in 75 years, why would the farmers not be dependent on other parts of the deal? No other parts of the water management system are maintenance free. If permanence per se is demanded, fractional water sales should accomplish the same purposes with the same transactions costs. As always, water rights management and flows are administered by the state once the transferred amount is decreed or permitted.

Urban Preferences. Urban populations may want cheap water rates (and free lunches) but they have also voted 110 times in Colorado to tax themselves about \$3.8 Billion for open space, agricultural land preservation, and similar amenities and values (Trust for Public Land 2008), not to mention enormous private support for easements, and environmental qualities through many organizations. Although there is considerable evidence of popular interest in maintaining some agriculture and agricultural land (e.g. Governor’s

Commission on Saving Farms, Ranches and Open Space, 2000), it is not clear that those constituent values affect the often repeated claim that “my job as a water provider is to get supply as cheaply as possible.” Only that? What about all those other interests?

Rural Futures. Rural interests are also poorly known, since there has been so little effort at defining present and future amenity values as well as recreational and environmental conditions that will make places attractive to residents or newcomers and new investment. The contrast between that lack of anticipation and real estate development advertising touting all the charms of the latest “green acres” is striking. As agricultural primary income decreases, and farm employment and families decrease, rural areas may seek post-agricultural economies, but with what? The anti-planning problem is real.

The race is on... but some of the runners may not show up. Others may like that.

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FARMERS AND URBAN WATER MANAGERS WORKING TOGETHER TO SEEK SOLUTIONS: IF WATER IS GOING TO BE TRANSFERRED FROM AG TO URBAN, HOW CAN WE “GET IT RIGHT?”

MaryLou Smith¹

ABSTRACT

Following a major investigation into its water supply needs by the year 2030 which projects a significant shortage, Colorado’s state legislature in 2006 enacted a Colorado Water for the 21st Century act. Stakeholders from each of the state’s major water basins formed roundtables to first assess their respective basins’ water challenges, and then to potentially agree on “interbasin” compacts to affect multi-basin solutions to the state’s water supply dilemma.

One of the issues of particular concern in the Arkansas Basin is the effect on the viability of agricultural communities when water is transferred from agriculture to cities—a practice which is expected to increase in the state as water supplies for urban needs fall short. A group of stakeholders from rural communities in the lower stretch of the Arkansas Basin proposed a set of guidelines to govern such transfers, upon which stakeholders representing basin urban areas proposed an alternate set of guidelines. In an attempt to resolve their differences, an “ag to urban water transfers” committee was established.

This paper provides something of a sociological case study of the committee’s progress in understanding their underlying beliefs and values, approaching such concerns as how to manage urban growth and revitalize rural economies, and attempting to develop prototypes for “how to get it right” when water is transferred, whether through “buy and dry” or such alternative practices as rotational fallowing. Their use of outside resources in “joint fact finding” is discussed.

Projected Reduction of Ag Lands to Meet Urban Water Needs

The Colorado Water Conservation Board’s “Statewide Water Supply Initiative” (SWSI) in 2004 projected that Colorado has only enough water to meet about 70% of its needs by the year 2030, with most of the gap occurring in the front range urban areas of the state. The SWSI report forecasted that a majority of the water needed for cities will transition from agriculture, which currently uses more than 80% of the state’s water: “Colorado will see a significantly greater reduction in agricultural lands as municipal and industrial water providers seek additional permanent transfers of agricultural water rights to provide for increased urban demand.”

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Following on the heels of SWSI, the state legislature in 2005 enacted a process by which roundtables made up of diverse stakeholders from each of the state's major water basins would be charged with looking for solutions to the water supply dilemmas uncovered by SWSI. The Arkansas Basin, which covers roughly the southeast quadrant of the state, is the state's largest roundtable, with more than 50 members.

When the findings of the SWSI report were presented to the Arkansas Basin Roundtable, some members representing rural communities in the lower Arkansas were alarmed at the graphic depicting that as much as 72,000 additional acres were projected to be lost from Arkansas Basin agriculture by the year 2030.

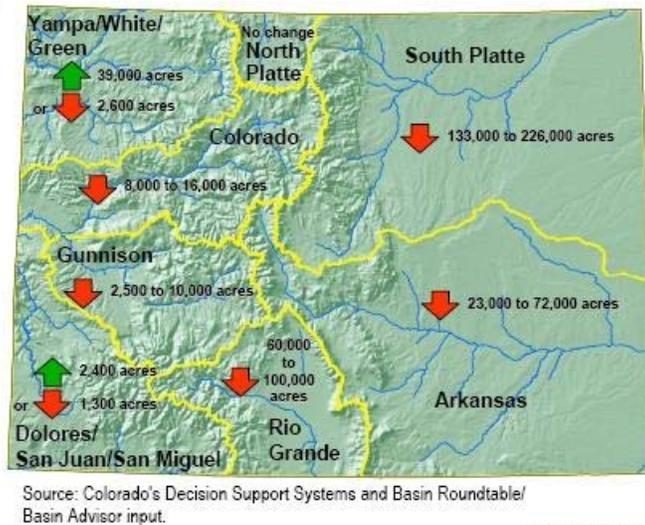


Figure ES-5
Projected Change in Irrigated Acreage by 2030

These acres are in addition to the approximately 78,000 acres of agricultural land permanently dried up in the past two decades as a result of agricultural to urban water transfers. These rural roundtable members proposed that the roundtable endorse a set of transfer guidelines they had written, part of which called for cities to control urban growth. Other members of the roundtable, particularly water managers representing urban interests, responded with an alternative set of guidelines for the roundtable to consider. When it became obvious that the differences in the two documents could not be easily settled, the roundtable appointed a Water Transfers Guidelines Committee.

Though the two sets of guidelines were not dramatically different, trying to wordsmith them into one document brought out significant conflict dividing the group. Early in the process, when it became obvious that the committee was spinning its wheels, funds available through the roundtable process were used to hire a facilitator to work with them.

Shortly thereafter, one committee member pointed out that most, if not all, of both group's beliefs and values were covered by the 2003 *Arkansas River Water Preservation Principles*, which had been signed by a number of diverse entities within the basin. The facilitator encouraged the committee to adopt these principles as their "working" set of guidelines, but more importantly, to turn its attention to the more critical matter—how to

put those principles into practice. Agreeing that they did not wish to create yet another document which might just sit on a shelf, the committee adopted the principles and began work on this broader goal.

The Committee

The committee is made up of a diverse group including:

- mayor of one of the small towns in the lower basin
- individual doing environmental compliance work for one of the rural counties
- water utilities manager for the largest municipality in the basin
- water utilities manager for a large municipality exporting water from the basin
- former commissioner of one of the counties who earlier sold water from his farm to a large municipality and now regrets it because of the effect on his rural community
- superintendent of one of the major irrigation canals in the basin
- cattle rancher
- manager of a water conservancy district providing to agriculture and municipalities water exported from the state's west slope
- owner of land in the upper basin whose community was affected by enlargement of upper basin reservoirs necessitated by transfers of water to major municipalities
- consulting engineer working with various entities throughout the basin

In addition, three individuals not on the roundtable have been adopted by the committee as standing advisors:

- university research associate studying ag to urban transfers for more than a decade
- anthropologist who published studies on the sociological effects of earlier "buy and dry" deals in the basin (permanent transfers of ag water to municipalities)
- municipal water manager who administered "on the ground" aspects of one of the earlier "buy and dry" acquisition deals

Building Trust

The facilitator used a number of strategies to break down animosity in the group. In an early exercise she asked members of the group to share with one another what the results would be if they were not able to come to solutions they could all agree to. Answers ranged from "we will continue to spend millions of dollars on litigation" to "we will have lost an opportunity to save the rural communities of this basin." At one point, a committee member repeatedly expressed his frustration that rural entities would continue to have to fight first one "head of the snake" and then another, never knowing where the next battle would come from. Recognizing that repetition of the same point often comes from a person not feeling as if they have been heard, the facilitator asked an urban member of the committee to "play back" what he heard expressed by the rural committee member. The urban committee member's quite accurate replay revealed an underlying empathy which yielded an opportunity for a connection between the two sides.

Another trust building exercise was employed which called on committee members to identify shared values. Some of the interests the group found they could agree on include:

- IF the water moves, move it in a way to benefit all entities
- Try to retain flexibility
- Find solutions so we don't all go broke paying lawyers
- Protect private property rights
- Protect communities from which water is transferred
- Look for ways to tweak water law to better meet all needs

That municipalities and conservancy districts have resources of money and personnel beyond those of rural communities which they can apply to study and address issues is most likely one of the factors dividing these committee members. One member even confided to the facilitator that he perceived that it was to the advantage of municipalities to create an endless loop of discussion about the issues affecting agriculture because meantime transactions were occurring to benefit municipalities. Though the facilitator recognized the importance of allowing opportunity for venting, particularly by those members of the committee coming from a less powerful position, a major challenge she faced was that of moving the group beyond “bellyaching” and continuous loop regurgitation of the issues to productive dialogue. When one member of the group would suggest a potential solution, another would inevitably respond with “yes, but....” Indeed, there were considerable obstacles to any solutions being offered, but the group needed some successes to build on if they were to move forward.

She asked the group to consider two questions from the joint perspective of the committee: “What Ties our Hands?” and What CAN we realistically do?” Under the category of “what ties our hands” the group agreed on:

- Intergovernmental agreements and other deals already underway
- Highly regulatory environment
- Economic transformations happening already
- The bigger universe that's involved (it's not just the water)

And under the category of “what we can do” they agreed on:

- Have objective, candid dialogue
- Tackle misinformation in a non-hostile environment
- Understand what each of us needs
- Produce a sense of we are all in this together
- Wrestle with the serious questions, but perhaps start with a small success
- Consider whether there are projects/processes/activities to move us forward, either new ones we can champion or ongoing ones we can support
- Build on our common vision

Urban Growth

Two issues the committee struggled with without much success at coming to consensus were that of urban growth and private property rights vs. the public good. A persistent

rural community concern is what they perceive to be uncontrolled, unsustainable growth of urban communities. Rural members argued that urban communities wouldn't need so much water if they would just control their growth. Urban members pointed out that studies have shown that you can't control growth by limiting water. In one meeting, strategies urban communities might use to control growth were proposed by rural committee members, while each strategy presented was shown by urban members to have unintended consequences.

Eventually, the committee agreed that regardless of who was right, the committee would have very little influence on the topic. They compromised by agreeing that they could all support the somewhat nebulous but descriptive term "smart, sustainable growth." However, the underlying concern remains, on the part of the rural and some of the urban members, that growth is an issue that cannot be ignored even if we do not appear to have answers to it.

Public Good vs. Private Property Rights

Another issue the committee struggled with revolves around the paradox of preserving private property rights while watching out for the good of the larger community. The classic example is a farmer who wants to farm until retirement and then sell his water to urban buyers in order to fund that retirement, albeit such sales diminish the viability of the rural community where he resides. Another example has to do with the right of rate payers in a municipality to insist that their water managers seek water at the best price available regardless of the effect on "third parties" to the transaction, such as rural communities. Some of the points made regarding this subject were embraced by most but not all of the committee.

- Economic/social mitigation is needed in the case of transfers, not just through cash payments, but for instance through economic redevelopment in ag communities.
- We need to promote an urban sense of responsibility that goes beyond the narrow view of a rate payer's own economic interest.
- We need a modification to the philosophy that "private property rights trump the public good."
- We need a process whereby the larger public can learn about the tradeoffs and weigh in on the desired balance.
- We should be promoting the concept of "distribution of impact" when water is transferred between urban and agricultural communities.
- Current practices and institutional rules regarding water transfers are proceeding from historic conditions that may no longer apply.
- We have a political standard that doesn't balance well the public interest and the private interest. Water court isn't designed to consider the public good.
- We need a full and serious public debate about this issue instead of a largely blind process. Private transactions set the pace and the public has no say in these transactions, though the transactions have repercussions which greatly affect the public.

In general, the committee agreed that, as in the case of the urban growth issue, they could have little influence on this issue and that their time could be better spent working on those arenas where they could have some influence.

Consensus Statement/Focus Question

After half a dozen meetings, the group was able to write a consensus statement and agree on a focus.

Consensus Statement

We support: smart, sustainable growth; sustainability of rural communities; and maximizing utilization of water to enhance the vitality of the environment and the economy of the basin, especially rural communities, while protecting private property rights.

Focus Question

“How should water be relocated/reallocated from agriculture uses in a way that supports the economy and environment of rural communities while recognizing ongoing processes and utilizing information from ongoing studies?”

By “recognizing ongoing processes” the committee was referring to the reality that a number of important processes are currently underway that would impact any decisions the committee might make. Examples of these are a nine party intergovernmental agreement being negotiated, and the reality that water transfer contracts are not public until the parties want to or have to disclose them.

By “utilizing information from ongoing studies” the committee was referring to work currently being done by university researchers on irrigation efficiencies/water quality, and Lower Arkansas River Water Conservancy District’s efforts to establish a “Super Ditch” cooperative group to rotationally fallow a portion of lands to make water available to be sold at competitive prices for urban uses.

Thinking about a Think Tank

Building on this foundation the facilitator challenged the committee to move into an action phase. What could the committee do to begin answering the question they had narrowed in on? Out of this discussion came the idea of forming a think tank made up of selected members of the committee willing to devote considerable and concentrated time, along with outside “experts.” The think tank was to perform two primary functions, one relating to research and the other to demonstration/model projects.

In regard to research, the emphasis was to be put on annotating existing research, evaluating such research to determine its relevance, and recommending additional research, taking care to “avoid needless restudy of problems so small or so complex that results will not be helpful in the next few critical years, or needless delay where enough

is known that prudent and effective responses can be identified without further study and delay.”

In regard to demonstration/model projects, the think tank was to explore water transfer strategies which could be incorporated in prototypes, demonstration projects and/or models that would showcase the necessary elements of “how to get it right when you transfer water.” Specifically: *“Develop a portfolio of prototypes to address issues and mutual benefits associated with transfers of water from agriculture.”*

The “experts” were envisioned to be not only state and federal agency and municipal specialists and researchers, but also farmers whose knowledge and experience are critical to understanding the issues. It was pointed out that a struggling water bank had earlier been launched without considering the views of the practitioners who would be using the bank or others who could have offered insights to increase its chances of success. Also, the agriculture community has traditionally responded to demonstration projects to help them understand the needs for their own applications before adopting an approach or strategy.

Several members of the committee emphasized that the transfer of water from agriculture to urban uses is only one factor in the difficulty rural communities are facing in remaining viable. Indeed, one member asserted that water is leaving agriculture *because* agriculture is not viable, not the other way around. Sustaining a rural economy and lifestyle was seen to include both agricultural transformation and rural economic development. For this reason, the committee felt it would be important for the think tank to include rural economic development and agricultural economy specialists to help it “uncover, develop, consider and propose ideas and proposals that extend beyond traditional water specific issues, such as promotion of rural economic development, diversification and sustainability; agricultural-business innovations and alternatives that yield more competitive and profitable products; and cooperative agricultural/municipal water management and use.”

The committee acknowledged what could be significant barriers to meaningful work by this think tank, including: advocacy obligations of those working for water entities and elected/appointed officials representing particular constituencies, the problem of proprietary information in a competitive water market, the burden of political and media influences that could attempt to sway or obstruct progress for parochial self interest.

Pilot Think Tank

The committee asked its facilitator to convene an all day work session with a sample of prospective experts or “outside advisors” to help them work out the details of how such a think tank might function. A half dozen members of the committee joined with four such experts to include a university agriculture economics professor, an environmental engineer in private practice, a former municipal water utilities manager now heading up the state’s Colorado Water Congress, and a rural economic development specialist from the state’s department of local affairs.

To get a flavor for how the think tank might work, the facilitator split the gathering into four small groups, each containing one of these outside advisors. Each group was asked to brainstorm ideas for water transfer prototypes which could provide the mutual benefits—rural and urban—sought by the committee. The exercise yielded creative ideas for the committee to build on in the future, but more importantly showed the benefits of bringing in outside advisors to work with committee members in a concentrated forum. From this experience came the conclusion that the committee would stage monthly all day work sessions in a think tank format, drawing on not a set group of outside advisors, but bringing in a variety of advisors depending on the particular issue to be addressed at each work session. The committee reported to the full roundtable that these advisors would help them flesh out, reality test and challenge their ideas, as well as lend them credibility later when their ideas are challenged by others.

Work Sessions: From Theory to Reality

Moving from the abstract to the concrete has been perhaps an even more difficult challenge for the committee than building trust. As one member said, “we had to go down some rabbit trails” before we hit on a format we believe will provide the structure needed to yield a tangible “deliverable” upon which the full roundtable can take action.

One such rabbit trail which provided substance for later work was an exercise assigned by the facilitator asking the group to develop a list of characteristics of a model water transfer. Some of the 56 characteristics which came out of this exercise include:

- Guarantee perpetual stewardship of de-watered, fallowed lands
- Provide certainty to both water provider and water receiver
- Add to water information for more transparent markets
- Have no negative impact on non-participating shareholders in a ditch company

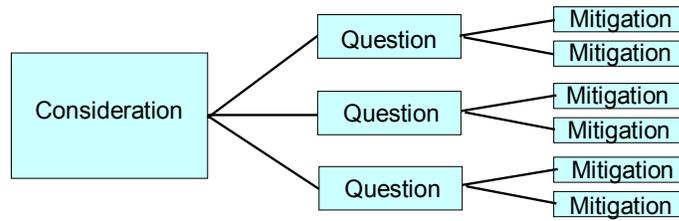
In one particularly difficult meeting, the facilitator asked the group to categorize these 56 characteristics such that they would provide a matrix the group could use to guide its investigation. That attempt morphed into listing characteristics of past “buy and dry” transactions in order to come up with a set of basic considerations and accompanying questions that should be addressed in any water transfer, whether a sale or a lease. As one of the committee members said, “Until we know exactly what the positive and negative impacts or consequences of a water relocation are, how is it possible to proceed with discussion of how such transfers can be done in a way that protects and/or enhances rural economies?”

Thus, the rabbit trail lead to a subcommittee of the group devising an “If—Then” type of matrix which the committee eagerly adopted to give structure to its work. The matrix has three basic components: Considerations, Questions, and Mitigation. Specifically:

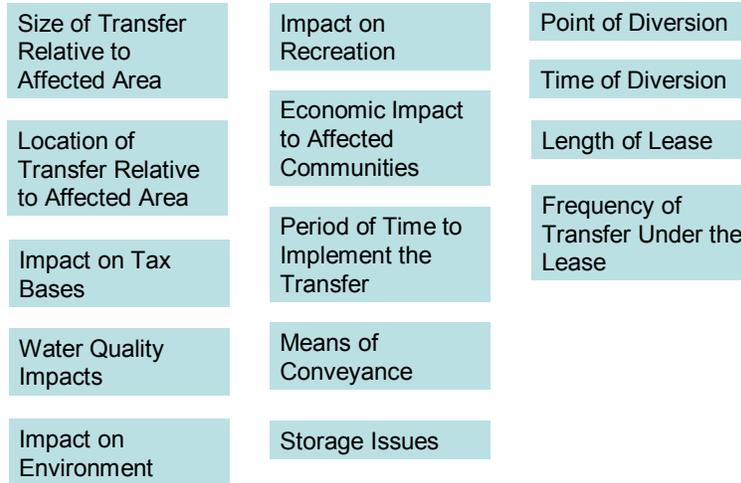
1. What must be considered when contemplating a transfer?
2. What questions need to be asked specific to each of those considerations?
3. What mitigation might be needed, depending on the answers to those questions?

The following figures illustrate the matrix format.

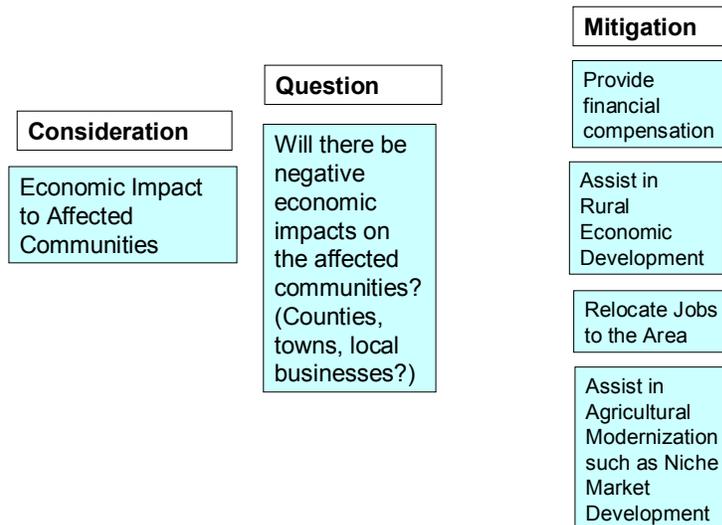
Water Transfer Matrix



Sample Transfer Considerations



An Example



One Consideration: Water Quality

The committee is fine-tuning its draft considerations and questions prior to tackling the third component of the matrix—potential mitigation. Following something of an “adaptive management” direction, the committee is taking one consideration at a time and calling in outside advisors to assist in ascertaining that the proper questions are being asked, then revising the matrix. For example, in investigating the issue of water quality considerations, the committee spent one work session in dialogue with three different advisors working from three different angles on the issue of water quality specific to the Arkansas Basin. Among the questions the committee asked the advisors are: What would be the effects of transfers and exchanges on water quality? Could there possibly even be an indirect beneficial effect if through a lease arrangement you were to fallow fields which you expect currently contribute a big source of selenium to the river through return flows? If you leave a field out of production for awhile, do you get more concentration of salts so that when you DO apply water you get a slug of salt going down into the soil?

This dialogue brought out the point that in the past 100 years our often inefficient irrigation practices have created something of an artificial environment which now supports a great deal of biological diversity that could be negatively affected by leaving more water in the river for urban transfers. The point was made that as we consider how to “get it right” when doing transfers, we may need to bring in these biological interests as another of the “third parties.”

Others Writing about Collaborative Problem Solving

The still unfolding experience of this committee can be seen as an “on the ground” example of the kind of collaborative natural resource problem solving being written about in recent years by a variety of individuals. Here are some examples:

John A. Kitzhaber, M.D., former governor of Oregon, in his forward to *WaterShed Solutions: Collaborative Problem Solving for States and Communities* asserts that collaboration in watershed matters reduces conflict and litigation which often results in unsatisfactory, narrow decisions that don’t address underlying problems, can turn apparently inflexible federal or state mandates into opportunities, and provides an alternative way of approaching problems that avoids the gridlock often associated with traditional governmental approaches.

Stephen Snyder, Special Master in the Pecos and Rio Grande water rights adjudications in the New Mexico courts discusses using joint fact-finding with groups encountering water conflict. He says joint fact finding can lead to shareholders “participating in an interactive dialogue with neutral experts so as to enhance their understanding of the complexities involved in addressing problems to which there are no clear answers.” He says that parties “often find themselves revising their original assumptions and preconceived notions about what must be done to resolve the problem, finding they are able to favorably consider negotiating proposals they would never have entertained had there been no joint fact-finding process.” Snyder says some may consider the approach

of experts being asked to identify alternative methods for addressing the problems underlying the conflict as antithetical to objective research. But he asks, “Are we missing out on tremendous wisdom when we don’t access this source of assistance?”

Dipak Gyawali, a Nepali engineer and political economist, gave a European Commission report at the 2006 World Water Forum on “constructive engagement” of scientists with stakeholders. He emphasized that the most critical need in solving water problems today is not more technical solutions, but socio-political solutions. “Water policy reform is a very challenging process impacting long established water-intensive livelihoods. In contentious circumstances where water demand has begun to exceed resources a wide range of new institutional capacities are needed to cope with unfamiliar ideas and new priorities voiced by society.” He says we can’t expect to find all the answers to water dilemmas in the water sector. We have to look at the full “watershed” beyond the watershed and look for ideas that draw from different, non-water sector solutions. “Constructively engaged research and communication requires a willingness to understand belief systems.”

Juan Carlos Alurralde, a Bolivian water engineer, was determined to resolve deep seated conflict between indigenous communities and the Bolivian government over how to manage water resources. He set out to apply a water simulation model to a computerized replica of Bolivian water systems to try out the conflicting approaches. But knowing that if indigenous groups did not trust the research there was a risk they would reject the findings, he included them in the research process—by inviting them to participate in the research design, asking them to help gather data, and regularly communicating and explaining findings. The research revealed that the approach favored by the government would lead to a more inefficient use of water and would cause larger differences in water availability between communities, actually resulting in water deficits in many cases. Subsequently the Government of Bolivia enacted a water rights law that has gained widespread acceptance.

William Ruckelshaus, the first director of the EPA, says adaptive management is just as applicable to social experiments as biological ones. We don’t have to get it right the first time, he says. We learn from our mistakes and keep on trekking. He warns that we have to break through the shallow façade of rhetoric and reach to the heart of the issue. “Only when people are united despite their differences by hard-earned trust, does the astounding political power of collaboration become effective.”

Peter Senge who writes about Appreciate Inquiry says “we are stuck in patterns where solutions are arrived at through the process of downloading, or taking an existing framework and applying it to the situation at hand.” He says we need to slow down and ponder a problem so that we can “illuminate the blind spot.” We need to create a deep awareness of the problem as a whole, not just its parts. He challenges us to retreat and reflect, to go to an “inner place of stillness, then listen and make sense of it.”

CONCLUSION

Delph Carpenter, famous for his leadership role as one of the negotiators of the 1922 Colorado River Compact, said that to work through differences in water issues, you have to really try to understand “the other fellow’s take on things.” And he said “it takes time, time, time.” Certainly the committee would concur with Mr. Carpenter.

Members of the committee have established a timeline for themselves, such that they anticipate providing a report to the Arkansas Basin Roundtable by September 2008. They expect that the report will outline a broad range of issues to be considered when water is transferred, questions to be asked pertinent to each of those issues which bring out both positive and negative aspects of the transfer, measures which could be employed to mitigate negative aspects, and identification of those alternatives which show the most promise for subsequent experimentation, demonstration, or academic research by others.

Recently asked what they think characterizes the strength of the committee, members cited: building on trust, grassroots effort, stakeholders finding solutions, looking forward not backward, diverse representation, tangible guidance for planners and policy makers. One member attempting to sum it up said, “You know, I think the underlying message in this whole thing is that we are going to have to do a better job of looking out for each other.”

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EFFECTS OF URBANIZATION ON THE ROOSEVELT IRRIGATION DISTRICT IN ARIZONA

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ABSTRACT

The Roosevelt Irrigation District, located in Buckeye, Arizona, is a non-profit irrigation district that was established in the early 1920's. The District has an approximate delivery area of 62 square miles within the municipalities of Avondale, Goodyear, Buckeye, and portions of unincorporated Maricopa County, Arizona.

Urbanization/development is very prominent in the District's delivery area boundary, which is requiring relocations of existing irrigation infrastructure to provide accessibility and safety to the general public.

The District's approach to the new growth and infrastructure in their delivery area has required them to modify and relocate existing infrastructure to accommodate new development. Additional District relocations and growth has also created the need for restructuring within their management, administrative and technical staff.

This paper will review the impacts that urban expansion has made into a historically irrigated agricultural area within the metropolitan Phoenix area. It will also discuss how the Roosevelt Irrigation District has responded to urban expansion demands with changes that include staff training, public involvement, new resident concerns, modifications to irrigation facilities for public safety, easement work and legal coordination, District liability with shared facilities, flood control alternatives and shared designs, well site review and increased District maintenance costs.

INTRODUCTION

The Roosevelt Irrigation District (RID) was established in 1923 by the Carrick Mangham Agua Fria Land and Irrigation Company (Carrick Mangham) in Phoenix, Arizona. At that time floods along the Verde River required the Salt River Valley Water Users Association (SRVWUA) to try to solve water logging problems within their association area. Due to the water logging problem, Carrick Mangham went into negotiations with SRVWUA to create a contract for the continuation of irrigation service to the Carrick Mangham service area. RID was formed to oversee this contract which would allow Carrick Mangham to receive power from SRVWUA to maintain their production wells in addition to overseeing Carrick Mangham's rights and obligations to run dewatering pumps in the waterlogged regions of the Carrick Mangham irrigation area (ADOT, 2006).

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In 1929 RID (District) moved to their current location in Buckeye, Arizona (Meck, 2007) and currently functions as a non-profit irrigation district providing irrigation services to the municipalities of Avondale, Goodyear, Buckeye and portions of unincorporated Maricopa County, Arizona.

The District has two distinct region/areas within their district, known to the District as their Collection and Delivery areas. The collection area of the District is the eastern section of the District and is bounded by 21st Avenue to the east and the Agua Fria River to the west. The District maintains three main canals that collect and convey ground water and reclaimed water to the delivery area of the District. The canals within the collection area are known as the Collection Canal 1 (CC1, also known as the RID Main Canal), Collection Canal 2 (CC2) and the Salt Canal. A number of production wells tie into these three main canals through pump laterals and all systems combine to create the RID Main Canal just east of the Agua Fria River.

The District's Delivery area is the western side of the district and is bounded by the Agua Fria River to the east and the Haasayampa River to the west. The District has an approximate delivery boundary area of 62 square miles which historically consisted of agricultural lands. Delivery laterals run south of the RID Main Canal and eventually outfall into the Buckeye Water Conservation and Drainage District's (BWCDD) Main Canal to the south. In addition to the Main Canal and delivery laterals, system facilities include wastewater laterals and multiple production wells. Refer to Figure 1 to view the District's Collection and Delivery System.

As development has increased within the District's two regions, The District accommodates development in a number of ways. District improvements are designed to enhance District accessibility to their existing facilities, while providing safety features for the growing general public. The District is required to accommodate development and meet the existing agricultural needs by relocating a number of their irrigation facilities within newly developed infrastructure all the while retaining their prior rights along the newly relocated facilities. In addition, the District restructured their business practices and provides training to staff to accommodate the new development and municipal requirements.

The District is growing consistently due to the urban expansion needs within their district coverage area has developed new standards and methods in addition to coordination with the general public, development and municipalities to provide safer irrigation alternatives for the growing needs of development. It is the intent of this paper to briefly describe the changes that The District has accomplished to meet the growing needs brought on by urbanization.

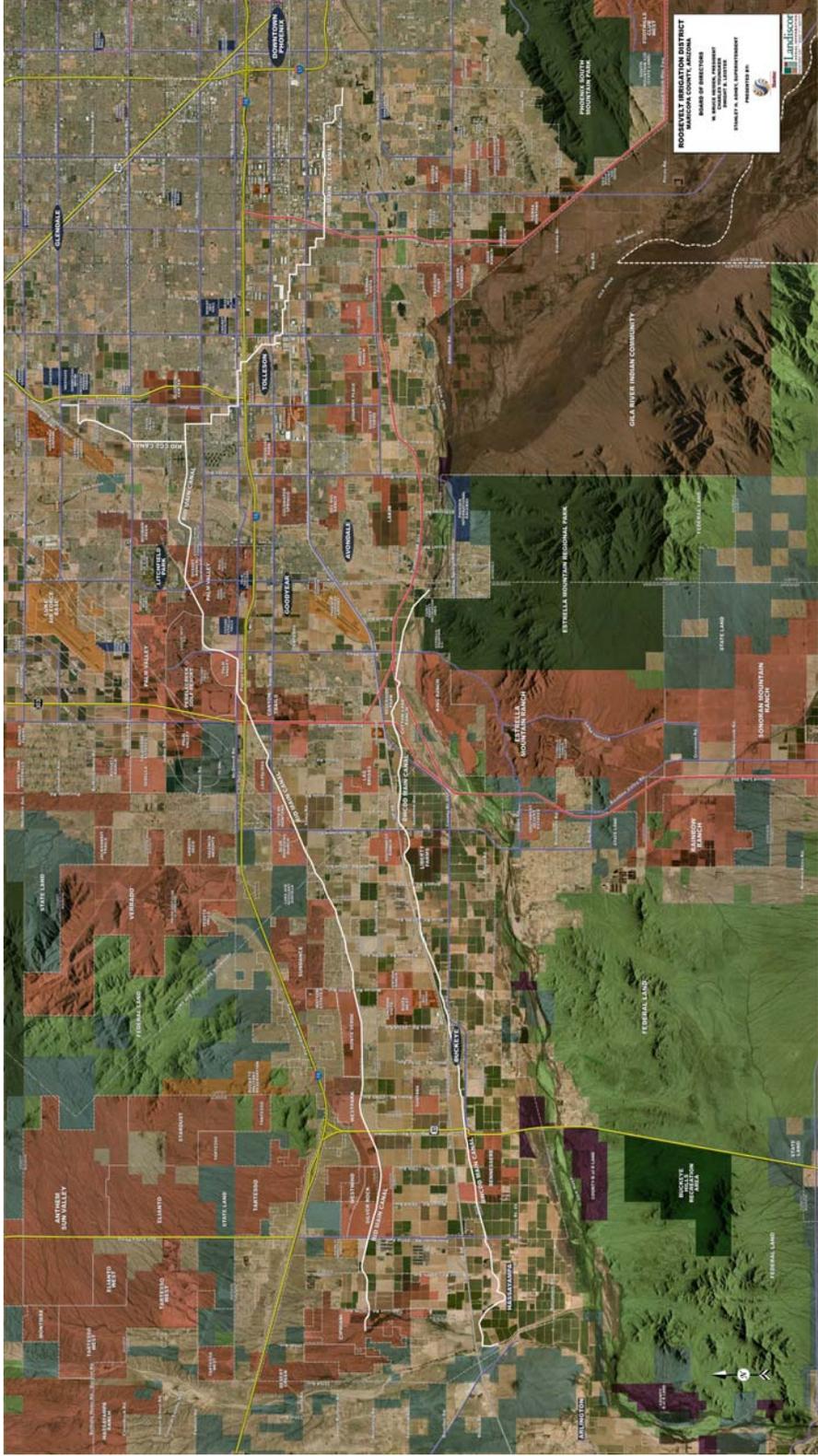


Figure 1. Roosevelt Irrigation District Collection and Delivery System

DISTRICT IMPACTS AND CHANGES DUE TO INCREASED URBANIZATION

With the metropolitan Phoenix area running out of available residential/commercial viable areas, the valley is expanding out into historically agricultural areas east and west of the metropolitan area. Infill within the District Collection area has occurred in addition to capital improvement projects, but the most activity in the District system is commercial, industrial and residential development within the District's Delivery area. The District has made considerable changes to their methods and business practices to accommodate this growth west of the Agua Fria River.

District Improvements for Accessibility and Safety to the Public

Existing District irrigation facilities date back to 1923 following the establishment of RID. These existing facilities were designed in mostly agricultural land as open earthen ditches and open turnout structures. As urbanization occurred throughout the valley, District facilities were piped, boxed or bridged to accommodate improvement projects throughout the valley. By 1964 the RID Main Canal and laterals were lined (ADOT, 2006) through much of the District's system which remains to this day.

Current commercial/industrial and residential development has required modifications to existing irrigation lateral facilities to allow for continued agricultural uses downstream of the development. The District, as well as surrounding municipalities, is requiring the piping of the District's irrigation laterals as development progresses. With piping, the need for District accessibility has made the District require manholes for maintenance purposes. Headwalls with trashracks are now a common sight on new construction to prevent the general public from access into piped laterals as well as decrease the maintenance within pipelines. New piped systems required new modified turnout structures. These structures are designed to allow for the additional hydraulic head due to the additional friction losses within the piped system. They are also equipped with protective covers to prevent access by the general public as well as domesticated animals. To assist in public safety, the District does not allow local nuisance roadway drainage or on-site residential, commercial or industrial drainage into existing or proposed irrigation facilities to decrease the possibility of surcharging the irrigation facilities.

Main canals require greater improvements to facilitate not only residential, commercial and industrial development, but also large scale infrastructure improvements. Use of free span bridges over the RID Main Canal are common on new improvement projects. If the use of a free span bridge is prohibited due to space constraints, The District employs the use of box culverts that allow for a larger infrastructure take and provides adequate structure design for vehicular traffic or landscaping loads. Box culverts are designed to provide open channel hydraulics so the use of trashracks is not required in most instances. Ladder rungs are provided to allow emergency egress out of the RID Main Canal.

The District works in conjunction with local, county and state departments in coordination on flood mitigation, transportation and capital improvement projects to

allow for safe upgrades to existing District irrigation facilities. The District works closely with designers on the design of flood conveyance facilities in, on or adjacent to District facilities. If existing floodplain flows are intercepted by the RID Main Canal, the District works in-conjunction with the flood conveyance designer to design a safe efficient design to convey flood waters into the RID Main Canal. In addition, RID has worked with Maricopa County and the Arizona Department of Transportation on county and state funded projects, providing updated safety design to coincide with infrastructure improvement projects. Modified designs to RID Main Canal operations and maintenance roads allow the safer ingress and egress for District staff as well as provide controlled access complementing infrastructure design requirements for the safety of the general public.

District Relocations of Existing Facilities and Coordination with Development and Industry

New District relocation design utilizes infrastructure improvements to run lateral improvements adjacent to and through new development. The District engineer designs irrigation improvements to follow curb and gutter, lot walls, paved parking lots and flood retention/conveyance facilities. The District works with the developer's engineers to relocate facilities within municipal right-of-way and outside of the public utilities easement. Relocated facilities run preferably centered below sidewalk or some distance from the top of a flood retention/conveyance facility. The District's engineer coordinates with the Developer's engineers and municipalities in the event additional municipal right-of-way or a landscape tract is needed so no relocated District Lateral facilities are running parallel within the paved roadway sections. The District does not want to take away any additional utility space from the paralleling utilities within the paved roadway section. Also being a non-profit irrigation district, they do not desire to replace paved roadway sections if maintenance of District facilities requires removal of paved roadway sections.

The District provides opportunities for coordination with developers and contractors on improvement projects. Developers have the opportunity to have District water provided as an improvement within their development projects for green space design. The District and their engineer will work with the developer's engineer to coordinate improvements that tie into District facilities for the purchase of District irrigation water. Construction water is also available to contractors when development projects are within the Districts boundaries.

District Production Wells and Development Concerns

Irrigation well sites were located prior to the development of the historically irrigated agricultural areas. This led to conflicts with either well sites existing within proposed roadway improvements or that well sites are adjacent to residential or commercial development. The District works with developers and municipalities if there is an opportunity for a well swap, which transfers either a municipal or private well to a District owned facility. Upgrades are required to bring the well site up to current District

standards, but the benefits of the well site new location outweighs the cost to restore a proposed well swap location.

Stranded wells are a growing concern with the District. Some locations within the District have industrial land uses and industrial landowners surrounding District well sites. These land users have provided for insufficient area for maintenance of existing irrigation well sites, and in some cases have created a hazardous working environment for District employees as well as their own employees. Stranded well sites are difficult to maintain, but due to their production capabilities are valuable assets to the District.

One example of a stranded well in a hazardous condition is shown in Figures 2 and 3. The well is located within a sand and gravel operation. The sand and gravel operation is mining up to the District defined maintenance boundary. This mining has created an elevated island with a narrow elevated operations road for maintenance equipment to access the well site. The earth around the island perimeter continually erodes, eating away the needed maintenance area boundary. As a result, the chain link fence surrounding the perimeter of the well site is in jeopardy. Currently a well swap is in process to mediate this hazardous condition.



Figure 2. Aerial of Stranded Well



Figure 3. Vertical Mining along Well Perimeter and Loss of Perimeter Fencing

Liability and vandalism are also concerns that require the District and developers to fully enclose well sites to prevent access from the general public. The District and their engineer work with the developer's engineer or architect on beautified wall enclosure designs. Although this alternative is generally an acceptable alternative to impede access to the general public, if the developer opts out of coordinating with the District on an improved site wall, the District requires adequate room for maintenance vehicle access but will only provide chain link fence around the perimeter with anti-access wire along the top edge of the fencing to prevent public access and vandalism. District costs to bring vandalized well sites back to working condition are on the rise, but the District requires the production well water to maintain deliveries to existing irrigated agricultural areas.

Restructuring of District Practices for Development

With the increased development activities within the District's boundary, long standing District practices have transitioned to accommodate development. The District is now coordinating with municipalities as well as public agencies to address publicly funded projects which incorporate District facility relocations. The District and their engineer

attend public meetings and forums discussing the development projects and the impacts involved to the public. The District does not hold public forums or meetings but works with the public entities in the preparation of collecting information to determine an acceptable engineered solution for development needs.

The District trains staff and their engineer on policies and procedures that are required for accommodating development within their District boundary. The District's Development Guidelines are updated as needed for newer procedures or materials that are available when working on irrigation relocation projects. Staff is trained to work with the general public and to handle the larger workload involved with urbanization and the growing needs of municipalities. Updates in billings methods and contract agreements are required for the growing demand of projects within the District boundary. The expedited growth within the District's boundary required the training and utilization of the District's engineer to track and monitor projects from the projects inception, including the need for the District's engineer to scope and manage projects outside of the District office.

District's Design Support. The District's engineer provides additional support with the implementation of updated structure designs. Created from design criteria from the United States Bureau of Reclamation (USBR) and Salt River Project, the District structures are modified and standardized by the District's engineer for pipeline relocation capabilities. This has allowed the District to provide structures with increased safety for the general public through the use of grated or framed covers on irrigation pipeline structures, framed manhole covers and trashracks. Current delivery structure designs now include fabricated steel slide gates with hydraulic measurement capabilities allowing the delivery of irrigation flows without the access of the general public. Bolted manhole covers provide a water-tight seal allowing District relocations to run in pressure flow while providing for the additional friction losses incurred within a closed pipeline system. In addition, trashracks are provided at the inlet of current irrigation relocations longer than 100-ft to prevent access to closed pipeline systems from the general public.

The District, their engineer and legal firms work with developers, municipalities and governmental agencies on developing alternatives or conceptual shared alternatives for flood mitigation. Following area-wide flood control master studies, the District, developers, municipalities and governmental agencies determine existing locations of inflow or outflow of the District's existing Main Canal system. The District and their engineer then works with the developer's engineers on inflow or outflow design criteria and review of the developer's engineer's design. Additionally, relocations of lateral lines adjacent to flood mitigation facilities can allow for conceptually shared designs as long as irrigation and flood flows remain separated. The District currently has existing flood mitigation and irrigation facilities, which upon municipal or governmental agency improvement is transferred to municipal or governmental agency control. The District's legal firms work with the municipality or governmental agencies to provide the legal documentation necessary for the transfer of ownership of the previously owned irrigation facilities.

District Easements, Right-of-Way and Wheeling Agreements. Following the creation of the District, easements were set up across the majority of the District's Delivery area for maintenance of their existing facilities. Dating back to the early 1920's, the blanket easements were written to cover parcels of land or even sections of townships and ranges to provide an "easement for the construction, maintenance and operations of canals, ditches and laterals upon, over, along and across described real estate". Currently, lenders are increasing the requirement for the retirement of the blanket easement across the majority of development parcels. The District, their engineer and their legal firms, work with developers to determine retirement areas within the blanket easements allowing the District to retain their prior rights for maintenance access but removing the blanket covering a majority of the property. In addition, existing right-of-way was dedicated to a majority of the RID Main Canal system. The District, their engineer and their legal firms, work with the developers on locating the existing RID Main Canal right-of-way. The District requests a Results of Survey to establish the RID Main Canal right-of-way and requires the adjustment, as needed, of the developments boundaries accordingly.

Easements and even deeded property were provided to the District by the use of Quit Claim deeds or Special Warranty Deeds for existing irrigation production wells. The District, their engineer and their legal firms, work with developers on appropriate well site boundaries which allow the access of current irrigation maintenance vehicles and well rigs uninhibited access to well sites for maintenance purposes. Modifications to the developer's final plat and construction drawings are coordinated through the District's engineer to allow for the appropriate sizing of the irrigation well site boundary. The District's engineer and legal firms then work in conjunction with the developer to prepare a modified Quit Claim Deed or Special Warranty Deed conveying the modified well site property and retaining its prior rights to the District.

It is the District's requirement, as well as the requirement for municipalities within the Districts service area, to pipe irrigation laterals adjacent to development for the safety of the general public. In some instances this is not a feasible requirement since the existing irrigation conveyance is also a privately shared facility, or partnership facility. Many District facilities provide shared or partnered use of facilities and are known as partnership ditches. These ditches function as private delivery ditches but also convey District well water from District production wells to District laterals. Because of this issue, many of these locations require the continued capabilities of the shared system although an adjacent property is under development. Liability is a concern since the general public access is not impeded from the existing facilities. The District and their engineer works with the developer to determine a feasible means of inhibiting vehicular access (such as requiring curb and gutter if the facility is adjacent to a proposed paved roadway section) where available. Otherwise, the District tries to maintain the location of the existing facility with a provided 12-ft field road for irrigator access but does not have any actual means to inhibit the general public from accessing the private irrigation ditch.

The District and their legal firms work with developers, municipalities and governmental agencies when these agencies request the acceptance of municipal flows into the District's Main Canal system. The District will accept reclaimed water as long as it meets the Arizona Department of Water Resources rules as published in the Arizona Administrative Code Type A reclaimed water (www.azsos.gov, 2007). Wheeling agreements are created between the District's legal firm and the agencies for the acceptance of flows based on continued Type A quality and a steady return discharge flow into the District's Main Canal system. Discharge facility design is coordinated with the District and their engineer with the agency's engineer and conforms to current District discharge facility standards.

District Practices for Dust, Insect, Weed and Access Control. New residents / developments have brought up concerns with existing District facilities due to dust, insect, weed and access control issues. The District works with each concern as requested to solve the problem in a reasonable cost effective manner. The District regularly sprays along the RID Main Canal to control insect and weeds. If dust is a concern, the District will coordinate with the developer on necessary ground cover requirements around newly relocated facilities for District maintenance equipment access. For access outside of developed areas, most operations and maintenance (O&M) roads are maintained as earthen lined facilities. If District O&M roads are being utilized for construction access, then it is up to the Developer's contractor to provide dust mitigation alternatives which most commonly consist of spraying water or a dust controlling material along the O&M road. Access control is provided with the use of traffic control gates when needed or the new resident/development provides traffic control gates as part of their improvement plans.

Increased District Maintenance Costs

The District strives to provide safer relocated irrigation facilities as development expands, but with development District maintenance costs are on the rise. In locations where District facilities run within a privately maintained homeowners association (HOA), removal of trash, debris and weeds are provided as part of the HOA Covenants, Conditions and Regulations (CC&R's). Structure vandalism though occurs frequently in the Districts urbanizing areas. Damage to structures includes metal work damage, damage to the structural concrete, stolen gate wheels, and graffiti to name a few. All this maintenance work is provided by the District unless the party responsible is found and convicted. The District provides the maintenance for the continued use of the irrigation system, while the District and their legal firms work to collect the damages from the responsible party.

In addition to irrigation structure vandalism, District well site vandalism is on the rise. Mostly due to the rising cost of copper, the vandals tend to vandalize the Districts transformer boxes and transmission lines for the valuable copper wire. Although the District has zanjeros (ditch riders) and maintenance workers driving throughout their Collection and Delivery area on any given day, the District has not been able to keep on top of all well site vandalisms that have occurred in the District boundary. Well site vandalism takes an existing running production well and completely cuts off the well

from the power company in the area. If and when this occurs, the power company requires the District to bring the existing well site electrical equipment to the power companies current design standards. This reconstruction fee for the well site electrical equipment can run between \$100K to \$200K depending on the equipment that must be brought up to current power company standards.

SUMMARY AND CONCLUSION

From the inception of the Roosevelt Irrigation District, historically irrigated agricultural lands have been slowly taken out of production with the onset of urban expansion. The District has responded and worked with developers, municipalities and governmental agencies over the years to coordinate District required relocations in coordination with development improvement plans. These relocations require safer structures for public safety and additional District maintenance to handle new residents concerns with dust, insects, weed and access control. New irrigation relocations are coordinated with developers, municipalities and governmental agencies to incorporate flood mitigation and shared design alternatives.

District staff, their engineers and their legal firms, respond to the growth and new requirements in the District area through training, public forums, modified irrigation design and legal coordination of easements, right-of-way and wheeling agreements. Production well sites within the District are affected by development either through modifications to the well site maintenance area, stranded wells, the need for well swaps or even restoration of vandalized electrical equipment. The District continues to strive for and to provide agricultural water to historically irrigated agricultural lands throughout urbanization in their Collection and Delivery areas. Although development is ever decreasing historically irrigated lands, the District will be required to maintain these deliveries for years to come.

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MITIGATING THE EFFECTS OF URBANIZATION ON IRRIGATION DISTRICT RIGHTS OF WAY AND FACILITIES

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ABSTRACT

The Turlock Irrigation District (TID) has experienced urbanization of property within its boundaries. To properly manage the effects of this urbanization on its irrigation facilities, TID has developed a comprehensive set of procedures, documents and design standards to assure that irrigation facilities within developed property will serve their intended purpose without imposing unreasonable costs on the irrigation customers of the District.

BACKGROUND AND HISTORY

The Irrigation System

The Turlock Irrigation District was established as California's first irrigation district on June 6, 1887, under provisions of the Wright Act, a law enacted in the state of California providing for the establishment of irrigation districts. After building the diversion and distribution facilities, the TID made its first delivery of irrigation water from the canal system on March 9, 1900. Today the TID irrigates 150,000 acres of land that consist of 7,500 parcels of property and approximately 5,000 individual irrigators. A location map showing the District is shown in Figure 1. The District extends from the foothills of the Sierra Nevada on the east to the San Joaquin River on the west. The Tuolumne River forms the TID's northern boundary, while the Merced River forms the southern boundary. The TID canal system stretches from La Grange in the foothills of the Sierra Nevada Mountains where water is diverted from the Tuolumne River, to Lateral 8 which ends 2 miles from the confluence of the Merced and San Joaquin Rivers. The irrigation system consists of 231 miles of canals, and 1,660 miles of ditches and pipelines.

Urbanization Effects and Response

Since the TID was formed over 100 years ago, various properties within its boundaries have been converted from agricultural to urban use. Some of the effects of urban development include an increased population near canals, higher valued property and improvements near canals, increased unauthorized usage of the canal banks, increased vandalism and trespassing affecting TID irrigation facilities, and increased need for consideration of outside impacts caused by canal operation and maintenance activities. Another effect of urbanization is the increased need for storm drainage services for developing property.

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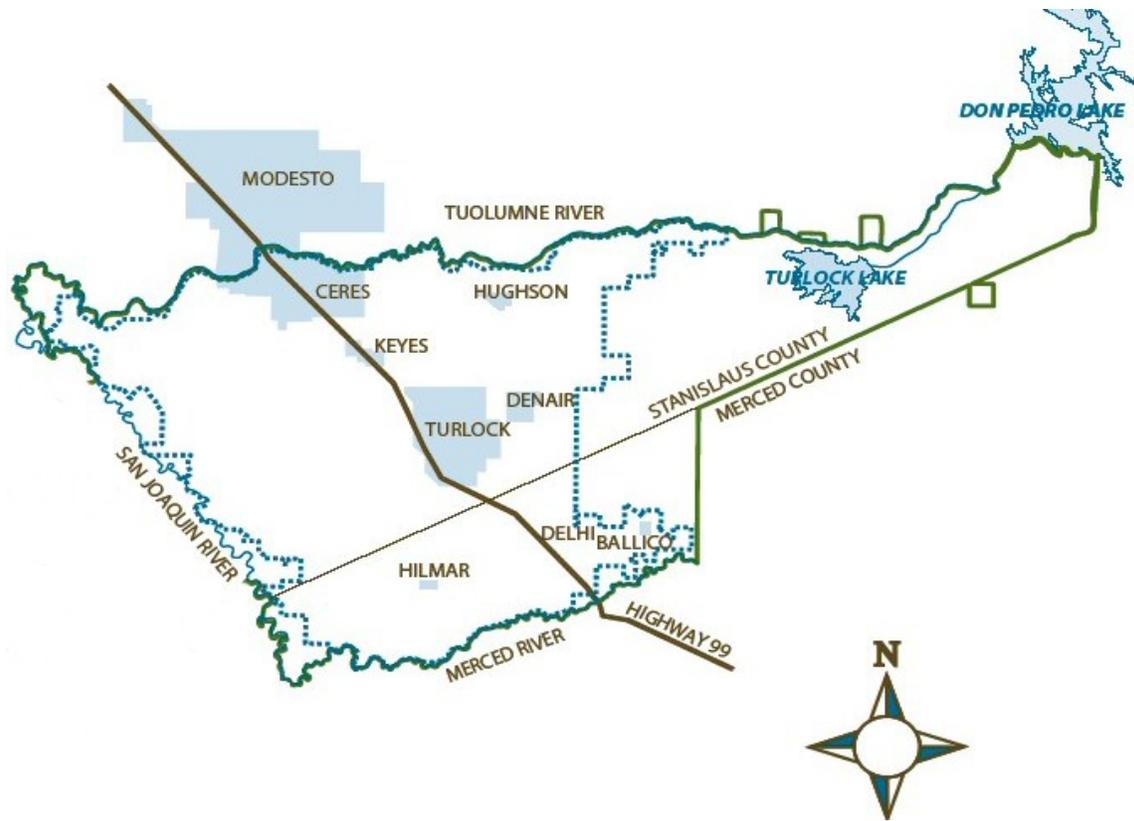


Figure 1. Map of TID

As a consequence of the development and urbanization activities, the TID has developed processes, procedures and standards to address changing land uses which impact the existing irrigation facilities. The processes include review of development plans during the proposal phase, and implementation of design standards for irrigation facilities to remain within developed areas. These processes are intended to protect the TID's assets along with maintaining the TID's property rights to access, operate and maintain the facility. Of utmost importance in the development process is a good working relationship with the cities within the District and the three counties within which TID is located. These agencies assist the TID in protecting the TID's facilities by requiring developers to obtain TID approval of the project if irrigation facilities are impacted by the proposed project.

RESPONSE TO URBANIZATION

Irrigation System Right-of-Way Usage

The TID's irrigation facilities are located within easements obtained early in the twentieth century as the irrigation system was being planned and constructed. Many of the easements are shown in the original development plats of property within the TID. In other cases, the easements are written deeds granting the TID the right to construct operate and maintain canals across properties. Some of the descriptions of the easement locations may be difficult to establish due to changes in property over the years. In other

cases, the location of the actual irrigation facility may not exactly match the written map or deed. In any case, the TID requires property developers to accurately locate the irrigation facility and provide a recorded easement that provides sufficient width for the facility and associated banks or roadway, along with any necessary access to the facility from a public street.

Once the canal or other facility has been properly located within an easement, the TID will consider giving other agencies and utilities access to the canal easement by use of a revocable license agreement with the other agency or utility. These agreements are a license for a specified usage of a portion of the easement and are revocable by the TID if the usage interferes with TID operations. Examples of such license agreements include installation of water mains by cities and installation of telephone or other communication utilities. The normal location of these encroachments is the outside five feet of the canal easement, past the catch point of the operation and maintenance roadway embankment for the canal.

If the proposed encroachment is of limited size and extent, less than 5 feet square, and the facility is a pipeline, the TID will consider granting an encroachment permit which allows for a small encroachment to be placed within the TID easement. The agreement specifies that the TID may require that the encroaching structure must be removed if it interferes with TID operation or maintenance activities. Typical facilities allowed by an encroachment permit are corners of sidewalks or existing structures inadvertently intruding on the TID easement.

TID historically allows public agencies to utilize available capacity in the TID canal system to convey urban storm drainage in TID canals to the river spill. This conveyance ability is limited to available capacity within the canal system. All discharges of storm drainage are by revocable license agreement with the requesting municipality. These agreements contain provisions that specify timing and flow rate of discharge and minimum water quality of the discharges into the canal system. Additional requirements are that the discharging municipality must construct detention capacity for their anticipated runoff. Even with these limitations, the municipalities' usage of the canal system for storm drainage must be carefully managed to allow the TID time to perform maintenance on the irrigation system.

The cities within the TID, when planning parkway, green belts, and walkways have begun to consider the TID easements and canals as assets to the community. As a result, the TID and the cities have completed several landscaping agreements. These agreements allow the city to install landscaping, lighting, walkways and other amenities that provide an urban green belt and walking path through the city. If public access is contemplated, the agreement requires the city to install and maintain a five foot high chain link fence to keep children and objects out of the canal. These agreements allow the city to place the improvements, but in return, the city must maintain the bank of the canal, controlling weeds, trash, and other objectionable materials. Figure 2 shows the urban greenbelt and pathway installed in the city of Turlock.



Figure 2. City Improvements on Canal Banks

Canal Protection Standards

When TID canals are located within the boundaries of or adjacent to proposed development, the TID meets with developers to verify that their development plans incorporate the appropriate TID standards. TID encourages developers to replace open canals or ditches with underground pipe to current TID standards. This replacement is usually accomplished easily for smaller facilities of capacity less than fifteen cubic feet per second (cfs). Larger capacity main canals have been placed underground in commercial development, but the economics for replacing a canal with a pipe are more difficult for developers proposing residential development. If the canal is not placed underground, then the TID requires that a six foot high masonry wall be placed on the developing property, to separate the developed property from the canal. In some instances, the developer installs wrought iron as part of the upper portion of the masonry wall for decorative purposes. The purpose of the masonry wall is to separate the TID's operation and maintenance activities from the new urban property. A typical masonry wall with wrought iron is shown in Figure 3.

If the banks of the canal within developing property do not meet current TID standards, the developer must bring those canal banks up to current standards.



Figure 3. Masonry Wall along Canal

Pipeline Protection Standards

TID irrigation facilities of 15 cfs capacity or less that are located within developing property must be placed in pipe to current TID standards. Generally, these facilities are routed around the periphery of the developing property. These standards require that the pipeline be constructed of reinforced concrete pipe and that appropriate easements for maintenance and access be provided. The usual pipeline easement is 25 feet wide, centered on the pipeline.

Property Protection Standards

In order to protect both the developing property and adjacent irrigated land, the TID requires that all property developing within the TID that will be adjacent to remaining irrigated property must be graded such that the developing property is six inches higher than the adjacent irrigated property. This requirement reduces the possibility of irrigation water reaching developed property.

Procedures for Constructing Improvements in Developing Property

The TID reviews the relevant engineering plans for development that impacts TID irrigation facilities. Once the necessary improvements are shown on the plans, the TID engineer will sign the plans, approving the irrigation related work. On a note in the plans, it is specified that an irrigation improvements agreement must be signed by the

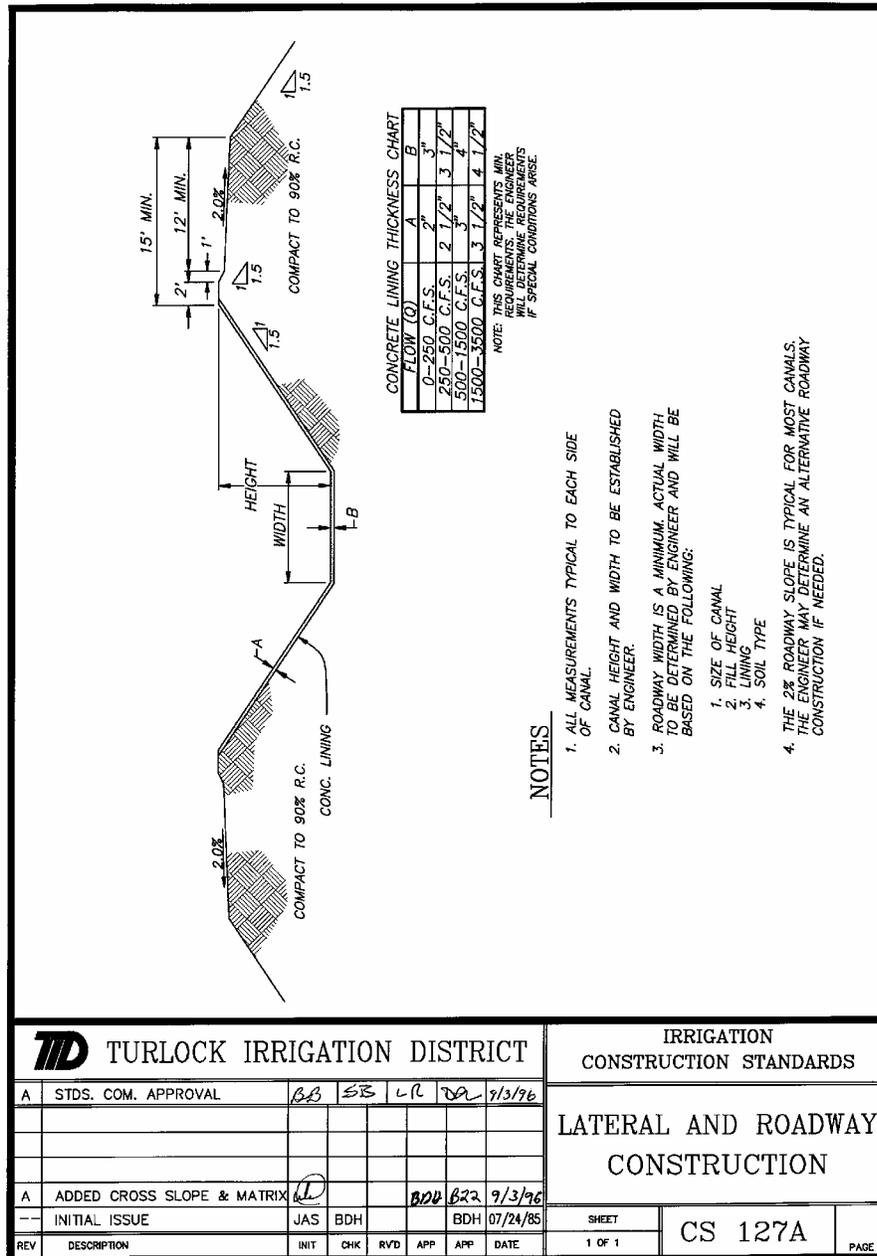
developer and the TID. The developer must provide performance and payment bonds in favor of the TID before any work is started on the developing property.

Engineering Design Standards

The TID has developed an extensive set of engineering and construction standards that assist developers and their engineers to specify and install facilities meeting the needs of the TID and its customers. Engineering standards specify parameters used by engineers to design TID irrigation facilities. Construction standards specify the actual construction dimensions, materials and details for irrigation facilities. For example, Standard ES 101, Figure 4, specifies various parameters for design of canals and ditches within the TID. Standard CS 127A, Figure 5, specifies the cross section of canals within the TID.

CANAL AND DITCH DESIGN SPECIFICATIONS									
VERTICAL TRANSITIONS IN GRADE Horizontal (H) : Vertical (V)									
Main Canals and Laterals: 4:1 OR 15° MAXIMUM									
Improvement District and Private Ditches: 2:1 OR 26° MAXIMUM									
HORIZONTAL TRANSITION IN ALIGNMENT FROM CANAL LINING TO A STRUCTURE:									
1 TRANSVERSE : 2 LONGITUDINAL (Minimum)									
STANDARD DESIGN FREEBOARD									
							Inches	Feet	
Upper Main Canals							18"	1.5'	
Main Canals (800 - 2050 cfs)							12"	1.0'	
Laterals (15 - 250 cfs)							6"	0.5'	
Ditches (5-30 cfs)							4"	0.2'	
MANNING'S "N" FOR CONCRETE LINED CANALS:									
0.015									
MAXIMUM DESIGN HEADLOSS TOTAL FOR CANAL SIPHONS:									
Up to 100 feet in length including transitions: 0.2 FT.									
Over 100: A site specific engineering design is required.									
FOR DESIGN OF CANAL SIPHONS FOR ROAD CROSSINGS:									
(To include transition structures)									
Refer to the Current Cal-Trans Siphon Standards.									
BANKS OF DITCHES:									
Refer To CS 143									
BANKS OF CANALS:									
Refer to CS 127									
TURLOCK IRRIGATION DISTRICT						IRRIGATION SYSTEM ADMINISTRATION ENGINEERING STANDARDS			
						CANAL AND DITCH DESIGN SPECIFICATIONS			
1	Revised Working for Clarification	HBS				BDH	1-27-92		
	Initial Issue	JAS	REV			BDH	9-12-86		
REV	DESCRIPTION	INT	CHK	RV'D	RV'D	APP	DATE	SHEET 1 OF 1	DWG NO. ES 101

Figure 4. Canal and Ditch Design Specifications



TD TURLOCK IRRIGATION DISTRICT

IRRIGATION
CONSTRUCTION STANDARDS

A	STDS. COM. APPROVAL	BB	SB	LR	DR	9/3/96
A	ADDED CROSS SLOPE & MATRIX	LD			BDH	9/3/96
--	INITIAL ISSUE	JAS	BDH		BDH	07/24/85
REV	DESCRIPTION	INIT	CHK	RVD	APP	DATE

LATERAL AND ROADWAY
CONSTRUCTION

SHEET
1 OF 1

CS 127A

PAGE

Figure 5. Lateral and Roadway Construction

Fees for Reviewing and Inspecting Development Related Construction

In order to reduce the financial impact of development on irrigation ratepayers, the TID has developed a fee schedule for the various services provided by the TID on the behalf of developers. The fees are tabulated in Table 1.

Table 1. Development Related Fees

ACTION	UNIT	COST
Improvement Plan Review and Construction Inspection	Each	Actual costs based on rates for full cost recovery
Revocable License Agreements	Each	\$200
Parallel Pipeline Encroachment Fee	Annual	\$250 (For first 1,000 feet) + \$25/100 lineal feet thereafter
Variances from standards	Each	\$200

CONCLUSIONS

The TID has developed a complete set of procedures to work with developers to minimize the impact of urbanization on the TID irrigation system. In addition to the procedures, a complete set of engineering and construction standards has been developed that is used to assure the TID's irrigation customers that irrigation water service will be perpetuated as property within the TID urbanizes. These procedures, documents and standards are used by developers, urban development agencies, and the TID to lessen the impact of development on the TID irrigation system.

SOURCES OF DEEP PERCOLATION FROM URBAN WATER USE IN THE UNCOMPAGHRE VALLEY

Delbert M. Smith, P.E.¹

ABSTRACT

Much effort has been expended to estimate the sources of salt and selenium loading in the lower Gunnison River Basin. The obvious large sources are from irrigated agricultural lands and the unlined water delivery system that serves these lands. Efforts to reduce salinity and also the trace element selenium are being supported by a wide group of stakeholders coordinated by the Gunnison River Selenium Task Force. The task force identified a need to better understand the contribution from urban water users and possible trends as irrigated land is continually converted to urban development. In addition to the trend in irrigated land being converted to housing developments, there is a trend of irrigated fields being broken up into small acreage farms often with constructed ponds. These ponds in many cases can leak significantly, adding salt and selenium to the Gunnison River. There is a desire to not let progress in reducing salt and selenium loading from agriculture to be offset by new sources from urbanization.

PROBLEM

Deep percolation has been estimated for irrigated agriculture in the Uncompaghre Valley including the unlined water delivery system of open channel canals and laterals. This is an obvious source of salt and selenium leaching, but non-agricultural uses of water also contribute to deep percolation.

In 1999, a reconnaissance-level investigation was performed to assess the amount of seepage and deep percolation that could be attributed to residential water use in the Uncompaghre Valley. The following three sources of domestic water use were identified as the main ground water contributors:

1. Septic Systems
2. Lawn Watering (including cemeteries and golf courses)
3. Pond Seepage (including stock water ponds)

Assumptions

To quantify the potential volume of water from the listed sources, some basic assumptions were made. The counties of Montrose and Delta, CO, use 75 gallons per day/person (6,000 gallons per month) for their leach field design estimates. There is uncertainty about how much of this leach field water makes it to the Gunnison River (River). Since this water is introduced underground and is not subject to direct evaporation, the main losses between the leach field and the River are likely from phreatophyte consumption and capillary transport to the surface that is evaporated. It was

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assumed that 50 percent of this water makes it to the River, which equates to approximately 0.11 acre-feet per year per leach field (3,000 gallon per month). The value of 50 percent was used because some of this water which enters underground is likely intercepted by tree roots in its flow path to the Gunnison River or Uncompahgre River. In areas where the depth to barrier is shallow, some of this water is forced close enough to the surface where capillary action can create some surface evaporation.

Indoor Water Use

It was also assumed that consumptive indoor water use was negligible. In other words, most indoor water use (showers, washing machine, dishwasher, and toilets) ends up in the leach field. Base indoor water use was assumed to be the average domestic water deliveries for November through February for water years 1994-1998. The monthly base-indoor water use is defined from a monthly average of November-February (non-irrigation months) for the four years of record.

Outdoor Water Use

Outdoor water use was assumed to be water volumes in excess of the base water use. This agrees with the value of 6,000 gallons per month that the counties of Montrose and Delta use for leach field design. It was assumed that 75 percent of the water applied to lawns and gardens is consumptively used and that 25 percent percolates into the ground and becomes ground water. This value likely varies greatly, and 25 percent may be a little high, but inexpensive water often leads to over watering.

Constructed Ponds

The number of ponds and acreage of ponds in the Uncompahgre Valley is steadily increasing. Using Reclamation Technical Assistance to the States funds, aerial photographs were purchased and digitized. This information shows that between 1993 and 1999, the acreage of ponds within the Uncompahgre River drainage area of Montrose County increased at the rate of approximately 15 acres per year. This is growth rate of approximately 5 percent a year in pond acreage. There have been many more ponds constructed in this same area since 1999, and it would be very useful to digitize a new aerial photograph survey (2004/2005) to see how many acres of ponds are currently in Montrose County.

Seepage from ponds was estimated to be one-third the rate of measured canal seepage (0.05 ft/day). Double ring permeameters were used to measure infiltration in three different ponds in November of 1999 to measure pond seepage rates. These tests would support using a rate of 0.1 ft/day. Double ring permeameters were used to measure seepage in two additional ponds in August of 2002. Seepage in these ponds was 0.1 ft/day and 0.3 ft/day. The pond with the seepage rate of 0.1 ft/day had a piping flow loss in excess of 0.1 ft³/sec. The piping flow loss in this pond is likely the result of a small animal burrowing through the bed of the pond when the water level was drawn down. Some large ground water seepage contributions may be occurring in artificial ponds.

Ponds in the Delta and Montrose Area contributing to the ground water system were estimated to be 500 acres.

Quantification

The communities of Delta, Montrose, and Olathe were contacted to obtain the number of leach fields. The total number of septic systems as of 1999 was approximately 5,500. A more detailed future study could identify which of these systems are located in areas that are underlain with Mancos shale. For this reconnaissance study it was assumed that all of these systems ultimately drain to the Gunnison River. The majority of these systems in Delta County are located on the east side where Mancos shale is consistently found. The location of leach fields in Montrose County may be more evenly split between soils underlain by Mancos shale and soils not underlain by Mancos shale.

The main domestic water purveyor, *Project 7*, provided water-delivery records from 1994 to 1998 for Montrose, Tri-County, Menoken, Chipeta, Olathe, and Delta. The total amount of water used per community divided by number of water taps was used to estimate the amount of water use per tap. A quantity of outside water use (lawn and garden watering) was estimated by subtracting base indoor water use from the total annual water use.

In addition to the water provided by *Project 7*, 1,000 acre-feet of domestic irrigation water is provided each year by the Uncompaghe Valley Water Users Association (UVWUA). These are referred to as City Garden Contracts by UVWUA. The UVWUA also provides 4,000 acre-feet of water per year for irrigation of cemeteries and golf courses. Total turf and garden irrigation is estimated to be 8,000 acre-feet of water.

There was no accounting for water use from private well systems. This is likely a small amount of use due to the plentiful supply of inexpensive and high quality surface water and mostly poor quality ground water.

Deep Percolation Estimates for Uncompaghe Valley

Leach Fields = 600 acre-feet per year (5,500 systems contributing 3,000 gallons per month)

Turf Watering = 2,000 acre-feet per year (25 percent of 8,000 acre-feet)

Leaks from Domestic Water Mains = 750 acre-feet per year? (10 percent average leakage for mains)

Ponds = 9,000 acre-feet per year (500 acres leaking 0.05 feet per day)

Total Deep Percolation Estimate from non-agricultural sources ~ 12,350 acre-feet.

Table 1. Estimate of Total Deep Percolation from All Sources in the Uncompaghre Project Area

Deep Percolation Source	Acre-Feet	Percent
Leach Fields	600	0.5
Turf	2,000	1.5
Leaks (Water Mains)	750	1
Pond Seepage	9,000	7
On-Farm Seepage (Ditch)	5,600	5
Agriculture	38,500	31
Canal Seepage	67,600	54
Total	124,050	100

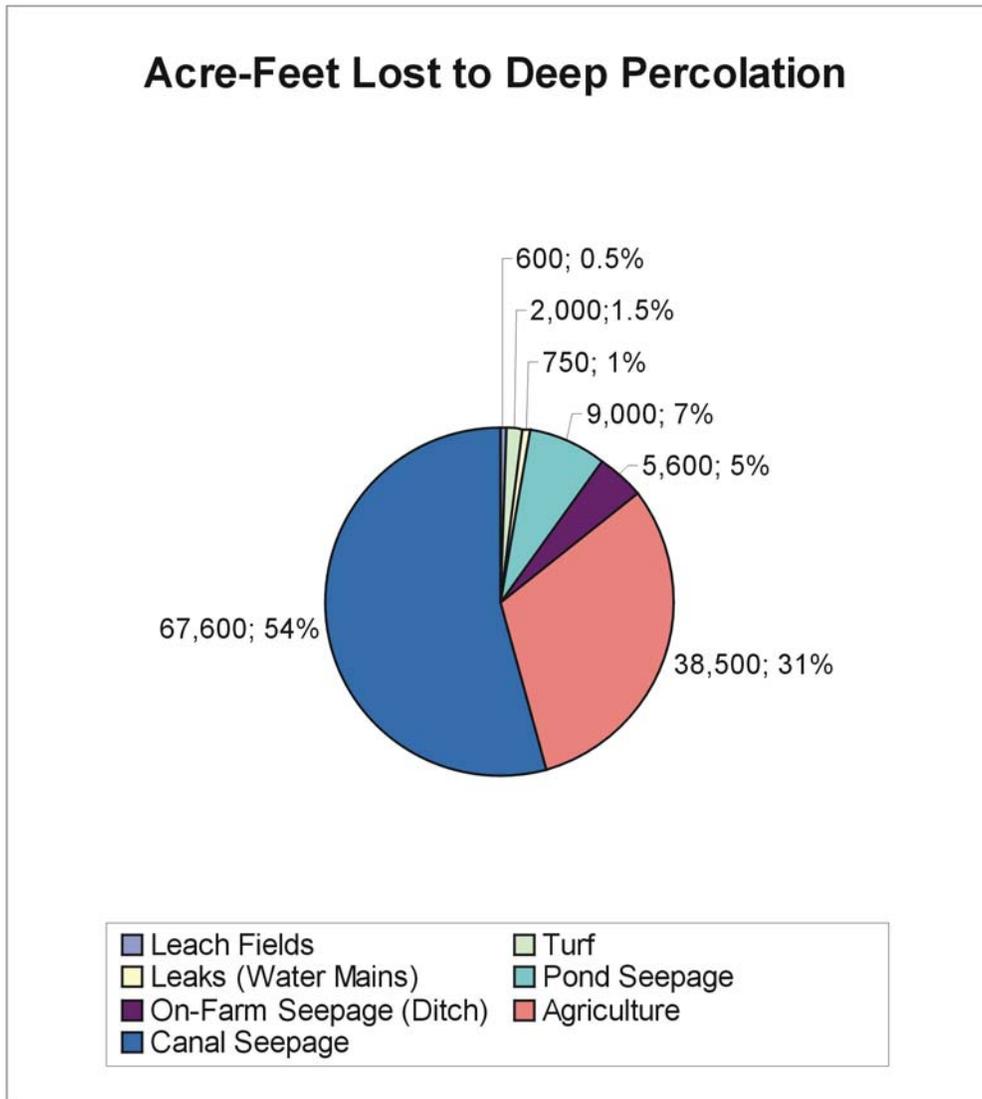
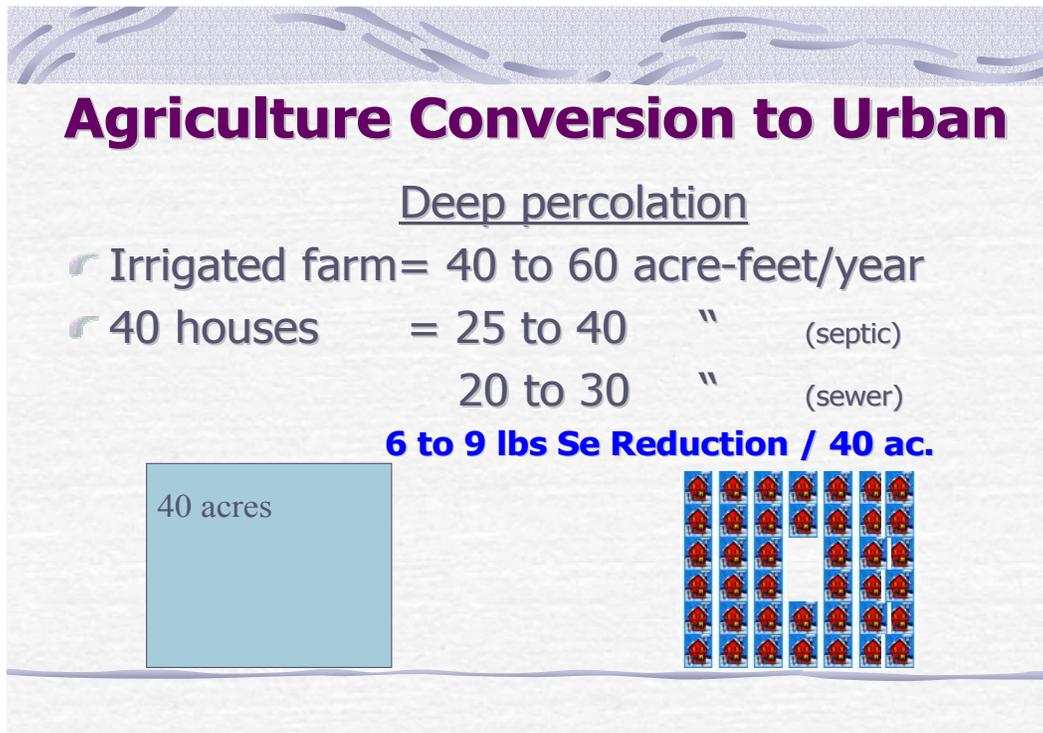


Figure 1. Estimate of Total Deep Percolation from all Sources in the Uncompaghre Valley Project Area

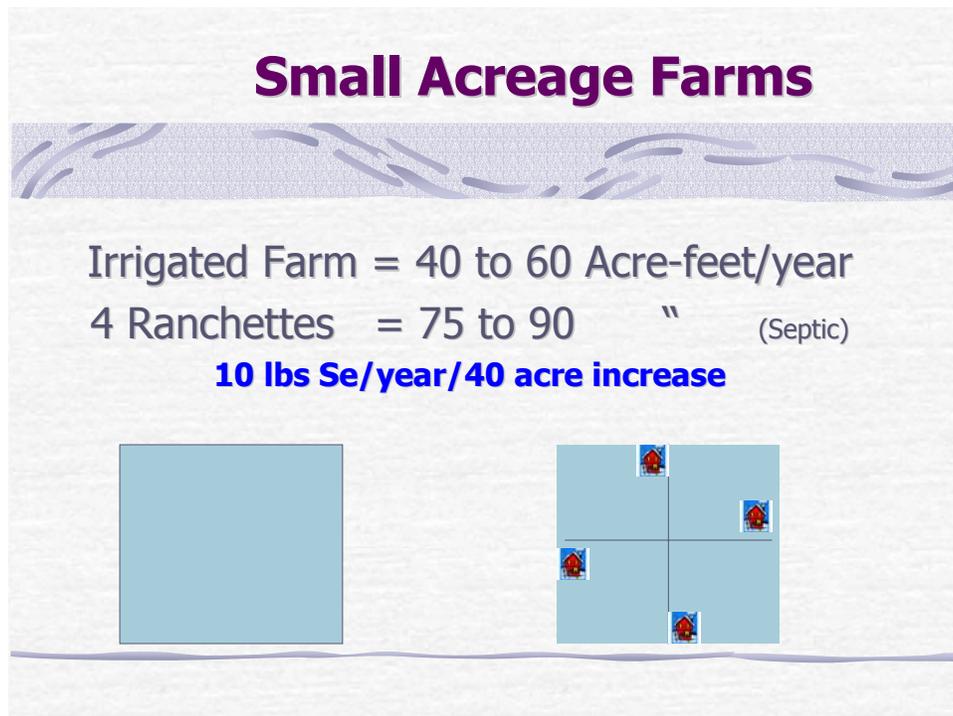
Agriculture-to-Urban Conversion

When irrigated land is converted to residential lots, how does the volume of deep percolation change? If development is concentrated, more than one house per three acres, there is a requirement that these developments are connected to sewers. The volume of deep percolation from irrigated agriculture is estimated to be 1 to 1.5 acre-feet per acre. Deep percolation from lawns and gardens is likely less than 0.5 acre-feet per acre for densely spaced residential development. The footprint of the house and driveways and streets greatly reduces the area that is irrigated. One way to look at the conversion of agricultural lands to urban is to consider a 40-acre parcel that is developed with homes on lots of less than 3 acres in size. When the entire parcel was irrigated, the volume of deep percolation was likely 40 to 60 acre-feet per year. With development of homes the same 40 acres would have a deep percolation volume of 20 acre-feet per year. This could be a 6 to 9 pound reduction in selenium for this parcel.



Small Acreage Farms

When larger tracts of irrigated land are broken down into smaller acreages, there is generally a decrease in irrigation efficiency. The Uncompaghre Water Users Association claims they have to deliver more water to these tracts of land when the water is split up into multiple users. Another reason efficiency decreases is that there is often less incentive to be efficient when one's income is not dependent on the irrigated land. The volume of deep percolation on small acreage farms is estimated to be 2 acre-feet per acre. If we consider a 40-acre parcel of land that is converted to four 10-acre farms, the volume of deep percolation is likely 80 acre-feet per year, which is an increase from the 40 to 60 acre-feet per year that previously occurred on the single parcel. This could be an increase of 6 to 12 pounds of selenium per year.



SUMMARY

This reconnaissance study is a first attempt to estimate the quantity of deep percolation that is a result of non-agricultural sources in the Uncompaghre Basin. It identifies the various other sources of deep percolation and their relative contribution. How much selenium leaching comes from these sources is unknown. Urbanization of irrigated lands will continue to cause water quality problems if not carefully planned.

USGS field measurements on the Gunnison and Uncompaghre Rivers indicate that about 11,600 pounds of selenium (60% of the 19,400 pounds measured at White Water) originates from the Uncompaghre Basin and the Uncompaghre Project service area. Dividing this selenium load by the 124,000 acre-feet of estimated deep percolation results in a loading rate of about 0.1 pounds of selenium per acre-foot of water. Field studies

related to the piping of the irrigation laterals in the Montrose Arroyo indicate selenium loading in that drainage is 0.5 pounds of selenium per acre-foot of water. Selenium leaching and loading rates are especially high in areas that receive water for the first time. The NRCS indicates that non-irrigated soils located on the Mancos shale contain 34 times more selenium than have been irrigated for many years. The new development of Devils Thumb Golf Course is a good example of how very high selenium loading can result from water being applied for the first time to land that is derived of Mancos soils. Conversely, development on previously irrigated soils may actually result in lower selenium loading rates. As urbanization occurs on irrigated land the amount of deep percolation can actually increase where less efficient water use is practiced and especially if a poorly designed pond leaks continuously. Developments that are connected to sewer systems and are dense will result in less deep percolation. Urban development unlike agriculture often has the ability to pay to implement water saving practices such as lining ponds so they do not leak. Land use planners can have an influence on how urbanization impacts water quality in the river basin.

SOURCES OF INFORMATION

Delta County Health Department – Keith Lucy 970-874-2170
Project 7 Water Authority – Dick Margetts 970-249-5935
City of Delta, Environmental Compliance – Scott Williams 970-874-7566
Montrose County – Rick Gibbons and Greg Pink 970-249-6688
Montrose City Engineer – Frank Mesarc 970-240-1446.
Natural Resources Conservation Service – Bill Self & Steve Woodis 970-249-8407
Consolidated Consulting Services – Joanne Fagan P.E. 970-874-5342
Idaho Department of Water Resources – Scott M. Urban 208-327-5441
Uncompaghre Valley Water Users Association – Mark Catlin 970-249-3813
Appendix B Hydrosalinity, “Lower Gunnison Basin Unit Feasibility Report,” November 1982.

OVERVIEW OF THE IMPERIAL IRRIGATION DISTRICT EFFICIENCY CONSERVATION DEFINITE PLAN

Grant Davids, P.E.¹
Ronald Bliesner, P.E.²
John R. Eckhardt, Ph.D., P.E.³

ABSTRACT

In 2003, the Imperial Irrigation District (IID), a 450,000-acre water district in Southern California, entered into a package of decisions and agreements known collectively as the Quantification Settlement Agreement and Related Agreements (QSA). As part of these agreements, IID agreed to a long-term transfer of water to the San Diego County Water Authority (SDCWA) and the Coachella Valley Water District (CVWD). According to the terms of the agreements, the water must come from conservation within IID. The transfer begins small but by 2026, IID must conserve and transfer 303,000 acre-feet of water each year or nearly 10% of their total annual water use.

In 2007, IID completed their Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings, and evaluated various alternatives for implementing a program of integrated system and on-farm conservation measures. This paper summarizes the pertinent terms of the QSA as they affected development of the Definite Plan and presents a broad overview of the seven main work elements involved with developing the Definite Plan:

1. Outreach and Public Involvement
2. On-Farm Water Conservation Opportunities and Costs
3. Delivery System Modifications to Conserve Water and Support Improved On-Farm Water Management
4. Delivery/On-Farm System Conservation Program Interrelationships
5. Incentive Programs for On-Farm Conservation
6. Decision Support System for Evaluating Alternatives
7. Alternatives for Implementing Efficiency Conservation

The paper concludes with observations regarding some of the challenges and insights realized in developing the Definite Plan.

INTRODUCTION

A combination of factors forms the framework within which IID's Definite Plan was developed. These fall into three general categories: the *legal obligations* manifest in the QSA, the *physics and economics* of conserving water within the IID delivery system and

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on-farm, and the *institutional and political* landscape of the Imperial Valley and the Colorado River Basin, including the export areas. Development of the IID Definite Plan considered factors in all three categories. The QSA terms were negotiated prior to development of the Definite Plan and were accepted, a priori, as bounding conditions for plan development. The physics and economics of water conservation are foundational and led to highly detailed technical evaluation of IID's water delivery and on-farm irrigation systems. The sociology and politics of water management are essential to any successful water management initiative. In this case, emphasis was placed on involving IID growers in plan development, due to the importance of their participation in implementing the Efficiency Conservation Program (ECP) that would evolve from the Definite Plan.

When IID negotiated the QSA, its staff and consultants performed high-level analyses to determine the amount of water that could feasibly be conserved in IID and the cost of conserving it. However, those analyses did not provide a detailed plan that IID could follow to actually implement conservation measures. Decisions that were left open at the time of QSA negotiation, among others, included the mix of on-farm and distribution system water savings that IID should target to produce the conserved water for transfer and how the on-farm and distribution system conservation programs should be designed to work synergistically. The Definite Plan was developed to address these and a variety of technical issues, thereby providing a concrete basis for producing conserved water for transfer on the stipulated schedule and within the financial constraints of the QSA.

Owing to the nature of water rights and the large number of parties involved, the QSA is a complex package of agreements. However, there are just a handful of critical contract terms that governed formulation of the Definite Plan:

- The water to be transferred under the QSA must be produced by efficiency conservation, not by land fallowing or other means⁴.
- IID must meet or exceed the conserved water transfer schedule (Figure 1). Water transfers begin in 2008 when just 4,000 acre-feet must be transferred, and gradually increase to the ultimate transfer amount of 303,000 acre-feet annually by 2026.
- Of the 303,000 acre-feet of total water savings, no less than 130,000 acre-feet must be produced by on-farm water savings. Thus, at program build out in 2026, on-farm savings could range from 130,000 to 303,000 acre-feet, and distribution system savings could range from zero to 173,000 acre-feet.
- Participation in the on-farm conservation program by IID landowners and growers must be voluntary; landowners and growers cannot be conscripted into the program, such as through an involuntary water allocation process. Furthermore, landowners and growers must be allowed to choose their own means of conserving water on-farm.

⁴ Under the QSA, land fallowing is allowed for a temporary period to generate water for transfer and for Salton Sea mitigation. Fallowing began in 2003 and must end by no later than 2017. Due to concerns about negative economic impacts, there is strong interest in the Imperial Valley to end fallowing as early as possible.

- Water savings, both on-farm and in the IID delivery system, must be verifiable.

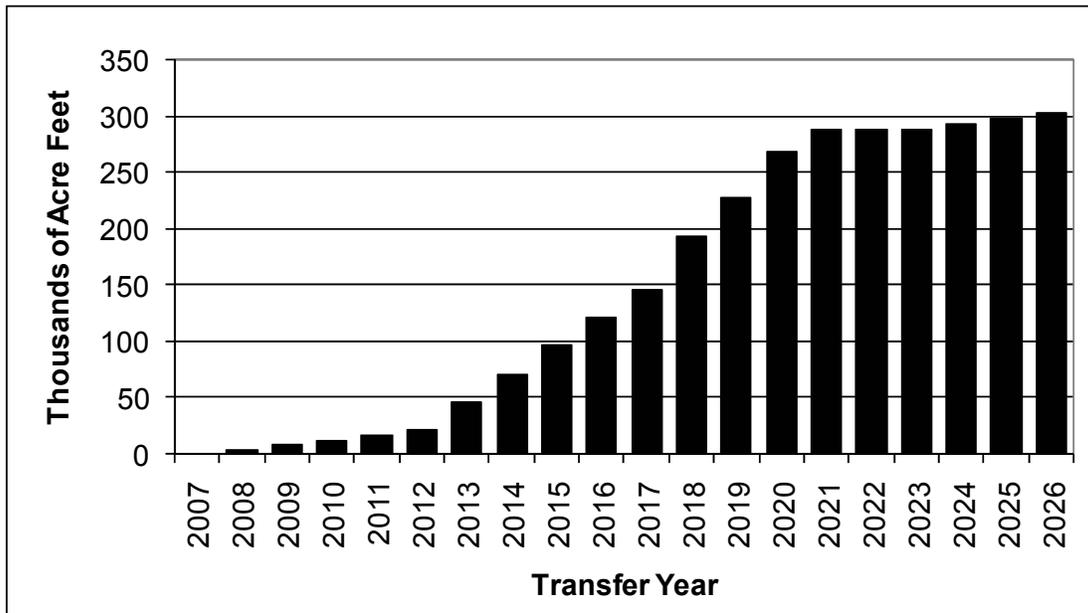


Figure 1. QSA water transfer schedule.

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

- The Definite Plan must be technically viable. It must rely on conservation measures and technologies that are proven and currently available, while allowing for the probability that new technologies will be developed during the life of the QSA.
- The on-farm and delivery system conservation programs must be integrated, recognizing that how water is used on-farm depends in part on how it is delivered, and, conversely, how the delivery system performs is influenced by the provisions allowed to water users for starting and ending their water deliveries.
- Implementing the conservation program involves risk due to the uncertainty in the costs and water savings associated with implementing conservation measures. These risks must be understood and shared fairly between IID and participating landowners and growers. This can be viewed as a condition that must be satisfied to attract a sufficient number of growers into voluntary participation.
- The overall conservation program must be cost-effective, meaning that its costs cannot exceed its revenues over the long term. Because of the voluntary nature of the on-farm program, and other factors, it is impossible to predict program costs with certainty. Also, program revenues are subject to re-determination according to provisions of the QSA. Contingencies should be provided to deal with these uncertainties.

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

The Definite Plan was developed by a consulting team comprising engineers, economists, and other specialists from several different consulting firms, working under the direction of IID's executive program manager, Dr. John Eckhardt. Davids Engineering of Davis, California, and Keller-Bliesner Engineering of Logan, Utah, were the lead consulting firms. Western Resource Economics, also based in Davis, and CONCUR, based in Berkeley, California, contributed key members of the Team. The Irrigation Training and Research Center, California State Polytechnic University, San Luis Obispo, California provided detailed delivery system analyses.

The seven main work elements involved with development of the Definite Plan are as follows:

1. Outreach and Public Involvement
2. On-Farm Water Conservation Opportunities and Costs
3. Delivery System Modifications to Conserve Water and Support Improved On-Farm Water Management
4. Delivery/On-Farm System Conservation Program Interrelationships
5. Incentive Programs for On-Farm Conservation
6. Decision Support System for Evaluating Alternatives
7. Alternatives for Implementing Efficiency Conservation

An overview of each element is presented in the following sections, along with concluding remarks. Detailed descriptions can be found in the six accompanying papers⁵.

OUTREACH AND PUBLIC INVOLVEMENT

A key facet of the Definite Plan initiative was the Public Involvement Plan, an effort intended to involve a broad cross-section of growers and farm landowners in the development of the Plan. It also aimed to ensure that the broader community was aware of and had input into the initiative. Specific objectives included:

- Foster the awareness and active involvement of Valley growers and farm landowners.
- Help the Definite Plan Team focus its needs for information gathering, analysis, and synthesis to assure the success of the program.

⁵ Work Elements 5 and 7 are covered in one accompanying paper; the other elements each have a paper dedicated to them.

- Reinforce the Definite Plan as a well-structured, transparent process that uses best readily available information.
- Identify on-farm conservation opportunities and incentives that can be embraced by growers and farm landowners.
- Inform the broader community of the approach, goals, and emerging direction.

The Definite Plan incorporated two distinct efforts: an extensive Grower Participation Plan (GPP) and a more streamlined Public Outreach (PO) effort. Below is a brief description of each.

The intent of the GPP was to elicit input to inform the technical analyses, seek feedback on evolving approaches and work products, and build legitimacy for the overall effort and final work products. In particular, the Team sought grower input into and feedback on three specific areas: Economic Incentives; On-Farm Technical Demonstration Projects; and On-Farm System Costs, Performance, and Service Requirements. The Team also sought grower feedback on the linkage between on-farm efficiency conservation measures and the IID delivery system. A key piece of the effort was the creation of an On-Farm Technical Advisory Committee, a standing body of 12 growers who met regularly with the Team to review and comment on the evolving analysis. Other facets included on-farm demonstrations, a grower/landowner survey, and one-on-one meetings.

The general PO effort, while more limited in scope, was nonetheless an important component of the effort. The Valley's economy is grounded in agriculture; what occurs on the farm is of interest and importance to the broader community. Accordingly, the Public Outreach effort was intended to – at strategic junctures – provide updates to and seek feedback from the general public and those growers who elected not to participate in grower-specific activities. Specific strategies included issuing bi-monthly project newsletters, developing and maintaining a project web site, and conducting periodic public workshops and other outreach activities.

ON-FARM WATER CONSERVATION OPPORTUNITIES AND COSTS

The IID water balance developed as a component of the Definite Plan was used to establish the total *potential* on-farm (and delivery system) water savings within IID. The water balance revealed that 2.55 million acre-feet (maf) were delivered to IID farms, on average, over the period 1998 through 2005. Of that amount, 1.80 maf were consumed as crop ET, with the residual split nearly evenly between tailwater (433,000 acre-feet) and tilewater⁶ (417,000 acre-feet). Tilewater is generally considered a requirement to maintain favorable salinity levels in the crop root zone. It is generally not targeted for conservation, except on the relatively few fields with permeable soils where more tilewater occurs than is needed to maintain acceptable rootzone salinity. Tailwater occurs almost entirely from surface-irrigated fields, which are dominant in IID. It is the primary target of the on-farm water conservation program.

⁶ Tilewater is applied irrigation water that infiltrates and drains through the soil carrying away potentially damaging salts. It is called “tilewater” because most fields in IID have buried tile drains beneath them that collect and remove it.

While the water balance reveals the volume of tailwater that could potentially be conserved, it was recognized at the outset that only some portion of the tailwater could be saved economically, within the financial limits of the QSA. One of the main objectives of the on-farm analysis was to determine the volume of *practical* water savings. This involved identifying the technically sound conservation measures that can be implemented to conserve tailwater. These measures fall broadly into two categories: ones that work to *reduce the production of tailwater* from irrigated fields, and ones that *reuse tailwater*. For example, irrigation scheduling, with emphasis on selecting not only the appropriate time to irrigate, but also selecting a combination of delivery rate and duration, has the potential to reduce tailwater production. Conversion from surface to drip or sprinkle irrigation also has the potential to reduce (or nearly eliminate) tailwater. Tailwater recovery, whereby water is captured from a field and reapplied to either that field or another one, is an example of tailwater reuse. Once the various conservation measures were identified, their adaptability to various combinations of IID crops and soils was defined.

Costs were developed for each conservation measure relative to field and crop characteristics, with field size and crop type being the main keys. This was approached on an incremental basis by identifying the additional costs, above those involved with existing irrigation practices, associated with adopting the various conservation measures. All costs were addressed, including capital, operation and maintenance costs. Cost savings associated with conservation measures that growers would likely take into account were also estimated. These include the reduced costs of water, fertilizer (which in IID is commonly applied in the irrigation water, or “water run”), and, for selected conservations like drip irrigation, crop yield increases.

It was also necessary to estimate the amount of water that could be saved by the various conservation measures so that their cost-effectiveness, or cost per acre-foot of water saved, could be estimated. This proved to be the most challenging aspect of the on-farm analysis, due to two primary factors. First, it was recognized that the decision to adopt conservation measures would be made by growers and landowners on a field by field basis, given each field’s unique conservation implementation costs and water savings. Profiling of IID historical water use at each field revealed wide variability in water use, even within families of fields with the same crop and soil types. This suggested wide variability in potential conservation among fields, and therefore conservation cost-effectiveness. This strongly suggested that the analysis should include each field explicitly, rather than all fields being represented by proxy using a set of typical, representative fields. Moreover, each crop season at each field has its unique characteristics. Thus individual crop-seasons were used as the basic element of the on-farm analysis.

Addressing crop-season explicitly led to the second challenging factor, which was error and uncertainty in some historical records of water delivery to some fields at some times. Relative to other irrigation districts in the western United States, especially those with open canal delivery systems, IID’s water measurement methods and protocols are excellent and have been adequate for supporting IID’s water operations and volumetric

water charge system. However, at any particular farm delivery gate and time increment, errors can exist for a number of reasons. These include mistakes in the manual observation and recording of delivery rates by IID operators (zanjeros), variability among gates in their hydraulic characteristics, and “moving” water, the name given to water recorded as delivered to a field at one gate but actually used on a field at another gate⁷. Various techniques were employed to correct and compensate for error in IID’s delivery records to the extent possible. The main one was to rely most heavily on the results for fields with the highest quality delivery records. The remaining error that could not be corrected or compensated for was considered in the contingencies applied during data interpretation.

Estimates of the amount of water that each field (during each crop season) would use if a particular conservation measure was adopted were based on a relative shift in irrigation performance, with the ratio of consumptive use to delivered water, called the consumptive use fraction (CUF) used as the indicator of performance. For groups of fields with the same crop and soil characteristics, called families, existing CUF distributions were plotted depicting recent historical performance. For each CUF family and applicable conservation measure, the CUF distribution was shifted relative to the historical distribution, and the new CUF denoted for each field within the distribution. This CUF shift was used to compute the amount of water that *would be* delivered if the conservation measure was applied. The difference between historical water use and predicted water use based on the CUF shift represents water savings.

Data tables were developed containing cost data and performance shift characteristics for all fields and possible conservation measures in IID. These were used in the Demand Generator, a component of the Imperial Irrigation Decision Support System (IIDSS), for development and testing of incentive payment structures and program alternatives.

DELIVERY SYSTEM MODIFICATIONS TO CONSERVE WATER AND SUPPORT IMPROVED ON-FARM WATER MANAGEMENT

IID’s water delivery system consists of an extensive network of more than 1,600 miles of open, branching main and lateral canals. They are sloping, upstream-controlled channels designed to convey the large intermittent water deliveries needed for effective surface irrigation. The 1998 through 2005 IID water balance revealed that, on an annual average, 2.88 maf⁸ are diverted from the Colorado River into the delivery system, of which 2.55 maf are delivered to IID farms. The difference of 330,000 acre-feet represents system loss, including 3,000 acre-feet of main canal spillage, 121,000 acre-feet of lateral canal spillage, 86,000 acre-feet of seepage and 22,000 acre-feet evaporation (net of precipitation). There is no practical way to reduce evaporation, so it was not targeted.

⁷ Moving water occurs for various reasons, and, from a water administration perspective, is inconsequential since the correct volume of water is recorded and billed to the customer. But the errors introduced in the record, over-recorded delivery at one gate and under-recording at another, are problematic from an analytic perspective.

⁸ Does not include All American Canal loss. Measurement is taken at just upstream of Mesa Lateral 5 at the beginning of the IID deliveries.

Main canal spillage is highly intermittent and is generally associated with precipitation events (when ordered water is refused due to rain, causing the main canal to spill), so it is not a prime conservation target either. Canal seepage and lateral canal spillage were the two primary conservation targets within the IID delivery system.

In general, as a result of past conservation programs, IID has identified and lined lateral and sub-main canals with high seepage characteristics. The remaining unlined canals were reviewed, revealing that only a very few of these reaches could be lined cost-effectively, and the savings would be small (<3,000 acre-feet). Thus, lateral canal lining was not a significant component of delivery system conservation.

Various reaches of IID's main canals have had interceptor drains installed along them on the down-gradient side, parallel to the canal. Originally, all of these were open drains that intercepted seepage from the main canal to prevent water-logging of adjacent, down-gradient fields. All of the intercepted water, most of it high quality, was discharged to the Salton Sea through the IID drainage system. In the 1960s and 1970s, IID converted some of these drains along the upper reaches of the East Highline (EHL) Canal to buried interceptor pipelines to capture the seepage and return it to the canal. As part of the Definite Plan development, remaining open interceptor drains along the EHL, All-American, and Westside Main canals were investigated. It was found the drains capture essentially all of the seepage that occurs from the canals, and therefore there is no need to convert these drains to buried pipes. Instead, intercepted flows can be captured and returned to the canals by simply installing check structures and pumping plants along the drains. Between 40,000 and 50,000 acre-feet of seepage can be conserved in this manner for about \$15 per acre-foot, making it by far the cheapest conservable water.

Spillage occurs from the ends of IID lateral canals because it is practically impossible with upstream controlled system for operators to exactly match the flow put into the lateral canal with the water deliveries and losses from the lateral canal. This is due primarily to the inherent nature of open canal operation, where the point of water control (at the head of the lateral canal) is typically distant from the point(s) of delivery. Any error in the delivery of water into the lateral canal, or change in delivery demand, results in a supply–demand mismatch. To mitigate the risk of shorting delivery to users, operators typically order a little more water into a lateral canal than needed to meet deliveries, sometimes resulting in spillage. Spillage also results when delivery gates are not opened at the correct time, or when deliveries are shut off before a corresponding cut can be made at the head of the lateral canal, or for a variety of other reasons.

The approach to reducing spillage from a sloping canal system involves just a few kinds of system improvements, which fall into the categories of either reducing the production of spillage or capturing it. Fortunately, the same kinds of improvements that can be applied to reduce lateral canal spillage also allow the lateral canals to be operated with greater sensitivity to changes in on-farm demands, thereby enhancing on-farm water management. The types of system improvements considered for the Definite Plan are as follows:

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

Alternative combinations of these improvements were formulated, ranging from capital-intensive, hardware oriented formulations to ones structured more around improved system management (but also involving significant capital cost). It was discovered early on that intensive, hardware oriented formulations are not affordable within the financial capacity of the QSA, leading to a focus on improved delivery system management, especially of lateral canals.

DELIVERY/ON-FARM SYSTEM CONSERVATION PROGRAM INTERRELATIONSHIPS

Achieving on-farm water conservation generally implies increasing water ordering and delivery flexibility so that growers can order water precisely according to their irrigation schedules, have it delivered as ordered, and adjust the delivery if needed before or during the irrigation event. This is especially true for surface irrigation methods like those used extensively in IID. Yet with an open channel delivery system, providing more delivery flexibility makes it more difficult to match system water supply with on-farm demand, thereby increasing the probable frequency, rate and duration of spillage, and therefore the spillage volume. Development of Definite Plan alternatives accounted for this interrelationship, and the tradeoff it denotes, to ensure that *net water savings* would be sufficient to achieve QSA requirements.

The interrelationship between system and on-farm water conservation was handled analytically using the concept of “rejected water”, which is water ordered into the system by growers with the expectation of its need, but not delivered because the actual need for water turned out to be different than expected⁹. Rejected water typically occurs in two ways, including reduction of the delivery rate during an event and early shutoff at the end

⁹ This is the central challenge of upstream-controlled irrigation delivery systems serving surface-irrigated fields when high levels of efficiency are being sought. No matter how well an irrigator schedules the delivery of water based on anticipated field conditions, there will likely be too much or too little water relative to actual needs, which cannot be known until the irrigation event is in progress or nears completion. Because the cost and inconvenience of not finishing a planned irrigation on time is appreciable, in terms of management and labor requirements, growers tend to order more water than will probably be needed, and to reject the unneeded portion, if permissible under the rules for water delivery. If the unneeded water cannot be rejected (to the delivery system), then it will be discharged as tailwater.

of the event. When these changes can be anticipated, water can be cut from the lateral canal heading in advance and lateral canal spillage minimized. In the Definite Plan analysis, this was called “upstream” rejected water because it is held in the main canal upstream of the delivery. Conversely, if the rejection cannot be anticipated, it unavoidably passes downstream and is either spilled or intercepted and stored for reuse. This is called “downstream” rejected water. Rejected water occurs now in IID corresponding to the level of delivery flexibility currently provided; rejected water is expected to increase as delivery flexibility is increased to enable on-farm efficiency conservation under the Definite Plan.

Rejected water characteristics (or functions) were assigned to each of the on-farm conservation measures included in the on-farm analysis, reflecting the degree of delivery flexibility needed to achieve each measure’s characteristic performance. The rejected water functions were used in the Demand Generator (see section below titled Decision Support System for Evaluating Alternatives) to estimate rejected water volumes under various on-farm conservation scenarios. These volumes were passed to the MODSIM model for system analyses.

INCENTIVE PROGRAMS FOR ON-FARM CONSERVATION

The success of the Definite Plan depends heavily on the effectiveness of its on-farm incentive program. As a voluntary program, the incentive structure and payments must be attractive enough to entice widespread grower participation. Three approaches or incentive payment options were considered: those that pay for performance or results (such as measured reductions in delivered water or tailwater); those that pay for actions (such as implementing specific on-farm conservation measures); and hybrids, where a portion on the payment is based on results and a portion on actions.

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

The analysis indicated that four incentive approaches appeared to be feasible (i.e., they could generate enough participation to achieve the needed savings within the financial constraints of the program). These four included two that paid growers solely based on the conservation measures they implemented (so-called “pay-for-measures” approaches), and two hybrid approaches (including both a pay-for-measures payment and a results-based payment).¹⁰

¹⁰ None of the purely performance-based incentive programs appeared viable for a combination of reasons, including: establishing accurate field-level water use baselines, likelihood of significant enrollment bias, concerns about perceived fairness of payments, and large payments to growers for fields that may have little or no real conservation.

DECISION SUPPORT SYSTEM FOR EVALUATING ALTERNATIVES

Over recent years, IID has been developing a set of analytic tools to enable evaluation of its water delivery system. Collectively, these tools are referred to as the Imperial Irrigation Decision Support System (IIDSS). Prior to development of the Definite Plan, the main IIDSS tool was a MODSIM (Labadie, 2006) link-node model of the IID delivery system. It was developed to support evaluation of environmental effects, especially changes to flows and water quality in IID's canals and drains that could be expected under a broad range of alternative water conservation programs.

A number of factors encountered in developing the Definite Plan required that IIDSS be updated and expanded. The primary factors were as follows:

- The need to simulate on-farm decisions on all of the more than 5,500 fields served by IID, not just a sample of them. This results from the voluntary nature of the on-farm conservation program, and the realization that growers will select from among all their fields the ones that will maximize their net financial benefit, not necessarily the ones that maximize water conservation.
- The need to design and test a wide range of possible on-farm conservation incentive structures under a consistent set of assumptions and conditions.
- The need to account for the interaction between the more than 5,500 farm delivery gates and the IID delivery system, through the tracking of changes to delivered water, rejected water and system spillage resulting from adoption of conservation measures. This is necessary to ensure that net water savings are sufficient to meet the QSA water transfer schedule.
- The need to account for changing land use in IID and its effects on irrigated agriculture and the IID delivery system, especially urbanization in and around the cities of El Centro, Imperial and Brawley.

The principal components of IIDSS, created or upgraded to support development of the Definite Plan are as follows:

- A GIS of IID's water delivery system, which consists of more than 1,600 miles of main and lateral canals linking over 5,500 water delivery points.
- The Demand Generator for assembling time series of demands and analyzing the effects of various on-farm conservation incentive programs on those demands.
- Geo-MODSIM (Triana and Labadie, 2007), the link-node network solver program which assembles the network from the GIS representation of the system, simulates routing water through the canal system to delivery points, and computes total IID water demand while accounting for predicted spills, seepage and evaporation losses associated with various alternative canal and operation configurations.
- Various databases of gaged flows, delivery details, field characteristics, and conservation measure attributes.
- A set of alternative comparison tools, which assist in summarizing results and facilitating the spatio-temporal analysis of large amounts of simulated data.

These tools were indispensable in the design and testing of alternative on-farm conservation incentive structures, and accounting for the effects of delivery system and on-farm conservation measures on system performance.

ALTERNATIVES FOR IMPLEMENTING EFFICIENCY CONSERVATION

Building blocks for alternatives formulation were the promising, incentive-driven approaches for achieving on-farm water conservation, and the set of delivery system projects for reducing losses and improving delivery flexibility. Alternatives were defined primarily by the volumes of water targeted for on-farm and system savings, respectively, to provide the 303,000 acre-feet of annual conservation savings at program buildout. Seven conservation mix alternatives were formed, ranging from a “maximum on-farm” alternative designed to produce 280,000 acre-feet from on-farm conservation and 23,000 acre-feet from system savings, to a “maximum delivery system” alternative designed to produce 158,800 acre-feet on-farm and 144,200 acre-feet from system savings.

For each of the seven mixes of on-farm and system savings, the four most promising incentive structures were evaluated to achieve the on-farm savings component. It was found that, from among the resulting 28 unique alternatives, half were economically viable, meaning that their costs were less than the available net revenue, and half were not. There were appreciable cost differences among the viable alternatives, with some being well below the cost threshold, and others only marginally below. Analysis of the alternatives suggested an optimal mix of between roughly 180,000 and 210,000 acre-feet of on-farm water savings combined with 93,000 to 123,000 acre-feet of delivery system conservation savings.

A set of six recommendations were developed that address: (1) the blend of on-farm and delivery system savings that IID should target; (2) the on-farm incentive approach that IID should employ to attract landowners and growers voluntarily into participation; (3) the improvements that should be implemented within the IID delivery system; (4) the need to improve measurement of farm deliveries; (5) provisions for fulfilling IID’s early-year (2008 – 2010) water transfer obligations; and (6) near-term actions to ensure IID has sufficient capacity to meet its water transfer obligations.

CONCLUDING REMARKS

The extensive analyses and rigorous processes used to formulate the Definite Plan revealed a number of important and interesting findings. Some of the more important findings and observations are summarized briefly below.

- Improved measurement of water delivered to fields is critical for implementing an effective on-farm conservation program. It is essential to verify savings at the field level and to establish water use for incentive payments under some incentive approaches.

- For small incremental cost, the improved measurement options examined may also provide automated flow regulation and control, reducing operator level and improving water delivery to the farms.
- Changes in delivery system management, supported by key automation elements with real-time data in the hands of system operators, allow prevention of nearly as much lateral canal spillage as much more expensive hardware only solutions. The key lies in operator training and a paradigm shift in system operation.
- The uncertainty in potential conservation of certain actions and the response of growers to incentive programs, suggests a test-period to further refine conservation savings estimates and test response of delivery system operators and farmers to the changes.
- The voluntary nature of the on-farm program suggests an adaptive management approach to implementation, with sufficient flexibility to accommodate unforeseen issues and new advances in irrigation technology over the life of the program.
- The analysis described in this paper and the companion papers focused primarily on quantitative evaluation of options and alternatives. However, other aspects of a conservation program were also of great interest during the Definite Plan process.
 - “Equity” among growers was an important concern throughout the Definite Plan development: the distribution of program costs and benefits among growers and whether all categories of growers would have an opportunity to participate. Growers expressed an interest in understanding the potential for different approaches to pay for existing, ongoing conservation. Opinions varied about whether and to what extent already-implemented conservation should be compensated.
 - Beyond a simple comparison of costs to benefits, the Definite Plan analysis also suggested a strong need for “financial headroom” – the difference between the projected cost of implementation and the available revenue – as a buffer to address implementation uncertainties, ensure IID can meet its water transfer obligations within the financial means of the program, provide adequate incentive to cover the farmer-perceived risk and encourage adequate participation and, if desired, provide some compensation for existing conservation.

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**BRIDGING THE GAP:
EFFECTIVE STRATEGIES FOR INVOLVING GROWERS IN TECHNICALLY
COMPLEX AND POLITICALLY CHALLENGING PROJECTS**

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ABSTRACT

Water use in the West is changing, and nowhere is that being felt as acutely as the Imperial Irrigation District (IID), a 450,000-acre area in Southern California. Four years ago, IID agreed to launch a massive conservation program that would free up roughly 10 percent of its water for transfer to San Diego and others. IID early on recognized the technical challenges inherent in the deal. But it also saw another set of equally vexing challenges: How to develop and build buy-in for a ground-breaking, technically complex and controversial program that could only succeed if growers willingly opted to participate? This paper takes a closer look at the multi-pronged outreach and public involvement process IID put in place to engage growers in the development of what is known as the Efficiency Conservation Definite Plan. The paper emphasizes both concrete strategies and lessons learned. It underscores the value of maintaining frequent and one-on-one contact, translating technical data into easy-to-understand presentations, and integrating growers' on-the-ground expertise into evolving analyses. It also highlights the importance of eliciting feedback through a variety of mechanisms, as well as the need to be sensitive to the rhythms and demands of growers' work in the fields, so as to make it possible for them to prepare for and attend meetings. Finally, it makes clear the imperative of transparency for building credibility and confidence in the analysis.

INTRODUCTION

Water use in the West is changing, and nowhere is that being felt as acutely as the Imperial Irrigation District (IID), a 450,000-acre area in Southern California where longstanding agricultural water users are under intense pressure to transfer water to the region's ever-thirsty and ever-expanding urban centers. Four years ago, IID agreed to launch a massive conservation program that would free up roughly 10 percent of its water for transfer to San Diego and others. The heart of the agreement (referred to as the Quantification Settlement Agreement, or QSA) called for IID to generate more than 300,000 acre-feet through a combination of IID and voluntary on-farm efficiency conservation savings.

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IID early on recognized the technical challenges inherent in the deal; complicated modeling would be needed to identify conservation potential, understand the interplay of on-farm and IID savings and assess the incentives needed to entice grower participation. But it also saw another set of equally vexing challenges: How to develop and build buy-in for a ground-breaking, technically complex and controversial program that could only succeed if growers willingly opted to participate?

This paper⁴ takes a closer look at the multi-pronged outreach and public involvement process IID put in place in 2006 to engage growers in the development of what is known as the Efficiency Conservation Definite Plan (Definite Plan). The paper examines the strategies used by the team of IID staff and consultants (referred to as the Definite Plan Team or Team) to integrate the unavoidably dense technical work with growers' inevitably on-the-ground, pragmatic perspectives. These strategies ranged from surveys and one-on-one meetings, to grower working groups, periodic newsletters and on-farm conservation measures demonstrations. At the same time, the paper emphasizes a "lessons learned" perspective – identifying those concrete strategies that proved most successful, as well as calling out those approaches and decisions that hampered the Team's efforts to build widespread grower support and understanding.

OUTREACH APPROACH

Objectives

From the outset, IID leadership recognized that the viability and success of the Efficiency Conservation Definite Plan (Definite Plan) would be tied to crafting on-farm conservation opportunities and incentives that could be embraced by IID growers and landowners. A conservation program grounded in voluntary participation simply had to be structured in a manner that made sense to and enticed the participation of growers and landowners.

The Team' Public Involvement Plan was intended to ensure that a broad cross-section of growers and farm landowners could participate effectively in the development of the Definite Plan. It also aimed to ensure that the broader community was aware of and had input into the initiative. Specific Public Involvement Plan objectives included:

- Foster the awareness and active involvement of Valley growers and farm landowners in the development of the Definite Plan.

⁴ The authors are aware of and have studied the vast array of literature that addresses public outreach, working with farmers, and other issues of importance to this outreach activity. We have used the overall knowledge we have gained from this literature along with our own experience in dealing with the related issues involving growers and other stakeholders in technically complex and politically challenging projects. However, we do not feel it would be productive or even particularly relevant to cite a meaningful array of the pertinent literature herein. The purpose of this paper is simply to tell the story of what was done to bridge this particular gap in understanding between the conservation planning process and the communities understanding of it in the politically challenging environment surrounding IID.

- Help the Definite Plan Team focus its needs for information gathering, analysis, and synthesis to optimize the success of the program.
- Reinforce the Definite Plan as a well-structured, transparent process that uses best readily available information.
- Demonstrate the water savings potential and cost effectiveness of various water conservation measures.
- Identify on-farm conservation opportunities and incentives that can be embraced by growers and farm landowners.
- Inform the broader community of the Definite Plan approach, goals and emerging direction.

Two-Pronged Strategy

The Definite Plan Team determined early on that there would be no one method that could successfully engage all facets of the affected public. To that end, the Team developed two distinct plans to guide its outreach efforts: an extensive Grower Participation Plan and a more streamlined Public Outreach effort. Below is a brief description of each of these two facets:

- **Grower Participation Plan.** The Grower Participation Plan (GPP) was at the heart of the Public Involvement Plan process. The intent of the GPP was to, in a strategic manner, elicit input to inform technical analyses, seek feedback on evolving approaches and work products, and build legitimacy for the overall effort and final work products. In particular, the Team sought grower input into and feedback on three specific areas: Economic Incentives; On-Farm Technical Demonstration Projects; and On-Farm System Costs, Performance and Service Requirements. The Team also sought grower feedback on the linkage between on-farm efficiency conservation measures and IID's delivery system. In designing the GPP, the Team sought to rely on a mix of outreach strategies to generate grower and farm landowner feedback. The key elements of the GPP included the following: On-Farm Technical Advisors; on-farm demonstrations; grower/landowner survey; and one-on-one meetings. The focus and results of these efforts are provided in the section below.
- **Public Outreach.** The general Public Outreach (PO) effort, while more limited in scope, was nonetheless an important component of the effort. The Valley's economy is grounded in agricultural; what occurs on the farm is of interest and importance to the broader community. Accordingly, the Public Outreach effort was intended to – at strategic junctures – provide updates to and seek feedback from the interested general public and those growers who elected not to participate in grower-specific activities. Specific strategies included: preparing project newsletters; developing and maintaining a project web site; and conducting periodic public workshops and other outreach activities. Again, the focus and results of these efforts are provided in the section below.

Results – Grower Participation Plan

On-Farm Technical Advisors. The On-Farm Technical Advisors, a standing body comprised of more than a dozen Imperial Valley growers with a demonstrated expertise in efficient irrigation management strategies and technologies and the associated changes in farming practices, served as the centerpiece of the Grower Participation Plan. The group, referred to as the OFTA, was composed by IID staff to bring together the Valley's diverse grower and landowner perspectives as a technical resource to the Definite Plan Team.

Given the complex and technically dense nature of the Definite Plan process, the OFTA was designed to provide an opportunity for the Team to have a focused and ongoing discussion with a consistent set of growers. This continuity was considered vital, as it allowed participants to develop a shared appreciation and understanding of the project challenges and approaches. Similarly, meetings were held as internal-to-the-Team discussions given the preliminary nature of the Team's analysis and the importance of fostering the candid exchange of ideas.

The OFTA met ten times between January 2006 and January 2007. The meetings were instrumental in providing grower input into the on-farm aspects of the Definite Plan process. Growers reviewed and provided detailed feedback – both at the meetings and in follow-on conversations – on a range of topics, with the bulk of the discussions focusing on the following overarching areas:

- On-farm efficiency conservation measure alternatives, costs and potential water savings.
- Options for structuring incentive programs to encourage on-farm participation.
- Interface between on-farm conservation measures and needed improvements to the IID delivery system.
- General feedback on Definite Plan approach and implementation considerations.

The Team carefully considered all OFTA comments and, to the extent practical and appropriate, incorporated their comments and suggestions into its evolving analysis. In some instances, where grower preferences conflicted with QSA and transfer requirements or were deemed technically or economically infeasible, the Team attempted to make clear the limitations.

Demonstration Project. Another key element in the Grower Participation Plan was a series of demonstration projects intended to better understand the extent to which on-farm efficiency conservation measures generate water savings, are effective and can be reliably replicated.

Working cooperatively with 15 growers, the Team launched 13 demonstration projects. Most of the efforts piggy-backed on growers' existing irrigation practices and formally monitored and measured the costs and results to assess the conservation savings potential and related cost effectiveness. In particular, the efforts sought to: a) develop reliable

information regarding the applicability, costs and performance of selected on-farm conservation technologies and management practices; b) test pilot projects to better understand the need for on-farm incentives; c) provide a means for gaining grower cooperation and support; and d) understand the level of IID delivery system flexibility needed to support the various on-farm conservation activities.

In choosing growers for the various demonstrations, the Team strived to identify projects that had the potential to answer critical unknowns and could be reasonably undertaken within the Definite Plan schedule and cost constraints. Of the growers involved in the demonstration projects, roughly half were OFTA members.

The projects were focused on the following areas:

- ***Scientific irrigation scheduling and irrigation event management.*** This study, conducted on a handful of farms, assessed the improved efficiencies linked to timing and quantifying irrigation applications based on a combination of water data, soil type and moisture sampling, crop physiology and irrigation methods.
- ***Tailwater reuse systems.*** Tailwater reuse systems provide a means for conserving water by reusing the tailwater from row or flat irrigation applications. The Team studied and evaluated the water savings potential associated with tailwater pump-back systems with and without reservoirs and systems that cascade tailwater from a higher to a lower field.
- ***On-farm reservoirs.*** This study sought to assess delivery system impacts and on-farm benefits of on-farm reservoirs. The reservoirs provide on-farm water delivery flexibility and a supply of water for starting and or completing irrigations and providing small freshening irrigation for vegetable or fruit crops, especially where drip or sprinkler irrigation is used.
- ***Enhanced farm delivery service.*** This project conducted an automation study on the Malva 1 Lateral to assess the potential for improved delivery consistency, steadiness, and flexibility (by allowing irrigators to adjust or shutoff deliveries) to yield on-farm water conservation savings.
- ***Irrigation application systems.*** The Team undertook several studies to better understand the water conservation potential of irrigation systems that do not produce tailwater. This involved two separate studies where the yield and water delivery differences were compared: 1) a row alfalfa field irrigated with subsurface drip irrigation and similar field with conventional row irrigation; and 2) a flat (border strip) alfalfa field part of which was sprinkle irrigated during the summer months. A basin irrigation system was also studied, but this was not a comparative study and there was considerable tailwater, so the results were not useful.
- ***Gated pipe irrigation and different row lengths.*** This project used field studies and computer models to compare the water savings potential of differing furrow lengths on various soils. For the field demonstrations, thin-wall, 18-inch diameter gated Poly-Pipe was used on one carrot and two lettuce fields.

Grower/Landowner Survey. Launched at the outset of this initiative, the survey was designed to gauge overall grower interest in the program, identify the on-farm practices and systems that growers might use to conserve water, and invite suggestions as to how growers wanted to be involved throughout the process of developing the Definite Plan.

The surveys were mailed to all identified IID growers and farm landowners. Nearly 300 individuals responded to the survey, representing roughly 16% of those surveyed (a very strong response rate for the Valley) and between 230,000 and 300,000 acres of farmland. Respondents represented the range of ownership, leasing and cropping patterns in the Valley.

General Grower Outreach. In addition to surveys, demonstration projects and the OFTA, the Team sought other more informal mechanisms to brief and seek input from growers on the evolving Efficiency Conservation Definite Plan. Team members had numerous one-on-one conversations with individual growers, farm service companies and others to gather data and perspectives related to many of the on-farm and distribution system facets of the analysis. Growers and the public also were invited to provide response and comments through the project website and newsletter.

Finally, the Team provided regular updates to IID's Water Department staff to keep them apprised of project progress and seek their ongoing input. Additionally, IID staff provided quarterly updates to the IID Board of Directors.

Results – Public Outreach

Project Newsletter. To ensure interested members of the Imperial Valley community and others were kept apprised of the Efficiency Conservation Definite Plan approach, activities and emerging results, the Team prepared project newsletters every two months or so.

The newsletters, distributed by IID and the Imperial County Farm Bureau to approximately 3,500 people and made available at IID offices and elsewhere, provided the latest information on the project results and directions. Originally conceived as a two-page publication, the Team expanded the newsletter to four pages to enable more in-depth communication on important Definite Plan topics. A total of five newsletters were published.

Public Workshop/Field Days. The Team created several in-person opportunities for interested growers and the broader community to learn more about and provide input into the Definite Plan process. These efforts centered on Field Days and public workshops.

In the fall of 2006, the Team hosted two Field Days to give growers, interested members of the public and IID staff the opportunity to see first-hand some of the ongoing demonstration projects. The first field day showcased a variety of on-farm technologies centered on testing and assessing different strategies to reduce and reuse tailwater. The second field day focused primarily on IID's distribution system automation and

improvements. Additionally, at both Field Days, participants had an opportunity to view poster presentations that offered greater detail on the water management science underlying each demonstration and the general cost, operational, and anticipated water savings associated with them. As well, Definite Plan team members and IID staff were on hand to address any follow-up questions.

The Team also hosted public workshops to brief interested members of the public on its evolving analysis. The first set of workshops focused on providing a project overview and seeking feedback on topics such as likely on-farm conservation activities and possible economic incentives to encourage efficiency conservation. The second and third set of public workshops – intended to center first on alternatives and then on a recommended approach – were combined with the Board workshop process between February and April 2007 to focus public involvement and input at the Board level.

The Team worked with the Imperial Valley Vegetable Growers Association, the Imperial County Farm Bureau, the Water Conservation Advisory Board and IID to improve notification and increase participation for the Field Days and the first round of workshops.

Project Web Page. The Team developed and maintained a project web page (www.definiteplan.com) to provide overviews and updates on the Efficiency Conservation Definite Plan process. The web page was continually updated to provide new information on the demonstration projects, outreach activities, newsletters and other project updates. As of February 2008, the web site had logged more than 4,133 visits.

LESSONS LEARNED

Without doubt, the Team's work on the Public Involvement Plan was challenging. The outreach to the agricultural community required tremendous effort and time, as Team members quickly learned there was no substitute for frequent and often one-on-one contact. The effort also required flexibility, as Team members needed to adapt planned approaches to ensure that growers were being engaged in a manner that made their involvement meaningful. The Team also needed to be sensitive to the rhythms and demands of growers' work in the fields, so as to make it possible for them to prepare for and attend meetings. Finally, transparency in the Team's work was essential for building credibility in the Team and its analysis.

Most broadly, the Team's experience underscored the unavoidable time and planning required to: (1) translate technically dense materials for a general audience; (2) build credibility with growers; (3) understand growers' perspectives and concerns; and (4) frame issues in a manner that attract and sustain grower involvement. It also made clear the importance of building linkages among the technical, policy, legal and outreach aspects of projects such as these.

Below is a closer look at some of the lessons learned associated with the various facets of the outreach effort.

Lessons Learned – Grower Participation Plan

On-Farm Technical Advisors. This group, referred to as the OFTA, was the centerpiece of the Grower Participation Plan. Not surprisingly, from time to time, some of the 13 participating growers would miss a meeting. The Team quickly learned that, in such instances, it was essential that it follow up directly with each grower in one-on-one sessions to brief them on meeting discussions. Additionally, the team also offered to meet off-line with any OFTA grower if they wanted more personal in-depth discussion about the complex and technically dense aspects of the Definite Plan process. The Team soon learned that these make-up sessions and individual in-depth discussions, while time-consuming, were essential to maintaining grower confidence and participation in the planning process. In fact, all but one of the original 13 growers remained interested and actively engaged with the OFTA over the course of the Team's work.

Specific insights gained from working and dialoguing with the OFTA included:

- Growers generally became uneasy as options were taken off the table. Thus, it was important to keep all or most options open – even if they were likely to prove technically or politically unviable.
- Transferring complex technological ideas to a mixed set of growers was both time consuming and difficult. Some growers struggled with the graphical presentations; others were unaccustomed to thinking in terms of formulas, numerical examples and modeling. The Team learned that no one outreach strategy was sufficient and a mix of group meetings, one-on-one sessions and presentation formats were essential to transferring complex concepts. Additionally, the Team needed to revisit technically dense topics numerous times.
- Growers are profit-maximizing individuals and, accordingly, information needed to be presented in a manner that allowed them to assess the bottom-line impact of various conservation and incentive strategies. This perspective also impacted how they assessed the Team's characterization of the projected costs and benefits of various conservation actions. (For example, growers usually felt that the Team overestimated the costs of implementing various water savings technologies.) More broadly, OFTA members' business perspectives frequently shaped the extent to which they were willing to accept various options and analyses. (Again, by way of example, growers and landowners tended to be biased towards having the proceeds from the water transfer agreement accrue to them rather than having it used to modernize or upgrade the IID delivery system. Similarly, OFTA members struggled with the concept that it would be difficult to pay for past conservation through the Definite Plan program.)

Demonstration Projects. The demonstration projects seemed to provide the intended results of providing a better understanding of the extent to which on-farm efficiency conservation measures generate water savings, are effective and can be reliably replicated. They also gave the growers some added degree of confidence in the costs of implementing, operating and managing the various conservation measures.

In particular, the demonstration projects:

- Allowed the Team to develop reliable information regarding the applicability, costs and performance of the various on-farm conservation technologies and management practices.
- Provided a reliable means for testing pilot projects to better understand the need for on-farm incentives.
- Afforded a non-threatening way for having in-depth dialogues with growers and gaining the confidence, cooperation and support of growers in general.
- Provided a means for understanding the level of IID delivery system flexibility needed to support the various on-farm conservation activities.

Grower/Landowner Survey and General Grower Outreach. The Team found the survey to be an invaluable tool for pinpointing growers/landowners interested in participating in the process of developing the Definite Plan. As a result of the survey feedback, the Team identified about 20 growers/landowners – in addition to the members of the OFTA – who were willing to participate in in-depth interviews about their operations and their ideas concerning the appropriate water conservation and incentive strategies for the Efficiency Conservation Definite Plan. The Team was able to use these interviews along with its findings from conversations with farm service companies and others, to obtain important data and perspectives related to the on-farm and distribution system facets. Conducting this survey at the project outset was particularly valuable, as it provided the Team with early grower contacts.

Lessons Learned – Public Outreach

Project Newsletter. The newsletters, which were distributed to approximately 3,500 people and made available at IID offices and elsewhere, were well received. They accomplished their purpose by providing the latest information on the planning process for the Definite Plan and the results of the on-farm demonstration project activities. They also helped contribute to the efforts transparency.

Public Workshops/Field Days. The attendance at the workshops and field days was generally small, but the few growers who elected to take the time to attend were generally pleased by what they heard and saw. However, the Team believes that the fact that it was being open and made the effort to hold them may have had a stronger general physiological impact than the numbers of attendees would suggest. The three workshops that were held at the end of the Definite Plan study for the IID Board of Directors were, not surprisingly, the best attended outreach activities as growers and others were most interested in voicing their views in front of the eventual decision-makers.

Project Web Page. The Team's project web page (www.definiteplan.com) that provided overviews and updates on the Efficiency Conservation Definite Plan process was relatively well used. For example, it provided a convenient repository for the power point presentations made during the three Board workshops. But the Team did not receive many comments concerning its usefulness, so how cost effective and useful it was

to maintain is unknown. In general, the Team found the website to be a necessary strategy, but not one that should be relied on as a key component of an outreach effort.

CONCLUDING THOUGHTS

The discussions regarding the Definite Plan process were inevitably contentious. A number of growers, landowners and other members of the public have strong views about the Quantification Settlement Agreement (QSA) and associated transfers, and some of their aspirations run contrary to the provisions agreed upon in the QSA. In fact, despite the extensive outreach efforts, many of these basic differences were not resolved by the time a draft Definite Plan was presented at the IID Board public workshops. Obviously, no Public Involvement Plan is likely to overcome such fundamental disagreements. Still, a carefully crafted outreach plan grounded in a transparent and inclusive process can at least help to narrow the areas of disagreement, sharpen the options under consideration and make more obvious the likely ramifications of different policy choices. The Team believes its work with growers and others helped build more shared perspectives, and positions IID to continue its work with the affected communities in the months and years ahead.

IMPERIAL IRRIGATION DISTRICT EFFICIENCY CONSERVATION DEFINITE PLAN: ON-FARM CONSERVATION OPPORTUNITIES AND COSTS

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ABSTRACT

Water use in the West is changing, and nowhere is that being felt more acutely than in the Imperial Irrigation District (IID), a 450,000-acre district in Southern California where longstanding agricultural water users are under intense pressure to transfer water to the region's ever-thirsty and ever-expanding urban areas. Four years ago, the District agreed to launch a massive conservation program that would free up roughly 10 percent of its water for transfer to San Diego and others. The heart of the agreement called for IID to generate more than 300,000 acre-feet annually through a combination of District and voluntary on-farm efficiency conservation savings. In 2007, IID completed their Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings. This paper, one of seven in this conference detailing the findings of the Definite Plan, addresses on-farm conservation.

On-farm conservation opportunities were evaluated by defining conservation families, which are made up of individual seasons for unique fields with similar crops, soils, and irrigation methods. Members of each conservation family are expected to respond similarly when incentives for conservation are offered. Sets of applicable conservation measures were identified for each conservation family. Incremental costs of implementing conservation measures were estimated for each field and crop season uniquely. The change in water deliveries resulting from implementation of each applicable conservation measure for each field and crop season was estimated based on the characteristics of the measure and the historical potentially conservable water. The resulting set of applicable conservation measures, projected costs, and estimated water savings for each field and season were used to simulate grower responses to a variety of incentive offerings under a voluntary conservation program.

Over 100,000 unique field-seasons from the 1998 to 2005 water years were evaluated. Typical net implementation costs ranged from \$35 per acre per year for management based conservation measures to more than \$800 per acre per year for capital-intensive

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conservation measures with pressurized irrigation. Typical savings ranged from zero acre-feet per acre per year for field-seasons with historically high performance to more than 1.5 acre-feet per acre per year for capital-intensive conservation measures on fields with historically low performance. The substantial variability in implementation costs and water savings among field-seasons results in a wide range of implementation costs per acre-foot conserved, which has important implications on the design of incentives for on-farm conservation.

OVERVIEW

Water use in the West is changing, and nowhere is that being felt more acutely than in the Imperial Irrigation District, a 450,000-acre district in Southern California where longstanding agricultural water users are under intense pressure to transfer water to the region's ever-thirsty and ever-expanding urban areas. Four years ago, the District agreed to launch a massive conservation program that would conserve about 10 percent of its water for transfer to San Diego and others. The heart of the agreement called for the District to generate more than 300,000 acre-feet annually through a combination of District and voluntary on-farm efficiency conservation savings. In 2007, IID completed their Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings. This paper, one of seven detailing the findings of the Definite Plan, addresses on-farm conservation.

On-farm water conservation, along with conservation from improvements to the delivery system and its operation, will represent a major component of the water conserved as part of the Definite Plan. Imperial Valley growers will need to collectively conserve at least 130,000 acre-feet and potentially a much larger share of the total needed to satisfy the transfer agreement. Conserved water will be generated through implementation of conservation measures rather than through decreased consumptive use (fallowing), with the net effect of maintaining or increasing agricultural production.

Historical cropping and water use data were compiled and used to evaluate on-farm conservation opportunities and costs. The period of analysis was selected as water years (WY) 1998 through 2005 to provide a baseline data set. A "water year" consists of the period from October 1 through September 30. Because the dataset evaluated contained some information for crops planted prior to October 1998 or harvested after September 2005, the dataset represents approximately 8.3 water years.

On-farm conservation opportunities were evaluated by first defining conservation families, which are made up of individual seasons for unique fields with similar crops, soils, and irrigation methods. Members of each conservation family are expected to respond similarly when incentives for conservation are offered. Water delivery and calculated crop evapotranspiration (ET) were used to estimate the portion of applied water not consumed and potentially conservable for each field and season in each conservation family. The applied water not consumed as ET was further divided into quantities leaving the field as tailwater (surface runoff) and tilewater (deep percolation).

Sets of applicable conservation measures were identified for each conservation family. Incremental costs of implementing conservation measures were estimated uniquely for each field and crop season based primarily on the field size, crop, and season length. The projected change in water deliveries resulting from implementation of each applicable conservation measure for each field and crop season was estimated based on the characteristics of the measure and the historical potentially conservable water. The resulting set of applicable conservation measures, projected costs, and estimated water savings for each field and season were used to simulate grower responses to a variety of incentive offerings under a voluntary conservation program.

CONSERVATION FAMILIES

As described previously, conservation families consisting of individual seasons for unique fields were developed based on similar crops, soils, and irrigation methods, based on the expectation that similar field-crop seasons will respond similarly when offered conservation incentives. This section describes the development of irrigation method families, soil families, and crop families. The combination of these families into conservation families is also discussed.

Irrigation Method Families

The most common irrigation methods used in IID are flat (graded border), row (furrow), sprinkle, drip, and gated pipe. A very small number of fields are also irrigated using level basins. For a given field and season, more than one irrigation method may be used. For example, many crops are established using sprinkle irrigation, which is then followed by surface irrigation methods (row or flat).

For purposes of defining the irrigation method families, five primary irrigation methods were defined: Flat (F), Row (R), Sprinkle (S), Drip (D), and Combination (C). The combination method is used to classify the irrigation method for field-seasons where between 10% and 70% of the seasonal volume applied is applied with sprinklers and between 30% and 90% is applied using row irrigation or gated pipe. The drip irrigation method family includes all forms of micro irrigation. The row method family includes gated pipe in addition to conventional furrow irrigation.

The total acre-feet of deliveries and percentage of water delivered over the period of analysis for each irrigation method family are provided in Table 1.

Table 1. Summary of Total Deliveries by Irrigation Method Family (1998 through 2005).

Method Code	Method Description	Total Deliveries	
		Ac-Ft	%
C	Combination of Sprinkle and Row	1,294,255	6.2%
D	Drip	208,494	1.0%
F	Flat (Graded Border)	12,551,601	59.9%
R	Row (graded Furrow)	6,637,836	31.7%
S	Sprinkle	257,655	1.2%
	Total	20,949,841	100.0%

Soil Families

Irrigation performance and management opportunities for a given crop and method vary in part due to differences in soil physical characteristics. Based on a review of available soils data and discussions with local growers, Imperial Valley soils were grouped into three classes (or families). The classes were based on permeability (saturated hydraulic conductivity) and cracking potential (linear extensibility percentage). The three classes are light soils (L), heavy soils (H), and heavy-cracking soils (C). Soil characteristics were quantified based on the Natural Resources Conservation Service State Soil Survey Geographic Database (SSURGO), which contains detailed spatial and tabular data describing the soils of the Imperial Valley as well as many other regions.

Soils are believed to have a strong influence on the absolute and relative magnitude of tailwater and tilewater production, impacting irrigation performance and the potential for water conservation. On light soils, infiltration continues at substantial rates after ponding and deep percolation losses may occur. On heavy non-cracking soils, infiltration is limited by low permeability and by the lack of cracks that could otherwise result in preferential flow. On heavy-cracking soils, infiltration occurs primarily through surface cracks that seal shortly after ponding. The choice of appropriate conservation measures and the resulting impact on losses varies substantially among soil families.

The total acre-feet of deliveries and percentages of the total water delivered over the period of analysis for each soil family are provided in Table 2.

Table 2. Summary of Total Deliveries by Soil Family (1998 through 2005).

Soil Code	Soil Type Description	Total Deliveries	
		Ac-Ft	%
C	Heavy-Cracking	15,797,127	75.4%
H	Heavy Non-Cracking	2,445,900	11.7%
L	Light Non-Cracking	2,706,814	12.9%
	Total	20,949,841	100.0%

Crop Families

A diverse mix of crops is grown in the Imperial Valley including alfalfa, Bermuda grass (for hay), Sudan, sugar beets, and wheat as well as a variety of truck and horticultural crops including carrots, onions, lettuce, asparagus, broccoli, cantaloupes, sweet corn, lemons, grapefruit, and date palms to name a few. The Imperial Irrigation District maintains a list of over 170 unique codes used to track cropping and other water uses such as leaching of salts from the root zone.

IID crops were grouped into nine general families based on anticipated responses to conservation incentives. Except as influenced by soil and irrigation methods, growers of crops within a crop family are expected to incur similar production costs, exhibit similar water ordering behaviors, and produce similar fractions of tailwater and tile water for any given level of performance. The nine crop families and corresponding total deliveries over the period of analysis are listed in Table 3.

Table 3. Summary of Total Deliveries by Crop Family (1998 through 2005).

Crop Code	Crop Type Description	Total Deliveries	
		Ac-Ft	%
AM	Alfalfa, Mature	5,789,195	27.6%
AN	Alfalfa, New (1st year)	3,299,804	15.8%
BM	Bermuda, Mature	2,458,997	11.7%
BN	Bermuda, New (1st year)	723,757	3.5%
FD	Field Crops	2,070,956	9.9%
LG	Leaching (to remove salinity)	1,511,651	7.2%
SB	Sugar Beets	1,140,703	5.4%
VG	Truck and Horticultural Crops	2,817,148	13.4%
WT	Wheat	1,137,630	5.4%
	Total	20,949,841	100.0%

Note that although sugar beets and wheat may be considered field crops, they are grown extensively enough in the Imperial Valley that they were assigned to unique crop families. The field crops family consists primarily of Sudan and cotton.

Conservation Families

Conservation families were formed from unique combinations of irrigation method, soil, and crop families. Based on the 5 method families, 3 soil families, and 9 crop families, there are 135 (5 x 3 x 9) unique possibilities.

Conservation families are formed to create groups of crop season data representing existing fields and recent past conditions in the Imperial Valley. Some combinations of method, soil, and crop are not typically or have never been observed in the Imperial Valley. Thus, for example, a conservation family was not created for sprinkle-irrigated Bermuda on either light, heavy, or cracking soils. Following the implementation of conservation measures in the future, there may be a substantial number of sprinkle-

irrigated Bermuda fields; however, historically there have been very few such fields in the Valley.

Based on observed patterns of cropping with respect to soils and irrigation methods, 54 unique conservation families were formed for analysis including 21 flat-irrigated families, 18 row-irrigated families, and 15 combination-, drip-, and sprinkle-irrigated families. The top-twenty conservation families based on total deliveries during the period of analysis are listed in Table 4. The water delivered to these twenty families represents more than 83% of all recorded agricultural water deliveries during the period of analysis.

Table 4. Summary of Deliveries for Top-Twenty Conservation Families (1998 through 2005).

Rank	Family Code	Family Description	Total Deliveries	
			Ac-Ft	% ¹
1	FCAM	Flat-Irrigated Mature Alfalfa on Cracking Soils	2,599,789	12.4%
2	FCBM	Flat-Irrigated Mature Bermuda on Cracking Soils	2,250,048	10.7%
3	RCAM	Row-Irrigated Mature Alfalfa on Cracking Soils	1,833,863	8.8%
4	FCAN	Flat-Irrigated New Alfalfa on Cracking Soils	1,290,091	6.2%
5	FCFD	Flat-Irrigated Field Crops on Cracking Soils	1,167,775	5.6%
6	RCAN	Row-Irrigated New Alfalfa on Cracking Soils	1,121,197	5.4%
7	RCSB	Row-Irrigated Sugar Beets on Cracking Soils	1,016,674	4.9%
8	FCWT	Flat-Irrigated Wheat on Cracking Soils	897,764	4.3%
9	FCLG	Flat-Irrigated Leaching on Cracking Soils	851,663	4.1%
10	RCVG	Row-Irrigated Truck Crops on Cracking Soils	720,301	3.4%
11	CCVG	Combination-Irrigated Truck Crops on Cracking Soils	676,271	3.2%
12	FCBN	Flat-Irrigated New Bermuda on Cracking Soils	576,328	2.8%
13	FLAM	Flat-Irrigated Mature Alfalfa on Light Soils	408,256	1.9%
14	FHAM	Flat-Irrigated Mature Alfalfa on Heavy Soils	373,858	1.8%
15	RCFD	Row-Irrigated Field Crops on Cracking Soils	324,348	1.5%
16	RLVG	Row-Irrigated Truck Crops on Light Soils	314,183	1.5%
17	CLVG	Combination-Irrigated Truck Crops on Light Soils	308,276	1.5%
18	RHAM	Row-Irrigated Mature Alfalfa on Heavy Soils	250,386	1.2%
19	FLFD	Flat-Irrigated Field Crops on Light Soils	238,592	1.1%
20	FLLG	Flat-Irrigated Leaching on Light Soils	222,591	1.1%
Total			17,442,254	83.3%

1. Refers to percent of total deliveries (20,949,841 ac-ft) during study period.

HISTORICAL ON-FARM WATER USE AND POTENTIALLY CONSERVABLE WATER

A major element of the Definite Plan on-farm analyses involved assessing the potential water savings that could be achieved if conservation measures were adopted by growers in response to financial incentives to conserve water. This was approached through the development of water balances for individual fields and crop seasons, or “field-seasons,” which enabled characterization of historical water delivery, crop water use, and water discharged as tailwater and tilewater. Historical field-season water balances over the

analysis period established baseline water use, providing a basis for estimating potential water savings, field by field, and season by season.

Figure 1 shows the primary flow paths used for the field-season water balances, which were delivered water, precipitation, crop evapotranspiration (ET), surface runoff (tailwater), and deep percolation (tilewater). As shown in Figure 1, the effects of rain were accounted for in the water balance for each field-season. As a result, the analysis focused on characterizing the destination of delivered water only, quantifying the ET, tailwater, and tilewater derived from irrigation deliveries. Rainfall was accounted for using a daily root zone water balance model based on daily weather data along with crop and soil information for each field-season. Field seasons were parameterized in the model based on crop, planting and harvest dates, and soil type.

Delivered Water

Historical water delivery data were obtained from databases maintained by IID and summed for each field-season. Field-seasons were limited to 365 days in length, so that a given field could have a series of field-seasons for the same crop across years—for example in the case of perennial crops such as citrus or alfalfa.

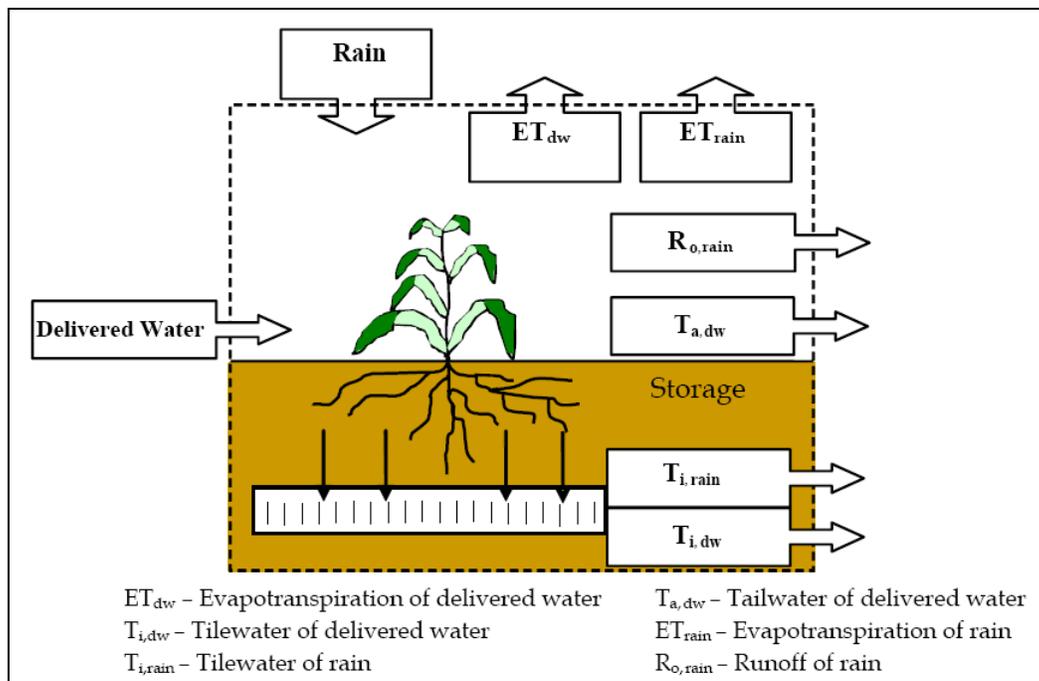


Figure 1. Conceptual Diagram of On-Farm Flow Paths.

Crop Evapotranspiration

Crop evapotranspiration (ET) is typically the largest outflow path in the field-season water balance. Crop ET was estimated by applying the daily water balance model to estimated potential ET (ET_p) based on the dual crop coefficient approach described in

FAO Irrigation and Drainage Paper No. 56 (Allen et al, 1998). Based on the daily model, total ET_p was disaggregated into ET derived from delivered water and ET derived from precipitation.

Estimates of ET_p are representative of ideal or nearly ideal growing conditions and may lead to overestimates of actual crop ET. In order to evaluate differences between actual ET under field conditions and potential ET from the crop coefficient approach, an independent analysis of ET was performed using the Surface Energy Balance Algorithm for Land (SEBAL[®]) on a monthly time step for the 1998 water year. The SEBAL model calculated actual ET (ET_a) based on information contained in Landsat Satellite imagery for each approximately ¼-acre image pixel (30 m by 30 m) in IID. The results of the SEBAL analysis were compared to potential ET from the FAO56 approach, and adjustment factors were developed to correct estimated ET_p to ET_a under Imperial Valley conditions. The resulting “inference factors” are the ratio of ET_a to ET_p for individual conservation families as presented in Table 5. Note that where the second letter of the family code is “A,” the results represent the combination of all soil types for a particular crop and irrigation method combination.

SEBAL ET results were validated by an independent water balance performed by Keller-Bliesner Engineering (2007). Total inflows and outflows for IID were quantified for the 1998 water year (excluding ET), and used to solve for ET as a closure term. Total crop ET was estimated as the total consumptive use minus the sum of canal evaporation; municipal and industrial consumption; and ET from other sources including drains, rivers and other non-ag land. For the cropped area, the total ET estimated using SEBAL was 1,838.6 thousand acre-feet (kaf) compared to 1,827.0 kaf based on water balance results, agreeing within 1%. The SEBAL results fell well within the water balance 95 percent confidence interval for crop ET of 5.1%.

Consumptive Use Fraction

The Consumptive Use Fraction (CUF) was calculated for each field-season in the period of analysis based on the estimated actual crop ET, net of precipitation, divided by the total IID recorded deliveries during the season. The CUF provides a means of normalizing water conservation potential among field-seasons. Within a given conservation family, a field-season with a low CUF will have relatively more potential for conservation than a field-season with a high CUF if the same conservation measure is implemented on both fields.

Table 5. Inference Factors Used to Estimate Actual ET from Potential ET.

Family Code	Field-Seasons	Season-Acres	ET, Acre-Feet		Inference Factor, f
			SEBAL (ET _a)	FAO56 (ET _p)	
CAVG	76	5,108	5,589	7,751	0.72
DAVG	12	858	1,127	1,624	0.69
FABM	185	16,268	67,244	85,206	0.79
FABN	58	5,038	9,242	10,203	0.91
FAWT	283	23,789	37,260	44,013	0.85
FCAM	356	24,902	105,075	124,873	0.84
FCAN	147	10,440	7,024	8,308	0.85
FCFD	125	9,455	20,358	19,347	1.05
FHAM	51	3,050	12,338	14,308	0.86
FHAN	23	1,309	1,136	1,372	0.83
FHFD	16	1,067	2,821	2,638	1.07
FLAM	60	3,263	12,461	14,650	0.85
FLAN	27	1,386	887	1,175	0.75
FLFD	23	1,193	2,716	2,533	1.07
RAAM	184	17,007	68,660	78,584	0.87
RAAN	43	3,991	2,540	3,120	0.81
RAFD	51	3,778	6,324	6,989	0.90
RASB	143	13,066	22,943	25,866	0.89
RCVG	73	5,147	9,551	11,513	0.83
RHVG	14	705	1,282	1,429	0.90
RLVG	23	1,083	1,253	1,535	0.82
SAAN	88	8,884	6,520	7,341	0.89
SAVG	60	4,889	4,069	5,397	0.75
All	2121	165,676	408,420	479,775	0.85

When CUF values for each field-season were calculated from available delivery data, it was found that some field-seasons had values that appeared to be greater than or less than practical bounds. For example, a CUF value greater than one indicates that more water was returned to the atmosphere as ET than was delivered to the field. Additionally, a CUF value less than 0.25 suggests that the amount of water delivered to the field was in excess of four times that amount used by the crop. In order to reduce potential inaccuracies, a series of quality control checks was applied when computing the CUF values. These included a filter to eliminate abnormally short or long seasons and a filter to eliminate fields where more than one field is served by a single gate, which presents challenges to the District in accurately accounting for delivered water. Finally, a set of practical bounds was established for CUF values of each family to identify field-seasons with an abnormally low or high CUF.

Based on the quality control procedures, a set of field-seasons passing the checks was identified for each conservation family. These field-seasons were then used to develop representative CUF distributions for the population of field seasons within each family.

As an example, the resulting cumulative CUF distribution for flat-irrigated mature alfalfa on cracking soils (FCAM) is provided in Figure 2.

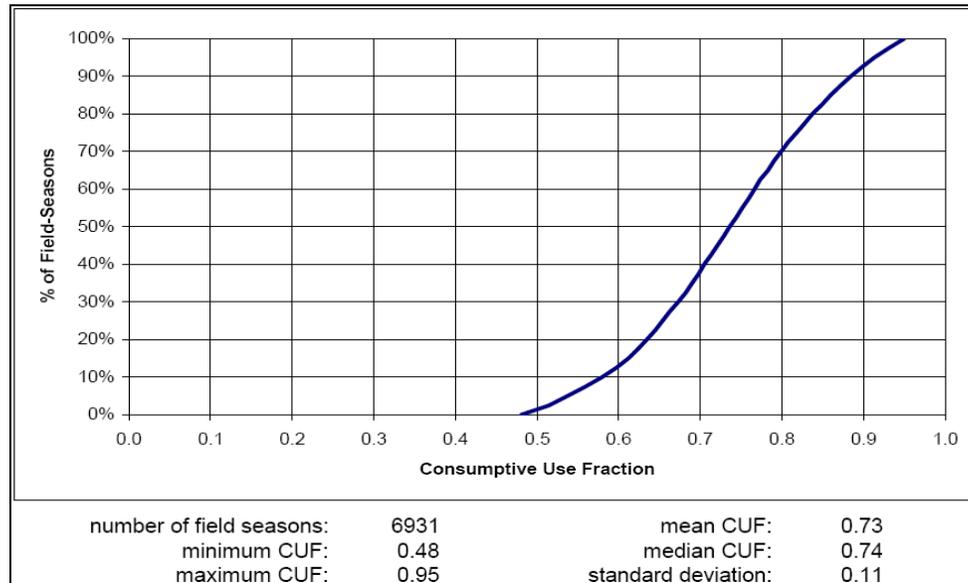


Figure 2. Cumulative CUF Distribution and Summary Statistics for Conservation Family FCAM (Flat-Irrigated Mature Alfalfa on Cracking Soils) (1998 through 2005).

The remaining field seasons not passing the quality control checks were randomly assigned a CUF value so that they would fall within the representative distribution. Then, the ET associated with the field-season was recalculated based on the delivered water records and the CUF values to maintain closure of the water balance. Delivered water values were not adjusted because of the reliance of other quality control analyses related to the IID distribution system on the delivered water records for individual field-seasons.

Tailwater (Surface Runoff) Production

Tailwater production for individual field-seasons was estimated by developing empirical relationships between CUF values and tailwater fractions (ratio of tailwater production to total delivered water) developed from a database of irrigation events. These included a total of more than 1,300 irrigation events during which tailwater production amounts were measured along with the water delivery to the field.

For each unique combination of surface irrigation method family (flat and row) and soil family (light, heavy, and heavy-cracking), the distribution of tailwater fractions was assembled from the monitored events. Additionally, the distribution of CUF values for each method-soil family was generated from the set of fields used to develop the ET inference factors for the 1998 water year. It was assumed that fields within a soil-method family with the least tailwater production tend to have the greatest CUF, and vice-versa. Then, relationships between tailwater fraction and CUF were developed by pairing the 90th percentile CUF with the 10th percentile tailwater fraction, the 80th percentile CUF

with the 20th percentile tailwater fraction, and so on. Relationships developed for flat- and row-irrigated soil-method families are presented in Figures 3.a and 3.b, respectively.

The relationship for row-irrigated fields on heavy soils was developed based on the results for flat-irrigated fields on heavy soils due to only a limited set of empirical data for row-irrigated fields on heavy soils.

Similar relationships were developed for sprinkle- and combination-irrigated families based on collective professional judgment by the project team. It was assumed that drip irrigation produces no tailwater.

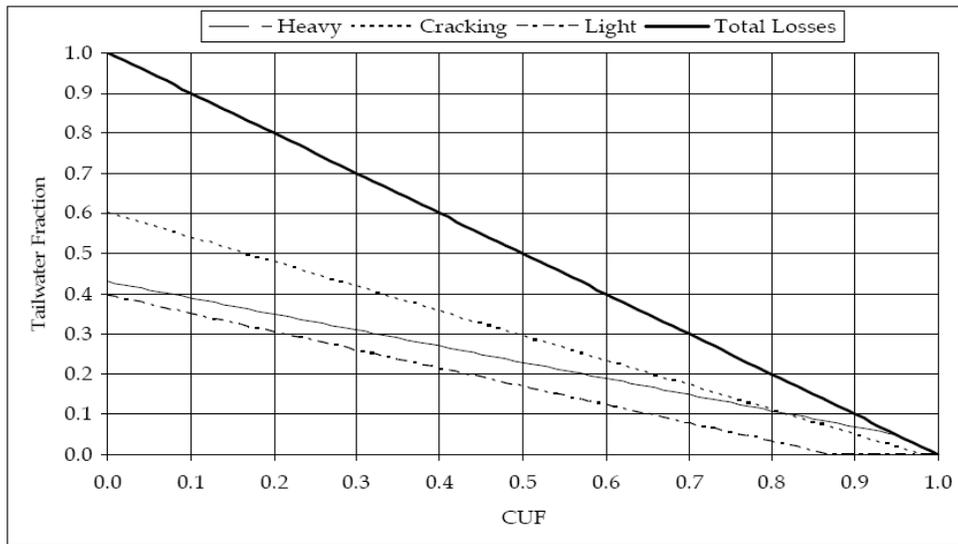


Figure 3.a. Relationship of Tailwater Fraction to CUF for Flat-Irrigated Soil-Method Families.

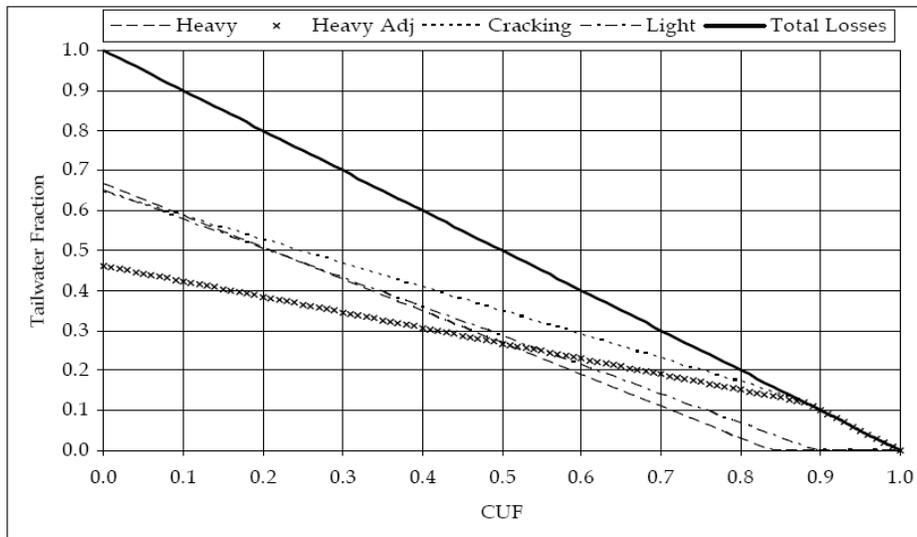


Figure 3.b. Relationship of Tailwater Fraction to CUF for Row-Irrigated Soil-Method Families.

Tilewater (Deep Percolation) Production

Tilewater production as a fraction of deliveries was estimated for each soil-method family based on the CUF-tailwater relationships developed from the tailwater monitoring data. It was assumed that both the head ditch seepage and evaporation are relatively small on-farm flow paths, and the change in soil moisture storage is relatively small across the season. Therefore, the fraction of deliveries that leaves the field as tailwater and tilewater must equal the fraction of deliveries that are not consumed by crop ET. Thus, the tilewater fraction is expressed by:

$$f_{Ti} = 1 - (CUF + f_{Ta}) \quad [1]$$

where f_{Ti} is the tilewater fraction and f_{Ta} is the tailwater fraction. The volumetric tilewater production is simply the delivered water volume multiplied by the tilewater fraction.

Summary

The on-farm water balance construct (Figure 1) was used in conjunction with available data and models to develop estimates of delivered water, crop evapotranspiration, tailwater, and tilewater for more than 100,000 individual field-seasons within the period of analysis. These water balances provide a basis for estimating the impacts of implementing conservation measures at the field-scale. A summary of the results of the historical on-farm water use analysis for the top twenty conservation families is provided in Table 6.

ON-FARM CONSERVATION MEASURES AND COSTS

Conservation measures (CMs) likely to be considered when water conservation incentives are offered were identified through consultation with Imperial Valley growers. The range of potential measures identified includes measures that are currently in use in the Valley as well as those that may be considered in the future. A subset of CMs was selected for detailed characterization of costs and water savings. CMs were selected to provide a representative set for analysis. The selection was made based on grower interest, applicability, cost, potential water savings, and delivery system impacts. In program implementation, the expectation is that growers will be allowed wide latitude in selecting the most cost effective measures for their operations. A list of the conservation measures included in the analysis is provided in Table 7.

The applicability of a given CM to a given conservation family requires that the CM be compatible with the irrigation method, soil, and crop present. The applicability of each CM to each conservation family was evaluated by considering any constraints limiting the ability to implement the measure or its effectiveness.

Table 6. Summary of Historical Delivered Water, Crop ET, Tailwater, and Tilewater for Top Twenty Conservation Families (1998 through 2005).

Family Code	Total	Crop Water Use (ET _{aw})		Tailwater		Tilewater	
	Deliveries (Ac-Ft)	Total (Ac-Ft)	Fraction of Deliveries	Total (Ac-Ft)	Fraction of Deliveries	Total (Ac-Ft)	Fraction of Deliveries
FCAM	2,599,789	1,896,599	0.73	400,073	0.15	303,117	0.12
FCBM	2,250,048	1,582,827	0.70	382,223	0.17	284,998	0.13
RCAM	1,833,863	1,360,257	0.74	373,330	0.20	100,276	0.05
FCAN	1,290,091	965,706	0.75	183,461	0.14	140,924	0.11
FCFD	1,167,775	790,237	0.68	217,547	0.19	159,991	0.14
RCAN	1,121,197	829,908	0.74	229,459	0.20	61,830	0.06
RCSB	1,016,674	734,380	0.72	219,076	0.22	63,218	0.06
FCWT	897,764	613,563	0.68	163,539	0.18	120,662	0.13
FCLG	851,663	237,252	0.28	42,583	0.05	571,828	0.67
RCVG	676,271	420,919	0.62	214,878	0.32	40,474	0.06
FCBN	651,274	460,464	0.71	109,212	0.17	81,598	0.13
CCVG	576,328	438,701	0.76	53,346	0.09	84,281	0.15
FLAM	576,328	369,522	0.64	60,967	0.11	145,839	0.25
FHAM	408,256	296,358	0.73	56,758	0.14	55,140	0.14
RCFD	324,348	216,195	0.67	80,639	0.25	27,514	0.08
RLVG	314,183	167,201	0.53	82,586	0.26	64,396	0.20
CLVG	308,276	192,569	0.62	28,836	0.09	86,871	0.28
RHAM	250,386	177,889	0.71	55,812	0.22	16,685	0.07
FLFD	238,592	157,048	0.66	23,405	0.10	58,139	0.24
FLLG	222,591	33,322	0.15	11,130	0.05	178,139	0.80
Total ¹	17,575,697	11,940,917	0.68	2,988,860	0.17	2,645,920	0.15
Total ²	20,949,841	13,880,037	0.66	3,439,026	0.16	3,630,778	0.17

1. Corresponds to top twenty families only.

2. Corresponds to all families

Table 7. Potential Conservation Measures Included Explicitly in Analyses.

Conservation Measure	CM Code
Center Pivot Irrigation	CPI
Level Basin Irrigation	LVL
Micro Irrigation	DRP
Minor Management and Physical Improvements	MNR
Scientific Irrigation Scheduling	SIS
Scientific Irrigation Scheduling and Event Management	SEM
Sprinkle Irrigation	SPR
Tailwater Recovery Systems with Reservoirs	TRS
Tailwater Recovery Systems without Reservoirs	TRP

Incremental Implementation Costs

The net on-farm costs of implementing selected CMs were estimated by considering capital costs, maintenance costs, and operations costs as well as additional costs and benefits of CM adoption. In all cases, the cost of CM adoption was estimated as an incremental cost above existing irrigation costs. Incremental costs were calculated as the

difference between the total implementation cost and the current cost of irrigation, including consideration of additional management time needed to implement each CM. Cost estimates were developed through consultation with irrigation equipment suppliers, on-farm construction contractors, and Imperial Valley growers. On-farm CM demonstrations provided a valuable source of input from growers regarding actual implementation costs. Additional information describing the studies may be found in Brooks et al. (2008). Budgets were developed across a range of field sizes and crop types to develop cost functions for estimating unique costs for individual combinations of CM, conservation family, and field size. Each cost function consists of annual capital and maintenance costs, expressed as a base cost per field plus an additional cost per acre along with seasonal operating costs, expressed as a base cost per field plus an additional cost per acre.

Example cost functions for scientific irrigation scheduling and tailwater recovery systems with reservoirs are shown in Figures 4 and 5, respectively. In the case of irrigation scheduling, the costs are shown as seasonal operating costs for different crops, which vary due to differences in irrigation practices and season length. For tailwater recovery systems, the costs are shown as annual capital and maintenance costs that vary for different reservoir sizes.

The point costs in Figure 5 represent individual budgets developed for alternative tailwater recovery system (TRS) configurations. In all, a total of 145 unique CM implementation budgets were developed and used to estimate the CM cost functions.

Additional costs and benefits of CM adoption included yield changes, fertilizer cost savings, and reduced water costs. The cost (or benefit) of yield changes was estimated based on anticipated changes in crop ET either due to changes in the cropped area (i.e.,

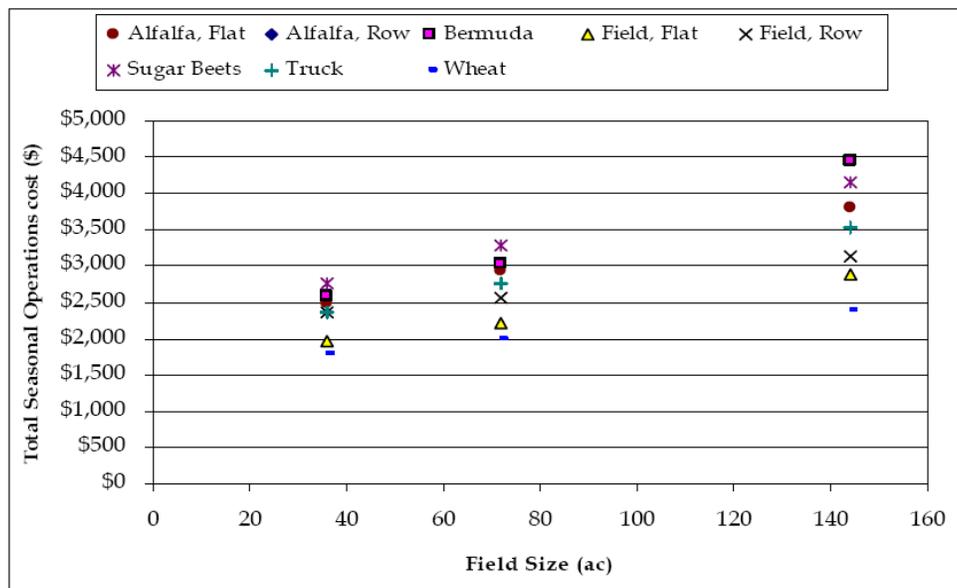


Figure 4. Operations Costs by Crop Type and Field Size for Scientific Irrigation Scheduling.

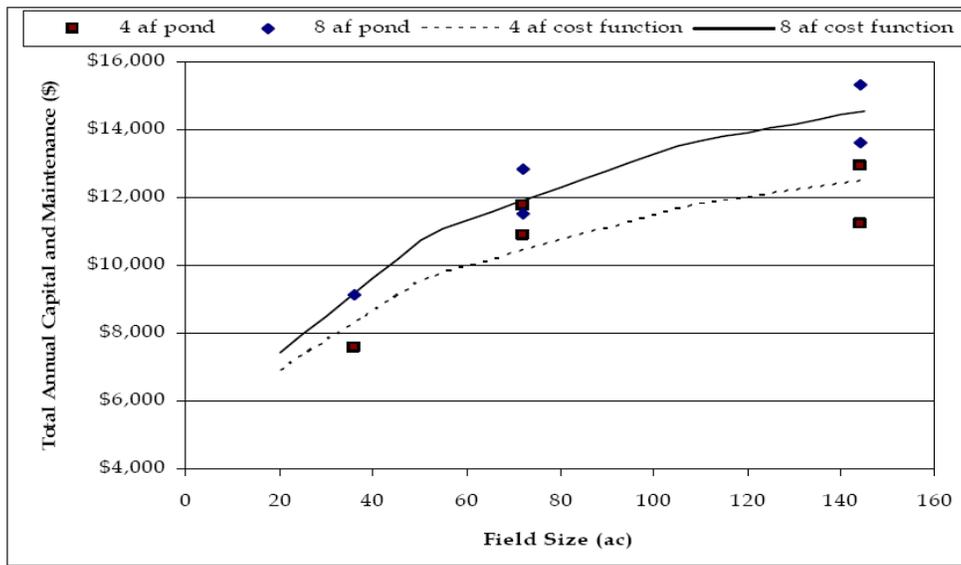


Figure 5. Capital and Maintenance Costs for Tailwater Recovery Systems with Reservoirs.

crop area lost for installation of a reservoir) or due to changes in crop vigor (i.e., resulting from more uniform irrigation). The change in crop ET was translated into a change in returns, net of harvest costs, estimated from Imperial Valley Agricultural Commissioner crop reports and Cooperative Extension cost and return studies. For drip and sprinkle irrigation, potential yield increases were estimated empirically based on historical drip and sprinkle adoption rates in the Imperial Valley.

Fertilizer savings for each CM-conservation family combination were estimated on a seasonal basis from aggregate water savings estimates, and in-season fertilizer cost estimates were made from Cooperative Extension cost-return studies. It was assumed that reductions in losses (tailwater and tilewater) following CM adoption would result in proportional reductions in fertilizer losses for in-season applications.

Reduced water costs for each field-season were calculated as the product of the water rate (estimated to be \$17 per acre-foot) and the estimated decrease in delivered water.

POTENTIAL ON-FARM WATER SAVINGS

Flow Path Impacts and Water Savings Characterization Framework

The IID water balance reveals that the main opportunity to save water on-farm is to reduce tailwater. For the large majority of IID soils, deep percolation (tilewater) is not excessively above leaching requirements. Exceptions include the roughly 10 percent of the irrigable area with light texture soils where deep percolation can easily occur or cracking soils where preferential flow through cracks below the root zone can occur.

Delivered water savings were estimated by developing estimates of the impact of CM adoption on the consumptive use fraction (CUF). Implementation of CMs by all members of a given conservation family would be expected to increase the overall CUF for the family by incrementally increasing the CUF of each field-season within the family. Additionally, members of a family would be expected to maintain rank following CM adoptions, so that a field-season with a relatively low CUF initially would remain a relatively low (though increased) CUF field following implementation. Finally, field-seasons with historically low performance are expected to experience increases in performance relative to the total potential for conservation that are less than for fields with historically greater performance. These assumptions were used to develop a rationale to estimate the increase in performance for individual field-seasons.

The change in the baseline CUF distribution for a conservation family resulting from implementation of an individual CM is based on two parameters. The first parameter, CUF_{max} , is the maximum expected baseline CUF for which a CM is expected to result in water savings. Field seasons that have a CUF above CUF_{max} prior to CM implementation are expected to have no change in the CUF following implementation. The second parameter, $CUF_{Typ,CM}$, is the estimated post-implementation median CUF for field-seasons with an initial CUF less than CUF_{max} . CUF values for individual field-seasons implementing a CM are estimated by shifting the baseline CUF value according to:

If: $CUF_{Base} \geq CUF_{max}$, then,

$$CUF_{CM} = CUF_{Base} \quad [2.a]$$

Otherwise,

$$CUF_{CM} = CUF_{Base} + \left(\frac{CUF_{Typ,CM} - CUF_{med}}{CUF_{max} - CUF_{med}} \right) \left(\frac{CUF_{med}}{CUF_{Base}} \right) (CUF_{max} - CUF_{Base}) \quad [2.b]$$

Where: CUF_{CM} is the estimated field-season CUF following CM implementation; CUF_{Base} is the field-season CUF prior to CM implementation; and CUF_{med} is the median CUF for field-seasons with values below CUF_{max} prior to CM implementation.

Equation 2 was applied to each unique combination of field-season and applicable CM to estimate potential changes to the CUF (and delivered water) resulting from CM implementation.

The curve-shift parameters and resulting shifted CUF distribution are depicted graphically in Figure 6.

Water savings resulting from CM implementation were further partitioned into savings resulting from reduced water orders and savings resulting from adjustment of orders after the start of delivery. For adjustments made after the start of delivery, water turned back to the distribution system must be stored, or another destination must be found to deliver the water in order to prevent it from spilling from the system. Interactions between on-

farm conservation and the delivery system are discussed in detail in Thoreson et al. (2008).

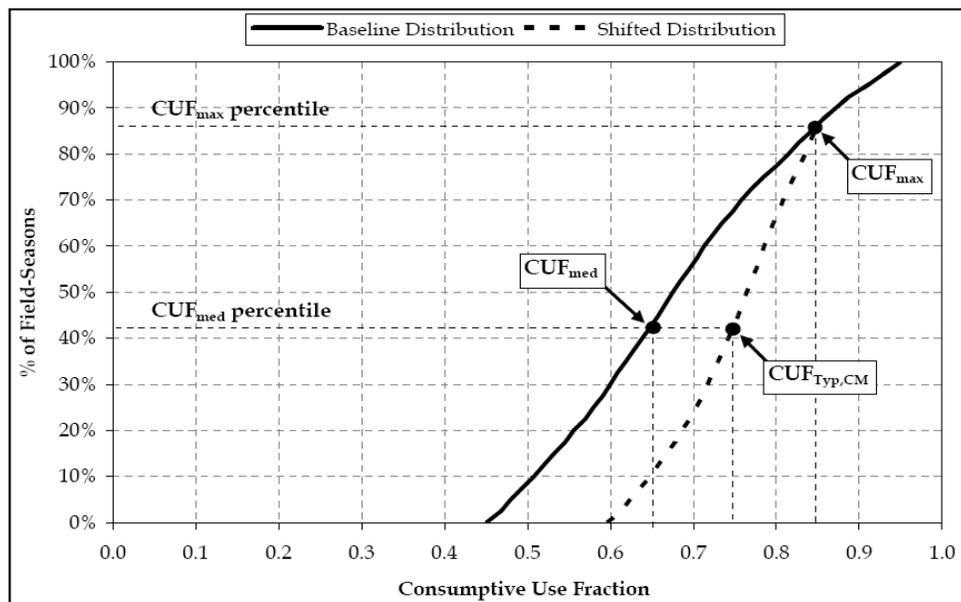


Figure 6. Example CUF Shift Parameters and Resulting Shift.

SUMMARY

Over 100,000 unique field-seasons from the 1998 to 2005 water years were assigned to conservation families based on expected similar response to incentives for adoption of conservation measures. For each field-season, a water balance was performed to estimate the amount of delivered water leaving the field as crop ET, tailwater, or tilewater. A performance indicator called the consumptive use fraction (CUF) was calculated for each field and used as a relative measure of conservation potential.

A set of representative conservation measures likely to be considered by growers under an incentive-based conservation program was identified. Each conservation measure was characterized with respect to its expected implementation costs and water savings. Implementation costs were calculated as the net cost of adoption, considering capital, maintenance, and operations costs along with incidental costs (or benefits) due to yield changes, fertilizer savings, and delivered water savings. Water savings for each unique combination of field-season and applicable CM were estimated by first estimating a change in the CUF resulting from its adoption, and then estimating the change in delivered water (after considering possible ET impacts).

A summary of the estimated typical range of costs and water savings for selected CMs on an annual basis is provided in Table 8. Cumulative distributions of the net implementation cost per acre-foot conserved for selected CMs are shown in Figure 7 for selected CMs.

Table 8. Estimated Ranges of Net Implementation Costs and Water Savings for Selected Conservation Measures.

Conservation Measure	Cost Range (\$/acre)	Savings Range (acre-feet/acre)
Scientific Irrigation Scheduling	\$ 35 to \$ 135	0 to 0.5
Drip Irrigation	\$ 395 to \$ 625	0 to 1.7
Sprinkle Irrigation	\$ 624 to \$ 812	0 to 1.4
Tailwater Recovery Systems	\$ 145 to \$ 442	0 to 1.5
Level Basin Irrigation	\$ 180 to \$ 312	0 to 1.4

As shown in Figure 7, there is substantial variability in the implementation cost per acre-foot conserved among different field-seasons. This variability is due to differences in water savings and implementation costs among fields. As water savings approach zero, the unit cost of conservation skyrockets. The variability in implementation costs and water savings among field-seasons for different CMs has important implications to the design of incentives for on-farm conservation. The development of incentive approaches is discussed in detail in Hatchett et al. (2008).

The results of the on-farm analyses completed for the Definite Plan provide a data set of possible choices that could be made by growers for individual field-seasons when offered incentives for on-farm conservation. This data set allowed for the evaluation of alternative incentive structures as part of the planning process. Full documentation of the Definite Plan is available from the Imperial Irrigation District website at www.iid.com/Water/EfficiencyConservationProgram.

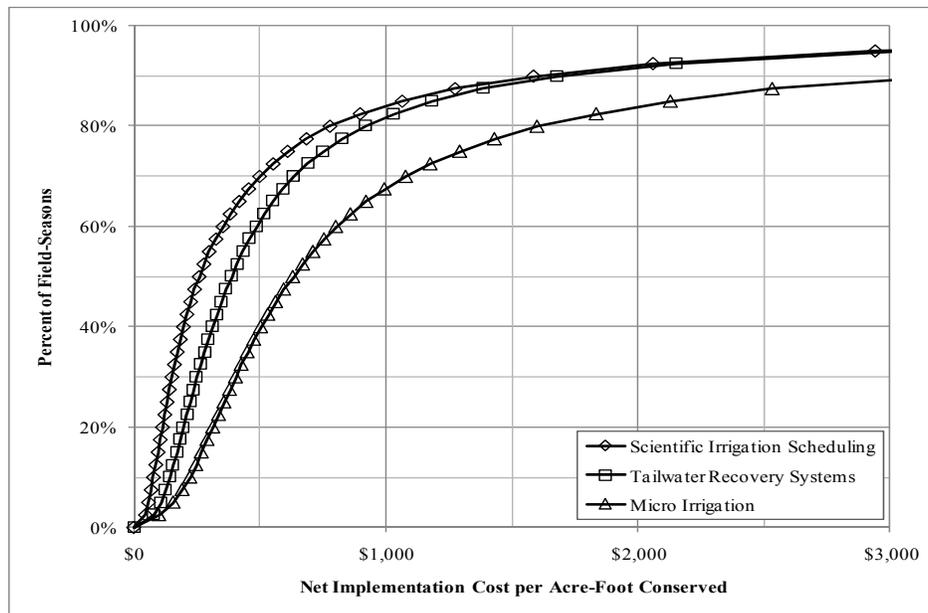


Figure 7. Cumulative Distributions of Costs per Acre-Foot Conserved for Selected Conservation Measures.

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IMPERIAL IRRIGATION DISTRICT EFFICIENCY CONSERVATION DEFINITE PLAN - MODIFYING THE DELIVERY SYSTEM TO CONSERVE WATER AND SUPPORT MORE EFFICIENT ON-FARM IRRIGATION

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ABSTRACT

In 2003 the Imperial Irrigation District (IID), a 450,000-acre water district in Southern California, entered into a package of decisions and agreements known collectively as the Quantification Settlement Agreement and Related Agreements. As part of these agreements, IID agreed to a long-term transfer of water to the San Diego County Water Authority (SDCWA) and the Coachella Valley Water District (CVWD). According to the terms of the agreements, the water must come from conservation within IID, ultimately reaching over 300,000 acre-feet of water each year or nearly 10% of its total annual water diversion.

In 2007, IID completed its Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings to meet the conservation objective. The Definite Plan included a comprehensive review of IID's delivery system, assessing everything from minor actions to prevent or recover seepage losses from canals and laterals to a complete revamping of IID's network of canals, laterals and headgates.

In its final recommendation, the Definite Plan concluded that total delivery system savings in the range of 93,000 to 123,000 acre-feet could be reasonably achieved at an average cost of around \$100 per acre-foot. The recommended actions include a main canal seepage recovery system that pumps canal seepage from existing parallel open drains into the canals, recovering from 35,000 to 44,000 acre-feet per year at an annual cost of from \$13 to \$15 per acre-foot. The balance of 58,000 to 79,000 acre-feet of savings would come from reduced system spills facilitated by a system improvement program titled "Integrated Information Management" at a cost of from \$150 to \$200 per acre-foot.

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INTRODUCTION AND BACKGROUND

In 2003 the Imperial Irrigation District agreed to launch a massive conservation program that would free up roughly 10 percent of its water for transfer to San Diego and others. The heart of the agreement called for IID to generate 303,000 acre-feet per year through a combination of delivery system and voluntary on-farm efficiency conservation savings. At least 130,000 acre-feet of this total must come from on-farm conservation. In 2007, IID completed its Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings.

No comprehensive efficiency conservation program can be conducted successfully without a detailed understanding of the operation of the Imperial Irrigation District delivery system. The Definite Plan is comprehensive in nature, with a large focus on on-farm efficiency conservation opportunities while still seeking delivery system conservation. Further, the on-farm portion requires voluntary participation with a broad range of possibilities. As some of these on-farm conservation measures impact water delivery and water delivery constraints also impact on-farm conservation, a good understanding of the system/on-farm interaction is required and any system improvements should consider this interaction.

Several discrete studies were designed to complete the required IID delivery system analysis. The studies fall into three categories: foundational analyses, stand-alone conservation projects, and interrelated conservation projects.

Foundational Studies

Foundational analyses do not examine conservation opportunities directly, but provide critical information to studies that do. These studies include a detailed look at the IID water balance and an examination of the need for, and approaches to, improved water delivery measurement. These studies are not detailed here, but provide key information upon which the system conservation studies depend.

The detailed water balance completed as part of the Definite Plan utilizing daily records from 1998-2005 identified a maximum potential system savings of 210,000 acre-feet per year if both canal seepage (86,000 acre-feet) and spills (124,000 acre-feet) could be reduced to zero. Since the on-farm efficiency conservation program must conserve at least 130,000 acre-feet, the maximum required savings from system conservation is 173,000 acre-feet or 82% of the maximum potential. This became the upper limit of system savings considered in the analyses.

Stand-Alone Projects

Stand-alone projects are those that can be accomplished without impact on the delivery of water to the farms or on delivery system operation. Lateral canal lining and seepage interception from main canals have been identified as stand-alone projects with conservation potential.

Canal lining has been demonstrated in the past as an effective conservation measure. While many of the lateral canals within IID have been lined under previous conservation programs, opportunity exists for additional water savings through canal lining. A study was completed to identify the cost and water savings of individual lateral canal segments, ranking them according to cost effectiveness. The analysis suggests that canal lining will yield just 3,000 acre-feet of savings, with the costs associated with individual lining projects ranging from \$100 to \$500 per acre-foot. The savings potential is small for feasible lining projects and no lining was included in the final recommendation, so the details of the study are not reported here.

It is not practical to line the main IID canals because water delivery cannot be interrupted to complete the lining. However, it is practical in several areas to intercept the seepage from these main canals with parallel drains, pumping the intercepted water back into the canal. Locations where this is practical have been identified and systems designed to accomplish the recovery of this seepage.

Inter-Related Projects

Inter-related projects are those that may impact both system operation and on-farm delivery. They typically have elements of conservation within the system, but may also facilitate on-farm conservation. These projects require a comprehensive examination of the existing system with identification of a broad range of individual components that act together to achieve water savings and enhance delivery performance. These projects are referred to as delivery system changes.

METHODS

Seepage Interception

IID presently has 10 seepage recovery systems that intercept seepage from 5.5 miles of the East Highline Canal. These are piped drains installed adjacent to the canal with a small turbine pump to lift the water from the drain to the canal. They were installed in areas with the highest seepage rate and recover about 28,000 acre-feet per year of seepage.

The original intent of the Definite Plan was to investigate the feasibility of extending this approach to other areas, primarily along the East Highline Canal. The complication with such installations is that, if they are installed such that the groundwater gradient away from the canal is steeper than presently exists, additional seepage is induced, which must be quantified and deducted from the total amount pumped to arrive at the net conservation. Further, these buried pipe drains are expensive to install.

An evaluation of candidate reaches for additional interception systems revealed that most of the reaches presently have open drains that parallel the canals. By using the existing open drains as the interceptor and installing pumps and pipelines to return this seepage

water to the canal, the cost would be greatly reduced and may allow recovering seepage in areas where the installation of piped drains would not be cost-effective.

The field investigation program was designed to determine the hydraulic conductivity in each drain reach by measuring the flow in the drain and the slope of the water table from the canal to the drain. The water table elevation was also measured 50 ft down slope of the drain. If the down slope water table elevation was equal to or higher than the drain, then the drain was collecting all the seepage from the canal and no pipe drain would be required. If such is the case, then the determination of hydraulic conductivity is not required and the drain flow, when adjusted for seasonal variation, represents the amount of canal seepage that could be retrieved. The field data revealed that the existing open drains were recovering nearly all of the canal seepage, so the computation of hydraulic conductivity for drain design purposes was not required.

Twenty-five systems covering 28.5 miles of canal were investigated for potential seepage interception systems. Twenty of these systems collect water from 18.2 miles of the East Highline Canal, one system covers 1.7 miles of the All American Canal and four systems collect seepage from 8.6 miles of the Westside Main Canal.

The electrical conductivity measurements taken in the field were used to compute the salinity effect of the recovered drain water. If the conductivity of the drain water is greater than the supply water, the leaching requirement for using it is increased, thereby making it less effective than supply water. To compute the effective savings, equation 1 was used:

$$\text{Salinity Adjustment Ratio} = (1 - EC_{dw} / EC_{br}) / (1 - EC_{cw} / EC_{br}) \quad \text{Eq. 1}$$

Where:

EC_{dw} = electrical conductivity of the water in the drain

EC_{br} = maximum allowed electrical conductivity at the bottom of the rootzone

EC_{cw} = electrical conductivity of the canal water

The Salinity Adjustment Ratio is 0 when EC_{dw} equals EC_{br} , but EC_{dw} is practically limited by economic feasibility long before the salinity reaches this level.

The canal water averaged 1,200 $\mu\text{S}/\text{cm}$ during the 2006 field work. EC_{br} was estimated at 6,000 $\mu\text{S}/\text{cm}$, requiring a 20 percent leaching fraction. The water balance suggests a leaching fraction of approximately 16 percent average for the valley for which EC_{br} would be 7,500 $\mu\text{S}/\text{cm}$. Using 6,000 $\mu\text{S}/\text{cm}$ discounts the savings a little more than the average would indicate, but is in keeping with safe management practices.

Seepage rates as evidenced by the records from the existing seepage recovery systems vary seasonally, typically peaking in July and reaching a minimum in December and January. The pumping capacities were based on the ratio between the typical September (measurement data) and July seepage rates. The average annual recovery was computed as the ratio between the average September rate and the average annual rate.

Each seepage interception system was design and a cost estimate prepared. They were ranked by the annual cost per acre-foot of net conservation.

Delivery System Changes

Design Process. The initial approach taken for analysis of system modernization was to formulate specific technical actions for the entire IID distribution system for two modernization and improvement scenario bookends. The first scenario focused on spill reduction with little change in delivery flexibility. The second considered both spill reduction and improved quality and flexibility of water delivery. The primary investments targeted by both of these approaches were for construction of interrelated physical elements, particularly re-regulation reservoirs as part of new dual-use lateral interceptors and stand-alone reservoirs in designated zanjero zones, along with major upgrades to existing main system reservoirs. The overall estimated costs were \$242 million and \$1.2 billion, respectively.

When it became evident that even the low bookend was not economically feasible, two additional, lower-cost scenarios were developed by selectively removing high capital cost components from the low bookend while retaining key SCADA and automation technologies. One of these lower-cost bookends (Spill Recovery without Lateral Reservoirs) was based on removing all the lateral reservoirs (33 reservoirs located in zanjero zones, ranging in capacity from 12 to 75 acre-feet). This reduced the overall estimated cost to \$181 million, or about \$61 million less than the low bookend.

An even lower-cost option was developed by removing additional items, such as the lateral inter-connections (some with terminal reservoirs), dual-use lateral interceptors with reservoirs, and non-leak gates, while adding automation of the lateral headgates and two large main system reservoirs on the Central Main Canal and the East Highline Canal, respectively. Two other reservoirs on the Westside Main Canal were retained in this least-cost formulation. This least-cost bookend was termed “Integrated Information Management” (IIM), even though about two-thirds of the estimated cost was associated with construction of the two large (1,500 acre-feet each) reservoirs. The concepts and components comprising IIM evolved along with development of the Definite Plan alternatives, especially considerations related to the locations and sizes of regulating reservoirs. The final version included both main system reservoirs and a number of small zanjero reservoirs (reservoirs on laterals under the control of zanjeros). The final recommended configuration of components that make up IIM is described here.

IIM Objectives. IIM has four main operational objectives: (1) reduce lateral canal spills, (2) re-regulate water “backed out” from laterals into main canals, (3) provide additional flexibility to growers to shut off or reduce deliveries, but with advance notice provided to IID, and (4) reduce or eliminate carry-over orders. The first two objectives are directly related to system conservation and facilitate on-farm conservation by preventing some of the water rejected by early or reduced deliveries from spilling. The second two facilitate on-farm conservation directly, with no system conservation.

Determining Additional Storage Requirement. Additional regulating storage capacity, both at the main canal and lateral levels, is a key component of IIM. The IIM reservoirs are strategically located and sized to provide benefits upstream and downstream of each reservoir location.

Criteria for sizing and locating IIM main system reservoirs are straightforward. Since the purpose of the IIM reservoirs is to temporarily store water (from early shutoffs) that will be put back into the main canals, their size is related to the amount of upstream rejected water per acre that can be back out by adjusting lateral headgates. The location of IIM reservoirs is related to how much water is needed downstream of the reservoir. The size and location of these reservoirs are interdependent; there is a zone along each canal where the water stored from upstream shutoffs can reliably be used to meet an appreciable portion of downstream demand. This concept is illustrated in Figure 1.

IID already has 10 reservoirs with a total combined storage capacity of approximately 3,300 acre-feet. Six are traditional main canal re-regulation reservoirs and four are integral parts of lateral interceptor systems. They are critical components of the existing operation, but would benefit from some modification and augmentation by additional reservoirs to accommodate the conditions anticipated in the future.

Estimating the Conservation Savings of IIM. The Imperial Irrigation Decision Support System (IIDSS) was used to estimate the reduction in spill that would result from implementation of IIM (Keller et al., 2008). Historical spill hydrographs were analyzed for eleven laterals, using only pre-interceptor data. To simulate the ability to back out spills with the new tools provided by IIM, it was assumed that there would be a three-hour average lag time between adjusting the lateral heading and seeing the result of the change at the spill point. It was further assumed that historical spills could not be reduced to less than 0.5 cfs, so spills less than this amount were not reduced. These assumptions were applied to all laterals longer than two-miles and with more than four gates. Short laterals (under two miles in length or with fewer than four gates) were similarly analyzed, except a one-hour lag was assumed with spills recoverable down to 0.2 cfs. The analysis predicted an average recovery of 58% of the spill in long laterals and 74% in short laterals.

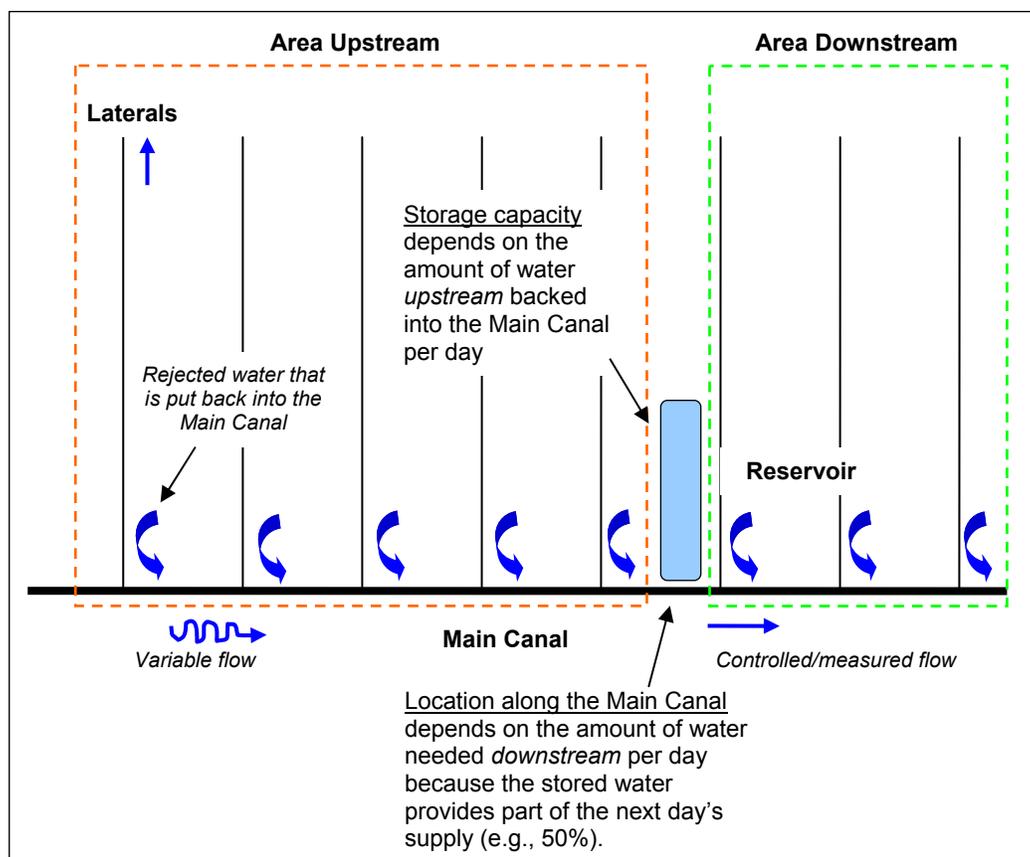


Figure 1. Concept for Sizing and Locating IIM Reservoirs

The IIDSS database was then populated with these values according to the lateral categorization with about 90% of the laterals considered long and 10% short. The MODSIM module of IIDSS was then operated for the 1998 – 2005 period of record with and without these multipliers to determine the amount of historical spill that could be conserved. The same values were applied to any rejected water from early shutoffs imposed by implementation of on-farm conservation.

In the portion of the system that would have zanjero reservoirs, it was assumed that the long-lateral relationships would apply. In other words, the reservoirs would be placed to allow response times and system savings similar to the simpler, steeper laterals upon which the analysis was based.

RESULTS

Seepage Interception

Designs were completed for 24 of the 25 seepage interception systems identified (Figure 2). The Myrtle Drain on the East Highline Canal had salt concentrations too high for use (13,000 $\mu\text{S}/\text{cm}$) and was eliminated. Pumping plants were located at points where drain alignment diverges from the canal alignment. This typically occurs at a junction point with a lateral drain or at the junction of two canal drains as they connect to a lateral drain.

In some cases this combines several reaches into one system. The basic design data and costs for the 24 systems are shown in Table 1.

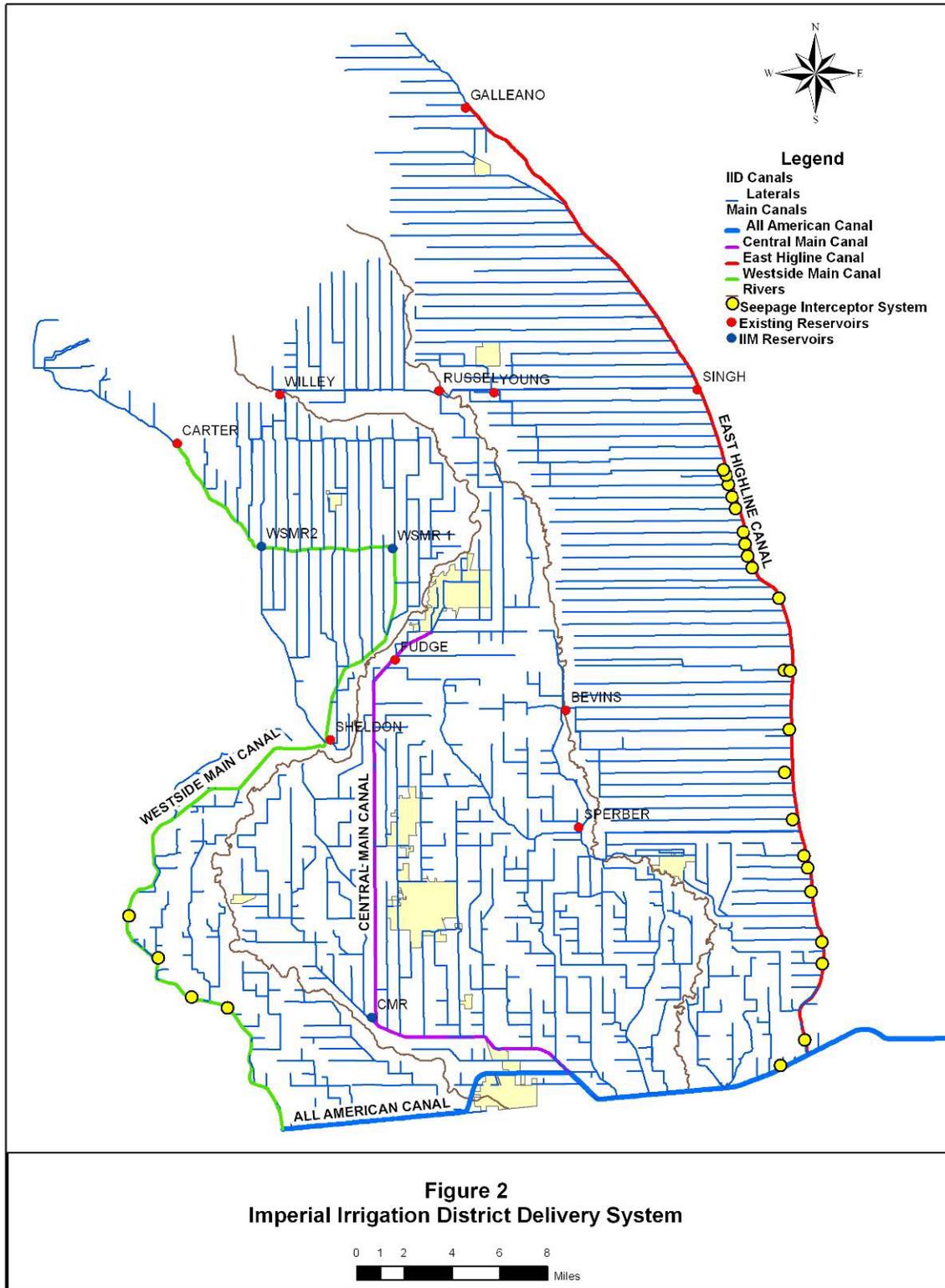


Figure 2
Imperial Irrigation District Delivery System

Table 1. Summary of Design Conditions and Costs for 24 Seepage Interceptor Systems

Drain	Electrical Conductivity μS/cm	Salinity Adjustment Ratio	Design Discharge cfs	Net Annual Volume AF	Total HP	Cost \$/AF
Holtville Main	1,107	1.00	4.38	3,847	15	\$7
14 drain	1,154	1.00	4.40	1,323	15	\$18
Pampas	1,269	0.99	3.42	1,988	15	\$15
Holtville 1-3	1,185	1.00	9.98	5,881	50	\$12
Township	1,123	1.00	3.38	1,992	15	\$14
Holtville 6-7	1,702	0.90	16.85	8,889	100	\$14
Orita	1,650	0.91	6.01	3,207	20	\$8
Moss	2,210	0.79	1.06	494	5	\$32
Magnolia	2,390	0.75	1.22	540	8	\$39
Mesquite	1,550	0.93	0.35	192	5	\$97
Maple	4,340	0.35	0.33	67	5	\$240
Myrtle	13,000	Can't use				
Munyon	3,550	0.51	0.81	244	5	\$72
Mulberry	1,400	0.96	1.93	1,130	8	\$19
Malva 1	1,440	0.95	1.18	659	5	\$29
Malva 2	1,550	0.93	1.71	935	8	\$20
Holtville 2C	1,480	0.94	1.83	1,137	8	\$14
Warren 2	1,377	0.96	1.10	698	5	\$27
Verde 2	1,645	0.91	3.30	1,972	15	\$14
Verde 4	1,500	0.94	2.20	1,358	10	\$14
Verde & Mesa	1,320	0.98	2.20	1,413	10	\$15
Fig & Fig 1	1,679	0.90	5.50	3,261	20	\$10
Dixie 3 & 3B	1,700	0.90	0.55	324	5	\$58
Dixie 2	1,780	0.88	2.20	1,274	10	\$20
Dixie 4	1,820	0.87	2.20	1,262	10	\$14
Average/Total	1,532	0.93	78.10	44,086	370	\$15

All flow values were based on a one-time spot measurement for each drain, so design capacity and conservation estimates were considered preliminary. In 2007, flow recorders were installed on several drains and bi-monthly readings began on the remaining drains to provide detailed design information and improved conservation estimates.

Total savings potential, discounted for salt concentration, is estimated at 44,100 acre-feet per year at an average cost of \$15 per acre-foot. There are a few systems that are significantly more expensive than the average, due to very small flow rates, elevated salt levels for a reduction in effective savings and somewhat larger costs in some cases. Cost begins to rise sharply at a cumulative savings of about 42,000 acre-feet per year. A savings of 40,000 acre-feet can be achieved for an average cost under \$13 per acre-foot.

Delivery System Changes

IIM Components. There are seven components that comprise IIM, each of which is described in this section: reservoirs (three types), SCADA system expansion (including new delivery scheduling and routing software), lateral headgate automation, remote spill monitoring, lateral tie-ins, upgraded spill structures, and non-leak gates.

Reservoirs. The combination of new and upgraded regulating reservoirs featured in IIM would provide 3,065 acre-feet of storage capacity, of which 2,266 acre-feet would be new storage. Together with IID's other existing reservoirs (not included in IIM), IID's total regulating storage capacity would be about 5,600 acre-feet. The reservoirs or reservoir types featured in IIM are summarized in Table 2.

IIM includes three new main canal reservoirs (Figure 2). The largest, with a capacity of 1,000 acre-feet, would be located on the Central Main Canal near the Dahlia Check (at the Elder and Eucalyptus Canals). This reservoir is positioned relatively high in the system to reduce carryovers, and to some extent re-regulate water backed out of upstream laterals. Two new reservoirs would be located along the Westside Main Canal, one near the Tamarack Lateral heading with 200 acre-feet of storage capacity and another near the Trifolium Lateral 11 heading with a capacity of 100 acre-feet. These reservoirs would serve primarily to re-regulate water backed out of upstream laterals. Combined, these new reservoirs would add 1,300 acre-feet of regulating storage to IID main canals (Table 2).

Table 2. IIM Regulating Reservoirs

Item	Total Storage Capacity after IIM (AF)	New Storage Capacity (AF)
Central Main Canal Reservoir	1,000	1,000
Westside Main Canal Reservoir (1)	200	200
Westside Main Canal Reservoir (2)	100	100
Upgraded Sheldon Reservoir	600	124
Upgraded Singh Reservoir	500	177
Zanjero Reservoirs ¹	665	665
Total	3,065²	2,266

¹ Zanjero reservoirs include reservoirs owned and operated entirely by IID, and possibly other reservoirs whose operations and costs would be shared between IID and landowners and growers.

² This sub-total only includes reservoirs listed in the table that will be added or modified as part of IIM. The overall total reservoir storage capacity in IID with the recommended IIM reservoirs would be increased by about 70% from the existing approximately 3,300 acre-feet to about 5,600 acre-feet.

As part of IIM, Sheldon Reservoir on the Westside Main Canal would be enlarged to 600 acre-feet from 476 acre-feet, and Singh Reservoir would be enlarged to 500 acre-feet from 323 acre-feet. Together, these projects would add approximately 300 acre-feet of regulating storage to IID main canals. The additional storage would increase IID's ability

to re-regulate water backed out from laterals into the main canals. In addition, the discharge capacities of both the Sheldon and Singh Reservoirs would be increased with new VFD-equipped pumping stations with 100 cfs and 75 cfs capacities, respectively. The increased pump capacity at these sites will allow the reservoirs to be emptied quicker, increasing the utility of the reservoirs and providing considerably more operating options.

Approximately 27 zanjero reservoirs with a combined capacity of 665 acre-feet would be placed primarily within large, flat, branching lateral systems, such as Ash, Acacia, Alder and Eucalyptus, where operations are more complicated and flow changes move slowly through the system. Seven of the reservoirs have been specifically sited. These have a combined capacity of 365 acre-feet.

Up to 20 additional smaller capacity reservoirs could be sited subject to additional site-specific investigations. It was assumed that these additional reservoirs would have an average capacity of 15 acre-feet. Recognizing that suitable reservoir locations along laterals are difficult to find, consideration would be given to incorporating existing or new private reservoirs into IID lateral operations through cooperative agreements between IID, growers, and landowners. Incentives could include ideas like letting growers use any recovered spill water on their land free of charge. Construction costs to IID could also be minimized by specifying that the pumps do not need to be automated or require complex pump platforms (e.g., low-head PTO propeller pumps would be suitable).

As a rule of thumb, these smaller reservoirs should be located approximately three-quarters of the way down the lateral. They could be placed on any lateral (branching or non-branching) where sufficient benefit in terms of combined on-farm and system savings could be achieved. The capital cost to IID for a typical smaller reservoir is estimated to be \$715,000; annual capital, operation, and maintenance costs are estimated to be \$51,000.

While these smaller reservoirs are recommended and costs are included in IIM, they were not specifically included in the conservation savings analysis, although their function was inferred in the process used to estimate total savings. They may provide opportunity for some additional savings or contingency in case the system cannot be operated to the potential assumed.

SCADA Expansion. Implementation of the IIM alternative would require a major overhaul of IID's SCADA and Information Technology (IT) systems. The existing hardware and software networks would have to be upgraded to have capacity for at least 500 more SCADA sites in the future. A common feature of all the modernization alternatives developed for the Definite Plan, including IIM, is a major upgrading and expansion of IID's SCADA system. An overall estimated cost of \$5.4 million was included in IIM for upgrading the existing IT systems, communications networks, human-machine interface (HMI) software, data management programs, etc.

Important aspects of the final configuration of the SCADA expansion and automation package depend upon *policy* considerations that require extensive input from district management staff and growers. At present, the following features are envisioned:

- Water Control Center (WCC) would receive frequent (once per minute, if there are changes in data) information from all key sites, including: automatic check structures in the main canals, water levels at all reservoirs, flow rate setting and actual flow rates at lateral headgates, reservoir outlets, lateral spill locations, and other key points.
- WCC would be able to remotely change target settings (i.e., lateral heading flow rates, flow rates discharging from reservoirs, levels in main canals) for various automatic structures in the system.
- Zanjeros would have remote monitoring and control capabilities within their run zones. They would be able, via mobile laptops, to see the same information that is seen at the WCC. Zanjeros would be given the discretion to change combined flows into and out of their zones within some maximum allowable variation (e.g., a net change of $\pm 10\%$). Greater changes would require permission from the WCC. The existing hydrographer positions may no longer exist as they are currently defined.
- “Routing” software would be used to immediately confirm the possibility that water orders from growers can be delivered. The routing software would compare the orders against available water supply and canal capacities. It is envisioned that this would considerably speed up the water order process – with either the zanjero or WCC being able to process orders. The rules for carryovers, and whether a final confirmation of a delivery can be immediately given, need to be resolved.
- Additional “scheduling” software would be available on two levels – (i) for each zanjero run, and (ii) for the main canal system. The “scheduling” software will enable the zanjeros or WCC to calculate when flow changes need to be made at critical points, so that the flow changes arrive at the intended location at the correct time.

Lateral Headgate Automation. One of the key SCADA-related components of IIM is the automation of lateral headgates. It was estimated that approximately 300 lateral headgates would have to be automated to cover the entire IID system. Lateral headgates are currently set by hydrographers. IID has already automated some lateral headgates using several different brands of gates. However, these automated gates are not presently under the direct control of the zanjeros, nor is flow information directly accessible to them remotely. These installations are estimated to cost \$76,900 with an annual cost (capital recovery plus operation and maintenance) of \$8,900.

Remote Spill Monitoring. Approximately 150 sites at the ends of canals/laterals (all those not presently monitored) would be equipped with remote monitoring (SCADA) equipment to provide real-time spill flow rates to zanjeros. The average estimated cost per site for spill monitoring is approximately \$45,400 with an annual cost of \$6,600.

Lateral Inter-Ties. There are numerous opportunities to physically connect the ends of laterals to other nearby laterals or main canals so spill can be recovered for use downstream. These lateral inter-ties would recover the operational spill and also greatly simplify operations upstream, although the spill must be remotely monitored so that operators can make the necessary adjustments when spill is occurring. It is anticipated that after several seasons of operation, the operators would gain experience with the approximate timing and flows of the inter-ties and be able to effectively route inter-connected spills. Seven laterals would be connected (by gravity) to adjacent laterals or canals and remotely monitored with an average estimated cost of about \$411,000.

Upgraded Spill Structures. Laterals spill into adjacent main canals at a number of locations in the IID system. Additional locations were identified for IIM as part of the Definite Plan where canals could continually divert more water than needed (for delivery demands) and easily spill back into a larger supply canal some distance downstream – moving the lateral control point to that downstream location. Eight locations for upgraded spills represent opportunities to improve the control of flows by effectively shortening the distance between the control point and the delivery gates. A Replogle flume would be installed to accurately measure spills from Mesa Lateral 3 to East Highline Lateral 1. At the other 7 locations, new spill structures would be installed using either long-crested weirs or ITRC Flap Gates. The total cost is estimated to be \$655,000.

Non-Leak Gates. Non-leak gates represent a simple, low-cost option for reducing lateral spills. Detailed planning was not completed for non-leak gates as part of the Definite Plan; however, investigations (unpublished, internal reports) related to the IID/Metropolitan Water District (MWD) conservation and transfer program showed that selective replacement of leaky gates (which would otherwise discharge water to drains) was the most cost-effective of all water conservation measures of that program. In 1999 the annualized cost was estimated to be \$44 per acre-foot of water saved. In the earlier IID/MWD program, only 14 of 127 potential non-leak gate sites were selected. It was estimated that non-leak gates installed at another 100 sites would cost an average of \$12,500 per gate and save 3,300 acre-feet annually.

Flow Measurement and Farm Delivery Automation. Although not included as a component of IIM, evaluation is underway for improved farm delivery measurement, including automated flow regulating gates with remote monitoring and control. This will influence farm delivery performance and the ability to reduce spills through improved lateral management anticipated by IIM and will play a key role in the routing and scheduling software anticipated as a part of IIM.

Estimated Water Conservation. The spill from IID laterals was estimated to average 120,600 acre-feet over the 1998-2005 time period. When modeled with the various IIM features in place, spill was reduced to 47,600 acre-feet for an estimated conservation savings of 73,000 acre-feet annually. This represents a 60% reduction in lateral spill. No influence on main system spill was assumed. In addition, 58% of water rejected due to early shutoff is assumed to be captured for reuse. The 42% that is lost has been accounted for in the net conservation savings of the on-farm conservation measures.

Cost Summary. The total implementation cost of these components is estimated to be about \$110 million; annual cost is estimated to be approximately \$10 million (Table 3 with values rounded). Over 60% of the cost is associated with increasing regulating storage in the IID system, at both the main canal and lateral levels. The average annual cost per acre-foot of savings at this level of performance is about \$137 per acre-foot.

CONCLUSIONS

Seepage Interception

At \$15 per acre-foot with the potential for up to 44,000 acre-feet of conservation, seepage interception is by far the most cost-effective of all the conservation programs analyzed in the Definite Plan. This program has moved forward to final design and it is anticipated to be fully operational by as early as December 2008. In final design, some changes have been made to the layout and the flow data being collected have changed conservation estimates of some of the units. As a result, four of the systems will likely not be built and one more is under evaluation. However, the resulting conservation is still expected to exceed 40,000 acre-feet per year. If less water is needed, fewer systems could be built.

Delivery System Changes

Of all the system changes evaluated, the most cost-effective are those described in the IIM configuration. At a cost of \$137 per acre-foot of conserved water the costs are well under the average annual expected revenue. Since these changes also facilitate on-farm conservation and capture some of the rejected water that will result from increased delivery flexibility, IIM also makes on-farm conservation more cost-effective.

The conservation potential of IIM is less certain than that of seepage interception as it is highly dependent upon the capabilities of operating staff given the new tools described. Therefore, the conservation potential has been given a range of from 58,000 to 79,000 acre-feet at a cost of from \$150 to \$200 per acre-foot.

Table 3. Recommended Components of IIM (May 2007)

Component	No.	Implementation Cost	Annual Cost
New Main Canal Reservoirs	3	\$32,102,000	\$2,683,000
Upgraded Existing Main Canal Reservoirs (Singh and Sheldon)	2	\$9,679,000	\$742,000
Zanjero Reservoirs ¹	27	\$28,530,000	\$1,780,000
SCADA Expansion	district-wide	\$5,392,000	\$916,000
Lateral Headgate Automation	300	\$23,063,000	\$2,663,000
Remote Spill Monitoring	150	\$6,863,000	\$1,003,000
Lateral Inter-Ties	7	\$2,876,000	\$197,000
Upgraded Spill Structures	7	\$655,000	\$57,000
Non-Leak Gates	100	\$1,250,000	\$79,000
Total		\$110,410,000	\$10,120,000

¹ Includes \$600,000 for electrical service for the 7 located reservoirs. The smaller reservoirs assume power availability, use of PTO pumps, diesel or compressed natural gas pumps or joint use with tailwater recovery system.

To test the effectiveness of the new tools provided for lateral operation, a test implementation was recommended in the Definite Plan and is expected to start in 2008. The software and hardware anticipated to improve lateral operation will be developed and implemented on a test lateral or set of laterals and the results monitored as the new operating conditions are implemented. This test program is anticipated to be completed in 2009 and the results will be used to finalize implementation plans and refine lateral operating procedures.

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**IMPERIAL IRRIGATION DISTRICT EFFICIENCY CONSERVATION
DEFINITE PLAN — DELIVERY/ON-FARM SYSTEM CONSERVATION
PROGRAM INTERRELATIONSHIPS**

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ABSTRACT

In 2003 the Imperial Irrigation District (IID), a 450,000-acre water district in Southern California, entered into a package of decisions and agreements known collectively as the Quantification Settlement Agreement and Related Agreements (QSA). As part of these agreements, IID agreed to a long-term transfer of water to the San Diego County Water Authority (SDCWA) and the Coachella Valley Water District (CVWD). According to the terms of the agreements, the water must come from conservation within IID. The transfer begins small but by 2026, IID must conserve and transfer 303,000 acre-feet of water each year or nearly 10% of their total annual water use. In 2007, IID completed their Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings. This paper, one of seven detailing the findings of the ECDP, describes the interrelationships between the delivery system capabilities, or service levels, and on-farm water conservation actions.

To achieve high combined delivery system and on-farm efficiencies, the delivery and on-farm systems must work in concert. Achieving the highest on-farm efficiencies requires the delivery system to accept water originally intended for delivery but rejected and to reroute the water to another delivery or store it temporarily in a reservoir, with the ultimate effect of reducing overall diversions. The amount of water ordered that would be expected to be returned to the system following implementation of on-farm conservation measures (termed dependent savings) was estimated and passed to the delivery system part of the Imperial Irrigation Decision Support System (IIDSS). Within IIDSS, the quantity of dependent savings that could be rerouted or stored was estimated and used to quantify net water savings. Incorporation of these interrelationships between on-farm conservation and net reductions in diversions at the district level was critical to evaluating conservation program alternatives.

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INTRODUCTION AND BACKGROUND

Water use in the West is changing, and nowhere is that being felt as acutely as the Imperial Irrigation District (IID), a 450,000-acre district in Southern California where longstanding agricultural water users are under intense pressure to transfer water to the region's ever-thirsty and ever-expanding urban areas. Four years ago, the IID agreed to launch a massive conservation program that would free up roughly 10 percent of its water for transfer to San Diego and others. The heart of the agreement called for the District to generate more than 300,000 acre-feet through a combination of District and voluntary on-farm efficiency conservation savings. In 2007, IID completed their Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings. This paper, one of seven detailing the findings of the Definite Plan, addresses on-farm conservation.

Achieving the highest on-farm efficiencies, particularly with surface irrigation, requires the ability to adjust the irrigation flow rate and time of application to match the soil intake characteristics at the time of the irrigation (Merriam, 1964). These intake characteristics vary from irrigation to irrigation and cannot be predicted in advance with certainty. This variability requires even the best managers to make changes to the stream size and duration of each irrigation event based on field observations to achieve the highest efficiencies (Walker and Skogerboe, 1987).

To prevent increased lateral spills potentially resulting from reduction of delivery flow rates and early shutoffs, flow at lateral headings must be reduced in a timely manner and the water re-routed to storage or another farm delivery. Especially for management improvements, the high on-farm efficiencies necessary to generate the required conservation volumes demand unprecedented levels of integration between IID's water delivery system and IID's growers.

The need for these increased levels of integration and determination of the volume of increased canal system reservoir storage required were important factors driving the development of the Imperial Irrigation Decision Support System (IIDSS), described in an accompanying paper (Keller, et al, 2008). IIDSS was configured to model the effects on the delivery system resulting from anticipated changes in delivery rates and durations associated with on-farm actions (termed conservation measures, or CMs) taken to achieve water savings.

This paper briefly outlines the constraining physical and institutional settings, describes the range of conservation measures considered and their anticipated effects on the delivery system, the modeling of these effects in the IIDSS, the modeling results and conclusions.

PHYSICAL AND INSTITUTIONAL SETTING

IID is located in Southeastern California. The land slopes gradually northward from the Mexican border to the south shore of the Salton Sea. Water for IID is released, per IID's

water order, from Hoover Dam and routed down the Colorado River to Imperial Dam near Yuma. At Imperial Dam, water is diverted into the All American Canal (AAC) for delivery to IID's service area. Water released at Hoover Dam requires between three and four days to arrive in IID's service area. Because little storage capacity exists within IID's service area and between Hoover Dam and IID's service area, any adjustments to the flow released from Hoover Dam must be small. This restricted capability for adjustment coupled with IID's practice of accepting water orders up to noon for delivery on the following day leads to the need for a mechanism of matching daily demand to the volume of water approaching the district.

IID matches the demand to the orders by ordering sufficient water to satisfy about 80 percent of the predicted demand. The IID then selects, based on defined criteria, orders to *carry over* until the next day to reduce the demand to match the ordered supply. This 20% under-ordering strategy has enabled IID to accept all the water ordered from Hoover Dam, except for rare instances of rain in great enough amounts to lead growers to cancel orders.

To maximize on-farm efficiency, growers must supply water to the crops at the right time and in the correct amount. IID provides growers the opportunity to order water any day they select and four out of five times (80% of the time); they will receive the water on that day. The volume of water is determined by the combination of the duration and rate. Growers select any rate they desire that does not exceed the capacity of the delivery gate to the field and are allowed to adjust the rate downward with three hours notice. Delivery rates can also be adjusted upward if water is available. IID requires growers to specify the order durations in 12-hour blocks.

Less than perfect estimates of the volume of water required and less than perfect measurements of the volume supplied result in the need to sometimes shut off water early and sometimes keep water longer. IID allows grows to shut off early when a three-hour notice is provided so that the water can be diverted to storage or another delivery. In addition, growers are often allowed to run two to three hours long, or up to 12 hours long if a finish head is requested not less than 15 hours before the delivery is scheduled to end.

These parameters within which growers are allowed to order and manage water with IID influence the effectiveness of the various conservation measures that may be applied to conserve water on farm. Without proper coordination with the delivery system, conservation measures operating within the framework of these rules and regulations, have the potential to conserve water on farm only to then spill it from the delivery system.

CONSERVATION MEASURES AND REJECTED WATER FRACTIONS

Conservation measures likely to be considered when water conservation incentives are offered were identified through consultation with Imperial Valley growers. The range of potential conservation measures identified includes measures that are currently in use in the Valley as well as those that may be considered in the future (Clark, et al, 2008).

Tailwater is the primary flow path targeted for reduction; however, adoption of conservation measures will potentially affect all on-farm flow paths, including delivered water, tailwater, tilewater, and crop evapotranspiration. Additionally, reductions in delivered water may occur within the normal delivery schedule or may require additional flexibility to shut off or reduce flows during an irrigation event. Conservation measures are characterized with respect to the amount of savings dependent on additional flexibility from the system.

Dependent savings is the portion of delivered water savings that results from changes to delivery flow or duration that are provided outside of IID's normal provisions for water delivery. Dependent savings for each CM were parameterized as a fraction of total savings, f_{DS} . Dependent savings ($DW_{sav,dependent}$) were estimated for each field-season and CM combination according to Equation 1.

$$DW_{sav,dependent} = f_{DS} DW_{sav} \quad (\text{Eq. 1})$$

Values of f_{DS} were developed for each CM based on the baseline irrigation method and are listed in Table 1. The derivation of these values is based on the mechanisms by which each conservation measure conserves water. First, if the conservation mechanism does not require delivery adjustments, the dependent savings fraction is estimated to be zero. Scientific irrigation scheduling, which as defined for the Definite Plan, simply leads to better initial estimates of the delivery flow rate and duration required, is an example of a CM that does not depend on delivery adjustments. Second, if the conservation mechanism requires delivery adjustments and includes on-farm storage, the fraction of savings that cannot be stored is estimated. Pressurized irrigation systems require a fixed flow rate and are anticipated to be operated in 12-hour and/or 24-hour blocks, thus, not requiring any additional flexibility.

DELIVERY SYSTEM IMPACTS DUE TO ON-FARM CONSERVATION MEASURES

Lateral spillage⁶ makes up the largest portion of IID delivery system losses, accounting for over half the total system losses and making up 70 percent of the potential conservable system losses. Some spillage is unavoidable and must be intercepted to be conserved. Other spillage can be reduced by improving system operations.

Observation of 15-minute recorded spillage hydrographs indicates that spillage is comprised of two components: an underlying base flow component and a variable component. The base component is related to the number of delivery gates and the existence of one or more service pipes (a service pipe supplies non-potable water to a farmstead). The variable component tends to cycle in association with the lateral

⁶ There are four general types of spills, or operational discharges, within the IID distribution system whereby excess delivery system water is discharged to drains: lateral spills, main canal spills, reservoir spills, and interceptor system spills. This discussion focuses on the first of these, lateral spills, which are by far the most numerous and significant in terms of total spill volume.

Table 1. Dependent Savings Fractions for CMs

Conservation Measure	Dependent Savings Fractions			
	Row	Flat	Drip	Sprinkle
Scientific irrigation scheduling	0.00	0.00	0.00	0.00
Scientific irrigation scheduling and event management	0.33	0.41	NA	NA
Minor management and physical improvements	0.00	0.00	0.00	0.00
Tailwater recovery systems with minimal storage	0.40	0.40	NA	NA
Tailwater recovery systems with minimal storage, extended delivery ⁷	0.20	0.20	NA	NA
Tailwater recovery systems with small pond	0.30	0.30	NA	NA
Tailwater recovery systems with small pond, extended delivery	0.10	0.10	NA	NA
Tailwater recovery systems with big pond	0.20	0.20	NA	NA
Tailwater recovery systems with big pond, extended delivery	0.00	0.00	NA	NA
Drip irrigation without reservoir	0.00	0.00	NA	NA
Drip irrigation with reservoir	0.00	0.00	NA	NA
Sprinkle irrigation without reservoir	0.00	0.00	NA	NA
Sprinkle irrigation with reservoir	0.00	0.00	NA	NA
Center-pivot irrigation, non-cropped corners	0.00	0.00	NA	NA
Center-pivot irrigation, cropped corners	0.00	0.00	NA	NA
Level basin irrigation, normal delivery	0.00	0.00	NA	NA
Level basin irrigation, flexible delivery	0.74	0.74	NA	NA

NA = Not Applicable

operational schedule, increasing a couple of hours before delivery setup and falling a few hours after. The early rise before the normal delivery setup time is associated with *rejected water* that results from irrigations finishing in less time than the 12 or 24-hour water order period. This is the volume of water that is returned to the delivery system from the farm due to delivery rate and duration adjustments during an irrigation event. The dependent savings discussed earlier result in *rejected water* in the lateral. To conserve this water, it must be prevented from spilling from the lateral. Starting, ending, and changing deliveries also contribute temporary flows to spills, which settle out a few hours after lateral setup is complete.

For example, a grower orders 15 cfs for 24 hours, but realizes after 18 hours that irrigation has proceeded faster than expected (perhaps because the estimated volume required was slightly high) and the irrigation will be complete in 21 hours. The grower calls IID and asks for his order to be turned off after 21 hours. In this example, three hours of 15 cfs of flow is *rejected water*. By requesting that his delivery be shut off three hours early, the grower has conserved this water. To ensure the water is conserved and not spilled, the delivery system must be capable of routing the *rejected water* to storage

⁷ Extended delivery is an operational strategy of reducing the flow rate and extending the duration to more effectively use the tailwater generated as a supply during the irrigation event.

or to another delivery. Characterization of *rejected water* according to the delivery system's ability to store and ultimately re-route *rejected water* to another delivery leads to two types: downstream and upstream.

Rejected water resulting from early order completion can be retained in the main canal if the water flowing into the lateral can be reduced in a timely manner. This is referred to as *upstream rejected water*. By keeping the water in the main canal system the options and likelihood of being able to store the rejected water and use it for another delivery are greatly enhanced. This is the purpose of the 3-hour notification rule described earlier. If the lateral heading cannot be reduced in a timely manner, the *rejected water* flows past the rejecting delivery gate and on downstream where it is diverted through lower open delivery gates, spills, or is intercepted, stored, and routed for use elsewhere. This latter type of rejected water is referred to as *downstream rejected water*.

On-farm conservation is anticipated to result in more of both types of *rejected water* than exists under current conditions. *Rejected water* occurs given the existing level of on-farm conservation. The average annual (WY1998 - WY2005) downstream rejected water was 21,000 AF. The average upstream rejected water was 76,000 AF/year. These existing levels of *rejected water* are expected to increase as the intensity of on-farm conservation increases.

To be conserved and not spilled, *rejected water* must be intercepted downstream or cut out upstream. Either generally requires storage so that the supply of *rejected water* can be matched with demand. Furthermore, *rejected water* routed downstream in tapered laterals could overtop the laterals if the downstream capacity is insufficient to carry the rejected flow on top of the normal flows. Hence, understanding the nature and fate of *rejected water*, and determining how it might be conserved by various system configurations was an important analytical aspect in the development of IID's Definite Plan. This understanding was developed through modeling in IIDSS.

DELIVERY SYSTEM MODERNIZATION OPTIONS TO CAPTURE AND REUSE REJECTED WATER

Two modernization and improvement scenario bookends were formulated including specific technical actions for the entire IID distribution system. The first scenario focused on spillage reduction with little change in delivery flexibility. The second, termed the maximum delivery system with delivery flexibility option, considered both spillage reduction and improved flexibility of water delivery including facilities to capture and reuse *rejected water*.

When it became evident that even the low bookend was not economically feasible, a least-cost option was developed by selectively removing high capital cost components from the low bookend while retaining key Supervisory Control and Data Acquisition (SCADA) and automation technologies.

This least-cost bookend was termed “Integrated Information Management” (IIM). IIM focuses on utilizing SCADA technology to set up an extensive real-time monitoring system for lateral canal spill and to automate all the lateral headings. Reservoir capacity would be increased by 2,266 acre-feet with three new and two upgraded main canal reservoirs and up to 27 additional small zanjero-controlled reservoirs to be located as needed for efficient lateral operation throughout the system. Water conservation would result from system operators (primarily zanjeros) making lateral heading flow adjustments based on real-time spill data, thereby reducing lateral spillage while maintaining farm deliveries. New and existing regulating reservoirs would absorb the inherent fluctuations in main and lateral canal flows, thereby minimizing lateral spillage and achieving steady main canal water levels. This option minimizes hardware and construction costs by relying on improved management through better information and control. A major change in system operation would be required. The final recommended configuration of components that make up IIM is reported by Bliesner, et al. (2008).

IIDSS MODELING OF REJECTED WATER

Downstream rejected water volume for each delivery is calculated as the delivered flow rate times the duration between the actual and scheduled delivery end time. Water must be ordered in 12- or 24-hour blocks. Thus, given the scheduled order duration, if the reported end time is less than the scheduled end time, the scheduled end time minus the reported end time equals the hours the order was rejected (turned back to the lateral). Multiplying the recorded delivery flow rate with the hours the order was rejected provides an estimate of the downstream rejected water volume. The maximum time an order can be rejected is assumed to be 6 hours. Any time a delivery gate closure occurs more than 6 hours early it is assumed the zanjero (lateral canal operator) would cut the flow at the lateral heading.

Upstream rejected water volume for each delivery is calculated as the ordered volume minus the delivered volume minus the downstream rejected volume. The ordered and delivered volumes are from the detailed delivery records. Upstream rejected water volume for each delivery is calculated as the ordered volume minus the delivered volume minus the downstream rejected volume. The ordered and delivered volumes are from the detailed delivery records. For 12-hour AM orders⁸ and 24-hour deliveries, IID brings into the main canal system 24 hours of water at the ordered flow rate. For 12-hour PM orders, IID does not bring in any water, thus the 12-hour PM orders are met with the unused portion of 12-hour AM orders. Accordingly, for the upstream rejected water volume calculation, zero is used for the ordered water in the case of 12-hour PM orders. Because the delivered plus downstream rejected water volumes can be greater than the ordered water, the calculated upstream rejected water can at times be negative.

MODSIM is the network solver component of IIDSS. The time series of delivery gate demands that are input to MODSIM consist of two time series for each gate. The first

⁸ 12-hour orders are either AM orders, starting in the morning (nominally at 6 am) and end in the evening 12 hours later, or PM orders, which start in the evening and end 12-hours later the following morning.

time series is used by MODSIM in its first pass through the delivery system network (see accompanying paper by Keller, et al. (2008), MODSIM Network Model, for a full description of MODSIM and the 3-pass approach used for simulating the IID delivery system). This first time series is called “ordered” water and is calculated as the sum of the delivered water volume plus the downstream rejected water volume estimated as described above. The second time series is the delivered water volume and is used for the second and third passes in MODSIM. Upstream rejected water is summed to the lateral headings and entered as a time series demand at the lateral heading.

It is assumed that the historical rejected water associated with each delivery gate will persist and that any additional rejected water resulting from program on-farm conservation will be added to it. Depending on the delivery system configuration, some portion of downstream rejected water may be reduced by cutting it out at the head of the lateral. When this occurs the cut portion of downstream rejected water is added to the upstream rejected water. Thus, under conservation the downstream rejected water, $R_{d/s}$, is calculated as follows:

$$R_{d/s} = (\text{Historical } R_{d/s} + \text{On-farm Conservation } R_{d/s}) * (1 - \text{cut fraction}) \quad (\text{Eq. 2})$$

In Equation 2 the cut fraction is the fraction of the rejected water that can be cut at the lateral heading. The upstream rejected water with conservation is equal to the historical upstream rejected water plus the cut portion of the downstream rejected water. Thus, under conservation the upstream rejected water, $R_{u/s}$, is calculated as follows:

$$R_{u/s} = \text{Historical } R_{u/s} + (\text{Historical } R_{d/s} + \text{On-farm Conservation } R_{d/s}) * \text{cut fraction} \quad (\text{Eq. 3})$$

The fraction of rejected water that can be cut out at the lateral heading (cut fraction) is dependent of the delivery system configuration. (See Bliesner, et al. 2008 for details on the various delivery system configurations.) Under the IIM configuration for “long” laterals (laterals longer than two miles and with more than four delivery gates), the cut fraction is estimated to be 58 percent. For “short” laterals (laterals less than two miles in length and with four or fewer delivery gates), the cut fraction under IIM was estimated to be 74 percent. These cut fractions were calculated as the portion of historical spill above 0.5 cfs with a duration longer than 3 hours for “long” laterals and longer than 1 hour for “short” laterals. The 3 hours and 1 hour are the average water travel times for “long” and “short” laterals respectively. The logic for these spill reductions under IIM is that if the spill is known in real time and the lateral heading is automated, the heading can be adjusted to cut the spill down to the target 0.5 cfs. Because of the water travel time in the lateral it takes 1 to 3 hours after the heading is adjusted before the cut at the lateral heading affects the spill.

RESULTS

Existing Rejected Water

The average annual (WY1998 - WY2005) *downstream rejected water* was 21,000 AF. Figure 1 shows a histogram of the *downstream rejected water* that was greater than zero (95 percent of all deliveries had no *downstream rejected water*). The *downstream rejected water* is less than 1 cfs-day (2 AF) for 55 percent of the deliveries with *downstream rejected water*.

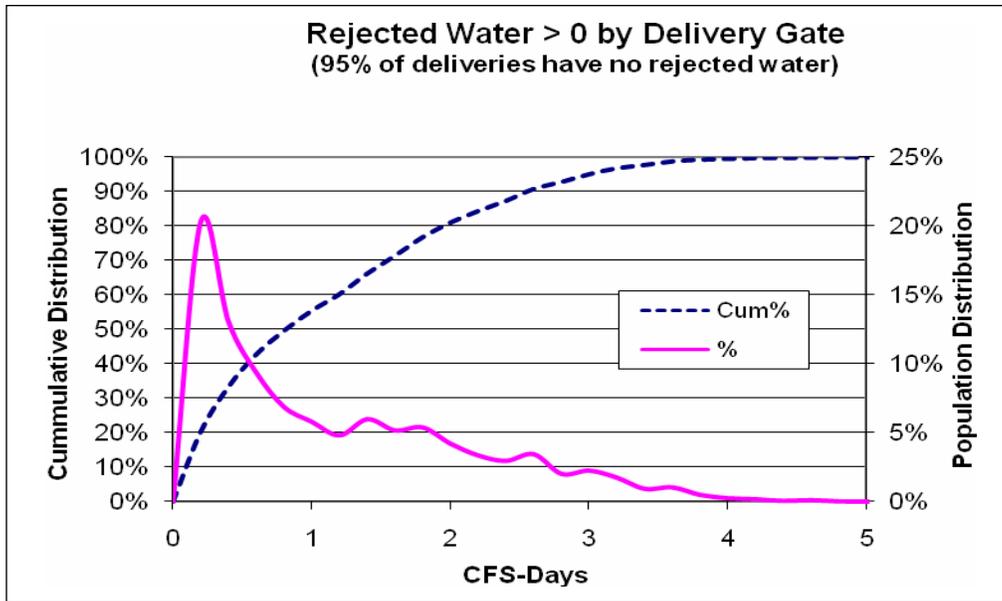


Figure 1. Histogram of Downstream Rejected Water Greater Than Zero

The average *upstream rejected water* was 76,000 AF/year. Figure 2 shows a histogram of the *upstream rejected water* that was not zero (34 percent of all deliveries had no *upstream rejected water*). The *upstream rejected water* is less than ± 1 cfs-day (2 AF) for 83 percent of the deliveries with *upstream rejected water*.

The high *upstream rejected water* estimate is a result of considering the 12-hour AM orders as equivalent to 24-hour orders and 12-hour PM orders are equivalent to zero order. Thus, every 12-hour order results in either a positive or negative upstream rejected water estimate. This reflects how IID operators order water from the Colorado River, including the AM 12-hour deliveries in the order and handling the rejected water from these orders by allocating the water to PM orders to the extent possible. The rejected water from AM orders not allocated to a nearby PM order is returned to the main canal and routed to the nearest downstream reservoir.

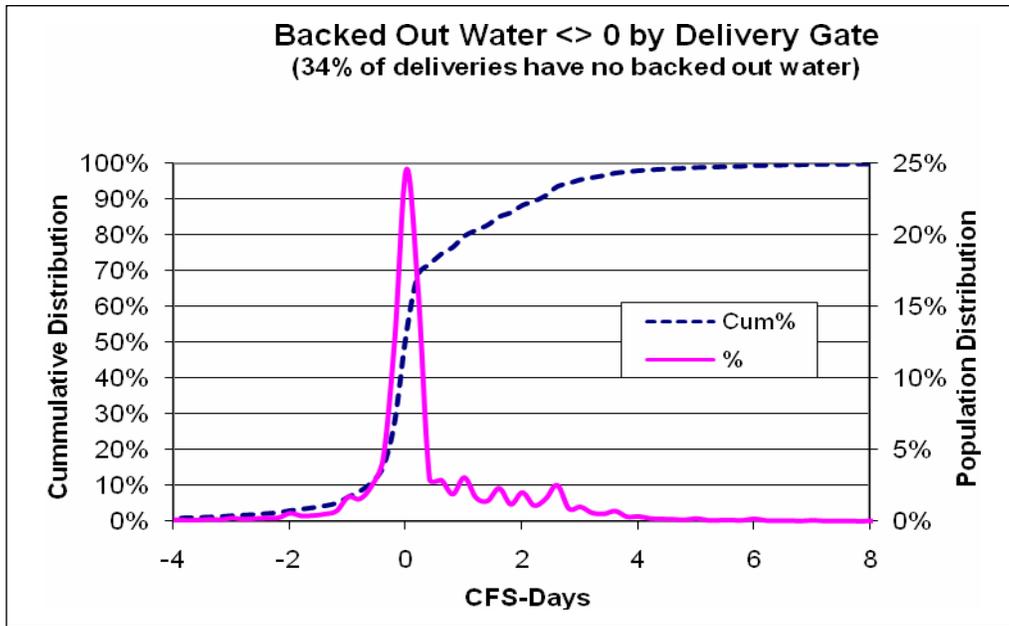


Figure 2. Histogram of Upstream Rejected Water not Equal to Zero.

Rejected Water with On-farm Conservation

The evaluation of on-farm conservation measures (CMs) and the savings that can be achieved with each measure (Clark, et al. 2008) indicated that to achieve the desired level of on-farm savings, those CMs that produce very little rejected water would dominate the on-farm mix. The various on-farm and system alternatives developed and analyzed with IIDSS runs showed about 8,700 acre-feet as the maximum increase in rejected water at a gross on-farm savings of about 143,000 acre-feet (Figure 3). From that point, as gross on-farm savings increase to 205,000 acre-feet, the increase in rejected water decreased to

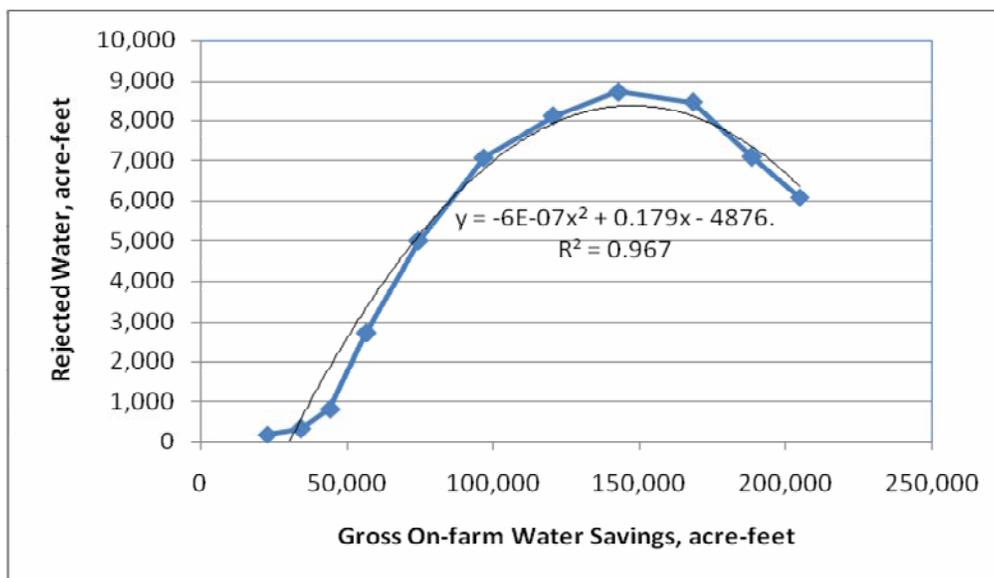


Figure 3. Rejected water as a function of gross on-farm water savings.

about 6,000 acre-feet. At the on-farm savings level of around 180,000 acre-feet for the least cost alternative (Hatchett, et al., 2008), only a small increase in the *rejected water* volume was observed. More than half of this increase was captured and saved by the IIM system improvement option and the remaining volume that was not captured was reduced from on-farm savings.

The maximum delivery system with delivery flexibility option did not provide any additional delivery system savings. However, it did provide the ability to intercept and use rejected water from implementation of on-farm conservation, thus providing for more flexible delivery and better on-farm irrigation performance. The net cost attributable to providing shutoff flexibility was found to be \$54,000,000 per year. Table 3 shows the cost per acre-foot of several levels of rejected water based on this flexibility cost allocation.

Table 3. Cost to Capture On-Farm Rejected Water for Delivery Shutoff Flexibility Option

Rejected Water Volume, AF	Cost, \$/AF
35,000	\$1,543
70,000	\$771
100,000	\$540

CONCLUSIONS

Considering the implications of on-farm conservation actions on the delivery system is critical to ensure that on-farm conservation is not eroded by increased delivery system spillage. When computing water conservation, care must be taken to ensure that on-farm savings that spilled from the delivery system are discounted from the on-farm savings total.

Enabling full delivery shutoff flexibility and capturing all rejected water is very costly. Other delivery system improvements capture a portion of the rejected water at a fraction of this cost. For example, the IIM option is capable of capturing almost 60 percent of rejected water, provided that growers give IID three-hour advance notification of early delivery shutoffs (Bliesner, et al., 2008). Also, the evaluation of on-farm incentive approaches (Hatchett, et al., 2008) suggests adoption of on-farm conservation measures (CMs) that produce very little rejected water at the level of water conservation required. Furthermore, if delivery gate automation is provided, the fraction of the rejected water that can be captured and reused will be increased. An operating guideline that requires a three-hour notice of early shutoff in conjunction with these other options is cost effective and will provide reasonable delivery flexibility.

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**IMPERIAL IRRIGATION DISTRICT
EFFICIENCY CONSERVATION DEFINITE PLAN:
DECISION SUPPORT SYSTEM FOR EVALUATING ALTERNATIVES**

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ABSTRACT

The Imperial Irrigation District (IID) completed their Efficiency Conservation Definite Plan (ECDP) in 2007. The ECDP outlines strategies for both delivery system and on-farm water savings totaling 300,000 acre-feet/year, roughly 10 percent of IID's water. This paper, one of seven detailing the findings of the ECDP, describes the Imperial Irrigation Decision Support System (IIDSS) used to examine alternatives to generate the savings and the effects of urbanization within IID occurring simultaneously with the planned implementation of the conservation measures.

The principle components of IIDSS are: 1) the geographic information system (GIS) of IID's water delivery system; 2) the Demand Generator; 3) a geo-referenced version of MODSIM (Geo-MODSIM); 4) various databases; and 5) a set of alternative comparison tools. IIDSS is geodatabase centered with its components closely coupled allowing seamless decision support system component interaction. The geodatabase is used to populate the Geo-MODSIM link-node canal system networks in IIDSS. All delivery system conservation and configuration alternatives are represented and manipulated through the GIS interface. The resulting geodatabases are then read directly by the Demand Generator and Geo-MODSIM. This paper describes these major IIDSS components, their integration, and the application of IIDSS to evaluate alternatives for the ECDP and the effects of urbanization.

INTRODUCTION AND BACKGROUND

Water use in the West is changing, and nowhere is that being felt as acutely as the Imperial Irrigation District (IID), a 450,000-acre irrigation district in Southern California where longstanding agricultural water users are under intense pressure to transfer water to the region's ever-thirsty and ever-expanding urban areas. Four years ago, IID agreed to launch a massive conservation program that would free up roughly 10 percent of its water for transfer to San Diego. The heart of the agreement called for IID to generate more than

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300,000 acre-feet/year through a combination of district and voluntary on-farm efficiency conservation savings. In 2007, IID completed their Efficiency Conservation Definite Plan (ECDP) that outlined strategies for both delivery system and on-farm water savings.

Simultaneously with the planned conservation, urbanization, particularly in the vicinity of the cities of El Centro and Imperial, will result in major changes to portions of IID's water delivery system. These changes include the conversion of irrigated land to municipal, industrial, and residential land use, associated modifications to water delivery schedules, and the piping and rerouting of canals.

The complexity of interactions between delivery system and on-farm systems, compounded by the dynamics of urbanization, necessitated development of an organized set of analytical tools configured specifically for IID to aid decision making, planning, and eventually operations. The Imperial Irrigation Decision Support System (IIDSS) was developed for this purpose.

IIDSS was originally developed to aid formulation and analysis of broad water conservation programs and projects. These programs and projects were analyzed to determine their feasibility, potential effects on the existing water delivery and drainage systems, and any consequential effects to the environment. In particular, the first phase IIDSS was applied to develop and analyze a "book end" range of feasible alternatives to achieve water conservation objectives and to characterize reasonable maximum and minimum effects to the environment that would be anticipated to result from application of conservation alternatives.

The ECDP Team took IIDSS to its second major phase of development by modifying the toolbox within the decision support system (DSS) from that used for "proof-of-concept" feasibility-level planning to that needed for definite project-level planning. The key role for this second phase of IIDSS was to aid in the completion of the ECDP Report detailing what water conservation projects need to be built; where these projects should be located; and the sequence and schedule in which projects should be constructed.

The primary goal of this second phase of IIDSS, reported here, was to understand the possible interactions between on-farm and system conservation projects as well as the on-farm project needs of the delivery system and the delivery system needs of the on-farm projects. Included in this second phase of IIDSS are "trade-off" tools to evaluate and determine the best projects for producing water as well as determining the most economically viable solutions.

IIDSS COMPONENTS

The principle components of IIDSS are:

- 1) The GIS of IID's water delivery system, which consists of more than 1,600 miles of canals and laterals linking over 5,500 water delivery points;
- 2) The Demand Generator for assembling time series of demands and analyzing the effects of various on-farm conservation incentive programs on those demands;

- 3) Geo-MODSIM (Triana and Labadie, 2007), the link-node network solver program which assembles the network from the GIS representation of the system, simulates routing water through the canal system to delivery points, and computes total IID water demand while accounting for predicted spills, seepage, and evaporation losses associated with various alternative canal and operation configurations;
- 4) Various databases of gaged flows, delivery details, field characteristics, and conservation measure attributes; and
- 5) A set of alternative comparison tools, which assist in summarizing results and facilitating the spatio-temporal analysis of large amounts of simulated data.

IIDSS is geodatabase centered with its components closely coupled allowing the various decision support system components to seamlessly inter. Geo-MODSIM uses the geodatabase to automatically create and populate the link-node canal system networks in IIDSS. All delivery system conservation and configuration alternatives are represented and manipulated (turned on or off) through the GIS interface. The resulting geodatabases are then read directly by the Demand Generator and Geo-MODSIM.

Figure 1 shows the relationship among the principle IIDSS components. The historical delivery time series and conservation measures are input from the IIDSS databases to the Demand Generator along with the delivery system configuration from the GIS. The Demand Generator creates a time series of demands that are passed to Geo-MODSIM. The Demand Generator creates a time series of demands that are passed to Geo-MODSIM.

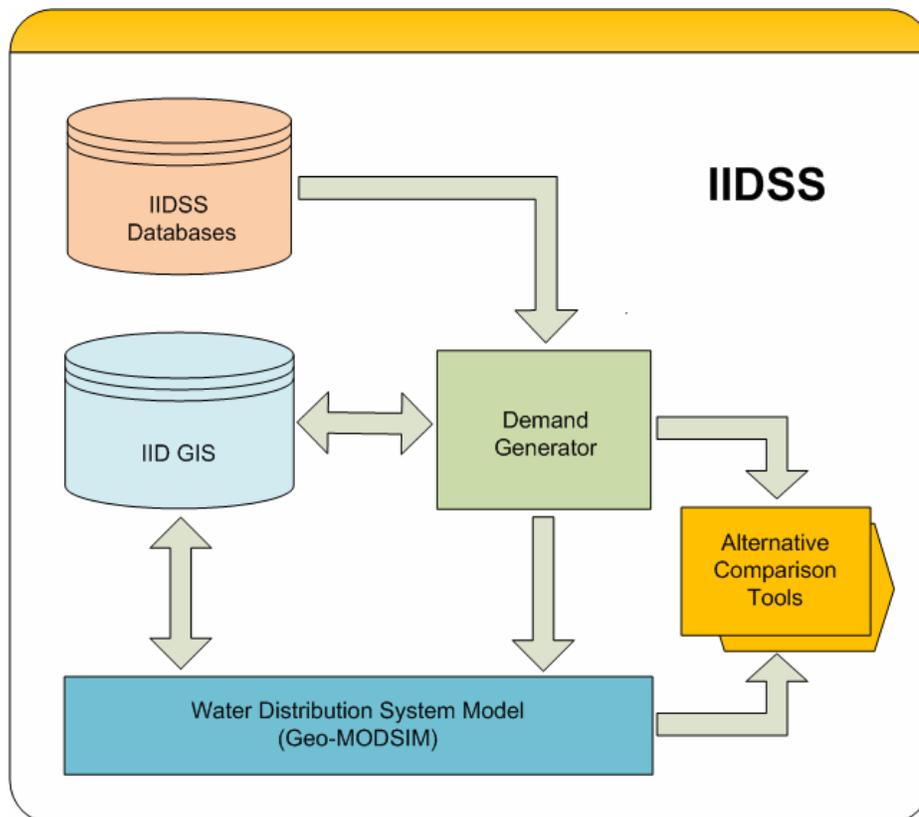


Figure 1. Relationship among Principal IIDSS Components

Geo-MODSIM then routes water through the delivery system to meet the time series water demands from the Demand Generator in accordance with the delivery system configuration detailed in the GIS. Both the Demand Generator and Geo-MODSIM can update the GIS. Alternative comparison tools then analyze results from the Demand Generator and Geo-MODSIM .

IID GIS

The upstream boundary for IIDSS is the All American Canal (AAC) at the Mesa Lateral 5 heading. This is the first major IID delivery and is located approximately 1/3-mile upstream from the East Highline Canal heading.

Orthorectified aerial photography served as the base for nearly all geographic information system (GIS) mapping efforts, and was pivotal for the Geo-MODSIM base mapping. Canals, delivery gates, interfaces, checks, fields, drains, reservoirs, pumpbacks, and other features of interest were identified on the high-resolution (1-ft and 2-ft) photography and digitized on-screen at appropriate scales.

Modeling the complex, large-scale water delivery system of IID begins with the design and implementation of an ArcGIS™ (ESRI, Inc.) data model. The data model is based on the standard Geo-MODSIM data model (Triana and Labadie, 2007) and customized to accommodate the IID modeling requirements. Geo-referenced objects are created that embrace the data required for application of Geo-MODSIM. The customized data model consists of:

- Canals—polyline feature class of all canals within IID. Attributes include reach length, capacity, lining status (lined, unlined, piped), seepage loss coefficients, water travel time, canal name and type (canal, lateral, interceptor, interface, etc). There are over 8,000 canal reaches in the IID GIS totaling more than 1,600 miles.
- Demands—point feature class of all water delivery points (farm delivery gates, M&I demands, pipe demands, and main canal spills) with IID. Attributes include name, associated canal, zanjero (ditchrider) run, and Geo-MODSIM modeling support variables for the IID system (e.g., base demand, associated *flow through* demand, downstream spill). There are over 5,500 delivery gates in the IID network.
- Non-storage—point feature class of non-storage nodes including generic junctions (changes in lining, changes in flow capacity, or modeling nodes), canal headings, canal interfaces (location where two canals join allowing flow to pass from one to another), terminal interfaces (end point of a lateral canal where it allows flow to another canal), interceptor interfaces (point connecting a lateral canal with an interceptor canal), reservoir interfaces (points connecting the lateral canal system with reservoirs), and return locations. There are almost 2,000 non-storage nodes in the IID geometric network.
- Reservoirs—point feature class of all reservoirs within IID. Attributes include name, capacity, surface area, depth, inflow and outflow capacity, and whether the inflow and outflow are gravity or pumped. There are 11 reservoirs.

- Sinks—point feature class of all spills, other than main canal spills, within IID. Attributes include name, associated canal, zanjero run, spill type (regular or interceptor), and base spill flow rate. There are nearly 250 spill nodes.

The data model contains an ArcGIS™ geometric network that includes of all GIS feature classes representing the system geometry and location and elements connectivity. Figure 2 shows the IIDSS calibration network from the GIS including demand, interface, reservoir, and spill nodes and canals by type.

Close coupling of the GIS in IIDSS allows the other DDS components to directly access the geodatabase. All delivery system conservation and configuration alternatives are represented in the GIS and turned on or off through the GIS interface. The resulting geodatabases are then read directly by the Demand Generator and Geo-MODSIM.

Demand Generator

The Demand Generator and Geo-MODSIM components of IIDSS operate on either a monthly or daily time step using programmatically modified historical water deliveries for October 1, 1997 through December 31, 2005. On-farm conservation is simulated by shifting the consumptive use fraction (CUF) of delivered water for each field and crop season based on an amount dependent on the economic incentive structure and array of potential conservation measures. (A critical component of the ECDP is a voluntary, incentive-based program to induce agricultural landowners and growers to conserve water.) The resulting CUF shift for each participating field and crop season is then used to adjust the ordered and delivered flow rate of historical deliveries.

On-farm water savings depend on the ability of the distribution system to re-route unneeded ordered water to another delivery or a storage location. Some of the simulated on-farm savings result in rejected water when water users use less water than ordered either because of finishing early or because of last-minute changes to actual deliveries. Some rejected water flows down the lateral where it spills, is diverted through delivery gates downstream, or is intercepted and routed to use elsewhere in the delivery system. Other rejected water is cut out at the heading of the lateral and is stored for later delivery, is delivered to another lateral, or is spilled. The Demand Generator estimates the rejected water and passes it to Geo-MODSIM along with the simulated deliveries.

Geo-MODSIM

Geo-MODSIM is a geo-referenced version of the MODSIM (Labadie, 2006) generalized network flow model developed at Colorado State University that has been incorporated as a customized extension in ArcGIS™. The geometric network (described above under IID GIS) provides the elements (i.e., objects and connectivity) to create a flow network in MODSIM capable of simulating the entire IID water delivery system.

A three-pass MODSIM computational scheme was designed and implemented to simulate the important structural and operational elements of the IID flow network. The three-pass scheme is performed sequentially, with each subsequent network building on



Figure 2. GIS Representation of Calibration Network

computations from the previous pass. The primary goal of the first two passes is to compute the spatially-located rejected water, making it available in the third pass where it is routed throughout the system (including interceptors) to meet demands. In the third pass, unused water is stored or spilled. The network is automatically transformed and loaded with data for each of the three passes used to simulate IID system operations.

The Geo-MODSIM interface provides synchronization of the multiple feature classes in the ArcGIS™ geometric network with MODSIM node and link objects and network topology. A customized Geo-MODSIM interface (Figure 3) was developed to implement a set of modeling tools specifically for the IID water delivery system in addition to the the general Geo-MODSIM functionality. The IIDSS enhanced modeling tools process and import IID specific data from the data model, import the Demand Generator time series at run time, and prepare and execute the three computational passes for solving the network. In addition, a set of analysis tools are implemented to provide summaries of the computational scheme consistency checks, including minimum flows, water shortages, and conveyance capacities violation. This customized version of the Geo-MODSIM (Figure 3) is the heart of the IIDSS. In summary, the enhanced Geo-MODSIM enables creation of the MODSIM network for the IID water delivery system, importing and processing of attributes from the data model, execution of the three-pass computational scheme, and post-processing for spatial display of output results and comparative analysis of individual elements.

IIDSS Databases

IID maintains computerized records of the water volume delivered to each tenant at each gate on the distribution system along with the crop grown on each field within IID's service area. These records begin in May 1986 and IID regularly reviews these records to ensure the highest, cost-effective quality of records to meet the goals of the record keeping program. The main goal of this record keeping program is to accurately implement a volumetric charge for the water delivered to each of IID's water customers. Secondary goals of the record keeping program include meeting Bureau of Reclamation data reporting requirements, supporting water balance analyses, water management plan development, and additional standard and ad hoc analyses to improve water management. The monthly billing process reports the charged water volume to each tenant at each gate.

Each month the delivery records are transferred from IID's water ordering system to a historical data warehouse known as IID's Water Information System (WIS). The WIS is a state of the art computer-based system used to store, process, retrieve, analyze and report high-quality historical data. It receives data from a number of different sources, applies quality control routines to ensure that the data stored is consistent and accurate, and generates both standard and special information reports.

The WIS was the primary source for the data used in the Demand Generator (and many other analyses supporting the ECDP). These data included daily time series of water orders and deliveries and crop, irrigated acreage, and planting and harvest dates for each field.

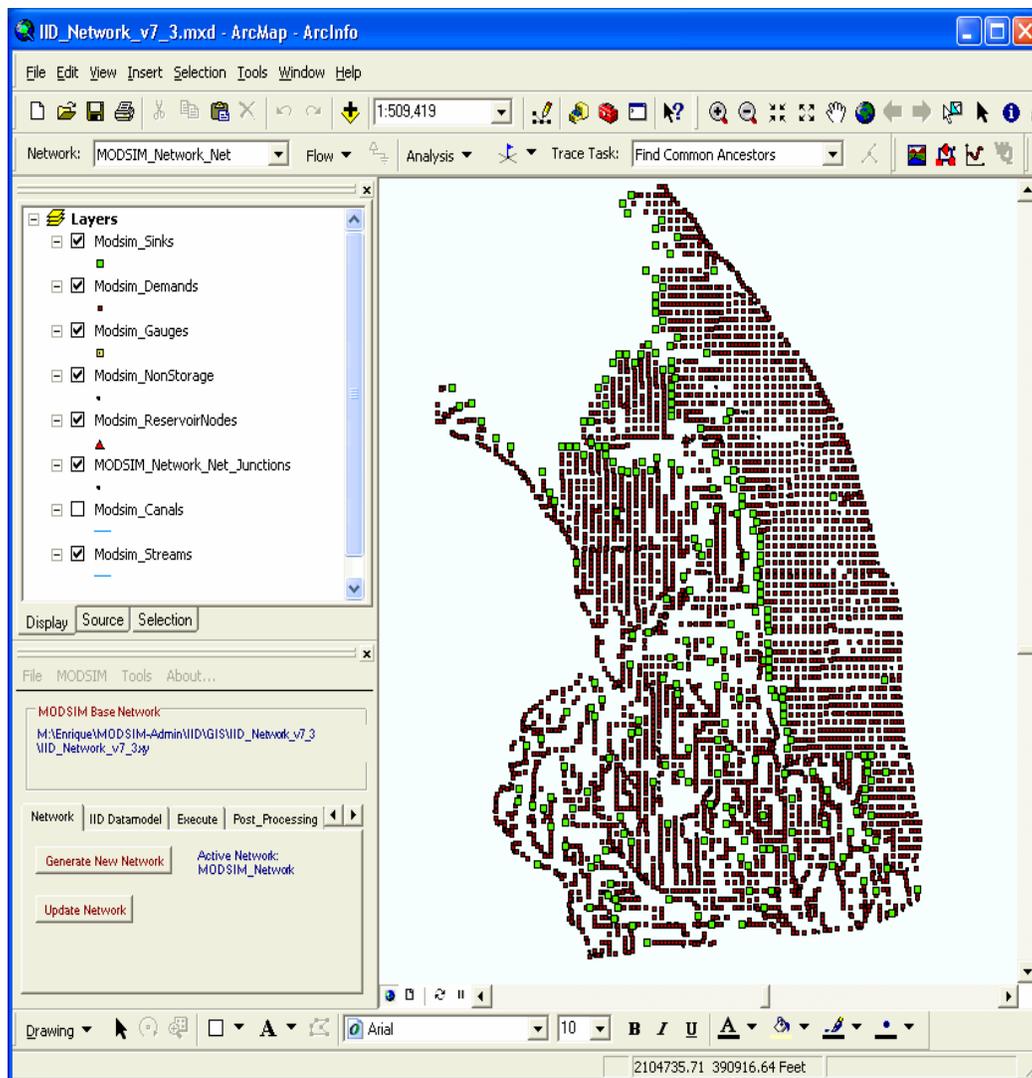


Figure 3. IIDSS Geo-MODSIM Interface Integrated into ArcMap™

Alternative Comparison Tools

The fifth principle component of IIDSS is a set of various tools for summarizing model results and comparing alternatives. Geo-MODSIM provides functionality to visualize the modeling results and compare scenarios directly in ArcMap™, and spatially display results by time step. Additional customized tools were developed for specific output post-processing and comparisons.

The Network Analysis Tool aggregates flows across the system features and generates a report of the water movement and placement. It summarizes inflow and outflow amounts by time step, allowing error checking of mass balance calculations in the system simulation. In addition, this tool performs summaries of the links that flow larger amounts than the nominal canal reach capacity per time step and also checks for minimum flows at selected locations guaranteeing adequate modeling of rejected water.

The tool lists information for the links that exceed the nominal capacity and computes the percent error.

Figure 4 is a screen shot of the IIDSS ArcMap™ interface showing time series spatial output from a Geo-MODSIM calibration run. The color of the canals indicates the percent of nominal capacity for each time step—greens for low relative flows and reds when simulated flow exceeds nominal capacity with yellows and oranges in between. The height of the bars at spill locations indicates the amount of spill for the particular time step.

The Performance Analysis Tool presents tabular and graphical comparisons of measured and simulated flow at several control points in the system. It is implemented with the ability to add a baseline run to the analysis and compare each run against the baseline and measured data. The tool computes errors, coefficients of correlation, and coefficients of determination to assist users in comparing runs and analyzing results.

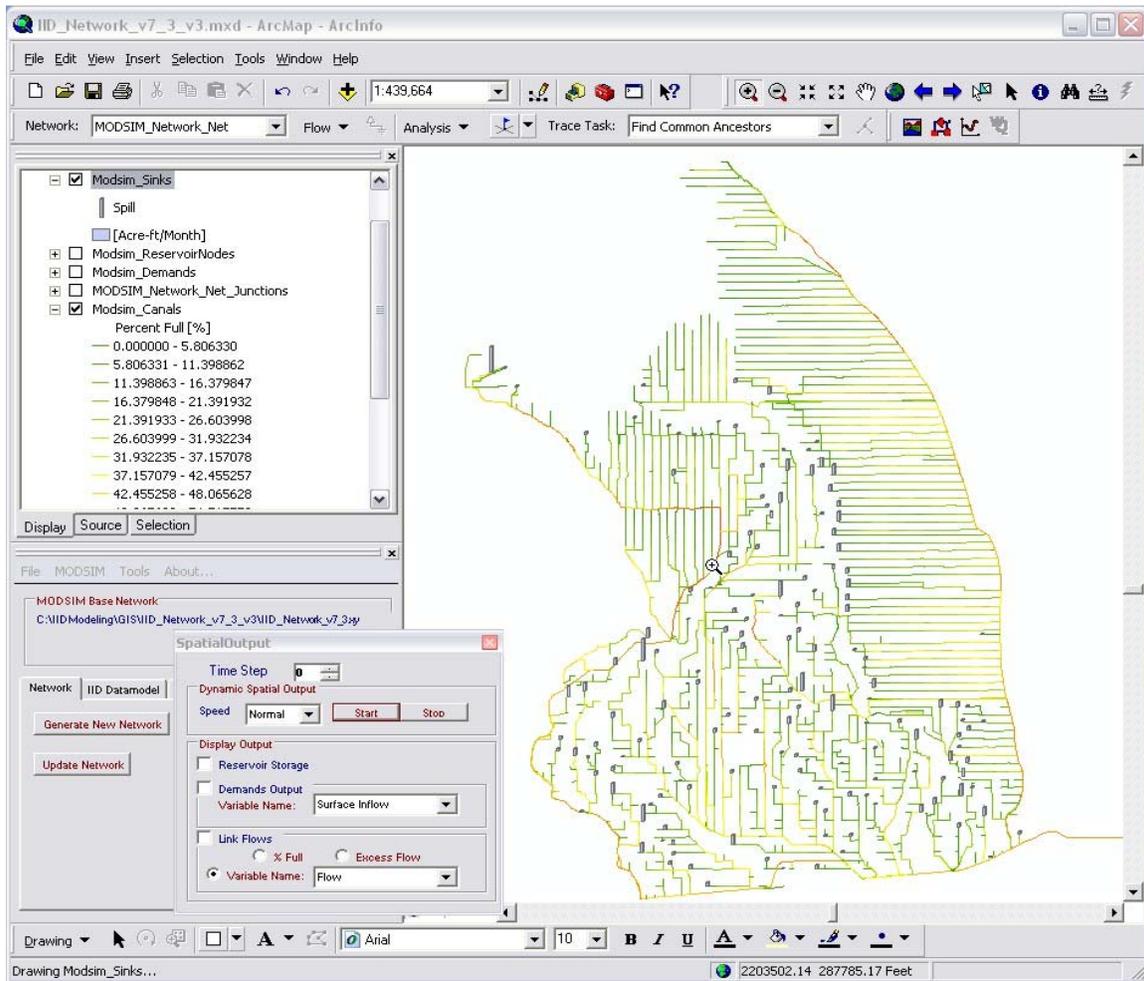


Figure 4. IIDSS ArcMap™ Interface Showing Spatial Output from Geo-MODSIM

Figure 5 shows the monthly calibration result for the All American Canal at the IIDSS boundary. The measured hydrograph is in red and the simulated is displayed in green. The scatter plot and statistics verify the excellent calibration.

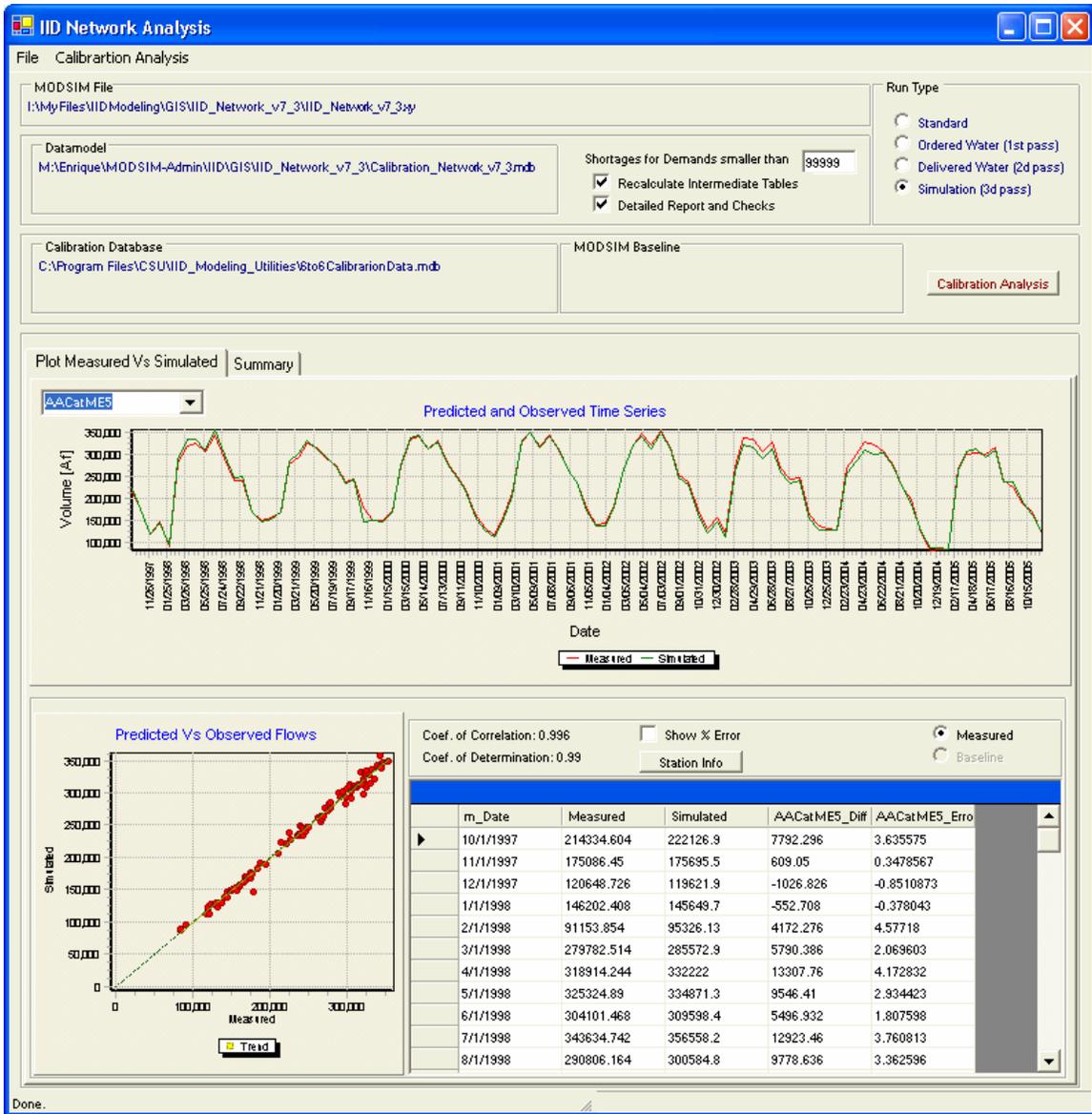


Figure 5. Performance Analysis Tool Interface (tabular and graphical analysis)

APPLICATION OF IIDSS

The ECDP Team used IIDSS to help determine what water conservation projects need to be built, where these projects should be located, and the sequence and schedule in which projects should be constructed. This involved evaluating numerous alternatives for on-farm conservation programs coupled with system alternatives to understand the possible interactions between on-farm and system conservation projects and to determine the best projects for producing transferable water as well as determining the most economically

viable solutions. The various alternatives evaluated are discussed in other papers in these proceedings.

Total water savings for an alternative was estimated as the difference between simulated inflows of the All American Canal for the “baseline” configuration less those for the alternative.

Accounting for Urbanization

Significant urban growth is occurring within the Imperial Valley, particularly in the vicinity of cities El Centro and Imperial. This growth has important implications to IID and, consequently, to the ECDP. First, urbanization reduces the pool of fields participating in on-farm conservation, and thus the on-farm conservation potential, as agricultural land use changes to residential, municipal, and industrial use. Second, it requires major changes to portions of IID’s water distribution system as some sections of canals are abandoned or need to be rerouted and whole new canals need to be added to supply delivery gates cutoff by the urban expansion. Third, it necessitates the addition of new delivery gates to supply new water treatment facilities. The same urbanization scenario of abandoned demands and canals and new bypass canals and delivery gates is used for the baseline configuration (Figure 6) and all alternatives.

Future Utility of IIDSS

The immediate next steps in the ECDP development are refinement of the recommended alternative and development of the implementation plan. These will require model enhancements and additions to the current second phase IIDSS. The most significant of these required changes is expansion of the Demand Generator functionality to simulate demands in addition to modifying historical demands.

The ECDP team anticipates that IIDSS will play an important role over the course of the next couple years in analyzing the various options for rerouting canals, determining required canal capacities, and planning for future urban growth.

The IID drainage system network is not currently implemented within the second phase IIDSS since it has not been a component in the ECDP analysis thus far. The drainage system was a key aspect of the first phase IIDSS for the environmental assessment of QSA water transfer. The ECDP Team anticipates that storm flow routing will be a necessary part of the urbanization impacts study and this will require incorporating the IID drainage system network into the second phase IIDSS toolkit. Because of the integrated nature of the DSS components, incorporating the drainage system network will be relatively quick and easy.

The ECDP Team envisions a third and fourth phase of IIDSS. The third phase of the development of IIDSS will be to refine new standard operating procedures for the water operations staff as well as to provide input for the “wet water” verification of the conservation projects. This phase will require the development of a user interface for less

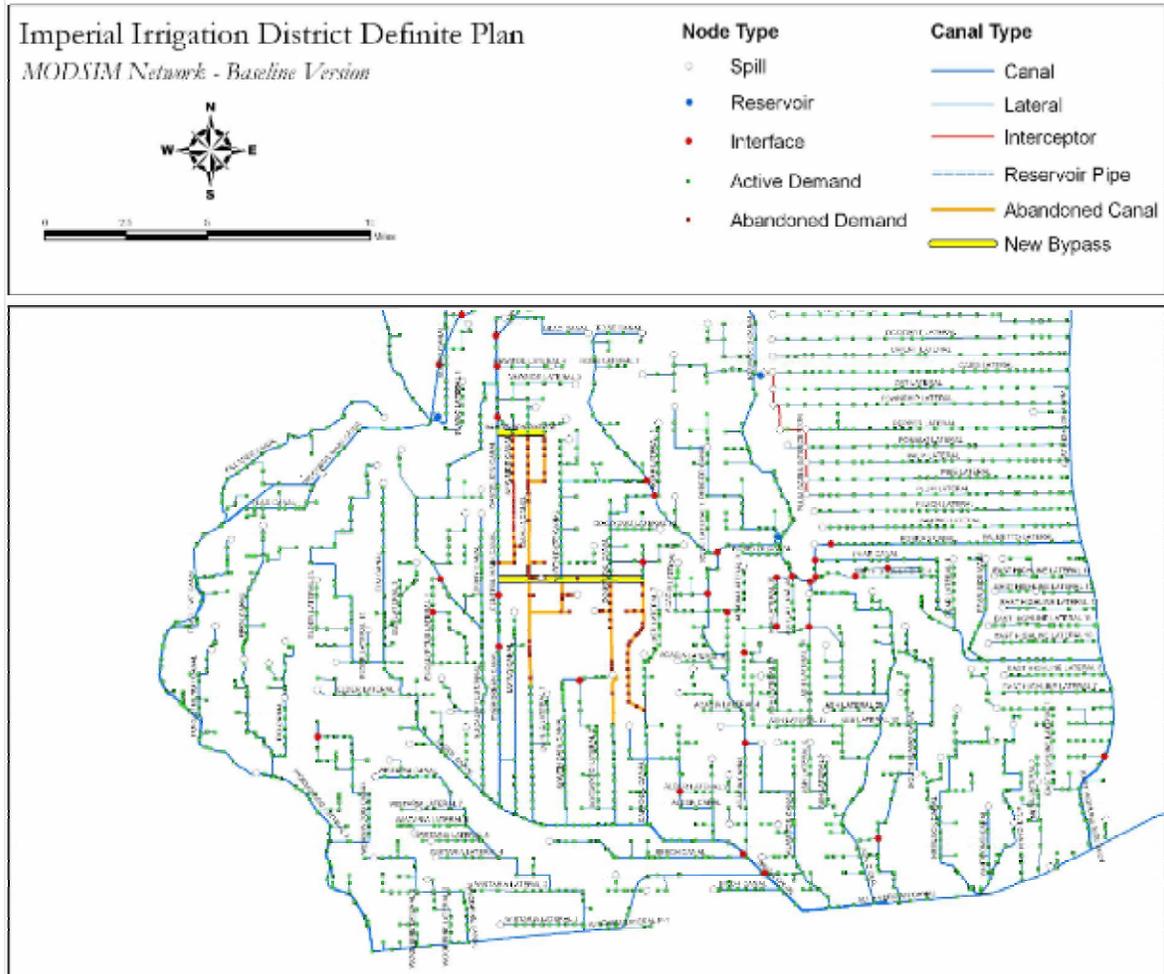


Figure 6. Baseline Configuration with Canal Network Changes Due to Urbanization

technical staff and models added to the tool box to allow short term time step analysis. In addition, tools will be added to IIDSS to aid water operations staff in forecasting water distribution and storage amounts based on water user orders.

The fourth and final phase of the development for IIDSS will be the integration of real-time data and linkage with the SCADA system for un-manned real-time operations decisions based on the status of the system water supply and user demands. This phase will codify the operations standard procedures and aid water operations staff in decisions related to gate settings and reservoir levels to maximize the distribution and allocation of water supplies to match user demands.

CONCLUSIONS

The principle components of IIDSS are: 1) the GIS of IID's water delivery system; 2) the Demand Generator; 3) a customized and enhanced version of Geo-MODSIM; 4) various databases; and 5) a set of alternative comparison tools. IIDSS was initially developed to analyze a "book end" range of feasible alternatives to achieve water conservation

objectives. Reasonable maximum and minimum effects to the environment that would be anticipated to result from application of conservation alternatives were characterized.

The IIDSS geodatabase centered approach with seamless integration of its components in a GIS environment represents a state-of-the-art decision support system for large-scale systems essential for the success of this project. The GIS representation of the system combined with the extended Geo-MODSIM capabilities and automated executions allowed an unprecedented detailed representation of the modeled system.

Future uses of IIDSS include developing and refining new standard operating procedures for water operations staff and the integration of real-time data and linkage with the SCADA system for support of real-time operations decisions based on the status of the system water supply and user demands.

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ALTERNATIVES FOR IMPLEMENTING EFFICIENCY CONSERVATION IN THE IMPERIAL IRRIGATION DISTRICT

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ABSTRACT

In 2003 the Imperial Irrigation District (IID), a 450,000-acre water district in Southern California, entered into a package of decisions and agreements known collectively as the Quantification Settlement Agreement and Related Agreements (QSA). As part of these agreements, IID agreed to a long-term transfer of water to the San Diego County Water Authority (SDCWA) and the Coachella Valley Water District (CVWD). According to the terms of the agreements, the water must come from conservation within IID. The transfer begins small but by 2026, IID must conserve and transfer 303,000 acre-feet of water each year or nearly 10% of its total annual water use.

In 2007, IID completed the Efficiency Conservation Definite Plan that outlined strategies for both delivery system and on-farm water savings. IID examined a large number of alternatives to generate the savings. Alternatives differed largely according to two features: the mix of on-farm versus delivery system savings, and the structure of the on-farm incentive program. Seven different mixes of on-farm and delivery system savings were evaluated, ranging from the maximum practical delivery system savings to generating nearly all savings on-farm. Four different incentive program approaches appeared to be viable ways of inducing sufficient on-farm enrollment. The incentive approaches differed in the way that growers would be paid for their participation.

The resulting alternatives varied significantly in their performance and cost-effectiveness. Costs included system conservation measures, payments to growers to implement on-farm measures, measurement and monitoring, and administration. System delivery savings of between 93,000 and 123,000 acre-feet per year provided the most cost-effective mix of savings. The complementary on-farm savings were 180,000 to 210,000 acre-feet per year, with average payments to growers between \$245 and \$300 per acre-foot saved.

This paper, one of seven detailing the findings of the Definite Plan, describes the development and analysis of alternatives to implement the conservation program, and summarizes important findings on how best to design on-farm conservation incentives to achieve cost-effective, real water savings without encouraging fallowing.

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INTRODUCTION

The objective of alternatives development is to identify the combinations of on-farm conservation and delivery system conservation that can best meet IID's requirements for implementation of the Quantification Settlement Agreement (QSA) and related agreements. Alternatives comprise different combinations of system delivery options, on-farm conservation volumes, and incentive program designs. These components are initially evaluated independently in order to screen out those that clearly cannot meet the requirements. Then the components are combined to evaluate different mixes of on-farm and system conservation. The most important requirement is that components be able to work within an alternative to produce the required level of savings within the financial constraints. The evaluation focuses on quantitative comparisons of options and alternatives, but includes other important criteria such as implementation considerations and verification of water savings.

The on-farm component of the Efficiency Conservation Definite Plan (Definite Plan) is a voluntary, incentive-driven program to implement irrigation conservation measures. The incentive program must induce sufficient voluntary participation by growers and landowners to meet the on-farm conservation component over the life of the water transfer agreement. At full implementation, it must provide a minimum of 130,000 acre-feet (AF) of annual, on-farm savings. Potentially, all 303,000 AF of annual savings could be provided by on-farm conservation.

Delivery system savings can range from 0 up to 173,000 AF per year. Because of the emphasis on on-farm water savings, delivery system conservation options should be low-cost and/or include elements that support on-farm conservation. The evaluation considered both stand-alone system options and integrated options aimed at improving system management and supporting on-farm conservation.

ALTERNATIVES DEVELOPMENT

Defining Efficiency Conservation

According to the QSA, at least 130,000 of the 303,000 acre-feet of conservation must come from contracted, on-farm efficiency conservation. Based on IID's understanding and intent when it signed the QSA, the following requirements were to be met by the Efficiency Conservation Plan⁵:

- All savings must be generated through efficiency conservation, defined as a reduction in losses associated with delivery and use of irrigation water. Water savings generated through actions such as fallowing, crop-shifting or deliberate deficit irrigation cannot be counted towards satisfying the terms of the QSA.

⁵ The Definite Plan evaluation team did not attempt to interpret the terms of the QSA – it simply followed these requirements as specified by IID.

- Grower participation is voluntary and incentive-driven. IID must provide sufficient incentive to compensate for the costs and uncertainties of changing irrigation practices.
- Growers choose the means of generating on-farm efficiency conservation.
- Water savings must be verifiable.
- The program must be financed through net revenues derived from the water transfers and related QSA provisions.

Verifying conservation will occur at two levels. First, IID's aggregate quantity of water diverted from the Colorado River must fall within its quantified allotment minus the amount transferred. Second, the on-farm savings must be verified as efficiency conservation rather than fallowing or other ET reduction. Therefore, IID must verify that participating growers have saved water relative to some reference level, or baseline, of water use.

But what is the appropriate reference level of field-level water use against which to measure savings? A number of ways to measure savings were considered, and they fall largely into three different categories: 1) measure a field's current water use relative to what the field would have used without the implemented conservation⁶; 2) measure a field's current water use relative to what that field had used in the past; or 3) measure a field's current water use relative to an aggregate (rather than field-specific) baseline.

Each of these ways of measuring savings has practical advantages and disadvantages. Also, each can provide growers with different incentives regarding which fields and crops to enroll in the program. The Definite Plan used the second approach to estimate savings, using historical water use records by field for the period 1998-2005. For each on-farm program evaluated, the water use on fields adopting conservation measures was compared to the water use on the same field in the historical database.

On-Farm Program Incentive Options

Measurement of savings is required to verify conservation, but it can also be used as the entire or partial basis for the incentive payment. The Definite Plan considered four ways to structure incentive payments to growers:

- **Pay for Conservation Measures.** Payment is based solely on the action taken by the grower. The grower is paid based on the conservation measure implemented (not on the measured amount of water saved). Water users could select from a set of approved practices or could submit their own proposals for on-farm practices that best suit their individual operations. Water users would be responsible for performing practices as specified in an agreement and would be paid on that basis, rather than based on achieving certain water use levels. Payments can be *uniform* per acre to all who implement a conservation measure or they can be

⁶ One way to implement this approach is simply to create a schedule of assumed savings by conservation measure, crop, and perhaps soil: for example, assume that conservation measure X (say, irrigation scheduling) reduces seasonal application rate on alfalfa by Y acre-feet per acre.

scaled to account for cost differences according to field size. This approach can assure that measures are implemented at a relatively low cost to the program, but it does not provide good incentive for growers to operate the measures well to achieve optimum savings.

- **Pay for Delivered Water Savings.** Payment is based solely on the result achieved (measured or estimated water savings). Regardless of the conservation measure implemented or its cost, the grower receives payment based on water use. The payment could depend on the amount saved relative to a reference level or the payment could depend on achieving a target rate of water use. This approach provides good incentive to hold water use low, but it can encourage fallowing or other ET-reduction activities. Also, depending on the choice of baseline, it may penalize growers who had been low water users in the past. Similarly, it can pay large amounts to growers that may have to do and spend very little to reduce water use.
- **Pay for Tailwater Savings.** Payment is based solely on the result achieved (measured or estimated reduction in tailwater volume or fraction). Regardless of the conservation measure implemented or its cost, the grower receives payment based on tailwater reduction. This approach has similar advantages and disadvantages to the Delivered Water Savings approach, plus it requires additional measuring devices for tailwater leaving the field.
- **Hybrid.** Payment is based on a combination of the action taken and the result achieved. Its purpose is to capture the best features of the two approaches above by basing a substantial part of the payment on actual cost of the implemented conservation measure (using either a *uniform* or a *scaled* payment as described above), plus an additional payment based on achieving verified water savings.

Payment based on water savings initially seemed the most likely to generate cost-effective savings because the payment is most closely tied to the overall program goal of reducing aggregate water use. As the Definite Plan evaluation team (team) began to analyze it using the historical database of field deliveries, several significant problems became apparent. First, the data showed a very wide range of apparent water use for a given crop and soil. Much of this variation appears to be real, but several data issues compounded the problem: recording errors, multiple-field gates, and moving water between gates introduced significant additional noise into the estimates of historical water use by field⁷. Under a pay-for-savings incentive, the same unit price is paid for all water saved, so large variation in savings per acre causes very large payments to some fields.

The team evaluated many combinations of unit payment amounts, baselines, and payment limits in an attempt to formulate pay-for-water options that were financially feasible, but it was unsuccessful for the reasons described above. Therefore, the payment for delivered

⁷ We did not detect any overall or systematic bias resulting from data errors. Total field water use matched well with District-level water balances, so positive and negative errors tended to balance. Nevertheless, use of the historical data as a basis for payments presents a substantial risk of enrollment bias for the on-farm incentive program – growers could choose to enroll fields that have data errors in their favor and omit fields that do not.

water savings and for tailwater savings were eliminated as feasible options for an incentive program. The team did recommend exploring ways to create a more consistent and accurate water use baseline, and IID will be developing such “certified gate histories” as part of the implementation phase.

Four incentive options were carried forward for further evaluation and for inclusion in comprehensive Definite Plan alternatives. These were:

- **Uniform Payment for Conservation Measures (Uniform PFM):** Growers are paid based on what they agree to implement, and each field receives the same payment per acre for a given conservation measure.
- **Scaled Payment for Conservation Measures (Scaled PFM):** Growers are paid based on what they agree to implement, but the size of the payment for a given conservation measure varies to account for economies of scale gained on larger fields, and possibly other factors.
- **Uniform PFM Hybrid:** The incentive payment would consist of two components. The larger portion would be a *uniform* payment based on the conservation measure implemented, and the smaller portion of the payment would be contingent on achieving a measurable level of performance.
- **Scaled PFM Hybrid:** The incentive payment would consist of two components. The larger portion would be a *scaled* payment based on the conservation measure implemented, and the smaller portion of the payment would be contingent on achieving a measurable level of performance.

Evaluation and Comparison of Incentive Options

The team evaluated and compared incentive approaches using both quantitative and qualitative criteria. The primary evaluation focused on quantitative analysis to estimate costs, payments, and other benefits to growers and landowners; to predict their selection of conservation measures based on the costs and benefits; and to estimate the resulting program savings, costs, and incentive payments. Other, qualitative criteria were also used to compare incentive program approaches that appeared to be feasible.

The evaluation of incentive approaches relied primarily on an analytical tool developed for the Definite Plan effort. The Demand Generator is a module of the IID Decision Support System (IIDSS), and is described in more detail in the companion paper titled “Decision Support System for Evaluating Alternatives.”⁸ The Demand Generator allows the user to define the features of an incentive approach. The Demand Generator then evaluates the costs, payments, and other benefits that each field in IID’s historical database would face under that incentive approach and selects the grower’s preferred decision.

The Demand Generator then modifies historical farm water orders to simulate the change in water demands anticipated from the adoption of its predicted selection of on-farm

⁸ Keller, Andrew et al. 2008.

conservation measures. These modified farm water orders and system delivery changes for an alternative are input to MODSIM, which simulates the flow of water throughout IID's canal delivery system, predicting spills, seepage, and evaporation losses associated with various alternative canal and operation configurations.

The Demand Generator can evaluate each of the candidate incentive approaches described above. The user selects the incentive approach and then chooses the necessary payment rates and other parameters and decision criteria needed to implement the incentive approach. For each approach, the user decides on a target level of average annual savings, and then adjusts parameters of the approach (e.g., payments per acre or per acre-foot of savings) as needed to achieve the target.

Figure 1 shows a comparison of the cost performance of these four incentive options for a target annual savings of 200,000 acre-feet. The figure shows the average implementation cost and the average payment to growers per acre-foot saved. Average payments exceed implementation costs because payments are somewhat standardized whereas costs vary from field to field. Fields which have costs higher than payments will not adopt a conservation measure, but fields having costs lower than payments will adopt.

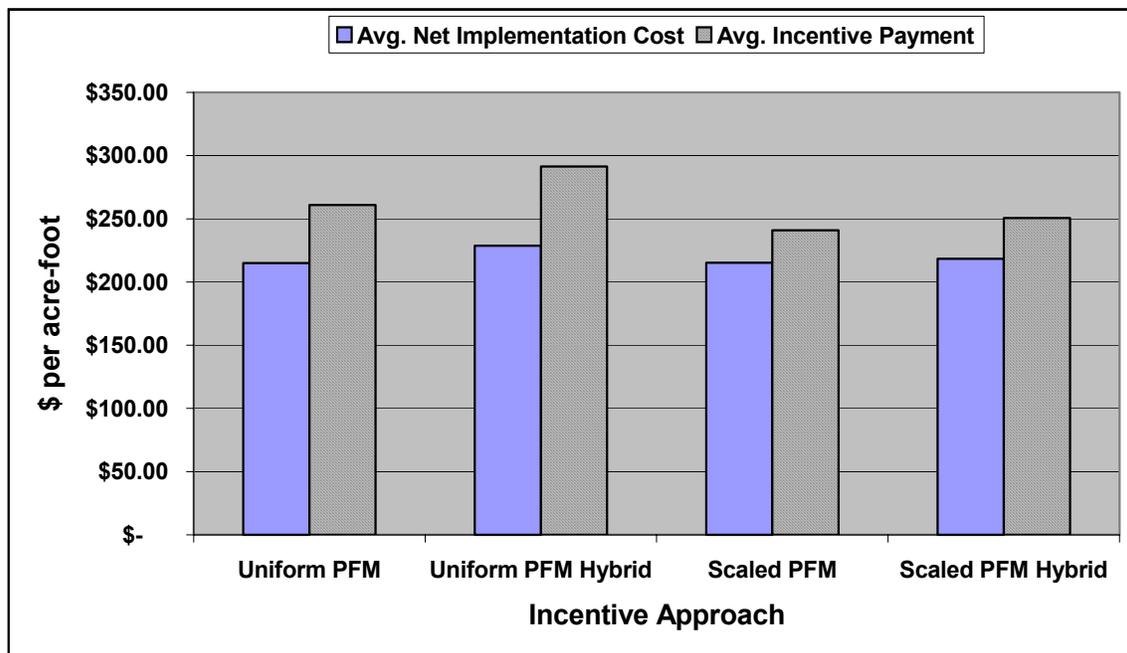


Figure 1. Comparison of net implementation costs and average incentive payments by incentive option at 200,000 AF per year, in \$ per net AF saved

Alternatives Definition and Evaluation

Alternatives are defined as combinations of system and on-farm conservation options that meet the overall financial and water savings goals while satisfying the other efficiency conservation requirements described earlier. One approach for selecting among a combination of options is optimization: scaling or parameterizing the possible options

and then using an algorithm that chooses the level of each to provide the “best” overall result. For the Definite Plan, a pure optimization approach was impractical for two reasons. First, a continuous range of delivery system options was not realistic. The screening and analysis of system options defined a set of discrete options that were feasible and cost-effective, and that provided the service level to support on-farm conservation. Second, the on-farm incentive options were structurally and conceptually different (they could not be nested within a more general mathematical formulation) and contained discontinuous and nonlinear payment formulas.

Therefore the analysis of alternatives was performed by developing a set of delivery system options and then formulating an on-farm program at a scale needed to generate the overall conservation target of 303,000 acre-feet per year.⁹ Table 1 shows the resulting set of combinations.

Table 1. Definite Plan Conservation-Level Alternatives

Conservation Mix Alternative	On-farm Conservation, ac-ft	System Conservation, ac-ft
1. Maximum on-farm	280,000	23,000
2. On-farm plus seepage interception	258,100	44,900
3. On-farm, seepage interception and least cost canal lining	255,720	47,280
4. System water for CVWD*	200,000	103,000
5. Least-cost combination	182,340	120,660
6. Maximum delivery system	158,800	144,200
7. Maximum delivery system with delivery flexibility	158,800	144,200

*The QSA includes up to 103,000 acre-feet of water per year (of the total 303,000) to be transferred to the Coachella Valley Water District (CVWD).

Each of these seven combinations was evaluated using the four incentive options, resulting in 28 alternatives.

The name of each alternative in Table 1 indicates the general parameters used to construct it. For most alternatives, the description also determined the split between system and on-farm savings. For the Least-cost combination, however, the exact savings split between system and on-farm savings was the result of a least-cost analysis. First, each of the four feasible on-farm incentive structures were evaluated in increments over the range of savings levels, with each increment achieving the targeted on-farm savings at the lowest cost to the program. Next, the cost and savings of the discrete delivery system

⁹ The delivery system option development is described in the companion paper: “Modifying the Delivery System to Conserve Water and Support More Efficient On-Farm Irrigation” (Bliesner et al., 2008). Note that the delivery system options were developed to save water on their own and to provide the service level needed to support the complementary savings from the on-farm program.

options were compared with the cost and savings of increments of on-farm savings. By ranking the options and on-farm increments in order of increasing cost per acre-foot saved, a marginal cost curve was constructed.

Figure 2 illustrates the results graphically for the Least-cost Combination alternative. The Figure shows the total annual savings along the horizontal axis as savings increments are added in order of increasing unit cost. The points denote on-farm increments or system savings options; the thin, stepped line is the marginal cost; and the dark line is the average cost. The red, horizontal line denotes the financial feasibility limit: the expected revenue received per acre-foot of saved water minus the estimated cost of administration and measurement. The average cost curve in Figure 2 indicates the minimum average cost (not including administration and measurement cost) to achieve any target level of savings.

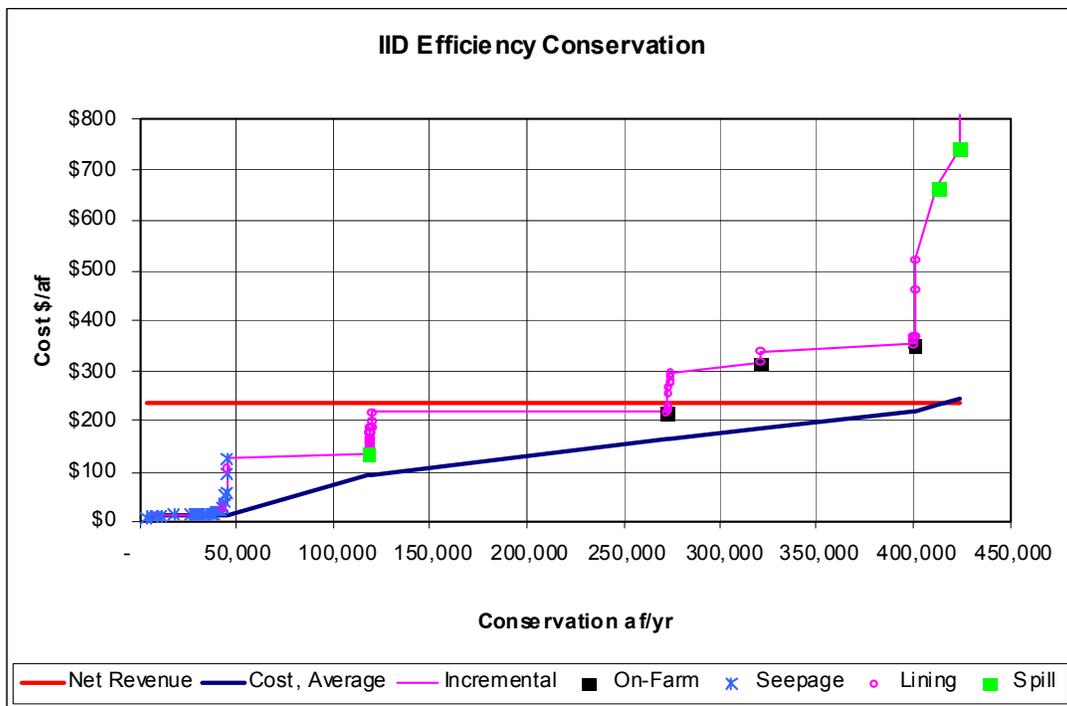


Figure 2. Incremental and average cost for the Least-cost Combination alternative

This approach was used for each of the four Least-cost Combination alternatives (one for each incentive option). The least-cost approach was used not because IID's intent was to minimize payments to growers, but because all of the incentive structures were close to or beyond the financial feasibility target. The incentive programs needed to be designed for the lowest program cost in order to provide a prudent amount of "financial headroom" to meet uncertainties in future conditions.

RESULTS

The graph of the alternatives presented in Figure 3 – each with the common measurement, administration and contingency costs of \$67 per acre-foot already added in – shows a wide range of costs for conserving 303,000 acre-feet. General findings are summarized as follows:

- Fourteen of the 28 alternatives analyzed had costs at or below the available revenue (estimated for the Definite Plan to be \$300 per-acre foot saved) and could be considered for evaluation and possible adoption as the recommended approach. Most of the Scaled Pay-for-Measures incentive alternatives fell below the \$300 threshold.
- Fourteen of the 28 alternatives exceeded the \$300 threshold and were not considered viable alternatives for consideration in Definite Plan implementation. More than half of the Uniform Pay-for-Measures Hybrid alternatives exceeded the \$300 limit. Uniform Pay-for-Measures fared second worst, with the cost of four of its seven alternatives exceeding the available revenue.
- A number of alternatives provided significant “headroom” between the alternative’s cost and the available revenue. Most promising were some of the Least-cost combination and System Water for CVWD (conservation mixes #5 and #4) alternatives, whose costs for most of the incentive options were between \$243 and \$268 per acre-foot – well below the \$300 threshold.
- Including a hybrid component with some of the incentive pay-for-measures approaches raised the cost across-the-board, but hybrid approaches provided better assurance that conservation measures would be operated to their potential.
- IIM is Integrated Information Management, a combination of automated lateral headings and spill monitoring to reduce canal spills. Configurations encompassing the IIM inter-related delivery system component (see Table 2 below) combined with seepage interception (Least Cost, conservation mix #5) or IIM plus seepage interception and canal lining (System Water for CVWD, conservation mix #4) had the lowest costs.

Based on these findings, five integrated alternatives were judged to be particularly strong candidates. These were: Least-Cost (conservation mix #5) with Uniform PFM, Scaled PFM and Scaled Hybrid; and System Water for CVWD (conservation mix #4) with Scaled PFM and Scaled Hybrid.

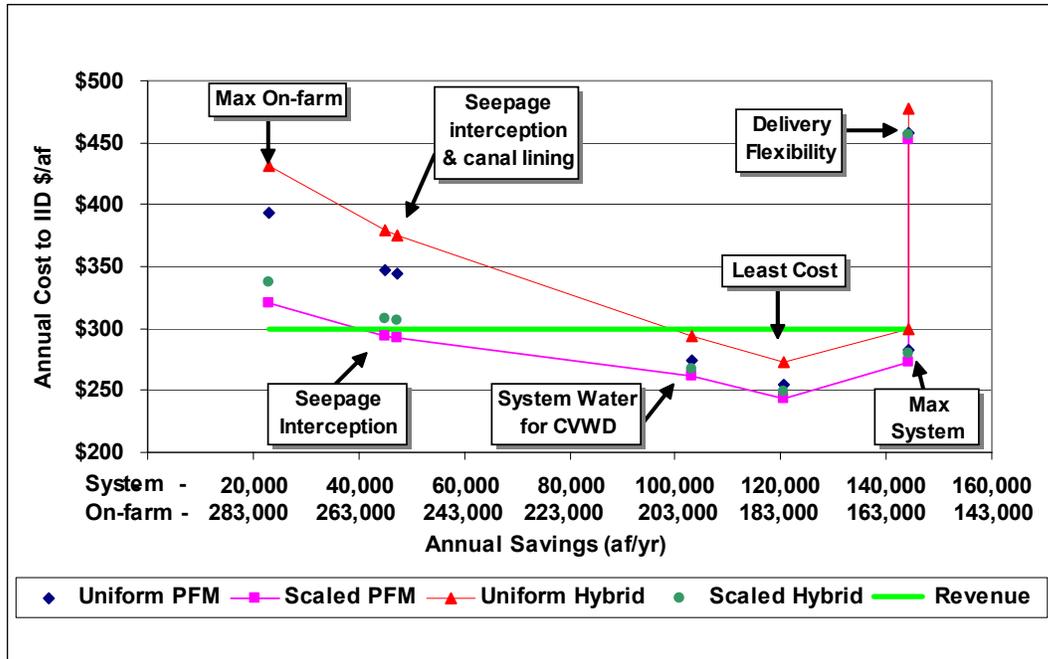


Figure 3. Comparison of Integrated Alternatives

Analysis of the alternatives suggested an optimal mix of between roughly 180,000 to 210,000 acre-feet of on-farm water savings combined with 93,000 to 123,000 acre-feet of delivery system conservation savings. Table 2 summarizes the range of conservation savings by component and average water savings costs over this preferred range.

Table 2. Component Savings and Average Costs Over Preferred Range of Savings

Conservation Component	Low On-farm Savings, acre-feet	High On-farm Savings, acre-feet	Average Cost at 180,000 acre-feet on-farm savings, \$/acre-foot	Average Cost at 210,000 acre-feet on-farm savings, \$/acre-foot
IIM	75,720*	53,000	\$136	\$189
Seepage Interception	44,900	40,000	\$15	\$15
Canal Lining	2,380	0	\$202	\$0
On-Farm	180,000	210,000	\$240	\$256
Total or overall avg.	303,000	303,000	\$247	\$279

CONCLUSIONS AND RECOMMENDATIONS

The analysis found that several alternatives can allow IID to fulfill its water transfer obligations through efficiency conservation within the limits of available revenues. A number of other alternatives either cannot work or are so marginal that they seriously reduce the prospects for success.

Based on this analysis, a set of six recommendations were developed that address: (1) the blend of on-farm and delivery system savings that IID should target; (2) the on-farm

incentive approach that IID should employ to attract landowners and growers voluntarily into participation; (3) the improvements that should be implemented within the IID delivery system; (4) the need to improve measurement of farm deliveries; (5) provisions for fulfilling IID's early-year (2008 – 2010) water transfer obligations; and (6) near-term actions to ensure IID has sufficient capacity to meet its water transfer obligations. Importantly, recommendations 1 through 4 are not separable; rather, they form an integrated package that cannot be separated without implication to the viability and performance of the overall efficiency conservation program.

- 1 ***Recommendation #1: IID should target on-farm savings in the range of 180,000 to 210,000 acre-feet and delivery system savings ranging from 93,000 to 123,000 acre-feet, at program build-out.*** This mix of efficiency conservation savings provides most of the savings through the on-farm program without imposing unnecessarily high costs that jeopardize the overall financial viability of the efficiency conservation program. Importantly, it affords the financial “headroom” that will give IID the flexibility to deal with inevitable program uncertainties.
- 2 ***Recommendation #2: IID should use the Scaled Pay-for-Measures Hybrid Incentive approach to attract growers voluntarily into the efficiency conservation program and to achieve the targeted on-farm savings.*** The Scaled Pay-for-Measures Hybrid approach offers the best combination of cost-effectiveness, administrative ease, and – importantly – the increased likelihood that on-farm conservation measures will be operated at or near their potentials. No other approach is as effective, and each would increase the risk that IID will not be able to meet its future water transfer commitments within the available budget.
- 3 ***Recommendation #3: IID should implement seepage recovery and Integrated Information Management to achieve the targeted delivery system savings, and to enable the targeted on-farm savings.*** The analysis showed that extensive physical modification of the IID delivery system is both extremely expensive and unnecessary for a viable efficiency conservation program. The recommended improvements are a more modest combination of physical and operational changes that will provide cost-effective system savings and provide growers with the improved delivery services needed for implementing the on-farm conservation measures.
- 4 ***Recommendation #4: IID should implement improved measurement of farm deliveries. Consideration should also be given to equipping the farm delivery gates with automatic flow control to hold deliveries steady and radios to enable remote control.*** IID's existing methods of measuring farm water deliveries, while adequate for present water administration purposes, will become inadequate for purposes of verifying on-farm water savings and administering incentive payments based on water use criteria.
- 5 ***Recommendation #5: IID should rely on selected seepage recovery projects and on-farm and delivery system pilot projects to generate early year – 2008 through 2010 – water savings.*** Main canal seepage recovery systems can be constructed easily, provide the ability to scale savings to match the transfer schedule, and are easily verified. However, to the extent on-farm pilot programs produce verified savings, these could be combined with system savings to fulfill early-year water transfer requirements.

- 6 ***Recommendation #6: IID should take a series of steps to ensure it is ready to meet its near-term water transfer obligations.*** Decisions on near-term actions will serve two aims: (1) to ensure IID is ready to meet its most immediate water transfer requirements; and (2) to prepare for launching a more comprehensive program. These actions include both concrete steps to generate near-term water; and on-farm demonstration and system pilot projects to refine longer-term program approaches.

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THE GILA RIVER: A TRANSITION FROM AGRICULTURAL TO URBAN ENVIRONMENT

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ABSTRACT

The headwaters of the Gila River are in western New Mexico. From that beginning, the river crosses the state of Arizona, joining the Colorado River near Yuma. The Salt River with its major tributary, the Verde River, joins the Gila River in the western Phoenix metropolitan area. The Salt/Verde/Gila River system is the largest source of agricultural water in Arizona. Numerous dams, beginning with Roosevelt Dam, were constructed on those rivers for water storage conservation and in the 1990s flood control was added. Diversion dams, such as Granite Reef and Gillespie, were built in the early 20th century to divert water into canal systems that provide irrigation water to large areas of agriculture. Irrigation districts such as the Salt River Water Users' Association, Buckeye Water Conservation and Drainage District, and Roosevelt Irrigation District rely on the Gila River both as a source of water and for collection of drainage water.

Urban growth is changing the character of the agricultural land and is placing new demands on the Gila River beyond its traditional role as a source of irrigation water and agricultural drain. The transition of the land from agricultural to urban is placing a greater need for flood control and bank stabilization of the river.

Concurrent with the use of the river for irrigation water supply and the recent urbanization of the adjacent land, the floodplain has been subjected to continued infestation by tamarisk trees which are not native to Arizona. More recently the riverbed is mined for sand and gravel to meet construction needs in the Phoenix metropolitan area. There is public and institutional interest in the river from a recreational, environmental and social perspective.

The Flood Control District of Maricopa County undertook the El Rio Watercourse Master Plan (El Rio Project) to address the changing nature of the Gila River, the growing need for flood management, concerns about riverbank stability, management of riparian

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vegetation, public safety and health needs, environmental sustainability and recreational opportunities. The El Rio Project investigated the historic and existing river and assessed the future form and function of the river to meet its changing needs.

This paper presents an overview of the hydrologic and hydraulic conditions of the Gila River in the El Rio Project area. The implementation of the El Rio Project will enhance public safety, economic growth, environmental sustainability and recreational opportunities in the study area. The El Rio Project is an example of meeting the changing demands on rivers to serve both agriculture and urban growth.

INTRODUCTION

The Flood Control District of Maricopa County (District) in cooperation with the City of Avondale, City of Goodyear and the Town of Buckeye, initiated the El Rio Watercourse Master Plan (WMP) project because of development pressures along the Gila River in the west Phoenix metropolitan area, the record of historic flood events and the increased need for health and safety measures.

The data analyses and conclusions that are presented in this paper are based on the El Rio WMP study of a portion of Gila River. That study area starts at the confluence of the Agua Fria River immediately downstream of the confluence of the Salt River with the Gila River and the project extends west about 17.5 miles. The conclusions presented in this paper are for that portion of the Gila River and the conclusions can be applied to downstream portions of the Gila River that have the same characteristics as the study area.

The El Rio WMP defines the existing river and the future desired form and function of the river. The focus of the plan is to maintain and enhance the natural functions of the Gila River through flood-control management strategies. Figure 1 depicts the location of the project area in relation to communities in the Phoenix metropolitan area.

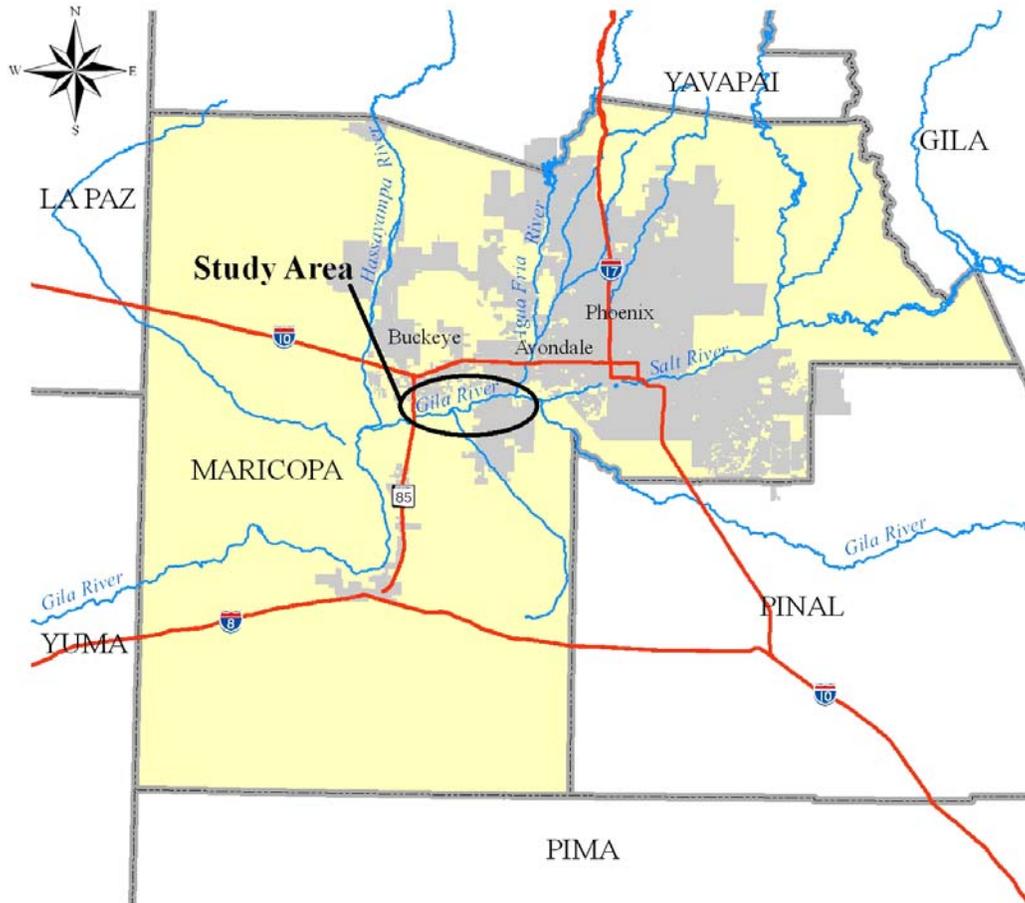


Figure 1. Vicinity Map

The Gila River is a source for domestic, agricultural and industrial water uses, offers nourishment and habitat for wildlife, is a source for building materials, and offers recreational opportunities. In high runoff years, the river transports the excess water to the Colorado River.

The Gila River watershed is about 46,000 square miles covering portions of New Mexico, Arizona and the Republic of Mexico, as shown in Figure 2. Numerous large tributaries drain to the Gila River including the Salt and Verde rivers. The upper reaches of the watershed consist of rugged, mountainous terrain with incised watercourses, some are perennial. The lower reach of the watershed is characterized as a basin and range physiographic region with braided, alluvial watercourses of intermittent flow.

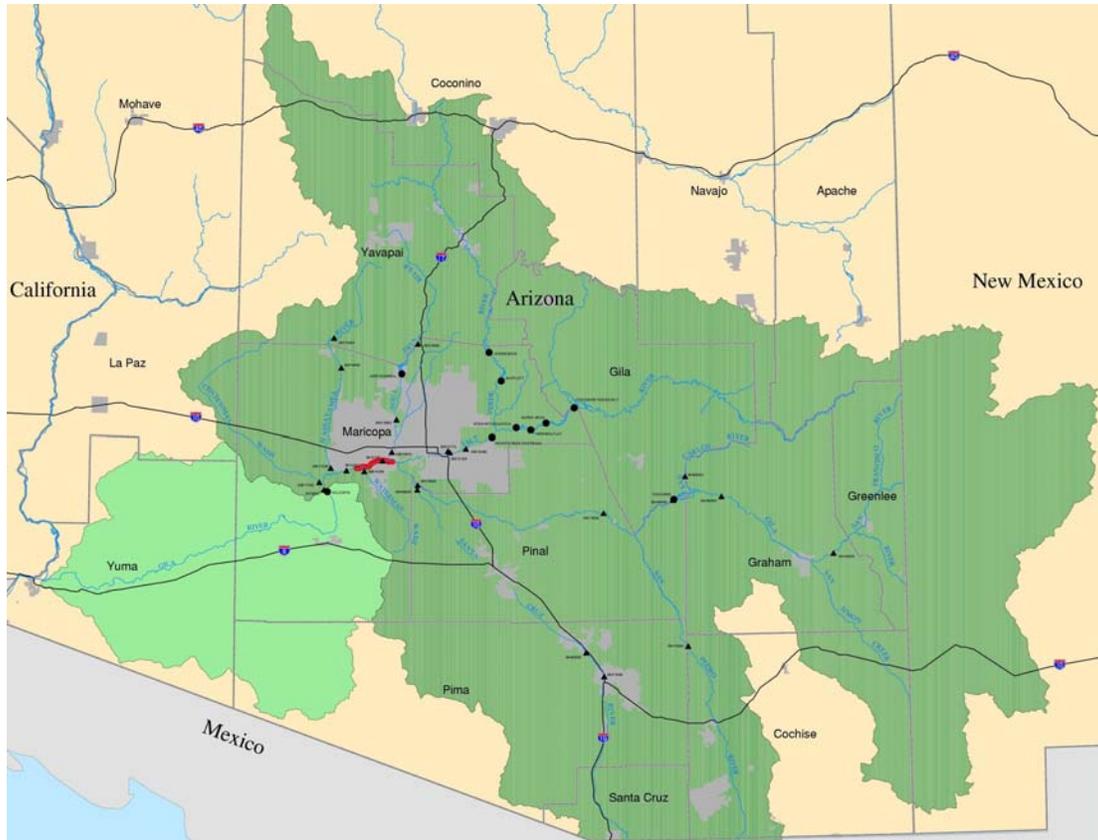


Figure 2. Gila River Watershed

BACKGROUND

Project Area

The Gila River in the west side of the Phoenix metropolitan area has a shallow groundwater table and inflows from agriculture result in a diverse natural environment of a high scenic quality. The public opinion is overwhelmingly for preserving the existing character of this reach of the river, and if possible enhancing it. The shallow groundwater and agricultural return flows support riparian vegetation, as shown in Figure 3. Where the groundwater is deep and where there is minimal irrigation return flow, riparian vegetation is sparse, as shown in Figure 4.



Figure 3. Flow supporting riparian vegetation (above Gillespie Dam)



Figure 4. Gila River with minimal riparian vegetation (below Gillespie Dam)

Dams and diversions on the Gila River and its tributaries (see Table 1) manage seasonal flood flows. These dams have affected the hydrology and water quality of the river by reducing peak flows. These peak flows were replaced by extended low-flow periods when irrigation return water and treated effluent dominate the flow in the river. The historically seasonal flows are modified by water management and flood control, but

major floods such as the 1993 flood, impact the form and function of the river. It is these major floods that drive the need for a more effective flood-management program for the Gila River.

Table 1. Dams on the Gila, Salt and Verde River

- 1908 Granite Reef Diversion Dam (D)
- 1911 Roosevelt Dam (S)
- 1914 Buckeye Heading (D)
- 1921 Gillespie Dam (D)
- 1923 Mormon Flat Dam (S)
- 1927 Horse Mesa Dam (S)
- 1928 Coolidge Dam (S, F)
- 1930 Stewart Mountain Dam (S)
- 1939 Bartlett Dam (S)
- 1946 Horseshoe Dam (S)
- 1959 Painted Rock Dam (F)

D-Diversion Dam

S-Predominantly conservation storage

F-Flood control

Historic Floods

Since 1920, the Gila River has experienced nine significant flood events in which peak flow rates of 60,000 cubic feet per second (cfs) or greater were recorded. These flood events occurred in 1923, 1927, 1938, 1966, March 1978, December 1978, 1980, 1983, and 1993. The annual peak discharges are illustrated in Figure 5 and the annual runoff volumes are illustrated in Figure 6.

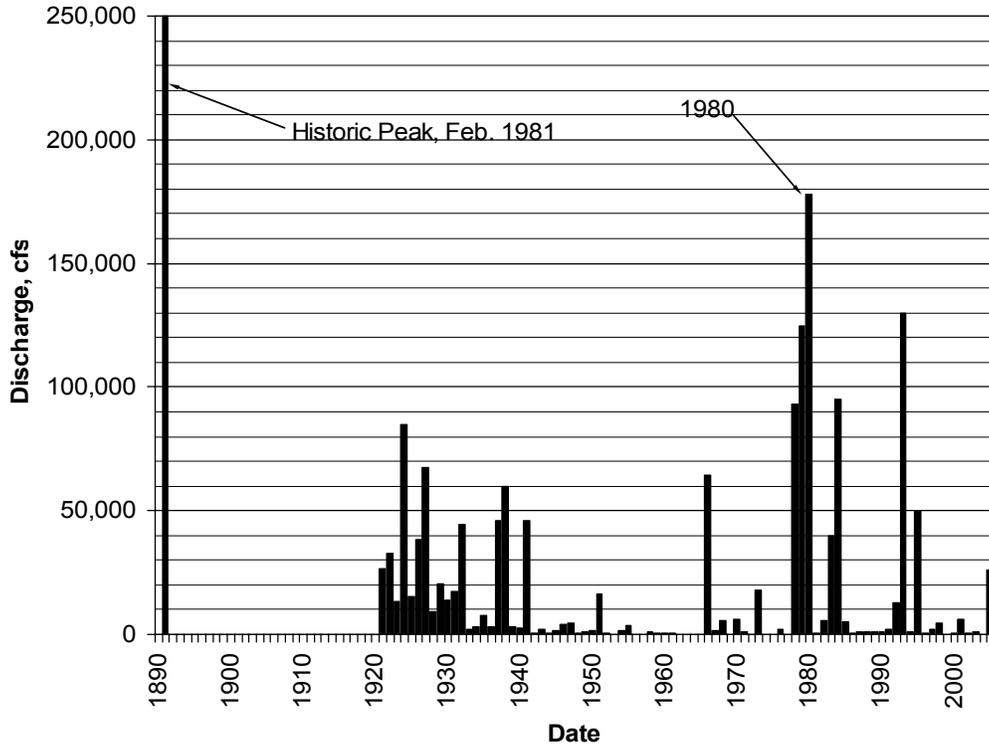


Figure 5. Flood Peak Discharge for the Gila River at Gillespie Dam

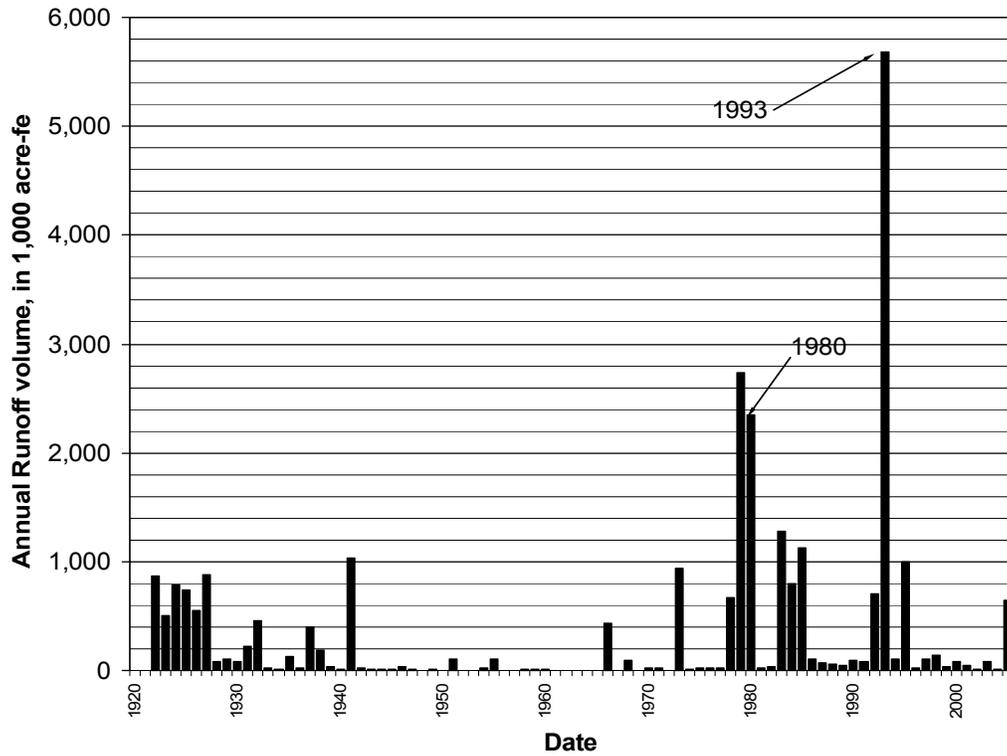


Figure 6. Annual runoff volume for the Gila River at Gillespie Dam

Notice that the largest recorded flood peak was about 170,000 cfs in 1980 with a runoff of about 3 million acre-feet. The largest flood volume was about 5.6 million acre-feet in 1993 with a peak discharge of about 130,000 cfs. The flood event in 1980 resulted in about 6.5 million dollars in flood damage, whereas the event in 1993 resulted in more than 38 million dollars in damage.

The 1993 flood in particular affected public and private assets. Entire stretches of mature, native riparian habitat, as well as stream channels, were overwhelmed, eliminated, or relocated by high floodwaters.

Physical Characteristics of the River

Aerial photographs from different time periods were reviewed to identify channel pattern characteristics and channel patterns over time. Review of aerial photographs from 1949, 1980, and 1993 indicate that the study reach is characterized by a corridor with multiple channels, bars, and islands where the position of the channels, bars, and islands change with time. The 1949 photograph depicts vegetation within the corridor being primarily confined to the channel and areas immediately adjacent to the channel, whereas the 1980 and 1992 aerials show vegetation is denser away from the channel, presumably because vegetation within and adjacent to the channel was removed during floods. For areas outside of channels, but still within the corridor, vegetation density increases with time. Field observations show that the vegetation type in the areas of dense vegetation is salt cedar (tamarisk), a non-native species.

Based on morphological characteristics of the study reach of the Gila River identified in aerial photographs and field investigations, inferences can be made as to the processes that formed the observed morphology. During a flood, channels within the conveyance corridor transport sediment from the watershed and from eroded upstream channel banks. At locations where the hydraulic conditions favor deposition, the sediment transport capabilities decrease and channel bars are formed. As the capacity of the channel decreases flow splits to adjacent channels again decreasing the channel's ability to convey the sediment load. Sediment deposits eventually clog the channel bars and coalesce forming bar/island complexes, forcing the remaining flow to adjacent channels. The sediment conveyance capacity of channels that receive flow increases because of the additional flow. As the sediment transport capacity of a channel increases, bank erosion occurs, supplying sediment to the channel which eventually forms bars and the process of erosion and sedimentation is repeated.

An example of the changes to the character and form of the Gila River during floods is shown in Figure 7. The 1977 photograph shows the river after a sustained period of no high flows (see Figures 5 and 6). The river is braided and heavily vegetated with no predominant channel. After the major flood of 1980, a cleared channel for flood conveyance is evident. Notice the proximity of agricultural fields and the loss of farm fields in the 1983 photograph.

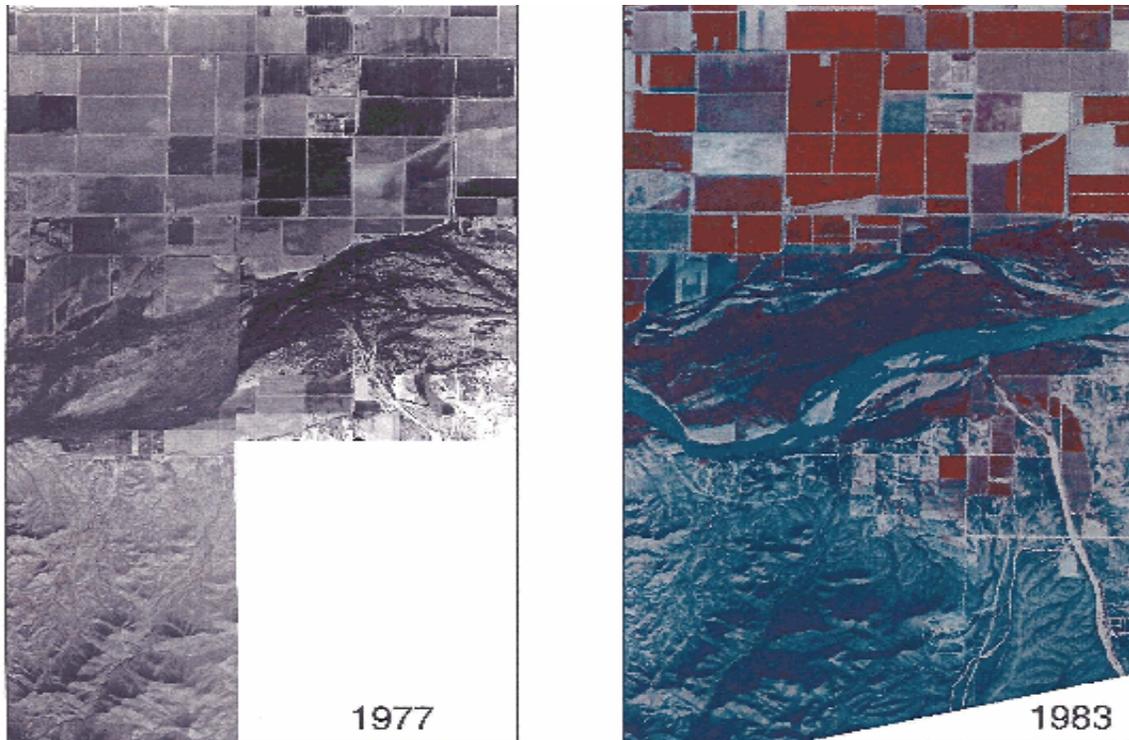


Figure 7. Effect of Floods on the Gila River
(near Buckeye at the confluence of Waterman Wash)

Geomorphic Factors

Within the past 10,000 years, the Gila River has meandered between 14,000 feet and 17,000 feet wide. The most recent active river corridor ranges in width from about 2,000 feet to more than 10,000 feet. Bedrock flanks portions of the river and provides lateral stability and locally constrains future channel-bank movement. An example of the river bank erosion and lateral migration of the Gila River is shown in Figure 8. Available data indicates that the natural river banks can erode laterally thousands of feet at depths of 20 feet or more. The maximum single-event lateral movements for the active banks are about 3,000 feet. All of the maximum single-event movements were attributed to the December 1978 flood event that recorded a peak discharge of 125,000 cfs.



Figure 8. Example of bank erosion of the Gila River (5 miles downstream of the state Route 85 bridge) during the 1993 flood

Sediment transportation defined in terms of erosion and sedimentation of the Gila River within the study area was investigated by modeling the sediment transport through the watercourse for streamflows that occurred between 1921 and 2001, followed by a synthetic hydrograph representing the 100-year flood. The modeling was performed using the HEC-6T sediment transport computer program. The results of the sediment transport analysis identified locations in which accumulations of sediment (aggradation), or erosion (degradation) would occur. The magnitude of sedimentation or erosion will influence the selection and implementation of flood-control management measures.

THE PRESENT GILA RIVER

The following summarizes the major factors that impact the Gila River. The form and function of the Gila River is defined, to a large degree, by the episodic nature of large floods separated by sustained low flows. However, anthropogenic factors are having a major influence on the form and function of the river.

1. The Gila River downstream of the confluence of the Salt River was greatly altered by agricultural development starting in the mid-nineteenth century with rapid development in the early twentieth century.
2. Numerous large dams for water conservation storage and flood control were built in the first half of the twentieth century in the Gila River watershed. Recently, Roosevelt Dam was raised to provide flood-control benefit.
3. Because of those dams, more than 90 percent of the time there is no flow in the river other than irrigation return flow and wastewater discharges.
4. Long time periods (several decades) may occur between floods, although floods often come in clusters. In the last 100 years there were only about 10 floods that caused significant changes to the river.

5. The majority of the time the river is very stable with little erosion or sedimentation, minor bank erosion and no lateral migration.
6. Large floods that overtop the banks, cause damage and result in large-scale bank erosion, have a 30-year return period.
7. The Gila River Valley downstream of its confluence with the Salt River has traditionally supported irrigated agricultural, and some of that agriculture is within the 100-year floodplain. Small, localized urban development in that area was mainly to support the agricultural economy.
8. The absence of more frequent large floods along with sustaining water from irrigation return flows and waste water treatment plant discharges has contributed to thick riparian vegetation that can increase flood hazard in the floodplain.
9. The river is a source of sand and gravel that is needed to support urban development.
10. Urbanization is bringing plans for major transportation corridors and bridges across the river.

THE FUTURE GILA RIVER

The urbanization of the historically irrigated agricultural land along the Gila River in the Phoenix metropolitan area will inevitably impact the character and management of the Gila River. The flood flows and seasonal patterns of flow in the river will continue to be regulated by the numerous dams and reservoirs in the upstream watershed, such as those operated by the Salt River Project. The sustaining low-flow of the river will change because of the absence of irrigation return flows to the river; however, the magnitude and direction of that change is complicated by uncertainty of groundwater response and potential increases in waste water discharges to the river. The low-flow regime of the river is critical to the planning and management of the river for multi-use recreation, riparian resource and wildlife enhancement.

Urbanization will bring the need to mitigate the flood hazard of land within the 100-year floodplain. That may require levees or channelization; however, structural solutions may adversely impact environmental and recreational benefits in addition to their high cost for construction and maintenance. Structural solutions to solve isolated instances of flooding may be justified in some instances if benefits exceed costs.

Transportation corridors and bridge crossings will continue to impact the river. Those structures must be carefully evaluated in regard to floodplain encroachment, loss of riparian habitat, disruption of wildlife corridors, and sedimentation impacts to the river.

The continual need for sand and gravel to support the building materials industry will stress the Gila River. The planning of that mineral extraction can enhance the multi-use aspects of the river and provide a broader range of recreational opportunities such as boating. The impacts of sand and gravel extraction needs to be fully studied in regard to long-term impacts to structures and the environment.

For the Gila River, the riparian vegetation is predominantly tamarisk (salt cedar) a nonnative species. Replacing tamarisk with stands of willow and native plants is desired.

The planning and execution of vegetation clearing and revegetation needs to be evaluated in regard to environmental impacts and flood hydraulics.

CONCLUSION

The Gila River on the west side of the Phoenix metropolitan area in Maricopa County, was traditionally a river that supported irrigated agriculture and also functioned as an agricultural drain. Within the last decade the land is changing from agricultural use to residential, commercial and industrial use. The Flood Control District of Maricopa County recently studied a portion of the river, the El Rio Watercourse Master Plan. That study will be used to preserve the multi-use character of the river and to enhance its recreational opportunities. The El Rio Watercourse Master Plan is an example of planning as land along river corridors transitions from agricultural to urban.

CONSUMPTIVE USE IN THE PHOENIX AREA—REMOTE SENSING TO EVALUATE CHANGES IN EVAPOTRANSPIRATION FROM URBANIZATION

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ABSTRACT

The Surface Energy Balance Algorithm for Land (SEBAL[®]) has been applied to quantify daily evapotranspiration (ET) rates for the Phoenix area using Landsat scenes from 3/18/1991 and 4/19/2000. For the 1991 image, ET rates for urban and suburban areas are compared against ET rates for adjacent, agricultural lands. Additionally, daily ET rates for each scene have been normalized based on estimates of reference evapotranspiration (ET_o) and used to develop water use coefficients (analogous to crop coefficients) for specific land use types. Changes in relative consumptive use for agricultural areas urbanized between the 1991 and 2000 image dates are evaluated, and potential implications to water resources management are discussed.

INTRODUCTION

Urbanization is fueled by increasing population, and in Arizona, population growth over the 10 years from 1990 to 2000 was 40.0% compared to 13.2% for the nation as a whole (U.S. Census Bureau, 2007). Nearly two thirds of the total population growth in Arizona during this period occurred in Maricopa County, where the growth rate was 44.8%.

Urbanization of the arid Southwest is resulting in changes in the way scarce water supplies are being used. As agricultural land undergoes conversion to urban land uses, the way water is used also changes. Water applied to agricultural lands leaves the land primarily as evapotranspiration, while in urban or suburban settings a combination of evapotranspiration and indoor water use occurs. In some cases, urbanization may result in a change from surface water to groundwater supplies or vice versa. For example, an agricultural field historically relying primarily on surface water for irrigation may be replaced by a subdivision relying solely on groundwater to meet water needs. If this is the case, less evapotranspiration may occur, but net extraction of groundwater increases due to increased pumping and reduced recharge from deep percolation of surface water as a result of the land conversion. These changes affect the amount of water consumed and returned to the atmosphere and the amount percolating into the ground and recharging groundwater aquifers.

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Understanding impacts of urbanization on surface and groundwater hydrology is critical to effective management of scarce water supplies. This is especially important in some areas in Arizona. In 1980, the State of Arizona enacted the Groundwater Management Act to provide a framework to deal with overdraft of groundwater supplies. The Act established a goal of reaching safe yield, a balance between the amount of water withdrawn from an aquifer and the amount of water returned to the aquifer through recharge, by the year 2025 in the Phoenix, Tucson, and Prescott areas. Thus, tracking and projecting the movement of groundwater in Arizona aquifers is necessary to determine progress towards the goal of safe yield.

Changes in consumptive use, extraction, and net recharge resulting from urbanization have important water management implications. These include hydrologic impacts connected to the status of safe-yield and regulatory programs such as the State's Assured Water Supply (AWS) program. The changes in land and resulting water use impact hydrologic conditions by changing the volumes of groundwater extracted from aquifers to meet demand and changes in the amount of water incidentally recharged to aquifers through water delivery losses. Both of these changes are important in determining the status of safe-yield.

The change in incidental recharge associated with urbanization has implications to the AWS program, which requires municipal water providers with growing demands to use renewable water supplies that are consistent with the goal of safe-yield. Municipal providers under the AWS program are allowed to pump groundwater volumes that are equivalent to the volume of water that is incidentally recharged through municipal use within their service territories. Thus, having a more definitive estimate of this volume would directly impact the water supplies available to a municipal provider.

A major flow path in the hydrology of arid regions is evapotranspiration (ET). Flow paths such as ground water recharge are estimated as a closure term in water balances, calculated as a residual of other water balance terms (including ET) measured or estimated for the place and time period of interest. Small uncertainties in evapotranspiration estimates and other large flow paths lead to large uncertainties in recharge and other closure terms. Thus, accurate estimation of large components of the water balance such as ET is needed to ensure accurate estimation of closure terms.

For irrigated land, consumptive use is typically estimated by the crop coefficient method. Limitations to this approach include the need for knowledge of specific crop type, planting and harvesting dates, local reference evapotranspiration, early season irrigation frequency (annual crops), soil water holding characteristics, and percent cover (horticultural crops). Commonly, actual field conditions, where various crop and management related stresses may exist, are not considered as published crop coefficients are often derived from crops growing in ideal conditions (Allen, et al.,1998). The use of published crop coefficients can therefore result in overestimation of consumptive use for irrigated crops.

The estimation of consumptive use rates for urban areas also presents challenges. In many cases, water use coefficients (analogous to crop coefficients) specific to an urban area may not be available. For urban areas, consumptive use is influenced by the amount of vegetative cover, landscape irrigation practices and types of plants, and other factors which vary significantly among different urban areas.

The development, refinement, and validation of techniques to estimate consumptive use (evapotranspiration, ET) from remotely sensed thermal data and the surface energy balance has led to improved quantification of ET across diverse landscapes. This approach avoids the need for much of the location-specific information needed to effectively apply the crop coefficient (or water-use coefficient) approach and provides actual consumptive use rates inclusive of all environmental stresses that may inhibit ET relative to ideal conditions.

Use of remote sensing techniques for ET estimation are cost effective when compared with the installation and maintenance of expensive measurement devices and weather stations such as Eddy covariance and Bowen ratio. Also, ground-based instruments are representative of much smaller areas (from couple of hundred meters to few kilometers) as compared to the area covered by a Landsat scene which has a swath of 180 km by 180 km.

To project a change in consumptive use from urbanization of undeveloped or irrigated land, the consumptive rate of an adjacent/nearby urban area may be compared with the consumptive use rate of the agricultural area expected to undergo urbanization. The relative difference between consumptive use rates for the two land areas provides an estimate of the future change in consumptive use.

Statement of Objectives

The overall objective of this paper is to apply a remote sensing based surface energy balance methodology (SEBAL) to quantify spatially distributed consumptive use in and around Phoenix, AZ (for two different years, 1991 and 2000) to evaluate changes in consumptive use when urbanization of agricultural areas occurs. This study considers only the consumptive portion of the exterior water use on urbanized lands. Thus, a complete water balance considering impacts of urbanization on surface and groundwater supplies or a direct comparison in total water demand between urban and agricultural lands was not made. Changes in water demands associated with the urbanization of agricultural lands could be evaluated by incorporating city water delivery information into the analysis.

The objectives along with their respective tasks are individually discussed below:

1. Apply SEBAL algorithm to compute spatially distributed consumptive use (ET) using satellite imagery for two days in the spring of 1991 and 2000, respectively, in and around Phoenix area.

2. Develop water-use coefficients for selected agricultural lands and adjacent urban lands for the 1991 and 2000 imagery.
3. For the 1991 ag lands, estimate water use coefficients on the same land in 2000 following urbanization.
4. Evaluate differences in consumptive rates and in the water-use coefficients between the selected agricultural areas and the adjacent urban lands from 1991. Additionally estimate the change in relative consumptive rates and water-use coefficients for agricultural areas that were urbanized between 1991 and 2000.

METHODOLOGY

The analysis presented in this paper utilizes the Surface Energy Balance Algorithm for Land, or SEBAL[®] (Bastiaanssen, et. al., 2005, 1998a and 1998b). SEBAL is applied to spatially quantify the consumptive use of water in and around Phoenix, Arizona for two dates: March 18, 1991 and April 19, 2000. The variability of consumptive use between adjacent areas with differing land use is evaluated within each image. Additionally, consumptive use rates, normalized for differences in weather on the date of each image, are compared for selected locations where land use changed between the image dates.

Input Data

A combination of multispectral and thermal Landsat imagery (Table 1), ground-based meteorological observations from the Arizona Meteorological Network (AZMET, Table 2), digital elevation models (National Elevation Dataset) and land cover classifications from the National Land Cover Dataset (NLCD) for the years 1992 and 2001 were used. The meteorological data from AZMET included instantaneous and daily measurements of incoming solar radiation, air temperature, relative humidity and wind speed. These input data were used in the SEBAL models to derive spatially distributed actual ET grids along with the other outputs.

Table 1. Selected Landsat Images

Sensor	Date	Path/Row	Acquisition Time (GMT)	Cloud Cover
TM 5	3/18/1991	37/37	17:25:28.60	0 - 10%
ETM +7	4/19/2000	37/37	17:56:16.50	0 - 10%

SEBAL Models

The SEBAL model applies radiative, aerodynamic, and energy balance physics in a series of 25 computational steps to estimate actual ET (ET_a) from the energy balance. ET_a is calculated at the pixel-scale using multispectral satellite imagery with a thermal band. SEBAL is internally calibrated for each image to estimate sensible heat flux between the surface and the atmosphere avoiding the need for absolute calibration of the surface temperature of each pixel. A detailed explanation of the algorithm is provided in Bastiaanssen et al. 1998a, 1998b, and 2005.

Table 2. Selected AZMET stations

Stations	Latitude	Longitude	Elevation (ft)
Anguilla	-113.19	33.95	2149
Coolidge	-111.60	33.98	1385
Dateland	-113.50	32.99	535
Litchfield	-112.40	33.47	1014
Maricopa	-112.00	33.07	1184
Phoenix E	-112.10	33.48	1099
Phoenix G	-112.11	33.62	1316
Waddell	-112.46	33.62	1335

SEBAL has been developed through 19 years of research and validation. Validation is ongoing as a means of quality control because of ongoing minor model refinements, sensitivity of model results to analyst judgments related to internal calibration, and interest in further quantifying the accuracy of the approach. The algorithm has been applied on more than 150 projects in 15 countries, including 19 projects in the United States. Comparisons have been made to six different ET estimation methods for a variety of vegetation types including irrigated pasture, sugar beets, riparian vegetation, playas, olives, rice, palm trees, cotton, wheat, sunflower, bare soil, grassland and forest. Seasonal ET_a estimates from SEBAL (multiple satellite images processed and integrated over time) compare well to seasonal ET_a from ground-based measurements, falling within 5%. The deviation of ET_a values from ground-based measurements for shorter periods (instantaneous and up to 10 days) may be as much as 15 to 20%. The SEBAL models and validation studies are discussed in detail in Bastiaanssen et. al., 2005. A brief overview of the SEBAL model follows.

Fundamentally, SEBAL solves the surface energy balance for latent heat flux (Equation 1):

$$\lambda E = R_n - G_0 - H \quad (1)$$

All the terms in Equation 1 are expressed in W/m^2 , where R_n is the net radiation, G_0 is the soil heat flux, H is the sensible heat flux and λE is the latent heat flux associated with evapotranspiration.

Land Use Classification and Characterization

Areas that were converted from agricultural use in 1991 to urban land in 2000 were identified by visually inspecting satellite imagery from both image dates and using the NLCD land use maps for each year. Adjacent/nearby urban areas (1991) and agricultural areas (2000) were also identified through visual inspection. A visual selection method was used because the NLCD land use maps from 1992 and 2000 were generated with slightly different classification methods (<http://www.epa.gov/mrlc/change.html>).

Data Extraction

The images were processed in ERDAS Imagine 9.0 software. The selected areas were digitized with Imagine software. Distributions of ET_a for pixels within the selected areas for each image date were obtained from the respective ET_a grids. A lumped water use coefficient, representing actual field conditions was estimated for each area as a ratio of ET_a / ET_o , where ET_o is the reference crop evapotranspiration (ET_o) obtained from the AZMET stations (selected stations, Table 2) for the respective days of the satellite image acquisition. This reference ET is estimated for a cool season grass, 8-15 cm in height, at full cover with no water stress (<http://ag.arizona.edu/azmet/>).

RESULTS & DISCUSSION

March 18, 1991 Satellite Image

A total of ten agricultural areas were selected from the 1991 image. These areas were identified as being primarily agricultural during the 1991 image and primarily urban during the 2000 image (Figure 1). Figure 2 presents the cumulative distribution of ET_a for the five of the selected areas identified as agricultural lands in the year 1991. Five representative ET distributions are shown (rather than all ten) to make it easier for the reader to distinguish between individual areas. Variability in ET was apparent within and among these areas due to differing crop types, stages of growth, crop stress, and other related factors.

Mean ET_a varied widely from about 0.12 - 0.20 inches among the agricultural lands (Table 3). Based on the NLCD land use data (1992), the selected areas were classified as agricultural lands with 80% or more of the pixels classified as agricultural, with the exception of AOI-2, which was classified as 62% agricultural.

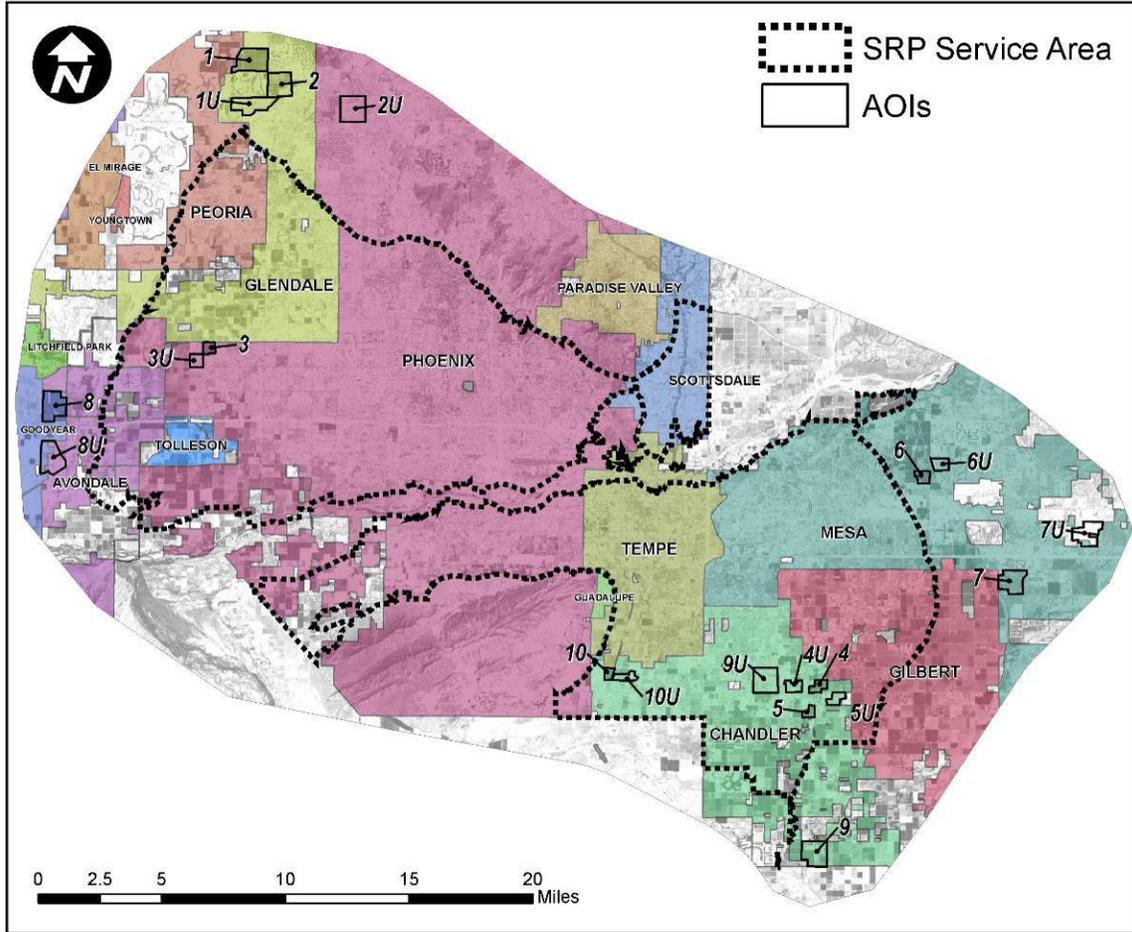


Figure 1. Salt River Project Service Area and Selected Agricultural and Urban Areas of Interest (AOIs).

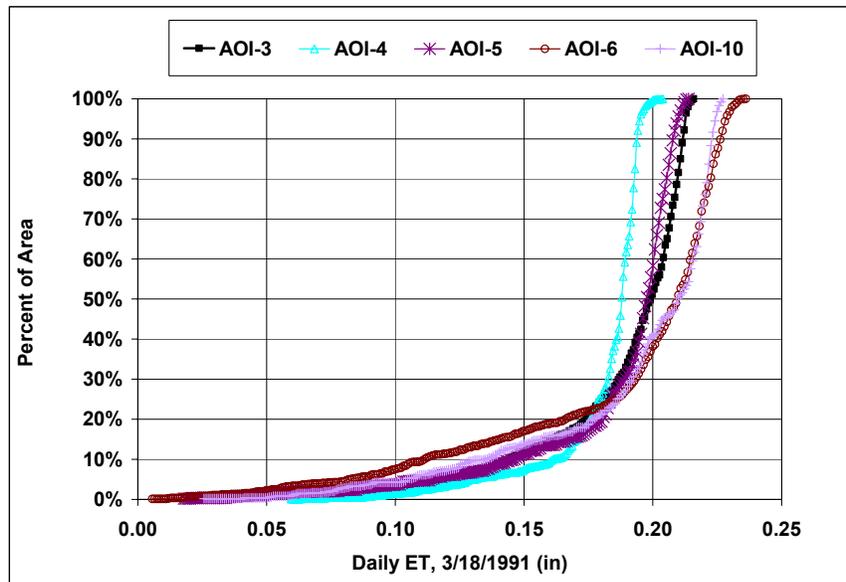


Figure 2. Cumulative Distribution of ET_a for Five Agricultural Areas, March 18, 1991

Table 3. Summary Statistics of Land Use and SEBAL ET_a for Selected Agricultural Areas, March 18, 1991

Area	Statistics						
	Area (ac)	% Ag	% Urban	10 th %tile ET_a (in)	90 th %tile ET_a (in)	Mean ET_a (in)	Std. Dev. ET_a (in)
AOI -1	753	90	2.7	0.05	0.23	0.20	0.02
AOI -2	625	62	14.8	0.03	0.20	0.14	0.04
AOI -3 ¹	157	92	7.5	0.05	0.20	0.19	0.02
AOI -4 ¹	191	99	1.3	0.07	0.19	0.18	0.01
AOI -5 ¹	120	94	6.1	0.04	0.19	0.19	0.02
AOI -6	188	82	13.1	0.03	0.21	0.19	0.03
AOI -7	581	89	3.0	0.02	0.16	0.12	0.02
AOI -8	676	82	1.6	0.02	0.20	0.14	0.03
AOI -9	643	83	14.9	0.03	0.22	0.14	0.05
AOI -10 ¹	119	92	6.7	0.05	0.21	0.19	0.03

1. AOI located within Salt River Project service area.

The consumptive use rates for the primarily agricultural areas were compared with those of adjacent, urban/suburban lands. For each agricultural area, a nearby urbanized area of interest was identified (Figure 1). These areas were all classified as being more than 80% urban, with the exception of AOI -5U, which was classified as being only 62% urban. The letter “U” has been added to the AOI labels to distinguish between the agricultural and adjacent, urban lands. Cumulative distributions of actual ET and the summary statistics for these urbanized areas are provided in Figure 3 and Table 4, respectively.

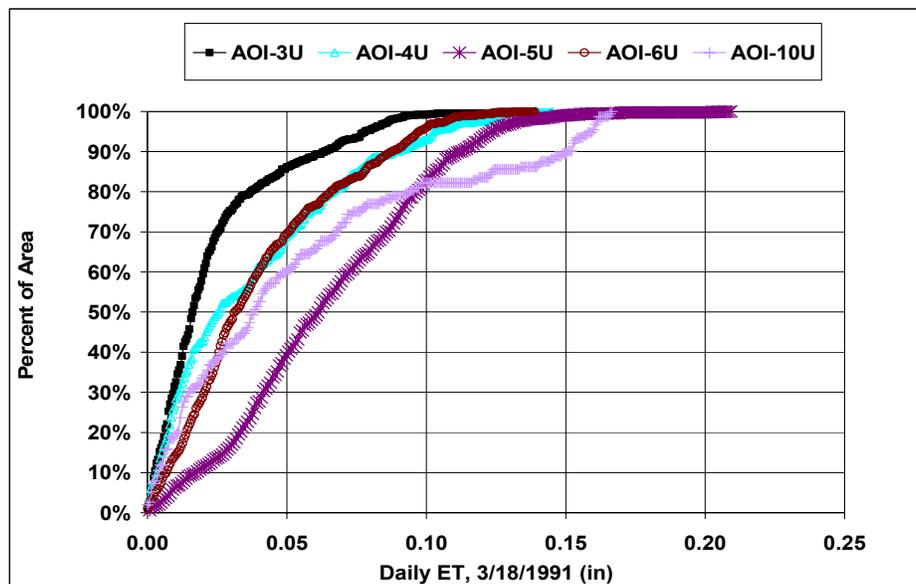
Figure 3. Cumulative Distribution of ET_a for Five Urban Areas, March 18, 1991

Table 4. Summary Statistics of Land Use and SEBAL ET_a for Selected Urban Areas, March 18, 1991

Area of Interest	Statistics						
	Area (ac)	% Ag	% Urban	10 th %tile ET_a (in)	90 th %tile ET_a (in)	Mean ET_a (in)	Std. Dev. ET_a (in)
AOI -1U	644	0.28	87	0.02	0.13	0.05	0.02
AOI -2U	691	1.2	99	0.02	0.15	0.04	0.01
AOI -3U ¹	193	9.5	90	0.01	0.12	0.02	0.02
AOI -4U ¹	204	15.5	82	0.01	0.13	0.04	0.03
AOI -5U ¹	185	32.4	62	0.02	0.19	0.07	0.03
AOI -6U	228	15.3	81	0.01	0.13	0.04	0.02
AOI -7U	581	3.8	86	0.01	0.08	0.02	0.02
AOI -8U	709	10.8	87	0.02	0.16	0.04	0.02
AOI -9U	667	6.4	91	0.02	0.17	0.06	0.02
AOI -10U ¹	191	9.3	90	0.02	0.15	0.05	0.04

1. AOI located within Salt River Project service area.

The results of Tables 3 and 4 can be used to project the change in consumptive use resulting from urbanization. For example, consider AOI-1 with a mean ET_a of 0.20 inches (Table 3). The change in demand for this area could be estimated by comparing the area's mean consumptive use rate with the mean rate for an adjacent urban area (in this case, AOI-1U from Table 4 may be used, with a daily ET rate of 0.05 in). Thus, about 0.15 inches less water would have been consumed in AOI-1 (Table 3) if converted to urban use on March 18, 1991, a decrease of 75 percent.

The change in consumptive use rate can also be estimated using water use coefficients obtained for these areas (Table 5). These water use coefficients are estimated by normalizing spatially distributed ET_a with ET_o obtained as an average for the day of the image from the selected AZMET stations.

Water use coefficients for pixels within agricultural areas ranged between 0.0 and 1.1 with approximately 40% of the agricultural area within the range 0.8 to 1.0 (Figure 4). The water-use coefficients for urban lands were found to be lower than for agricultural lands for the 1991 image, with approximately 60% of pixels having coefficients between 0.1 and 0.3.

Table 5. Water Use Coefficients for Agricultural and Adjacent Urban Lands, March 18, 1991

Areas	Agricultural Lands				Adjacent Urban Lands				% Decrease
	Area (ac)	% Ag	% Urban	Mean	Area (ac)	% Ag	% Urban	Mean	
AOI -1	753	90	2.7	0.87	644	0.28	87	0.22	75
AOI -2	625	62	14.8	0.64	691	1.2	99	0.18	72
AOI -3 ¹	157	92	7.5	0.83	193	9.5	90	0.11	87
AOI -4 ¹	191	99	1.3	0.81	204	15.5	82	0.17	79
AOI -5 ¹	120	94	6.1	0.83	185	32.4	62	0.29	65
AOI -6	188	82	13.1	0.85	228	15.3	81	0.18	79
AOI -7	581	89	3.0	0.54	581	3.8	86	0.11	80
AOI -8	676	82	1.6	0.63	709	10.8	87	0.16	75
AOI -9	643	83	14.9	0.61	667	6.4	91	0.26	57
AOI -10 ¹	119	92	6.7	0.86	191	9.3	90	0.24	72

1. AOI located within Salt River Project service area.

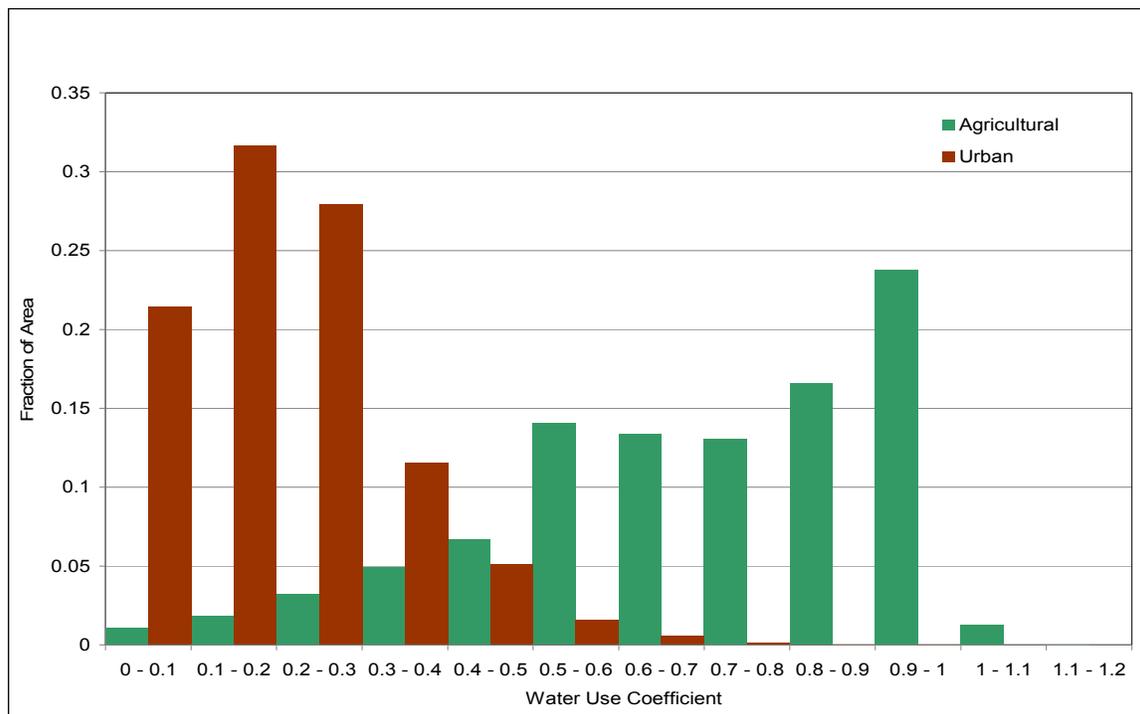


Figure 4. Distributions of Water Use Coefficients for Pixels within Agricultural and Urban Areas, March 18, 1991

April 19, 2000 Satellite Image

Results from April 19, 2000 image are presented in Figure 5 and Table 6 respectively. Each of the areas shown in Figure 5 and Listed in Table 6 correspond to the same locations as the agricultural areas from the 1991 image. Figure 5 presents the cumulative ET_a distributions for areas that were originally agricultural in 1991 image and then were

urbanized prior to the 2000 image. Based on the NLCD 2001 land use data, more than 90% of the area for the selected areas is classified as urban with the exception of AOI-1, which is reported as 83% urbanized. The mean consumptive use rate of the urbanized areas was estimated to be 0.10 inches on April 19, 2000 (Table 6).

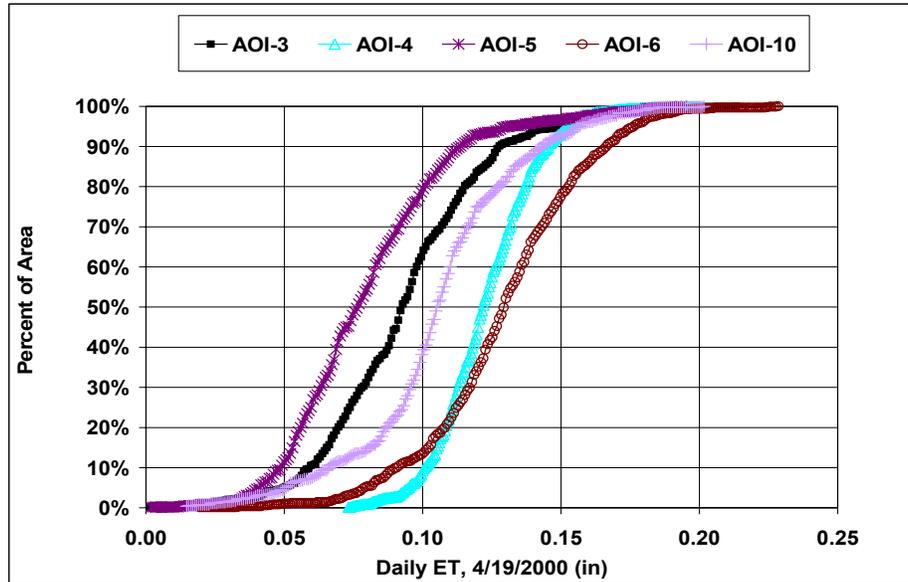


Figure 5. Cumulative Distributions of ET_a for Five Urbanized Areas of Interest, April 19, 2000

Table 6. Summary Statistics of SEBAL ET_a for Urbanized Areas, April 19, 2000

Areas of Interest	Statistics						
	Area (ac)	% Urban	% Ag	10 th %tile ET _a (in)	90 th %tile ET _a (in)	Mean ET _a (in)	Std. Dev. ET _a (in)
AOI -1	753	83	0	0.04	0.31	0.13	0.03
AOI -2	625	95	0	0.03	0.29	0.12	0.04
AOI -3 ¹	157	94	5	0.02	0.19	0.09	0.02
AOI -4 ¹	191	100	0	0.09	0.19	0.12	0.01
AOI -5 ¹	120	94	6	0.02	0.17	0.08	0.02
AOI -6	188	94	4	0.04	0.21	0.13	0.02
AOI -7	581	94	1	0.02	0.19	0.12	0.02
AOI -8	676	92	4	0.03	0.25	0.09	0.04
AOI -9	643	96	4	0.03	0.27	0.11	0.05
AOI -10 ¹	119	98	2	0.03	0.18	0.11	0.02

1. AOI located within Salt River Project service area.

Comparison of ET Rates for AOIs: Agricultural (1991), Adjacent Urban (1991), and Following Urbanization (2000)

Maps were developed showing daily ET_a rates for the agricultural and adjacent urban areas from the March 1991 image along with the urbanized areas (formerly agricultural) from the April 2000 image. These maps are presented in Figure 6.

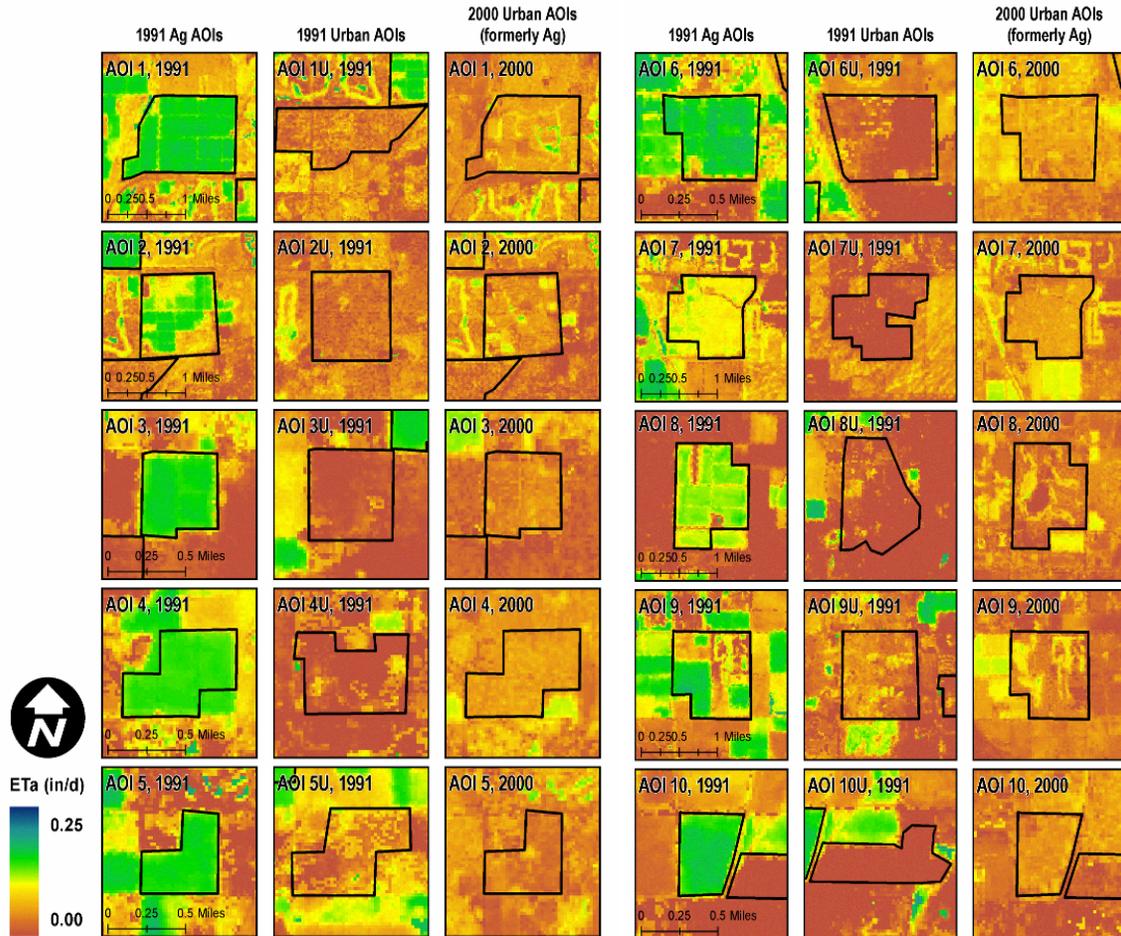


Figure 6. Daily ET_a Rates for Selected Agricultural (1991), Adjacent Urban (1991), and Urbanized (2002) Areas.

Comparison of Water Use Coefficients Prior to and Following Urbanization

Water use coefficients for urbanized areas were compared with the water use coefficients from the same locations prior to urbanization (Table 7). Distributions of water use coefficients for pixels in the ten selected areas prior to and following urbanization are provided in Figure 7. A similar trend of overall decrease in consumptive use was observed based on the water use coefficients for the urbanized agricultural lands with a mean decrease of approximately 49%.

Table 7. Comparison of Land Use and Water Use Coefficients for Areas under Agricultural (March 1991) and Urban (April 2000) Land Uses.

Areas of Interest	March 18, 1991 (Agricultural)			April 19, 2000 (Urban)			% Decrease
	Area (ac)	% Ag	Mean Water Use Coefficient	Area (ac)	% Ag	Mean Water Use Coefficient	
AOI -1	753	90	0.87	753	0	0.44	49
AOI -2	625	62	0.64	625	0	0.40	38
AOI -3 ¹	157	92	0.83	157	5	0.32	61
AOI -4 ¹	191	99	0.81	191	0	0.42	48
AOI -5 ¹	120	94	0.83	120	6	0.27	67
AOI -6	188	82	0.85	188	4	0.44	48
AOI -7	581	89	0.54	581	1	0.40	26
AOI -8	676	82	0.63	676	4	0.29	54
AOI -9	643	83	0.61	643	4	0.38	38
AOI -10 ¹	119	92	0.86	119	2	0.36	58

1. AOI located within Salt River Project service area.

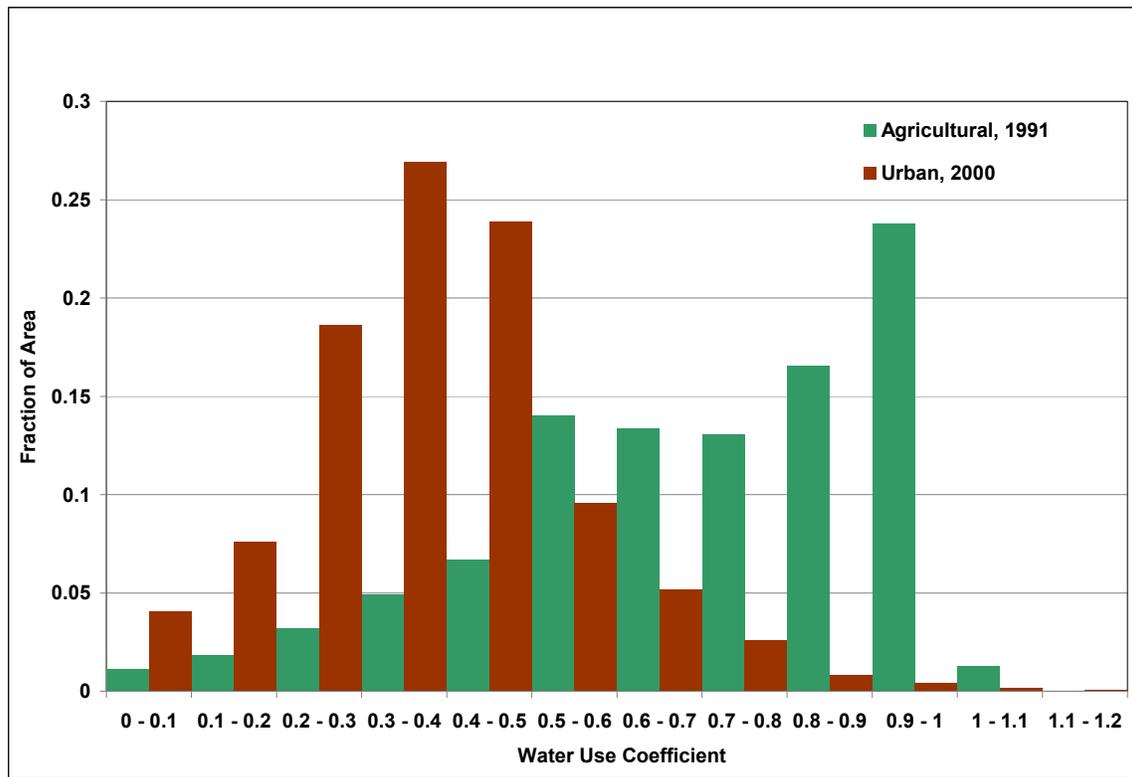


Figure 7. Distributions of Water Use Coefficients for Pixels within Areas of Interest prior to and Following Urbanization

CONCLUSIONS

The comparison of water use coefficients for agricultural areas with that of urban areas for each individual Landsat image and across the two images from different years suggests a decrease in consumptive use rates when agricultural lands are transformed into urban or suburban uses. A comprehensive analysis of the change in consumptive use over an annual basis rather than for a single pair of images would provide more reliable estimates of the magnitude of the long-term change in consumptive use resulting from urbanization. It is possible that over the course of a year differences between consumptive use in agricultural and urban areas are less dramatic.

Decreases in consumptive use resulting from urbanization, if verified through additional analysis, do not necessarily denote a decrease in water demand. The way in which water is used by farmers and families differs, and the quantity of water demanded by agricultural and municipal customers on a per-acre basis may not vary proportionally to differences in consumptive use; however, changes to incidental recharge resulting from changes in other hydrologic flow paths are important to the management of scarce water supplies.

This study demonstrates the capability of SEBAL to estimate actual ET at the pixel scale, quantifying spatial variability across agricultural and urban landscapes. Volumetric consumptive use rates (derived from actual ET rates and knowledge of the area over which they apply) combined with land use projections could be used to estimate the change in consumptive use that has occurred or to predict changes that will occur in the future. Additionally similar projections for change in consumptive use resulting from the urban development of native, undeveloped lands could be made using this analysis approach. Additional information describing the demand for water for agricultural and urban areas could be combined with estimates of actual ET to further examine the hydrological impacts of urbanization, including its impact on incidental recharge.

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SECONDARY WATER SYSTEMS FOR LANDSCAPE IRRIGATION: ISSUES AND OPPORTUNITIES

Stephen W. Smith¹

ABSTRACT

Secondary or dual water systems are described as those providing pressurized raw water for landscape irrigation. Often, the native water supply that was historically used for agriculture irrigation can be successfully “repackaged” for landscape irrigation as urbanization occurs. There are numerous examples of secondary systems throughout the western United States, primarily in Utah, Idaho, Washington, and California. Some of these systems have been successfully implemented and continue to expand with new housing projects. Other systems can be shown to be problematic in various ways and might be implemented differently in hindsight. Successes and failures will be generally described to include both engineering and organizational issues. Case studies will be referenced based on personal visits and interviews with system managers.

INTRODUCTION

In various regions around the western U.S., secondary water supply systems or dual systems are common and readily acknowledged as a benefit to the region and the community. Often times, the availability of raw water for the landscape is perceived to be an amenity for a housing project because it is considered to be the right thing to do and the cost of raw water is generally lower to the homeowner than the cost of potable, culinary water.

In 2001, the Colorado Water Conservation Board funded a project at Colorado State University to do an in-depth study of dual systems in other states and attempt to understand the benefits of such systems for Colorado. The results of this particular, detailed and comprehensive study of secondary supply systems were completed in the fall of 2003. Both the executive summary and the full report can be found on-line at:

<http://waterlab.colostate.edu/DualStudy/dualstudy.htm>

The purpose of this paper is not to review or describe secondary supply systems in great detail but to make observations as the underlying reasons why larger regional systems have not come about to date in northeastern Colorado.

CONCEPTS OF SECONDARY SUPPLY

Under the prior appropriation system as utilized by 19 of the western states, water is generally decreed for a given use, in a given quantity, and as diverted from a decreed point in the river system. The original decreed use is very commonly “irrigation.” As

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urbanization occurs and farms are turned into housing projects, it makes good sense to continue using the native water supply for the decreed purpose – namely, irrigation, but for landscapes instead of agricultural crops.

The mutual irrigation companies that often hold significant decrees can benefit from secondary supply systems by becoming a participant in some manner. Changes in use wherein a municipality is buying, or being provided with, native water and altering the decreed use to municipal and industrial use are common but these changes are time consuming and costly. In Colorado, it can take three or four years to change a water right and the legal and engineering costs grow in proportion to the number of objectors in the water court case. The return flows on the changed shares are likely accounted for and stay in the canal so there is no injury to other shareholders in the mutual irrigation company or downstream to other water rights.

The hard engineering details of secondary supply systems are many and varied. The resolution of questions and the approach to secondary supply implementation is important but these engineering aspects of the project are, in the author's experience, generally easy to resolve. Organizational and sociological issues may trump engineering issues overall.

Prevalent technical questions and engineering issues include:

- Pipe burial depths.
- Standard installation details for all primary components such as the point-of-connection.
- Standard specifications for equipment and installation for the secondary system (overall system uniformity).
- Landscape irrigation standards and potential for review by the secondary supply system entity.
- Design criteria.
- Suitable water window and approach to scheduling (daytime irrigation allowed or not?).
- Meters versus no meters.
- Potential for self-adjusting irrigation control systems.
- Piping offsets with the potable pipes or any utilities of others.
- Drought response plan.
- Minimum and maximum operating pressure at the point-of-connection.
- Level or primary filtration.
- Demand management plan and prediction of maximum and peak period flows.
- Back of lot versus front of lot points-of-connection.
- Point-of-connection size.

SUCCESSFUL AND EXEMPLARY BUILT PROJECTS

Projects that have survived the test of time and continue operating effectively are described in the literature (Wilkins-Wells 2003) but two projects are briefly described here as to the elements of those projects that have relevance to the topic at hand. These two projects exemplify what can be and has been accomplished when the sociology, politics, and engineering moons can come into alignment.

Davis and Weber Counties Canal Company

The Davis and Weber Counties Canal Company in Sunset, Utah was established in 1894. In modern times, the Company delivers agricultural water to shareholders but also secondary water to approximately 8,000 customers in the area around Kaysville, Utah. The secondary supply project is now almost 25 years old and was originally funded via concessionary loans made available by the State of Utah. It is notable that the community accepts and very much appreciates the raw water availability for landscapes since this source of water is so much less costly than the potable, culinary water. Billboards for housing developments in the area often cite secondary supply as a key benefit of that project. Further, it is notable that the Company enjoys a revenue stream from the secondary supply customers that has allowed the Company to make substantial improvements to the canal infrastructure over time. These improvements include canal lining, pump stations, equalizer reservoirs, and supervisory control and data acquisition (SCADA) implementation. An important part of the success of this secondary supply project is that there was strong cooperation between the ditch company supplying the raw water and the municipal water departments supplying the culinary water.

Kennewick Irrigation District

Another example of an older and successful built and building project is found with the Kennewick Irrigation District in Yakima, Washington. The following quote can be found on KID's home page website:

“The Kennewick Irrigation District began ninety years ago as an agricultural water supply system. Today it still supplies water, but more and more of it goes to keep lawns green and gardens growing. Farms are turning into residential subdivisions at a surprising rate around the Tri-Cities. More and more cropland is going into vineyards, too. Things keep changing, but the Kennewick Irrigation District still sticks to its main job: they keep the water moving!”

At present, KID had more than 14,500 customers to which raw water is delivered for landscape irrigation. KID's web site can be found at: <http://www.kid.org/>

The District has 88 miles of canal, four ditch riders, and a maintenance crew of six. Local improvement districts, known as “LIDs” used to take water from the District at the historic headgate. But as the demands on the KID organization grew they ultimately came to accept the operation and maintenance of the distribution system downstream of the

headgate as long as it was designed and built to KID standards. Currently, KID has 153 LIDs to which KID delivers raw pressurized water.

One success of the KID secondary supply system was the staff and Board acceptance of the opportunity to serve the new customer base as a suitable extrapolation of their mission and an opportunity.

RECENT CIRCUMSTANCES IN NORTHEASTERN COLORADO

Following completion of the dual systems study (Wilkins-Wells 2003) in the fall of 2003, several mutual irrigation companies undertook and commissioned more specific feasibility study efforts so that the potential for dual system projects could be fully understood for their circumstance, initial and annual costs estimated, revenues forecast, and so on. These feasibility level studies were accomplished by working directly with the boards of the companies and the study generally resulted in:

- Estimates of construction costs that allowed for an understanding of the loan commitment.
- Analysis of the water right or rights on a seasonal basis.
- A drought response plan.
- Analysis of housing growth rates to understand phasing and growth of the secondary supply system.
- Analysis of rate structures and revenues.
- Analysis of cash flows and cash position over the term of the loan.

HINDSIGHT ANALYTICAL COMMENTS

From 2003 to the present, the author participated in multiple regional secondary supply feasibility level projects and numerous (several hundred) mutual irrigation company board meetings where options were discussed, analyzed, or debated. As noted earlier, the technical questions, in the author's experience, can likely be solved in a series of workshops. Resolution of the technical questions is not particularly difficult especially when successfully built and operating projects can be toured and so much can be learned from the successes or failures of others. A key question in this regard for the managers of existing systems is "what would you do differently if you had it all to do again?" Answers to that question are easily obtained.

The difficult lessons learned from participation in various northern Colorado feasibility-level studies can be summarized as follows:

1. **Cooperation between the various players:** the synergy and cooperation between the potable water purveyor and the secondary supply entity is paramount. If these two entities can mutually support one another, then success can be assured. (The concept for one potential secondary supply entity stalled because the intent was to be "for profit" and the potable water entity was "not-for-profit". This philosophical disconnect could not be overcome.)

2. **Development agreements:** generally the housing developer has an agreement with the municipality or the county. This agreement identifies the source of all utilities. If the municipality communicates to housing developers in a directive way as to where the potable versus raw water sources come from, the long term success and expansion of a regional system becomes more predictable.
3. **Project cash flow:** negative cash flow in the early years is probable due to over-sizing of project elements but housing growth tends to create a positive cash flow in a financially reasonable period of time. If state's water development money can be obtained at concessionary interest rates, then the negative cash flow period tends to be short and predictable.
4. **Understanding the concept and the future:** many mutual irrigation companies, even though they have been in business for 100 years or more, operate in a low-key and often volunteer way. If the vision of the managing board is to "roll" under the pressures of urbanization and development, then the likely outcome of discussions concerning provision of pressurized raw water delivery are predictable – the no action alternative will likely prevail. Under these circumstances, secondary supply is an "insurmountable opportunity."
5. **Water rates:** financial models can generally predict a successful venture when initial and annual operating costs are known and the intent is to cover those costs and gradually move into a stable and positive cash flow position. The financial aspects of a project can be greatly enhanced when a raw water rate is set more or less artificially as a percentage of the potable water rate. Homeowners in northern Colorado are generally accepting of raw water rates that are 80% of the potable water rates.
6. **Water share ownership and control:** the issue of who actually owns the raw water shares that are dedicated to secondary supply has been a difficult issue. The secondary supply entity wishes to own the shares if the water is to be delivered through a raw water system. The potable water entity may insist on owning the water shares to ensure unequivocally that the water is there into perpetuity. This question is not easily resolved.

SUMMARY

Successful regional secondary supply or dual system projects can be found in several western states. Provision of raw pressurized water for landscape irrigation is a sound concept and means continued use of the decreed water supply without administrative or water court changes. Pitfalls or fatal flaws associated with intended regional systems are often more related to sociological and political problems as opposed to engineering problems.

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IRRIGATION FACILITY RELOCATIONS ALONG THE STATE ROUTE 85 CORRIDOR

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ABSTRACT

In 1999 the Arizona Department of Transportation (ADOT) began improvements along the State Route 85 (SR85) corridor between Gila Bend and Interstate 10 (I-10). At the time SR85 was a two-lane highway that carried a large volume of truck traffic between Interstate 8 near Gila Bend and Phoenix. The SR85 roadway improvements project is broken into phases. The first phase includes the construction of frontage roads and using these roads as a divided highway. Once the divided highway has been completed, the final freeway cross section will be constructed between the frontage roads. The project impacted existing irrigation facilities for three irrigation districts located between the Gila River and I-10, the Arlington Canal Company, Buckeye Water Conservation and Drainage District (BWCDD) and Roosevelt Irrigation District (RID).

The roadway improvements impact three main canals, turnouts from the main canal, main canal check structures, delivery structures, laterals, groundwater wells and tailwater collection systems. Three miles of irrigation facilities relocations were completed in various phases between 1999 and 2006. Total construction cost as of March 2008 is about \$9.4 million. The remaining one mile of relocations is to be completed during the later part of 2007 and early 2008.

In this paper we will present the institutional and functional constraints to infrastructure modernization in an urbanizing area with historic irrigated agriculture. This process was complicated by the need to continue to operate the irrigation delivery facilities on an almost year-round basis.

INTRODUCTION

During the early 1990s ADOT began design improvements to State Route 85 (SR85 or Oglesby Road) between Gila Bend and Interstate 10 (I-10) (see Figure 1). At the time, SR85 was a two-lane highway that carried a large volume of truck traffic between Interstate 8 in Gila Bend and Phoenix. The project was divided into two phases. The first phase included building frontage roads and using these roads as a divided highway. Once the divided highway is built, the main line cross section will be constructed between the frontage roads (see Figure 2).

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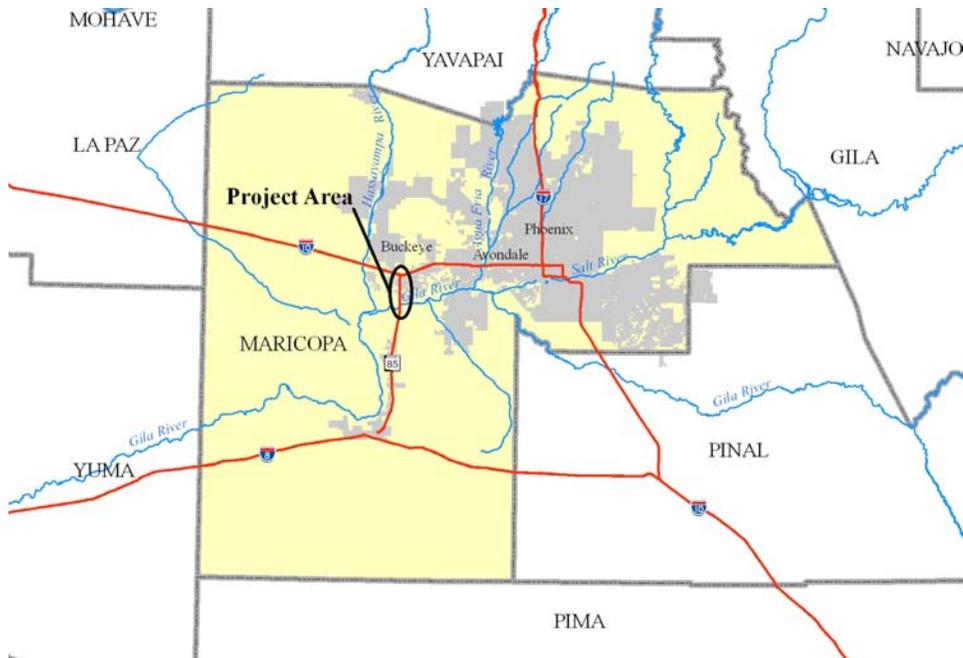


Figure 1. Vicinity Map

The road improvements made between the Gila River and I-10 impacted various irrigation districts and private irrigation systems (see Figure 2). Those irrigation districts are Arlington Canal Company, Buckeye Water Conservation and Drainage District (BWCDD) and Roosevelt Irrigation District (RID). Facilities that were impacted by the SR85 improvements are summarized below.

- Arlington Canal Company owns and operates a conveyance canal just north of the Gila River.
- BWCDD owns and operates a main canal, groundwater well and two laterals along the corridor. The BWCDD facilities are located between Maricopa County 85 (MC85) roadway and Old Highway 80.
- RID owns and operates a main canal, two groundwater well sites, and two laterals. RID facilities are located between MC85 and Broadway Road.

The following agencies and municipalities were involved in the project:

- ADOT is the lead agency conducting improvements along the SR85 corridor.
- Maricopa County Department of Transportation (MCDOT) has jurisdiction over and/or maintains right-of-way within Broadway Road, Southern Avenue, Baseline Road, MC 85 and Hazen Road.
- Town of Buckeye at sometime in the future will annex areas that include impacted reaches of Broadway Road, Southern Avenue and Baseline Road.

Considerations for the design and construction of the relocated irrigation facilities include:

- Accommodates for future urban development
- Changes in operations and delivery requirements
- Inclusion of modern safety requirements which were not required in the 1920's
- Encroachment into the irrigation districts' rights-of-way and easements
- Coordination with a number of stakeholders impacted by the project (ADOT, Town of Buckeye, Maricopa County Department of Transportation, farmers, landowners and developers)
- Relocation/abandonment groundwater well sites
- Liability issues concerning irrigation facilities located within and under future highway right-of-way
- Issues concerning who would relocate the facilities and the cost of relocating the facilities
- Obtaining licenses and permits to complete the work

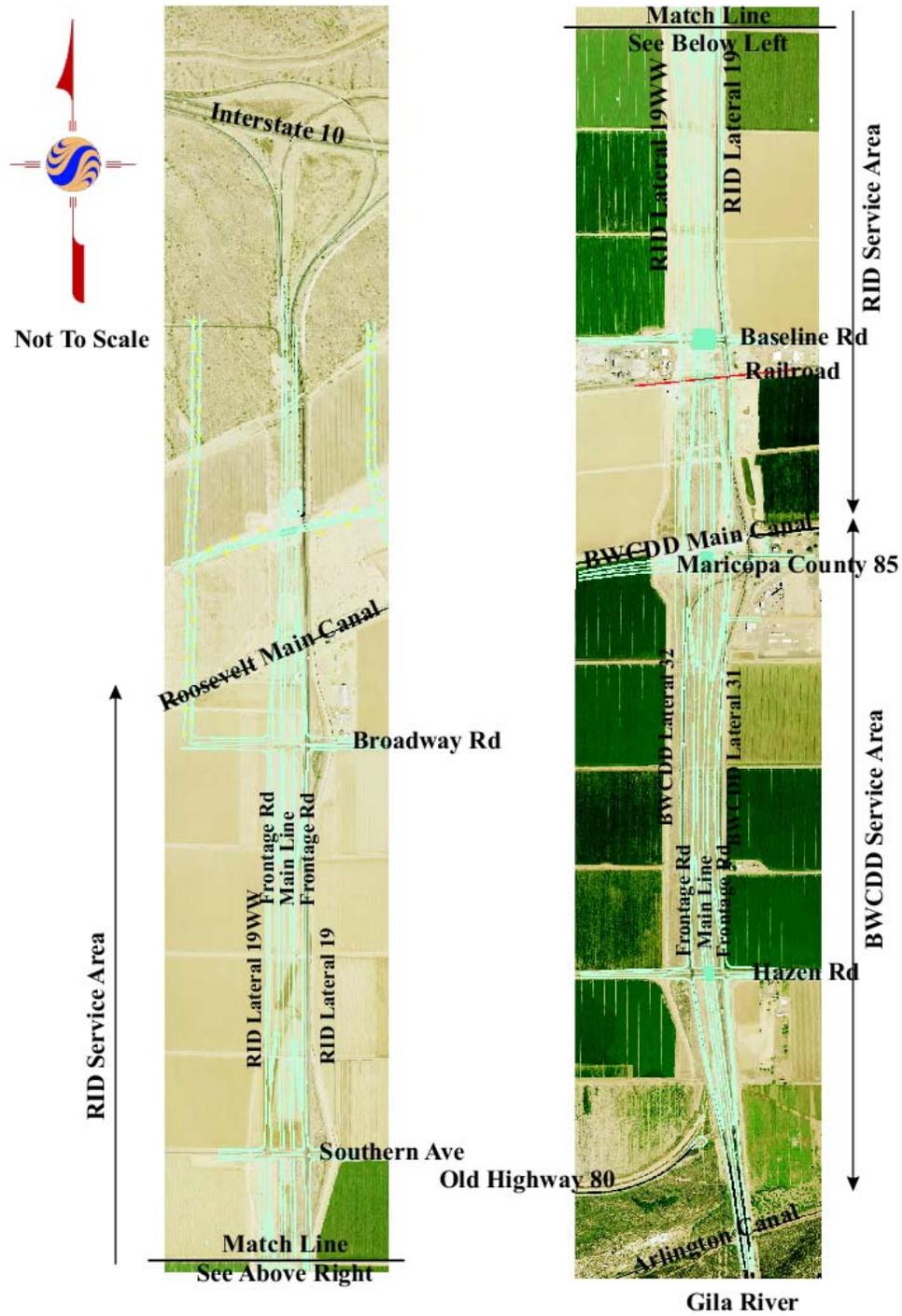


Figure 2. Site Plan Showing the SR 85 Corridor

Relocation Hurdles

The relocated irrigation facilities were not replaced “in-kind,” but were changed to accommodate future development. Many of the existing structures were constructed during the 1920s. Since then, the Buckeye area has experienced a rapid increase in population. Along the SR85 corridor several developments are in the planning stages. Changes to irrigation facilities included modifying the typical delivery structure from an open-lateral turnout (OLTO) to a pipeline lateral turnout (PLTO). OLTO structures typically use weirs and check boards to regulate and measure the flow leaving the irrigation district’s lateral and entering the private system (see Figure 3). These facilities are large and are easily accessed by the public. PLTO structures use a smaller box with gates to regulate flow (Figure 4). Locked covers are placed over the structure to discourage changes by someone other than district personnel.



Figure 3. Open Lateral Turnout



Figure 4. Pipeline Lateral Turnout

Other changes included using more pipeline to convey irrigation water instead of open channel systems. The construction of pipeline laterals is typically more expensive than constructing open channel systems, but pipeline lateral systems are buried, which reduces their visible and physical impact to development. Also, the construction of pipeline laterals typically requires significantly less right-of-way or easement than an open-channel system. Irrigation districts require as much as a 40 to 50 foot right-of-way for an open channel canal system versus a 24 to 30 right-of-way for a pipeline.

Operation and maintenance of the system has changed to accommodate transportation improvements. ADOT has restricted access to the SR85 corridor along with the improvements. Historically, irrigation district personnel could freely cross the corridor, especially at the main canals, by just driving over the highway. At the main canals for RID and BWCDD, turn-arounds were constructed on each side of the highway (see Figure 5). The districts use the turn-around to gain access to the opposite side of the main canal. To cross the corridor the districts must now transition from canal operation and maintenance roads to adjacent highway roads such as Broadway Road or MC 85.

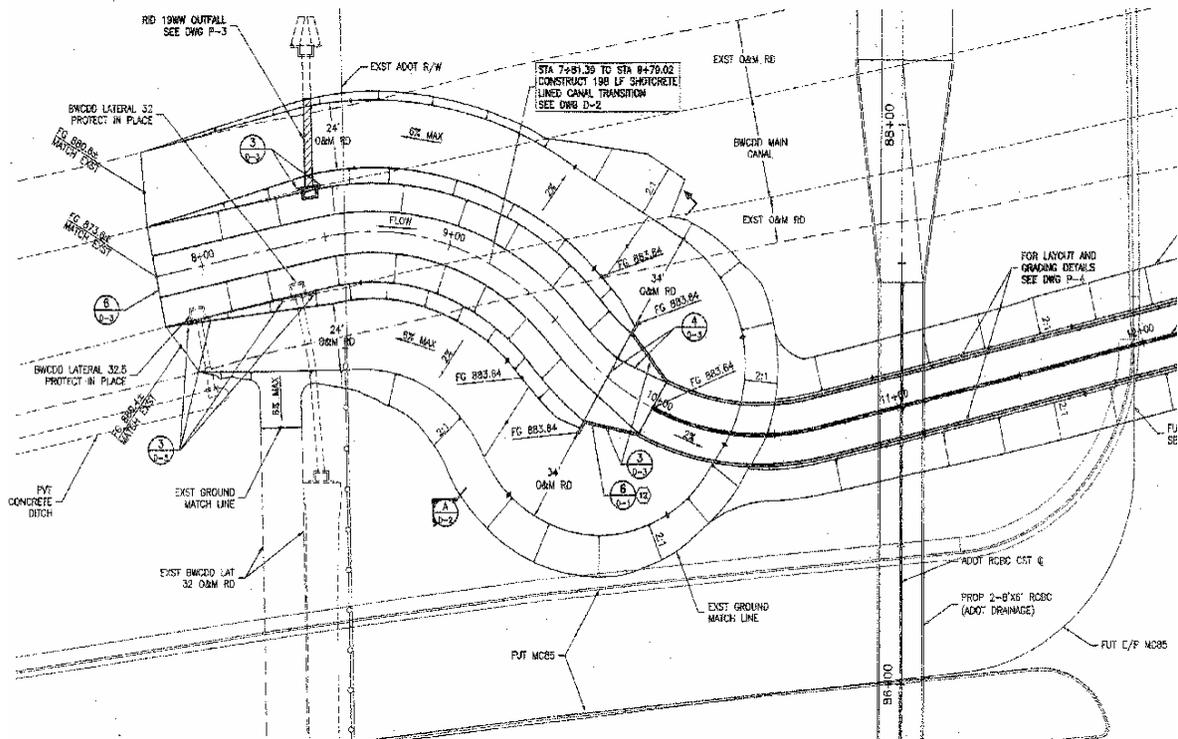


Figure 5. Main Canal Turn-around

Other changes include reducing or eliminating irrigation crossings of the highway. The RID system originally included seven drainage crossings from the west side of SR85 to the east side between Broadway Road and Baseline Road. ADOT elected to construct a new lateral along the west side of the corridor (now Lateral 19 Wasteway or 19WV) and eliminated all seven crossings.

A majority of the existing facilities in the corridor were constructed during the 1920s (see Figure 6). Safety was not an important consideration for design of the facilities and the facilities were constructed within areas with a low population density. With the increase in population and traffic the relocated facilities were designed with additional safety features such as handrails, safety cables and lockable covers. One good example of this is the RID check structure. Figures 7 and 8 show the original and new check structures, respectively. The new structure includes handrails on the upstream and downstream sides and a safety cable upstream from the structure. The walk way on the structure was constructed to be at an even level with the operation and maintenance road to provide safe access from the roadway.



Figure 6. Existing Headwall Constructed in 1928



Figure 7. Original RID Check Structure



Figure 8. New RID Check Structure

The highway improvements encroached into the irrigation district's rights-of-way, especially at the main canal. Agreements were negotiated between the districts and ADOT for the construction, operation and maintenance of the irrigation facilities. Since the districts had prior rights to the facilities, land and right-of-way, ADOT was responsible for funding the relocating of the facilities. In areas where districts' laterals were moved to accommodate the future frontage roads ADOT purchased land for the new facilities.

Coordination with ADOT, MCDOT, the irrigation districts, landowners, developers and farmers was crucial to maintain almost year-round irrigation deliveries. The districts typically only have one short (11-day) system wide dry-up in November. It is only during this period when major construction projects on the main canals and major laterals can be completed. One example was the construction of a box culvert for irrigation flows, box culvert for stormwater flows and check structure in the RID main canal. The sequence of events was as follows:

During 2005 annual dry-up bifurcation or "Y" structures were constructed in the main canal (see Figure 9). The structures were buried until the contractor was ready to finish building the bypass.



Figure 11. Construction of RID Box Culvert

During the 2006 annual dry-up the remainder of the box culvert (67 ft) and headwalls were constructed. Also during this dry-up a new main canal check structure was constructed. Figure 12 shows the outlet headwall of the box culvert with handrails.



Figure 12. RID Main Canal Final Product

The construction included the coordination between ADOT, ADOT's consulting company, RID and RID's consulting company.

The irrigation districts owned three groundwater wells within the SR85 corridor. The wells were located in the alignment of either the frontage roads or the main highway alignment. ADOT and the irrigation districts came to an agreement for the abandonment of the groundwater wells.

Some of the irrigation facilities will be located under future highway facilities, especially at the main canals. The districts were concerned with the liability of constructing and maintaining these more complex structures. They were also concerned with the construction cost of the structures. It was agreed by the districts and ADOT that these structures would be designed by RID engineers and constructed by an ADOT contractor. It was also decided that ADOT would own and maintain the structures, but RID would have perpetual use of the structures. ADOT would not be allowed to modify the structures without prior approval from the districts.

The districts were formed during the 1920's to provide irrigation water to farmers between the Agua Fria River and the Hassayampa River. Because the districts were formed before ADOT obtained right-of-way for the highway all relocation costs are paid by ADOT. The irrigation district facilities were designed by the district's engineer. For minor relocations contractors under contract by the irrigation district were used to construct the facilities. These facilities included laterals along the west side of the corridor. For large facilities that are under the future frontage roads or the main alignment a contractor obtained by ADOT was used. The facilities included the box culverts and check structure in the main canals. Permits were obtained from ADOT and MCDOT for construction of various facilities.

PRESENT STATUS

The following is a summary of the structures constructed as part of the irrigation relocations in the SR85 corridor.

- 1 main canal check structure
- 4 manholes
- 63 headwalls
- 10 lateral drop structures
- 4 delivery structures
- 4 main canal turnout structures
- Approximately 1 mile of pipeline
- Approximately 3 miles of ditch
- Approximately 1402 ft of large double barrel box culvert in the main canals

Total construction cost for the irrigation relocations as of March 2008 is about \$9.4 million. ADOT has completed construction of the frontage roads between the Gila River and MC 85. The frontage roads between MC 85 and Southern Avenue are currently under construction as of March 2008. The final segment of the frontage roads between Southern Avenue and I-10 are scheduled for construction starting 2008.

THE IMPACT OF THE ARIZONA WATER SETTLEMENT ACT ON URBAN WATER SUPPLIES

Rosalind H. Bark-Hodgins¹

ABSTRACT

The 2004 Arizona Water Settlements Act (AWSA) when implemented will allocate eight percent of Arizona's 8.1 million acre-feet a year (afy) water supplies to a single Native American tribe, the Gila River Indian Community ("GRIC" or "Community"). Yet despite the size of the GRIC settlement, there were 35 signatories and 85 side agreements attached to it. The side agreements not only resolved litigation, but also developed new contractual arrangements between the Community and non-Indian parties. The rationale for the AWSA given the scale of the Community's quantified water rights is the topic of this research. Key motivations for the settlement are: (1) the 653,500 afy GRIC water budget is just a third of the GRIC's 1.8 million afy Gila River Adjudication claim; (2) GRIC signed a number of water leases and exchanges with municipal and industrial (M&I) users and has not ruled out signing more; (3) the AWSA settled more than just the GRIC's claims; it also settled thorny issues of Central Arizona Project (CAP) debt repayment and water allocation between state and federal governments; and (4) it incorporates innovative elements that improve water supply reliability for both tribal and non-tribal parties in a time of increasing water supply uncertainty.

INTRODUCTION

The AWSA is the largest tribal water settlement in the history of Arizona and there are implications for water users throughout the state. The rationale for the settlement and the potential future implications from an urban water supply perspective is the topic of this paper. The basis for the GRIC water right claim is the 1908 *Winters* doctrine. In *Winters v. United States* (207 U.S. 564) tribes were found to have reserved water rights appurtenant to reservation lands. The seniority of these water rights was to be determined by the date each reservation was established. The GRIC Reservation was created in 1859 (11 Stat. 388) and enlarged twelve times over the next half century by Executive order. The 1879 expansion incorporated lands in the Salt River basin (S. 3227 at Sec 1(3)). The *Winters* doctrine did not establish a mechanism for quantifying *Winters* rights and this lack of resolution meant in practice that these "rights" were not secured from non-Indian water development.

GRIC's 150,548 hectare reservation is located downstream of numerous diversions on the Gila and Salt Rivers. These diversions, most of which are for non-Indian irrigated agriculture, reduced river flow and consequently water access for the downstream tribal lands. Litigation to secure GRIC water access to the waters of the Salt was successful and in 1903 *United States v. Haggard* (U.S. v. N.W. Haggard, No. 19 (D. Ariz. 3d Jud. Dist. June 11, 1903)) the court adjudicated the Community's right to approximately 5,900 afy

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from the Salt. The U.S. federal government on behalf of the Community in accordance with its federal trust obligation to tribes (McCarthy, 2004) also litigated water rights to the Gila River. In 1935, the Community obtained water entitlements to 300,000 afy in the *Globe Equity* decree (Globe Equity, 1935). However, the actual “implementation of the Globe Equity Decree produced numerous legal skirmishes over the years” (Blumm, Becker and Smith, 2006).

The water rights established by court decree in the 1900s fall far short of the GRIC’s 1.8 million afy claim in the Gila River Adjudication proceedings. A water right of 1.8 million afy would: (1) reallocate 22% of the State’s current 8.1 million afy total water supplies, or 43% of all surface water supplies, or 64% of Arizona’s Colorado River allocation, or 113% of CAP supplies (ADWR, 2006) to one tribe; and therefore (2) significantly reduce available supplies to non-Indian water rights holders. This claim was based on the Practicably Irrigable Acreage (PIA) standard articulated by the courts in *Arizona v. California* (373 U.S. 546 (1963)) as a mechanism to quantify *Winters* rights. PIA quantified *Winters* claims are calculated by multiplying an irrigation application rate by the reservation’s PIA. This formulaic standard is not without its flaws (Smith, 2005) and an alternative articulated by the Arizona Supreme Court is the homeland test (Gila River V, 35 P.3d at 76). This test allows tribes to base water rights claims on their current and future needs. The advent of the homeland test coincided with the AWSA negotiations and added a new level of uncertainty to the negotiations. As with tribal water rights quantified through PIA, the development of senior tribal water uses based on the homeland test can pose a threat to junior water rights holders in an over-allocated watershed. The Community’s claims remained an exceptional risk for the water rights and future development of the central valley cities and to a degree, for the rest of the state. Many participants believed that the GRIC had a very strong reserved right claim based on their location at the confluence of two rivers, a long-term documented history of irrigated agriculture (AWSA Hearing, 2003), and large tracts of irrigable and developable reservation land. Other regional water users were concerned that the Community might also have a strong ability to limit significant groundwater pumping near the reservation boundary as per the 1999 Gila River III case. Given this exposure, the surrounding cities were primed for settlement.

Settlement

The AWSA contains four Titles. In order they are: Central Arizona Project Settlement (the repayment and allocation components); Gila River Indian Community Water Rights Settlement (GRIC WRS); Southern Arizona Water Rights Settlement (SAWRSA) (to resolve outstanding Tohono O’odham (TON) settlement issues); and the San Carlos Apache Tribe Water Rights Settlement. The GRIC WRS resolves the water rights of the GRIC Reservation which is located at the confluence of the Gila and Salt Rivers just south of Phoenix and the SAWRSA amendments resolve outstanding disputes from two earlier settlements with the TON whose reservation is located just south of Tucson the second largest metropolitan area in the state (see Figure 1). The proximity of the reservations to urban areas explains the extreme water availability risk to non-Indian

water users posed by the lack of certainty regarding the water rights claims of the tribes and the consequent support from cities for the comprehensive settlement.

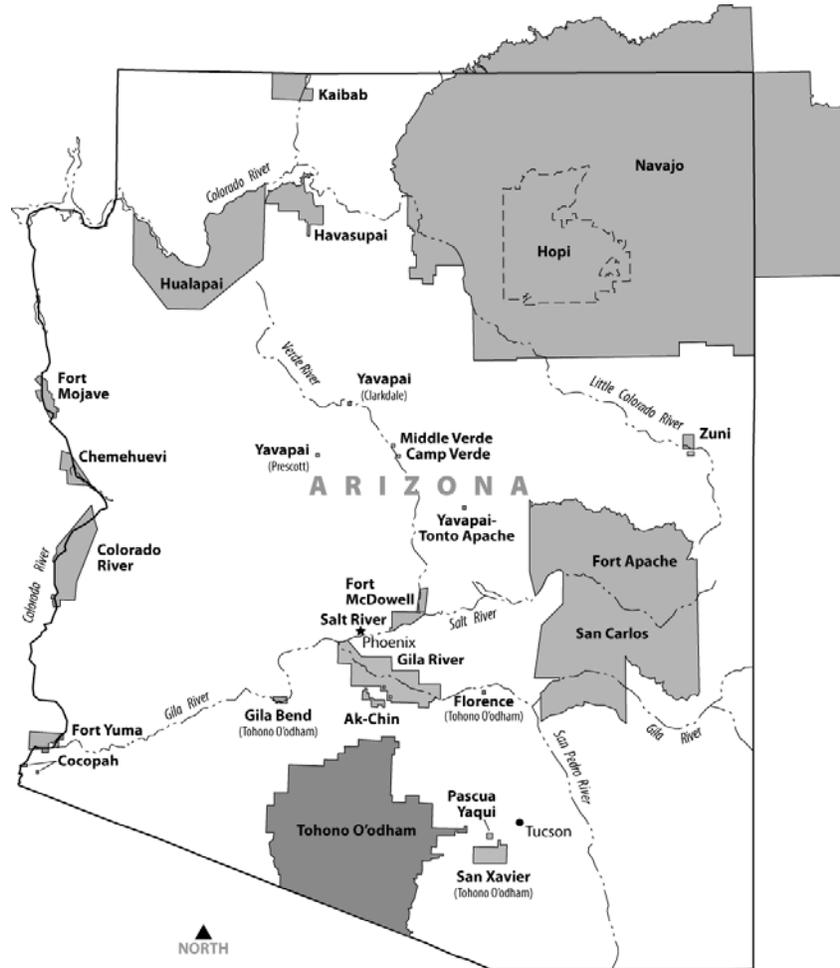


Figure 1. Arizona's Indian Reservations and Rivers

A large Indian water rights settlement like the AWSA necessitates the (re)allocation of either: (1) already allocated; or (2) unallocated, 'excess' water to the signatory tribes. If previously allocated water is reallocated to satisfy a tribal water right, Federal criteria for Indian water rights settlements (Fed Reg, 1990) require that incumbent water rights holders in the affected watersheds are compensated with money or alternative water supplies. Without this criterion, tribal water settlements would increase the opportunity costs of agreements to non-Indian water users and reduce these parties' incentives to negotiate and settle outstanding tribal water claims. But it also elevates incumbent water rights, many of which are for irrigated agriculture, at the expense of future water uses, which are mainly M&I. The AWSA (re)allocates both previously allocated water and unallocated excess water to the tribes included in the settlement (Table 1). The settlement of these claims has reduced available water supplies that might have been allocated to rapidly growing urban and urbanizing areas in the three-county CAP service area

(Maricopa, Pinal and Pima), but also creates certainty for water planning and opportunities for Indian water leases and exchanges.

Table 1. GRIC Water Budget

Water Source	AF
Community CAP Indian Priority	173,100
Groundwater	156,200
<i>Globe Equity Decree</i> (of 300,000 allocated in 1935)	125,000
New CAP non-Indian Agricultural (NIA) priority	102,000
Salt River Project (SRP) Stored	20,500
Roosevelt Water Conservation District (RWCD) CAP	18,600
Harquahala Valley Irrigation District (HVID) CAP	18,100
Asarco CAP	17,000
<i>Haggard Decree</i> ²	5,900
Mesa reclaimed exchange premium	5,870
RWCD surface water	4,500
Chandler contributed reclaimed	4,500
Chandler reclaimed exchange premium	2,230
TOTAL	653,500

The AWSA was practicable in large part because unallocated CAP-delivered Colorado River water (part of Arizona's 2.8 million afy allocation (1928 Boulder Canyon Project Act, 43 U.S.C. 617 et seq., Sec 4(a)(1)(a))) was available for allocation to tribal interests. In practice, excess CAP water will replace a block of *Globe Equity Decree* (Gila River) water undelivered to GRIC (Glennon and Culp, 2002:928) without this substitute water the water rights of non-Indian agricultural users and municipalities in the Gila River watershed would have had to be reduced. With the agreement the water rights of these users remain undiminished or compensated, but the quid pro quo is that the proportion of CAP water designated for Indian uses expanded and the proportion designated for non-Indian uses was reduced.

The SAWRSA amendments incorporated into the AWSA resolved a long-standing dispute over the acceptable quality of water designated for the TON as well as issues related to the water rights of allottees, who own parcels of land within the reservation boundaries. The TON's refusal to accept 28,200 afy of treated effluent as partial fulfillment of its earlier settled 66,000 afy water budget (SAWRSA, 1982 and 1992) meant a substitute water source had to be identified and delivered to the reservation. By attaching themselves to the AWSA, southern Arizonan tribal and non-tribal water users were able to push through SAWRSA amendments, because excess CAP water was made available to the umbrella settlement. The AWSA framework greatly benefited the SAWRSA amendment process, specifically a replacement water source for the disputed 28,200 afy of treated effluent included in the original SAWRSA agreement was made

² In lieu of Haggard Decree water SRP shall deliver to the reservation, at no cost to the Community of the U.S. the 5.9 KAFY from a pumping plant, the so-called Booster, on the Maricopa Drain. Exhibit 7.2 Articles I and II. Article IV provides provisions for pumping in excess of this limit from this site, however, the electrical pumping charges would have to be borne by the Community or the U.S. This agreement is in return for waivers of liability for Salt River diversion that may have impacts water supplies for GRIC irrigation (Article X).

available to the Nation. Furthermore, the availability of CAP water removed any obligation for local supplies to make up the 28,000 afy of treated effluent or for the federal government to purchase water rights elsewhere in the state for delivery to the TON. Meanwhile the 28,200 afy of treated effluent (approximately one-third of the treated effluent generated by metropolitan Tucson's largest wastewater treatment plant, the Roger Road Wastewater Treatment Plant) remains assigned to SAWRSA and is not legally available to the Tucson metropolitan area that generated it, though it continues to be discharged to the Santa Cruz River bed, resulting in aquifer recharge. Monies from the sale or lease of this effluent or storage credits that result will be used to fund the SAWRSA agreement (AWSA, Title III, Sec 310(a)(2)(E)(i)-(ii)) and to purchase any substitute water or to pay compensation as per Sec 301(b)(1)(A)-(D).

The solution of utilizing excess CAP water means that this water is neither available for future allocation to non-Indian uses nor for water banking to firm future supplies. Some issues associated with fully allocating CAP were moderated by GRIC's and the TON's acceptance of water leasing and exchanges (AWSA, Title II, Sec. 205(a)(2)).

Urban Surface Water Supplies: CAP Service Area

The agreement with GRIC and the TON necessitated the reallocation of previously non-Indian subcontracted CAP water in the CAP service area. A key provision of the AWSA is the division of CAP water between Federal and non-Federal uses. Of the total 1.415 million afy stipulated for delivery under long-term contracts by the CAP, 650,724 afy is contracted to Arizona tribes, or to the Secretary of the Interior (Secretary) for allocation to Arizona tribes, and the remainder, 764,276 afy is set aside for non-Indian M&I entities, the Arizona Department of Water Resources (ADWR), and for non-Indian agricultural (NIA) Agricultural Pool water (AWSA, Title I, Sec. 104, (a)(2)(c)(1)(A)(i)). An outcome of this volumetric division is that NIA priority water has been converted into fixed volumes. Voluntary relinquishment of now volume-based NIA contracts in return for retired debt released 295,263 afy for Indian water rights settlements.

New allocations: A source of new urban water was incorporated into the overall settlement. This new water is one reason why the AWSA received robust local support. The AWSA reallocates 65,647 afy of uncontracted CAP-M&I priority water to twenty cities in the three-county CAP area (AWSA, Title I, Sec. 104(a)(2)(b)(1)). To put this volume in context, 65,647 acre feet of water could supply 130,000 average households for a year (ADWR, 2006). An example of the significance of these new allocations to a city's water portfolio is the City of Tucson's new 8,206 afy allocation (AWSA, Title I, Sec. 104(a)(2)(b)(1)(S)) which increases CAP-M&I renewable, supply-secure water supplies by 6%³ from their initial 1985 CAP-M&I subcontract of 135,966 afy (CAP, 2007) to 144,172 afy. CAP-M&I priority water meets state Assured Water Supply (AWS) standards (A.R.S. Chapter 2, Article 9, Title 45-576(J)) and therefore can be used to support additional growth. Furthermore, this supply of reliable water is available to these

³ The actual increase will be somewhat more than 6% because a proportion of this additional supply will be reused by the city in the form of treated waste water.

cities at CAP-M&I rates which are less expensive than developing an acre foot of treated wastewater which in Tucson costs around \$260.92 per acre-foot (IGA,2000).

Future allocations: A 96,295 af block of unallocated CAP water as part of the settlement was allocated to ADWR (AWSA, Title I, Sec 104, (a)(2)(A)). This water will be held in reserve for future allocation to non-Indian uses. The Director of the ADWR must submit to the Secretary a recommendation for how to reallocate this water and if approved, the Secretary will enter into a subcontract with the entity. A likely motivation behind this staged allocation is to give growing communities in the CAP service area the chance to participate in future CAP allocations. Without this provision, it is likely that large cities would contract for this water: with it, smaller cities have an opportunity to secure additional water supplies and improve water supply reliability for their residents.

Water leases: Leases fulfill one of the Federal settlement criteria that state beneficiaries of Indian water rights settlements contribute to the overall settlement and thereby reduce federal costs. Tribal water leases provide flexibility for tribal water to be used off-reservation. The AWSA facilitates water leases and exchanges through guarantees that these market mechanisms will not be counted against possible future allocation or reallocation of water by the Secretary (AWSA, Title I, Sect 213(d)). This provision reinforces ‘buyer’ incentives. There are several restrictions on leases: (1) only non-*Winters* water can be marketed (AWSA, Title I, Sec 205(f)(2) states that Gila River agreement, *Globe Equity Decree*, and *Haggard Decree* water cannot be sold, leased, transferred, or used off-reservation other than by exchange); (2) CAP water can only be leased within Arizona (AWSA, Title I, Sec 205(a)(2)(A)). Exceptions are detailed in Title I, Sec 104(e)(2) for water leased or exchanged with the Arizona Water Banking Authority (AWBA) or for an exchange with New Mexico as per the NM Consumptive Use and Forbearance Act ratified under Title II, Sec 212; (3) water can only be leased for no more than 100 years (AWSA, Title I, Sec 205(a)(2)(B)); (4) Community CAP water must be delivered through the CAP system, thereby securing funding for the system (AWSA, Title I, Sec 205(a)(4)(A)); and (5) leased water is subject to the CAP system’s priority-based shortage-sharing arrangements in times of drought (AWSA, Title I, Sec 205(a)(4)(B)). Essentially AWSA-CAP allocations to GRIC and TON, and previous CAP contracted water, can be transferred under short- or long-term leases and exchanges. It is unclear what proportion of these new allocations the tribes will eventually lease off-reservation.

GRIC is not yet physically able to use all of its newly allocated CAP water supplies, but if the settlement moves forward by the December 31, 2007 enforceability date (AWSA, Title II, Sec 207(c)), then short-term leases will allow GRIC to lease water to non-Indian users or the AWBA. As on-reservation water uses build out, GRIC CAP water available for short term leasing is likely to diminish. As part of the GRIC WRS, the Community signed initial leases with M&I users. No lease agreements were attached to SAWRSA but provisions for them are incorporated into the settlement.

The lease agreements between GRIC and four Phoenix valley cities are incorporated as side agreements to the AWSA (Exhibits 17.1 A-D). These side agreements lease a total

41,000 afy of GRIC CAP Indian or M&I priority water to Goodyear and Peoria (7,000 afy each), Phoenix (15,000 afy) and Scottsdale (12,000 afy). Although the lease volumes differ, all the agreements have the same cost and payment options. The actual price of leased water is determined by a pricing formula based on a water valuation completed for the Salt River Pima-Maricopa Indian Community Water Rights Settlement Act of 1988 (SRP-MIC WRSA, 1988). The water price is based on a cost analysis of replacement CAP water capitalized over the period of the lease and a price escalator, the consumer price index (CPI). The one-time base payment to the GRIC for the right to lease this water for the entire term of the lease is \$1,203 per af which is multiplied by the CPI escalator. This ratio is the CPI for Urban Consumers in the month the term begins divided by this index value in December 1991. For example, if the City of Goodyear agreement were paid in full in October 2007 the formula would be $\$12.76 \text{ M} \left(\left(\frac{208.94}{137.9} \right) \times \$1,203 \right) \times 7,000 \text{ afy}$. The cities do not pay CAP water service capital charges on this water (AWSA, Title II, Sec 205(a)(8) states that CAP water service capital charges are not payable for Community CAP water whether or not the water is used on-reservation). These charges were \$21 per af in 2007, although operation, maintenance and replacement (OM&R) charges must be paid (AWSA, Title II, Sec 205(a)(6) provides that the Secretary shall pay the OM&R costs for the delivery of Community CAP water to GRIC, given adequate funds in the Lower Colorado River Basin Development Fund (LCRBDF), but not for water leased by others). These lease contracts benefit: (1) the cities which secure relatively inexpensive AWS-compliant water; (2) the Community which would receive a total \$74.73 M, if the cities paid the leases on the entire 41,000 afy upfront (in October 2007), for investment on the reservation; and (3) the U.S. Treasury which would have had to pay the CAP OM&R costs if the water remained with the Community. These costs were \$52 per af in 2007, hence the leases save the U.S. Treasury just over \$2.13 M a year.

The four cities with lease agreements have accessed secure water at the cost of the lease price and CAP OM&R costs. These costs are lower than the cost of securing an additional acre foot of water through water treatment. However, it is possible that the cities could have made even better water deals, for example with agricultural and tribal interests along the main stem of the Colorado River. Nevertheless, these opportunities remain open for future deals. The opportunity costs of the cities' investment in 100-year leases are foregone alternative spending priorities in the cities. However, any opportunity costs are diminished by the ability to re-lease the water to others, to bank the water, and from the benefits of securing a diversified water source portfolio. On the other hand the Community is bound by the lease pricing mechanism even if the value of water in the region rises substantially, for example in response to possible diminished future Colorado River supply and shortage sharing arrangements (Christensen and Lettenmaier, 2007; Hoerling and Eischeid, 2007; Reclamation, 2007). The designated pricing formula accounts for inflation but has little connection with forces affecting future water demand, supply and market value.

The SAWRSA amendments have improved TON's bargaining position vis-à-vis potential water lessees. Prior to the amendments, the Nation?? could only lease within the Tucson Active Management Area (AMA), but now it can make leases or exchanges for CAP

water and storage credits within the three-county CAP service area (AWSA, Title III, Sec 309 (b)(B)), though there is a right of first refusal within the Tucson AMA. There is a possibility that the competition inherent in this amendment might raise lease prices if the City of Tucson has to compete for contracts with Phoenix area cities. In turn this provision could mean that the TON would benefit from higher lease prices.

Water exchanges: Water exchanges are an innovative water resource tool to promote water efficiencies and match water uses with the appropriate water quality. For example, water might be exchanged to reduce conveyance losses, reduce energy requirements or construction costs, or to reduce treatment costs by conserving higher-quality water for household use. Water exchanges are not new to Arizona as they were previously utilized in the SRP-MIC WRSA, 1988 and are authorized in Arizona Revised Statutes. The AWSA facilitates exchanges in its accounting rules. Any entity that receives CAP water in exchange for reclaimed water does not have to count this CAP exchange water against its contracted CAP allocation (AWSA, Title I, Sec 104(d)(2)(E)(i)). A similar rule in the settlement facilitates water leases (see above) and both illustrate how the AWSA is responsive to the new reality that excess CAP water is fast dwindling and that no agent is willing to sign an agreement that diminishes its future options to secure a block of this remaining water supply.

A side agreement between the cities of Mesa and Chandler and GRIC authorizes exchanges of reclaimed water for CAP water (Exhibit 18.1). GRIC will receive up to 29,400 afy of “Mesa Reclaimed Water” and up to 11,200 afy of “Chandler Exchange Reclaimed Water” (Exhibit 18.1 at para. 2.1.1-2.1.2). These exchanges are based on a 4-to-5 ratio: the cities receive 1/5 less CAP water (a total 32,480 afy) for their reclaimed water. The benefit of this exchange to the cities is that it delays new investment in wastewater treatment, or in recharge facilities, and converts reclaimed water into potable water. The cities likely incur cost savings and the Community benefits from securing reclaimed water as a drought-proof agricultural and golf course irrigation water supply. In addition Chandler has pledged 4,500 afy of “Chandler Contributed Reclaimed Water” to the GRIC water budget (Exhibit 18.1 at para. 2.1.3). This small contribution is an example of how local entities can bolster Indian water settlements.

The Community also has an exchange agreement with Phelps-Dodge Corporation (now Freeport-McMoRan Copper & Gold) whereby the corporation can divert upstream Gila River water, in accordance with environmental laws, in lieu of CAP water that is then exchanged with the Community. This exchange provision allows for a limited decoupling of beneficial use and location of the exchanged surface water right. There may be unintended impacts of these water exchanges on critical habitat or other water users, including the San Carlos Apache Tribe and New Mexico (Raley, 2003) that will need to be resolved by the Secretary. These potential third party impacts might diminish some of the increased efficiency gains gained through the exchanges that facilitate water use close to water availability.

The outcome of these leases and exchanges is that a proportion of GRIC’s newly quantified water budget will be reallocated to non-Indian users, who will benefit from

additional, secure water supplies. The sum of all of these lease and exchanges just discussed is that the GRIC will have a net additional 93,500 afy of mostly CAP-NIA grade water for agricultural development. Leases, exchanges and options will reduce availability for the period of the lease of the Community's combined higher priority CAP-IA, CAP-M&I, and CAP-firmed NIA water (a total 205,100 afy) by 95,500 afy while increasing revenues by around \$78M.

After-acquired trust land: The AWSA also dealt with water rights for off-reservation trust land. GRIC can still "seek to have legal title to additional land in the State outside the exterior boundaries of the reservation taken into trust by the United States for the benefit of the Community pursuant only to an Act of Congress" (AWSA, Title II, Sec 210(a)). However, "after-acquired trust land shall not include federally reserved rights to surface water or groundwater" (AWSA, Title II, Sec 210(b)). What this means is that any new trust lands created by an Act of Congress in the Phoenix valley for the benefit of GRIC will not receive a further (re)allocation of water. GRIC's water budget is final except to the extent that it contracts for leased water or leases water. This new provision may extend to other lands taken into trust in Arizona post-AWSA.

Urban Groundwater Supplies: CAP Service Area

The settlement requires new state legislation to protect on-reservation groundwater for the GRIC and TON. This provision is essentially unprecedented in Arizona law, because it protects groundwater supplies on-reservation by limiting pumping on adjacent lands that are off-reservation. Specifically, Titles II and III contain provisions that create a buffer zone around the Reservations, within which groundwater pumping by non-Indians will be strictly monitored and controlled. These buffer zones are a regulatory innovation that will protect groundwater levels for the benefit of sovereign tribes. State law has already been amended to comply with these requirements (A.R.S. §45-2602 (A-B)).

The Southside Replenishment Program establishes five protection zones along the southern border of the GRIC Reservation in which water conveyance outside the Eastern or Western Protection Zones is prohibited for non-irrigation use, with certain exemptions (§45-2611(A-B)), and where the state has obligations to replenish groundwater pumped in excess of set limits. For example, in the Eastern Protection Zone replenishment obligations are triggered when pumping is in excess of 2.33 af per acre (§45-2602(3)(d)). Notably, these replenishment requirements are stricter and use a different physical mechanism than state well spacing rules (which are based on maximum allowable reductions in groundwater levels rather than the volume of water that is removed). The Southside replenishment obligations are spatially connected to groundwater pumping so that the spatial integrity of the aquifer is respected and as a result, subsidence risk is reduced. This spatial aspect of the replenishment was a sticking point with the Community, which was concerned about existing impacts on their groundwater reserves by non-Indian pumping. To resolve this issue the state agreed to an additional replenishment volume to compensate for historic pumping.

Firming and aquifer space: The quid pro quo for reallocating uncontracted CAP-M&I water to M&I users rather than to tribal settlements was a federal and state assurance to “firm” an equivalent volume of CAP-NIA water to CAP-M&I priority for tribal settlements. This was a creative solution; the firming volumes and division of responsibilities between state and federal governments are detailed in Title I, Sec 105. Firming legislation at the state level was adopted in early 2006 (A.R.S. Chapter 14, Article 5 §45-2491). The AWBA was designated the state’s agent for firming. Firming requirements based on expected probabilities of shortage on the Colorado River, possible water sources, and payment vehicles were identified in the legislation. The Firming Program Study Commission estimated that to firm the state’s 23,724 afy commitment for 100 years, a total 548,770 af would need to be banked (IFSC, 2005). Reclamation, the lead federal agency for federal firming estimates that firming SAWRSA and future settlements, will require a firming obligation of 1,107,720 af (Arizona will contribute \$3M in groundwater credits to this federal firming program (ASWA, Title III, Sec 306(b)). Reclamation’s firming obligation calculations are more risk averse than those of ADWR; using Reclamation’s formula ADWR would have to firm approximately 30% more water.

An outcome of dividing firming responsibilities rather than dividing up the cost of a single firming program is that federal and state agencies may compete for excess water and storage capacity in recharge facilities, raising program costs. In addition the large volumes of water that will be banked to firm the AWSA will reduce available water and aquifer space and raise firming costs for M&I firming to secure reliable water supplies for urban users.

DISCUSSION

The AWSA removed the risk and uncertainty associated with the GRIC Gila River Adjudication water claim. But this certainty came at the cost of (re)allocating 172,800 afy of CAP supplies, or CAP-sourced treated wastewater to GRIC. In addition SRP is responsible for making available 26,400 afy in stored and in-lieu *Haggard Decree* water to the Community. The new GRIC CAP allocation effectively replaces *Globe Equity Decree* water – incumbent water rights were prioritized over potential future contractors to CAP water. Meanwhile, the SAWRSA amendments allocated an additional 28,200 afy to the TON and have left southern Arizona communities wrangling over groundwater credits for the previously allocated treated wastewater. The inducement for this (re)allocation of water that could have been used for non-Indian uses is that the AWSA also provided twenty cities with new allocations of CAP-M&I water and the AWSA incorporated provisions for water leases and exchanges with the tribal parties to the settlement.

The opportunity costs of the AWSA are hard to quantify. The key opportunity costs are those associated with reallocating water to GRIC that could have been allocated to current and future competing uses. There may also be opportunity costs in terms of future settlements. To the extent that tribal water settlements are a zero-sum game, that is there is a finite quantity of water and federal funds to settle tribal water claims in Arizona,

GRIC's settlement may have reduced the probability of other settlements in the state. Why? A large fraction of excess CAP water was devoted to the GRIC settlement and significant federal indirect and direct funds were authorized for the AWSA. In 2007 only a small proportion of CAP water remains uncontracted, 1,218 afy of former HVID water and 154,569 afy of NIA priority water. Of this total the AWSA set aside 67,300 afy to facilitate other settlements (AWSA, Title I, Sec 103, (a)(A)(iii)), of which 6,411 afy is dedicated to a future settlement with the Navajo Nation (Id. at Sec 103, (a)(B)(ii). The time when CAP renewable supplies fueled growth, settled Indian water claims, and, as initially intended, shifted irrigated agriculture from groundwater to CAP supplies, may soon be over. Future non-Indian water development in the three-county CAP service area will have to find alternative water supplies that are likely to be more costly (these new supplies might be delivered by increasing the capacity of CAP canal) and new Indian water settlements are also likely to be more costly and complex.

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CAN LITTLE COLORADO RIVER WATER BE USED FOR RECREATION OR HABITAT ENHANCEMENT?

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ABSTRACT

Sever and transfer efforts by Arizona Game and Fish Department (AGFD) along the Little Colorado River (LCR) under the Norviel Decree were initiated to gain recreation storage water in reservoirs in the 1960s. The first effort was for Lee Valley reservoir, which severed and transferred water from land that was irrigated with water from the LCR. The AGFD repeated this process for Nelson Reservoir in the 1980s. The court system officially approved these transfers for different uses (recreation) by 1989. Since then AGFD has purchased other properties in the LCR watershed for recreation and habitat enhancement purposes including the Becker Lake, Grasslands, and Wenima Wildlife areas.

More recently a settlement, titled the “Zuni Indian Tribe Water Rights Settlement Agreement”, in the LCR Basin was reached with a number of parties including the AGFD and the Zuni Indian Tribe (Tribe) that resolves water rights claims of the Tribe on the LCR. The objective of the Settlement is that the parties are to provide 3,600 acre-feet per year of surface water and groundwater to meet goals of the Tribe without disrupting existing surface water use by other water users within the LCR Basin. As part of the Settlement, AGFD was tasked with providing 1,000 acre-feet of surface water per year to the Tribe as measured at Lyman Lake. This objective must be met in accordance with State law and the AGFD charter, which is to expand an ongoing Stream Rehabilitation Program above Lyman Lake.

Over the past three years Stantec⁴ has helped AGFD identify the water rights and their associated yields to facilitate the severance and transfer of water from agricultural or other off-channel uses to instream beneficial uses of wildlife, including fish and recreation. This paper describes that study and the results of the modeling effort to identify water availability in the basin for this purpose. A number of legal and local issues make the process interesting and complex. This paper will describe how the LCR is governed, how the AGFD is working to meet their objective, and the water rights model Stantec developed to assist the AGFD achieve their objectives.

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INTRODUCTION AND BACKGROUND

In the Little Colorado River (LCR) basin from just below the community of Saint Johns the use of LCR water is allocated according to the Norviel Decree and governed by the Court system in Apache County, see Figure 1. This is the only location in the State of Arizona where the water use is not governed by the Department of Water Resources.

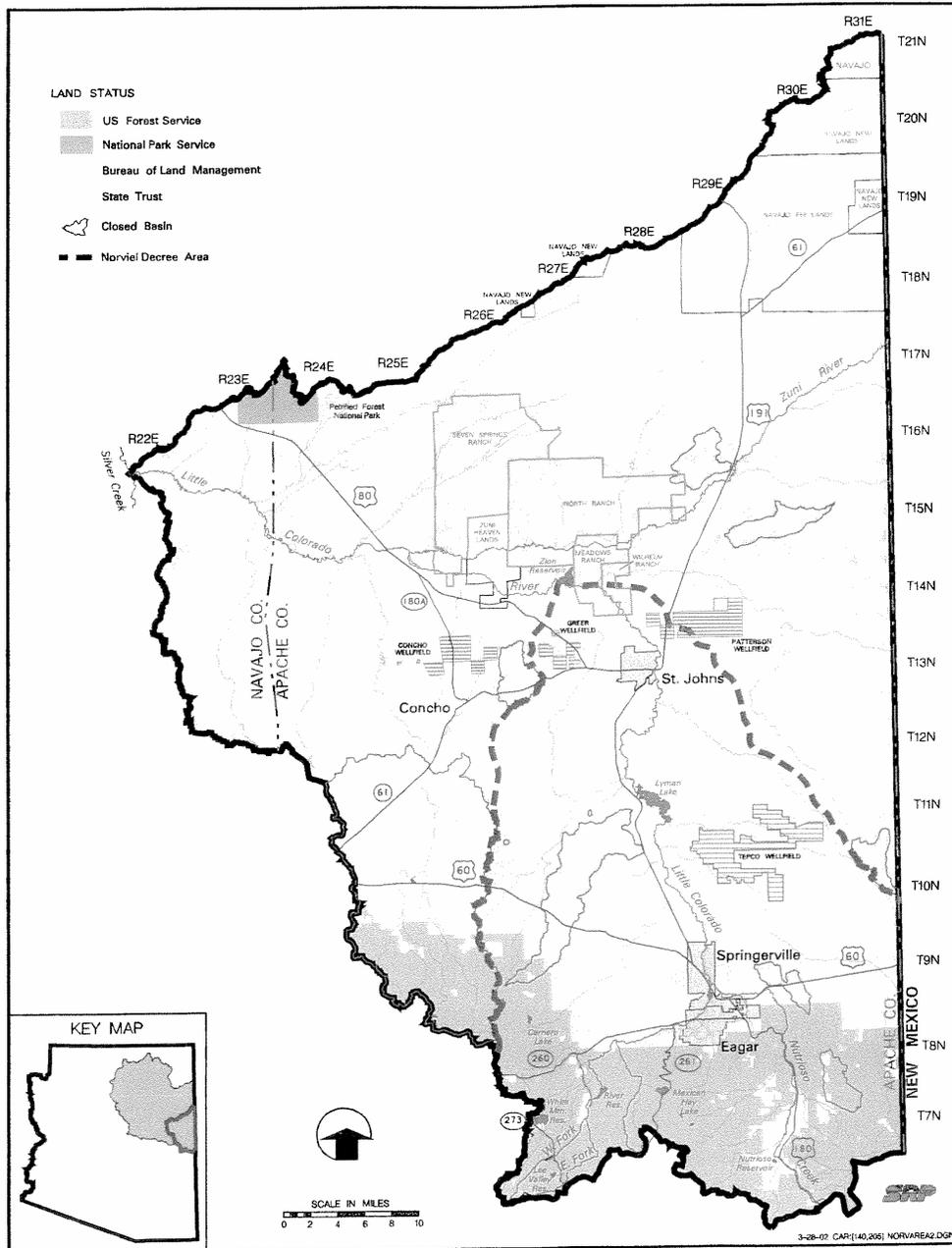


Figure 1. LCR Governed by the Norviel Decree

This basin is also home to a number of Arizona Game and Fish Department (AGFD) recreation sites developed specifically for fishing and boating on lakes or reservoirs, or

hiking and hunting in wildlife areas that they operate and maintain for the residents of Arizona to enjoy. To improve their wildlife and water resources the AGFD started in the 1960s with sever and transfer efforts to gain recreation storage water in reservoirs. The first effort was for Lee Valley reservoir, which severed and transferred water from land that was irrigated with water from the LCR. The AGFD repeated this process for Nelson Reservoir and land in the 1980s. The court system officially approved these transfers for different uses (recreation) by 1989. Since then AGFD has purchased other properties in the LCR watershed for recreation and habitat enhancement purposes including the Becker Lake, Grasslands, and Wenima Wildlife areas, Figure 2.

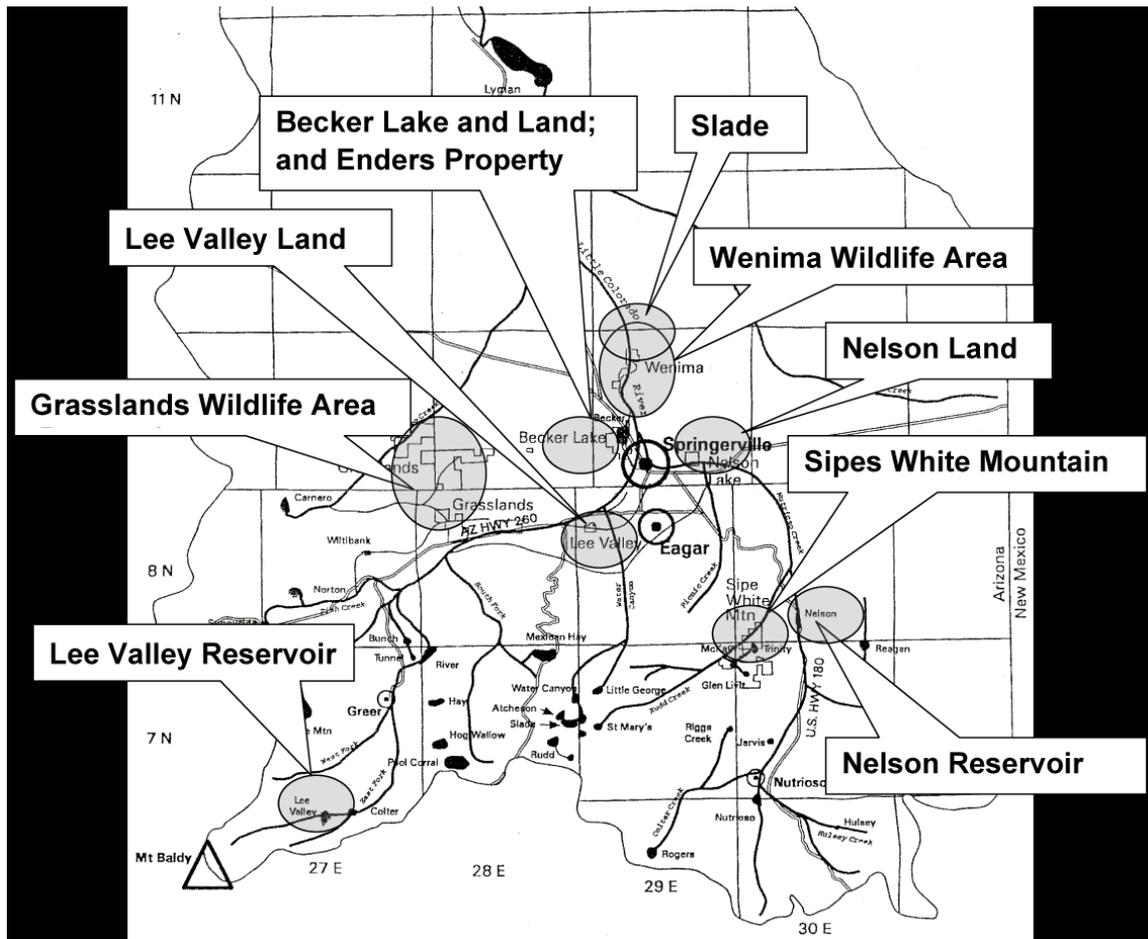


Figure 2. Properties Owned and Managed by AGFD in the LCR Watershed

As can be imagined in the arid State of Arizona, many others seek this LCR water. The majority of existing diversions along the LCR are made to irrigate pasture land. Many of these diversions were constructed and operating before Arizona became a state. To share and have some order to the use of water in the basin, the irrigators were ordered by the Court to work with the Norviel Decree which was made law in 1918, refined in 1921 and again in 1923. The decree establishes water rights by granting a priority date according to

when the water was first put to beneficial use and provided the authority to the water master to manage the water rights for the Superior Court in Apache County. Since then, with each sale of a water right, the court has kept track of the original right with a chain of title and no new water rights have been established on the over-appropriated LCR until the recent Settlement Agreement titled the “Zuni Indian Tribe Water Rights Settlement Agreement in the LCR Basin” (Settlement Agreement) was adopted.

This agreement was reached with a number of parties including the AGFD and the Zuni Indian Tribe (Tribe) that resolves water rights claims of the Tribe. The objective of the Settlement Agreement is to resolve all outstanding water-related litigation and to settle, once and forever, the water rights of the Tribe to surface and underground water within the LCR Basin in the State of Arizona. The objective of the Settlement is that the parties included in the agreement are to provide 3,600 acre-feet (acft) per year of surface water and groundwater to meet the goals of the Tribe without disrupting existing surface water use by other water users within the LCR Basin.

As part of the Settlement, AGFD was tasked with increasing the volume of surface water by 1,000 acft made available on a yearly basis to the Tribe as measured at Lyman Lake. This objective must be met in accordance with State law and the AGFD charter, which is to expand an ongoing Stream Rehabilitation Program above Lyman Lake according to the AGFD’s Mission as stated below:

“To conserve, enhance, and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs, and to provide wildlife resources and safe watercraft and off-highway vehicle recreation for the enjoyment, appreciation, and use by present and future generations.”

Funding to achieve this objective includes money made available through the:

- Heritage Funds (Title 17, Chapter 2, Article 6) program for the Identification, Inventory, Acquisition, Protection and Management of sensitive species and their habitats or
- Waterfowl Conservation Funds Fund (Title 17, Chapter 2, Article 4) for developing migratory waterfowl habitat.

Such funds were used to develop the Wenima Wildlife Area which also met objectives established in the Pittman-Robinson Wildlife Restoration Act as administered through the U.S. Fish and Wildlife Service's Federal Aid Program. Such funds can be used to assist AGFD, and the State of Arizona, meet their obligations under the Settlement Agreement. The Wenima Wildlife Area is an example of what can be accomplished within the AGFD’s mandate to increase flows to Lyman Lake as described in the following discussion on modeling the watershed by using direct flows for instream flows.

Lyman Lake Location

Lyman Lake is located on the LCR below Springerville in T11N and R28E near State Highway 180, see Figure 3.

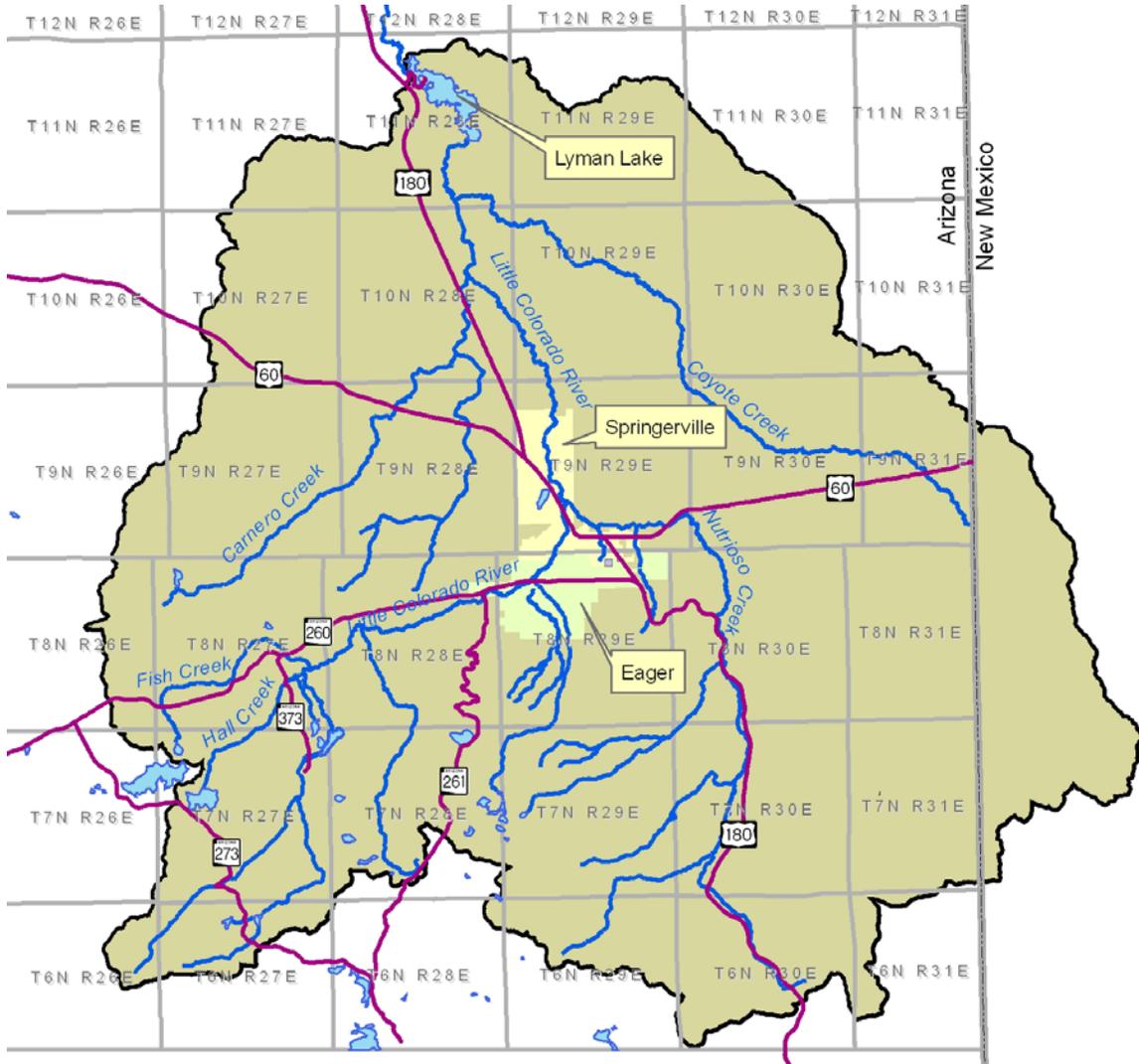


Figure 3. LCR Watershed Above Lyman Lake

The Lake’s watershed of about 703 square miles starts near Mount Baldy in the Apache-Sitgreaves National Forest and includes grasslands below the forest and north of State Highway 260 and US Highway 60. Upstream of Lyman Lake are a number of other reservoirs and AGFD-managed properties with associated surface water rights that could be utilized in some way to achieve the Settlement’s objective.

Wenima Wildlife Area

This 355-acre wildlife area includes approximately:

- (1) 2.5 miles (50 acres) of sensitive stream and riparian habitat along the LCR, which currently provides habitat for the Federally-threatened LCR Spinedace, and known and potential habitat for many other dependent wildlife species;
- (2) 121 acres of adjacent riparian and wetland floodplain that was managed as irrigated pasture and cropland, which holds tremendous potential for restoration of riparian wetland values;
- (3) 184 acres of upland pinyon-juniper, grassland and canyon rock cliff habitats that provide habitat for big game, small game, nongame and potential threatened and endangered species;
- (4) A quarter-acre artificial pond filled by pumping groundwater;
- (5) A 146 acre-foot storage water right upstream in Becker Lake;
- (6) The eighth, thirteenth and twenty-sixth priority direct river irrigation rights from the LCR, with 1876, 1881 and 1895 priorities in the Norviel Decree;
- (7) Several cultural resource sites; and
- (8) Several buildings, corrals and wells.

Stantec's Role

Over the past three years Stantec has helped identify the water rights and associated yields to facilitate the severance and transfer of water rights to instream recreation and habitat flows. This paper describes that study and the results of the modeling effort to identify water availability in the basin for that purpose. A number of legal and local issues make the process interesting and complex. The project's focus is on establishing the yield based on Norviel Decree water rights and then developing an understanding of the potential yield under different water right use and location scenarios that could be implemented in the future.

LCR WATERSHED STUDY - LYMAN LAKE YIELD ANALYSIS

The Project started in 2005 due to an urgent need to identify the means and ways AGFD could achieve their goals of the Settlement Agreement. The first year of work covered two very important Phases of the Project. Phase I focused on data collection and research. The results of Phase I were verification of the AGFD's water right abstracts and a data collection document on their property and facilities. The abstracts, shared with all the parties to the Settlement Agreement, described the AGFD's property, its water rights, its yield potential, and how it is currently managed. Information gathered was confirmed with field investigations and site visits to ground truth collected data.

Those documents served as the basis for the hydrologic and water rights analyses started in 2006 during the second phase of work, and eventually will be used in a future alternatives analysis phase.

A water rights model (model) was started during the second phase and developed further during the third phase to be used in the fourth phase to determine:

- The quantity of water that AGFD properties could yield under historical water use based on Norviel Decree water rights.
- The quantity of water that the AGFD properties yield under the present management operation plans.

This work coincides nicely with the quantification of the hydrologic and hydraulic conditions of the watershed and leads to the determination of the mean yield currently reaching Lyman Lake. A key component to the model is an understanding of the water delivery methods and management. As noted under from field visits to support the model development, a number of diversion locations and assessment of the ditch conveyance efficiencies determined that much of the system has efficiencies as low as 40% as noted from field visits to support the model development.

The model's output will help determine:

- How available water supplies meet water users' demands.
- How to handle shortages or excess yields from those supply sources in a way that all Settlement Agreement parties could agree upon.
- What are the gains from improving the system's efficiency,

The model would assist in the determination of methods to send additional waters to Lyman Lake. It would also AGFD in the assessment of opportunities to convert irrigation water rights to instream flows for wildlife and recreation.

A fifth phase will follow to analyze and estimate the cost of the alternatives to increase the delivery of water to Lyman Lake as required by the Settlement Agreement.

LYMAN LAKE HYDROLOGY – LCR MODELING PROJECT

The modeling question is - *how to model the LCR irrigation system above Lyman Lake that is over appropriated essentially unaged and only loosely regulated?* Operation of the system is largely accomplished by the individual water right holders based on an "honor system." The Water Master is only involved when there is a dispute. Without monitoring, the opportunity to irrigate based on need rather than by allotment is ever present. Without gage records it is difficult to determine what could be considered virgin (what the river's natural flows would be before diversions or transbasin additions ever happened) flow.

Demand Side of Model. The first step is to assume the system should be operated according to the Norviel Decree and set out to create the demand side of the model. The

principle that governs the demand side is – if there is water, the water right holders receive the water right plus allowances for transmission loss per the decree. The water rights are met in the model in order of their priority. A lack of water limits who receives their rights.

The main difficulties with developing the demand side of the model include (1) deciding what land is being irrigated (the decree description covers a greater area than what there is a right to irrigate i.e. in 160 acre area one has the right to irrigate 10 acres), (2) deciding what diversions and ditches bring water to this decreed acreage (some are served by 2 or more ditches), and (3) what portion of a split area receives the decreed water (the decree description sometimes covers different parts of a section. An example is illustrated in Figure 4 where the green areas represent the description of lands associated with a water right. The water right is for 100 acres of land on four different parcels. The distribution of the 100 acres across the four parcels is not documented. The land encompasses a total of 200 acres. Also shown in Figure 4 as the light blue dotted lines is the ditch system. The light blue triangles indicate points of diversion. The aerial photo background is circa 1997 – 98. Three different points of diversion are used to irrigate the land associated with this water right. How much water is to be diverted at each location for irrigation of the 100 acres is not known.

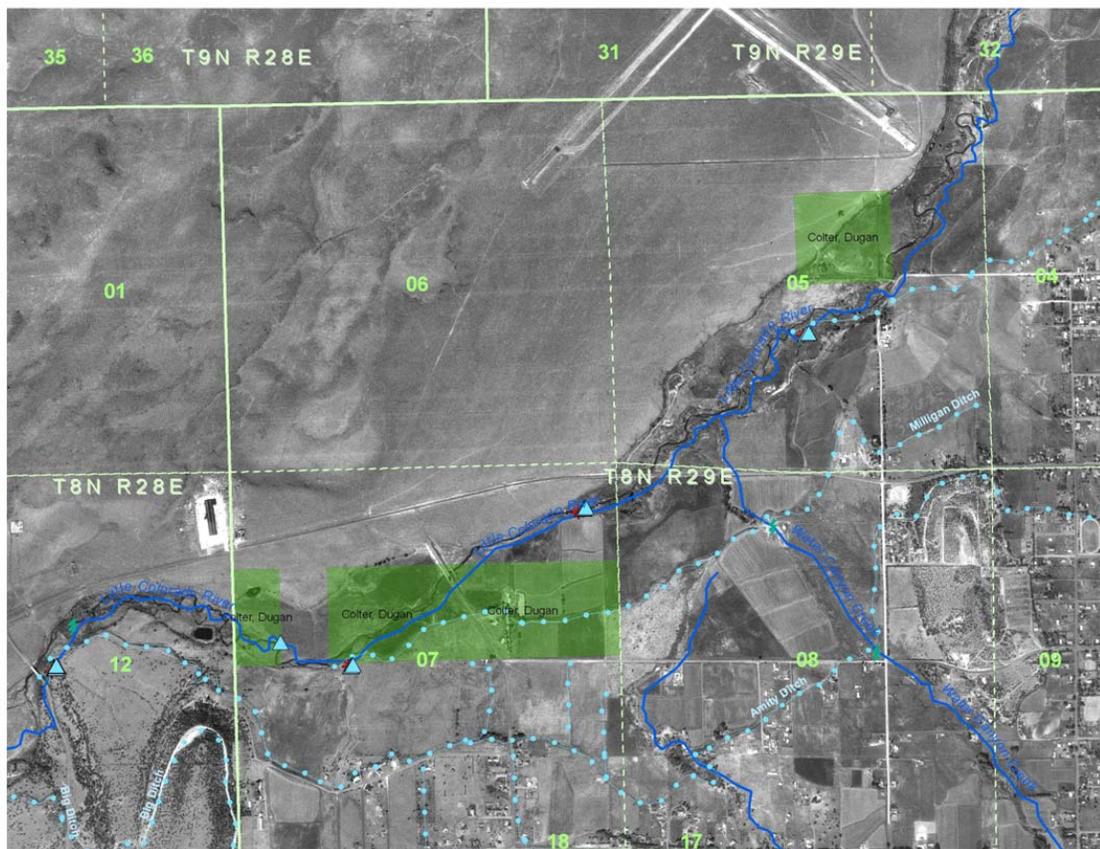


Figure 4. One Norviel Decreed Right of 100 acres In Three Areas

Other difficulties associated with the model development include (1) accounting for conveyance losses, (2) deciding which areas are served by which ditch and (3) timing of the diversion (storage and direct flow rights) as described and discussed below.

In the Norviel Decree, it is stipulated that “all measurements shall be made at the head of canals, but an allowance of two percent per unit mile from the point of diversion to the head of the lateral shall be allowed for soakage and evaporation to all canals.” Losses of just 2% per mile of canal represent a very efficient delivery system even for a lined canal. Presumably this loss is applied to each water right separately even though multiple places of beneficial use are fed by the same ditch and likely simultaneously.

More realistically for unlined canals, losses range from 10 – 40%. Conveyance losses of 10% are typical for very clean, well-maintained earthen canals of a fine-textured (clay) soil. Conveyance losses of 40% are more typical for vegetated canals of a granular (loam-sandy loam) soil. Without consideration of the 2% per mile loss as stipulated in the Norviel Decree, the total diversion for irrigation from the LCR per the decree is approximately 84 cfs of “continuous” flow, which is 25,660 acre-feet per year due to the limits of the irrigation diversion season from mid April to late September.

The Filler Ditch, located in the upper portion of the watershed, delivers water for irrigation and storage purposes by the Round Valley Irrigation District. There are 11 irrigation water rights and three storage rights served by the Filler Ditch. Priorities of the irrigation rights range from 11th to 24th. The total annual diversion is approximately 80 acre-feet. Of the three storage rights, Bunch and Tunnel Reservoirs are 3rd priority and River Reservoir is 6th priority. River Reservoir is located on the LCR but also receives outflow from Tunnel Reservoir.

The Big Ditch diversion is the largest diversion next to Lyman Lake and is located in the middle of the watershed. Approximately 4,700 acre-feet per year are diverted to Big Ditch prior to adjustment for conveyance losses. The Big Ditch delivers water to the Eagar Ditch and Reservoir Company, Round Valley Water Storage and Ditch Company and four individual water right holders. The two ditch companies account for more than 90% of the total diversion to Big Ditch. Both ditch companies have relatively low priorities (Eagar Ditch: 12th, 21st, and 23rd; Round Valley: 17th). However, Round Valley has storage rights at Bunch, Tunnel and River Reservoirs. The most senior water rights in the watershed are located downstream of the Big Ditch Diversion.

This work lead to a model, as shown in Figure 5, that could be used to allocate water when it is available for diversions based on the list of priorities. On Figure 5 the color ramp represent the water priorities with dark green having the highest priority and dark red having the lowest. Typically, the highest priority rights are close to the LCR and at the head of the diversion ditches. The yellow shades are the middle of the priorities. They are a little farther away from the LCR and farther down the ditches. The lowest rights are generally farthest from the LCR and at the ends of the ditches. The colors cover the LCR direct flow diversion rights under the 1918, 1921 and 1923 Norviel Decree. The storage rights are the color shades around the reservoirs on the figure.

Water Availability. The longest gage record Figure 6 in the watershed is at Lyman Lake. This lack of adequate gage data within the watershed makes the union of the demand side of the model and the water availability difficult. Using this record is made more difficult because the diversions were already taking place before the gage recording started. Virgin flow records are not available. Steps were then taken to correlate spotty ditch records with the Lyman record as well as to seek correlation between rainfall records and runoff. This led to the identification of similar watersheds with useable gage records that could be correlated. One of correlation steps used was a comparison of runoff to elevations, Figure 7.

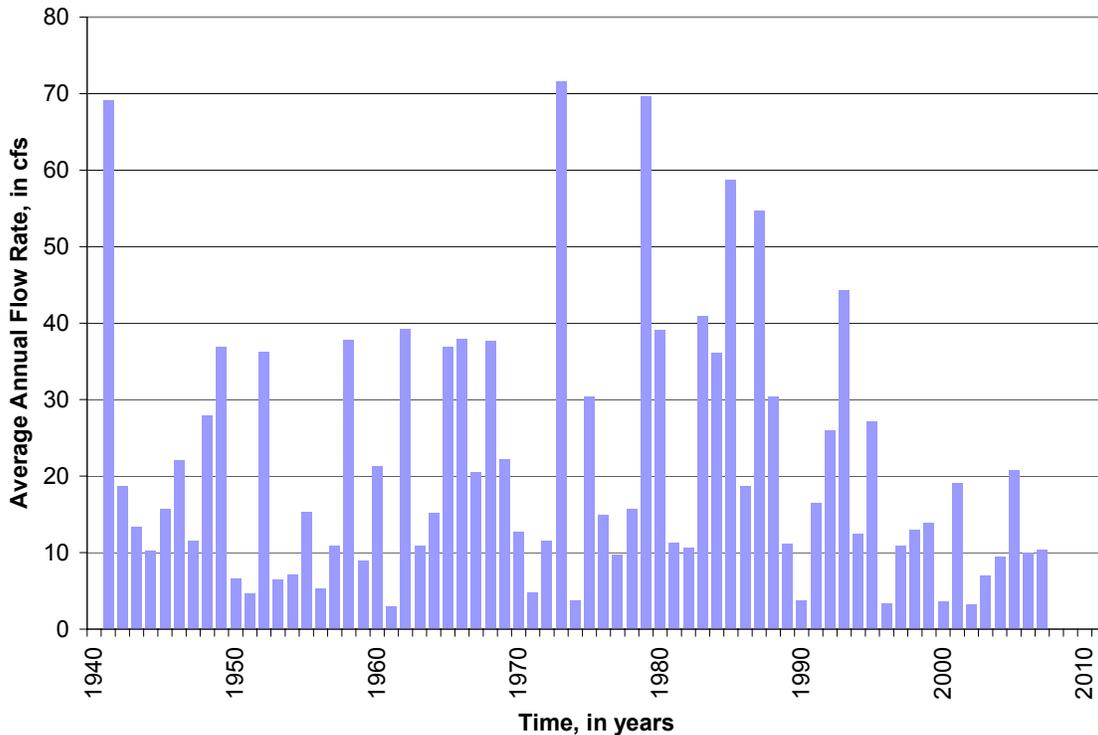


Figure 6. Flow Record for the Gage Above Lyman Lake

On Figure 7 the LCR watershed is shown along with USGS gaging stations. The LCR starts on the slopes of Mount Baldy, the white shade followed by shades of grays, browns, yellows, and finally greens. Each shade represents a 1,000 foot drop in elevation.

The water availability determination effort generates a flow record that is used to model a typical low flow, mean flow, and high flow water year. Modeling the three flow records for the typical water year results in identification of which water right has priority and what are the shortages or excess flows.

Results of the modeling confirm existing water shortages and who has priority. The next step is to work with the AGFD on developing methods of improving the system’s efficiencies and developing control and records through automatic water flow gage recording stations.

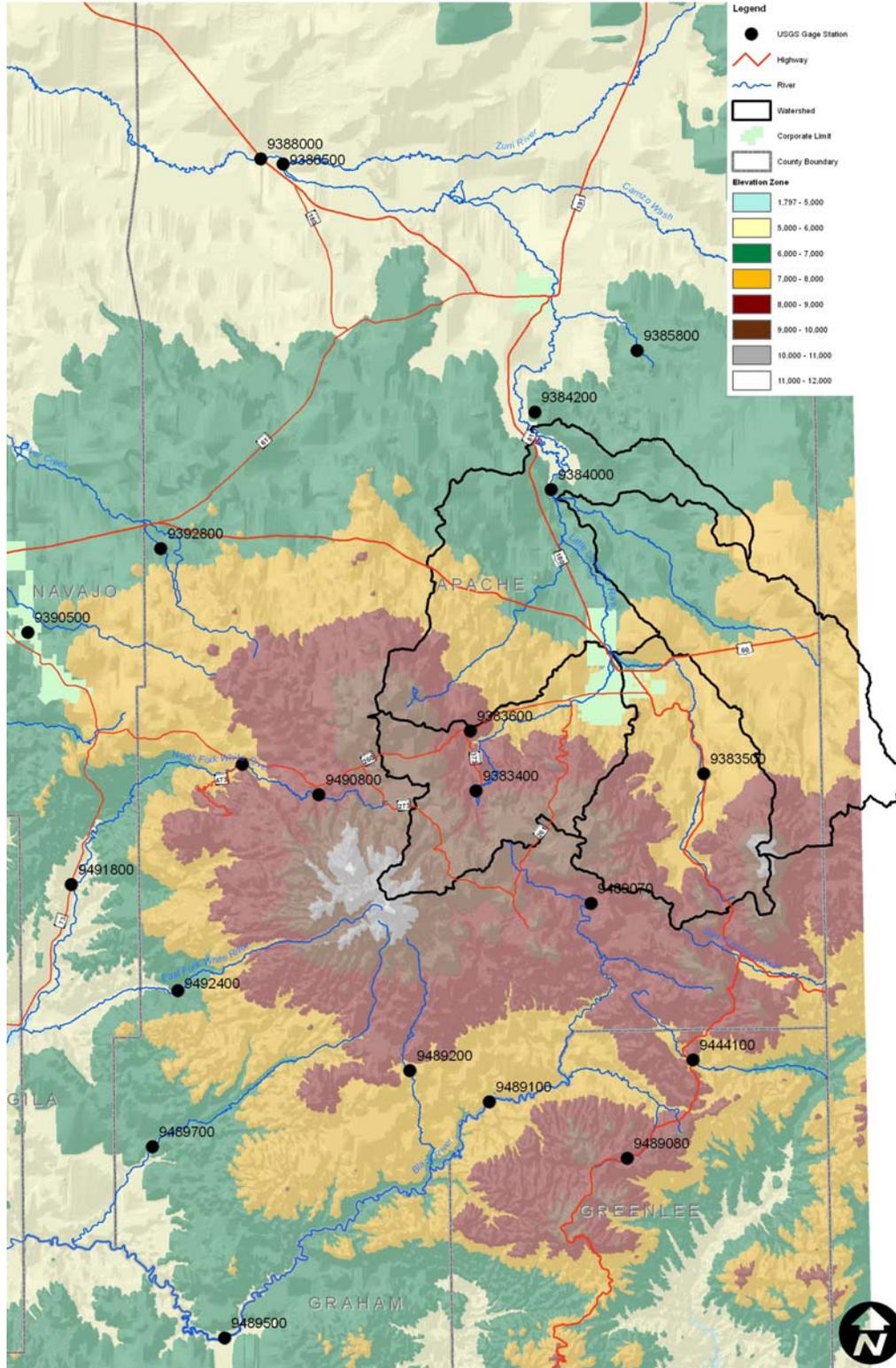


Figure 7. Elevation Zones and Gages

SUMMARY

The effort to develop a water rights model for the LCR provides a tool to the AGFD to improve the management of their holdings in the watershed. It also provides a means to determine if additional water rights purchased by the AGFD would improve their water storage and wildlife habitat areas. The Courts have already approved the conversion of a direct flow water right to recreation water right and in recent cases have approved the use of an instream water right. Thus if the water right can be obtained the AGFD could apply to Apache County Superior Court to change the beneficial use as appropriate.

Can the combination of using an instream water right and an improvement to the system efficiency be the vehicle to provide 1,000 acft to Lyman Lake in accordance with the Settlement Agreement? The answer is it might be possible. The model will be used with new assumptions and better records to adequately answer this question.

Without monitoring, the opportunity to irrigate based on need rather than by allotment is ever present. Irrigation by need is potentially a central issue in the ability to demonstrate why the terms of the Zuni Settlement Agreement have never been met.

The Decree allows for conveyance losses of two percent per mile applied from the point of diversion to the head of the lateral/turn-out for the place of beneficial use. For long reaches, the conveyance loss provided in the Decree may approach (and possibly exceed) what is expected due to the soil and vegetative conditions. In the case of two of the larger ditches, the conveyance losses, regardless of the manner of estimation, are significant in regard to the 1,000 acre-foot per year agreement. In fact, it is possible that the 1,000 acre-foot per year could be satisfied by putting key sections of ditch into pipe.

The AGFD contribution to the agreement is to sever and transfer 1,000 acre-feet of water per year to Lyman Lake. Based on the perception of irrigation by need and the assumption that canal losses are greater than what is allowed for in the Decree, it can be concluded that the actual diversion is greater than 60,700 acre-feet per year plus the 2% per mile of conveyance losses.

Furthermore, the difference between what is currently being diverted and what the diversion should be per the Decree could easily be greater than 1,000 acre-feet. While it can be shown that severance and transfer can, on paper, yield 1,000 acre-feet it is possible that the “additional” flow would never reach Lyman Lake due to the system operational practices, lack of regulation and greater conveyance losses.

One example of the potential gain available through improved efficiencies is the AGFD’s improvements to their diversion to Becker Lake.

Diversion to Becker Lake. The diversion to Becker Lake services relatively senior irrigation rights (ranging from 3rd to 18th) and a first priority storage right. The irrigation right yields a total diversion of approximately 600 acre-feet per year without any allowances for losses.

The storage right is 420 acre-feet per year. Conveyance losses along the ditch are due primarily to seepage losses. The total length of the ditch is approximately 1.7 miles. Based on the decree, an addition of approximately 20 acft per year is allowed for losses. At a minimum (conveyance losses of 10 %), 60 acre-feet per year during the irrigation season can be expected to account for conveyance losses with another 40 acre-feet per year during the storage season. However, given that AGFD has already replaced a reach of the ditch with pipe due to high seepage losses, much higher losses should be expected in the remainder of the ditch. If the conveyance losses were 40 percent, the total loss would be approximately 410 acre-feet per year.

Again in Figure 8 the green shade is the location of the AGFD water right per the Norviel Decree, the darker blue line is the LCR, and the lighter blue line is the ditch feeding Becker Lake with storage water and irrigating the lands between the LCR and the Lake.

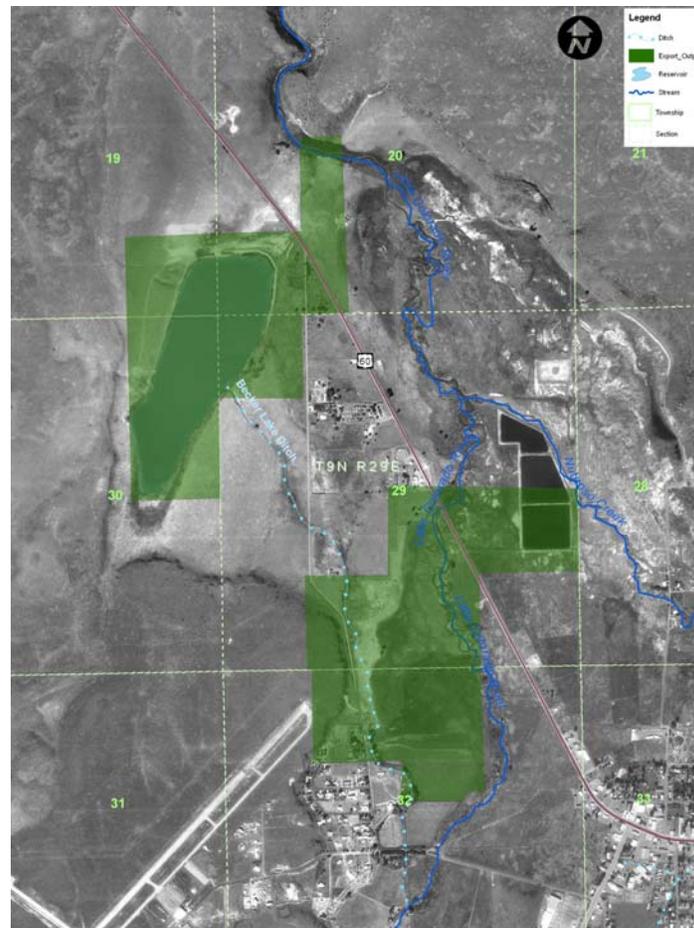


Figure 8. Becker Lake

Recommendations. It is therefore recommended that the issue of conveyance losses be further investigated. In particular, it is recommended that:

- Monitoring of flow at the upper and lower end of the Becker Lake and Wenima ditches be conducted.

- Assessment of riparian vegetative consumption use be conducted
- The model be refined and developed into the tool the AGFD requires.

REFERENCES

Norviel Decree: Final Decree dated April 29, 1918 and Modifications in the Superior Court, State of Arizona in and for the County of Apache

Settlement Agreement: S. 2743 - Zuni Indian Tribe Water Rights Settlement Act in 2003.
The Zuni Indian Tribe Water Rights Settlement Act

USGS gage data taken (downloaded) from USGS website in 2006
(<http://waterdata.usgs.gov/az/nwis>)

AGRICULTURAL WATER CONSERVATION POLICY IN AN URBANIZING ENVIRONMENT: THE ARIZONA BMP PROGRAM

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ABSTRACT

The Arizona legislature authorized in 2002 an agricultural water conservation program based on best management practices. The program is voluntary and an alternative to one based on allotments that has been in operation since 1980. The program requires the farmers to adopt conservation practices from an approved list and, in exchange, removes the allotment limitation. This program was launched at a time when housing development was rapidly expanding in the Phoenix metropolitan area at the expense of irrigated farmland. A study is being conducted to examine the initial response of the farming community in the Phoenix and Pinal Active Management Areas to the program. This paper discusses the initial findings of the study, with particular emphasis on the reasons for the farmer to enroll given the existing pressures from urban encroachment.

BMP PROGRAM BACKGROUND

Since 1980, water use in Arizona has been regulated by the Groundwater Management Act (GMA) (ADWR, 1999). The GMA identified hydrologic regions with severe groundwater overdraft and designated them as Active Management Areas (AMAs). Most of the state's population and irrigated acreage are found within three of those AMAs, Phoenix, Pinal, and Tucson. The Arizona Department of Water Resources (ADWR) is responsible for administering the provisions of the GMA.

Water management objectives specific to each AMA are expected to be met by 2025 through a series of multi-year water management plans. These plans impose water conservation requirements for cities, industry, and agriculture that affect both surface and groundwater use. Key provisions for the agricultural sector include:

- A prohibition on the development of new irrigated areas in AMAs and restricting irrigation to lands with a certificate of Irrigation Grandfathered Rights (IGFRs⁵).

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IGFRs were established based on lands that were historically irrigated five years prior to the GMA's enactment.

- A requirement to measure all pumping from groundwater wells discharging more than 35 gpm, and to report all agricultural water use.
- The establishment of a program, known as the Base Program, that defines maximum annual groundwater allotments (AA) for agricultural users.

Since its inception, the Base Program's rules have been controversial. The Base Program's annual allotment (AA) (in Ac-ft) is the product of the irrigation water duty (ID) (Ac-ft/Ac) and the irrigation duty acres (DA) (Ac) $AA = ID \times DA$ (ADWR, 1999). The Irrigation Duty is defined as the ratio of the irrigation requirement (IR) and the assigned irrigation efficiency (E). The value of E was set at 0.65 for the First Management Plan (1980-1990) and was intended to increase to 0.75 and 0.85 over the Second and Third Management Plan periods (1991-2000, 2001-2010) (Wilson and Needham, 2006), therefore producing increasing levels of conservation. Irrigation duties were determined based on the crops grown on an IGFR during the same period used to define the IGFR's irrigable acres, 1975-1979. The water duty acres are the maximum number of acres irrigated on an IGFR during that period and are equal or less than the irrigable acres.

The GMA instituted groundwater flexibility accounts to provide flexibility in the water supply given variations in weather and cropping patterns. IGFRs accumulate credits or debits in their flexibility account depending on whether the annual groundwater use is less or more than the allotment⁶. There is no cap to the amount of credits that can be banked in the flexibility account and the credits can be used at any future time. A negative account balance will result in a code violation and a fine, but only if the accumulated debits exceed half the yearly allotment. The flexibility credits are transferable to other IGFR holders who can use them to meet their demands or offset debits, but only in the second year after they were accumulated⁷.

In principle, the Base Program constrains groundwater supplies. In practice, it has not constrained water use for many users and has had a marginal impact on water conservation in comparison with others agricultural provisions of the GMA (Jacobs and Holway, 2004; Megdal et al 2008). In fact, a recent study concluded that weather, water and commodity prices were the only significant factors explaining agricultural water use patterns in the AMAs since the enactment of the GMA (Needham 2005; Needham and Wilson 2005). Average water use per IGFR over that period has been less than the

⁵ In the following discussion, the acronym IGRF will refer both to the irrigation grandfathered right and the irrigable land tied to that right.

⁶ When calculating water use, ADWR accounts for all sources of water, but it uses a "stacking" order to debit accounts with groundwater given the highest priority. Hence, if water use exceeds the allotment but all water is from surface sources, then the account is debited only up to the allotment. If only groundwater is used, then all the water is debited to the account. Other rules apply for commingled water.

⁷ The flexibility account provisions have been modified since the GMA first became law. Currently, transfers are allowed to other IGFRs operated by other landowners in the same irrigation district, or to IGFRs in another district but in the same sub-basin if the IGFRs are owned or leased by the same operator.

allotment and has resulted in an average accumulation of flexibility credits equal to about six times the annual allotment. According to this study, one factor that explains this outcome is that irrigation duty acres were determined based on the period of highest historical irrigated acreage in the state. Also, idle lands accrue credits and extensive acreage was idled in Arizona during the 1990s because of federal set-aside programs and agricultural credit limitations. Additionally, planted acreage can vary substantially from year to year in irrigated areas that rely mostly on uncertain surface supplies. Finally, an early economic study suggested that the high price of groundwater was already promoting efficient irrigation within the Phoenix AMA, irrespective of the allotments imposed by the GMA (Cory et al. 1992). Those results likely apply as well to the Pinal and Tucson AMAs, where water prices are comparable.

However, not all IGFR holders have been able to accumulate flexibility credits. Agricultural producers who were growing crops with low water demands on limited acreage during the 1975-1979 period, have faced real water supply constraints. These growers perceive the program as unfair, and have strongly objected to the GMA's provisions (Jacobs and Holway, 2004; Megdal et al 2008). Also, producers have contested the feasibility of a 0.85 irrigation efficiency value which was supposed to be adopted during the current 3rd Management Plan (Jacobs and Holway, 2004). This target was set under the assumption that level-basin irrigation and other modern irrigation technologies would eventually be widely adopted, and that water deliveries from irrigation districts would support those on-farm irrigation technologies. Such assumptions were eventually challenged by a study commissioned by ADWR (CH2M Hill 1995).

ADWR has been considering alternative conservation mechanisms in response to the agricultural sector's concerns. One of the proposed alternatives is the Best Management Practices (BMP) program, which was finally approved by the Arizona Legislature in 2002 (ADWR, 2004). The BMP program's features, including the list of approved practices and oversight and compliance rules, were developed by ADWR and an advisory committee (the BMP Program Advisory Committee). The Advisory Committee consists of representatives of the farming community and relevant state agencies. The first BMP farms were enrolled in late 2003.

BMP PROGRAM FEATURES

The BMP Program provides producers with increased flexibility in their water supplies by removing the annual allotment limitation, but in the expectation that water will be used efficiently. Ultimately, the program intends to achieve conservation levels at least equivalent to those of the Base Program (ADWR, 2004). An enrolled farm, consisting of one or more IGFRs, has to adopt infrastructural and management water conservation practices from a menu of approved practices. Flexibility credits for each IGFR in the BMP farm are frozen at the time of enrollment and only IGFRs that are in compliance with the Base Program can be enrolled.

Farms qualify for the BMP Program based on a point system. There are four categories of approved BMPs (Table 1). Except for category 1, several BMPs are available within each category. Detailed definitions of approved BMPs are provided at the ADWR website (ADWR, 2008). Each selected BMP is assigned a value in the point system and a total of 10 points is needed for enrollment. A minimum number of points is needed in each category to qualify for the program, but at the same time the farm can only be awarded a maximum number of points in each category (Table 1). Note that on-farm irrigation system BMPs require a minimum of 2 points in comparison with a minimum of 1 point for other categories. The points awarded under the categories 1 and 2 are a function of the infrastructure (e.g. lined channel, irrigation system type) and the percentage of the irrigated acreage serviced with that infrastructure. Overall, the point system is intended to balance infrastructural with management practices to determine farm eligibility.

Table 1. BMP point system

BMP Category	Description	Minimum Points	Maximum Points
1	Water Conveyance System	1	3
2	Farm Irrigation System Irrigation Water	2	3
3	Management	1	3
4	Agronomic Management	1	3

BACKGROUND TO THE EVALUATION

The USDA-ARS Arid Land Agricultural Research Center is evaluating the BMP program in collaboration with the Department of Agricultural and Biosystems Engineering of the University of Arizona, under an agreement with ADWR. Because the evaluation report will be advisory to ADWR and the BMP Advisory Committee, research scope and methods have been developed with extensive input from ADWR and the Committee. Because of the BMP Program's short history, the evaluation does not seek to assess to the program's worth, i.e., as a water conservation policy, but rather its program design and implementation based on initial outcomes. The evaluation was designed around five principal questions:

- 1) Are participants representative of Central Arizona agriculture?
- 2) What motivated growers to enroll?
- 3) Based on their experience, what is the growers' assessment of the program?
- 4) How has crop mix, crop acreage, and water use changed for participants since enrolling in the program and how do those changes, if any, compare with changes in central Arizona agriculture?
- 5) Are the BMP practices being applied rigorously?

These questions are being examined by analyzing ADWR and public records, and data obtained through a survey of a sample of BMP participants and of farmers who elected to stay in the Base Program. ADWR and public records were initially reviewed to develop

an understanding of issues relevant to the BMP program and to develop tentative answers to the principal research questions. A framework for the field survey, consisting of a set of hypotheses for each principal research question, was developed based on this initial understanding of the issues. Survey questions were then developed based on these hypotheses. The survey instruments consist mainly of Yes/No and multiple-choice questions, and a few open-ended questions. Where applicable, multiple-choice questions allow the respondents to provide more than one answer, add an alternative answer (Other), or not answer the question (No Opinion). The survey is being applied through face-to-face interviews to elicit additional discussion of issues raised by respondents. All BMP enrollees were contacted and asked to participate in the survey but only about half responded. The sample of Base Program farmers is being selected through referrals from BMP operators who participated in the survey and lists of farm operators supplied by irrigation districts.

At the time that this article was written, surveys had been completed for the sample of BMP farmers and were still in progress for the sample of Base Program farmers.

SUMMARY OF ENROLLMENT

The following discussion will refer only to the farms enrolled in the first three years of the program, 2004-06. 61 farms were enrolled in that period, for a total of 138 IGFRs and 37,000 acres, all of which are located in the Pinal and Phoenix AMAs. Two of those farms eventually dropped out of the program. The enrolled acreage represents 9% of the non-exempt IGFR acreage that is currently being irrigated in Phoenix and Pinal AMAs⁸. Thirty-three separate farm operators enrolled one farm while nine enrolled two or more.

URBAN GROWTH AND A CHANGING AGRICULTURAL ECONOMY AS A BACKDROP TO THE BMP PROGRAM

Urban growth in the state of Arizona, and in particular in the Phoenix AMA, is one of the highest in the nation. Population has more than doubled since 1980 in the Phoenix metropolitan area, where the population growth has average 2.4% per year for more than 10 years (MAG, 2005). As a result, a considerable amount of agricultural land has been converted to urban and industrial uses. State-wide, nearly 137,000 IGFR acres were extinguished⁹ during the period 1998-2007, with the Phoenix AMA accounting for 83% of that acreage and the Pinal AMA for 14%. Figures 1 and 2 summarize that information for selected irrigation districts in the Phoenix and Pinal AMAs, respectively (irrigation district acronyms are defined in Table 2). All districts with BMP farms are included in these graphs. Irrigated land conversions in the Phoenix AMA peaked in 2002, and were

⁸ Of the total IGFR acreage in the Phoenix and Pinal AMAs (540,000 acres), 26% is not being irrigated and nearly 7% is exempted from regulation, primarily because the acreage is very small.

⁹ IGFRs need to be extinguished with ADWR to convert the irrigated agricultural land to other uses. The reported figure includes acreage converted to agricultural industrial uses, such as feedlots and dairies, and land that has not been urbanized yet. Still, most of the reported acreage is land that has been converted to subdivisions.

led by SRP. Since that year, conversions have been occurring in the Pinal AMA at an increasing rate, mostly in MSIDD where bedroom communities for the Phoenix area have emerged.

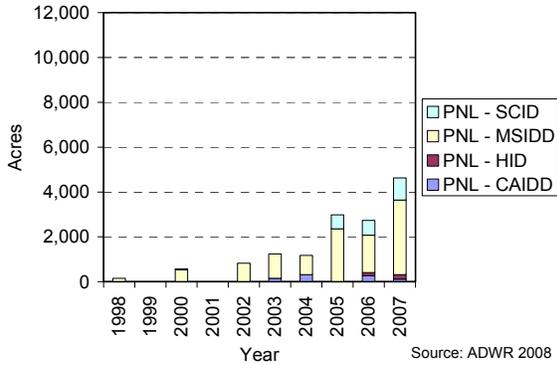
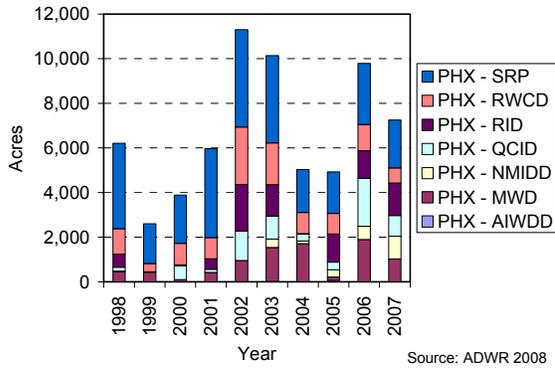


Figure 1. IGFR acres extinguished in the Phoenix AMA, 1998-2007

Figure 2. IGFR acres extinguished in the Pinal AMA, 1998-2007

Table 2. Selected irrigation districts in the Phoenix and Pinal AMAs

Acronym	Name
AIWDD	Adaman Irrigation Water Delivery District #36
SRP	Salt River Project
RID	Roosevelt Irrigation District
MSIDD	Maricopa-Stanfield Irrigation & Drainage District
HID	Hohokam Irrigation & Drainage District
NMIDD	New Magma Irrigation & Drainage District
RWCD	Roosevelt Water Conservation District
QCID	Queen Creek Irrigation District
MWD	Maricopa Water District
CAIDD	Central Arizona Irrigation & Drainage District
SCID	San Carlos Irrigation & Drainage District

Population growth affects land uses in those lands that continue to be farmed. In particular, it has fueled an increased demand for milk and meat products. The impact on Pinal County¹⁰ is a 535% increase in the number of dairy cows over the 1998-2006 period, accounting for most of the change in the state’s dairy cow population (NASS, 2008). Over the same time period, the acreage of alfalfa hay has increased over 230% in Pinal County and 132 % in Maricopa County (NASS, 2008). Given the change in agricultural acreage and the changes in cropping patterns, it is not surprising that a decrease in agricultural water use has been reported in irrigation districts closest to the

¹⁰ The Phoenix AMA includes Maricopa County and a small part of Pinal and Yavapai Counties. The Pinal AMA is all within Pinal County

Phoenix area, while an increase was reported in farming areas farther away from Phoenix (Hetrick and Roberts, 2004; Needham, 2005).

INITIAL EVALUATION RESULTS

The remainder of this article discusses some BMP program outcomes and their relationship to land use changes in the Phoenix and Pinal AMAs. The discussion centers on four particular evaluation hypotheses:

1. Producers with long-term farming objectives are more likely to enroll in the BMP program; speculative farm land prices, urban sprawl, and short-term land leases are disincentives to enrollment
2. Producers' historical water duties and flexibility credit balances are factors that influence their decision to participate in the BMP program
3. Enrolled farmers are seeking to enhance their water supply flexibility
4. Producers are less likely to enroll if, in order to qualify, substantial investments are needed to improve the existing irrigation infrastructure or if substantially altered irrigation management practices are needed

Effect of long-term farming objectives, urban pressure, and lease length

The BMP Program rules were developed recognizing the fluidity of the state's agricultural land market and the typical tenure structure of farming enterprises. Like in most of the U.S., most commercial farms in Arizona consist partly or entirely of leased land (NASS, 2002). Depending on the owner, agricultural lands can be rented on a year-to-year basis or for multiple years. The BMP Program's rules allow farm operators to include leased IGFRs in their farm, and only require the applicant to obtain a signed affidavit from the landlord. Once enrolled, the operator can add an IGFR or de-enroll an IGFR from the farm, independently of whether the land is acquired or lost through a lease or an ownership change. In making these changes, the only requirements are for the operator to file a new application, and for the modified farm to continue to meet the point requirement. At the same time, the rules require approval from ADWR to drop out of the program and discourage participants from dropping out without a valid reason. In this regard, the farms were expected to remain in the program until at least 2010, when the program is supposed to be reviewed.

Despite the flexibility of the rules, the BMP Advisory Committee anticipated limited participation in areas under intense urban pressure, where farm operator planning horizons are potentially shorter. A similar concern was expressed in a recent evaluation of AMA Management Plans conducted by the Water Resources Research Center of the University of Arizona (Megdal et al 2008). Enrollment results are consistent with this assumption as most enrolled farms and acreage are in the Pinal AMA (Figure 3). Still, the program attracted farms in areas undergoing rapid urbanization, noticeably the RID and AIWDD (see Figures 1 and 3), located on the west end of the Phoenix AMA, and MSIDD (Figures 2 and 3), located just south of Phoenix.

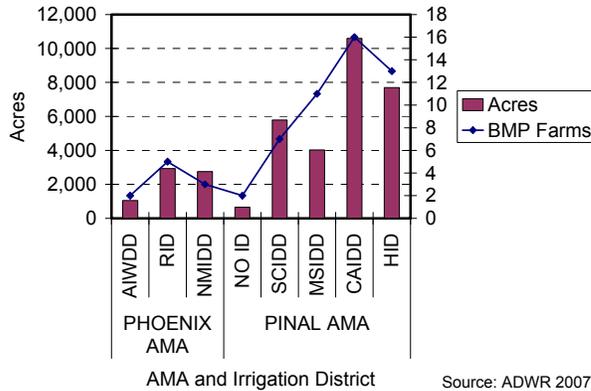


Figure 3. Enrollment by AMA and irrigation district

of those operators have to deal with year-to-year leases. While this suggests that short leases are not an impediment to enrollment, some interviewed BMP farm operators indicated they had not enrolled leased properties into the program because of landlord objections or the uncertainty of the lease.

During the interviews, BMP farmers were asked about their long-term farming plans, the possibility of all or part of their farm being converted to non-agricultural uses, and the impact of the BMP program on their long-term planning ability. Of the 21 respondents, only three were planning to farm for five years or less and 9 stated they were planning to continue farming for the foreseeable future. Although eight operators expected part of their farm to be converted to non-agricultural uses in the near future, those respondents expressed a strong desire to continue farming. More importantly, 12 of the respondents indicated that the BMP program enhanced their long term planning ability. In one particular case, an operator was considering purchasing a farm at the time that the program was launched, and the final decision to invest in the farm was partly influenced by the increased flexibility in water supplies offered by the program. Overall, the interview results suggest that farm operators are well adapted to the fluidity of the land market and tenure situation, and that the program provides the necessary flexibility to enroll a farm within that environment.

Water duties and flexibility credits

Survey results support the hypothesis that the Base Program's allotment limitation influences the operator's decision to enroll, as nearly all interviewed participants identified this factor as the main motivation for enrolling. However, this response seems to be less a function of present flexibility credit problems, and more of their concern with long-term water supplies and the respondents' perceived unfairness of the Base Program.

Of the 61 farms enrolled in 2004-06, 31 had one or more leased IGFRs at the time of enrollment. Since enrolling, entire or partial IGFRs have undergone an ownership change and/or have been retired for alternative uses in 21 of those farms. The transfers include lands sold to developers, some of which were rented back to the operator. Hence, the program's enrollment rules do not appear to restrict the operator's

ability to make changes to his farm. Within the sample of interviewees, 12 operators have leased IGFRs and seven

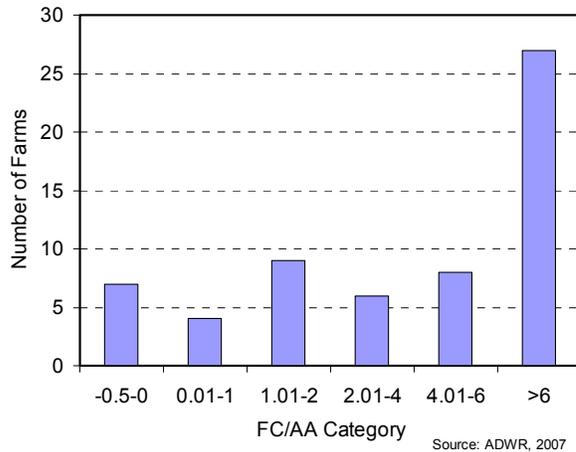


Figure 4. Distribution of BMP farms by the ratio of Flexibility Credits (FC) over the Annual Allotment (AA).

and acreage decisions, while a ratio greater than 6 would certainly suggest that the farm does not face supply constraints in the near future. Thirteen BMP farms enrolled with ratios less than 2.0 and may have had medium-term concerns when enrolling. However, two thirds of the enrolled farms have ratios greater than 2.0 and over 40% have a ratio greater than 6.0.

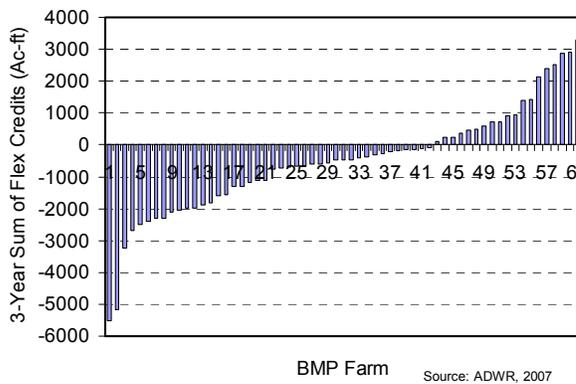


Figure 5. Sum of flexibility credits or debits 3 years prior to enrollment for each BMP farm

also saw their credits erode in the three years prior to enrollment (Figure 5). Considering all farms, the average flexibility credits loss exceeded 170 ac-ft/year over the three year period. Most of this loss was concentrated in farms in the Pinal AMA, in all likelihood as a result of cropping changes. During the interviews, some operators stated that their sole

The histogram of Figure 4 illustrates the distribution of enrolled BMP farms by the ratio of Flexibility Credits (FC) over the Annual Allotment (AA)¹¹. This ratio was calculated based on the frozen flexibility credit balance at the time of enrollment. As was previously indicated, the AMA-averaged FC/AA ratio has been estimated at about 6.0 (Needham 2005). 7 of the farms enrolled with a negative ratio and, thus, with a short-term flexibility balance problem and water supply concerns.

Assuming reliable water supplies from all sources, a FF/AA ratio less than 2 may signal medium-term (2-3 year) constraints when making crop selection

The interviewed operators manifested a keen awareness of the limited dependability of their long-term surface water supplies, especially those dependent on Central Arizona Project (CAP) supplies. Supply reductions will necessarily have to be compensated by an increase in groundwater pumping to maintain current production levels. Hence, they are concerned with maintaining large flexibility accounts

for the uncertain future. Most of the BMP farms were enrolled with a healthy flexibility balance, but most

¹¹ Allotments and flexibility credits are computed for individual IGFRs, not BMP farms. However, since IGFRs are managed as part of a farm unit, it makes sense to compare allotments and credits using the entire farm.

purpose in enrolling was to freeze their existing flexibility credits for future use, in the expectation that the BMP program may not be reauthorized after 2010.

The perceived unfairness of the Base Program is an issue that was not investigated by the survey. Rather, it was brought up by many of the respondents when asked if their allotment constrained their crop selection and acreage decisions. In this regard, their objections centered on the perception that farms that were using water frugally in the late 80s (when farms in most districts depended exclusively on groundwater), and investing in improved conveyance systems and land leveling, were penalized with smaller allotments

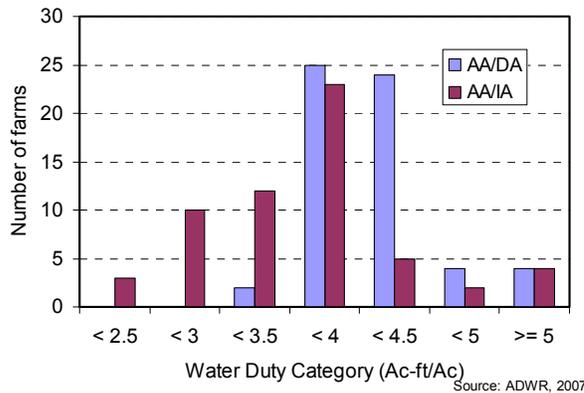


Figure 6. Distribution of BMP farms by water duty, computed based on duty and irrigated acres.

in comparison with farms that were using more water. Differences in water duty by BMP farm are illustrated in Figure 6. The series labeled AA/DA represents the water duties per duty acre (i.e., the total allotment divided by the duty acres). The series labeled AA/IA is the duty per irrigated acre. When considering only the duty acres, 49 of the farms have a duty between of between 4 and 4.5 ft, with an average of 4.15 ft for all farms. When considering the irrigation acres, 15 of the farms have duties of 3.5 ft or less, with some farms having less than 2.5 ft (average= 3.6 ft).

Independently of whether the allotments are fair or not, an important issue for operators with long-term farming objectives is that a farm with relatively large allotments or flexibility credits is more attractive than one with limited water supplies. The BMP program enhances the farm's water supply flexibility and, therefore, has the potential for increasing the viability of the farming operation and the value of the farmland if that land will continue to be used for agricultural purposes. The hypothesis that operators enrolled in the BMP program to enhance their water supply flexibility is discussed in the next section.

Enhanced water supply flexibility

The survey explored whether operators need larger allotments than their present entitlement given their current crop mix and acreage and anticipated future changes. The operators were asked if their allotment constrained their crop mix and acreage decisions, if changes had been made in cropping patterns in the previous three years, and if future changes were planned that were being facilitated by the BMP program. Nearly two thirds of the respondents indicated their allotments constrained their cropping decisions half, most, or all of the time. At the same time, a comment repeatedly made by the operators was that water use was dictated by crop mix and acreage decisions, and not the other way around. If crop prices encourage operators to switch to more water intensive crops or

expand their acreage, and thus increase their water use, then the operators will find the supplies (i.e. purchase or transfer credits) or will work around the supply constraints.

A third of the respondents indicated they had made changes in their crop mix and acreage over the previous three years. While those changes were attributed mainly to economic and agronomic factors, five of the respondents also acknowledged that the BMP program had influenced those decisions. These operators increased their acreage of alfalfa, forages, or double crops, all of which are more water demanding than the traditional cotton and grain rotations. While these same respondents foresaw future changes with the help of the program, all other interviewees (75%) did not think the program would change in any way their future cropping decisions. Increases in alfalfa cultivation at the expense of cotton acreage have been documented in Maricopa County (Judkins, 2008). Such changes are happening because of a declining cotton economy, an increasing demand for alfalfa, but also because alfalfa production requires less on-site work and presents fewer complications in an urbanizing environment.

While survey suggests that a minority of respondents enrolled in the program to facilitate cropping changes, other respondents expressed a concern about the increased alfalfa and double crop acreage and the consequent water use increase. At the time that the interviews were conducted, there were rumored reductions in CAP supplies to districts and respondents were concerned about BMP farms with high water-using crops program limiting future water supplies for other operators in the same irrigation district. At the same time, some respondents indicated that in the event of a reduction in district supplies, districts were planning to limit individual farm allotments. This would evidently erase the flexibility advantage offered by the BMP program. These reductions will not happen this year, but have taken place in the past (as recently as 2004, as a result of drought) and will be more likely to occur in the future as urban demands increase¹².

Improvements to irrigation infrastructure and changes in water management practices

The BMP program rules require farms to have approved conveyance and irrigation system BMPs in place at the time of enrollment and, therefore, rewards operators who have made past investments on their farms. Of the 21 operators that were interviewed, only one reported infrastructural improvements (to his conveyance system) that were made to qualify for the program. Furthermore, only four of the respondents reported making changes to their irrigation or agronomic management practices in order to qualify. All of these producers were already implementing one or more of the BMPs included in the program. These results, therefore, support the hypothesis that operators will not make substantial investments or changes in their practices in order to qualify for the BMP program. Further evidence of this is provided by the responses of operators with other farm properties not enrolled in the BMP program (7). One of those operators

¹² When the CAP was built, CAP districts subcontracted for water with the Central Arizona Water Conservation District. Those long-term rights to water were waived in 1995 for rights to subsidized water available in a spot market (Wilson, 1997).

stated land improvements were needed to qualify but that such improvements were uneconomical given the benefits of the program. Three others reported they had farms that qualified but had not enrolled because of a favorable allotment.

The survey asked additional questions about farm infrastructure and management improvements. The answers to those questions revealed that most of the operators have made improvements over the years, with nearly half of them (9) reporting investments in physical improvements within the last five years. These operators continuously seek ways to improve their irrigation management to reduce their water and related labor costs. Some of them discussed at great length particular changes they made that helped them reduce their water use. In this regard, it is useful to review the BMP enrollment scores. Under the point system, a score of 3 in category 1 implies that 100% of the farm is serviced by lined channels or pipelines. The average score in this category for all enrolled farms was 2.95 and, therefore, BMP farms have nearly 100% upgraded conveyance infrastructure. In Arizona, over 80% of the irrigable land is watered with surface irrigation methods (NASS, 2002). Under the BMP point system, laser leveled fields with flat or nearly flat slopes, together with drip and low-pressure sprinkle irrigation, get the highest scores. Nearly a third of the enrolled acreage qualified with nearly-flat laser-leveled irrigation systems.

Interviewees were also asked about opportunities and constraints for other operators to improve their water management. Virtually all responded that there were still farms requiring improved conveyance systems and laser-leveling to a uniform grade. Most respondents identified financing as the main constraint, but some also mentioned short leases, and urban pressures. It is not uncommon in the AMAs for lands to be leased for 10 years and, under such conditions, operators have an incentive to make improvements to the farm, much more so than when the land is leased from year-to-year. At least in one case, an operator indicated that urban pressures might force him out of the program. That operator enrolled with a farm with a shared runoff recovery system in an area that is under intense urban pressure. If the farm with the shared recovery pit is sold, then the farm will no longer qualify for the program. Furthermore, according to the operator, other farm operators in the area have been encouraged to sell their land when they lose such type of facilities, because of the resulting difficulties in managing the irrigation water.

The interviews with Base Program operator are investigating whether the BMP program provides incentives for landowners to make farm improvements. While only a few of such interviews have been conducted at this time, one of those interviewees did state that the program provides additional incentives for making those improvements. In that case, the primary incentive is simply the need to improve the operator's water and labor use, reduce production costs, and stretch his water supplies over his farm.

DISCUSSION

Initial evaluation results indicate that farmers who enroll their farm in the BMP program do so for a variety of reasons, some of which address short-term needs, but others which

are more strategic. For example, one factor that was examined by the interviews, but that was not discussed in this article, is the reporting advantages of the BMP program in relation to the Base Program. For a few operators the BMP program resolves many administrative difficulties of the Base Program and this was an important factor in their decision to enroll. However, for most interviewed operators the reliability of their future water supplies is a critical concern. Obviously, such operators have a long term-perspective and strong attachment to irrigated agriculture as an occupation.

The evaluation is not attempting to assess the program as a water conservation policy, as was indicated earlier. However, it should be clear that changes in cropping patterns facilitated by the program toward more water intensive crops will result in greater water use, even with the best of irrigation management. In such case, the program will have to be evaluated more from the perspective of agricultural conservation rather than water conservation, especially since the change in cropping patterns is happening in response to changes in demand from a growing urban population.

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THE ROLE OF THE DITCH AND RESERVOIR COMPANY ALLIANCE (DARCA) IN DEALING WITH URBANIZATION ISSUES AND ENHANCING THE FINANCIAL VIABILITY OF DITCH AND RESERVOIR COMPANIES

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ABSTRACT

The Ditch and Reservoir Company Alliance (DARCA), a 501(c)(6) non-profit organization, is governed by a 10-member Board of Directors. Established in 2001, DARCA is for the benefit of all types of irrigation enterprises - ditch companies, reservoir companies, laterals, private ditches, and irrigation districts.

DARCA has become the definitive resource for networking, education and advocacy for its members in Colorado.

The featured benefits include updated and useful information for the water community through personal communications, a listserv, a web site, email correspondence, an annual convention, workshops, and a ditch company handbook.

This paper describes the importance of groups like DARCA in dealing with the urbanization and the financial viability issues facing water providers in Colorado.

INTRODUCTION

DARCA was created in 2001 with the goal of becoming the definitive resource for networking, education and advocacy among mutual ditch and reservoir companies, incorporated laterals and private ditches. It was incorporated as a non-profit corporation under the laws of Colorado and received 501(c)(6) federal non-profit status as a business league type of organization. Its approximately 160 members not only include mutual ditch and reservoir companies but also irrigation districts, municipalities, suppliers, consultants, professors, engineers, and lawyers. It is governed by a geographically diversified 10-member board of directors comprised of ditch company personnel and water experts from across the state. The staff includes an executive director and two additional employees that assist in the annual convention coordination; all employees serve in a part-time capacity. Accounting services are provided by an individual that is the secretary/treasurer of 15 ditch and reservoir companies in the Boulder, Colorado, area.

The revenue sources for DARCA include: membership fees (ranging from \$50 to \$500), workshop income, *DARCA Ditch Company Handbook* revenue, annual conference revenue (attendees, exhibitor fees, and conference sponsorship), and grants from public agencies. Its 2007 budget was approximately \$60,000. Its expenses consist primarily of salaries, printing, and postage. The office is located on the family farm of John McKenzie, DARCA's Executive Director, in Boulder, Colorado.

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PROBLEM STATEMENT

Colorado's ditch and reservoir companies have a fascinating and storied history in the development of the state. Many were created by the entrepreneurs of their time - bankers, speculators, and developers, as well as a substantial farmer base. Over time, most of these ditch companies have become predominantly farmer owned but in some areas of the state the farmer base has been substantially diminished with the competing pressures for water resources.

Urbanization issues, municipalities seeking ditch company water for urban use, and the increasing cost of doing business in today's regulatory and legal environment have complicated the matter of running ditch companies in Colorado. In reality, many of these companies are no longer able to carry on business as usual if they are going to adequately protect their ditch companies and shareholder interests. These interests of the shareholders include, but are not limited to, protecting their water portfolio, providing water to the farmers at a reasonable cost, and even enhancing shareholder value. This last point of enhancing shareholder value is more than likely not an issue that boards of directors of ditch companies address.

Unfortunately, many of these ditch companies have not been operated in a manner that approaches the optimal use of their resource base. For these ditch companies to contend and prosper in the 21st century, they need to be able to conduct business as successful companies do in corporate America. Most ditch companies probably believe that the exclusive purpose of their enterprise is to provide water to farmers when in reality they should regard their company as one that provides water, not only to farmers but to other users. Even better, management of these companies should run their company with a goal of making a profit and enhancing shareholder value while making water available to its farmers as inexpensively as possible.

Many of ditch company problems can be traced to a limited financial ability to adequately deal with problems, pressures, and opportunities. There are inherent characteristics of ditch company structure that thwart business strategies for growth and prosperity. Broadly speaking, these limitations can be due to a lack of information on behalf of policy makers, the reliance on the wrong experts, and the improper implementation of strategies. Many ditch companies rely on their attorneys - who may lack business savvy and who may not have a sense of a long business planning horizon - for business advice, when in fact a business planning expert may be more appropriate. Many companies are risk-averse to the point of not being willing to undertake deals that may be extremely lucrative to their company. Some of these companies feel that they would be out-lawyered, and that agreements would not be honored by the other parties.

DARCA'S ROLE WITH ITS MEMBERS

DARCA was created to find solutions to these problems of Colorado ditch companies through networking and education. Although there are numerous water organizations in Colorado, there is a disconnect between some of these organizations' stated goals and the agricultural constituents that they purport to represent. Some tend to be provincial in their

scope - interested in only their particular region and issues and not willing to cooperate with others outside of their watershed. DARCA is more comprehensive and not limited to geographical locations within Colorado.

Perennially, the state legislature is reactive in the water arena, usually enacting legislation as a crisis develops. Some bills can be described as “feel good” legislation that have little practical significance at the headgate and farmgate. DARCA is not active in the legislative process and feels that its resources are better directed in dealing with practical and applied issues.

The players in the world of Colorado water - including the media – often view the problems of water as ones of conflict, *e.g.*, west slope versus east slope, farmers and ditch companies versus municipalities. During periods of the state’s history, ditch companies were somewhat litigious with one another but nowadays, ditch companies rarely battle with one another. Much of the case law during the early development of the state bears witness to the litigation among ditch companies. When DARCA was created in 2001, it was a innovative idea that ditch companies from different basins within the state should sit down, exchange information, and help one another. The members of DARCA have found that this information exchange has benefited them financially and through improvements in efficiency. These mutual ditch companies are in a somewhat unique position. They are in the same line of business of providing water but are not in competition with one another. Most other businesses do not wish a greater market share and enhanced efficiency for their competition but the strengthening of one ditch company effects the other companies in a positive ways. It raises the bar in the ways of doing business and this usually manifests as a greater revenue stream for all.

Urbanization should not be characterized with a broad brush as inherently bad. Urbanization is a two-edged sword, one edge is replete with trouble while the other side may contain opportunities. These opportunities are only limited by the imagination of those running the ditch companies. Examples of benefits of urbanization include: revenue derived from reservoir recreational leases, easements, and property owned in fee simple; partnerships with municipalities with deeper pockets; dual systems, and other leases of water.

DARCA has been proud of its accomplishments in its efforts of promoting a better transfer of information among its members. The strategic plan for DARCA is centered on providing value to its members and growing its membership base through its high quality deliverance of needed goods and services. To effectuate this transfer it has provided services and goods through: 1) communication and networking; 2) education; and 3) partnerships.

Communication and Networking

Personal Communication. The members have the ability to easily communicate and share information on a timely basis through telephone, email, or fax with the Executive Director, the members of DARCA board and among the members. The Executive Director, staff, members of the board, and DARCA members are experienced and have

shown enthusiasm in sharing their wealth of information regarding ditch company issues with one another.

Website. The DARCA website, maintained and updated on an almost daily basis, is an integral part of information exchange. The website takes the place of a newsletter for its members. The DARCA website uses an open source template called Mambo which makes it fairly easy to design and implement a professional looking site. The site is a repository of current and past DARCA activity including news articles and sample agreements. So that members are aware of their legal rights, major decisions that affect ditch companies from the Colorado Supreme Court are available on the site. Most of the material is not restricted, but a substantial portion is available for members only through the issuance of a login name and password. The members-only section provides value to those who choose to join DARCA.

Listserv. The listserv has been shown to be very valuable way for members to communicate with one another. The listserv host is through Google Groups and is limited to DARCA members and a few select friends of DARCA. A recent email to DARCA from one of its members is a testimonial to the value of the listserv.

You might recall back in October, I contacted you asking what other companies do about Shareholders wanting to pump directly from the ditch? At your suggestion we contacted our fellow DARCA members and received 16 replies to our question. This was a gold mine of input from which we have formulated our pumping policy. On behalf of our Board of Directors... We would like to thank DARCA for your help. Being able to network with people who have similar problems was not possible before DARCA came into existence.

Annual Conference. DARCA's annual conference is held during the off-period of the irrigation season in different locations within the state in the latter part of February. The first convention held in Durango in 2003 was followed by conferences in Greeley, La Junta, Montrose, and Sterling. The convention planning committee continually strives to develop unique and distinctive types of conferences. The 2008 Convention, *Learning from Others, Acequias in Colorado*, took place in San Luis, Colorado, the oldest town in Colorado and also home to the oldest water right in Colorado. The conference's focus was on local issues involving land and water including the history and current day operations of acequias. The communities in San Luis and in Costilla County were gracious in their help, hospitality and local participation in making the conference a success. The conferences are usually preceded by a pre-convention workshop. The pre-convention workshop for 2008 was *Flow Measurement for Ditch Companies* for ditch company personnel interested in learning about the latest technologies of measuring, recording, and reporting water flows in canals and for on-farm delivery applications. Although the 2008 Convention in San Luis was held in one of the coldest parts of the state and remote from the population centers of Colorado, it sold out one month prior to the start of the convention.

Education

DARCA Workshop Series. The DARCA workshops are a very integral part in helping to inform and educate board members, superintendents, ditch riders, engineers, and lawyers about Colorado water enterprises. The workshops, taught *pro bono* by experts in the Colorado water community, cover a variety of topics. These experts include ditch company personnel, professors, lawyers, engineers, university personnel and consultants. They are provided to members so that more efficiency, professionalism, and better running organizations may result. New workshops are added each year and the locations are changed to different parts of the state. The description of the classes in the 2007-2008 Workshop Series follows:

Records Management for Ditch Companies – This workshop details the best practices for maintaining and storing ditch company documents. Most ditch companies are nearly a century old, and many have files dating back to the company’s inception. In this workshop the best methods for properly storing and cataloguing documents and how to institute procedures today that will insure files are in order tomorrow are explained.

The Power of Microsoft Excel – Spreadsheet Techniques for Ditch Companies
This course is a hands-on workshop in the computer lab. The course is designed to teach smart spreadsheet strategies for typical ditch company data processing and analysis tasks.

Real Estate Law for Ditch Companies - Ditch and reservoir companies in Colorado are not only concerned with water law issues but many spend the majority of their efforts and time dealing with their portfolios of real estate assets. Many canal companies realize property rights can be extremely valuable. If properly managed, they can increase the company’s financial health.

Flow Measurement for Ditch Companies - The workshop is essential for ditch company personnel interested in learning about the latest technologies of measuring, recording and reporting water flows in canals and for on-farm delivery applications.

Directors and Officers Training for Ditch Companies - There is a limited pool within ditch companies for its directors and it is extremely important that these directors are acting to their best abilities. The workshop details the corporate basics for ditch companies. Extensive handouts citing Colorado statutory and case law are provided. Some of the instructors, who are ditch company personnel, discuss their experience of how to lead stockholder meetings, the biases of ditch company directors and officers, the importance of business planning, barriers and pitfalls to optimal decision and conflict avoidance and resolution.

GIS I for Ditch Companies - A one-day survey of the use of GIS in ditch company operations, the course demonstrates how GIS is used in Colorado, as

well as internationally. GIS can be a valuable working partner in operating a ditch, and how it can be used to address urban encroachment.

GIS II for Ditch Companies - This course guides you through the basic data creation steps in ArcView 9.2 beginning with how to open the ArcView 9.2 user interface, then how to create and add notes to point data, create linear data and use the measuring tool, create polygons and use the area measurement tools. Participants are able to put together a layered view of different feature layers, such as section lines, rivers, highways and county boundaries in a given geographical area.

Ditch Hazards Awareness & Safety - Irrigation ditches have been instrumental in the development of Colorado. For more than 100 years urbanization occurred along ditches and their riparian corridors. They are valuable environmental and aesthetic assets for the community, in addition to their historic importance for local agriculture. For ditch companies, urban growth has produced unforeseen consequences. Questions surround liability involved with open water in a populated environment. The workshop addresses how ditch companies, municipalities and the community can promote safety and prevent drownings.

Future workshops currently being developed include: *Alternatives to Buy and Dry; Crossing, Carriage and Relocation Agreements*; and *Augmentation Opportunities*. The workshops have been well received and DARCA has assisted the Bureau of Reclamation in educational efforts with their member projects.

DARCA Ditch Company Handbook. The first edition, published in 2005, was provided to DARCA members to assist them in the operation of their ditch and reservoir companies. A diverse team of Colorado water experts authored the initial publication's eight articles. In the second edition, 13 new chapters are included, along with revisions of the originals. These articles are generally applied and practical in nature but do include innovative ways of doing business. The handbook is also available in PDF format and on DARCA's web site. See Table 1 for a list of articles.

Table 1. Contents of the DARCA Ditch Company Handbook

Preface: How Water Ditches Help To Invent and Reinvent Colorado Water— <i>Justice Greg Hobbs, Colorado Supreme Court</i>
Introduction and Table of Contents
Articles of Incorporation— <i>Jack F. Ross, Joanne Herlihy, & John R. Heronimus, Esqs., Dufford & Brown P.C.</i>
Sample Articles of Incorporation of a Mutual Ditch Company
Bylaws— <i>Randolph W. Starr, Esq., Starr & Westbrook, P.C.</i>
Sample Bylaws, Sample Policy Statement, and Request for Information Form
Water Distribution— <i>Ray Anderson Ph.D., Sociology Water Lab, CSU</i>
Finance & Personnel— <i>Cecil McPherron, Anderson & Whitney, P.C., CPAs</i>

- Water Rights**—*Joe Tom Wood P.E., Martin and Wood Water Consultants, Inc.*
- Dealing With Urbanization and Development**—*Jeffrey J. Kahn, Bernard, Lyons, Gaddis & Kahn P.C.*
- Sample Standard Crossing Agreement, Sample Ditch Relocation Agreement, Sample Reimbursement Letter, Sample Boring Agreement, Sample Discharge Agreement**
- Information Management**—*Patricia J. Rettig, Water Resources Archives, CSU*
- History of DARCA**—*Karen Rademacher P.E., Northern Colorado Water Conservancy District*
- An Introduction to GIS**—*Nils Babel, Riverside Technology, Inc.*
- Moderately Priced SCADA Implementation for Canals**—*Stephen W. Smith, Aqua Engineering Inc. & Donald O. Magnuson, New Cache La Poudre Irrigating Co.*
- Section 404 Permitting Associated with Irrigation Ditches and Drains**—*Steve Dougherty, ERO Resources Corp.*
- Secondary Water Systems: Case Studies**—*John Wilkins-Wells, Ph.D., Sociology Water Lab, CSU*
- Urbanization of Irrigation Systems**—*John Wilkins-Wells, Ph.D., Sociology Water Lab, CSU*
- Directors and Officer Responsibilities and Liabilities**—*Carrie L. Ciliberto, Esq., Ciliberto & Associates, LLC and Zachary Smith, University of Denver, J.D. Candidate*
- Holding a Great Meeting**—*Janet Enge, Animas Consolidated Ditch Company*
- Conflict is Not a Four-Letter Word: Some Advice for Ditch and Reservoir Companies**—*MaryLou M. Smith, Aqua Engineering Inc.*
- Current Issues with Changes of Water Rights Involving Shares of Mutual Ditch Companies**—*Jeffrey J. Kahn, Mark D. Detsky, & Matthew Machado, Esqs., Bernard, Lyons, Gaddis & Kahn P.C.*
- Sample Catlin Bylaws**
- Using Water Markets to Preserve Rural Economies in Colorado: A Brief Look at Alternatives to Buy-and- Dry Contracts**—*Troy Lepper, Sociology Water Lab, CSU*
- Decision and Risk Analysis**—*John D. McKenzie, Innovastat Corporation*
- A Guide to Weather and Climate Information**—*John Wiener, Ph.D., Institute of Behavioral Science, CU*

Other Services. DARCA has recently established a GIS/GPS committee that is looking into providing GIS/GPS services for its members. Several DARCA ditch companies have been using GIS for planning purposes and in their everyday operations. DARCA feels that this type of technology is of extreme value for ditch and reservoir companies. The committee believes that DARCA, its Colorado State University colleagues, and collaborating private consultants would be able to offer state of the art services including personalized training at a very reasonable cost for its members. As a non-profit, DARCA

would be in a position to apply for grants that would furnish software and provide funds for creating the ditch company mapping projects.

Partnerships. DARCA is continually seeking partnerships with water-related entities in Colorado. The Colorado Water Congress (CWC) and DARCA have an agreement whereby members of their respective organization can attend conferences and workshops at member rates. The Colorado Water Conservation Board (CWCB) has assisted DARCA in providing funds for its *DARCA Ditch Company Handbook*. The Sociology Water Lab at Colorado State University has provided expertise and guidance in the development of DARCA. DARCA is working with the Colorado Acequia Association in developing an agreement to collaborate on educational projects. It is currently exchanging information with similar water user associations in Montana and New Mexico.

CONCLUSION

Historically, ditch companies have not been very accomplished at communicating with one another. It is DARCA's goal to change the landscape of ditch company interaction. Optimal remedies and solutions are needed in Colorado for ditch company water issues. Many in the Colorado water community are to be thanked for the support that they have provided DARCA in becoming a sustainable organization for its members.

RESOLVING URBAN CONFLICT ON AN AGRICULTURAL DITCH—A DEMONSTRATION OF INTEREST BASED NEGOTIATION

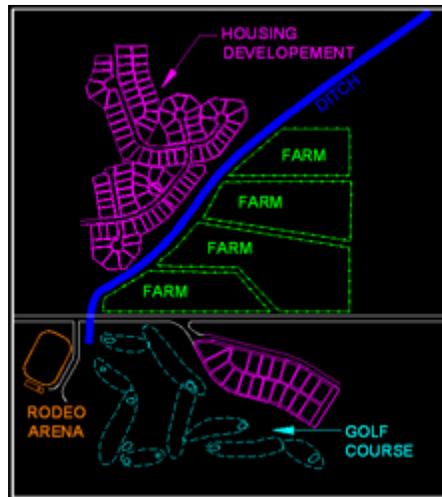
MaryLou M. Smith¹

ABSTRACT

As agricultural land is increasingly being encroached upon by housing developments, conflict is bound to occur. The traditional farmer and the typical suburbanite often have different values. However, ditch companies who find their canals surrounded by houses can learn how to resolve the issues that arise.

Using role-playing, this presentation will provide an active demonstration of the principles of interest based negotiation to show how conflict between rural and urban stakeholders can be resolved. Participants will learn how to build relationships, explore interests, and frame the issues as first steps in reaching a realistic agreement, prior to the steps of inventing options and creating and testing alternative solutions.

Role players, selected ahead of time from volunteers, will be given a scenario to be played out, along with supporting details about their various positions. Roles include farmers, homeowners, a golf course developer, and a county administrator operating a rodeo arena. The presenter will serve as the facilitator to demonstrate how positive results can be achieved. The following graphic depicts the conflict.



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THE SCENARIO

The Longview Ditch Company

Formed in the late 1800's to build a ditch to bring water from the river to farms, the ditch company is owned by shareholders receiving the water. Annual shareholder assessments pay for improvements and maintenance.

The Private Lateral

An extension to the ditch was added fifty years ago by some of the shareholders wanting to bring water to more remote acreage. As was typical in those days, the group did not bother to form a new entity to manage the lateral, instead choosing to operate it informally, as a private lateral. When their water comes through the main ditch, it is measured with a flume, but after that point they don't measure it. They simply cooperate among themselves to call on and distribute the water, and every spring they have a family "ditch burning" picnic to keep the ditch free of weeds and trash.

A New Development

A few years ago, one of the largest farmers on this lateral sold her land along with her shares in the Longview Ditch Company to an east coast developer who built an upscale golf course community with 350 luxury homes. She put the developer in touch with one of the farmers on the lateral so he could find out how to take delivery of his water, which he planned to use to irrigate the golf course. (The luxury homes are being supplied with potable water through a domestic utility.)

First Signs of Trouble

The golf course/luxury homes developer hired a manager to take care of the irrigation and other day to day details at the golf course. This manager has had a number of run-ins with the farmers about the timing and amount of his deliveries, escalating into some name calling at times. He thinks the farmers are disorganized, resulting in bad management. The farmers say he is naïve about how irrigation has to work.

The luxury homeowners like the view of the water flowing under the cottonwoods on the edge of the development and the red-winged blackbirds attracted to the cattails that grow along its banks. But the farmers periodically have to chase the homeowners' kids out of the ditch and they have had to put up with the president of the homeowners' association complaining about their cutting down cattails that impede the flow of water.

Proposal for a Pipeline

The farmers heard about a low interest state loan to replace the open lateral with a pressurized underground pipeline. The pipeline would prevent drownings and it would conserve water currently lost to evaporation and seepage losses. It also would let them measure the water distribution on the lateral so they could prove to the golf course that they are getting their allotted amount. It would eliminate having to burn the ditch every year to remove cattails and other weeds and trash.

The farmers couldn't pay off the loan by themselves, so they approached the golf course developer about participating. When he showed initial interest, they started the paperwork. First step was to apply for feasibility study funds, after which, if the plan was sound, they could apply for a construction loan.

However, when it came time to co-sign the loan application, the developer seemed to have had a change of heart. He said the farmers should get the loan for the feasibility study on their own and once it came time for the construction loan, he would consider participating. The farmers became disgruntled and shelved the whole idea.

A Question of Authority, Increased Liability

Now, a new wrinkle has developed. Recently one of the farmers read that Pleasant County was filing with the State for a water rights change for some water they want to use to irrigate the grounds of their rodeo arena. The legal notice said the water would run through the Longview Ditch. Knowing the water would have to run through their lateral to reach the rodeo arena, the farmer called the County who told him they had made a deal with the golf course developer to bring their water through "his" ditch, and have him pump it up to their higher ground. The County was surprised to hear the lateral was owned by not just the developer, but a number of farmers as well.

Incensed, the farmers are considering filing an objection to the County's water rights change filing. They see that as their only leverage to protect themselves from the additional liability of the County's water coming through their lateral. Because they are a government entity, the County would not share in the liability in case a kid drowns on the ditch lateral.

The Longview Ditch Company isn't happy either—for the same reasons, increased liability with no sharing of risk. Though they are playing it low key, they have filed what's called a "friendly objection" to the County's water rights change application.

THE ROLES

The Longview Ditch Company

You have come to the meeting on the request of the farmers, but you would rather stay out of the matter. However, you do share the farmers' concern that the County has government immunity and won't be sharing the additional risk. The pipeline makes sense from an operational and liability point of view, but since the majority of your shareholders aren't on the lateral and wouldn't enjoy any benefit, you doubt they would be willing to help fund it. Your prime goal is to keep your shareholders happy, and of course that now includes not only the farmers on the lateral but the golf course/luxury homes developer.

Pleasant County

The County can save money by irrigating the rodeo grounds with ditch water instead of potable water, and that's why you bought the water rights and made the deal with the golf course developer. Though you would prefer not to have to help pay for it, the pipeline the farmers want would have some advantages. For one, the County would actually get more water because of increased transmission efficiency (no seepage losses or evaporation.) And even though the County has government immunity and can't be sued if a kid were to drown in the ditch, a drowning would be a publicity nightmare. Maybe the County Commissioners would agree to put in something toward the pipeline cost, if they could be convinced it would be good for PR.

Bighomes HOA

Bighomes, with the gorgeous golf course out in the country, is a great place to live. The ditch provides a bucolic touch to the mountain view. But something has to be done about the danger to the children. Couldn't those farmers put up an attractive fence? And why did they have to come in last spring and cut out all the cattails that attract the red-winged blackbirds?

You would hate for the farmers to replace the ditch with a pipeline because of the beauty of the open water and the birds, but maybe you could convince them to put in an open space trail in its place.

Country Air Golf Course Developer

Those farmers are about to drive you nuts. That pipeline would cost a fortune and there's no way you would ever see a return on your investment. If they want to block your deal with the County, they are just going to have to take you to court. Boy, are they mad you didn't consult them before you made the deal.

The farmers' worry about the liability is overblown. How often do you hear of a kid drowning in an irrigation ditch? And besides both you and the farmers have plenty of

insurance to cover you in that event. (You don't agree with the farmers that the maximum coverage allowed, which they already have, wouldn't be high enough in the event of a drowning.)

Farmers

Farming isn't the same now that urbanization has hit your area. The golf course developer is the one who upset the apple cart, and he has plenty of money. Why can't he help pay to put the ditch underground? That would solve all your problems, and his too.

You wouldn't have any problem with the County running their water through the lateral if it weren't for the increased liability of having water in the ditch about twice as often as before. That, and the fact that as a government entity they are immune from a suit if somebody's kid drowns in the ditch. What really burns you up is that the golf course developer made a deal with the County without even consulting you. What makes him think his more or less 25% ownership of the lateral gives him that prerogative?

If you could get the developer and the county and maybe even the HOA to go in on the underground pipeline, you could get rid of all these problems. Nobody's kid would be at risk of drowning, nobody would have to maintain the ditch, more accurate measurement of the water would keep everybody happy, including that blasted golf course manager. Besides, a pipeline would cut down on evaporation and seepage, so everyone would actually get more water.

THE SETTING

The farmers want to resolve this conflict without having to hire an attorney, which they cannot afford. Since there are multiple issues, they decided to call a meeting of all the players, including the golf course developer, the homeowners' association, the County and the Longview Ditch Company. A facilitator known for her use of interest based negotiation has been asked to facilitate the meeting.

ABOUT INTEREST BASED NEGOTIATION

Interest based negotiation is increasingly being promoted in place of positional bargaining as a technique more likely to result in lasting resolution of conflict. By bringing their interests to the table and leaving behind preconceived positions, players are more likely to come up with solutions favorable to everyone instead of each going home with half of what he wanted. Sometimes interest based negotiation is referred to as making the pie bigger instead of splitting the pie.

Interests versus Positions

What is the difference between a *position* and an *interest*? A simple story will illustrate:

Two men were quarreling in the library. One man wanted the window open. The other man wanted the window closed. They bicker about how much to leave it open: a crack, halfway, three quarters of the way—that's positional bargaining. No solution satisfies them both. Enter the librarian. She asks the first man why he wants the window open. His answer? Fresh air. She asks the second man why he wants the window closed. His answer? To avoid the draft blowing around his papers. After thinking a minute, the library opens wide a window in the next room, bringing in fresh air without a draft.

The positions were “window open” and “window closed.”

The interests were “fresh air” and “no draft.”

By looking at interests vs. positions, a solution was not far away.

You and Me Together Against the Problem

Interest based negotiation calls for a different paradigm. Instead of players with a conflict opposing one another, they consider themselves united in opposition to the problem needing resolution. From this vantage point, they work together to understand all their interests as thoroughly as possible. Seeking to deeply understand what *your* interests are is just as important to me as it is for you to deeply understand what *my* interests are. If I can truly understand your interests, and you can truly understand mine, we will be in much better position to carve out solutions which will work well for both of us. As William Ury and Roger Fisher say in Getting to Yes: Negotiating Agreement Without Giving In:

“The ability to see the situation as the other side sees it, as difficult as it may be, is one of the most important skills a negotiator can possess. It is not enough to know that they see things differently. If you want to influence them, you also need to understand empathetically the power of their point of view and to feel the emotional force with which they believe in it. It is not enough to study them like beetles under a microscope; you need to know what it feels like to be a beetle. To accomplish this task you should be prepared to withhold judgment for a while as you ‘try on’ their views.” (Fisher and Ury, 1981)

People listen better if they feel they have been understood. The better you really listen to them, and replay for them what you heard their interests to be, the better they will really listen to you and your interests. Don't worry: understanding their point of view is not the same as agreeing to it. If you show you are interested in them and that you respect their interests, they will think of you as an intelligent person whose ideas might also be worth listening to!

Building Relationships

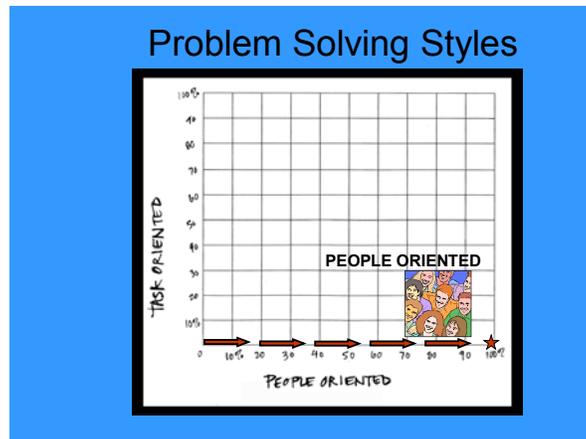
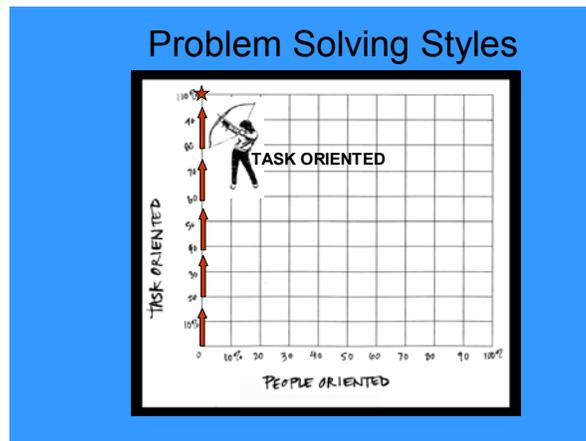
Interest based negotiation places as much importance on relationships as it does on problem solving process. Seeing the value of building relationships as a first step in negotiation is neither new nor understood only by those in the social sciences. Delph Carpenter, famous for being one of the key negotiators of the 1922 Colorado River

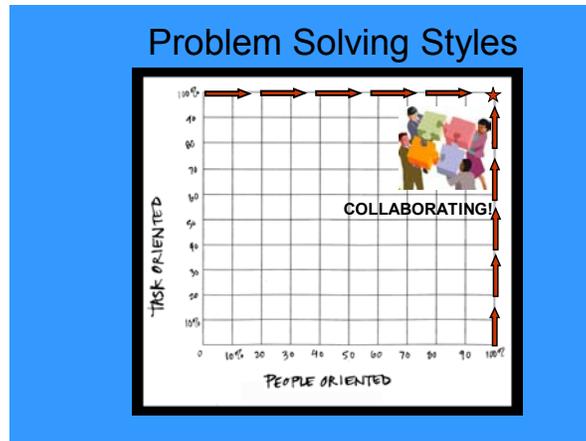
Compact, said that successful negotiation calls for “really understanding the other fellow’s take on things.” (Tyler, 2003)

J. Geringer said that his “kitchen table dialogues” for solving conflict when he was governor of Wyoming were successful because they started out with folks getting to know each other—what they do for a living, what they care about. (Geringer and Kitzhaber, 2004)

First director of the EPA, William Ruckelshaus said “Only when people are united despite their differences by hard-earned trust, does the astounding political power of collaboration become effective.” (Ruckelshaus, 2005)

Successful collaborators employ a problem solving style both highly task oriented and highly people oriented, as illustrated below.





Education

Exploring Interests. In interest based negotiation, education comes before problem solving, including educating one another about interests, data, and relevant history. It starts with in-depth analysis of what drives each party, and what each party perceives to be its prime interests to be met and difficulties to be avoided. Since these are *interests*, not *positions*, other parties have no reason to debate them, but every reason to understand them as thoroughly as possible, for the glimpses they may give for later mutual gain solutions. Bringing out hidden interests can best be accomplished when trust has been built from paying attention to the relationships first. Each player is more likely to reveal hidden interests if the other players are willing to do the same.

Gathering Data. The process of educating one another about data and relevant history often leads to debate about accuracy. Acknowledging that we all have different views of the elephant, players can objectively list their different points without debate, and then attempt to reach agreement on how the differences will be resolved, for instance through a neutral party, hiring experts, joint research, or other methods. This process is much easier when players view each other as mutual problem solvers than when they view one another as adversaries.

Identifying Problems, Framing Issues

Groups trying to resolve conflict often spin intricate webs of debate which lead to hours of rehashing, whining, and unproductive labor. Working together to objectively identify problems to be addressed can cut through this miserable activity. This process takes time, but groups find it more palatable because it is more productive and leads to tangible results.

Ferretting out the core issues from peripheral ones is a first step, though peripheral issues are not discarded. "How can we most clearly describe the essence of the problem in all its aspects?" is the question the group is wrestling with. Getting this work done before attempting to resolve the problem builds a sense of team effort. Players must be restrained from proposing solutions at this stage, even though sometimes it seems as if

the perfect solution becomes clear during this process. Prematurely jumping to solutions may jeopardize coming up with more appropriate solutions, and more importantly, it shortcuts the process designed to give all players an opportunity to fully participate, which is important for eventual buy-in.

Inventing Options

Likewise, the next step, *inventing* options, should not be confused with *evaluating* options. The two activities must be kept separate. Brainstorming ways the various interests might be met is most effective when the group is encouraged to be creative, to think “outside the box.” When players feel free to be a bit off the wall, the atmosphere can result in a free-flowing exercise which breaks down animosity and occasionally leads to truly brilliant solutions. Even when brainstorming is conducted in a more sober, practical way, the activity of working together to look in every corner for options that might work builds on the joint problem solving nature of interest based negotiation.

Most folks have engaged in group brainstorming and know that the rules prohibit criticism since the practice of brainstorming is not for evaluating but for creating. Other guidelines for brainstorming include looking at things from multiple angles and recording ideas fully, in full view of everyone, to give them credence.

Evaluating Options, Creating Alternative Solutions

Finally, it is time to get down to the matter of looking at the pros and cons of various options or alternatives. In positional bargaining, this step comes first, with each party presenting their alternative or position and then bargaining for who gets what part of the pie. But in interest based negotiation, this phase, coming after a great deal of preparation, takes on a decidedly different tone. Instead of each party lobbying for his or her position, the parties are manipulating the various options to come up with optimal alternatives which offer mutual gain. Shaping, whittling and dovetailing are words that can be used to describe the process. Piggybacking is another. Piggybacking is the process of adding to an idea previously generated. Whittling is taking some part of an option away to make it work better. Dovetailing is taking two or more ideas and putting them together in a way that fits well. The concept of shaping incorporates all these techniques, a process of trimming off pieces that don't seem to fit, filling in with something extra where required, sanding off the rough edges.

Coming to Agreement

Interest based negotiation does not produce miracles, but it is more likely to result in lasting resolution as the various players have an active hand in crafting a solution. Coming to the stage of working out an agreement takes place in many different ways. Sometimes evaluating options yields an agreement everyone can agree with. Sometimes impasses occur which require further work. Often the group will assign a committee or its facilitator to write up a draft of what has been preliminarily agreed on, with the opportunity for all players to take a fresh look at what has been resolved so far before

tackling the next step. Sometimes the group chooses to edit a model agreement to fit its needs. At the conclusion of this stage, the group should discuss how to implement and monitor any agreement that is made.

Professional Facilitation

Conflict caused by urban encroachment on agricultural lands frequently goes unresolved, resulting in degradation of sense of community and reduced satisfaction of all with their freedom to pursue their chosen lifestyles. Sometimes a meeting will be called by one of the parties to try to iron out differences, but more often than not, resolution is incomplete or not achieved to the satisfaction of all the parties, resulting in poor compliance and continued conflict.

Interest based negotiation can be accomplished most effectively with the assistance of a neutral party experienced in guiding the process and assuring that participants work through the steps in a productive way. Unfortunately, it is rare to bring in a facilitator or mediator. Occasionally, one party or the other is so aggrieved, or has enough to lose financially that he will hire an attorney. Though water lawyers are increasingly willing to work with parties to avoid litigation, bringing in a lawyer instead of a facilitator or mediator almost always sets an adversarial tone. Having to resort to litigation is not only expensive, but it typically solidifies barriers between people when issues might well have been resolved in a way that could actually improve relationships.

CONCLUSION

Many folks reading about the process of interest based negotiation are skeptical that it would be effective in resolving the conflicts in which they are involved. They cannot visualize their adversaries being willing or able to do the hard work required. In reality, we are usually the ones who are unwilling to put in the hard work and the time to resolve issues in a manner that provides mutual gains.

Some will say “I tried that, and it didn’t work.” Interestingly, the same folks who would never expect a scientific experiment to work perfectly the first time and are willing to keep working through the variables, are unwilling to see sociological experiments in the same light. If we want to learn better ways to deal with conflict we must be willing to engage in practice and experimentation. It is unfortunate and wasteful of human resources for us to throw in the towel so quickly when it comes to “people problems.”

Fortunately, more scientists and engineers are beginning to understand the need for research and experimentation to improve techniques for resolving conflict. William Ruckelshaus says adaptive management is just as applicable to social experiments as biological ones. We don’t have to get it right the first time, he says. We learn from our mistakes and keep on trekking. He warns that we have to “break through the shallow façade of rhetoric and reach to the heart of the issue.”

“The most critical need in solving water problems today is not more technical solutions,

but socio-political solutions” according to Dipak Gyawali, a Nepali engineer and political economist speaking at the 2006 World Water Forum in Mexico City (European Commission, 2006.) Gyawali promotes the view that to solve our water problems we need to be putting our resources not into more technical research, but into research to figure out “appropriate ways to better understand and deal with distinct mindsets people use to filter data.” He proposes that we need research integrating water law, economics, human mindsets and behavior, and that we should conduct such research as confidently as we now address hydrology and hydraulics.

Finally, we need to look beyond our intellectual skills and tap into our emotional skills in order to put our best foot forward in resolving conflict. Peter Senge, well known for his writing about Appreciative Inquiry says “we are stuck in patterns where solutions are arrived at through the process of downloading, or taking an existing framework and applying it to the situation at hand.” He says we can no longer rely on old approaches to problems, which more often than not favored those in a position of money or power over others. To achieve resolution that promotes people being able to live together peacefully we need to slow down and ponder a problem so that we can “illuminate the blind spot.” We need to create a deep awareness of the problem as a whole, not just its parts. He challenges us to retreat and reflect, to go to an “inner place of stillness, then listen and make sense of it.” (Senge, 2005)

As the face of agriculture changes, we have much to lose. Not just farmers, but all of society will be negatively affected if we allow agriculture to be swallowed up by urbanization. Not only will our source of food and fiber be jeopardized, but we will lose open space, wildlife habitat, and a way of life historically valued. By facing our challenges proactively and making policy decisions that address the potential conflicts before they occur, we can potentially build new institutional patterns which meet the broadest needs. When conflict occurs, we can draw on our courage and our inventiveness to say “How can we work this out?” instead of heading to the courts or just hiding our heads in the unhappy sand. Urban conflict on a rural ditch can be resolved constructively. We just have to work as hard at cooperating with our neighbors as our forefathers did when they first built those ditches.

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PLANNING AND MANAGEMENT MODELING FOR TREATED WASTEWATER USAGE

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G.P. Merkley²

ABSTRACT

Due to urban growth, some agricultural lands have been replaced by residential, municipal, and industrial areas. In some cases the remaining agricultural land will not have enough water because of transfers from agriculture to M&I users. Therefore, in many places, especially in arid and semi arid regions, the use of treated wastewater as a reliable source of irrigation water has already been or will be considered in the future. Due to its unique characteristics, this new resource has many challenges that cannot be ignored, such as health issues, water quality, long- and short-term effects on soils and crops.

This study considered the development of a new GIS-based model for planning and managing the reuse of treated wastewater for the irrigation of agricultural and green lands, considering various factors such as population and urban growth. The model is composed of several different modules, including an urban growth model. These modules help the user make better decisions for allocations of water resources to agricultural areas, considering factors such as crop types, crop pattern, water salinity, soil characteristics, pumping and conveyance costs and also by comparing different scenarios. Appropriate crops that can be grown with a specific water salinity and soil characteristics, proper water resources for each farm (according to pumping and conveyance costs, and analysis of water demand, and water supply) can be determined through the application of this model. The model can also rank agricultural areas and open spaces in and near an urban area according to their suitability for irrigated agriculture.

INTRODUCTION

This study considered the development of a new Geographic Information System (GIS)-based model for planning and managing of the reuse of treated wastewater for irrigation of agricultural lands and green areas, considering various factors such as population and urban growth. The new model will be coded in Microsoft[®] Visual Basic .NET and is composed of five different modules:

- 1- Agricultural Land Suitability Module.
- 2- Agricultural Land Availability Module.
- 3- Water Availability Module.
- 4- Water Storage Module.

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5- Planning and Project Comparison Module

The first four modules are related to each other and GIS-based, while the last module optionally uses GIS data from the first four modules, or another data source. The details of all these modules are discussed in this paper.

AGRICULTURAL LAND SUITABILITY MODULE

The Agricultural Land Suitability Module can help planners in making better decisions for the locations of future agricultural areas. Agriculture is not possible without two important resources: appropriate lands (soil) and water. In this module, preferred lands for agriculture will be determined and ranked according to these two resources. First, it is considered that appropriate land for agriculture should have proper soil texture and land slope. Second, it should not be too far from water resources. In this study, the water resources considered are treatment plants. Therefore, to determine the appropriate locations for agricultural lands the transportation and conveyance of the water to the land should also be considered in terms of pumping and conveyance costs. Conveyance costs are related to the size of the lands and also to the distance between the land and the water resource. On the other hand, pumping cost is related to the elevation difference between land and the treatment plant, as well as the flow rate, which is related to the land area and crop water requirements.

In this study, according to the distance and the elevation difference between the treatment plant and the agricultural land, and also according to the land area, land slope, and soil texture (if available), the lands are ranked into three different levels of suitability for agriculture. Therefore the input data include:

- A current GIS map of the urban area, including land-use layer and topography layers.
- A GIS layer with the location of the water treatment plants.
- Soil characteristics, including soil texture, infiltration rate, and water-holding capacity.

The output data will include a GIS map of the area in which the available lands are ranked by three levels of suitability for agriculture.

AGRICULTURAL LAND AVAILABILITY MODULE

Through the years, due to population growth and urban growth, a lot of agricultural lands have changed and transformed to residential, municipal and industrial developments. Many studies have shown that after a few years there will not be any agricultural lands left in or near some urban area.

The Agricultural Land Availability Module helps the user determine how much time it will take for all of the agricultural area to disappear due to population and urban growth. This module is composed of two sub-modules: 1- Population Sub-module; and, 2- Land-Use Change Sub-module.

Population Sub-Module

This sub-module is responsible for the prediction of the population of an urban area in the future. The population of a society is related to the rates of birth and immigration, and to the rates of death and emigration. These factors cause the population of that society to increase or decrease.

There are many different methods for calculation and estimation of population growth of an urban area, such as the exponential method, the logistic method, and others. In this model, one of the simplest methods of estimation of population growth is used: the exponential method.

The exponential trend of population growth is shown as Malthus (1798):

$$P = P_0 e^{rt} \quad (1)$$

in which P is the future population; P_0 is the starting population; t is the duration of time; and, r is the natural rate of population increase; and, r is related to the amount of births and deaths, and also the amount of migration to or from an urban area. Therefore, the needed input data include:

- Base population of the Urban Area
- Time Duration (years)
- Growth Rate

The output from this module will simply be the population of an urban area after t years.

Land-Use Change Sub-Module

This module predicts the land use changes (especially for agricultural lands and green areas) in an urban area due to population and urban growth. For this sub-module, an appropriate land-use change model is used. There are many urban growth models such as GSM, INDEX, UPLAN, TRANSUS and etc. (EPA, 2004). According to the goals of this study, a Land Transformation Model (LTM) developed by Pijanowski et al.(2002) is used as a sub-module. LTM uses GIS and Artificial Neural Network (ANN) in order to forecast the land use changes.

LTM can consider many different socioeconomic, political and environmental factors that affect land use changes. These factors can be determined by the user for different case studies.

These sub-modules and especially LTM helps us to forecast after how long the agricultural area in the region of the study will disappear.

WATER AVAILABILITY MODULE

This module is composed of four different sub-modules and it calculates the amount of water demand and water supply in an urban area, comparing the results with changes in land use and population. These calculations are done in order to estimate when there will not be enough fresh water resources to support agricultural irrigation.

The sub-modules are:

- 1- Population Sub-Module
- 2- Land-Use Change Sub-Module (LTM)
- 3- Water Supply Sub-Module
- 4- Water Demand Sub-Module: 1- Municipal and industrial water use; 2- Agricultural water use.

The first two sub-modules were explained in the previous sections of this paper.

Water Supply Sub-Module

This sub-module is responsible for gathering the information about water supplies and analyzing them. Water supplies for an urban area can be divided into two parts: 1- Treated wastewater; 2- Fresh water (Surface water, ground water, and imported water). This study emphasizes on treated wastewater. The locations and capacities of the water treatment plants, the quality of the released water from different treatment plants and the time series of released water from treatment plants are some of the important input data for this module. The information for freshwater supplies is some other input data for this part of the model.

Water Demand Sub-Module

Water demand is divided into two parts:

Municipal and Industrial Water Use: In this module, M&I water use is predicted for the future of an urban area.

M&I water use is the daily per capita use, which includes (Bhave, 2003):

- Domestic water use, that is the water use for residential areas (like houses), such as water for drinking, showering, air conditioning and for watering the gardens. Domestic water demand, related to the population and economic level of users, is about 30-50% of the total water use.
- Public water use, is about 5-10% of total water use and is the water needed for public buildings such as schools, hospitals and etc.
- Commercial and Industrial water use, is the water demand for commercial and industrial purposes such as factories, shopping centers, offices and etc.(about 10-30% of total water use).

- Loss and Waste use, is about 10-20% of water that gets lost from pipes and valves, also the unauthorized usages of water and error in water-meter readings.

Therefore, the amount of municipal and industrial water use is related to many different factors, including population, city size, users' income, climate, and many other factors. According to these factors, there are different methods for forecasting the water demand in an urban area. Some of the methods are very simple and others are quite complex. The per capita method is one of the simplest methods used for water demand forecasting. This method simply multiplies the per capita use of water in an urban area by the population of that urban area for the future. The disadvantage of this model is that it ignores all other factors affecting water demand –it only considers the population. There are also some other multi-variate models, such as IWR-MAIN, that use a lot of different factors to forecast the water demand (Hillyer et al., 1998). In this study the simplest method, which is per capita, is used.

Agricultural Water Use: Agricultural water demand is the amount of water needed for irrigation of an agricultural land and is related to crop types, crop pattern, and climatic parameters. In this module, the amount of water needed to irrigate the remained agricultural area is calculated on yearly and monthly bases. This calculation can be done using the following equation:

$$ET_C = K_C ET_0 \quad (2)$$

in which ET_C is the evapotranspiration of a specific crop; K_C is the crop coefficient, which is different for various crops and in different growth stages. ET_0 is the reference crop evapotranspiration (FAO, 1998).

Using the above equation, the amount of water required for the irrigation of a specific crop will be calculated in mm/month. ET_0 could be calculated according to different estimation methods. In this model two methods are considered for calculation of water demand: 1) FAO Penman-Monteith equation; and, 2) Hargreaves equation.

FAO Penman-Monteith Method (FAO, 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3)$$

In which:

ET_0 - Reference evapotranspiration [mm day⁻¹],
 R_n -Net radiation at the crop surface [MJ m⁻² day⁻¹],
 G - Soil heat flux density [MJ m⁻² day⁻¹],
 T - Mean daily air temperature at 2 m height [°C].

Hargreaves Method

This equation is more practical, due to very few data that it needs. Hargreaves equation is (FAO, 1998):

$$ET_0 = 0.0023(T + 17.78)T_D^{0.5} R_s \quad (4)$$

Where:

ET_0 - Potential daily evapotranspiration (mm/day),

T - Mean temperature ($^{\circ}C$), and;

R_s - Incident solar radiation converted to depth of water, mm/day; and;

The model also has the information of crop coefficient for different crops, saved. Crop coefficient changes the reference evapotranspiration to crop evapotranspiration. The crop coefficient is different for different crop growth stages. FAO has determined the crop coefficient for different crop types in different growth stages, which will be used in this model. Therefore, the model would be capable of estimating the water demand in agricultural area according to the crop types and crop pattern determined by the user.

Other than crop demand, for different types of water supply an extra amount of water is used for leaching in order to protect the soil from getting salty and inappropriate for agriculture. In the next part the calculation method of this excessive amount of water for leaching is shown (Feigin et al., 1990).

Leaching ratio can be calculated as follows (FAO, 1994):

$$LR = \frac{EC_w}{5EC_e - EC_w} \quad (5)$$

In which:

LR - Leaching ratio.

EC_w - Irrigation water salinity (dS/m).

EC_e - Saturated soil extract salinity for 90% yield potential.

Therefore, the calculations of water demand and water supply for the future of an urban area with more population, and comparing them can show if there will be enough water available for agricultural irrigation or not and if there is not, after how long there wont be enough water left. This calculation will also be done assuming higher water use efficiencies for municipal users.

According to the calculations of water demand for agricultural and green lands, water demand for each month can be plotted. Also, the released water data from treatment plants in different locations as input data can be plotted as water supply for each month of

a year. Using these data, different analysis could be done for matching the supply and demand, such as:

- 1- Plotting the variation of wastewater supply and agricultural water demand during a year for different time intervals chosen by the user.
- 2- Comparing the changes of wastewater supply and agricultural water demand during a year and for different season, for specific time intervals defined by the user.

STORAGE MODULE

In an urban area the production of wastewater is continuously along the year, while the agricultural water demand is limited just for a short period of time in the agricultural season. Therefore, storing the treated wastewater at the season of low demand could make a reliable water resource for when it is needed especially for arid and semi arid regions. In this model, the possibilities of storing treated wastewater also will be investigated. According to the previous part, the changes of treated wastewater supplies and agricultural water demand will be available and therefore, the amount of water that can be stored can be calculated.

According to Juanico and Dor (1999) and Mancini et al.(2007), the case studies in Israel and Italy have shown besides other benefits, the wastewater reservoirs also have improved the water quality to large extents.

Storing the wastewater could be in two ways: 1- Surface reservoirs; 2- Groundwater Basins (Guymon et al., 1990). In this study just surface reservoirs will be considered.

Comparing the changes of water supply and water demand in agricultural area for specific time intervals, this module will determine if there is need for storing wastewater or not. Also the amount of water that needs to be stored will be determined by the model. Considering the pumping and conveyance costs, the open spaces near the urban area will be ranked due to suitability for building the reservoir.

It should be noted that this module is related to Water Availability Module and it can not be run without that. In other words, this module uses the output data from that module and uses them as an input module.

PLANNING AND PROJECT COMPARISON MODULE

The purpose behind making this module was to make it possible for users and decision makers to be able to check some planning options and scenarios without the need of having the GIS maps of an area. This module makes it possible for the users to check and compare different planning scenarios that they have in mind for reuse of treated wastewater for agricultural irrigation, with changing many different factors and parameters and finally to make better choices and decisions in this matter. The scenarios are compared considering the crop yield produced, environmental effects in terms of the effects of nitrate and phosphate and pumping costs.

This module is composed of two different sub-modules:

Input Sub-Module

In this part the user can define different scenarios for the model by changing various factors mentioned below.

- a) Land Characteristics Sub-Module, in which the agricultural land area and locations and the distance between them and their elevation and slope would be determined by symbolic shapes such as rectangles for agricultural lands and lines for the distance between them.
- b) Crop Sub-Module in which the crop types and pattern for each agricultural land could be determined.
- c) Soil Sub-Module in which soil characteristics for different agricultural area if available could be determined.
- d) Wastewater Sub-Module, in which the locations, time series and characteristics of water released from treatment plants would be determined.

Output Sub-Module

It should be noted that the user chooses the crop types and crop pattern for each agricultural land. Then, according to the standard quality of water for irrigation of agricultural area, the water resources (treatment plants) that are appropriate will be chosen by the model and others will be eliminated. In the next step, it will be checked if the salinity of the water resources is appropriate for the crops chosen and if it is not, how much fresh water should be added in order to be able to use that specific treatment plant as water resource. This is done by the model using the mass balance equation.

For all the water resources or scenarios these calculations are done:

- 1- Crop yield is calculated.

Salts in the soil water can reduce the crop yield by decreasing the ability of crop roots to take the soil water. The amount of salt till a specific threshold won't have any effect on the crop yield, but after that threshold, increase in the salt amount would decrease the yield with a linear relation (Maas and Hoffman, 1977) or S-shaped curve (Van Genuchten and Gupta, 1993).

Maas and Hoffman suggested the following equation for calculation of the crop yield under salinity stress (FAO, 1994):

$$Y = 100 - b(EC_e - EC_{eThreshold}) \quad (6)$$

in which Y is relative crop yield (percent); EC_e is salinity of the soil saturation extract (dS/m); $EC_{eThreshold}$ is the salinity of the soil saturation extract at the threshold (dS/m), which can be determined from Table 5; and b is the reduction in crop yield per unit increase in salinity, which is (FAO, 1994):

$$b = \frac{100}{EC_{e(0\%)} - EC_{e(100\%)}} \quad (7)$$

Usually, EC_e is defined as:

$$EC_e = 1.5EC_w \quad (8)$$

where EC_w is the irrigation water salinity (dS/m).

It should be noted that the model uses this equation in order to calculate the relative crop yield reduction according to soil water salinity.

- 2- Each water resource is ranked according to pumping and conveyance costs (or distance between the land and the plant), and elevation changes between the plant and the land.
- 3- Using another model as sub-module, the effects of nitrate and phosphate are investigated on ground water and surface water. In other words, the environmental effects of nitrate and phosphate are assessed.

Two important constituents in the wastewater that have adverse effects on the environment are nitrate and phosphate. Although, they are essential nutrients for crop growth, nitrate can leach to lower levels of the soil and pollute the groundwater, which can cause health problems and phosphate and nitrate transported by irrigation runoff can pollute the surface water and increase the growth of algae (Nathanson, 2007; Feigin et al., 1990).

There are many different models that can predict the amount of nitrogen leaching to deeper layers of soil considering different factors, such as crop uptake, nitrate transport in the soil and others. Nleap (Shaffer et al, 1991), RZWQM2 (Ahuja et al., 1999), WHNSIM, HYDRUS (Simunek et al., 1998) and GLEAMS (Leonard et al., 1987) are some of these. Also, there are many models that can investigate the effects of nutrients on surface runoff from irrigation such as HYDRUS-2D, GLEAMS (Leonard et al., 1987).

In this study, considering the effects of nitrate and phosphate was important. Therefore, a model that could model the effects of water quality both on surface water and groundwater due to irrigation management practices should be chosen. GLEAMS (Leonard et al., 1987) is the model that was chosen to be used in this study as a sub-module. GLEAMS, or Groundwater Loading Effects of Agricultural Management Systems, is a field-scale mathematical model that considers the effects of non-point-

source pollution on ground water and surface runoff from a field with different agricultural management systems (Leonard et al., 1987).

All these are summarized in a table as output data and could be used by the user to decide and choose the better option and scenario.

SUMMARY AND CONCLUSIONS

Using Microsoft[®] Visual Basic .NET, a new model is being developed to:

- Investigate the effects of population growth and urban growth on agricultural lands and food production in terms of land (soil) and water resources availability.
- Compare different scenarios for water resources allocations for agricultural area (with the emphasis on water treatment plants as water resources), in various ways, such as: crop yield, conveyance and pumping costs and environmental impacts (in terms of the effects of nitrate and phosphate on surface and groundwater).

The model is composed of five different modules and various sub-modules, including a GIS-based urban growth model, LTM (which relies on ANN) (Pijanowski et al., 2002), and a model for investigating the effects of nutrients on groundwater and surface water, GLEAMS (Leonard et al., 1987). The main modules of this model are:

- 1- Agricultural Land Suitability Module.
- 2- Agricultural Land Availability Module.
- 3- Water Availability Module.
- 4- Water Storage Module.
- 5- Planning and Project Comparison Module.

The results of this model include:

- A GIS map of suitable that ranks the area for agricultural purposes, considering the soil characteristics, soil slope, water resources available and pumping and conveyance costs.
- A prediction of the time that all the agricultural area in or near an urban area will be disappeared.
- A prediction of the time when the fresh water resources won't match the demand in an urban area, assuming: 1- the current trend of water use for municipal users and; 2- higher municipal water use efficiencies.
- Prediction of the time that water resources will be limiting factors for agriculture.
- The plots of water supply (treated wastewater) and agricultural and green area water demand along a year for specific time intervals and checking if there would be a need for water storage facilities.
- Comparison of different scenarios defined by user (by changing water resources (water treatment plants) characteristics, land characteristics, crop types and pattern and etc.), in terms of crop production, conveyance and pumping costs, some environmental effects.

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BOOTS ON THE GROUND: CONSTRUCTION MANAGEMENT OF URBANIZING IRRIGATED FARM LAND

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ABSTRACT

Since its inception in 1885, the Buckeye Irrigation Canal has delivered irrigation water in the Buckeye Valley, southwest of Phoenix, Arizona. Throughout its tenure, the owners of the canal have consulted design professionals for its engineering needs. Early engineering in 1885 established canal alignments, delivery points and increased channel capacity. Until recently, the Buckeye Valley was a rural area relying on agricultural revenues to drive the local economy. Now, due to the recent housing market boom new homes started springing up like corn in September driving the existing open-channel laterals below grade into a patch work redesigned pipeline system. Because of these changes, construction management is an enormous benefit to the Buckeye Water Conservation and Drainage District (BWCCD), the owners of the canal.

As a result of this urbanization, contractors working for home developers are installing irrigation pipelines and systems with the focus of completing the project as quickly and economically as possible. Irrigation providers, on the other hand, focus on meeting the agricultural needs of their clients with consistent and uninterrupted water delivery. The services of a professional construction manager help both entities achieve their respective goals in addition to shielding the District from the construction of sub-par systems and risk, maintaining uninterrupted service to the District landowners and providing the technical expertise to communicate with both the District and contractors.

Construction managers provide a number of services to rural irrigation districts undergoing urbanization. First they team with the District by:

- Understanding irrigation design concepts
- Understanding agricultural demands
- Providing a thorough knowledge of construction practices and standards

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- Creating long-term design functionality
- Reducing stress and increasing the productivity of District personnel
- Coordinating construction activities with water deliveries
- Verifying constructed facilities perform as designed, reducing maintenance

Construction managers represent the District in the field by:

- Reviewing development plans for adherence to current construction standards and practices and construction schedules for coordination with water delivery needs;
- Observing construction for proper installation;
- Clarifying installers understanding of plans and specifications;
- Coordinating interruptions in service;
- Tracking multiple construction projects;
- Explaining agricultural practices to contractor personnel;
- Providing a single point of contact for construction related correspondence.

These “boots on the ground” create a local presence with a focus on the specific needs unique to an irrigation district. They provide the District with the required functionality and quality while minimizing the impact to its customers and growers.

This paper will discuss the strain of urbanization on an irrigation district and the benefits of consulting an engineering firm to manage construction projects. The benefits include expertise, technical resources, design capability, coordination and inspection. Construction engineers can help protect an irrigation district from being overwhelmed by rapid urbanization.

INTRODUCTION AND BACKGROUND

The cash crop produced in the Buckeye Water Conservation and Drainage District has been cotton and several cotton gins are located in the Buckeye Valley. Other staples include alfalfa and wheat, with a considerable increase in corn thanks to the demand for ethanol. Although a number of privately owned irrigation wells are scattered throughout the BWCDD service area most of the farms rely on irrigation water supplied by BWCDD as their primary source. BWCDD water is comprised of water collected from the Gila River, treated effluent and groundwater.

BWCDD System. BWCDD operates two major canals, the Main Canal and the South Extension Canal. The Main Canal runs from its origin at the Gila River in Avondale, Arizona, to the Hassayampa River in Palo Verde, Arizona. The South Extension Canal

branches off of the Main Canal approximately 5 miles from the origin and roughly follows the north side of the Gila River.

The major canals feed an extensive system of smaller ditch and pipe laterals that deliver irrigation flows to individual farms and housing communities. The laterals generally flow along the north-south roadways. Laterals have a measurement point off the major canals to meter demand down the lateral. Delivery points at most turnouts have additional measurement structures for billing each user.

In addition to these distribution and delivery facilities, BWCDD operates and maintains an extensive system of drainage ditches for the collection of tailwater and excess lateral flows. These drains ultimately discharge to either the Gila River or the neighboring Arlington Canal. Figure 1 show the BWCDD system.

Stakeholders

Development in Buckeye, Arizona, exploded in 2001. As housing developments sprouted up in the middle of last years cotton fields, the municipalities involved generally require the developers to address corresponding off-site improvements such as street widening, sewer and water system expansions, and the establishment of new drainage conveyance systems. As most of the BWCDD laterals are located immediately adjacent to rural two-lane roads, nearly all the development projects undertaken within the BWCDD service area require the relocation of BWCDD irrigation facilities.

To accommodate developers desire to maximize the developable space within their project, and often in response to municipal requirements, most of the BWCDD relocations undertaken since 2001 include piping of the open lateral ditches. The extensive use of pipe within the lateral system has meant a drastic change from tried and true BWCDD operational, management and measurement practices using open-top structures, and broad-crested weirs. In addition, the complexity, and construction tolerances, of the structures used to control, deliver and measure irrigation water within a pipeline system increase substantially in comparison to the open-channel structures historically used throughout the BWCDD service area.

As the pace of urban development within the BWCDD service area spiraled upward, the District's maintenance and repair staff were faced with escalating demands on their limited resources to deal with the shear number of projects involving their facilities, contractors that may or may not be knowledgeable regarding the construction of irrigation facilities, and an array of new irrigation structures with which they were unfamiliar. In addition, the BWCDD staff was suddenly bombarded with issues stemming from poor construction practices including:

- Leaking pipe collars under roadways,
- Structures not capable of being measured

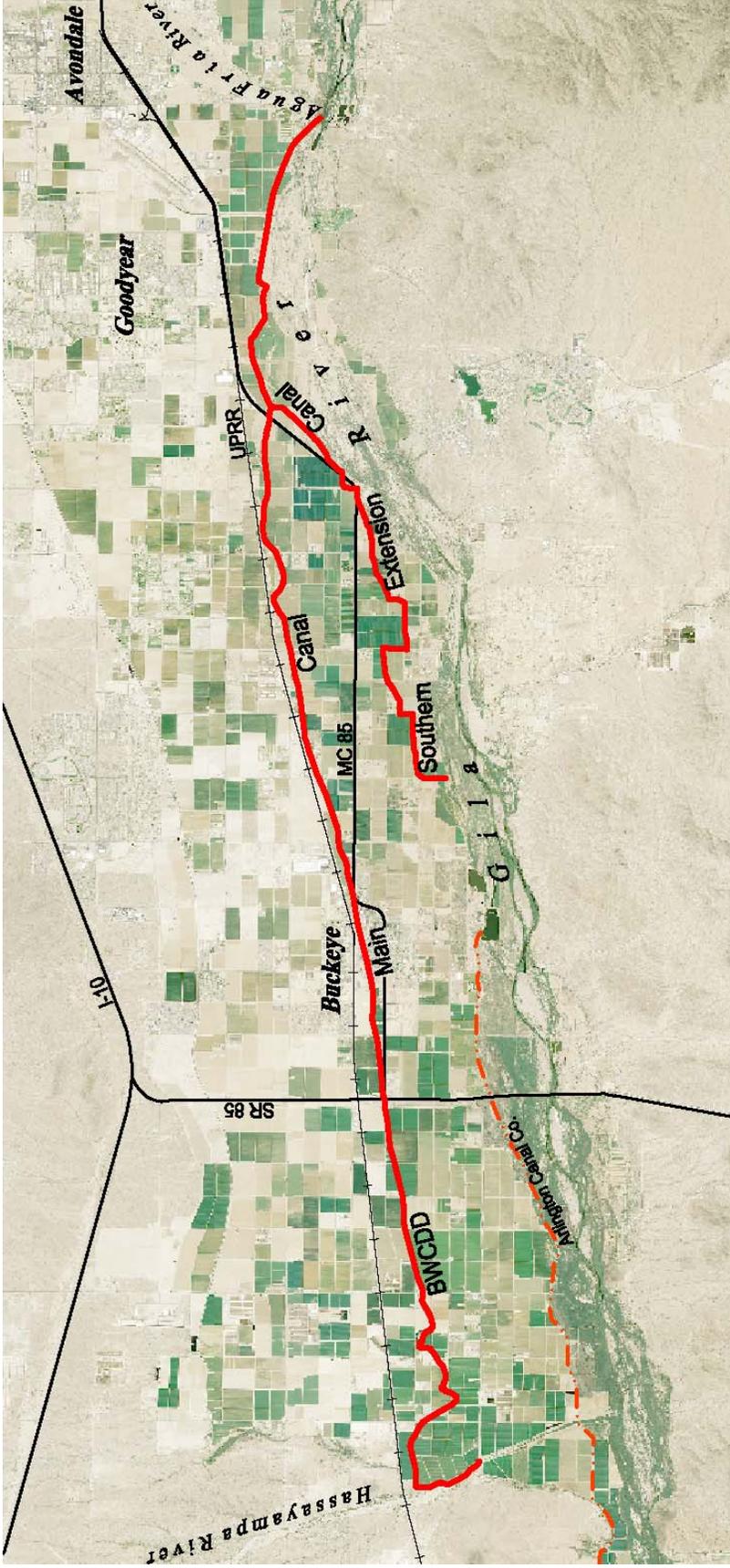


Figure 1. Map of the BWCDD System and Delivery Area

- Pipes that would not withstand traffic loads,
- Reductions of capacity within in the laterals,
- Overtopping/flooding of existing open ditches upstream of a newly piped lateral section.

Increasingly more BWCDD personnel were forced to turn away from their traditional mission to address these new problems. These problems can be handled if only one or two developments are under construction, but when the number of active construction projects increased the District staff found that the details involved became overwhelming.

Problem Statement

The heart of the problems is in the details. Each project has its own set of challenges. Sustaining a functional irrigation district through continued urbanization can become a full-time job. The irrigation district needs a point-of-contact for construction issues to address specific questions and problems as they present on a project-by-project basis. Construction managers can coordinate with the irrigation district, engineers, farmers, developers and contractors to provide status reports and solve construction issues day-to-day.

To help resolve the mounting construction related problems faced by BWCDD staff as a result of the rapid urban development within their service area, the District employed the services of a sub-contracted construction manager.

BENEFITS OF CONSTRUCTION MANAGERS

A sub-contracted construction manager is a common practice among many utility companies and municipalities. Salt River Project, Qwest Communications and the Town of Buckeye have construction managers on staff as well as sub-contractor construction managers on standby. The cost of the managers is commonly passed along to the developer or municipality. Their work is billable to a project, which is invoiced to a developer as part of a review fee, a construction bond or inspection fees. The construction manager protects both the contractor/developer as well as the District.

Some of the benefits recognized by BWCDD with use of a construction manager are;

- Reduced chance of catastrophic events from coordination and monitoring,
- An additional pair of eyes advocating for BWCDD throughout their service area
- No in-house staff adjustments are needed as the housing market or construction activity fluctuates
- Competent field representation to interpret the true meaning of the construction drawings.

- Qualified representation to address field adjustments required due to construction practices and site requirements.
- Construction managers reduce the daily workload to BWCDD by creating a single point of contact and responding to contractor requests, coordinating with municipalities and developers.
- A single point repository for contact information, project status, shop drawings, concrete mix designs and punch lists associated with multiple construction projects.

APPLICATIONS

If construction projects went smoothly and all things are just as they seem there would not be a need for construction managers. However, most projects need some clarification or competently directed field adjustments. Listed below are some examples of BWCDD projects that illustrate the value and service provided by the construction manager to BWCDD, and all the multiple parties involved in a project.

Municipal Infrastructure Improvements

Watson Construction Facilities District. The Town of Buckeye has seen a population explosion over the last six years. The influx has taxed the existing infrastructure and required some immediate improvements. One improvement is the Town's sewer system and the construction of a wastewater treatment plant. Connections were made to the plant from all over the south side of Buckeye before the plant ever went operational. The Watson Construction Facilities District (CFD) was one of these connections.

The CFD project is intended to service several proposed development projects and crisscrosses the BWCDD irrigation system at multiple points. The CFD project included a crossing of the Main Canal and several laterals; Lateral 13 was even crossed twice.

One of the crossings on Lateral 13, a portion of the existing lateral pipeline was supported in-place as the sewer line was installed below, then backfilled without apparent incident. However, as the lateral was brought back into operation a section of pipe sprouted a geyser just south of the Main Canal, see Figure 2.



Figure 2. Broken Pipe Section

At this location the contractor had set up a staging area on one side of the lateral opposite of the roadway. As a result all equipment and supplies crossed over this section of the lateral. After excavation of the leaking pipe it was discovered that the pipe was constructed out of un-reinforced concrete in the older 2-foot sections. Such pipe was never intended to withstand today's construction loads.

The leaks were isolated and the damaged pipe was removed until connections could be made to an unbroken section. Once this section was repaired and orders were made water was put back into the pipe and another section of pipeline a mile south began to soak the ground.

At this second location it was determined that one section of pipe had settled and pulled out of joint where the sewer line crossed under the pipe. The joint was grouted from the inside and a collar was poured around the joint.

About a week later an irrigation delivery was made to a farm along the CFD alignment. The connection pipe from Lateral 9 to the farmer's ditch saturated the soils along the entire length of the connection. It was subsequently determined that the contractor had used a small area adjacent to the connection to store materials and that loaders and excavators working in this area had broken several sections of pipe. The contractor was once again required to replace/repair the damaged sections of pipeline to the satisfaction of the construction manager.

Each time a new problem was found BWCDD called upon their construction manager to deal with the situation on behalf of the District. The manager in turn contacted the contractor to repair each section and monitored the repairs for future operation of the lateral.

Southeast Buckeye Interceptor Sewer (SEBIS). A future project of a similar nature is slated to begin construction this summer. The SEBIS project will connect a number of proposed developments to the Buckeye treatment plant. The SEBIS project has many more conflicts with the BWCDD laterals and crosses under the Main Canal. The BWCDD construction manager has actively participated in multiple design-phase reviews of the SEBIS construction plans on behalf of BWCDD.

Each crossing of the BWCDD facilities with this project will be unique and the means of construction is highly dependent on the soil conditions, quality of the nearby irrigation facility and the construction techniques used. It was decided to leave the treatment of each crossing up to the discretion of the construction manager. Some of the crossings will be under old and possibly corroded sections of BWCDD pipe and that will need to be replaced. Other sections of the SEBIS alignment are parallel to BWCDD laterals and may require that a temporary by-pass be constructed, depending on the size of the trench and soil conditions. These decisions can only be made in the field.

Maricopa County 85 Extension. With this project Maricopa County is extending highway 85 an additional mile to Turner Road on the west side of Buckeye. The proposed alignment approximately parallels the BWCDD Main Canal and crosses four laterals. The scope of the project also impacts multiple private irrigation facilities on the adjacent farms. An engineering consultant under contract with Maricopa County completed the design of private irrigation facilities. The design of the BWCDD facility relocations was handled by the District's own engineering consultant

Since a substantial portion of the construction work on the irrigation facilities would have to be done during the annual BWCDD dry-up, the drawings were split into two separate phases. The first phase detailed work that was to be completed during the dry-up. Phase two plans detailed the remaining construction items. At first the resulting four sets of plans; two BWCDD sets, and two private irrigation sets were confusing to the field personnel. The BWCDD construction manager coordinated with the county's construction administrator to discuss coordination between the four sets of plans. Figure 3 shows a BWCDD headwall connecting to a private delivery ditch and gate.



Figure 3. BWCDD Structures and Private Ditch and Gate

The annual dry-up is typically during November and lasts two weeks on the Main Canal and two weeks on the South Extension Canal. Every year the dry-up is a great deal of work for both BWCDD staff and for the construction manager.

Projects such as these can become a time consuming process for an irrigation district. Most municipal improvement projects require coordination with municipalities, utility companies, inspectors and design engineers. Ultimately final acceptance is dependent on the successful operation of the relocated BWCDD facilities. Beware of the utility plans that claim to have no conflicts with existing facilities.

Residential Development Projects

255th Avenue Project. For this project three individual developers combined forces to build an improved municipal roadway along a ½ mile section of the 255th Avenue alignment for access to their developments. Prior to development, 255th Avenue existed only as a dirt maintenance road for BWCDD Lateral 23. The Lateral 23 relocations completed for these developments represent a “typical” relocation project, and included piping of a half-mile of ditch and a new delivery structure. The parties involved in the project included,

- Three development companies,

- Developer's construction manager,
- Town of Buckeye,
- Maricopa County,
- Pipe Contractor,
- Concrete Contractor,
- Southwest Gas,
- Qwest Communications and
- Two individual growers farming adjacent to the developed properties.

The developers' hired their own construction manager to oversee the contract and verify that the work was progressing. The Town of Buckeye and Maricopa County was involved in the roadway crossings within their respective rights-of-way. Southwest Gas and Qwest both had to install dips to avoid conflict with the proposed BWCDD pipe. The construction manager monitored the project on behalf of BWCDD and regular progress reports were provided to BWCDD for their review. Approximately one year after the completion the BWCDD relocations, requests were made for the District to mark their pipes for nearby roadway construction. A quick phone call to the construction manager provided BWCDD with a set of as-built construction plans and an eyewitness report of the installation.

A residential development project near 255th Avenue went on hold and all construction associated with the project was abruptly halted. This included the partial construction of a BWCDD lateral. Half of the structures are built and the majority of the pipe is installed. Figures 4 and 5 show the abandoned construction.



Figure 4. Abandoned pipe waiting to be installed.



Figure 5. Abandoned structures waiting for a connection to the lateral

While this project remains on hold, the lateral has been urbanized downstream. The BWCDD construction manager directed field adjustments to the downstream construction, as a connection could not be made to the abandoned construction. The construction manager has continued to maintain contact with the builders, and has provided BWCDD with status reports of ownership changes and future construction.

CONCLUSION

Everyone benefits when irrigation districts have construction manager's boots on the ground. The irrigation district wins as they have an additional shield against the risks of urbanization. Contractors' benefit from the quick resolution to real-time problems. Developers know that BWCDD will accept the work since the manager has observed the installation.

The level of trust developed over the years between the construction manager and BWCDD also improves the benefits of construction management service. BWCDD has confidence that they have an advocate for their interests and do not have to carry the load of liability, staffing, and administration. Should questions arise a quick call can clarify or provide resolution.

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AUTOMATION OF SURFACE IRRIGATION BY CUT-OFF TIME OR CUT-OFF DISTANCE CONTROL

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ABSTRACT

An automated surface irrigation system is described that demonstrates control by either cut-off time or cut-off distance using off-the-shelf commercial products. The cut-off time control uses a standard commercial sprinkler controller to operate the gates. The cut-off distance system uses commercial radio transmitters and transceiver-relays commonly used to operate security systems or industrial processes. These systems were each installed in four irrigation basins in a 7-ha surface irrigation research facility. Over 15 irrigation events have been performed satisfactorily with minimal maintenance. While the immediate impetus for automation is likely to be the growing labor shortage, it is anticipated that water conservation benefits will be realized as well. Future research and development needs include logic control based upon variations in flow rate and soil intake rate.

INTRODUCTION

Even with rapidly increasing urbanization, agriculture is still by far the major water user in the lower Colorado River region (LCRR) accounting for 80% of the total water consumption (Arizona Department of Water Resources, 1981). Within the agricultural sector, about 95% of the area utilizes surface irrigation systems. Because of water costs, leaching requirement for salinity management, and complicated crop rotations, surface irrigation will continue to be the predominant method of irrigation in the LCRR into the foreseeable future.

Research and demonstration projects in the LCRR have shown that surface irrigation systems can be efficiently managed using volume balanced based methods for the determination of irrigation cut-off time or distance (Bali et al., 2002; Sanchez et al., 2007). Application of these methods could produce substantial water and labor savings while maintaining agricultural productivity. But adoption of these proposed efficient methods of surface irrigation management is constrained due to more intensive and skilled labor requirements and more frequent and inconvenient times at which irrigation gates must be operated. Surface irrigation is not automated like trickle and sprinkler irrigation, the presence of an irrigator is currently required, and human error and negligence are factors contributing to over irrigation.

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Considerable research on automation of surface irrigation systems has been conducted in past years. (Dedrick, 1984; Erie and Dedrick, 1978; Humpherys and Fisher, 1995). Most of this research was conducted more than fifteen years ago. Since that time, new and inexpensive products have become more widely available which can be used to automate surface irrigation systems, such as electronic timers and spread-spectrum radios. In fact, the inflation-adjusted cost of an automated system may be less (Dedrick, 1989). At the same time economic pressures have made automation more feasible, including the availability and cost of irrigation labor due to increasing economic opportunities for laborers in other sectors of the economy and more effective enforcement of immigration laws. The objective of this evaluation is to engineer and demonstrate automated systems for distance and time based cutoffs using simple off-the-shelf commercial products. Both methods have utility in the LCRR depending upon the consistency of water delivery to the farm and the soil characteristics.

MATERIALS AND METHODS

Field Description

A 7-ha of a surface irrigation system designed for previous experiments (Sanchez et al., 2007) was automated to demonstrate both distance and time based irrigation cut-off. This irrigation system uses large field turnout structures to deliver water to the borders through jack gates (gates that utilize a jack mechanism in contrast to a screw mechanism). Flow rates up to 0.6 m³/s can be delivered. The location of this demonstration project is the University of Arizona, Yuma Agricultural Center-Mesa farm (32° 36.69N 114° 37.70W). The soils are Superstition sand (sandy, mixed, hyperthermic Typic calciorthid) and the crop is mature lemons (*Citrus Limon*, Limoneira 8A Lisbon” on “Volkamariana). Four basins for each distance and time based cut-off irrigation were automated in June of 2007 and remain in use. A layout of the system is shown in Figure 1.

This field is irrigated with the downstream border (1) first and proceeding upstream in the order of the turnout number. The ditch check is operated by the sprinkler controller. After borders 1 through 4 are irrigated by cut-off time, the ditch check closes automatically and transmits a signal to turnout number 5 to open. When the water advance reaches transmitter number 5, turnout number 5 closes and turnout number 6 opens, and so on, until turnouts 5 through 8 are irrigated by cut-off distance. Turnout number 8 remains open until the operator arrives to shut off the delivery flow.

Design of the System

The system was designed to use off-the shelf commercial components and to be adaptable to any location and without a customized engineering design. For that reason, each turnout has an independent battery and solar panel. It was thought that this would be more economical since the cost of copper wire has risen sharply in recent years. It should be noted that the turnout structures are more closely spaced and the basin size is smaller than normal in the LCRR. Turnout structures are normally from 67-m to 200-m apart, and a level basin or low-gradient graded border system will normally have two turnout

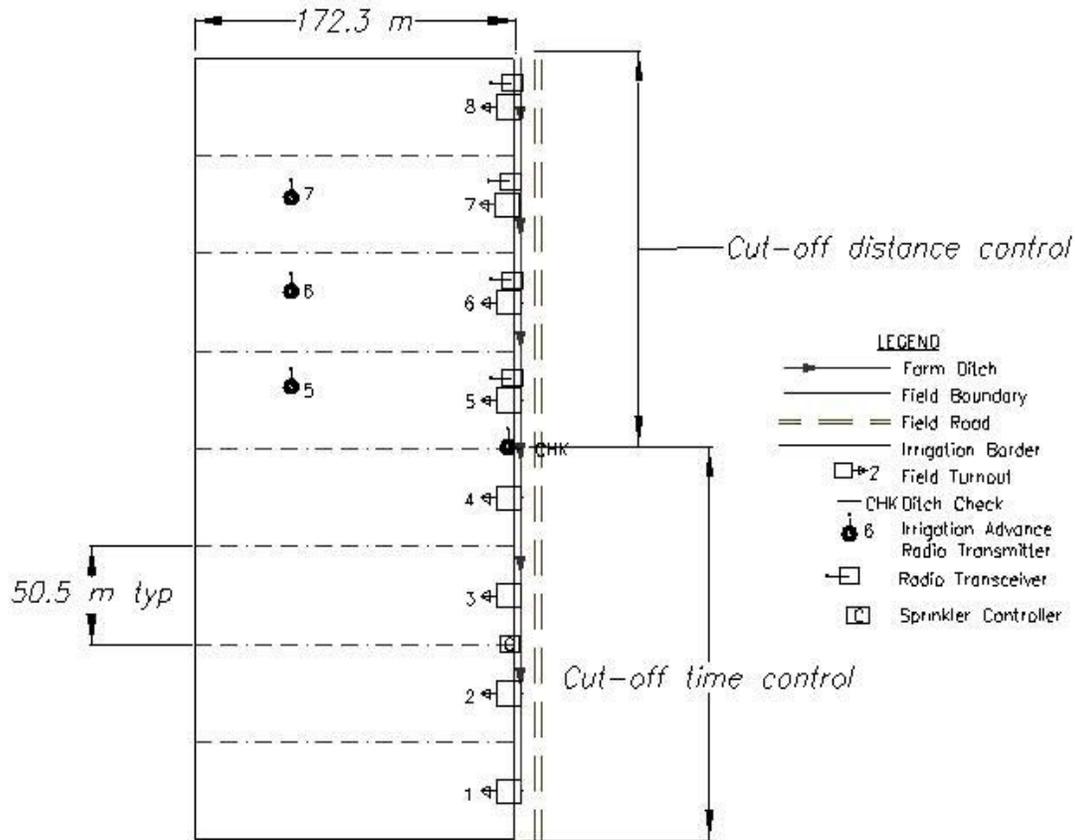


Figure 1. Layout of the system

structures opposite each other at the same location along the ditch. In practice the battery and solar panel could be used to power both turnouts, which would lower the unit cost per turnout.

The cut-off time control portion of the system uses an off-the-shelf sprinkler controller to operate the gates through standard commercial sprinkler valve control cable using 24 VAC power. The 24 VAC, normally used to operate a solenoid valve on a sprinkler system, in this case trips a relay to operate the 12 VDC actuators. A commercial-grade controller was used for this system in order to have the capability of remote, radio control in the future, but for this purpose a standard household controller would have been adequate.

The cut-off distance portion of the system uses commercial radio transmitters and transceiver-relays commonly used to operate security systems or industrial processes. For this project 2.4 GHz Spread-Spectrum radios were used due to their reliability and cost. The product that was selected was BWI Eagle model SR transmitter and transceiver. Radio transmitters were mounted on 3.2-cm diameter PVC pipe. At the base of each pipe

is a perforated section that encloses a magnetic float switch. The transmitter pole is held upright by a steel brace that can be placed by stepping on the brace with foot pressure. In this way, the transmitters can be easily moved or moved out of the way to perform tillage operations. Each transmitter is programmed with a specific frequency. There are 128 selectable digital addresses and 8 selectable frequencies with this model of radio. The range is 366 m, but the range can be doubled with some modification. When the advancing front of water reaches the float switch, the radio transmits a signal to the transceiver at the turnout gate to switch a relay and shut the gate. At the same time a signal is transmitted to the next gate in line to open.



Figure 2. Cut-off distance radio transmitter in field and transceiver at turnout

Actuators

At each jack gate, the jacking mechanism was left intact for emergency use, but disconnected by removing the bolt on the drive. The drive and the clutch were held in place with stainless steel tie wire to prevent them from catching on the jack stem during automatic operation. A 12-Volt DC actuator with a 76-cm stroke was mounted to the jack stem gate with a clamp that can be disconnected from the jack stem with a wrench during an emergency.

The jack gates are 1.16-m wide. It was determined that 113-kg force was the minimum needed for gate operation, but for safety factor a 181-kg actuator was selected. Maintenance of the gates and seals is very important in determining the amount of force that is needed. Old seals should be replaced and existing seals should be lubricated. For flow rate capacity a 0.61-m stroke would have been adequate, but a 0.76-m stroke was

selected due to the small difference in cost. These actuators operate at a speed of 1.0 cm/s at 5 amps at full load, and 1.3 cm/s at no load.



Figure 3. Actuator on Ditch Check Gate with Field Turnouts in Background

Emergency Overflow Protection

Turnout numbers 1 and 5 were wired for emergency overflow protection. A circuit similar to a tank emptying circuit was used. This is not completely secure protection against a failure of the system and consequent overflow because it depends upon a functioning power supply and actuators at turnout 1 or 5. An overflow structure in the ditch would be a preferred alternative for overflow protection. It was thought that electrical switch protection may be a second-choice alternative since it is relatively cheap and simple to adapt to an existing irrigation system. Testing showed the emergency overflow to be sufficiently reliable.

RESULTS AND DISCUSSION

During the past five months of operation, the system has performed well over 15 irrigation events with minimal maintenance. Selected cutoff times and cutoff distances were selected to optimize application efficiency based on models developed in previous research (Sanchez et al., 2007). Cut-off time control would be applicable in a situation where the grower has a dependably uniform flow rate, for example, at the upstream end of a large canal system where the canal water level is kept under close control, or a pump well for a water supply. However, cut-off time control cannot always be reliably used due to variability in flow rate that is experienced in many locations (Palmer et al., 1989).

If the flow rate of delivery could be automated to provide a uniform flow, then a cut-off time system would be more universally applicable. Cut-off distance control would likely be more reliable at the lower end of a canal delivery system or anywhere the flow rate is not dependably uniform. Both the cut off time and cut off distance systems performed adequately in our evaluations because canal delivery is relatively uniform at the location of our turnout from the main canal..

Costs of materials and labor for installation are presented (Table 1). The cut-off distance control system installation costs are about twice the cost of the cut-off time control system costs. Currently, experienced irrigators in the LCRR earn 8 to 9 dollars on hour and it takes approximately 25 to 60 minutes to irrigate a basin or border, depending on inlet flow rate, friction and bed slope, and border width and length. However, a trained irrigator could concurrently operate multiple systems in close proximity where the limitation would likely be the capacity of the district canal system in delivering water to multiple locations in close proximity. Or the irrigator could perform other farm operations concurrently with irrigation. Although these savings in labor costs would partially off-set initial capital costs, it would take more than 20 irrigations to recover the lowest installation costs presented (Table 1). Nevertheless, hiring agricultural labor is increasing difficult in LCRR, and in the short run the unavailability of labor will likely be the major impetus for such automation. The consistent application of cut off time or distance criteria will also result in water savings (Sanchez et al., 2007) but the cost of water is currently so low in irrigation districts of the LCRR (<0.4 dollars per ha/cm), these cost savings would not emerge as an important consideration in the region. However, due to a prolonged drought in the Colorado River basin, irrigation districts in the LCRR are beginning to limit total annual deliveries on an area basis and water conservation will be required to continue with the year-round cropping systems currently practiced in the region. In regions outside the LCRR, where water costs are significantly higher, reduced expenditures for water might more quickly off set the high costs of installation.

Cut-off distance control appears to be more expensive than cut-off time control and it has the additional inconvenience of having to move the transmitters whenever field machinery operations are performed. There are three ways to address or evade the additional cost and inconvenience of the cut-off distance control system: (1) Find cheaper yet robust methods of signaling the turnouts when the desired advance has been achieved; (2) Develop a system using programmable logic control that utilizes the flow rate of delivery as an input, and vary the set time to respond to variations in the flow rate; (3) Combine time control with flow rate control of the district delivery gate.

Cracking clay soils present additional needs in the development of a useable automation system. Cracking clay soils constitute a significant portion of the LCRR. A volume-balance method based on advance rate is used with these soils to determine cut-off time (Bali et al., 2001). This method requires a measurement of the advance rate on the first set that is irrigated in a soil type in order to determine the volume to apply to each set or border on the remaining borders that have the same soil type. An automation system for cracking clay soils would need one or more measurements of advance rate per irrigation

system depending on the number of soil types, and a measurement of flow rate of delivery. Other important subjects of concern in future research are cost, robustness in the elements, protection or at least discouragement against vandalism and theft, and adaptation to other types of field turnouts, in particular, pipe or “port” turnouts

Table 1. Materials and installation costs for cutoff distance and time automation.

Cost per Turnout	Cut-Off Time Control		Cut-off Distance Control:	
	One Turnout per Enclosure	Two Turnouts per Enclosure	One Turnout per Enclosure	Two Turnouts per Enclosure
Actuator	\$129	\$129	\$129	\$129
Actuator Mount	\$50	\$50	\$50	\$50
Battery	\$50	\$30	\$50	\$30
Solar Panel	\$35	\$25	\$35	\$25
Regulator	\$24	\$12	\$24	\$12
Enclosure	\$70	\$35	\$70	\$35
Radio Transceiver			\$350	\$350
Radio Transmitter			\$300	\$300
Relay	\$24	\$24		
1-mm/9wire cable (based on 120-m spacing)	\$24	\$12		
Pro-rated Trencher Rental	\$50	\$25		
Electrical Conduit and Fittings	\$20	\$20	\$40	\$40
Pro-rated Cost of Controller	\$50	\$50		
Labor for installation	\$90	\$45	\$90	\$45
Miscellaneous	\$40	\$40	\$40	\$40
Total per turnout	\$656	\$497	\$1,178	\$1,056

SUMMARY

An automated surface irrigation system was installed and operated on the University of Arizona, Yuma Agricultural Center-Mesa Farm. Automation of irrigation based on cut-off time and cut-off distance was demonstrated using off-the-shelf components. The system proved reliable over 15 irrigation events. This project should provide the basis for research into more effective and robust automation systems using programmable logic control. Automation of surface irrigation systems could provide a partial solution to growing labor shortages in the LCRR and likely result in water conservation by reducing the human error component of over-irrigation. This system could ultimately have application to surface irrigation systems across the southwestern United States.

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DISPELLING MYTHS ASSOCIATED WITH SPREAD SPECTRUM RADIO TECHNOLOGY IN THE IRRIGATION INDUSTRY

Dan Paladino¹

ABSTRACT

Each year, the irrigation and drainage industry deploys an increasing number of Spread Spectrum communication solutions. As recently as five years ago, the use of wireless telemetry in irrigation and drainage SCADA systems was almost exclusively in the licensed radio realm. However, the scarcity of available licensed channels as well as its improved technology has made the Spread Spectrum radio an increasingly popular choice. With the install base of Spread Spectrum devices rapidly increasing, there have been a number of urban legends, superstitions and myths that have circulated. With the introduction and advancement of any new technology, misconceptions and misunderstandings will always surface. Spread Spectrum, like any technology, can be an extremely valuable tool when used in the correct environment and with correct network deployment. The objective of this presentation is to explore these “myths” and provide a better understanding of how to use Spread Spectrum technology in irrigation and drainage applications and also show where you can expect to succeed with Spread Spectrum communication solutions.

INTRODUCTION

Every year the irrigation industry deploys more Spread Spectrum communication solutions. As recently as five years ago, the telemetry of irrigation data was almost exclusively in the licensed radio realm. However, the scarcity of available licensed channels as well as its improved technology has made the Spread Spectrum radio an increasingly popular choice. With the install base of Spread Spectrum devices rapidly increasing, there have been a number of “Urban Legends” or “Superstitions & Myths” that have circulated. Among the more prevalent of these are the following:

Myth	Summary
Security	Spread Spectrum is not secure; someone can steal your data
Saturation	Spread Spectrum radios will shut down when there are too many radios on the same frequency.
Range	Spread Spectrum radios are only one watt and won't perform as well as licensed radios.
Compatibility	If you have licensed radios you have to buy only licensed radios for expansion.
Interference	If you mix licensed radios and Spread Spectrum radios or different brands of Spread Spectrum in the same system they will cause interference and data will be lost
Obstructions	You must have clear line of sight, or Spread Spectrum will not communicate.

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With the introduction and advancement of any new technology, misconceptions and misunderstandings will always surface. Spread Spectrum, like any technology, can be an extremely valuable tool when used in the correct environment and with correct deployment. The objective of this paper is to explore these “myths” and provide a better understanding of how to use Spread Spectrum technology and also show where you can expect to succeed with Spread Spectrum communication solutions.

Security

Spread Spectrum was originally designed for security purposes. It was invented for the US Navy during World War II to prevent the Germans from “jamming” American radio transmissions for radio guided torpedoes. The technology was invented by Hedy Lamar, a famous movie star of the 1940’s. The original radios contained a roll of paper slotted like a player piano to cause channel switching. Lamar’s close friend Inventor/Musician George Antheil designed the first successful synchronization device that brought Lamar’s idea to fruition. In 1941 Lamar and Antheil were granted a U. S. patent for the first “Secret Communications System.” This original system used merely 88 frequencies. Today, the switching is controlled in embedded software code that enables a radio to change frequencies in excess of 200 times per second and use more than 100 channels.

The technology behind spread spectrum radio is complex enough that anyone trying to intercept a signal would have to match more than 186,000 possible parameters to be on the same channel with the radio and then would only be in sync for about 1/100th or possibly 1/200th of a second. In addition to matching parameters, the entity attempting to intercept data would find that today’s Spread Spectrum radios also utilize advanced encryption protocol to insure additional security.

Saturation

The common fear in Spread Spectrum is that as more and more companies go to this “shared” frequency, it will become saturated and unusable. However, if there is a saturation point, it has not yet been reached. In many areas of the country, thousands of Spread Spectrum radios are delivering data to multiple end-users without conflict or data loss. Examples of these networks can be found in various regions around the country and in other industries. In Wisconsin, a major generation and transmission utility is using more than 100 radios in the field with another 300 radios to be deployed over the next year. The end-users’ offices and their base stations are in a proximity where repeater towers can be shared by multiple networks, as appropriate. If there were any potential for “saturation,” it would happen at these repeater sites where the wireless traffic is at its highest, and the antennas are installed very near to one another.

Over the past several years, considerable research and development has gone into developing Spread Spectrum radios that can work in close proximity to one other and share the same frequency bands. To accomplish this goal, radio networks are programmed to share common bands, but use separate frequencies. Each radio network is programmed to “hop” to a different frequency than the other radio networks in the area.

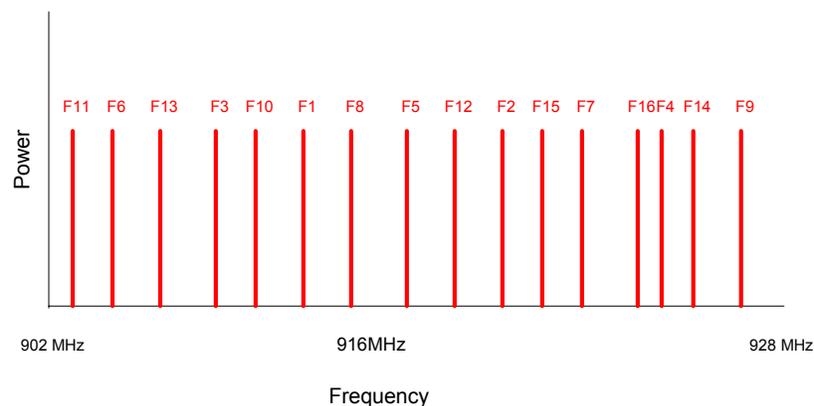
This hopping allows users to build distinct communication networks that will not conflict with other networks in the immediate area.

An analogy to this is your car radio in which there are multiple channels available, but you only hear the channel you are actually tuned to. When you change channels, you no longer hear the old channel, only the channel you just switched to. The same is true of Spread Spectrum networks: multiple users can share the Spread Spectrum band as long as they are all set up to use different frequencies at different times.

FREEWAVE TECHNOLOGIES



How Frequency Hopping Works



SPREAD SPECTRUM RADIOS

COMMUNICATION WITHOUT BARRIERS

In the previous Wisconsin example, there are many other organizations in various industries using Spread Spectrum radios. The combined total of radios is growing each day as these companies continue to add more radios to expand their communication networks. It is highly unlikely that this or any other area will achieve “saturation” so long as the networks are managed and deployed properly.

Range

Another common myth associated with Spread Spectrum is that it is good only for short-range communication. To the contrary, Spread Spectrum can be deployed as a complete (long-range and short-range) communication network solution. This technology is a result of the lower maximum output power of a Spread Spectrum radio. By federal regulation, a Spread Spectrum radio can only have an output of 1 Watt of radiated power at the radio and 4 Watts at the antenna. Licensed radios, by contrast, can have higher output power, typically 5 Watts at the radio and 20 Watts at the antenna. In a contest of

which radio will broadcast the furthest in a straight line, the licensed radio will clearly win the distance contest, however it is extremely rare to have a line of sight range exceed 20 miles. Typically, an obstruction such as a building, valley, hill, or vegetation will interrupt a signal in longer-range applications. Spread Spectrum radios can easily establish links of 20 miles and they have even been able to link at distances greater than 60 miles. Spread Spectrum radios have been used in relay protection schemes and for utility SCADA applications where data must be passed accurately over many miles of obstructions. At great distances, the curve of the earth becomes one of the major obstacles to overcome. In order to establish a 30-mile link in an application, the end user will have to have radio antennas mounted at least 100 feet above the ground to compensate for the curve of the earth.

Mountains often create the opposite challenge. In mountainous regions, Spread Spectrum radios have been used to establish radio communication at distances of 60 miles. This link is from a mountain top at a 9500 feet elevation down to a valley floor where the elevation was 5000 feet.

Another factor influencing complete long-range communication is repeaters. With a licensed radio system, there is only one repeater in a network. All slave sites must communicate to either the Master unit directly or through a maximum of one repeater. However, with Spread Spectrum technology, it is possible to have multiple repeaters. These repeaters can either be arranged in series (serial repeater) to extend the range or in parallel to improve coverage around obstacles such as hills, buildings, or vegetation. It is also possible to mix repeaters in parallel and series to provide the benefit of all capabilities in large systems. Some manufacturers produce products where the use of repeaters is unlimited, meaning there are no limits to the number of repeaters you can have in a single network. Some complex networks actually use more than 100 repeaters in a single network.

Another Spread Spectrum feature offered by a limited number of manufacturers is the ability to have the radio to operate as a slave and repeater simultaneously. This feature provides both a network extended capability and a cost reducing tool. The slave/repeater function eliminates the need for multiple dedicated repeaters while also reducing installation costs. The “magic” here is that any PLC (programmable Logic Controller), RTU (Remote Terminal Unit), or other intelligent devices can multitask as both a slave unit, sending data back to the host and as a repeater for other devices further down the network hierarchy. Spread Spectrum radio systems can track and control Utility SCADA systems and/or delivery systems for hundreds of miles using a wireless “daisy chain” to bring data through a series of repeaters back to the host in a distant location. Spread Spectrum can also move data in a “micro-network” that is set up to work around a mountain or any other obstruction and ultimately deliver data to a host that is not within line of site.

Compatibility

Many people believe that if they install a base of licensed radios, they must use the same manufacturer and model of radio they originally purchased. However, it is possible to mix Spread Spectrum radios into an existing licensed radio system enabling features such as multiple repeater functionality and reduced deployment costs. This network can be accomplished by placing a new repeater in the existing system. You simply need to take an existing slave site and put a Spread Spectrum (Master) radio back-to-back with the licensed slave and join the two radios together by using a ‘Null Modem’ cable between their respective RS-232 ports.

When the licensed master transmits to the licensed slave, the request is passed through the licensed slave’s RS 232 port to the Spread Spectrum radio’s RS 232 port. The Spread Spectrum Master will then retransmit the message to the Spread Spectrum “network extension” down stream from the Spread Spectrum master. This “Hybrid” system offers many advantages over any single system network.

It is also possible to create hybrid systems by combining CDPD (Cellular Digital Packetize Data), Satellite, Cell Phones, and landline telephone modems individually with Spread Spectrum. The beauty of these systems is that the end user can use a communication device, such as a landline, to cover a long distance of 100 miles and then “mate” to a Spread Spectrum network to gather data over a wide area network (WAN). This configuration would allow an end-user to gather data from 100 devices through a single telephone connection. Since landline telephones, cell phones, and satellite communication come with monthly charges, it is much more cost effective to spread these cost over multiple devices in the field. Combining these technologies will produce the most efficient and cost effective solution.

Interference

Another common misconception is that Spread Spectrum and other radio communications will interfere with each other. The most common Spread Spectrum band in the United States is 902 Megahertz to 928 Megahertz. This frequency band is set aside by the federal government to be allocated for Spread Spectrum devices and the rules are structured to allow the band to be shared by multiple users. The official designation for this band is ISM, which implies this was established for Industrial, Scientific, and Medical usage.

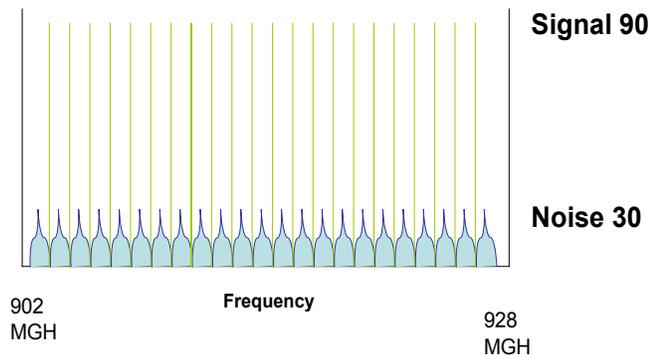
The Licensed radios utilize frequencies outside of this band. No licenses are granted for any frequencies inside the ISM band. Consequentially, there will be no overlap between licensed systems and Spread Spectrum systems. These two technologies will always broadcast on separate frequencies and thus cohabitate without negative results.

The closest frequencies to the ISM bands 902 Megahertz to 928 Megahertz range are cell phones and microwave signals. If the power of one of these two communication devices is high enough and the device is not precisely tuned to its licensed frequency, it is

possible for the signal to “bleed over” into the ISM band. The cure for this occurrence is an inexpensive Band Pass Filter. This filter will block any noise or interference that is outside the 902 MHz to 928 MHz range.

Signal to Noise Ratio

$$\begin{aligned} \text{Signal} - \text{Noise} \\ = \\ \text{Margin} / \text{Delta} \\ \text{Signal } 90 \\ - \text{Noise } 30 \\ = \text{Delta } 60 \end{aligned}$$



Obstructions

Many times you might hear that radios must have clear “Line of Sight” (LOS). It is also a common myth that Spread Spectrum radios are more restricted by line of sight than other communications devices. However, while line of sight is always preferred, Spread Spectrum radios will indeed pass data through obstacles such as buildings, trees, and in many cases over hills. What happens to a radio signal in these environments is that the obstacles introduce “attenuation” into the signal path. Attenuation is a resistance that reduces the strength of the signal. Attenuation occurs over a distance: the greater the distance the greater the attenuation. Attenuation also increases with the presence of tree branches and foliage. A radio may transmit for 20 miles with clear line of sight, but it may not be able to do so if the 20 mile path is through a dense forest. The signal loss over the distance combined with the signal loss or attenuation of the forest would be too great. While the radio can often transmit through one or the other obstacles, the combination of the two may be too great to overcome.

Buildings offer a challenge similar to that of a forest. Radio signals will often transmit through buildings, but not through both a building and then a distance of 20 miles. There are many applications where Spread Spectrum radios are used to gather data from multiple floors in a building and bring it to a central collection point in the basement or lowest level. The signal is weakened with each concrete floor that is penetrated. After some finite number of floors, the signal will become so weak that it will not penetrate any

more floors. Even in this case, the radio may sometimes find a path (elevator shafts) that allows the signal to continue. This illustrates an example in which there is no clear “Line of Sight” for the transmitted signal, yet the signal still reaches its destination. A radio will communicate through multiple floors depending on the environment and the antennas being used; the limitation may be 5 floors, 6 floors, or even more than 10 floors. The common term for this degradation of signal is “Path Loss” or “Signal Fade.” In outdoor field applications, this point can be computed by the use of software programs. The common mistake many end-users make is not preparing a ‘Path Study’ prior to starting installation. This is the quintessential case of “an ounce of prevention being worth a pound of cure.”

Performing a “path study” prior to starting a project will create a network design that allows you to work around any obstacle and insure a solid robust communication system, regardless of “line of sight” in the area.

CONCLUSION

Spread Spectrum is a relatively new technology for data communication. As with any new technology, there are many misconceptions about the best way to utilize its features. In the case of Spread Spectrum radios, there are still many people who are quick to tell the myths, yet have never actually used the product. In practical application, Spread Spectrum can be used in almost any data acquisition system that would work with licensed radios. Spread Spectrum systems are designed to perform and be trusted, but they are dramatically different from licensed systems.

Remember that the use of multiple repeaters and slave/repeaters allows for long-range, flexible, and secure networks. When you add the option of “Hybrid” communication to the mix, you now have the opportunity to match the “best fit” technologies for your data network.

In building a communication system, its effectiveness will increase with the more tools you have at your disposal. Spread Spectrum radios enable both a reduced communication cost while also increasing both the reliability and throughput of any system.

It was only a few years ago that radio systems used Bell 202 modems and a 1200-baud throughput was commonplace. Spread Spectrum radios are capable of delivering data at speeds up to 115 K-baud. Speed and error-free results (accomplished by utilizing CRC up to 32-bit) provide a viable communication option for applications never before thought to be within the realm of wireless communication.

The natural evolution of data communications has brought us to understand the benefits of Spread Spectrum radios and the power of their versatility. Spread Spectrum’s ability to be coupled with other communication mediums adds yet another layer of versatility never before imagined.

It is reasonable to foresee the day when Spread Spectrum radios and their closest relative, the Ethernet radio, will be the dominant communication device in data collection for the irrigation industry.

YIELD RESPONSE TO WATER IN IRRIGATED NEW MEXICO PECAN PRODUCTION: MEASUREMENTS & POLICY IMPLICATIONS

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A.S. Bawazir³
M. Bleiweiss⁴

ABSTRACT

Pecans are a major agricultural crop in New Mexico. Currently there are approximately 11,000 hectares of pecans in the Elephant Butte Irrigation District, consuming more than one third of the annual diversion. The research presented here provides previously unavailable broad-scale estimates of pecan ET and pecan yield response to water. The data at the foundation of this paper were generated using the Regional ET Estimation Model (REEM) developed at New Mexico State University for agricultural and riparian vegetation (Samani et al. 2005, 2006, 2007). REEM uses remotely sensed satellite data to calculate ET as a residual of the energy balance. This research extends the results of REEM to an analysis of yield response to water in irrigated pecan production in the EBID. The study region is rapidly urbanizing and experiencing growing competition for scarce surface and groundwater supplies. The results of this research provide new insight into pecan water use and yields. This research illustrates the linkages that can be made between remote sensing technology, farm-level water management, and yield outcomes. This research sheds new light on the long-standing practice of deficit irrigation in pecans, the yield and conservation impacts of this practice, as well as water conservation policy implications.

ACKNOWLEDGEMENTS

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INTRODUCTION

The need for accountability by water resource users is increasing worldwide and is especially acute in the western United States, where more than 90% of the region's water is consumed by irrigated agriculture. The West's population and economy are growing and diversifying, and there is pressure to transfer water to non-agricultural uses, including municipal, industrial, recreational, and environmental. It is commonly assumed that agricultural irrigation wastes large quantities of water due to inefficient tools and technologies. It is often further assumed that reducing inefficiencies in agricultural water use will result in supplies of freshwater that can be reallocated to other sectors, or used in expanding agricultural output. Adjudication of water rights is also underway in many basins throughout the West, where state-level water managers are seeking to define, verify, and formalize water resource property rights.

Adjudications often involve quantification of water consumed through evapotranspiration (ET) in the process of crop production. Basin-wide ET accounting is now feasible as a result of recent advances in remote sensing technology. Remote sensing has made it possible to combine ground measurement of ET with large scale remotely sensed satellite data and ground level climatological data to arrive at regional values of ET. This combination of ground-level and remotely sensed data provides the most advanced and cost-effective approach to estimating ET over large areas with non-uniform, field-level crop production conditions. Remote sensing also provides a means to assess the degree to which crops are produced under water deficit conditions, provides insight into consumptive use thresholds, and allows for predictions of the potential outcomes of conservation efforts or investments designed to improve an irrigation system.

The research presented here provides previously unavailable broad-scale estimates of pecan ET and the pecan water production function in southern New Mexico. The data which form the foundation of this paper were generated using the Regional ET Estimation Model (REEM) developed at New Mexico State University for agricultural and riparian vegetation (Samani et al. 2005, 2006, 2007). REEM uses remotely sensed data to calculate ET as a residual of the energy balance. This paper extends the results of REEM to an analysis of the yield response to water in irrigated pecan production in southern New Mexico, specifically within the Elephant Butte Irrigation District. The results of this research provide new insight into pecan water use and yields. This research illustrates the linkages which can be made between remote sensing technology and farm-level water productivity analysis. This research also sheds new light on the long-standing practice of deficit irrigation, as well as the yield and conservation impacts of this practice. The research results lend new insight into the true "thirst" of southwestern pecan production, and the hydrological and policy impacts of pecan water use in the region.

IRRIGATED PECAN PRODUCTION IN SOUTHERN NEW MEXICO AND PREVIOUS RESEARCH

The pecan tree (*Carya illinoensis*) is native to the southern United States, and is the only native tree nut grown for commercial use in the United States. The pecan is an alternate bearing tree, with a deep and phreatophytic rooting habit (Sparks 2005). Commercial pecan production is dispersed throughout 14 states, with the major production occurring in Georgia, Texas, and New Mexico. The United States is the world's largest pecan producer, although pecans rank number three in total U.S. tree nut production behind almonds and walnuts. Pecans are traded internationally, with the United States and Mexico accounting for almost all world exports.

The pecan industry is important to the Southwest, and especially in New Mexico. Pecans ranked fourth in New Mexico's cash receipts for agricultural commodities in 2003, behind milk, cattle and hay (USDA-NASS 2003). Pecans are a high value crop, and unlike the other leading U.S. pecan-producing states, all New Mexico nut production is from improved rather than native varieties. More than 70% of New Mexico's pecan production occurs in the south-central region of the state, along the Rio Grande, in the Elephant Butte Irrigation District (EBID), also home to the Las Cruces, NM metropolitan area and several smaller towns and settlements. Pecans are also grown in the Rio Grande Valley in the nearby El Paso, TX metropolitan area.

Pecan trees in the EBID account for a large proportion of the region's consumptive use of limited ground and surface water supplies. Pecan trees also have significant aesthetic value in the rapidly urbanizing river corridor, and are grown across the spectrum of farmers (e.g., lifestyle or rural residential as well as commercial growers of all sizes). The 2002 U.S. Census of Agriculture identified 10,514 hectares of pecans in the study region; this is approximately one third of the region's irrigated farmland. Surface water in the District is supplemented by ground water on some, but not all, farms. Most of the EBID is irrigated via traditional basin or basin-furrow methods (with no runoff from the end of the field), and on-farm efficiency (crop consumptive use relative to farm delivery) can be very high as a result of deficit irrigation practices. Efficiencies are also high as a result of level basins and short advance times on heavy soils. For example, Samani and Al-Katheeri (2001) used on-site flow measurement and chloride tracing and found basin and basin-furrow irrigation efficiency to be as high as 95% for pecans. Al-Jamal et al. (1997) also used chloride tracing and found efficiencies ranging from 70-76% for chile pepper fields, 77-80% for onions, and 97% for alfalfa. Deras (1999) applied the same methods and found on-farm efficiencies ranging from 79-98% for pecans, 87-98% for alfalfa, 88-87% for cotton, 89-97% for corn, and 83-94% for chile peppers.

The conventional wisdom is that pecans are a particularly thirsty tree, and require more irrigation water to maximize yield than any other crop grown in the Southwest U.S. (Sammis et al. 2004), that pecan water use is greater than that of most row crops (Andales et al. 2006), and that pecans naturally require large quantities of soil moisture to thrive (Kallestad et al. 2006). Given the steady and growing competition for water resources in the Southwest, the question of how much water is needed or consumed by pecan trees in

the region has been studied extensively throughout the years. Miyamoto (1983) provides a brief summary of earlier researchers which found that mature trees in Brownwood, TX and the El Paso, TX – Las Cruces, NM region require 18 cm per month during the summer, and may consume as much as 130 cm per season, and usually between 68 and 100 cm per season depending on tree size. Miyamoto (1983) extended this research in the El Paso – Las Cruces region using the soil water depletion method, and determined that the seasonal (1 April through 15 October) consumptive use of full-grown trees ranged from 100-130 cm for close-spaced, full-grown trees.

Worthington et al. (1987) found seasonal (April through October) consumptive water use in one mature pecan orchard in El Paso, TX was 109 cm, while seasonal consumptive water use in a younger orchard was 27 cm. These researchers used lysimeters and Class A evaporation pan techniques. Steinberg et al. (1990) used weighing lysimeters to measure water use of young pecan trees in Stephenville, TX. Daily ET for these immature trees measured during the month of August was 8.8 mm. Frias-Ramirez (2002) estimated ET using the water balance method in a Las Cruces, NM commercial pecan orchard in 1996-1997. The seasonal ET estimated was 112 cm in 1996 and 102 cm in 1997.

Sorensen (1997) used the water balance method and a computer model to estimate ET in a Las Cruces area commercial pecan orchard in 1994 and 1995. From the water balance method, the yearly estimates for two sites were 269 cm and 216 cm in 1994 and 206 cm and 399 cm in 1995. Sorensen (1997) reported that his calculated ET was overestimated due to underestimation of drainage. His estimates of ET on two sites using the Arizona Scheduling System (AZSCHED) were 109 cm and 118 cm in 1994, and 108 cm and 134 cm in 1995.

More recently, ET in a mature, commercial pecan orchard south of Las Cruces was studied intensively by Sammis et al. (2004) in 2001 and 2002. Using the one-propeller eddy covariance and energy budget methods, these authors found that the seasonal (April through November) ET measured in 2001 was 126 cm and 117 cm in 2002. Annual ET measured in 2001 was 146 cm and 137 cm in 2002. The yields measured by the farmer/owner of the research orchard were 2349 kg/ha in 2001 and 3681 kg/ha in 2002.

Reveles (2005) used one-propeller eddy covariance and energy budget techniques to measure pecan ET in 2004 in a large commercial orchard located south of Las Cruces. An annual pecan ET of 139 cm was estimated for 2004, after adjustments for missing data.

Although extensive pecan ET research has been conducted over the last 25 years, all previous research is site-specific, and clearly dependent upon production conditions at each farm or orchard studied. The feasibility of extending these research results spatially or temporally over an entire production region is problematic, given the extreme variability in pecan orchards at the farm level. Excluding Sorensen's (1997) self-described over-estimates, previous research has found a fairly narrow range of pecan ET. The most recent Sammis et al. (2004) and Reveles (2005) annual results ranged from 137

cm to 146 cm. However, the two orchards from which these results were obtained are intensively managed orchards, both part of the region's largest commercial pecan farming operations. The management characteristics of these farms are distinctly different from the majority of pecan farms in New Mexico's Elephant Butte Irrigation District.

Furthermore, although researchers have investigated pecan tree water consumption, there has been very little research on pecan water production functions, i.e., the relationship between yield and water applied to or consumed by the pecan tree. Thus, there is a large gap in our knowledge of the economic outcomes of water consumed in pecan production. Sammis (Undated) attempted to address this knowledge gap using ET results reported by Miyamoto (1983) to derive a pecan water production function. Sammis (Undated) assumed that the dry yield of pecans was similar to that of alfalfa, and arrived at the following water production function (WPF) for pecans (in his original units): $Y = -27 + 50.5 ET$, where Y = yield in pounds/acre and ET is in inches. Even assuming that this derived water production function relationship for pecans is correct (i.e., the dry yield assumptions hold), this WPF is subject to the spatial and temporal limitations of Miyamoto's (1983) original experimental data.

Pecan tree water consumptive use is currently a subject of intense debate in the state of New Mexico. As shown in Figure 1 below, EBID pecan acreage has grown significantly since 1960, as the acreage shares of other historically important crops such as cotton have shrunk. The current water rights adjudication process has yet to determine each crop's duty of water; however, pecans are believed to be the most water-needy crop, and are also relative newcomers to the region's irrigated agricultural economy. Numerous water resource stakeholders and managers in the region currently are demanding to know the nature of agriculture's water use, the outcomes achieved as a result of each crop's water use, and the degree to which water can be conserved by agricultural irrigators.

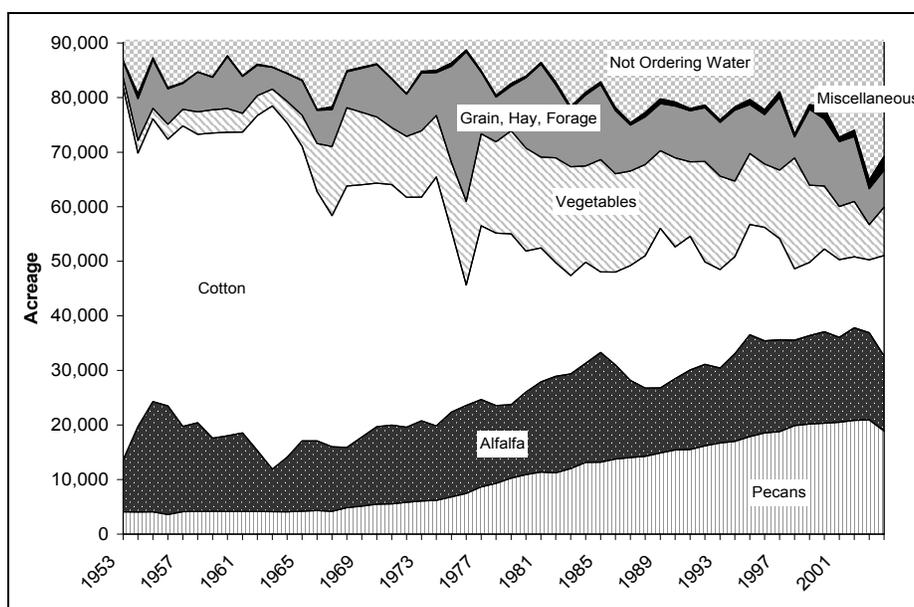


Figure 1. Changes in irrigated acreage in New Mexico's Elephant Butte Irrigation District, 1960-2004. Source: EBID.

METHODS AND PROCEDURES FOR BROAD SCALE ESTIMATES OF PECAN CONSUMPTIVE USE

Over the last two years, the boundaries of 228 mature pecan orchards (≥ 10 acres) in the Elephant Butte Irrigation District were delineated using the 2005 Digital Orthophoto Quarter Quadrangle (DOQQ) maps. REEM estimates of monthly ET in these orchards were generated for 2002.⁵ Figure 2 shows the distribution of total annual REEM-calculated ET for these orchards. As shown in Figure 2, there is a high degree of variability in ET across the 228 orchards. The maximum annual ET found was 131 cm (4.27 feet) while the minimum was 66.7 cm (2.19 feet). The average ET weighted by land area was 105.2 cm (3.45 feet). Eighty-five percent ($n = 213$) of the orchards had total annual ET ranging between 80.1 and 120.0 cm. It was noted above that the Sammis et al. (2004) and Reveles (2006) research was conducted on orchards which belong to intensively managed, large, commercial pecan farms. The ET results of these previous studies place these farms into the far right-hand tail of the distribution of broad-scale pecan ET estimated through REEM. Clearly, these previously researched farms are not representative of typical pecan consumptive use in the EBID. As will be shown below, the yield outcomes of these model farms are also atypical.

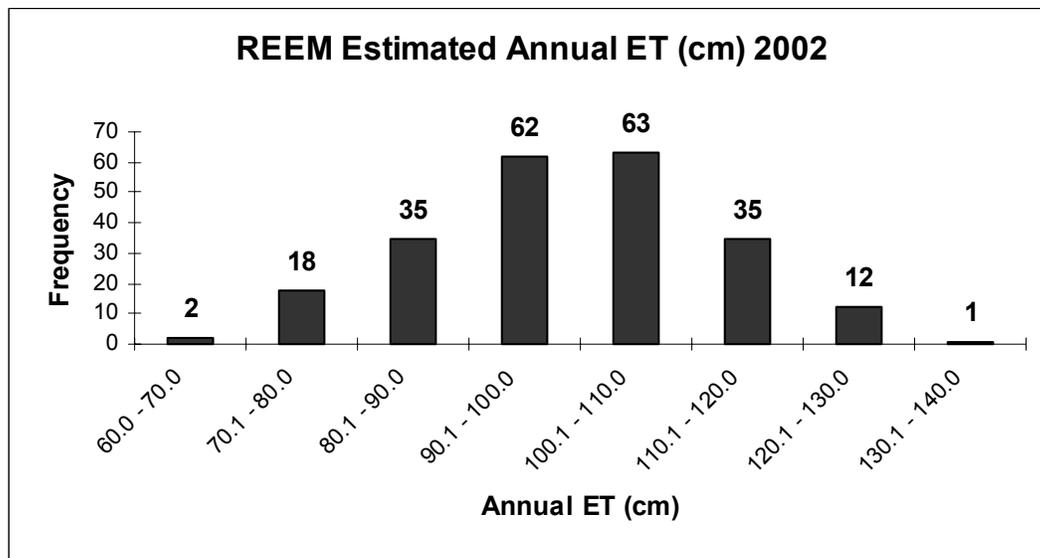


Figure 2. Annual pecan ET by farm ($n = 228$), Elephant Butte Irrigation District, New Mexico, 2002, estimated using REEM (Samani et al. 2005, 2006, 2007).

THE RELATIONSHIP BETWEEN WATER AND CROP YIELDS

Much research effort has been expended and much literature has been published on crop-water relations. Extensive experimental work has resulted in numerous water production functions which represent yield response as a function of water applied (e.g., Hexem and Heady 1978). These production functions have been used to predict yields under a range of soil, climate, and management conditions and are often used in irrigation project

⁵ Technical information about REEM can be found in Samani et al. 2005, 2006, 2007.

planning to aid in optimal water use decision making and to derive estimates of irrigation water demand. Water production functions can be simple two-variable functions where all other inputs are assumed to be held constant, or they can incorporate different levels of another key input, such as fertilizer. Complex water production functions which include several inputs other than water (e.g., fertilizer, soil characteristics, varieties, stand density, etc.) as well as interaction effects, are relatively rare, given the high cost of generating the necessary experimental data. Complex water production functions derived using experimental data from long-lived perennial tree crops are extremely rare.

As noted above, remote sensing technology now provides the means to assess ET across large areas, on potentially hundreds of farms or parcels. ET results for 228 pecan farms presented in Figure 2 above illustrate that the results of such an analysis. Unfortunately, data to characterize the relationship between ET and yields over large areas are not as readily available. Farmers typically are reluctant to disclose their on-farm yields and often consider requests for such information to be invasions of their privacy. Even when yields are reported, there are numerous reasons why farmers may either under- or over-report their actual crop yields.

Doorenbos and Kassam (1979) have suggested that the relationship between yield and ET is generally linear. They note differences in the linear relationship between crops and recommend that the relationship be defined in terms of maximum potential ET and yield in order to account for differences in climate, crop variety, etcetera. Their formula,

$$(1 - Y_a/Y_m) = k_y(1 - E_{Ta}/E_{Tm}) \quad (1)$$

where: Y_a = actual harvested yield
 Y_m = maximum harvested yield
 k_y = yield response factor
 E_{Ta} = actual evapotranspiration
 E_{Tm} = maximum evapotranspiration,

relates relative yield decrease to relative ET deficit through an empirically-derived yield response factor (k_y) estimated from analysis of experimental field data. A k_y of 1.0 means that for the total growing period, yield deficits are directly proportional to ET deficits, a k_y of less than 1.0 indicates that the decrease in yield is proportionally less than the increase in the ET deficit, and a k_y of greater than 1.0 means that yield decreases are proportionally greater than increases in ET deficit. Doorenbos and Kassam (1979) indicate that in most cases 80-85% of yield variation due to different water treatments can be explained using the relationship shown in equation (1).

Knowledge of k_y provides insight into the yield cost of limited water supply to the growing crop. In order to estimate k_y , yield data must be obtained experimentally, or accurate yield information must be forthcoming from producers. In this research, remotely sensed parcel-level estimates of crop ET were combined with yield information obtained from a small group of producers. Simple regression techniques were applied to the available yield and ET data to reveal k_y for pecans in the broader study region.

EMPIRICAL DERIVATION OF AN ET-YIELD FUNCTION FOR SOUTHERN NEW MEXICO PECANS

Operators of ten geographically dispersed pecan parcels for which ET estimates were calculated using REEM provided reliable yield information to this research project. Both the yields and the estimated ETs for the ten orchards were normalized, and subjected to simple regression analysis, such that $(1 - Y_a/Y_m) = f(1 - E_{Ta}/E_{Tm})$, where Y_a and E_{Ta} are actual yield and ET and Y_m and E_{Tm} are maximum yield and ET. The parcel with the highest REEM-calculated ET was established as the maximum ET value, this parcel also had the highest reported yield. The data points for the “maximum ET” farm are plotted at the origin, because for this observation $Y_a = Y_m$ and $E_{Ta} = E_{Tm}$.

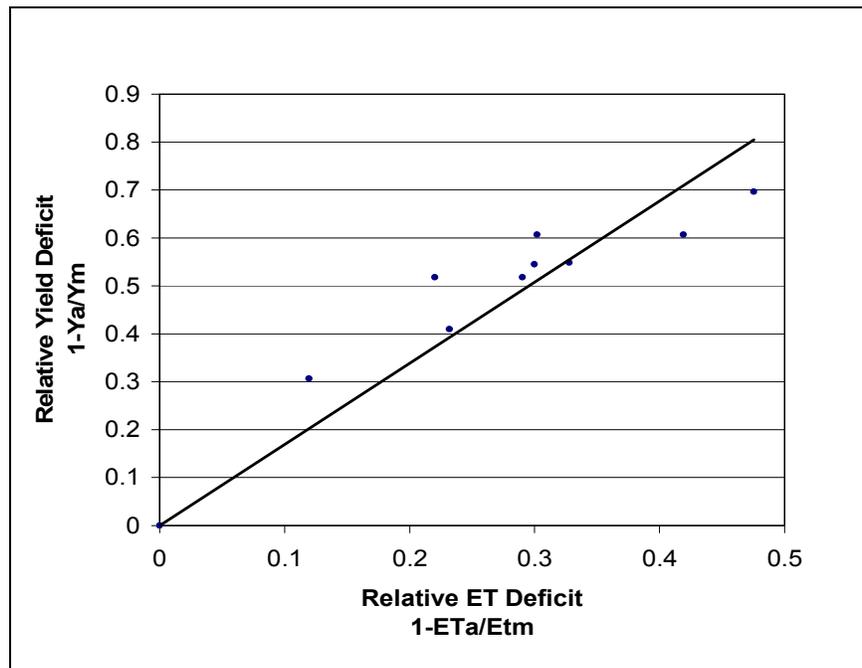


Figure 3. Linear function of relative yield deficit vs. relative ET deficit, 10 pecan orchards, Elephant Butte Irrigation District, New Mexico, 2002.

When the normalized relative yield deficit is regressed on the normalized relative ET deficit in a linear function, the result is shown in equation (2). The R^2 value for this equation was 0.82, thus these results are consistent with Doorenbos and Kassam (1979) findings of the simple equation’s ability to explain water-related yield variation.

$$(1 - Y_a/Y_m) = 1.692*(1 - E_{Ta}/E_{Tm}), n = 10, R^2 = 0.82 \quad (2)$$

(SE = 0.09)

The constant slope coefficient (1.692) of equation (2) is ky . This coefficient is the yield penalty which results from pecan consumptive water use at less than the regional maximum obtained under field, not experimental, production conditions. If a pecan orchard is experiencing a 20% ET deficit (i.e., it is being irrigated such that the trees are consuming 80% of the water they are able to consume), then there is a 34% yield penalty

(i.e., actual yield is 66% of potential yield). This high k_y value indicates a high sensitivity to water deficit, and places pecans in the same category as bananas, maize, and sugarcane with respect to yield response to water deficit (Doorenbos and Kassam 1979). While the simple function with constant k_y provides previously unavailable insight in pecan yield response to water, it does not capture yield responses to water deficits in different growth phases, and thus represents the ET-yield deficit relationship over the total growing period.

There are clearly both large yield costs and decreased water use efficiency from deficit irrigation of pecans. REEM results indicate that of the 228 orchards (covering 5,842.7 hectares) analyzed, 90% (or 205) had ET deficits greater than 10% in the year of analysis (relative to the most well-watered orchard found among the 228). Assuming that all 228 orchards actually *could be* irrigated at the level found on the most well-watered and highest yielding commercial production orchard, what is the total yield “cost” of deficit irrigation? It is estimated that the yield cost on these orchards as a result of deficit irrigation is 5,931 metric tons. Relative to actual 2002 pecan production, the state’s pecan crop would have been more than 36% larger if the yield potential had been reached in 2002 (USDA-NASS 2003). At the 2002 season average price of \$2.76/kg, the value of lost production would be almost \$16.4 million. There is currently no information available to indicate that such an increase in production would result in a significant decrease in nut price paid to pecan producers, thus we have used the season average price to value the yield cost. Given the total size of the New Mexico pecan crop (16,329 metric tons in the 2002, and 24,948 metric tons in 2003), this yield cost is large from an industry perspective.

If all 228 orchards studied in this project were technologically and financially able and willing to decrease their ET deficits as a result of timely and accurate application of irrigation water in accordance their tree’s water needs, pecan yields in the region would likely increase. However, total consumptive use of water by pecans in the region would also increase. Using the results and analysis presented above, we estimate that total consumptive use by the 228 orchards studied would increase by approximately 14.5 million m^3 (or 11,755 ac-ft) if the orchards were well-watered. Thus, current low levels of water productivity and deficit irrigation practices are actually resulting in a relatively large water savings.

SUMMARY, CONCLUSIONS AND IMPLICATIONS

The native range of pecan trees follows the river bottoms of the Mississippi River and its tributaries and the rivers of central and eastern Texas and their tributaries (Sparks 2005). As a result, pecans are a thirsty tree. Nut size and kernel development in pecan trees is also especially sensitive to soil moisture availability (Sparks undated). In this research, ET for 228 pecan orchards was estimated using a model which incorporates remotely sensed data. Reliable nut yields for a small number of orchards were used to develop a function relating ET and yield deficits in the study region. Using the methods of Doorenbos and Kassam (1979), a strong relationship between ET deficit and yield deficit was found and the total yield cost and total ET deficit for 228 orchards was estimated.

This research illustrates value of remote sensing procedures and models in deriving broad-scale consumptive use estimates. Estimates derived from a single farm or from a small sample of farms cannot comparably represent basin-wide consumptive use. This is due to field-level variability in production, management, and irrigation system characteristics. Previous research by Skaggs and Samani (2005a, 2005b) found extremely long irrigation durations, inefficient irrigation practices, inadequate irrigation infrastructure, and lack of interest in making improvements to the current irrigation system or methods on smaller, non-commercial pecan farms in the Elephant Butte Irrigation District. These findings were attributed to the nature of residential/lifestyle or retirement agriculture in the study region. In addition, Kallestad et al. (2006) reported on a project that introduced a small group of the region's pecan producers to soil monitoring instruments and internet-based irrigation scheduling resources, with the objective of improving irrigation and water use efficiencies in the interest of water conservation. Kallestad et al. (2006) indicated that they had negligible success in transferring the soil moisture monitoring technologies to growers for several reasons, including because the growers lack a substantial financial incentive to improve yields.

On-farm application efficiencies on commercial farms in the study region have been found to be relatively high, and basin-wide water balance analysis shows that little irrigation water escapes consumptive use somewhere in the basin. This phenomenon occurs because any upstream water users' "sloppy" water management results in downstream water users' supplies, including legally-required deliveries of water from New Mexico to Texas. Although pecans have the *potential* to be a very thirsty crop, this research has found that few producers are actually achieving potential ET levels (and yields) in their orchards. The current operating and structural limitations of the EBID make it difficult for pecan producers to change their irrigation practices (i.e., through scheduling) if they rely heavily on surface water. Furthermore, most farmers with wells depend on shallow, partially saline groundwater. These farmers are reluctant to apply low quality water to their crops unless it is absolutely necessary. Many producers are not dependent upon pecan production (or farming) for their livelihoods, thus they do not appear to be interested in making significant changes in their on-farm irrigation systems (e.g., intensive scheduling, drip irrigation, ditch lining). The common property nature of those segments of the water delivery system not owned by the irrigation district creates an additional disincentive for investments and improvements by individual water users (Skaggs and Samani 2005a, 2005b). All these limitations mean that many pecan producers are not motivated to strive for or reach potential consumptive use and yields. Indeed, the majority of pecan producers studied in this research are well below ET and yield levels achieved by the region's leading commercial producers. Thus, we question the conventional wisdom that significant water conservation (and release of water for other sectors or users) will result if pecan producers "improve" their irrigation practices or technology.

Efforts to increase water "conservation" by EBID pecan producers through public and private investments designed to increase the ability of those producers to more accurately and effectively irrigate their trees will likely increase total consumptive use of water in the region. Examples of popular technical remedies conventionally believed to conserve

water include drip irrigation, irrigation scheduling, and canal lining. From a pecan producer standpoint, these remedies would indeed “conserve” water, because yields and water productivity would increase. For other, downstream and/or future users, the increased “conservation” by pecan producers would likely increase net depletions and result in a severe reduction of their surface and ground water supplies.

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