Emerging Issues in Water Management Governance

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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 Water Management Conference**, held November 17-20, 2015, in Albuquerque, New Mexico. The Theme of the Conference was ***Emerging Issues in Water Management Governance***.

As with most endeavors, irrigation system and water managers are under increasing pressure to address and adapt to a myriad of issues and societal expectations regarding the operations of their systems. In the good ol' days, a manager's primary responsibilities were to ensure that water supplies were available at its diversion, and to distribute diverted water to water users. Although that fundamental responsibility has not changed, the number and extent of contemporary issues that are faced by managers to fulfill this responsibility continues to grow.

The most immediate needs for irrigation district and water managers are addressing **legal and regulatory issues**, including those related to **environmental laws**, and dealing with current **drought conditions**. In the longer term, irrigation districts must continue to plan for **long-term water supply reliability and sustainability**, maintain and improve irrigation system reliability, and look for new opportunities to **partner with urban and industrial water users** regarding water supplies and system management. Fortunately, **technology** is also advancing at a rate that allows managers to gather much more data and information to more intelligently and efficiently react and adapt to these needs.

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

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

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LEWISTON ORCHARDS PROJECT WATER EXCHANGE AND TITLE TRANSFER

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ABSTRACT

The Lewiston Orchards Project (LOP) is a Bureau of Reclamation (Reclamation) project located near Lewiston, Idaho, providing residential irrigation water to the Lewiston Orchards Irrigation District (LOID). Continued operation of the LOP faces challenges related to water supply reliability, impacts to tribal interests and effects to Endangered Species Act (ESA)-listed steelhead.

Many features of the LOP are located within the Nez Perce Indian Reservation and the Nez Perce Tribe (Tribe) have concerns over impacts to cultural, natural and spiritual resources. For nearly a decade, the operation and maintenance of the LOP has been the subject of ESA litigation between the Tribe, NOAA Fisheries and Reclamation. Resulting minimum flow requirements impact LOID's water supply. The LOP watershed is small and does not produce a reliable water supply from year to year and is susceptible to climate change impacts due to its location. Additionally, LOID faces major system rehabilitation in the near future.

Stakeholders are interested in finding a long-term solution to these issues. A group was formed in 2009 with the goal of seeking a reliable, quality water supply with permanent resolution of ESA and tribal trust issues. The stakeholders completed a study in 2011 that evaluated alternatives to meet these goals, focusing on a water exchange concept utilizing an alternate source to meet LOID's needs. The use of deep wells to replace surface water is currently being explored. If feasible, wells can be brought on line replacing the use of surface water, which can in turn be left instream.

INTRODUCTION

Bureau of Reclamation projects are typically associated with large reservoirs or multi-reservoir systems supplying water to a network of canals distributing water to thousands of acres of agricultural lands. However, the LOP is the antithesis of such an image. It is a very small and antiquated system with an unreliable water supply that mostly serves residential tracts less than 1 acre in size. The LOP is not a typical Reclamation project. Reclamation's role in this project was given by Congress in 1946 to rehabilitate an existing private system designed to provide water to large tracts of orchards, hence the Project's name. Not all the orchards materialized, and those that did failed to last as the land was converted to residential use.

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The complex issues surrounding the LOP have made it one of highest priority areas within Reclamation's Pacific Northwest Region, despite its small size. In many respects, the LOP displays a broad sample of the many issues Reclamation currently faces throughout the West: water reliability, climate change impacts, aging infrastructure, Endangered Species Act (ESA) issues, natural resource impacts, and multiple tribal trust issues.

Some of the issues surrounding the LOP go back over a century to the initial creation of the project, whereas others are more recent due to ESA listings in the basin. All the issues are interconnected and have culminated over the last decade, leading toward the current effort to find a comprehensive, permanent solution. After a lengthy history of court action, former litigants and other stakeholders are collaborating in good faith to find a comprehensive solution that addresses the issues facing the LOP.

BACKGROUND

The LOP is a Federal Reclamation project located near Lewiston, Idaho within the Lapwai Creek and Captain John Creek watersheds, tributary to the Clearwater and Snake Rivers in the Columbia River basin.

Through a contract with Reclamation, the LOID operates and maintains the LOP. The LOP provides water to approximately 18,000 patrons for residential irrigation purposes within a 3,828 acre service area. The current system draws water from Craig Mountain, utilizes storage in Waha Lake and Soldier's Meadow Reservoir, and conveys water through a gravity system to Mann Lake. The gravity conveyance system, including Mann Lake, is primarily located on the Nez Perce Reservation.

For nearly a decade, the operation and maintenance of the LOP has been the subject of litigation between the Nez Perce Tribe (Tribe), NOAA Fisheries and Reclamation regarding effects to ESA-listed Snake River steelhead. Likewise, the Tribe has long-standing concerns over impacts of LOP operations on the Tribe's cultural and spiritual resources.

Many local stakeholders are interested in finding a long-term solution to these issues. The Lower Clearwater Exchange Project (LCEP) was formed in 2009 and brought many stakeholders together with the goal of seeking a reliable, quality water supply for the LOID and permanently resolving ESA and Federal tribal trust issues surrounding the LOP. Through Reclamation's Rural Water Supply Program (RWSP), the LCEP group completed a RWSP Appraisal Study (JUB 2011) that evaluated alternatives to meet the group's objectives. The current LOP water exchange and title transfer concept evolved out of the well field alternative evaluated in the LCEP's Appraisal Study.

Project History

Early settlers to the confluence of the Clearwater and Snake rivers made their living by dryland farming, mining, and lumbering. Many of the settlers found the climate at the lower elevation provided for comfortable living with a good growing season for crops and orchards. In 1906, the Lewiston Land and Water Company of Portland, Oregon initiated irrigation in the area with the construction of the Sweetwater Creek Canal and Mann Lake, to deliver irrigation and domestic water to the dry bench above Lewiston, Idaho. To accomplish this, the company pursued condemnation in state court in Lewiston of Indian trust lands on the Nez Perce Reservation owned by the United States in trust for individual Indians. The company failed to notify or include the United States as a party, and this remains a disputed action to this day.

The project began with the construction of the Sweetwater Creek Canal and Mann Lake. In 1915, irrigation supply was augmented by pumping water from Lake Waha. In 1922, the LOID formed, purchased the water system from the prior company, and constructed the following improvements: increased capacity in Mann Lake from 2,000 to 3,000 acre-feet (af); constructed Soldiers Meadow reservoir; and constructed Webb creek diversion dam and necessary conveyance systems to move water from Webb creek drainage to Sweetwater creek drainage. In 1934, the water supply again was supplemented by construction of the Captain John Creek diversion[3].

In the 1940s, the facilities in the LOID were in disrepair and LOID requested assistance from the federal government to make improvements to LOID infrastructure. This assistance would be provided by (or through) Reclamation.

On May 31, 1946, the LOP was found to be feasible by the Acting Secretary of the Interior, and an act of Congress specifically authorized construction of the LOP in accordance with the recommendations of the Regional Director, as described in his report dated December 3, 1945. This report to Congress regarding the proposed federal acquisition of the project did not recognize any Tribal interests or the location of the project on and relative to Reservation boundaries. Reclamation's authority was, and remains to this day, to construct and operate the LOP for purposes limited to irrigation and municipal and industrial water supply. Flood control, fish and wildlife, recreation and other potential purposes are not included in LOP authorization. Under this authority, Reclamation rehabilitated and/or constructed the irrigation works and domestic water facilities on a reimbursable basis according to the terms of contract with LOID.

LOP System Overview

The LOP is a small project compared to other Reclamation projects, but is nonetheless complex and subject to many operational challenges. The system derives its water supply from the Craig Mountain watershed via a series of combined diversion, conveyance and storage structures located primarily on Sweetwater and Webb Creeks (Figure 1)

[3]Captain John Creek is a small tributary of the Snake River.

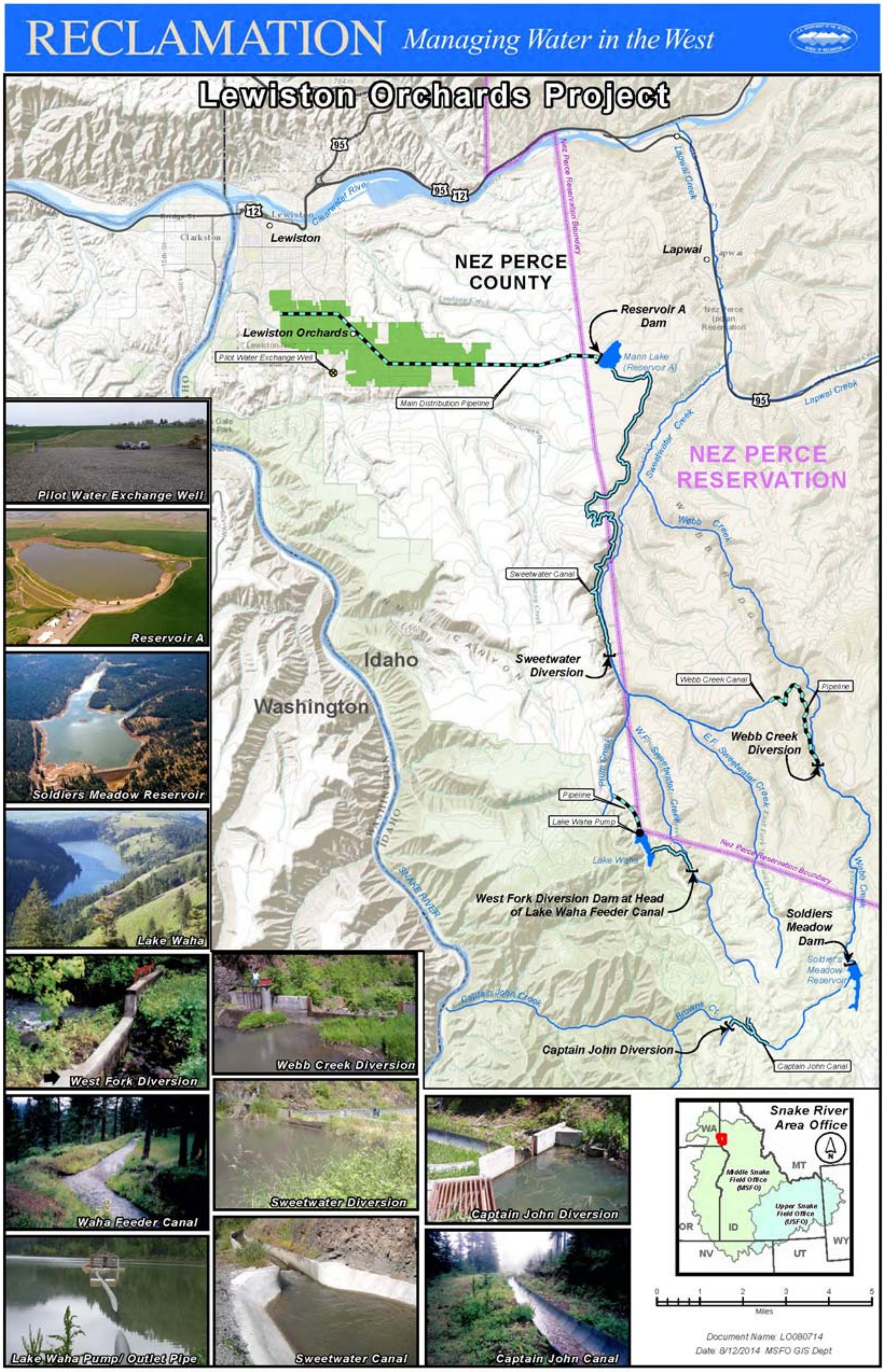

Figure 1. Overview of the Lewiston Orchards Project

Water is supplied from a combination of winter snowpack and spring time precipitation. Runoff in the upper watershed is captured in Soldiers Meadow Reservoir on Webb Creek and Lake Waha on Sweetwater Creek, where it is later released for diversion down Sweetwater Canal for delivery to Mann Lake.

Flows in Webb Creek, including releases from Soldiers Meadow Reservoir, reach the Webb Creek diversion dam several miles downstream of the reservoir and are diverted over to Sweetwater Creek. Webb Creek below the diversion was historically dewatered, except during times when available flows exceeded the diversion canal capacity.

Lake Waha on upper Sweetwater Creek is a natural lake formed by an ancient landslide that blocked the entire valley. There is no outlet channel, hence water from Lake Waha emerges naturally from a series of springs downstream from the landslide. These springs are of high significance as they have important cultural and spiritual implications to the Tribe, and are an important and unique resource important to fisheries.

Since 1915, Lake Waha levels have been manipulated by the addition of a feeder canal to divert water from West Fork Sweetwater Creek into the lake, and a pump system to supply late season irrigation water to the LOP. This manipulation results in much larger annual fluctuations in lake level, and likely more extreme highs and lows than what naturally occurred. Spring discharge is directly related to, and subsequently impacted by, lake levels.

Water derived from the surface system flows down Sweetwater Creek to Sweetwater Diversion dam, where it is conveyed via the Sweetwater Canal north to Mann Lake. The Sweetwater Diversion dam historically dewatered the downstream reach of Sweetwater Creek, except during times in the winter or spring when the diversion was either not operating or available flows exceeded canal capacity.

Beginning at Mann Lake, water is released directly into a piped system to serve the LOID patrons via an on-demand pressurized system. The original project purpose of suppling irrigation for agriculture was never fully realized and existing agricultural lands were eventually developed for residential use. The majority of surface irrigation water within the LOID now largely supplies residential yards and gardens.

The Lapwai Creek system, including both Sweetwater and Webb Creeks, supports a reproducing population of ESA-listed Snake River steelhead. Steelhead move from the Clearwater River into the Lapwai system in the spring to spawn. Most juvenile steelhead will reside in the system until that fall or the following spring at which point they begin the downstream migration to the ocean while others continue to rear in the watershed until the following year.

Legal Framework

To understand the complex nature of the current collaboration effort, and the inter-related issues involved, one must have an understanding of the legal history surrounding the LOP.

Litigation over the LOP has an extensive history. In 1998, Reclamation initiated ESA consultation with the National Oceanic and Atmospheric Administration, Division of Fisheries (NOAA) on the effects of ongoing operations and maintenance at Reclamation facilities in the Snake River Basin, upstream from Lower Granite Dam. ESA consultation specific to the LOP was suspended during the State of Idaho's Snake River Basin Adjudication (SRBA) negotiations, at which time replacement of the LOP with a new water source for LOID was under discussion. Those discussions were subsequently dropped from the SRBA process, and ESA consultation on the LOP resumed between Reclamation and NOAA.

In 2006 NOAA completed a Biological Opinion (NMFS 2006) for operation and maintenance of the LOP, recommending certain operations, including minimum flows in Sweetwater Creek. The Tribe challenged the validity of the 2006 BiOp and filed suit against both NOAA and Reclamation. In 2008, the U.S. District Court for Idaho ruled in favor of the Tribe, finding the 2006 BiOp deficient, particularly as to effects of the LOP on ESA-designated critical habitat for listed Snake River steelhead. The Tribe, LOID, Reclamation, and NOAA (Parties) then participated in a court-ordered mediation. A new BiOp was to be written under a collaborative remand process, and the Parties were ordered to simultaneously explore resolution to long-term LOP issues through mediation.

Separate from the ESA and the ongoing litigation process, LOID and the Tribe began meeting on a regular basis with lower Clearwater River Basin regional stakeholders to discuss long-term resolution of LOP issues, beginning in May 2008 with a series of meetings organized by Jerry Klemm of the Lewiston Chamber of Commerce. Discussion during these meetings culminated in a Memorandum of Understanding (MOU) in 2009 with three core objectives to permanently resolve: LOID water quantity and quality problems; ESA problems surrounding the LOP; and federal-tribal trust problems surrounding the LOP as a result of its predominant location on the Nez Perce Reservation. This effort was termed the Lewiston Orchards Exchange Project (LCEP) and formed the foundation of the collaborative solution process now underway.

Concurrently with the mediation process, NOAA completed the final 2010 Biological Opinion (NMFS 2010). Within the 2010 BiOp, NOAA summarized a proposed action for operation and maintenance of the LOP and established minimum stream flows in the watershed, including Sweetwater and Webb Creeks.

The Tribe challenged the validity of the 2010 BiOp and filed suit in August 2010 under the ESA in the U.S. District Court of Idaho against NOAA and Reclamation. On January 28, 2011, the Tribe, Reclamation, and NOAA filed an agreement and a joint stipulated motion to stay proceedings for a period of three years. The parties' stay motion was granted and a 2010 Term Sheet Agreement approved. The agreement addressed 2011-2013 mediation, operations, and included a commitment to advance the study and investigation of the then-ongoing LCEP concept as a potential comprehensive solution to the LOP issues (discussed in greater detail later in this document), at the suggestion of then Reclamation Commissioner Connor.

Based on progress being made toward a comprehensive solution, the 2010 Term Sheet Agreement was replaced with a 2014 Term Sheet Agreement which provides for the stay of the case Nez Perce Tribe v. NOAA Fisheries and the Bureau of Reclamation, Civ. No. 10-286-BLW (D. Idaho). That stay continues through January 31, 2020 so as to allow for the potential comprehensive resolution of this water exchange project, unless the stay is terminated earlier by any party. The January 31, 2020 date corresponds to the expiration date of the 2010 BIOP. If a comprehensive solution cannot be achieved, then it is assumed that federal litigation would again proceed and the LOP would once again be driven by litigation, with uncertain outcomes for all involved.

SUMMARY OF ISSUES TO RESOLVE

In order to satisfy the needs of all the parties involved, a comprehensive solution must address several major issues associated with the operation of the LOP. These issues are summarized here.

Water Supply and Reliability

Regional climatic variability and subsequent precipitation patterns have resulted in impacts within the Craig Mountain watershed. This has, to date, primarily been evident through changes in annual snowpack depth, water content and timing, as well as changes in surface-runoff patterns and timing. Essentially, warmer winter conditions have recently resulted in a higher frequency of rain events, as opposed to precipitation in the form of snow. This change in precipitation has resulted in less water available for storage within the system which translates to an insufficient volume of water supply to the LOID. Water stored within the watershed in the form of snow can typically be slowly captured by the system and either stored or diverted for use within the LOID, whereas rain events are shorter in duration and in many cases, largely pass the system. The canals that convey water through the LOP are generally undersized and do not allow for the dynamics of capturing all the rain from events that occur within the watershed.

Minimum stream flow requirements within Sweetwater and Webb Creeks add an additional demand on an already insufficient supply. This flow requirement further serves to reduce water available to LOID for annual use. During many water years, sufficient water is available to satisfy instream flow requirements as well as meet LOID system demands. During low-water years, however, instream flow requirements have the potential to further reduce water available to LOID to meet system demands.

Lastly, multiple system physical constraints complicate LOID’s ability to store and deliver water. For example, reservoir storage limitations on Mann Lake associated with the Safety of Dams Act reduces reservoir storage capacity from 3,000 acre-ft to 1,960 acre-feet. This reduction in storage capacity results in a loss to an already constrained system.

With a supply that is insufficient, new and increased system demands, and additional physical and operational constraints, the patrons of the LOID face a future of greater irrigation restrictions to ensure water supplies persist through the irrigation season to meet the needs of the patrons.

Aging Infrastructure

Due to the age and annual use of the diversion and conveyance system, many system features are in a state of extensive deterioration. Annual maintenance activities have been conducted by LOID to ensure continued operation of the system, however multiple features are in need of either significant rehabilitation or total replacement. Annual maintenance to this point has largely consisted of small, localized actions designed to address specific, small-scale performance issues. Continued successful and reliable operation of the current system will necessitate extensive rehabilitation in the near future (i.e., within 10 years) at great cost to LOID. Additionally, any repairs or replacement would have to be conducted in a short period of time so as not to interrupt annual water-delivery operations, resulting in additional costs. Although not known with certainty, these rehabilitation costs could easily range from $3 million to $25 million or more.

ESA-Listed Anadromous Fish

The Lapwai Creek system, including both Sweetwater and Webb Creeks, supports a reproducing population of ESA-listed Snake River steelhead. Steelhead move from the Clearwater River into the Lapwai system in the spring to spawn. Most juvenile steelhead will reside in the system until that fall or the following spring at which point they begin the downstream migration to the ocean while others continue to rear in the watershed until the following year.

Sweetwater Creek in particular is considered to be a unique biological resource within the lower Clearwater River watershed due to the natural springs that emerge below Lake Waha. These springs historically provided reliable high quality year-round flows that supported anadromous fish such as steelhead trout. This resource was unique in that the rest of the Lapwai Creek watershed is subject to low flows and high water temperatures during summer that are detrimental to fish survival, as well as icing conditions in the winter that further limit fish production. The springs on Sweetwater Creek provide nearly constant temperature water year-round that provide both cold water refugia in the summer, and warmer water refugia during winter. Manipulation (drafting) of Lake Waha has decreased the spring output in most years, and diversions from Sweetwater Creek to Mann Lake prevent any downstream benefit. Establishment of minimum flows does not restore the benefits of the spring-fed flow, as water diverted to Sweetwater Creek from Webb Creek reduces the quality of water in Sweetwater Creek. Reestablishment of spring discharges to a more natural regime and subsequent benefits to Sweetwater Creek are a high priority of the Tribe.

Tribal Trust

The Nez Perce Tribe has a number of important tribal trust concerns over the operation of the LOP. While the current litigation brought by the Tribe involves ESA-listed steelhead, the Tribe's primary concern is the location of the LOP itself. The LOP is located predominantly on and adjacent to the Nez Perce Reservation and alters the stream hydrology in Captain John Creek, Webb Creek, Sweetwater Creek, and Lapwai Creek. These streams (with the exception of Captain John Creek) run though the Nez Perce Reservation and are among the treaty-reserved fishing areas of the Tribe. The Tribe does not receive LOP water and its position is that the LOP impacts Tribal natural, cultural and spiritual resources. The Tribe's culture is inextricably linked to the land and its natural resources, and they view the alteration of the Sweetwater Creek watershed and its impacts to fisheries, both on and off the reservation, as untenable. In addition, the natural springs emerging below Lake Waha hold a high level of spiritual significance to the Tribe, and the natural creation of Lake Waha by a massive landslide is a part of the Tribe's cultural legend passed down through oral history.

The Tribal focus on tribal trust issues is further reinforced as the LOP was originally developed through illegal condemnation of Federal Tribal trust lands in state court, and that no recognition of the Tribe occurred when the project was federalized in 1946. Litigation has been ongoing and is expected to continue under the ESA or Federal/Tribal trust responsibilities until LOP facilities are removed from the Nez Perce Reservation.

PATH TO RESOLUTION

As discussed earlier under Legal Framework, the path to resolving many of the issues associated with the LOP began through litigation brought by the Tribe under the ESA beginning in 2007. This litigation was contentious at times and had the prospect to continue for many years with uncertain results.

As previously discussed, an MOU was signed by multiple stakeholders to address long-term resolution of LOP issues, ultimately forming the LCEP. The MOU was executed in July 2009 by LOID, the Tribe, the City of Lewiston, Lewiston Chamber of Commerce (now known as Lewis Clark Valley Chamber), and Nez Perce County. The MOU set forth the direction and fundamental concepts of the LCEP partners in order to solve water issues including water quality, quantity, and reliability, as well as other implications of the LOP and its present location on the Nez Perce Reservation, such as ESA issues, watershed impacts, and habitat impacts. The three core project objectives of the MOU were:

- Creation of a reliable, quality water supply for LOID;
- Permanent resolution of the ESA issues surrounding the LOP;
- Permanent resolution of federal-tribal trust issues surrounding the LOP.

Beginning in October 2010 a series of meetings was held over the next year to complete an application for a Reclamation Rural Water Supply Program (RWSP) Appraisal Study (JUB 2011). The LCEP group received the grant and completed their RWSP Appraisal Study in September 2011 to evaluate if there was an alternative that met the objective of the group. The study process involved identification of all conceivable options to provide water to LOID. This allowed for a comprehensive alternative-identification process to ensure a full-range of alternatives were identified. Through this process, a total of 32 alternatives were identified. The process also involved the development of a set of criteria to screen the alternatives based on requirements identified by the LCEP stakeholders. This process reviewed each alternative against the screening criteria, resulting in three final alternatives being carried forward for technical analysis. Those alternatives were: 1) a pumping plant located on the Clearwater River; 2) a pumping plant located on the Snake River; and 3) a fully developed well field that would tap into the deep regional aquifer to supply LOID with groundwater. Each alternative would involve exchanging LOID's current surface water supply in its entirety with the new water source.

Although the final three alternatives, relative to other alternatives identified in the study, were determined to have a generally reasonable capital cost, each alternative was nonetheless cost prohibitive to LOID and LCEP partners. Up-front capital costs for constructing pumping plants along either the Snake or Clearwater Rivers and constructing the Tammany Creek well field were substantial. Additionally, cultural and historical resource impacts associated with prospective pump station sites further complicated the two river pump alternatives.

There was no readily identified funding source for the significant up-front capital costs involved with any of the alternatives, so although technically feasible it did not appear that any of the alternatives could progress in the timeframe and certainty required by the Parties in litigation. Subsequently, Reclamation evaluated all the alternatives and focused on a modified approach to resolve ESA and Federal/Tribal trust issues. Based on one of the three final alternatives evaluated in the RWSP Study, Reclamation developed the LOP Water Exchange and Title Transfer concept which involves incrementally exchanging the existing surface water system with an off-Reservation groundwater-pumped system consisting of multiple wells. This concept uses Fish and Wildlife Coordination Act authority (FWCA), and, unlike the LCEP concept, can be constructed in phases as funding becomes available, thus substantially reducing initial capital costs for alternative implementation. Individual wells would be constructed and incorporated into LOID's water distribution system as funding becomes available. Each well would be connected to the LOP system in exchange for relinquishment of an incremental amount of surface water for instream flow use as an ESA Section 7.a.1 voluntary action. Once the full LOP surface water supply is exchanged, title transfer of LOP facilities would take place.

The project is now proceeding during the period of a new 2014 Term Sheet Agreement (2014 Agreement) entered into between the Tribe, Reclamation and NOAA, effective April 29, 2014, which provides for the stay of the case Nez Perce Tribe v. NOAA

Fisheries and the Bureau of Reclamation, Civ. No. 10-286-BLW (D. Idaho). That stay continues through January 31, 2020 so as to allow for the potential comprehensive resolution of this water exchange project. If this project were discontinued at any point prior to January 31, 2020, it can be assumed that the federal litigation would renew shortly after that earlier date.

The primary focus of the 2014 Agreement is to continue efforts to complete a LOP Water Exchange Project as a comprehensive solution to LOP system issues. To this end, in August, 2014, Reclamation and LOID initiated a Pilot Well Project to test the groundwater capability and determine if the aquifer is capable of supporting the long-term operation of a well field. The pilot well has been drilled to a depth of 1,900 feet and is still in development, but pump drawdown testing indicates that the well will provide its target goal and that the aquifer is suitable to support a well field. With this finding of viability, Reclamation is entering the environmental compliance phase of the project in the fall of 2015. This includes National Environmental Policy Act (NEPA) compliance. Following successful completion of environmental compliance, subsequent phases would include the construction of a transfer station for power, the construction of additional wells, and the eventual transfer of title of Reclamation property interests. As each additional well is brought on line, surface water supply corresponding to the sustainable production rate of the respective well would be exchanged and left instream. Once the full exchange has occurred, title transfer of LOP surface water facilities would take place. Reclamation assets downstream of Mann Lake would be transferred to LOID; this is essentially the pressurized irrigation system. All Reclamation assets upstream from and including Mann Lake would be transferred to the Bureau of Indian Affairs to be held in trust for the Tribe, including the surface water rights.

Mann Lake would remain an integral part of the irrigation system. Rather than being supplied by gravity diversion from Sweetwater Creek, it would be fed by groundwater pumping during times when pumping exceeds system irrigation demand. This would primarily be in the winter and spring, and Mann Lake would draft during the summer when irrigation demand is heaviest, consistent with current operations. Mann Lake would thus act as a large re-regulating reservoir for LOID and avoid the need for the many pumps that a closed, on-demand system would require. Mann Lake would continue to provide the fishing and recreation options that currently exist.

The rest of the system, including Soldiers Meadow Reservoir and Lake Waha would revert to the Tribe's operation (via the Bureau of Indian Affairs) following title transfer. The Tribe's stated goal would be to operate the system in a manner that restores the natural flow regimes to the greatest extent possible, while managing the reservoirs to enhance fishery benefits both in-reservoir and for downstream anadromous fish. Diversion structures would be utilized as needed to maintain optimum conditions within the respective systems, with the exception of Sweetwater diversion, which would likely be removed to restore system connectivity. Lake Waha would revert to a natural lake which would equalize to a smaller range of annual fluctuations and produce a higher and more consistent discharge from the associated springs.

Completing the full title transfer and water exchange may take several years, depending upon available funding and legislative progress.

CONCLUSION

The issues facing the LOP are dynamic, complex and controversial. Water reliability, water quantity and quality, climate change, aging infrastructure, ESA-listed species, competition for finite natural resources, and Tribal trust responsibilities are each recurring themes that define many of the issues facing water supplies in the western United States. Litigation is often the initial path to a resolution, but litigation isolates the issues and forces those involved to focus on and protect their respective interests. Litigation over the LOP has been a long and sometimes difficult process, however it has brought the parties involved together to pursue a comprehensive and collaborative solution that acknowledges the importance of each position and their respective needs. The collaborative process has been very successful thus far in making real and measurable progress toward a solution. A neutral facilitator is utilized to keep the process moving and to ensure that consensus is reached at each step. Trust has been established between the parties and all are acting in good faith. This will be essential to maintain as the project moves forward, as there are many elements and details yet to be fully determined and unforeseen issues will likely arise. Additionally, there is uncertainty on future funding, with all parties actively seeking potential funding sources. Reclamation is hopeful that the progress made to date, and the working relationships established, will provide the momentum to complete the project by 2020.

ACKNOWLEDGEMENTS

Reclamation would like to acknowledge the tireless efforts of Mr. Jerry Klemm, Lewiston Orchards Irrigation District, the Nez Perce Tribe, the Bureau of Indian Affairs, NOAA Fisheries and facilitator Ed Sheets in their pursuit of a comprehensive solution to the issues surrounding the LOP through ongoing collaboration.

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PROVO RIVER DELTA RESTORATION PROJECT

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ABSTRACT

Projects designed to provide water have occurred within the Utah Lake Drainage Basin since the time of European settlement in 1847. These projects have affected Utah Lake and the endangered June sucker (*Chasmistes liorus*) which occurs naturally only in Utah Lake and spawns primarily in Provo River. As recent water development projects have been planned and constructed, commitments have been made to aid in the recovery of the June sucker. The Provo River Delta Restoration Project (Project) addresses several of these commitments by restoring a more natural deltaic ecosystem essential for a healthy June sucker population. Specifically, habitat would be created suitable for adult spawning, egg hatching, larval transport and survival, and young-of-year rearing and recruitment into the adult population on a self-sustaining basis. Other purposes of the Project are to provide recreational improvements and opportunities and to adopt flow regime targets for the lower Provo River. Great efforts have been made to acquire sufficient water for in-stream flows needed during the June sucker spawning season. Currently, June sucker recruitment is severely limited in-part because of degraded rearing habitat. The Project would remove man-made levees, re-connect the river and lake with adjacent wetlands, restore natural fluvial processes and ecological conditions, and re-establish and reconnect habitats. Restored rearing habitat would support juvenile June sucker until they are capable of surviving in the larger open water environment of Utah Lake. The lower 1.5 miles of Provo River channel would be relocated so that the main flow would be directed into the restored river delta area. This natural area would also provide a variety of public recreation opportunities. The existing channel will continue to receive a minimum flow of 10 cfs to a maximum of 50 cfs as well as an aeration system to improve water quality. The Project addresses specific downlisting and delisting criteria for the June sucker and is a major component of broader efforts of the June Sucker Recovery Implementation Program. A Final Environmental Impact Statement and Record of Decision were published for the Project in April and June of 2015, respectively. The Project is a joint effort of the U.S. Department of Interior's Central Utah Project Completion Act Office, the Utah Reclamation Mitigation and Conservation Commission, and the Central Utah Water Conservancy District.

INTRODUCTION

Utah is the second driest state in the union. It receives most of its moisture from winter snowfall with the remainder of the year being relatively dry. Early pioneers faced

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challenges to provide water in sufficient amounts and at times needed for successful crop production. To cope with these challenges, irrigation systems were developed and maintained to store and deliver the winter snow. Water providers in the state continue to maintain and develop new infrastructure to provide water not only for agricultural purposes but for municipal and industrial purposes as the population expands.

Efforts to provide this needed water have come with great costs not only in funds but also in terms of natural habitat modification and loss. As we move forward with the continued operation and future development of existing water facilities and resources, we must consider the impacts of these activities on wildlife and wildlands. The Provo River is a prime example of the situation.

The Provo River originates east of Provo City, Utah in the Uintah Mountains and empties into Utah Lake (Figure 2). Before the river empties into the lake, it passes through Provo City, which is adjacent to the lake. Through the city, the river has been diked and straightened to reduce the threat of flooding. These dikes extend to the mouth of the river. This has eliminated most of the natural habitat needed by native species.

June suckers (Figure 1) were one of the species dependent on the natural deltaic habitat that existed. The fish is named for the timing of its annual spawning migration, which typically occurs sometime around June. This species was federally listed as an endangered species in 1986. The lower 4.9 miles of the Provo River was identified as critical habitat because it was the only known spawning location for the species. In 1994, the U.S. Fish and Wildlife Service (Service) determined that the continued operation of water storage and delivery infrastructure within the Provo River Drainage would likely jeopardize the continued existence of the species. A Recovery Plan for the species was developed in 1999 by the Service (U.S. Fish and Wildlife Service 1999). It established criteria that would need to be met in order to prevent the extinction of the June sucker as well as promote its recovery. These criteria included the acquisition and delivery of flows essential for spawning and recruitment activities of the fish, the enhancement of natural habitats in the Provo River and Utah Lake, reduction or elimination of nonnative species, at least two self-sustaining spawning runs within the Utah Lake drainage system, a refuge population, and removal of any other threats to the species.

Figure 1. June Sucker

A June Sucker Recovery Implementation Program (JSRIP) was begun in 2002 involving the Service, Central Utah Water Conservancy District (District), Department of the Interior – Central Utah Project Completion Act Office (Interior), Bureau of Reclamation (Reclamation), Utah Department of Natural Resources (UDNR), Utah Reclamation Mitigation and Conservation Commission (Mitigation Commission), Provo River Water Users Association, Provo Reservoir Water Users Company and outdoor and environmental interest groups. The goals of the JSRIP were to recover the species while allowing for the continued operation of existing water facilities and future development of water resources for human use.

Figure 2. Project Vicinity Map

The Central Utah Project Completion Act (Public Law 102-575 of 1992, as amended) (CUPCA) authorized the completion of the Diamond Fork System under Section 202 (a)(6). Subsequently, the 1999 Diamond Fork System ROD and the 2005 Utah Lake System ROD committed Interior to participate in the JSRIP. The JSRIP identified the restoration of the Provo River Delta as a priority for recovery of the June sucker. The Mitigation Commission, Interior and the District (Joint Lead Agencies) have teamed to plan and implement the Provo River Delta Restoration Project (Project) aimed at meeting the habitat needs of the June sucker.

NATURAL STREAM FLOW RESTORATION

Early recovery efforts were focused on acquiring sufficient water to meet flow recommendations from the JSRIP. Section 302 of the Central Utah Project Completion Act (CUPCA) authorized the District, with funding provided by the Mitigation Commission, to acquire water supplies with the goal of establishing a year-round minimum flow of 75 cfs on the lower Provo River. In addition, several environmental commitments aimed at providing these needed flows were agreed upon during the NEPA process for the completion of water development projects (ie. Diamond Fork System and the Utah Lake Drainage Basin Water Delivery System). When completed, these systems will provide additional water for instream flow purposes in the lower Provo River that, with water supplies acquired to date, should provide for substantial improvement of the lower Provo River ecosystem and contribute to the recovery of June sucker.

Water has been acquired under section 207 of the CUPCA which authorized a comprehensive program to improve water management within the Central Utah Project service area, including the establishment of water conservation goals that have been achieved and exceeded over the years. Specific purposes of Section 207 are to encourage water conservation and wise use, reduce the probability and duration of extraordinary water shortages, and reduce water use and system costs, and prevent unnecessary depletions that adversely affect environmental values or other public purposes. To date, over 19,000 acre-feet of water has been acquired annually on a temporary or permanent basis for lower Provo River flows.

The Mitigation Commission funded a study to determine flows appropriate for improving and maintaining a natural riverine ecosystem along the lower Provo River. In 2008 a recommendations report was finalized (Mitigation Commission 2008). This report provided an adaptive approach for making decisions about the allocation of acquired water for instream flows. It established guidelines for base flows as well as seasonal variation to these flows.

PLANNING FOR THE DELTA RESTORATION

Although an appropriate streamflow regime is critical to the proper functioning of riverine ecosystems, it is only one of several vital components that contribute to the health and function of these systems. The lower Provo River is substantially compromised by the alteration of its physical and morphological characteristics due to channelization and the influence of Utah Lake water backing up into the channel during those times when the lake level is high.

The Joint Lead Agencies made great efforts to develop, study, and analyze for effectiveness various alternatives to restore the Provo River Delta. A technical memorandum was finalized in November of 2011 (Mitigation Commission, et al. 2011) which summarized these efforts and ultimately provided four designs for the restoration of the delta. These represented a reasonable range of alternative that addressed identified issues and meet the need for the proposed restoration. At this stage of development, the alternatives reflected only a cursory consideration of issues and ideas. Three of the four original alternatives were carried forward for detailed analysis during the preparation of the Provo River Delta Environmental Impact Statement (EIS). Also, two design options for the existing Provo River Chanel were analyzed. A Record of Decision was finalized in May of 2015. In it, an alternative was selected for restoration of the delta and an option was selected for developing the existing channel (Mitigation Commission, et al. 2015).

PROJECT PURPOSE AND NEED

Each spring in the lower Provo River, adult June sucker are observed spawning, and significant numbers of recently hatched larvae are subsequently monitored drifting downstream. However, post-larval survival rates of June sucker have been found to be low to zero. Monitoring efforts have not documented the successful recruitment of wild June sucker from Provo River, and research has shown that larval fish generally do not survive longer than about 20 days after hatching. It is believed that the larval fish die because of a lack of suitable nursery or rearing habitat and are therefore unable to recruit into the adult population. The Project is needed to facilitate recovery of June sucker by implementing requirements of the June Sucker Recovery Plan to restore naturally functioning habitat conditions in the Provo River/Utah Lake interface that are essential for spawning, hatching, larval transport, survival, rearing, and recruitment of June sucker.

The purposes of the Project are to implement specific criteria of the June Sucker Recovery Plan (USFWS 1999) to restore the Provo River Delta ecosystem; provide recreational improvements and opportunities compatible with the habitat restoration project; adopt the flow regime targets for the lower Provo River; and provide delivery of supplemental and conserved water to the lower Provo River.

PROJECT DESCRIPTION

The Project involves restoring a more natural river/lake interface in the lower Provo River at Utah Lake and reestablishing essential spawning and rearing habitat for June sucker (Figure 3). This habitat will support juvenile June sucker until they are capable of surviving in the larger Utah Lake environment.

Historically, a broad delta and floodplain existed at the lower Provo River/Utah Lake interface. This delta was eliminated by the straightening and diking of the main channel. In a naturally functioning deltaic ecosystem, the river zone is characterized by a meandering channel across a broad floodplain. As the river approaches a still body of water, it slows down and suspended sediments drop out of the flow. When these

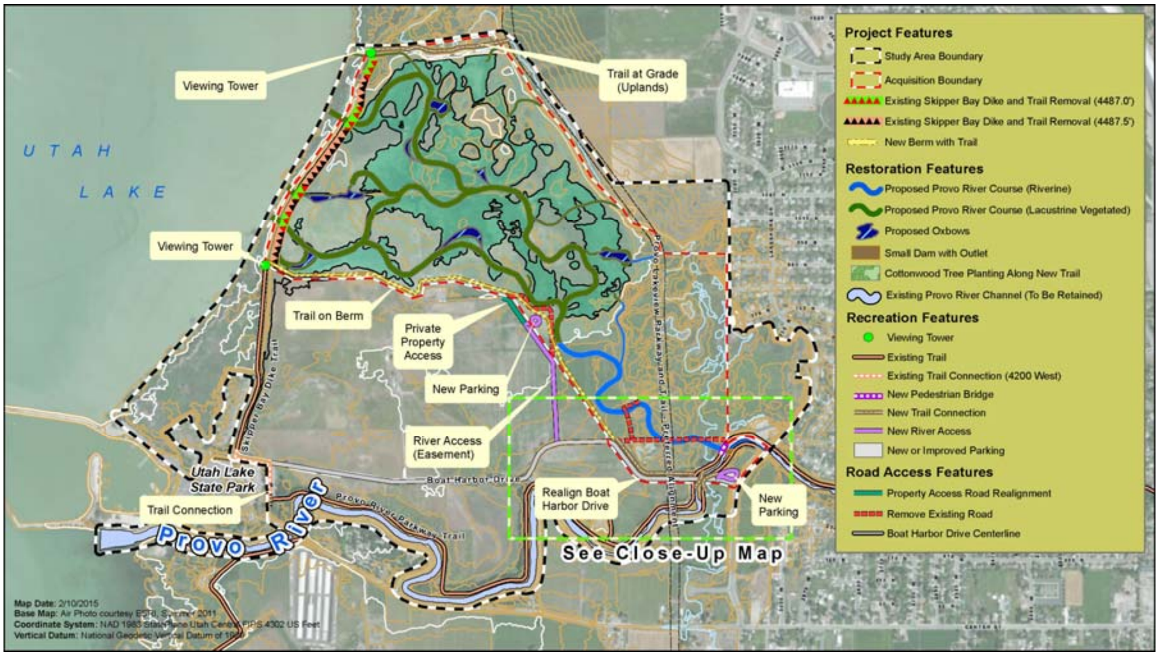

Figure 3. Provo River Delta Project

sediments accumulate over time, the river begins to braid into a series of distributary channels. Sediment accumulation causes the threaded channels to shift position over time, creating a diversity of aquatic habitat features in the delta plain zone such as abandoned channels and oxbow wetlands. These shallow and warmer areas off the main river channel support growth of submerged and emergent vegetation that provide food resources for larval fish as well as cover from predators. In the case of historic Utah Lake tributaries, these off-channel habitat zones would have been critical to June sucker survival and recruitment to more developed life stages.

Under the Project, the majority of the water in the Provo River would be routed north of the existing channel corridor into a newly created riparian river corridor and river delta area. In addition, conditions will be improved within the existing Provo River channel. Newly created braided channels will promote the development of a diverse, vegetated aquatic environment capable of supporting young-of-year and juvenile June sucker and other aquatic life.

The acquisition of higher-valued private agricultural crop lands will be kept to a minimum while still providing adequate space for a naturally functioning river delta and sufficient habitat enhancement for achieving the Project's need and purposes. Approximately 310.3 acres of property will be acquired and/or included in the Project.

The existing river channel will remain in place and be provided with a guaranteed flow of 10 to 50 cubic feet per second depending upon the volume of flow in the river. A small dam will be constructed at the downstream end of the channel near Utah Lake State Park. This dam will maintain the water level in the existing channel at a relatively constant elevation year round.

The Project includes the design, construction, and operation of an aeration system for the existing channel. The purpose of the aeration system will be to increase dissolved oxygen concentrations and improve water quality during the hot summer months compared with existing baseline conditions. The aeration system will also reduce or eliminate blue-green algae and reduce the release of manganese, iron, nitrogen, and phosphorous from the bottom sediments. Additional details for improving the condition of the existing channel as a recreation resource, such as safer access for anglers and other recreational water users, will be incorporated during final design and will involve additional coordination and cooperation with Utah County, Provo City, landowners, and interest groups.

RECREATIONAL FEATURES

Creating or enhancing recreation opportunities is one of the purposes of the Project. The existing Provo River channel and associated trail facilities are valuable recreational resources for activities such as running, walking, cycling, boating, and fishing. Existing recreational facilities and activities will be retained and new facilities and opportunities will be created.

The newly developed natural area will provide a variety of public recreation opportunities, including trails that will connect with the existing Utah County/Provo River Trail system. A berm will be constructed along a portion of the property acquisition boundary to prevent lake inundation and river channel migration onto the adjacent private lands. A trail will be integrated into the construction of the berm and, will connect with other trails in the area. A parallel, unpaved trail intended for equestrian use would be constructed at the base of the berm if it is determined to be reasonably practicable in final design. A viewing tower will be constructed near the Utah Lake shoreline.

Public access to the new river delta area will be provided from several new parking areas. Access into the river delta area will be provided for non-motorized activities, such as canoeing and fishing, and potentially for waterfowl hunting, as will be determined in cooperation with the Utah Division of State Parks and Recreation and the Utah Division of Wildlife Resources. While the proposed delta is designed to provide prime habitats for the early stages of development for June sucker, these habitats will also benefit some sport fishes found in Utah Lake, including various bass species (*Centrarchidae* sp.) and catfish species (*Ictaluridae* sp.).

PROVO AIRPORT BIRD-AIRCRAFT STRIKE RISK

During scoping and through subsequent interagency consultations, concern was expressed about the potential for increased risk of bird-aircraft strikes in association with air traffic at Provo Airport. This is a serious matter and substantial effort has been devoted to analyzing this risk and in developing monitoring and mitigation procedures if adverse effects are found. Several approaches were taken to evaluate bird-aircraft strike risk, and assessment methods were developed in consultation with wildlife specialists from the Federal Aviation Administration (FAA) and U.S. Department of Agriculture (USDA) Wildlife Services.

The concern is whether the Project will cause changes in bird species composition, abundance, and/or movement patterns that would result in an increased risk of aircraft-bird strike, given the proximity of the Project area to Provo Airport. The Provo Airport is positioned less than 0.5 mile south of Provo River on the eastern shore of Utah Lake. The Provo Airport is currently surrounded to the northwest, west, southwest, south, and southeast by a combination of emergent marsh and open water. To the north, northeast, and east it is surrounded by intermittently flooded agricultural land and the Provo River. The current mouth of the Provo River is approximately 2,000 feet northwest of the runway that was expanded in the 1990s. The airport was built in the center of the historic Provo River delta. Utah Lake is immediately west of the Provo Airport and Provo Bay is immediately to the south. The airport is surrounded by a levee and drain system to keep it from being flooded by Utah Lake. A variety of deep water, emergent marsh, wet meadow, and upland habitats currently occur within the airport property.

Under existing conditions, the Project study area supports a majority of bird species that are known to present a risk to aviation. The Project will create new areas of open water and improve wetland habitats. While many lake-wide factors will continue to influence the abundance and diversity of avian species and movement patterns of birds in relation to the airport, the Project is expected to have an overall net decrease in bird abundance for those species identified by the FAA as creating the most concern for air traffic bird strikes. Although many species would decrease in overall abundance under the Projct, certain individual species are projected to have increased abundance at certain times of the year. Numerous factors influence the risk of a bird-aircraft strike. Abundance alone is not necessarily the sole, or sometimes even the major, factor in risk assessment. Birds only become a potential hazard to aircraft if/when they fly through the aircraft operating air space, typically near the approach and departure space of an airport.

Analyses were summarized in a Bird-Aircraft Strike Risk Technical Memorandum (Mitigation Commission, et al. 2015). It predicts changes in abundance for various species of birds known to be hazardous to aircraft. Because a change in abundance may not be directly correlated with strike risk, the analysis also includes observations of bird movement in the Project area and airport vicinity under existing conditions. While the analysis predicts changes in bird abundance, it remains uncertain how bird movement patterns might change as a result of the Project and other changes that may also happen in the airport vicinity over time. Consequently, the Joint Lead Agencies commit to continue to coordinate with Provo City, USDA Wildlife Services, and FAA to determine and then to carry out appropriate pre- and post-project wildlife monitoring and mitigation.

PRIVATE LAND ACQUISITION

Private lands and interests in lands including water rights will be acquired to implement the Project. These proposed acquisitions have been a major issue of concern. The Project was formulated to reduce the necessary land acquisition while still being sufficient in size to meet the underlying need for the Project. Because of the extensive coordination with landowners during the past several years, Interior anticipates acquiring all lands and waters needed for the Project on a willing-seller basis. Lands and water that can be acquired on a willing seller basis will be acquired by the Mitigation Commission under their authorities. However, the Draft and Final EIS recognize the potential use of eminent domain authorities as one method available for land acquisition. Reclamation Authorities will be used to acquire land and water for the Project when these lands and water cannot be acquired on a willing seller basis.

WATER QUALITY

Recent water quality monitoring in the lower Provo River indicates that existing summertime water-quality conditions on the lower Provo River can be poor for aquatic life due to low concentrations of dissolved oxygen (Mitigation Commission, et al. 2015). In 2013 dissolved oxygen concentrations were found to be below the lethal limits published in the scientific literature for most fish species and Utah State water quality standards during extended periods of the hot summer months. Current conditions indicate an impairment of designated beneficial uses such as recreation, aesthetics, cold water fisheries, and warm water fisheries.

Aeration is included as an element of the Selected Action and is expected to stabilize dissolved oxygen concentrations throughout the water column and the sediment–water interface. The water column would have a minimum of 5-6 ppm of dissolved oxygen during system operation and would eliminate constantly rising and falling dissolved oxygen levels. This reduces stress in fish and improves growth rates, vitality and overall health. Stable dissolved oxygen levels also increase aquatic invertebrate populations (natural fish food) and natural populations of beneficial aerobic microbes, which can all be killed when the lower part of the water column is anoxic. Aeration will provide a reduction in nutrients and suspended solids in the water column that can contribute to algae growth. It would also provide a reduction in organic sediments and Sediment-Oxygen Demand, thus reducing muck on the bottom of the river and improve river sediments.

THREATENED AND ENDANGERED SPECIES

Three federally listed species are known or have the potential to occur in or near the Project study area. The first, June sucker, is an endangered fish species endemic to Utah Lake and is the focus of the Project. The second, Ute ladies'-tresses (*Spiranthes diluvialis*), is a threatened orchid flower species that is found in the study area and in other sparse populations throughout the west-central United States. The third species, the yellow-billed cuckoo (*Coccyzus americanus*), is a bird species that may use the existing riparian vegetation habitat during migration.

The Project would have similar effects for these species. Possible negative effects could occur through construction impacts and/or hydrologic modification and habitat modification; however, each of the species may also experience long-term benefits from habitat expansions and habitat quality improvements that would be implemented. The Joint Lead Agencies began informal consultation with the U.S. Fish and Wildlife Service (USFWS) in February 2011. A Biological Assessment, submitted to the USFWS in

August 2014, indicated potential to adversely affect some Ute ladies'-tresses individual plants as a result of hydrologic modification.

Through coordination with USFWS, it was concluded that the Project could adversely affect some June sucker individuals because some larval or juvenile fish drifting downstream in the Provo River after hatching could be diverted into the existing channel, which would be semi-isolated from Utah Lake and the river delta. These fish would thus be trapped and would likely be consumed by game fish. The potential for this to occur can be minimized in the design of the diversion feature. Another concern was that spawning June sucker may attempt to enter the old river channel, which would no longer provide access to spawning areas of the Provo River. However, research has indicated that June sucker are highly mobile throughout the Utah Lake environment (Buelow 2006), and tend to aggregate near mouths of all major tributary streams during both pre-spawning and post-spawning periods. The same individual fish have been observed in multiple tributaries during the same year, suggesting that they are adaptable with respect to tributaries where they will spawn, seeking out available and functional habitat. The Project will exclude fish from entering the old channel. It is also expected that routing higher flows through the river delta area will result in the necessary environmental cues for spawning to occur in the restored delta area and accessible areas higher up in Provo River.

Through subsequent formal consultation with USFWS, appropriate conservation measures were identified to reduce potential effects to all three of the listed species. The USFWS plans on issuing a Biological Opinion during August, 2015.

WETLANDS

A net gain of 25.2 acres of wetlands is expected as a result of restoring the surface water hydrologic connection between the Provo River and Utah Lake. Existing wetlands within the property acquisition area will be restored to a more natural condition and would have a significant functional unit gain. Long-term management of the developing vegetation community will be necessary to prevent further spread of invasive common reed and other weeds. A vegetation management plan has been developed for this purpose.

FISHERY RESOURCES

The Project will have an overall positive effects on fishery resources by restoring a naturally functioning river-lake interface and increasing acreage of open water (deep water, riverine, lacustrine vegetated aquatic bed), delta and wetland habitats. Aquatic habitats will be increased in the area. The Project is specifically designed to benefit June sucker, but will benefit other species as well, with some benefitting more than others. As a generalist species, common carp would likely take advantage of the restored delta area; thus, an ongoing effort to reduce this species to a manageable level in Utah Lake is important. Positive effects of the Project would combine with other efforts being pursued by multiple entities to improve the ecological condition of Utah Lake and this would benefit the Utah Lake fishery. Overall, angling opportunities would be expanded and improved over existing conditions.

CULTURAL RESOURCES

The area of potential effects was surveyed for cultural resources in November 2013, to the extent that access was granted by private property owners. No cultural resource sites were found that were considered eligible for listing on the National Register of Historic Places. It was determined, however, that there was a high probability that buried sites would be uncovered during construction. Since those sites are now covered by soil and the effects to historic properties cannot be fully determined prior to selection of an action alternative, it was decided, in consultation with the State Historic Preservation Office, that a Programmatic Agreement would be the best method for addressing potential impacts to eligible resources.

The Programmatic Agreement, which was signed by the parties to the agreement in April 2015, represents a commitment on the part of the Joint Lead Agencies to implement a plan to mitigate the effects of the undertaking. The Programmatic Agreement includes the development of a testing plan, which would be implemented prior to construction. The purpose of the testing plan is to identify potential subsurface historic properties through the use of hand testing, heavy machinery, or other appropriate methods. Testing would focus on areas of high archaeological probability and/or low ground visibility. If the testing results in the identification of eligible resources, then the Joint Lead Agencies would evaluate design changes that would eliminate or minimize impacts. If the impact cannot be fully eliminated through design changes, then a treatment plan would be developed and implemented. The treatment plan would identify non-design measures that would be implemented to mitigate for residual impacts. The Programmatic Agreement also provides for an archaeological construction inspector to be onsite during construction. If buried resources are uncovered during construction, construction activity would be stopped in the vicinity of the uncovered site and the eligible site would be mitigated in accordance with the treatment plan. Impacts to eligible cultural resources, if any, would be fully mitigated under the Selected Action.

MOSQUITO ABAREMENT

During scoping and through subsequent public involvement activities and agency consultations, concerns were expressed that the Project would increase mosquito production, becoming a nuisance and health risk for area residents and recreation users. Under existing conditions, the study area supports significant production of mosquitoes. Some of the Project area would support mosquito production, resulting in the need for the Project to provide for abatement consistent with abatement efforts implemented by Utah County in surrounding areas. A Mosquito Management Plan was developed to address these concerns.

NOXIOUS WEEDS

Species on the Utah Noxious Species List within the Project area require management consideration. In particular, stands of common reed (*Phragmites australis*) will out-compete native wetland vegetation and are considered to have low habitat value for wildlife. A Vegetation Management Plan was developed to address these concerns.

ACCOMMODATION OF PROVE CITY PLANNING

The designs for the PDRP accommodated Provo City's preferred alignment for the proposed Provo Lakeview Parkway and Trail. The Joint Lead Agencies met with Provo City staff periodically throughout the EIS process to discuss designs for Project alternatives to accommodate the future transportation facility. Design requirements for modifications to Boat Harbor Drive were also discussed and accommodated. A final road design for Boat Harbor Drive will be developed in consultation with Provo City and Utah County.

LONG TERM MANAGEMENT OF THE PROJECT

The United States would enter into a management contract with a local entity, most likely the State of Utah, to manage the Project. Specific terms and conditions of the contract would be developed at the completion of the construction phase of the Project, consistent with the Project's purposes, need, goals, and objectives.

ACKNOWLEDGEMENTS

We would like to thank the joint lead agencies for their continued efforts to restore the Provo River Delta and its historic habitats. We are appreciative of all the various agencies that have graciously provided consultation services during the development of this Project. Their help and guidance has been invaluable in the development a Project that is best suited to the needs of the public while addressing wildlife conservation goals.

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OLMSTED HYDROELECTRIC POWERPLANT REPLACEMENT PROJECT

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David Pitcher, P.E.[2]

ABSTRACT

The Central Utah Project (CUP) located in the central part of Utah is the largest water resources development effort ever undertaken in the State. The project provides Utah with the opportunity to beneficially use a portion of its allotted share of the Colorado River water through a transbasin diversion. The CUP was originally divided into units, of which the Bonneville Unit was the largest and last to be completed. Part of the development of the Bonneville Unit included the acquisition of water rights, a diversion facility and pipeline associated with the Olmsted Powerplant in order to provide a water supply for municipalities in Salt Lake and Utah Counties. This acquisition ultimately also included the Olmsted Powerplant.

Lucien L. Nunn completed construction of the run-of-the-river hydroelectric Olmsted Power Plant at the mouth of Provo Canyon, Utah, in 1904. Operating it for eight years, he sold it to, Utah Power & Light (now PacifiCorp) in 1912. In 1990, the Bureau of Reclamation (Reclamation) acquired the powerplant from PacifiCorp. The acquisition agreement allowed for PacifiCorp to continue to operate the facility until September 2015. The Olmsted water right is a key component of the Bonneville Unit water supply, and at times represents over sixty-five percent of storage capability in Jordanelle Reservoir. The capability of continued power generation up to 429 cfs capacity is necessary in order to maintain the Olmsted water rights. It was recently determined that the Olmsted Powerplant needed to be replaced to protect the water supply and continue the hydroelectric power generation. Through a partnership among the Department of the Interior, Central Utah Water Conservancy District, and Western Area Power Administration, an agreement was reached for funding, construction, operation, and power marketing for the Olmsted Hydroelectric Powerplant Replacement Project.

INTRODUCTION

Lucien Lucius Nunn, typically known as L.L. Nunn, grew up in northern Ohio, He became a successful American entrepreneur and educational reformer Largely self-educated due to a reading disability, Nunn eventually earned an L.L.B. degree from Harvard Law School. At the age of 27, he migrated west to seek his fortune. He landed in Telluride, Colorado, in 1881. Within seven years Nunn had become an influential banker, entrepreneur, and mine developer whose properties included the Gold King Mine in the

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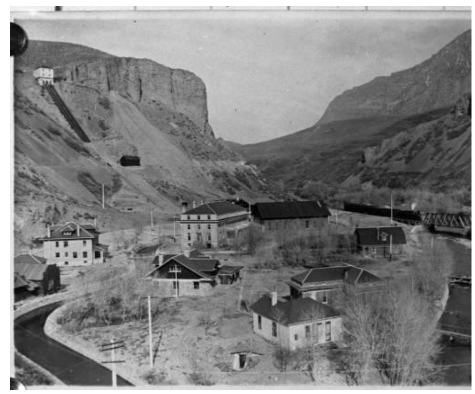
Silver Mountains southwest of town.[3] Responding to an energy crisis that threatened mine profits and the whole local economy, L.L. promoted the idea of using Tesla's theory of high voltage alternating current (AC) to generate and transmit power two and a half miles from a site along Howard's Fork to his Gold King Mine. He and his brother Paul N. Nunn eventually used $50,000 in gold from this mine to persuade George Westinghouse to build an alternating current generator and motor for a hydro plant they designed. This investment resulted in the world's first commercial AC powerplant, the Ames Hydroelectric Generating Plant that began operations in June, 1891.[4] The plant became part of the L.L. Nunn's Telluride Power Company which was absorbed into the Utah Power and Light Company.[5]

Lucien Lucius Nunn



Olmsted Campus circa 1925

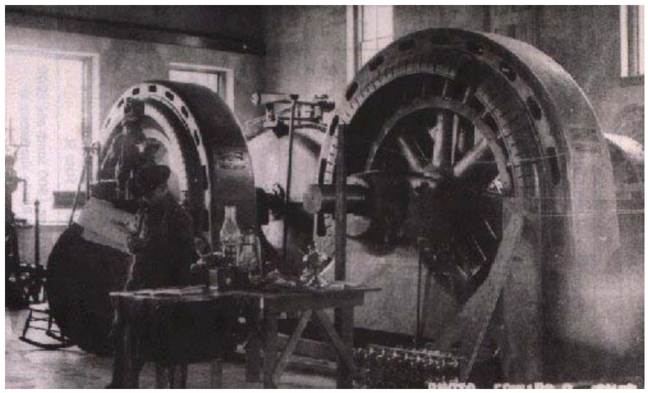
With this new technology in place Lucien and his brother also constructed the first powerplant at Niagara Falls between 1902 and 1906. To staff the powerplants, L.L. Nunn created a work study program called the Telluride Institute, located in the Provo Canyon near Orem, Utah. The Provo Canyon location was chosen to take advantage of the Provo River to develop a hydroelectric powerplant. In 1897 the Nunn brothers diverted a portion of the Provo River to Nunn's Station (now known as Nunns Park), a powerplant that generated and transmitted 44 kv, 32 miles to the mines in Mercur, Utah. This was the first truly long distance, high voltage line in the United States.

One of the engineering students at the Telluride Institute, Fay (Fred) Devaux Olmsted, helped design a larger powerplant capable of generating 12 MW to be located downstream of the Nunn Station to capture more hydraulic head. Before the plant was completed he died of tuberculosis. The Nunn brothers named the new plant in his honor. In 1904 the Olmsted plant was commissioned and began transmitting power to the growing mines in Mercur and Eureka, Utah.

The Olmsted Powerplant initially had three generators, each with the capacity of 100 cfs. The Olmsted Powerplant still retains some of the original equipment. The original equipment includes three general Electric generators (2300 volts) and nine general

3 Ira A. Fulton College of Engineering and Technology, Brigham Young University
4 Montrose Mirror, January 16, 2013
5 The Electric Edge of Academe, 2015

electric transformers (2300–44,000 volts). In 1917, the Olmsted wood flume conveyance facility was rebuilt and another generator was added. This generator had an additional capacity of 225 cfs. The wood flume from Nunns Park to the Olmsted Powerplant was replaced with an above ground steel pipeline in 1949 and from the diversion dam to Nunns Park in 1952. This steel pipeline was painted green and was called the Olmsted Flowline. It was a visible landmark in Provo Canyon. Between 1990 and 2004, the Central Utah Water Conservancy District replaced or upgraded the entire diversion facilities and flowline.



Original Olmsted Generators

The Olmsted campus continued to operate as an educational facility until 1912 when Utah Power and Light acquired Olmsted and closed the Telluride Institute. Since then the Olmsted Powerplant has continued to produce electricity and the Olmsted campus has been used to house plant workers and offices for staff. The film industry has also been drawn to the secluded area and well preserved buildings. Filming has been shot on location for several films, and most recently Brigham Young University's TV series, Granite Flats.[6]

CENTRAL UTAH PROJECT

The Central Utah Project (CUP), located in north-central Utah, is the largest water resource development ever undertaken in the State. The project benefits the State and provides much of Utah's rapidly expanding population, now surpassing 2 million, the opportunity to use a portion of its allotment from the Colorado River, by means of a transbasin water diversion.

Investigations for a project for central Utah were conducted by Reclamation from 1939 to 1943. Eventually the Central Utah Project (CUP) was authorized in 1956 as a participating project under the Colorado River Storage Project Act. The CUP was introduced in two phases: the Initial Phase included four of the six units: Bonneville Unit, Jensen Unit, Vernal Unit, and the Upalco Unit, and the Ultimate Phase involved the remaining two units, the Uintah Unit and the Ute Indian Unit. The Ultimate phase was

[6] Utah Valley 360, September 9, 2013

never authorized. The largest CUP unit is the Bonneville Unit which is still under construction. A critical feature of the Bonneville Unit is Jordanelle Reservoir located in Wasatch County, Utah. The construction on Jordanelle Dam was completed in 1993 and the reservoir was initially filled in 1996. The reservoir yields 90,000 acre-feet for Salt Lake and Utah counties and 14,500 acre-feet for Wasatch County.

Jordanelle Reservoir

During the planning for Jordanelle, planners took notice of the Olmsted Facilities. With an existing diversion dam conveniently located across the Provo River, it would be an ideal location to divert CUP water. The diversion would then continue through the Olmsted pipelines and on to municipal and industrial customers. Federal officials initiated discussions with Utah Power and Light regarding Olmsted and by the mid 1980’s began the process for acquisition of not only the diversion and flow line but eventually for the pressure box, penstock, powerplant and many of the buildings at the Olmsted campus.

A settlement agreement was reached in September 1990 between the Central Utah Water Conservancy District, Department of the Interior, and Utah Power and Light. The agreement outlined the compensation and provided for interim operation of the Olmsted Hydroelectric Powerplant. Utah Power and Light merged with PacifiCorp in 1989. Although the United States gained ownership of the Olmsted facilities in 1990, the agreement provided for Utah Power and Light (now PacifiCorp) to continue to operate and benefit from power generation as part of the compensation for the acquisition. The Settlement Agreement was to remain in force until September 21, 2015, after which the operation of the Olmsted facilities would be conducted by CUWCD.

The water supply for Jordanelle Reservoir is provided through a series of water right exchanges involving Strawberry Reservoir, another CUP reservoir, and Utah Lake, a natural water body. Water is stored in Jordanelle Reservoir from the Provo River which historically flowed into Utah Lake. To replace the water that should have flowed into Utah Lake, water is released from Strawberry Reservoir into Utah Lake. This exchange compensates water users who are dependent upon water from Utah Lake.

WATER RIGHTS

The acquisition of Olmsted by the United States not only provided the diversion and facilities to convey CUP water to rapidly growing communities but also the water rights associated with the original Olmsted Project. As planning for the Bonneville Unit progressed it became clear that the Olmsted water rights were critical to the operation of the Bonneville Unit and storage at Jordanelle.

The water rights authorizing the use of water for power generation at the Olmsted Powerplant are identified in the Provo River Decree from 1921, Civil No. 2888. The total quantity of water decreed for power generation use is 429 cfs. This flow right is comprised of two separate water rights. The first is a right with a priority date of 1897; it allows the diversion of 229 cfs for power generation. The second right is for 200 cfs with a priority date of 1917.

Historically the water represented by these two rights has been diverted at the Olmsted Diversion Dam and conveyed through the Olmsted Flowline for generation at the Olmsted Powerplant and returned to the Provo River. The Power Water Rights are non-consumptive because they flow through the turbine and then return to the river. During irrigation season other water right holders had appropriated this water for irrigation use downstream from the powerplant.

As the Olmsted Power Water Rights are non-consumptive in nature, they can only be protected if the ability to use the water for generation remains in place. Without the Olmsted Powerplant and the ability to generate, the Olmsted Power Water Rights could be lost to forfeiture for non-use.

The Olmsted Settlement Agreement provided for the continued use of the Olmsted Power Water Rights. Among the parties, the 429 cfs water rights would be treated as if legally subordinated in priority to the water rights of the Bonneville Unit for storage in Jordanelle Reservoir. This in essence gives the CUP the ability to interfere with its own power generation at the Olmsted Powerplant. CUP water rights are used in order avoid interference with downstream water rights. This allows water to be stored under the Bonneville Unit's water rights in Jordanelle Reservoir.

The continued operation of the Olmsted Powerplant, which enables the preservation of the Olmsted Power Water Rights, is essential for the storage of water for the Bonneville Unit. During the 2014 water year the Olmsted Power Water Rights provided sixty-five percent of the total storage in Jordanelle Reservoir.

There are some parties who hold consumptive use rights associated with the Olmsted water rights. Some of these water users have filed change applications which have changed the points of diversion or places of use that preclude the generation of water at the Olmsted Powerplant. Because these applications are junior in priority to the Olmsted power Rights, the holders of these rights make a power interference payment or provide replacement water at a later time.

NEGOTIATION PROCESS

In 2007, the CUWCD and CUPCA Office began discussions regarding Olmsted. With the pending expiration of the Settlement Agreement and operation of the powerplant by PacifiCorp in September, 2015, it was clear that CUWCD and the Department of the Interior needed a long term sustainable plan for continued operation of power generation at Olmsted. After that date if the plant was not generating power for a sustained period, the Power Water Rights would be in jeopardy, which in turn jeopardizes the Bonneville Unit water supply. Also, in accordance with the Settlement Agreement, CUWCD would be responsible for operation and maintenance of the 100 year-old Olmsted facilities.

At the Request of the CUPCA Office, in 2008, Reclamation conducted a review of the Olmsted facilities and summarized their findings in a report[7]. The purpose of the study was to determine improvements needed to keep the powerplant in operation for twenty-five years. The report listed repairs needed for continued operation. In particular the report listed needed maintenance recommendations to eliminate safety hazards. These included securing the pressure box to prevent unauthorized access as well as repair of the trash rack covers.

Several options were identified to protect the Power Water Rights. One option was to apply to the State Engineer for a change from non-consumptive to a consumptive water right and change the place of use to Jordanelle Reservoir. This option was not followed because the water rights arrangements at Olmsted were also connected to other situations through a 1938 agreement. Opening discussions on Olmsted had a chance of a negative outcome not only for Olmsted but potentially for other Reclamation projects.

Another option was to attempt to extend the Settlement Agreement with PacifiCorp for continued operation of the Olmsted Powerplant. The Settlement Agreement included a provision for extending the agreement under certain conditions. CUWCD and the CUPCA Office approached PacifiCorp with the idea to extend the Agreement. Some of the considerations for the extension included rehabilitation of the facilities to provide for long term operation and maintenance. In 2009, a Renewal Agreement was drafted and negotiators from the CUWCD, CUPCA Office, and PacifiCorp were appointed. Negotiations zeroed in on who would pay for the facility upgrade and who would benefit from continued power generation. PacifiCorp policy would not allow them to make capital expenditures on facilities they did not own. The United States could not justify expending federal funds on a project where no revenue would be generated. Ultimately negotiations were discontinued in 2010.

Considering recent experience with power development at Jordanelle Reservoir, the option of non-federal power generation under a Lease of Power Privilege was considered. This option would allow a non-federal entity to take over operation of Olmsted, make the necessary upgrades or construct a new facility. This idea was not pursued because the primary purpose for power generation was to protect the water rights and the parties were

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[7] Reclamation, 25 Year Life Extension Report, June 17, 2008

concerned with leaving the generation in the hands of a third party without direct ties to the Bonneville Unit.

The option finally adopted was to allow the Settlement Agreement to come to an end and assume operation as a federal facility. This would be done through rehabilitation of the existing facility or construction of a replacement facility.

In a separate analysis, CUWCD hired CH2MHill to conduct a technical evaluation of the Olmsted Powerplant[8]. The purpose of the study was to provide an evaluation of the potential for rehabilitation, upgrade, and improvement of the Olmsted Powerplant. The evaluation study began in 2010 with a review and survey of the existing Olmsted facilities. CH2MHill evaluated the preservation of project water rights, took into consideration the useful life of the existing facilities, associated risks balanced with reliability of the powerplant. A rough estimate for repair and replacement of Olmsted facilities was estimated to be $12,826,743.

NEPA

As early as 1949 the planning for the Bonneville Unit assumed there would be impacts to the Olmsted power generation as a result of development of the Bonneville Unit[9]. The 1964 Definite Plan Report mentioned the need for agreement with Olmsted and states "It is anticipated the project will acquire the Olmsted Powerplant under Section 14 (as amended August 6, 1935) of the Federal Power Act[10]."

As environmental documents were being prepared, planners incorrectly assumed that as demands for project water increased, flow available for operation of the Olmsted Powerplant would correspondingly decrease and the plant would ultimately have to be shut down. The 1979 M&I System FEIS states; "On the basis of predicted population increases and the corresponding demand on project water, it would be economically feasible for the plant [Olmsted] to remain operational until about the year 2000."[11]

The early planners saw the critical role the Olmsted Facilities would play in diverting and conveying water to the water uses in Salt Lake and Utah counties but they seemed to underestimate the importance the Olmsted Power Water Rights would play in the ultimate operation of the Bonneville Unit.

As the parties considered the past statements in environmental documents and the work that would be undertaken to replace the existing Olmsted facilities, a decision was made to proceed with National Environmental Policy Act (NEPA) compliance. CUWCD hired Horrocks Engineering to help with the preparation of an Environmental Assessment

[8] CH2MHill, Assessment and Planning Summary, July 2012
[9] 1949 Report to the Regional Director on the Central Utah Project, page 6
[10] Power Appendix (Appendix F) of the 1964 Definite Plan Report for the Bonneville Unit of the Central Utah Project, page 79
[11] 1979 Central Utah Project, Bonneville Unit, Municipal and Industrial System, Final Environmental Impact Statement, Page A-11

(EA). The purpose for the project as stated in the EA is "The need for the Olmsted Hydroelectric Powerplant Replacement Project is to maintain the full water supply for the Bonneville Unit of the Central Utah Project and to continue safe and efficient hydroelectric power generation."[12] The document details the importance of power generation at Olmsted and the intent to continue operations indefinitely. As stated in the EA the Proposed Action would make improvements at Olmsted including:

- Constructing a new powerhouse
- Replacing the penstocks
- Modifying water delivery system
- Improving site access

Adverse effects identified in the EA were mainly due to cultural resources. Impacts were to be mitigated by working with the Utah State Historic Preservation Officer. An agreement was reached whereby the existing powerplant building would be preserved and maintained to be available for scheduled public tours while other buildings would be removed. A Finding of No Significant Access was signed January 16, 2015.

AGREEMENTS

As planning for the project proceeded it was apparent that a partnership among several entities was necessary for successful implementation. These parties included the CUPCA Office, CUWCD, Reclamation, and the Western Area Power Administration. The responsibilities of each party were outlined in a memorandum of agreement called the Implementation Agreement[13]. This agreement is among the CUPCA Office, CUWCD, Reclamation, and Western. It acknowledges that the Olmsted Facilities are necessary to maintain critical water rights essential for the CUP and that the Olmsted Facilities are features of the Bonneville Unit of the CUP and that the CUP is a participating project of the Colorado River Storage Project Act (CRSPA). As such, the revenues, collected from the sale of power from the Olmsted Facilities can be deposited into the Basin Fund, managed under CRSPA, and can be used by the CUPCA Office to contract with CUWCD for the operation, maintenance, and replacement of the Olmsted Facilities.

Another agreement is the Funding Agreement[14] which is between the CUPCA Office and the District. This agreement also acknowledges that the Olmsted Facilities are necessary to maintain critical water rights essential for the full development of the Bonneville Unit of the CUP. The agreement defines the role of the CUPCA Office and allows it to perform several functions under the authority of CUPCA and CRSPA; including providing funds for the construction of the project, monitoring the expenditures of the funds, and reviewing the final design, as well as construction monitoring of the project. The Funding Agreement also defines how contributed funds will be provided and accounted for.

[12] 2015, Olmsted Hydroelectric Power Plant Replacement Project, Final Environmental Assessment, page 1-5

[13] Implementation Agreement to Provide for the Olmsted Hydroelectric Power Plant Replacement Project, No. WS-15-100, February 5, 2015

[14] Funding Agreement No. 15-WC-40-566, February 5, 2015

Funding the replacement of the Olmsted facilities was a very complex issue. Olmsted is unique in many ways. As a part of the Bonneville Unit, the facilities would be operated and maintained by CUWCD according to the 1964 Repayment Contract. Unlike other Bonneville Unit facilities where CUWCD collects money from water users to pay for Operation, Maintenance and Replacement (OM&R), the Olmsted OM&R would be paid by revenue collected from power generation and power interference.

Although the Olmsted facilities are and will remain the property of the United States there was no specific congressional authorization for appropriating funds for the replacement of the facilities. Other funding sources needed to be identified.

Estimated Funding Sources (subject to change)	
Escrow Account	$3,400,000
CRSPA MOA	$8,000,000
Basin Fund - 5(c)	$5,300,000
CUWCD Contributed Funds	$2,400,000
Future funds	$10,593,000
Total Estimate	$29,693,000

The concept behind the Settlement Agreement was that part of the payment to PacifiCorp would come through revenues from power generation until September 2015. An estimate of the revenues was described in the Agreement. It was recognized that as the Bonneville Unit water supply was developed there was a potential for decreased generation at Olmsted. In consideration of a potential reduction in revenues the Agreement included a provision to establish a fund, termed the Escrow Account, whereby PacifiCorp would be reimbursed if the revenues from power generation were less than the estimates. The remaining funds in the Escrow Account when the Settlement Agreement came to an end could be used for the Olmsted Replacement Project.

Because the Olmsted Power Right is one of the most senior rights on the Provo River, if water users removed water upstream of the powerplant, they are required by the State Engineer to pay an interference charge for lost generation at Olmsted. Some of these funds were collected by CUWCD and could be used for the Olmsted Replacement Project and were considered part of the CUWCD Contributed Funds.

Under the Reclamation Act of 1939, funds received from power generation and other incidental revenues can be credited to the project where the revenues are generated. In the case of the Central Utah Project, revenues are generated from lease payments under a Lease of Power Privilege, carriage fees, etc. These funds could be used for the Olmsted Powerplant Replacement Project.

Through a Memorandum of Agreement among the Department of the Interior and Colorado River States, the states could use some of the revenues from CRSP power generation for federal projects. The State of Utah identified funds that could be used for the Olmsted Powerplant Replacement Project.

Recognizing the importance of protecting the Olmsted Power Rights, CUWCD committed to provide funds towards the project. The Department also committed to seek additional funds for the project. With these funding commitments in place, the parties moved forward with the execution of the agreements on February 5, 2015.

DESIGN

The replacement of the Olmsted Facilities was not described in the 2005 DPR. To comply with policy, an Olmsted Project Report was developed by CUWCD and submitted to the CUPCA Office and congress in February 2015. This essentially amended the 2005 DPR.

Prior to final design federal projects are required to undergo a detailed review called Value Engineering (VE). In December 2014, a VE study was conducted on the preliminary design of the Olmsted Hydroelectric Powerplant[15]. The VE Study team was comprised of construction, engineering, geotechnical, structural, and environmental experts that reviewed the preliminary design plans. The VE Study confirmed the conclusion that the existing powerplant could not be economically and reliably rehabilitated and needed to be replaced. The recommended plan for the project was estimated to cost $30,193,000. The study recommended moving the rehabilitation of the existing powerhouse to a future OM&R activity as soon after the new powerplant is constructed and recommended several valuable design suggestions. It also investigated and recommended several new configurations of the generation equipment in the powerplant. The new cost estimate agreed by the parties was $29,693,000, as shown below. The VE Study recommended that the Utah Lake System use the proposed Olmsted Powerplant penstock to connect to the Alpine Aqueduct, a large diameter CUP pipeline, instead of a separate pipeline. It was estimated that this recommendation would save nearly $4 million on Utah Lake System which is a project separate from the Olmsted Facilities.

Estimated Project Costs (subject to change)	
Conveyance	$4,376,000
Power Plant	$20,125,000
Micro Hydropower	$1,328,000
Project Administration	$3,864,000
Total Estimate	$29,693,000

Facilities to be constructed at Olmsted include the following:

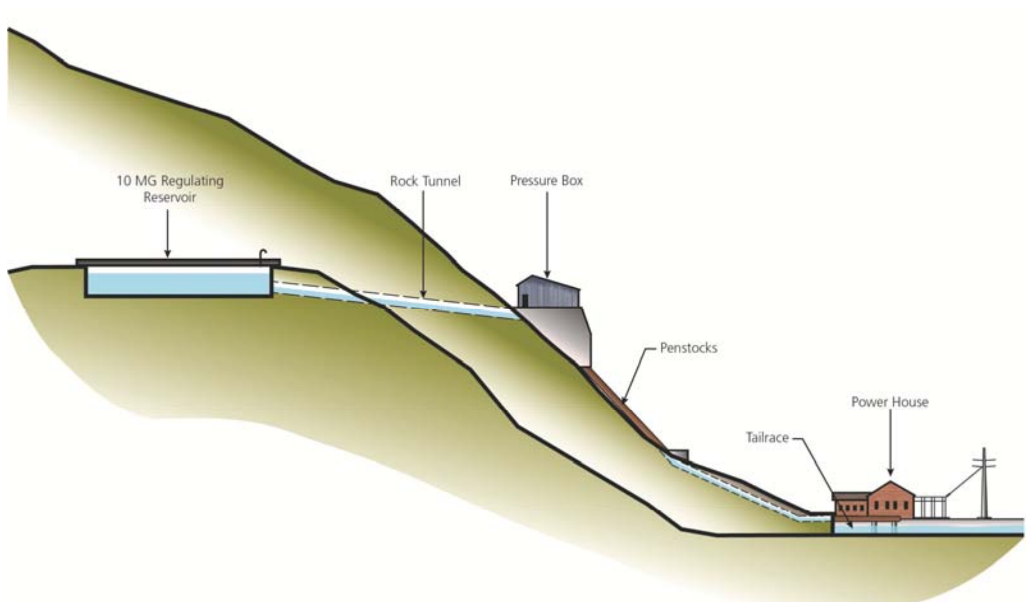
- The new powerhouse will be constructed within the existing land owned by the United States, located north and east of the existing powerhouse. The existing powerhouse will remain in-place and receive seismic upgrades as part of the future OM&R activities, but will no longer be used for hydroelectric power generation. Several existing structures north and east of the existing powerplant

[15] Olmsted Hydroelectric Power Plant Value Engineering Study, December 2014

will be removed to provide space for the new powerhouse. In addition to a new powerhouse, the project will include smaller micro hydropower units to handle flow deliveries below the limitations of the units in the powerhouse.

- The existing Olmsted Hydroelectric Powerplant includes three 48-inch and one 72-inch riveted/welded steel penstocks. These existing penstocks will be replaced with one 84-inch diameter, buried penstock in the same general alignment.

- The new powerplant will utilize an improved upstream conveyance system with a higher hydraulic head and operational storage benefits of the existing Olmsted Flowline Regulating Reservoir to replace the constantly changing existing pressure box radial gates. Using the reservoir will provide a constant water surface elevation for the powerplant, increase power generation and simplify the operation and control of water. In order to use the reservoir modifications and improvements will be made to the Rock Tunnel, spillway structure, and pressure box. An atmospheric surge tank will be constructed to help control surge events.



Profile of Existing Olmsted Facilities

To size the hydroelectric turbine generators to be installed for the project, a basis for the flows and net head was developed. The analysis included historical flow data from 1992 to 2012 recorded as bimonthly volumes in acre-feet. In addition to historical flows, information from the PROSIM (Provo River Simulation) Model was used. Data in the PROSIM model covered the period of 1950 to 1999 and assume the Bonneville Unit was under full demand. The analysis indicated that the historical data delivered approximately 80 percent more average annual flow compared to the PROSIM data. This was expected because the future demands from municipal and industrial deliveries will be greater than historical demands. To provide an accurate estimate for energy generation, an average annual hydrograph was developed by reducing the historical hydrograph based on input from CUWCD operation staff and their understanding of the PROSIM model.

The selection of generating units for the new Olmsted Powerplant was based on the ability to generate at a maximum flow of 429 cfs, which is directly related to the water rights. Multiple manufactures were consulted to provide configurations of generating units that could be used. The preliminary design included a large 280 cfs unit and two smaller tandem 75 cfs turbines with a common generator. This configuration would allow for generation from 30 cfs to 429 cfs and maximize the electrical generation from the site. Given the selected generating units, the energy production based on the adjusted historical flow data of 1992 – 2012 would be an annual average of 24,901 Megawatt Hours. To capture flows below 30 cfs the project also includes the installation of a smaller, micro hydropower unit that would utilize flows in the 7 to 20 cfs range. The actual request for proposals for the generation equipment ended up receiving proposals that included two separate turbines and generators rather than the more expensive tandem turbines with a common generator option. CUWCD is awarding the equipment supply contract in the fall of 2015 and will proceed to complete the final design of the new powerhouse after receiving design submittals of the arrangement of the specific turbines, generators and appurtenant equipment. The construction of the powerhouse and installation of the generating equipment is anticipated to commence in June, 2016 and start-up of the new powerplant is anticipated in March, 2018, with commercial generation in July, 2018.

CONCLUSION

The Olmsted water right is a key component of the Bonneville Unit water supply and particularly Jordanelle Reservoir. Jordanelle provides municipal and industrial water for over 400,000 people. The decision to re-build the Olmsted Powerplant was foremost a decision about projecting the water rights of the Bonneville Unit. Through continued generation at Olmsted, the water rights will be maintained and there will be a benefit through providing renewable energy. It is anticipated that construction of the Olmsted Hydroelectric Powerplant Replacement Project will begin the fall of 2015 and commercial generation of power will begin in September 2018.

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HYDROLOGY OF THE RECENT CALIFORNIA DROUGHT AND COMPARISON WITH PAST DROUGHTS

Maurice Roos[1]

ABSTRACT

The last four water years, 2012-15, were a period of severe drought in California. It was particularly dry across the middle part of the State, especially the San Joaquin River region, where the 4 year runoff deficit was the biggest of the 115 year historical record and also more than any 4 year period in a runoff reconstruction back 1100 years based on tree rings. The main problem was the lack of sufficient rainfall during the 3 winter months in the primary mountain watersheds. There were severe cuts in local surface water and in deliveries from the major State and federal water projects. The shortfall, especially in the San Joaquin Valley, was made up in part by additional ground water pumping from an already over drafted groundwater basin and by fallowing land. Existing reservoir storage does not provide enough water storage capacity to handle a multiyear drought.

INTRODUCTION

Water years 2012-15 turned out to be a severe 4 year drought in California (and the drought may not be over yet). Other notable droughts of the past 100 years included 1918-20, 1924-26, 1929-34, 1976-77, 1987-92, and 2007-9. Using the Sacramento and San Joaquin River system 8-river runoff as a base, the past year, WY 2014, was the 4th driest of the historical record. WY 2015 runoff was about 20 percent more than 2014 on the Sacramento, but worse on the San Joaquin River system where WY 2015 was second driest exceeded only by the severe 1977 year. For the combined 8 rivers, the current water year, October 2014 through September 2015, will probably be the 6th driest in a record of 110 years. The 4 year runoff, WY 2012-15, for the 8 river system will be the driest 4 year set of record, exceeding slightly the previous record of 1931-34. However, on the southern group, the San Joaquin River system, the past 4 years were by far the worst 4 year period in a 114 year record, and about 20 percent drier than any 4 years in a reconstructed record of over 1000 years estimated from tree rings. This drought was most severe across central California, including the Central Coast, San Joaquin Valley, and southern Sierra regions. Figure 1 compares multi-year droughts of the Sacramento and San Joaquin River basins. Figure 2 shows the hydrologic regions of California and the percentages of normal precipitation for the rainy season during the past water year 2014-15, the 4th year of the drought.

PRECIPITATION DEFICITS

The underlying cause of drought is lack of precipitation. Most of Northern California rainfall occurs during the 5 winter months from November through March. On average about ¾ of the yearly precipitation comes then. The third figure, a northern Sierra

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precipitation bar chart, shows by month what happened during the last 4 water years in the northern Sierra Nevada, our primary water supply region. The horizontal bar gives the monthly average for the 4 recent years in the bar portion of the chart. The first water year, 2011-12 started out poorly, with almost no rain during December, near normal January, and again dry in February with seasonal deficit of about 50 percent at that point and a 30 percent of average snowpack. But March precipitation was triple average with an April 1 snowpack of 50 percent alleviating major concern that year since carryover storage was good coming out of the wet 2011. Water year 2012-13 started well with November and December about twice normal, and led to concerns about floods later in the season. Then the water shut off, with no significant rain or snow for the rest of the year except for one moderate storm in March. That led to the driest calendar year of record during 2013 (See Figure 4 for the 2 year monthly precipitation record). Carryover storage from 2012 was about average and remained near average into early 2013, but would not rise much in spring because of a low 40 percent snowmelt.

The extreme dryness continued into the next water year, with December and January, normally our wettest two months, being very dry at about 12 percent average. By January, 2014, with a bone dry winter thus far, a 10 percent snowpack, and with reservoir storage at 65 percent of average and 40 percent of capacity, we realized that California was heading for serious drought and the Governor declared on official drought on January 17. February produced one significant storm with some runoff and March was above average which gave some relief. But the April 1 snowpack was only 25 percent and drought resumed in April and continued into the following winter.

The following winter, water year 2014-15, started hopefully. There was some rain in October and November and a wet December, 2014, with a couple good atmospheric river events, and about twice normal in the north. The southern Sierra did not fare as well with December a bit below average. There was virtually no rain in January which was very dry again, followed by one major warm storm in February. The wet season wound up with about 75 percent in the north and a bit under 50 percent in the southern half of the Sierra. The real surprise was the almost non-existent snowpack with a record low 5 percent measured on April 1. That was due to lack of storms and much warmer temperatures during the few storms which did come.

Shortages during the last two years of drought were severe; the State Water Project delivered only 5 percent in 2014 and the federal Central Valley Project was not even able to supply the San Joaquin Valley Exchange Contractors, which reduced the Friant deliveries to near zero. Figure 5, SWP Water Allocations, shows annual SWP delivery percentages. The State Water Project was able to garner a 20 percent supply out of the winter storm events, but the Central Valley Project saw a repeat of the dismal supply of 2014. For the second year in a row the meager flow of the San Joaquin River at Friant had to be sent downstream to the Exchange contractors, leaving little for the Friant Kern and Madera Canals.

WATER SUPPLY

California has built many reservoirs to cushion drought severity; these work pretty well for a single year drought, but multiple years cause trouble. This time there were new fishery constraints, especially in the Sacramento-San Joaquin Delta export operations, which decreased supplies further over that of past droughts, including loss of some of the federal Central Valley Project Exchange Contract water, which severely affected southern San Joaquin Valley water users.

Water year 2011 had been a good year with a good snowpack which generated about as much carryover storage as one could ask—at 130 percent of average statewide water storage on September 30. Three years later, statewide storage had dropped to 12.5 million acre-feet, 57 percent of average and 33 percent of capacity (see Figure 6, Storage in 154 California In-state Reservoirs), a bit lower than the driest year of the 6 year 1987-92 drought, but more than the driest year in 1977 when only 7.8 million acre-feet, 36 percent of average, remained. Storage in this 2015 water year is tracking lower than a year ago. Beginning in early 2014, after the driest calendar year of record, new criteria for operation of the Central Valley Project and the State Water Project with the limited supply available were developed with priorities for minimum urban health and safety (fire) needs, control of salinity intrusion from the ocean in the Delta and minimum protection of endangered species, including cold water for Sacramento River salmon. Some storms in December and February provided enough for a 20 percent delivery for the State Water Project in 2015, but comparably small amounts for CVP Delta exports, leaving major shortages in CVP supply for Project users south of the Delta again.

One of the notable factors in this 4 year drought is the warmer than average temperatures during the past two winters which impacts the portion of winter precipitation carried into the irrigation season by mountain snowpack. All four of the drought years had well below average snowpack ranging from about 50 percent in 2012 to only 5 in 2015. Figure 7 shows the history of April 1 snowpack water content for California. The previous low during 1977, our worst drought year, was 25 percent. But the winter storms of the last two years have been warmer than average with more rain than snow in the mountain watersheds. The measly 5 percent on April 1 of 2015 marks a new low and may presage what global warming would be like.

By the fall of water year 2015, estimated statewide water storage had fallen to about 12 million acre-feet, 29 per cent of capacity, but still above the historical low of about 7.5 million acre-feet in October 1977, our driest year. Part of the reason for higher levels was the strategy of keeping the CVP 4.5 million acre-feet Shasta Reservoir over 1 million acre-feet higher than the low of record in 1977 at the end of summer 2015 to maintain enough cold water to preserve winter run salmon below the dam in the river. This reduced the amount which otherwise would have gone into San Joaquin Valley water supply.

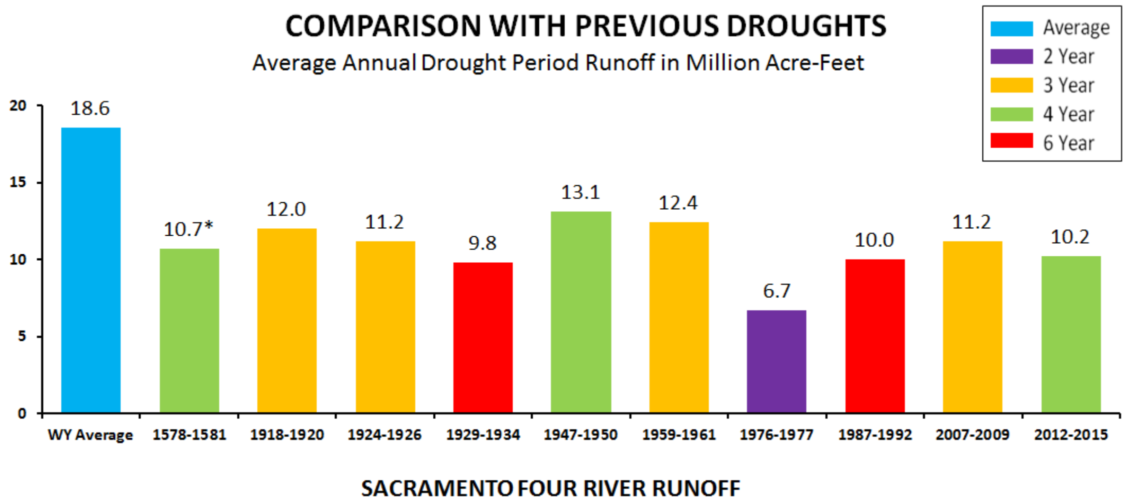
IMPACTS

There are about 9 million acres of irrigated land in California. In 2015, as estimated by the University of California, Davis[2], about 540,000 acres were fallowed. The surface supply deficit, mostly in the Central Valley, was 8.7 million acre-feet. Additional ground water pumping (mostly from overdraft) of about 6 million acre-feet partly offset the deficit, leaving an agricultural deficit of 2.7 million acre-feet.

Urban water users were required to reduce 2015 water use by 25 percent with a range of 4 to 36 percent depending on past rates of water usage. Normal urban applied water use is about 9 million acre-feet statewide, although the net water use (depletion, which accounts for reuse) is more like 6 million acre-feet, which is about a quarter of the normal irrigated agriculture usage.

Another impact example is the effect on Pacific Flyway waterfowl. An estimated 4 to 6 million migratory birds winter in the Central Valley each year. Rice is an important crop in the northern Central Valley. According to the California Rice Commission, normally about 550,000 acres are grown. After harvest these farmers create about 300,000 acres of managed wetlands. In 2014, with 25 percent CVP water supply reductions, rice acreage was reduced to 435,000 acres and, in 2015, to 375,000 acres. After harvest, many of the rice lands are flooded and provide excellent food and forage for migrating waterfowl, vital for the Pacific flyway. Reduced acreage can lead to more crowding of birds with increased disease outbreaks.

[2] Economic Analysis of the 2015 Drought for California Agriculture, R. Howitt, D MacEwan, J. Medallin-Azuara, J. Lund, and Daniel Sumner, Aug, 2008, UC Davis Center for Watershed Sciences, Davis, CA



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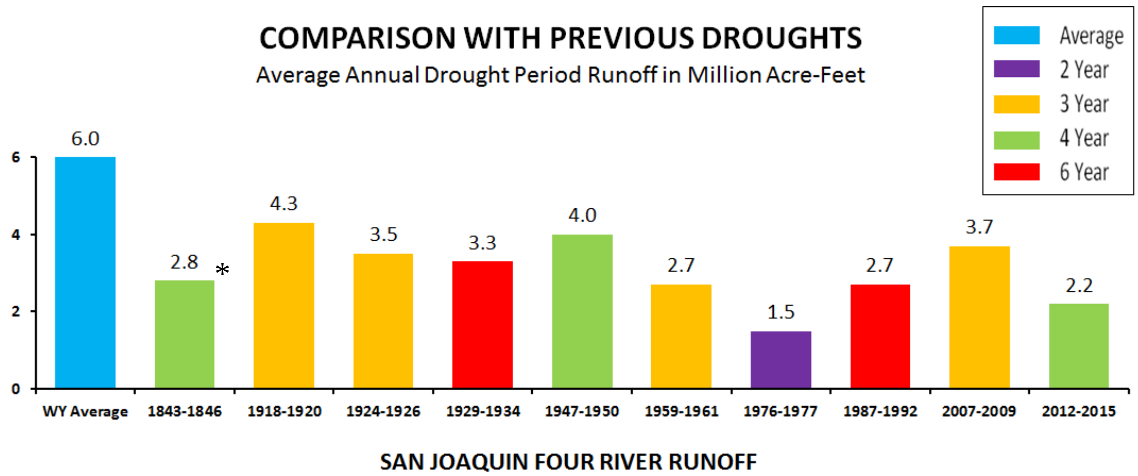

*from tree rings

Figure 1. Multiyear droughts of the Sacramento and San Joaquin River Basins

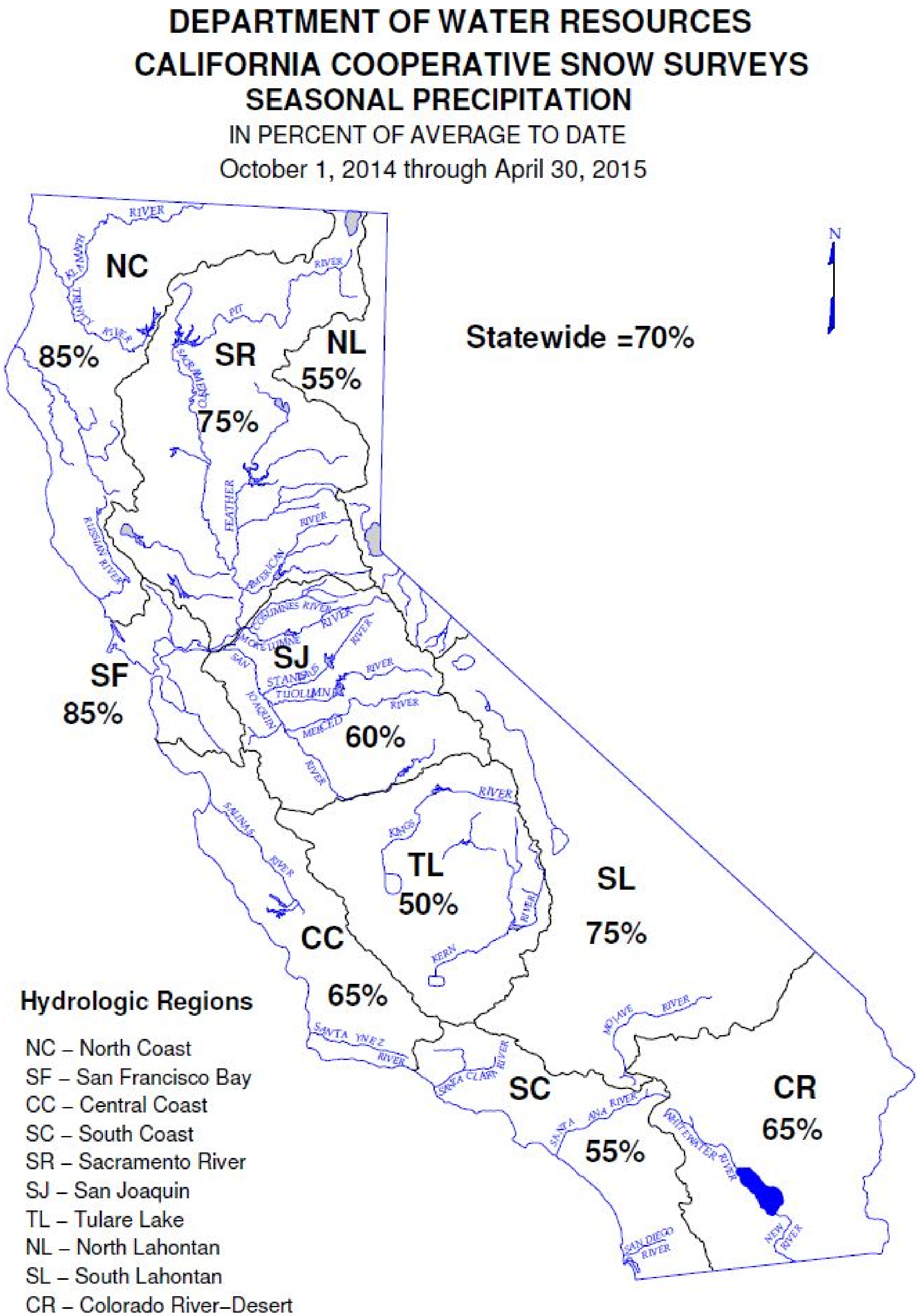

Figure 2. California Precipitation for the 2014-15 Rainy Season.

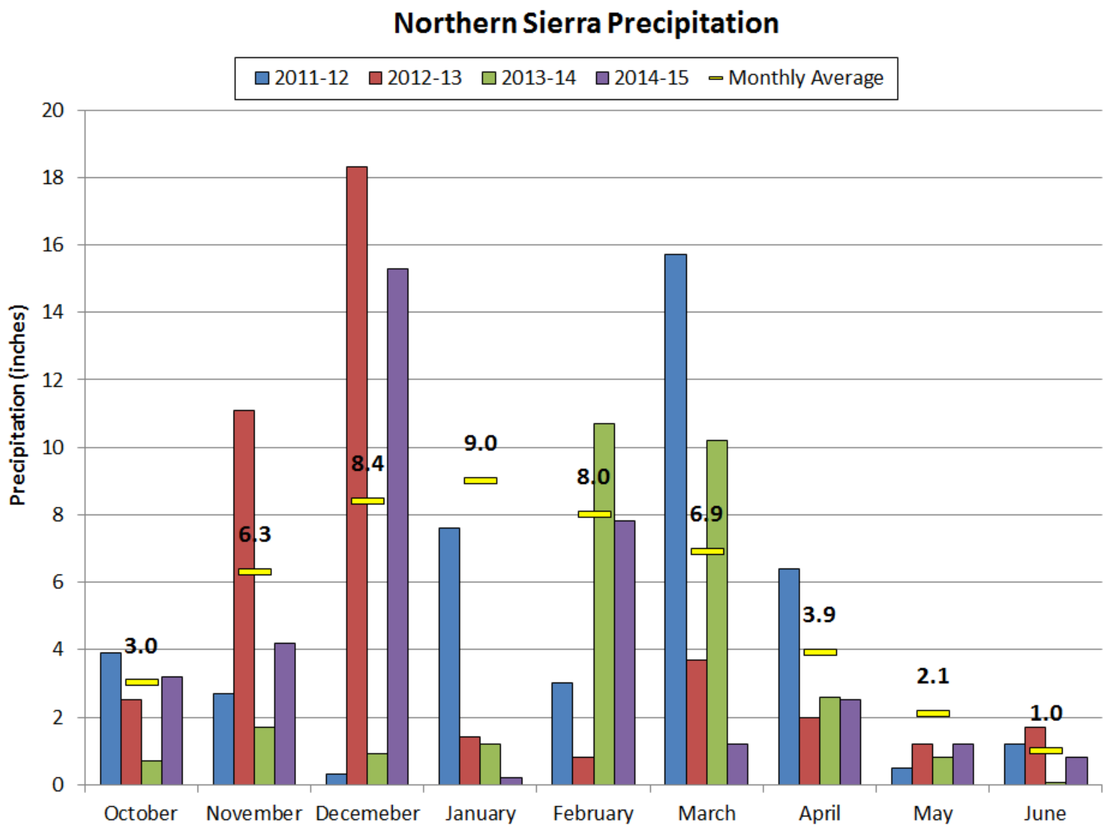

Figure 3. Northern Sierra 8 Station Monthly Precipitation

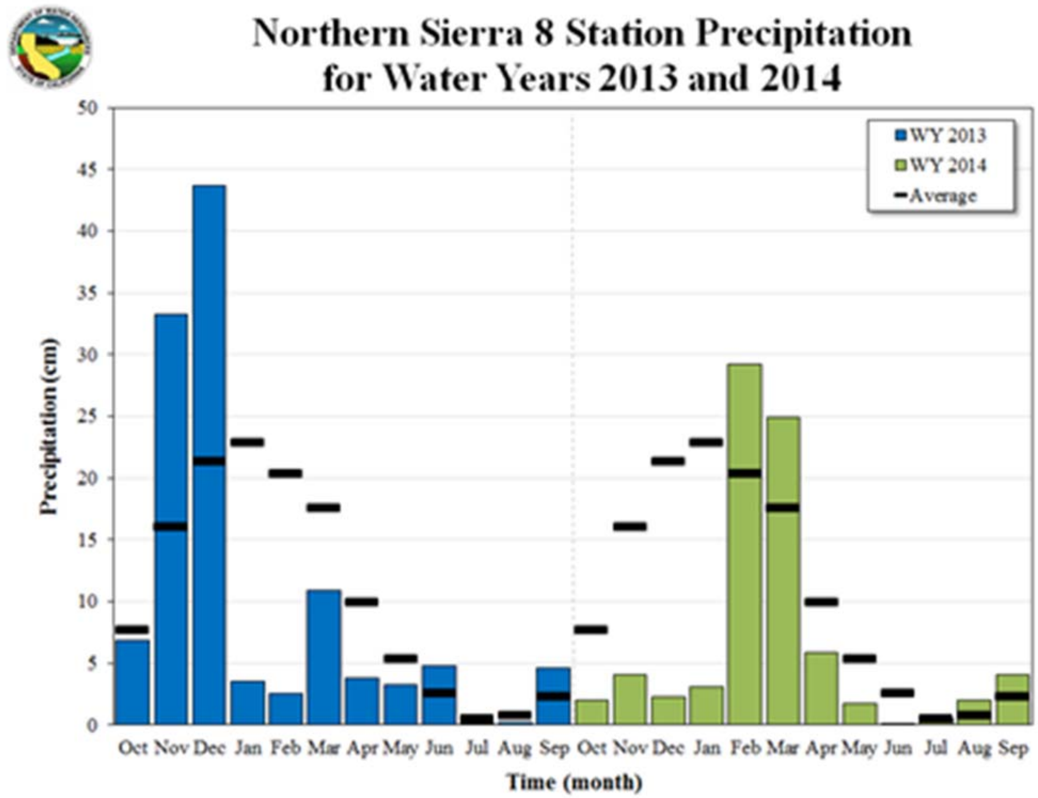

Figure 4. Northern Sierra Monthly Precipitation

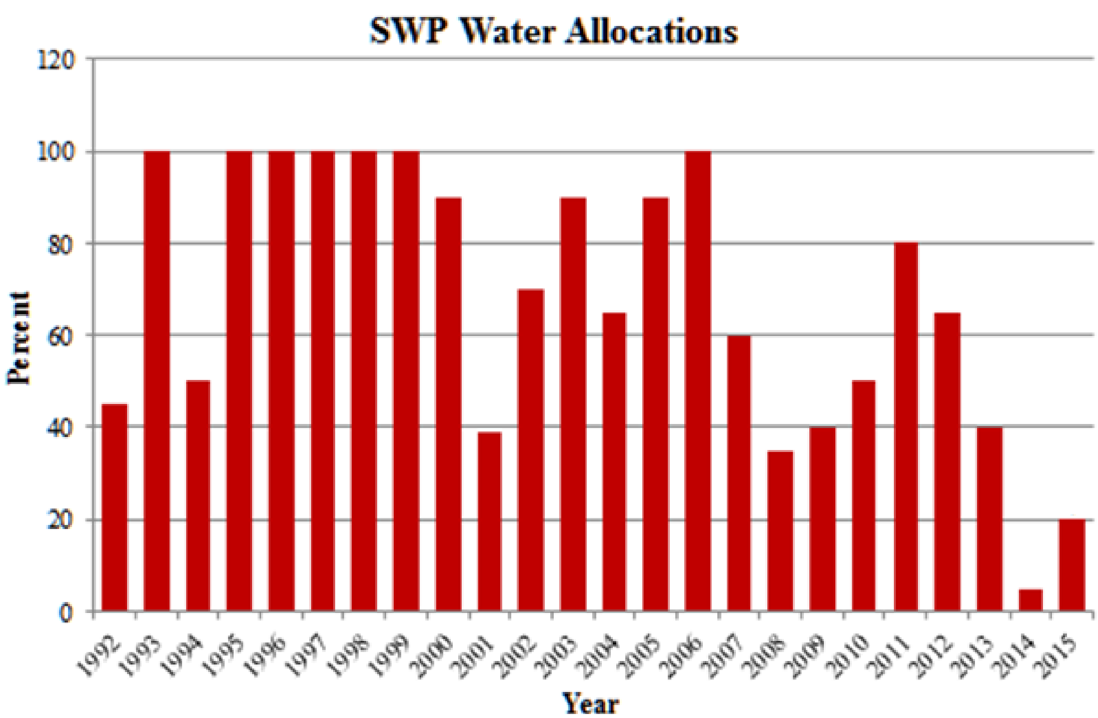

Figure 5. Annual State Water Project Delivery Allocations

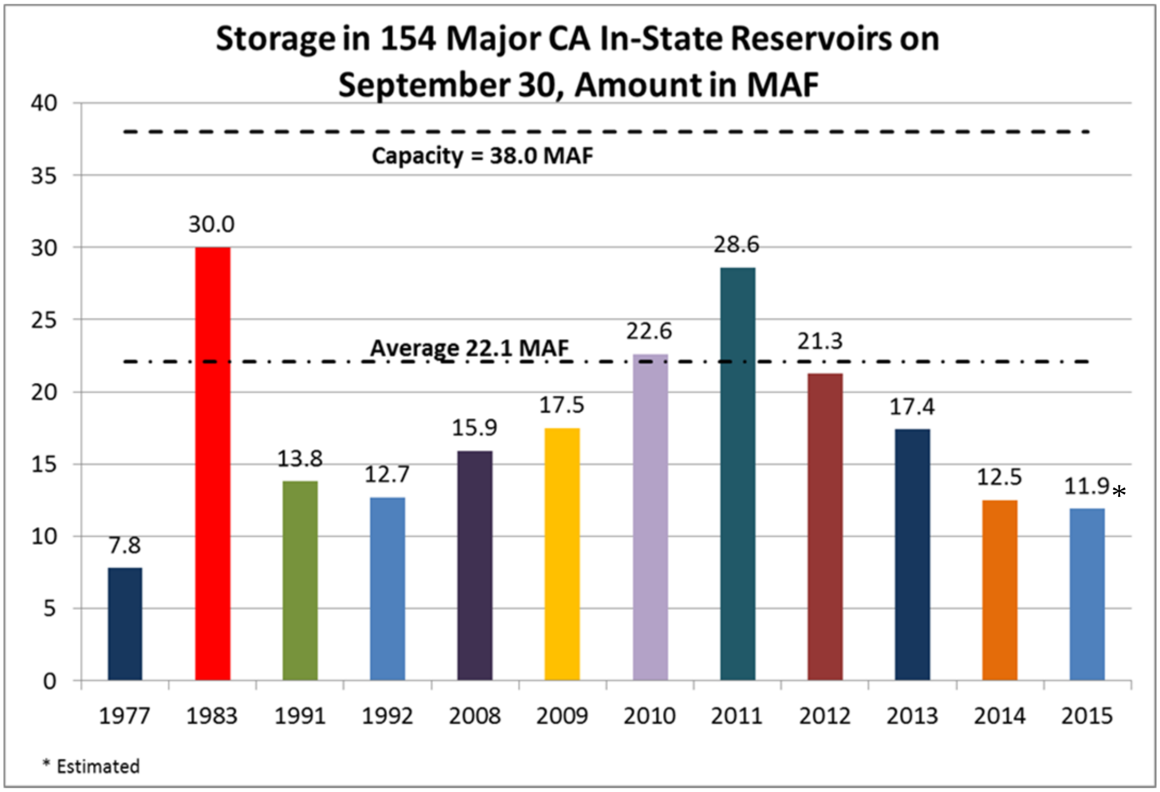

Figure 6. Water Storage in 154 Major California Reservoirs

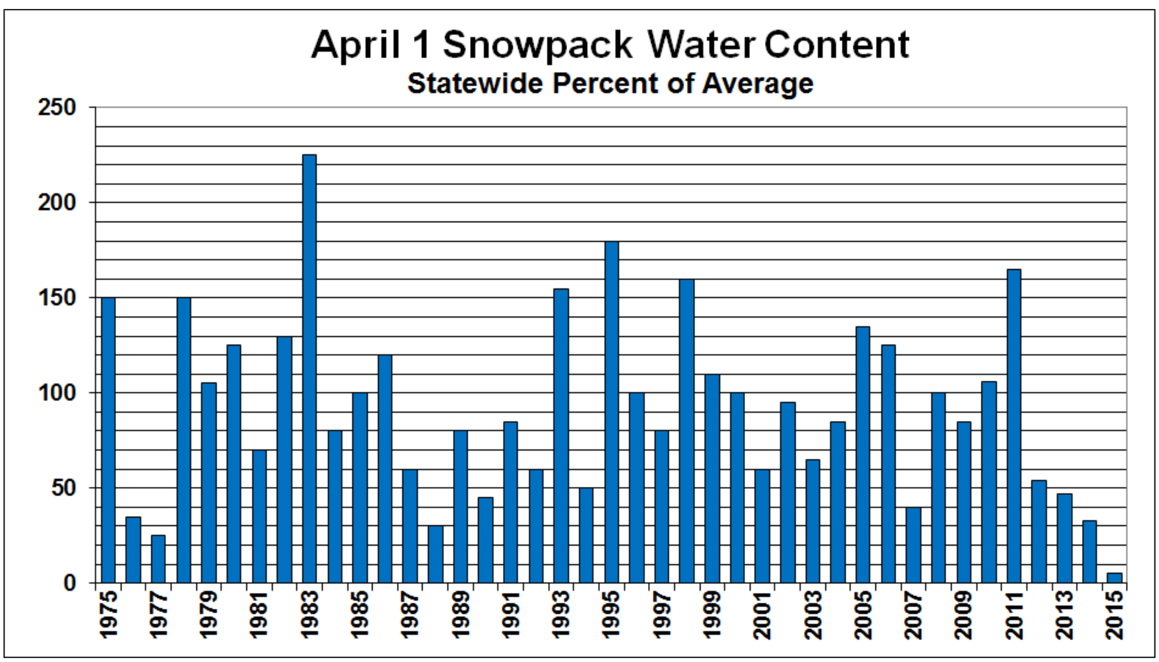

Figure 7. April 1 California Snowpack

TRUCKEE CANAL FAILURE: FORENSIC ANALYSIS AND LESSONS LEARNED

Rob Lyons, P.E., CFM[1]
Walter Winder[2]

ABSTRACT

The Truckee Canal breached on January 5, 2008 flooding 590 homes in Fernley, Nevada. The devastation from the breach aftermath resulted in a class action lawsuit against the Truckee Canal Irrigation District (TCID) and the US Bureau of Reclamation (USBR). This paper will include documentation of the storm and breach event, the extents of the flood devastation to the homes in the flood wave path, emergency actions taken by TCID staff, unique approaches to forensic investigations to the numerous possible causes for the canal breach, and lessons learned by TCID staff during litigation including:

- Canal Operator Development Review Authority
- Emergency Action Planning and Training
- Regular Correspondence with the USBR
- Relationship with USBR During Litigation

INTRODUCTION

A Truckee Canal embankment breached in Fernley, Nevada on January 5th, 2008, flooding 590 residential homes. The flooding event led to a class action lawsuit against several public agencies including the United States Bureau of Reclamation (USBR), the Truckee Carson Irrigation District (TCID), the City of Fernley, and others. This paper will discuss the lessons learned from the breach event, the lawsuit, and the technical analysis conducted as part of the TCID defense.

STORM EVENT

The January 4-5, 2008 precipitation event that preceded the TCID Canal breach occurred mostly as light, continuous drizzle until about 10:30 PM when the system moved off to the east. NEXRAD and rain gage data indicate a rainfall duration of 11 to14 hours. NOAA Atlas 14 statistics were retrieved for Fernley, NV to determine the approximate frequency of the event. The closest statistical rainfall total and duration to the January 4 event is 1.09 inches in 12 hours which corresponds to a 5-year return interval (5-Year Storm).

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The Truckee River typically experiences seasonal high flows in the spring due to snowmelt runoff from the upper watershed. The TCID canal experiences its highest flow stages and longest sustained flows during the irrigation season. Stream flow records are available from several sources including the USGS stream gages on Truckee River closest to the TCID Canal are at Tracy (USGS #10350340), Below Derby Dam (USGS #10351600), and at Wadsworth (USGS #10351650). The Truckee River gage below Derby Dam has the longest period of record, extending back to 1918. The Wadsworth gage has the second longest record, which extends to 1965. Figure 1 shows the location of each USGS gage.

During the January 2008 flood, the Truckee River at the Tracy gage peaked at 2,430 cfs at 8:30 PM on January 4, 2008. The river didn't return to the pre-flood base flow level (~400 cfs) until several days later. Figure 2 shows recorded hydrographs for USGS streamflow gages near the TCID.

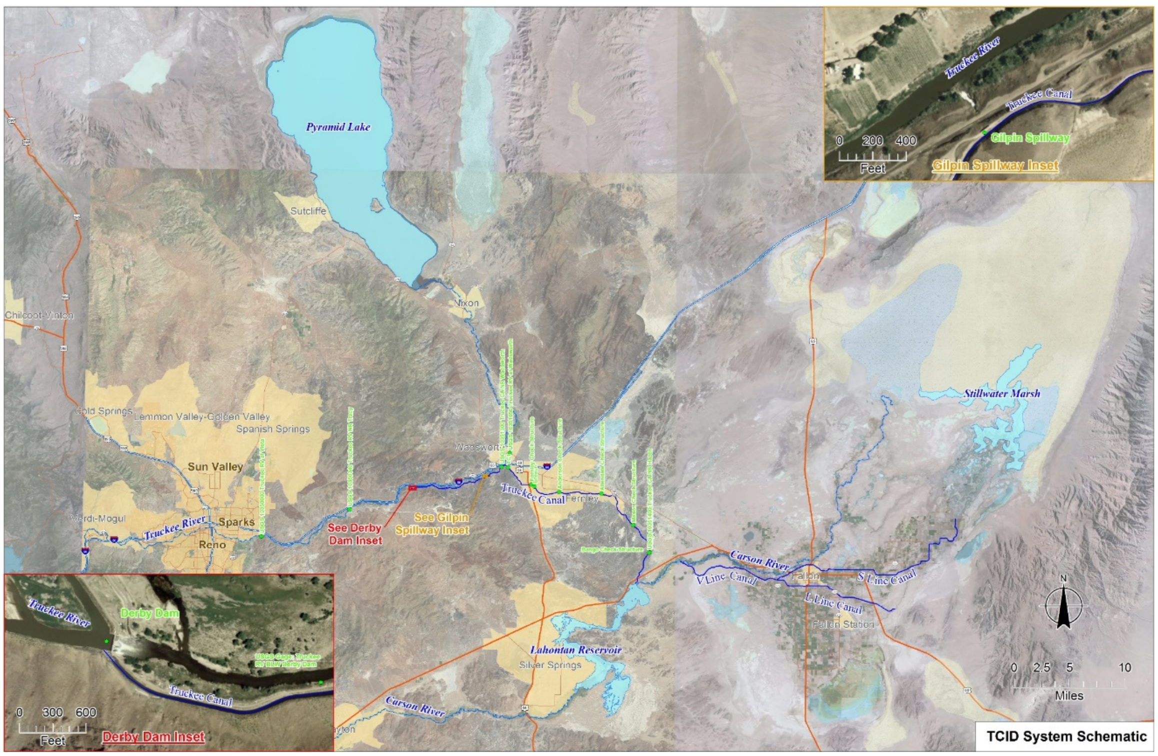

Figure 1. Truckee Canal Schematic and USGS Gage Locations

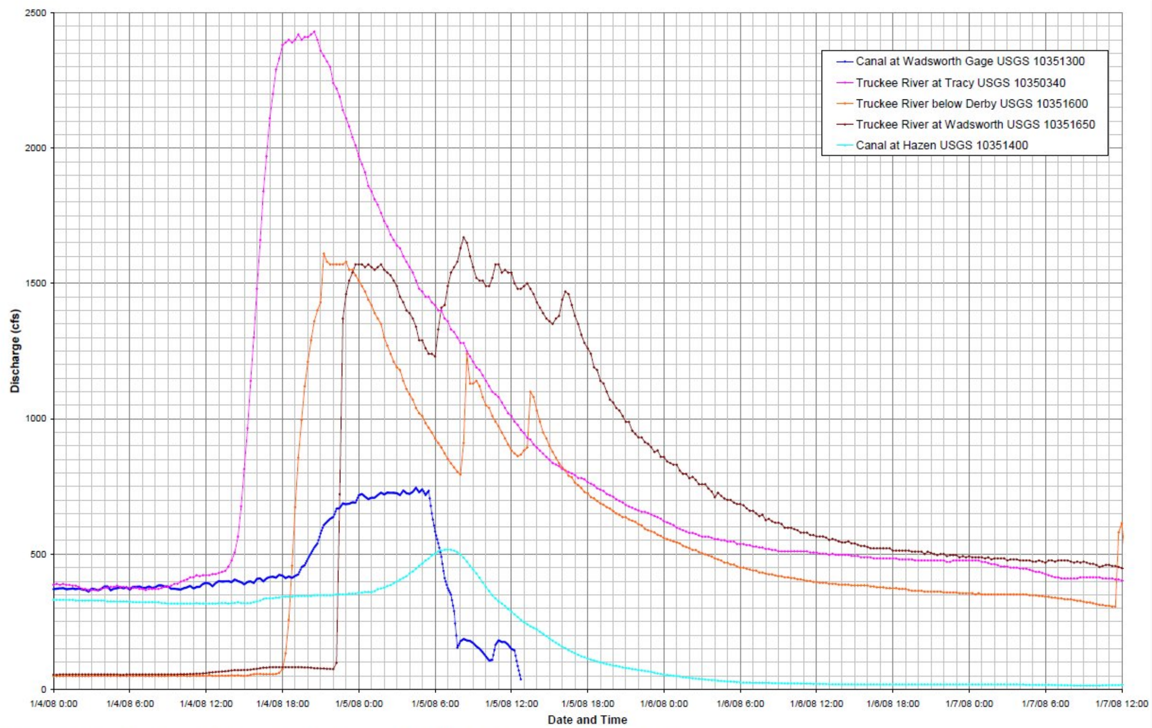

Figure 2. Flood hydrographs from Truckee River and TCID USGS Gages

BREACH EVENT

The breach occurred upstream of a low lying area with limited drainage facilities resulting in flood damage to 590 residential structures. Figure 3 is an aerial photo taken January 5, 2008 following the breach event. Note that the flooded areas have a brownish color from the sediment picked up from the eroded canal embankment. Figure 4 is a screen a capture taken from news video footage of one of the deepest flood depths resulting from the breach event. The breach occurred downstream of the Fernley Check structure as shown in Figure 5.

Figure 3. Aerial Photo - Breach Event Flood Inundation

Figure 4. Breach Event Flooding in Residential Neighborhood

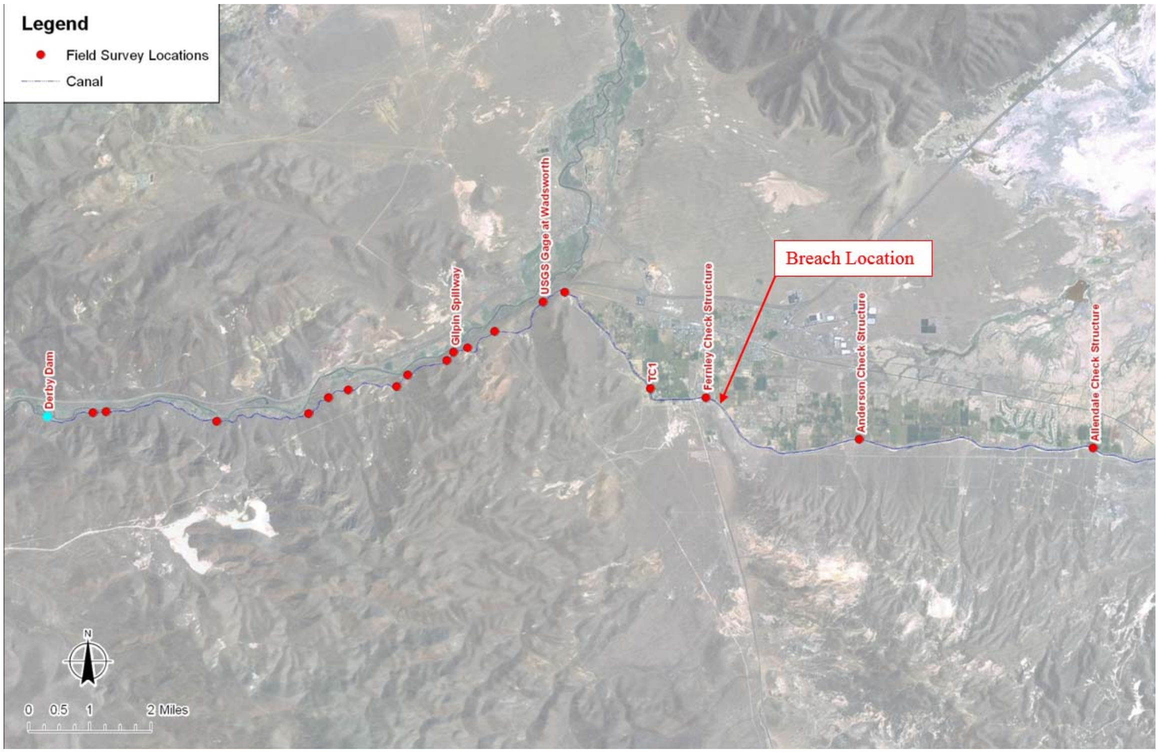

Figure 5. Breach Location and Pertinent Canal Structures

EMERGENCY ACTIONS TAKEN

Emergency actions were taken by TCID staff prior to the breach. TCID staff opened up emergency overflow gates at the Gilpin Spillway structure to limit flows in the canal downstream of the Truckee River intake. Furthermore, TCID staff took immediately action following the first 911 call that reduced the magnitude of the flooding event. These actions including operating gates and check structures (see Figure 5) as described below:

- Opened Lateral Gates at the Gilpin Spillway
- Closed Intake Gates to the Truckee Canal at Derby Dam
- Opened up River Gates on the Truckee River at Derby Dam
- Closed the Fernley Check Structure when appropriate
- Closed the Anderson Check Structure to prevent backflow when appropriate
- Closed the Breach by 4:00 PM on January 5, 2008

FORENSIC INVESTIGATIONS

Numerous complex technical analysis was conducted as part of the defense including:

- Prior canal breaches – the 2008 event wasn't the first time the canal had breached
- Forensic canal inflow hydrograph development – no canal stream gage was available at Derby Dam

- Breach event hydraulic modeling based on TCID emergency actions taken – multiple gates closed
- Hydraulic model geometry development – traditional and bathymetric surveying
- Breach event initiation - based on iterative breach outflow hydrograph routing in FLO-2D model (2-dimensional modeling)
- What if scenarios – what if TCID did nothing?
- Prior irrigation season hydraulic conditions - baseline comparison hydraulic modeling
- Side tributary inflow modeling – were there other flood sources besides the Truckee River?
- Geomorphic investigations – is there evidence of sedimentation in the canal?
- Rodent hole investigation – did the canal fail due to rodent burrows?

LESSONS LEARNED

Canal Operator Development Review Authority

TCID had limited review authority of development downstream or downhill of the Truckee Canal. TCID did provide comments and require development to maintain the existing capacity of lateral drainage systems downstream, however, facilities were not built as agreed. It is imperative that Irrigation Operators have the proper authority to review and regulate development as it pertains to lateral drainage and infrastructure failure as follows:

- Development downstream of old canals should not be built assuming all offsite runoff will be diverted
- Developers should be made aware of canal deficiencies and/or past canal failures
- Development downstream of canals should have emergency outlets that can accommodate large offsite flows without major damage
- Open communication with City and County officials key
- Maintain good written communication with City and County development review officials
- Insist at all costs that provisions for flood mitigation facilities should be designed and constructed during development, not after

Emergency Action Planning and Training

TCID has maintained emergency action plans (EAPs) and conducted emergency training for decades. It is important to maintain documentation of a well-planned EAPs and training exercises.

Regular Correspondence with the USBR

Canal operators should maintain open dialogue with original system owners. Pay attention to USBR Review of Operations & Maintenance plans (RO&M) reviews and insist on good written records. If canal operators don’t agree with the reviews, dispute and insist on revision. Finally, take immediate action to address deficiencies identified during RO&M reviews.

Relationship with USBR during Litigation

Take immediate actions to mitigate canal failures and prepare a defense. Don't rely on the original agency who built the system for defense. During litigation, agencies tend to defend themselves first.

CONCLUSION

The Truckee Canal breach of January 5, 2008 devastated Fernley, Nevada. The resulting lawsuit against TCID was very difficult considering funding and resource limitations. TCID strives to maintain the regional irrigation system. As with most canal operators, while adjacent urban development is constantly growing, TCID's budget doesn't. TCID hopes other Irrigation Districts can benefit from the lesson's learned from 2008 flood event.

DEMONSTRATION FLOW MONITORING AND DATA RECORDING SYSTEM FOR THE YUMA PROJECT RESERVATION DIVISION

Tom Gill, P.E. [1]
Kent Walker, P.E.[2]

ABSTRACT

The Reservation Division of the Yuma Project delivers Colorado River Water to the 7,120 acre Bard Unit and the 7,556 acre Indian Unit. The Bard Water District (BWD) administers water deliveries to both units. Turnouts from the All American Canal into the Reservation Division include headgates for the Reservation Canal, the Yaqui Canal, the Pontiac Canal, the Walapai Canal, and Ypsilanti Canal. The Yuma Main Canal which also receives its flows from the All American Canal passes through the Reservation Division and through an inverted siphon under the Colorado River. Approximately 15 turnouts along this reach of the Yuma Main deliver water to lands in the Reservation Division. Seven lateral canals that originate in the Bard Unit deliver water to lands in both the Bard Unit and the Indian Unit. Engineers from Reclamation's Hydraulic Investigations and Laboratory Services Group, supported by the Water Conservation Field Services Program of the Yuma Area Offices are working to establish a demonstration-scale project to initiate automated flow measurement and data collection in the Reservation Division. The demonstration project will provide access to real-time flow data at the BWD office. Automatically retrieved data will be stored on the hard drive of a PC linked to the office base radio/control unit.

INTRODUCTION

This project is being carried out in parallel with an in depth study of the Reservation Division distribution canal network. The study was commissioned by Reclamation's Yuma Area Office (YAO) and is being performed by Reclamation's Technical Service Center (TSC). The authors are charged with identifying opportunities for integration of electronic communications and control technologies that can enhance project water delivery efficiency. Funding made available through the YAO Water Conservation Field Services Program have enabled this demonstration project to be scheduled to complement the ongoing canal network study.

PROJECT SCOPE

The demonstration project includes four field sites plus establishment of an office base station at the BWD office. Three of the four field sites, the Ypsilanti headworks, the 103E turnout from the Yuma Main Canal and the Pima lateral at a location just west of

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Baseline Road are located in the Indian Unit of the Reservation Division. The fourth field site is the heading of the Hopi Lateral where it takes off from the Mohave Lateral. This site is located along the east edge of the delivery system in the Bard Unit. Figure 1 is a site map showing the locations of the field sites and the Bard Water District office.

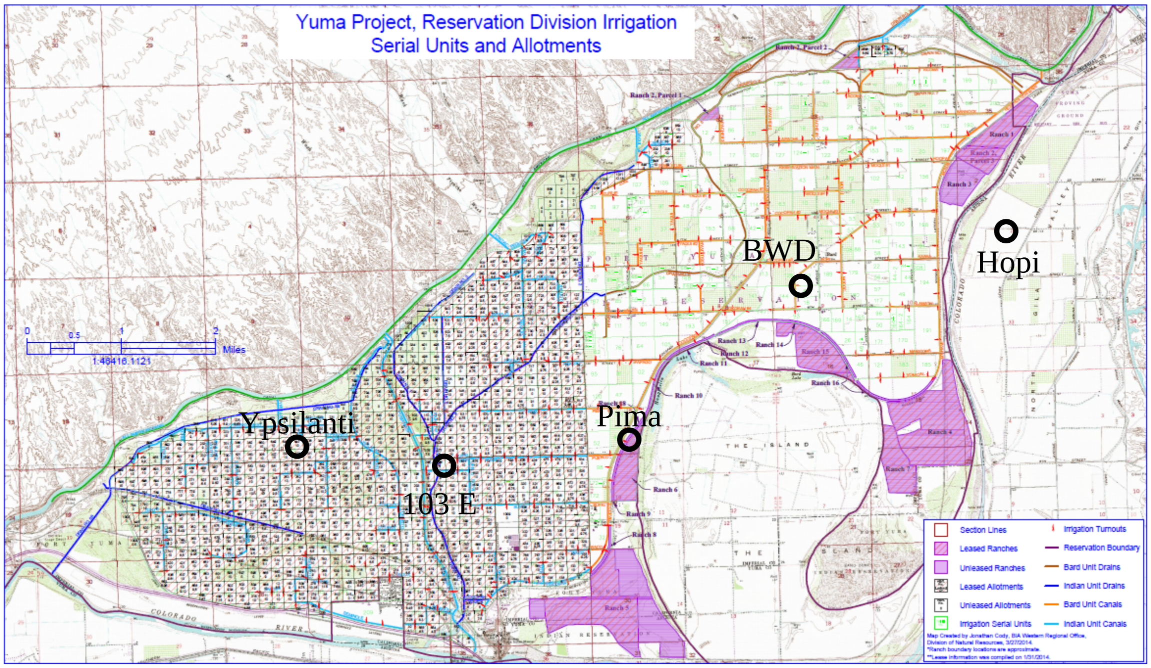

Figure 1. Map of the Reservation Division of the Yuma Project

SITE DETAILS

Ypsilanti Headworks

The Ypsilanti headworks features a headgate on the All American Canal from which water is conveyed via pipeline approximately 1420 feet. At the pipe outlet water enters a stilling pond from which flow exits over a Cipoletti weir. Immediately below the weir water may proceed eastward via the East Ypsilanti Lateral, westward via the West Ypsilanti Lateral or southward into a field canal. Ramp-type long-throated flumes are installed to measure flow in each the East and West Ypsilanti Laterals.

Two factors were considered in selecting the Ypsilanti headworks. One factor is the multi-directional split of flow that may occur at this site. A second consideration is that this site had been selected as a gate automation demonstration site in 2001. The 2001 automation demonstration project was discontinued within a year after the prototype control device being demonstrated was taken out of production. The equipment that enabled remote operation of the motorized turnout gate on the All American canal including a solar charged 12 volt DC system and wiring to the site near the Cipoletti weir remained. Figures 2 & 3 show the gate on the All American and the stilling pond with the Cipoletti weir at the stilling pond respectively.

Figure 2. Ypsilanti motorized gate

Figure 3. Ypsilanti stilling pond and weir

Since shortly after the 2001 installation of equipment for the previous demonstration project the gate on the All American has been remotely operated via hard-wired linkage from the stilling pond location. For the present project the Bard staff expressed the desire to continue the current gate operating procedure. Thus gate operation (either automated or wireless remote operation) was not a function included in the current demonstration project. The programmable control equipment installed for the current project is fully capable of performing gate operating functions if so desired at a future date.

For the demonstration project water levels just upstream of each of the three flow measurement structures (the Cipoletti weir, the East Lateral flume and the West Lateral flume) are all being monitored and flows passing each of the measurement structures is being calculated. The three water level measurements are being performed using a single bubbler level sensor equipped with an output manifold with three solenoid valves. At fifteen minute intervals, calculated data is logged on-site by a programmable controller with an integral 450-470 Mhz radio. This radio allows communication with the BWD office base unit radio. All of the field sites in this demonstration project used radios operating in the UHF 450-470 Mhz licensed frequency band utilizing the Modbus communications protocol and are powered by a 12 volt DC solar- charged system. Figures 4 and 5 show the East Lateral flume and the West Lateral flume respectively.

Figure 4. East Ypsilanti Flume

Figure 5. West Ypsilanti Flume

Yuma Main 103E Gate

The 103E Gate is one of approximately 15 turnouts from the Yuma Main Canal to lands in the Indian Unit. The Yuma Main diverts water from the All American Canal approximately 1.4 canal miles upstream from the Ypsilanti. The bulk of the water is conveyed southward from the All American to an invert siphon under the Colorado River in the northeast part of Yuma. From there a water delivery network distributes flows to lands in the service area of the Yuma County Water Users Association (YCWUA) – the entity which manages operation of the Yuma Main Canal.

The bulk of the turnouts from the Yuma Main have no capacity for real-time monitoring. This creates operational and accounting challenges for YCWUA in administering operation of the Yuma Main and for BWD in accounting for water usage within the Reservation Division. It is also an issue for water users served by these turnouts with no measurement capability. These factors led to the decision to include one of the turnouts from the Yuma Main as a field site for the demonstration project.

From among the unmonitored turnouts along the Yuma Main, the 103E was selected due to the fact that water from this site is conveyed to multiple fields while many of the other sites serve only one or two fields. The strategy for measuring flow at this site was to measure the gate opening along with upstream and downstream water levels and utilize these measured values in submerged orifice flow calculations. An economical and reliable gate position sensor may be constructed by equipping a multi turn potentiometer with a gear that has tooth spacing that will engage in gate stem threads. The 103E gate was initially equipped with a “jack” type gate operator with a smooth stem. The first installation task was to convert the gate from the jack system to a threaded stem with a hand-wheel nut to position the gate. Figures 6 and 7 show the “before” and “after” conversion of the gate operator.

Figure 6. Jack operator on 103E gate

Figure 7. Hand-wheel nut/threaded rod operator

Along with the gate operator conversion and gate position sensor installation, bubbler outlet tubes were installed both upstream and downstream from the gate for measuring the two levels with a two-output bubbler sensor. A targeted capability for the Yuma Main turnout site was for one control unit to provide real time data to two entities (YCWUA and BWD) via independent wireless communications systems. The integral 450-470 Mhz radio provides communications linkage with the BWD office base while a 900 Mhz spread spectrum radio linked to an auxiliary Modbus port on the control unit feeds data into the YCWUA SCADA network. Figures 8 and 9 show the gate position sensor and the dual antenna installation at the 103E gate respectively.

Figure 8. Gate Position Sensor

Figure 9. Dual Wireless Communications

Pima Canal at Baseline Road

Baseline Road represents the boundary in the Reservation Division between the Bard Unit on the east and the Indian Unit on the west. While BWD administers water deliveries to both the Bard and Indian units, the two units have separate water rights. The Pima canal is one of seven laterals that cross Baseline Road delivering flow to both units. BWD identified monitoring of flow crossing Baseline Road from the Bard Unit to the Indian Unit in each of these laterals as a priority capability for operational and water accounting purposes.

For the demonstration project the Pima Canal was selected on the basis of comparatively high usage among the canals crossing Baseline Road plus the fact that no measurement structure had previously been installed. The fact that Pima Canal has existing concrete lining in the vicinity where a flow measurement would be desired was also a consideration in site selection.

In discussing flume design for this site with BWD personnel, a laterally-contracted long-throated flume was preferred due to superior sediment passage compared with ramp-type flumes. The site was viewed multiple times prior to designing a flume. It was noticed that ponded water is frequently present at the site. For typical flume operation relying on only a water level measurement in the flume approach section, ponded water conditions would pose a problem for electronically monitored flow conditions. With only the approach section level being measured, it would appear a measurable discharge was flowing when there was actually no flow.

In order to detect ponded conditions, the flume design included level measurements in both the approach and throat sections of the flume using a single bubbler level sensor equipped with an output manifold with two solenoid valves. The bubbler sensor is connected to the programmable controller which allows communication with the BWD base unit. Ponded conditions will be detected when both level measurements are essentially equal. Additionally, with the two level measurement capability, flows may be calculated with a suitable level of accuracy when submergence is well above the modular limit for accurately measuring flow using only the flume approach depth. Figures 10 and 11 show the Pima site before and after flume construction.

Figure 10. Pima Flume Site with Ponded Water

Figure 11. Newly-Constructed Pima Flume

<u>Hopi Lateral Heading</u>

The Hopi Lateral heading is representative of an internal node in the upper reach of the delivery system. The capability to monitor flow coming into branches of the delivery system at sites like this can be a key factor in improving delivery operations. Like the Ypsilanti headworks, the Hopi site had previously been selected as a demonstration site. During 2004, a prototype flow monitoring device developed at Reclamation's Hydraulics Laboratory that utilized a hobby robot programmable controller was installed in conjunction with an existing ramp-type long-throated flume at this site.

The prototype device called a "CFM" (continuous flow monitor) operated on solar-charged power and would provide instantaneous readout of electronically sensed flow level and calculated discharge. The CFM was not developed with datalogging memory or automated data retrieval capability. While it was a comparatively low cost system for electronically acquired flow data, the information developed was only available on-site. The CFM system provided little if any utility over a staff gage calibrated to provide reading in discharge. The CFM system at the Hopi site had been vandalized at some point and was no longer functional. The Hopi site was an attractive site to include in the current demonstration project due being located in the upper reach of the delivery system as discussed above and due to the opportunity to utilize some components remaining from the earlier demonstration project.

A single bubbler level sensor was installed at the ramp-type long-throated flume to measure the upstream water level. A radio/control unit similar to those installed at the other field sites provides wireless linkage to the BWD office. The vandalized electrical enclosure at the site was repaired and reused. Figures 12 and 13 show the heading of the Hopi Lateral before and after upgrades for the current project were installed.

Figure 12. CFM installation at Hopi

Figure 13. Hopi site w/upgrades installed

BWD Office Base

The base unit consists of a programmable controller with integral 450-470 Mhz radio that is identical to most of the field units used for the demonstration project. The base unit is installed in the ditch rider's room at the BWD office. The base has been initially set up with a program loaded in the controller that enables direct two-way communication with each of the field sites to retrieve current data using keypress inputs following on-screen prompts. This capability does not require linkage to any other device (such as a PC).

A new omni base antenna was installed as well. Using a temporary base antenna mount, a radio pathways check was performed between the base and each of the demonstration project field sites – along with numerous additional (potential future) sites throughout the district. The test was performed using a mobile radio unit with a small magnetic mount antenna atop a pickup cab. During the radio test suitable signal strength was measured at each of the field sites and at most other sites around the Reservation Division. Insufficient signal strength was only observed from the extreme western end of the Indian Division.

Subsequent to the radio test, a permanent base antenna mount was installed which increased the base antenna elevation of approximately eight feet above the temporary mount. This increase in base antenna height alone could be expected to provide improved signal strength for more distant points in the canal network. A further signal quality enhancement will be the superior gain of antennas being used for the field sites compared with the magnetic mount vehicle antenna used for the test. An additional factor for extending radio performance is that any of the field units may also function as a repeater if further enhancement in signal strength is needed. Figure 14 shows the office antenna installation.

Figure 14. BWD Office Base Antenna

The newly installed antenna is seen near the corner of the BWD office building in Figure 12. The antenna was located near the location of the office base unit inside the building to minimize coaxial cable length and associated signal strength degradation.

The next project task will be to link the base unit to a dedicated PC. Software that may be downloaded from the radio/control unit manufacture's website will be set up to automatically retrieve data that is being logged on-site at each of the field sites. The retrieved data will then be written to files for each site on the PC hard drive.

SUMMARY

At the time this report is being prepared, equipment installation has been completed at each of the field sites and site-specific programs have been developed for each site. Remaining tasks include on-site sensor calibration (slope verification) at each of the field sites and flow measurement verification at each field site. As noted in the office base discussions there is additional remaining work linking the base unit to a PC and setting up automated data collection and data archiving functions.

The limited scope of the demonstration project can be expected to enhance BWD's operating capability in the short term and enable BWD to experience some of the potential benefits of a more expansive monitoring and control system. The radio/control equipment installed for this demonstration project will be suitable for any level of system expansion BWD may contemplate. The "hands-on" experience this demonstration project will provide for BWD staff, along with the work products from the ongoing TSC study of the Reservation Division water distribution network will be tools to aid BWD in developing strategies for achieving operational improvements and increasing water delivery efficiency.

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USING THE TI 84 FOR IRRIGATION SCHEDULING TRAINING

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David Berg [2]
Manoj Shukla [3]
Kulbhushan Grover [4]

ABSTRACT

An irrigation scheduling program is written for a TI 84 calculator. The program includes crop type, crop growth behavior, and soil water holding capacity. The Hargreaves equation is used to estimate reference evapotranspiration (ET_o). The calculator is programed to track ET and schedule water irrigations. It is hoped that the program can be used in high school and college class instruction. An initial high school class demonstration resulted in a very positive reception from the students.

INTRODUCTION

Irrigation scheduling is an effective water management method that can maximize profits and conserve limited water supplies (Pair et al. 1983). There are several techniques that can be used to achieve irrigation scheduling. These may involve hand feel methods, electronic sensor methods, and water budget methods (Broner, 2005). All methods have their advantages and disadvantages. Water budget methods have the advantage of limited field work and irrigation forecasting. However, the extensive calculations that are required can be daunting for individuals.

A key part in the water budget method is estimating evapotranspiration (ET). Several methods have been developed to estimate ET that use weather data to estimate crop water use. The Penman-Monteith (Monteith 1965; Jensen et al. 1990; Allen et al. 1998) method is considered by many to be one of the most accurate. This method requires the measurement of several variables including maximum temperature, minimum temperature, relative humidity, and solar radiation. This method is difficult for a farmer to use because he does not have the necessary infrastructure as well as technical knowhow to maintain the system with the appropriate quality control. Nor is he willing to acquire and maintain the expensive equipment that is required for these measurements.

Hargreaves and Samani (1985) determine ET with just temperature data and crop location. Though this is a simpler method, it is still difficult for untrained users to understand and use (Stringam and Grover, 2014). In many cases people that would benefit from using ET equations do not have the training or knowledge to utilize any ET estimating method and tools are needed to simplify the process. (Kallestad et al. 2008; and Hill and Allen 1996).

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When water users are presented with the concept of irrigation scheduling, it appears to be received well but few water users use the method. It causes one to ponder why the scheduling method is not extensively used.

It is believed that if irrigation scheduling can be presented to students enrolled in high school and in college, there will be more acceptance and use of the concept. Moreover, general public including students must be informed of the scarcity of water and the global and regional issues that are associated with water use. In this context, irrigation scheduling and related methods become an important topic to discuss with high school students. Experiential learning or learning by doing is one of the best methods for scholarly teaching (Grover and Stovall, 2013; Uchanski et al., 2015). Involving students in a hands-on exercise would help them grasp the concept better.

The Texas Instruments TI 84 calculator is a common device that is used by a large number of high school students. It can be programmed with complex code and it can be programmed with ET estimation equations, plant growth data, as well as soil water holding capacity data. In addition, it has the ability to record the date and time. The date function is needed to remember and track crop water use and schedule irrigations (Fig 1).

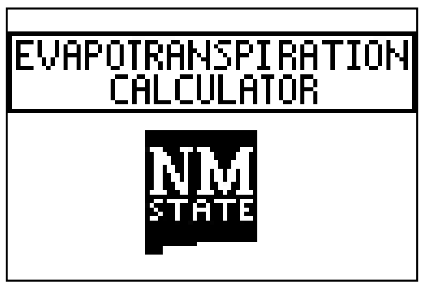

Figure 1. Calculator opening screen.

The goal of this project was to develop a tool that could be used to estimate ET and track soil water content for a user with a minimal data input requirement. While the Penman-Monteith equation is considered to be the most accurate method, the Hargreaves method was selected because a minimal amount of data is often available.

HARGREAVES

In an effort to estimate crop water needs, researchers have expended a great amount of effort to develop equations that estimate crop water use. Some equations are based on theory while others are based on empirical data. The theoretical equations require measured values from several sources. The empirical relationships require temperature data (In many cases, temperature data is all that is available.). The empirical equations have slightly more error but considering that ET can vary throughout an individual field, an empirical equation can satisfy the majority of irrigation needs. The Hargreaves equation is a temperature based equation that has undergone a great deal of refinement. The equation takes the following form:

$$ET_o = 0.0023R_A(T + 17.8)TR^{0.5} \quad (1)$$

Where ET_o = evapotranspiration based on a grass reference, R_A = extraterrestrial solar radiation, T = the mean daily temperature, TR = is the average daily temperature range for the time period considered.

Additional equations are needed to complete the ET estimation. Extraterrestrial solar radiation is required for the ET equation and can be computed using the following relationships:

$$R_A = 37.6\ d_r\ (\omega_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_s) \quad (2)$$

$$\delta = 0.4093 \sin(\frac{2\pi(284+J)}{365}) \quad (3)$$

$$d_r = 1 + 0.033\ \cos(\frac{(2\pi J)}{365}) \quad (4)$$

$$\omega_s = \cos^{-1}(-\tan\varphi \tan\delta) \quad (5)$$

Where d_r = the relative distance from earth to the sun; ω_s = the sunset hour angle; φ = the latitude (rad) this value is positive for northern latitudes and negative for southern latitudes; δ = is the declination of the sun (rad). (Note: R_A has to be multiplied by a factor of 0.408 to convert from MJ/m^2/day to mm/day)

CROP K_C VALUES

In order to adjust the reference ET_o to crop ET_c a K_c value must be applied to the reference ET_o. The relationship is simple however, other factors can be applied. The goals of the project just asked for the simple ET relationship which is indicated in the following equation.

$$ET_c = ET_o \bullet K_c \quad (6)$$

Where ET_c = crop evapotranspiration; ET_o = reference crop evapotranspiration and K_c = crop characteristics coefficient.

The K_c values that are used in the calculator program are from the FAO 56 document (Allen et al. 1998). Users of the program can choose from over 100 different crops. When a crop is selected the calculator program accesses a table of growth periods and corresponding K_c values that are relevant to the crop and the stage of growth. The proper K_c value is selected by the program and eliminates the tedious task of selecting a K_c from a table. It also reduces the possibility of user error.

ROOT DEPTHS

In addition to K_c values, effective root depths that correspond to the crop growth stage are also integrated into the calculator program. When a user selects a crop and inputs the planting date, the program estimates the depth of root penetration from the root growth stage table. This simplifies the use of the program as well as reduces the possibility of error. The root values that are used in this program are from the FAO 56 document (Allen et al. 1998).

SOIL WATER RELATIONSHIP

This program requires some assumptions in order to make the program capable of handling the majority of crop water use estimations. The program has the soil water holding capacity for 12 general soil types including course sand, fine sand, loamy sand, sandy loam, fine sandy loam, loam, sandy clay loam, sandy clay, clay loam, silty clay loam, silty clay, and clay soils (Ashley et al. 1998). It was found that many program users do not know the water carrying capacity of the farm soil so they can choose from the soil types. If a water user has the soil water holding capacity data for their particular soil type, then they can manually input that data. Once a soil type is selected the calculator program can estimate and track water use.

PROGRAM

When the user starts the program, they will be prompted to input the crop type. Because the program has over 100 crops to choose from, the crops have been organized into subcategories similar to the FAO crop table (Allen et al. 1998). The subcategories include vegetables, roots/tubers, legumes, berries/melons, tropical plants, fruit trees, cereals, fiber/oil crops, and forages (Fig 2). When the crop is selected, the user may be prompted to specify specific cropping practices. For example, the user could select seed production or hay production for alfalfa crops.

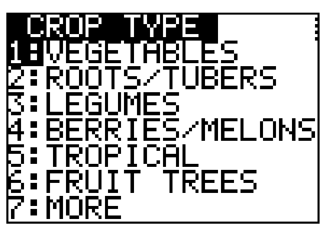

Figure 2. Crop Selection Screen

The user is then prompted to select a soil type (Fig 3). Once the soil type is selected, the program selects a corresponding water holding capacity for the soil. The program then asks if the crop is located in a northern or southern latitude. Once this is selected, a latitude in degrees is asked for.

Figure 3. Crop Selection Screen

The program then displays the growth periods for the crop that was selected (Fig 4). Four growth periods are displayed. The user has the option of selecting those displayed or specifying other periods. The user then can select English or metric units for the calculations. The user is then prompted to select the planting date (month and day). The next input is the last irrigation date or precipitation date (month and day) (Fig. 5). They are asked for the temperature units (Fahrenheit or Celsius).

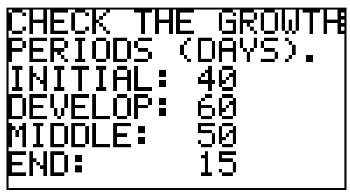

Figure 4. Crop Growth Periods Screen

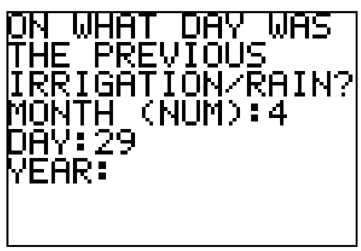

Figure 5. Irrigation or precipitation screen

At this point the user is asked for the maximum and minimum temperatures for the area from the last irrigation date to the present date (Fig 6). These values can be recorded for the individual farm area or they can be obtained from the internet or local newspaper (Fig 7). The program can then compute the estimated crop ET_c for all of the days after the last irrigation (Fig 8). The remaining water in the soil profile is also estimated. A graph is generated that shows the crop water use as well as a graph or line that indicates when the user should be irrigating next (Fig 9). Finally a summary of the calculations is printed out and the number of days before the next irrigation is displayed (Fig 10).

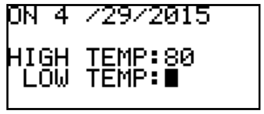

Figure 6. Temperature input screen

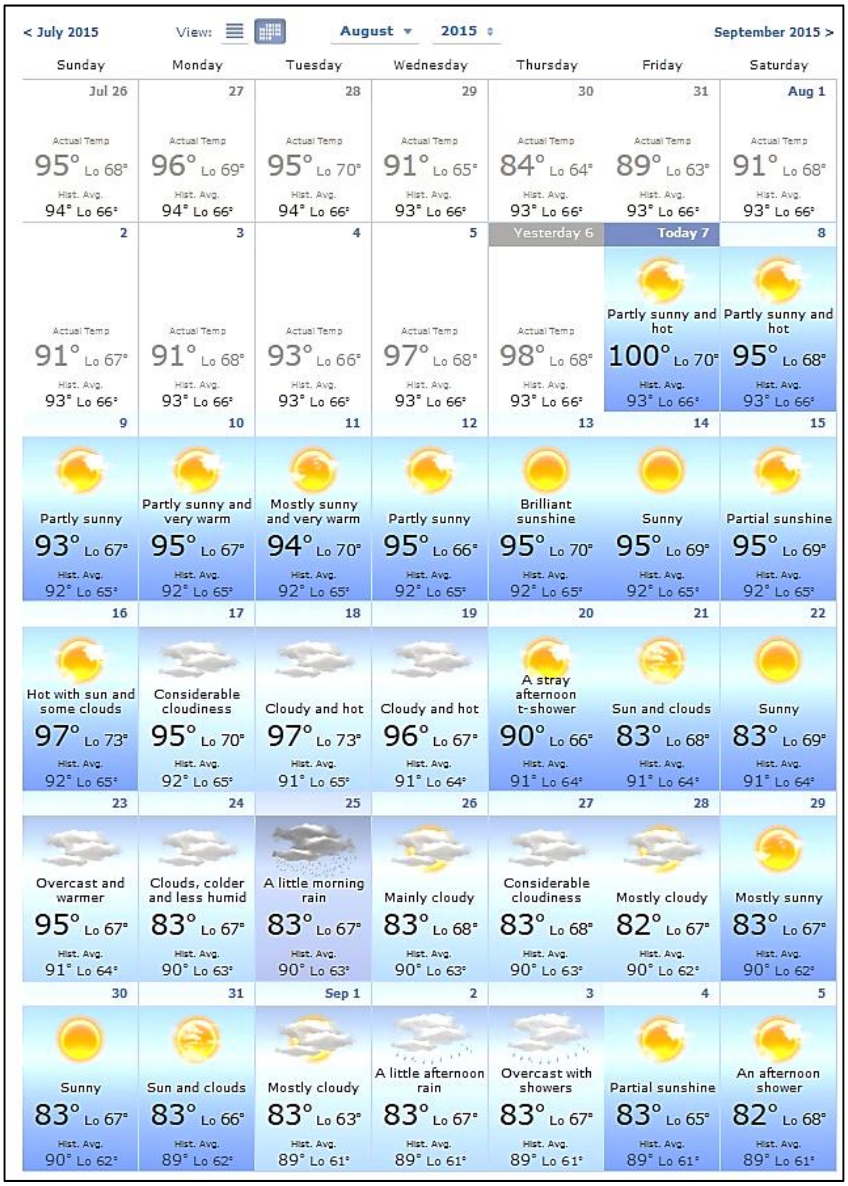

Figure 7. Temperature data that can be used for input to the TI 84 program. (www.accuweather.com)

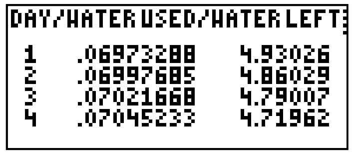

Figure 8. Summary of Crop ET

INITIAL TESTING

This program was introduced to a small group of high school students where it was downloaded into their TI 84 calculators. They were introduced to ET estimation and irrigation scheduling. The students then had the opportunity to run the program and work through a simple exercise. The response from the students was very positive. They talked about how they could use the program and were eager to use it on their family farms.

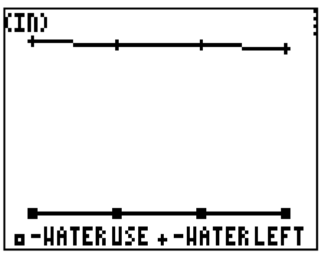

Figure 9. Graph of Crop ET. The upper line is ET.

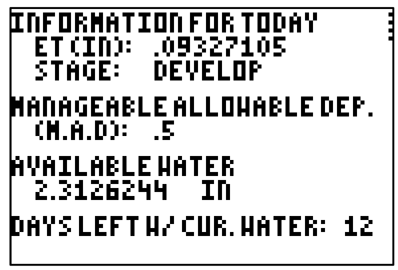

Figure 10. Summary with estimate for next irrigation.

CONCLUSIONS

After the development period, initial testing of the program indicates that it is working with little difficulty. When the program was introduced to high school students they had little difficulty understanding how to use the program and obtain results from the input data. They were excited to use the program on their own family farms.

We plan to introduce the program to students in several high schools to determine how they receive and use the program. We will also use the program in college instruction as well. We hope that this calculator based program will encourage water users to track water use and conserve water.

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IDENTIFICATION OF AGRICULTURAL LAND USE IN CALIFORNIA THROUGH REMOTE SENSING: PRELIMINARY RESULTS

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ABSTRACT

Ground truthing actual crop types within an area can be expensive and time-consuming. The California Department of Water Resources attempts to ground truth land use in each county in California every five years. However, this is limited by budget constraints and often results in infrequent (more than every ten years) surveying of many counties. An accurate accounting of crops growing in a region is important for a variety of purposes including farm production estimates, groundwater and surface water modeling, evapotranspiration estimation, water planning, research applications, etc. Currently, USDA NASS provides georeferenced land use maps of regions throughout the U.S. While these are beneficial, the accuracy is not very high for California due to the wide variety of crops grown throughout the state. This paper presents the methodology and preliminary results behind a more accurate crop classification tool developed utilizing remotely sensed data for California's Central Valley from available satellites. The project is on-going and future work aims to improve the current model and validate the preliminary results. Background on existing methodologies, current procedures, and data requirements used in crop classification are also discussed.

INTRODUCTION

Due to its long growing seasons and economic strength, California is home to one of the most productive and varied agricultural industries in the world. Agricultural awareness and land use classification is becoming more important as population, limited water supplies, environmental issues, and climate change concerns continue to increase. Accurate land use classification can be a key component for on-farm decision-making, economical assessment, and policy development. Historically, many agencies have required accurate land use classification to monitor land use changes for a variety of applications (Vogelmann et al. 1998).

Since the late 1940's the California Department of Water Resources (DWR) has continually surveyed and monitored land use changes (Wall et al. 1984). DWR attempts to ground truth land use in each county in California every five years. However, due to budget constraints, some counties are only examined once every ten years or more. The classification of crop types using remote sensing has proven to be difficult, as season lengths often exceeds 280 days (Wall et al. 1984).

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It is the goal of this research to utilize remotely sensed data from available satellites to more accurately classify crop types spatially throughout California's Central Valley. This paper describes the steps used to derive an accurate land cover classification product for California. It will include: background information regarding current methods used in land-crop classification; the development of training data using DWR ground survey data and Landsat 5/7 spectral data from 2001/2002 within an ArcGIS application; pre-processing and data elimination by implementation of algorithms based on human expertise and observed temporal trends; and utilization of a decision tree classifier algorithm to provide discrimination between crop land types.

BACKGROUND

The U.S. Department of Agricultural (USDA), National Agricultural Statistics Service (NASS) provides crop land classification via a web-based application called CropScape (http://nassgeodata.gmu.edu/CropScape/). CropScape provides an accessible, user-friendly platform capable of customizing, downloading, analyzing and broadcasting geospatial data for agricultural applications (Han et al. 2012). USDA NASS also provides georeferenced land use maps throughout the U.S. at 30-56 meter resolution.

As a result of the USDA program, Cropland Data Layer (CDL) datasets have been processed by the NASS field offices and analyzed by the Spatial Analysis Research Section (SARS) of NASS since the program's beginning in 1997. The program expanded over the years with funding from outside sources. The CDL dataset primarily utilizes satellite imagery to provide acreage estimates for the Agricultural Statistics Board (ASB). ASB uses a supervised classification of the cropland cover with training sample points from the Farm Service Agency (FSA) and National Land Cover Data (NLCD) for the See5 decision tree (DT) classifier. Shortcomings of the dataset include the exclusion of double crops or areas that include more than one crop type, which can limit the dataset's accuracy in agricultural areas where crop rotation is common (Boryan and Craig 2005).

With the increasing availability and power of the internet, accessing and processing agro-geoinformation is not only viable but also widely done. The past several decades have produced extensive literature discussing land cover classification products and procedures. Some examples include discrimination of forest types (Vieira et al. 2003), crop field types (Price et al. 1997, Kandrika and Roy 2008, Yan and Roy 2014), and land cover characterization on a global scale (Townshend et al. 1991, Running et al. 1995, De Fries et al. 1998, Vogelmann et al. 1998, Hansen and Loveland 2012). Further research has utilized multi-spectral satellite data to increase accuracy in urban land use classification through the use of vegetative indices (Yuan and Bauer 2007) and impervious identification to map urban spread (Ridd 1995, Lu and Weng 2006).

Review of global and regional land cover methods reveals the importance of consistency and reliability of sensors (Townshend et al. 1991). The increase in sensor resolution and the availability of various spectral bands have presented an opportunity for the remote sensing community to develop a plethora of models and approaches to land cover classification. A broad range of methods and approaches have been reviewed and range anywhere from utilization of human cognition and traditional methods to newer computer-assisted and algorithm-based predictor models.

A review and survey of recent methods and techniques developed is provided by Lu and Weng (2007) and Nath et al. (2014). Otukei and Blaschke (2010) found that methods for classification can be divided into common or advanced schemes. They found that the performance of the DT methodology was most advantageous for classification and provided the highest accuracy. Friedl and Brodley (1997) determined that DT classification outperformed other advanced schemes. Further literature provides insight to pre-processing methods, utilization of vegetation indices and spectral bands with advanced schemes and various algorithms including neural networks and fuzzy classifiers (Wang 1990, Shimabukuro and Smith 1991, Bischof et al. 1992, De Fries et al. 1998, DeFries and Chan 2000, Huang et al. 2002, Mountrakis et al. 2011).

It has been shown that DTs have advantages over traditional classification methods (Hansen et al. 1996). DTs can be defined manually based solely on professional expertise (Running et al. 1995, De Fries et al. 1998) or defined using more complex computer-assisted algorithms such as s-plus statistical software (Hansen et al. 2000), C5.0 software (Friedl et al. 1999) or regression tree analysis (Michaelsen et al. 1994). Methods used to increase accuracy may include boosting, bagging or pruning (Pal and Mather 2001).

As land cover mapping and assessment is a key area in remote sensing data analysis and application (Foody 2002), derivation of applicable classification techniques is critical for successful application to land cover discrimination. Image discrimination is complex and paramount importance is placed on the selection of appropriate classification methods to improve accuracy.

METHODOLOGY

Data Collection

Two data sites for classification were used: (1) Landsat 5 Thematic Mapper (TM) for path/row 43/34 and (2) Landsat 7 TM for path/row 43/34. Land-use ground survey data classifying crop types were downloaded from DWR for the Madera (2001 data) and Merced (2002 data) Counties in California. DWR descriptors were matched to NASS descriptors for the year of respective data set in order to identify approximately 80 land cover classifications including crop types and non-crop, impervious, and water areas. The Madera and Merced County data sets were selected because they have been ground surveyed by the DWR and the Landsat scenes have been pre-adjusted in-house for atmospheric effects. The metrics imported included maximum, minimum, mean and amplitude for each of the scenes available during the subject year for indices and spectral bands. Spectral bands consisted of Albedo, Emissivity, Leaf Area Index (LAI), Normalized Difference Vegetation Index (NDVI), surface temperature (adjusted for elevation), humidity, reflectance channels 1-7, and radiance channels 1-7 (raster format). Top of atmosphere (Crist 1985) reflectance bands were used to calculate the Tasseled

Cap transformations to include brightness, greenness, wetness, fourth, fifth and sixth indices using coefficients presented by Huang et al. (2002) for the Landsat data.

Additionally, these Landsat scenes have been processed using the ITRC-METRIC procedure to compute actual evapotranspiration and crop coefficients by pixel. It is hypothesized that crop coefficient information gathered throughout the year may help in the classification. An additional land use survey for Madera in 2011 will be processed as part of future work. The metrics along with a shapefile created by the DWR identifying parcels and cover type from the ground survey were imported into an ArcGIS computer program and re-projected into the Universal Transverse Mercator coordinate system (zone 11) and the WGS 84 datum.

Data Extraction

Within ArcGIS the raster training data was extracted for analysis by applying a buffer of 45 meters to each of the parcels/fields. Buffered areas less than 1 acre in size were eliminated. It was discovered that the buffer eliminated noise that may be associated with items such as roads, poor crop uniformity, etc. typically located at the edge of the field. Cloud cover was analyzed for both years and the authors concluded that the occurrence of clouds in the scenes was negligible in the areas of interest during the time period. Therefore, no adjustments were made to the data for cloud cover.

Land Classification

The objective of the proposed scheme is to produce a model that is simple, observable and repeatable. Previous studies have shown a decision tree (DT) can be an effective tool for crop classification due to the crop's non-parametric nature and ability to effectively handle non-linear relations and non-homogenous inputs (Quinlan 1993). A schematic diagram of the DT process developed for this study is shown in Figure 1.

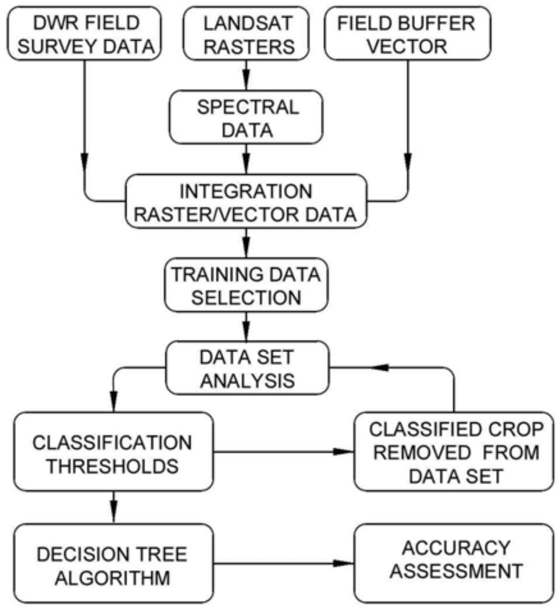

Figure 1. Schematic DT diagram

For simplicity, the analysis focused on a subset of 11 of the 80 land type classifications provided by DWR for the 2002 Merced County data, including: asparagus, beans (dry), broccoli, cotton, onions and garlic, peppers, sugar beets, sweet potatoes, table grapes, unknown grapes, and unknown rice.

Available spectral data for the subset was scrutinized in hopes of creating a DT model for effectively identifying ground crops. Upon initial review of the data, observable trends were identified for certain crops throughout the year. The observed trends provided relative certainty that the crop types, as identified by DWR, were present in the field during the analysis. Because crop planting and harvest dates varied, the initial DT was created based on multi-temporal spectral data between the dates of March and September 2002.

The first step for land classification involved the authors' expertise in identifying temporal trends and vegetation index thresholds for each of the classifications. Initial thresholds for the DT were created using average values from single indices for one or more image dates. Once a crop type was classified based on a particular index, it was removed from the subset and the remaining data was re-analyzed.

For example, Figure 2 shows average albedo and reflectance 5 values for the various crop types on August 25, 2002. Error bars were used to show ± two times the standard deviation (σ). Onions and garlic can be easily identified in the figure as the upper bound in both plots. Thus, the use of a threshold value for either albedo or reflectance 5 can be applied to the data to discriminate this crop type from the remaining subset. Onions and garlic were then removed from the analysis and each index was visually re-scrutinized for further classification.

With the removal of the onion and garlic crop from the data set, additional thresholds were determined from the average net radiation and LAI parameters which led to the discrimination of asparagus and unknown rice crops. As shown in Figure 3, when using the ten crop subsets (onions and garlic omitted), asparagus and unknown rice plot appear distinctively above the remaining data considering average LAI and net radiation, respectively.

This approach was applied to 21 indices for each month of the year and resulted in thresholds or discrimination of the data subset. **Figure 4** illustrates the decision tree created for the Merced 2002 data subset. It was observed that as the decision tree grew the spectral signatures became more similar, which made them more difficult to classify and required some spectral overlap to determine the appropriate thresholds. It is postulated this limitation may be mitigated through the incorporation of crop coefficient data in the analysis.

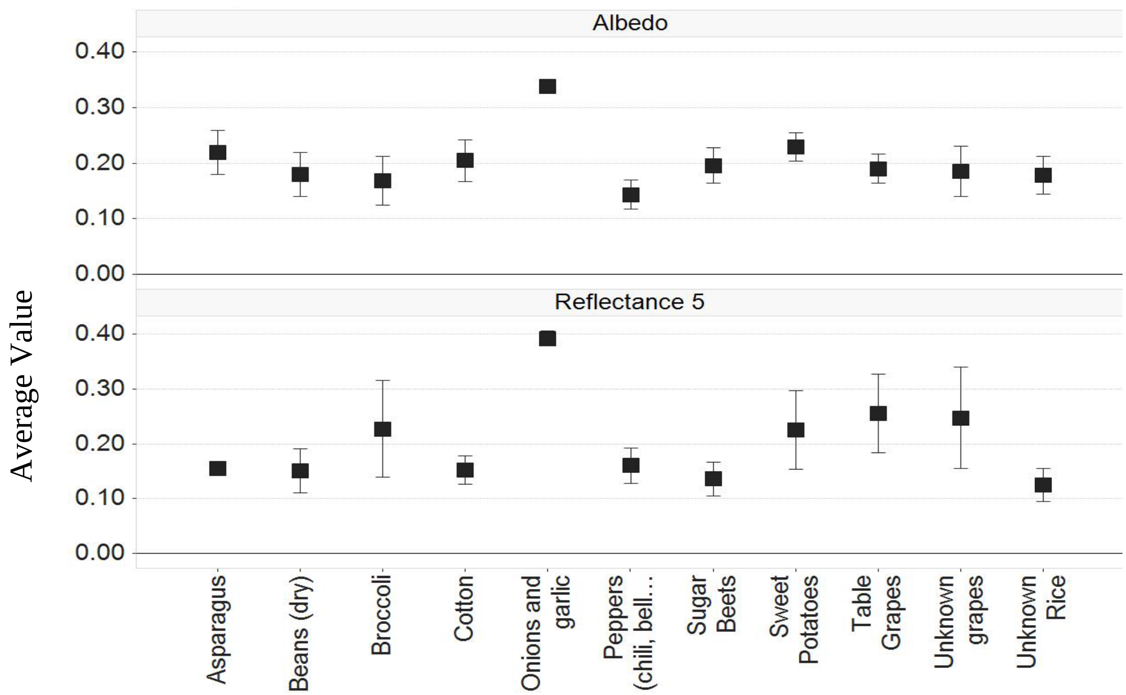

Figure 2. Average albedo and reflectance band 5 values for selected crops on 8/25/2002 (vertical error bars represent ± 2σ)

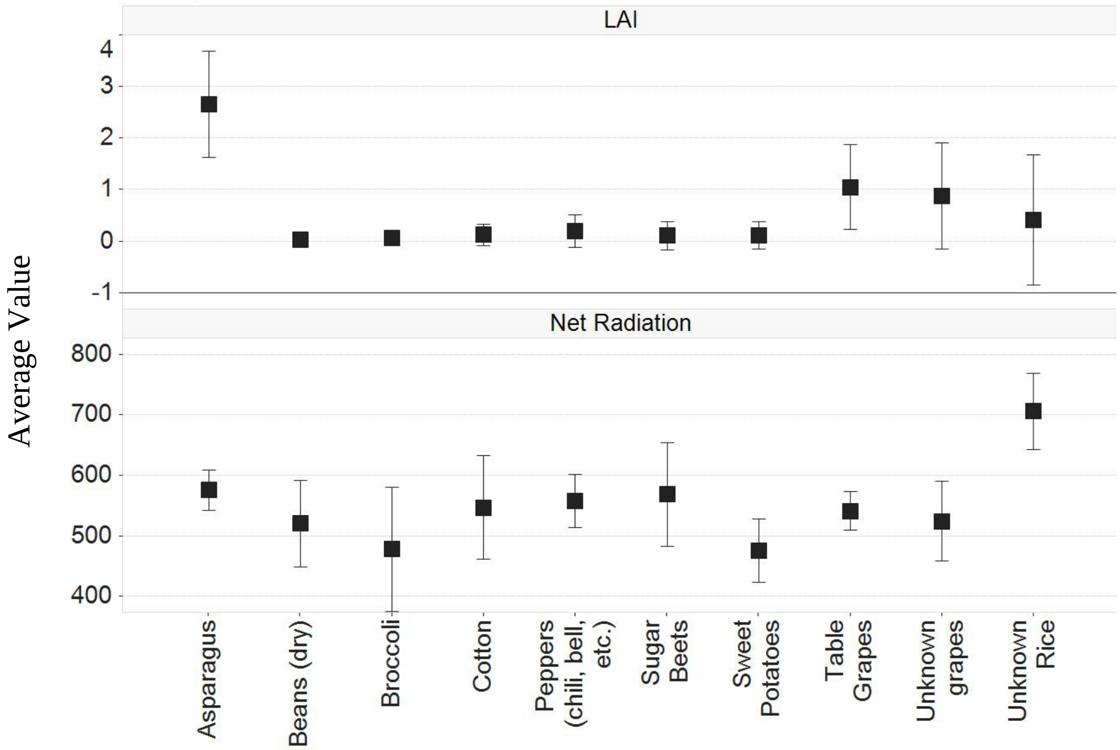

Figure 3. Average LAI and net radiation values for selected crop subsets on 6/6/2002 (vertical error bars represent ± 2σ)

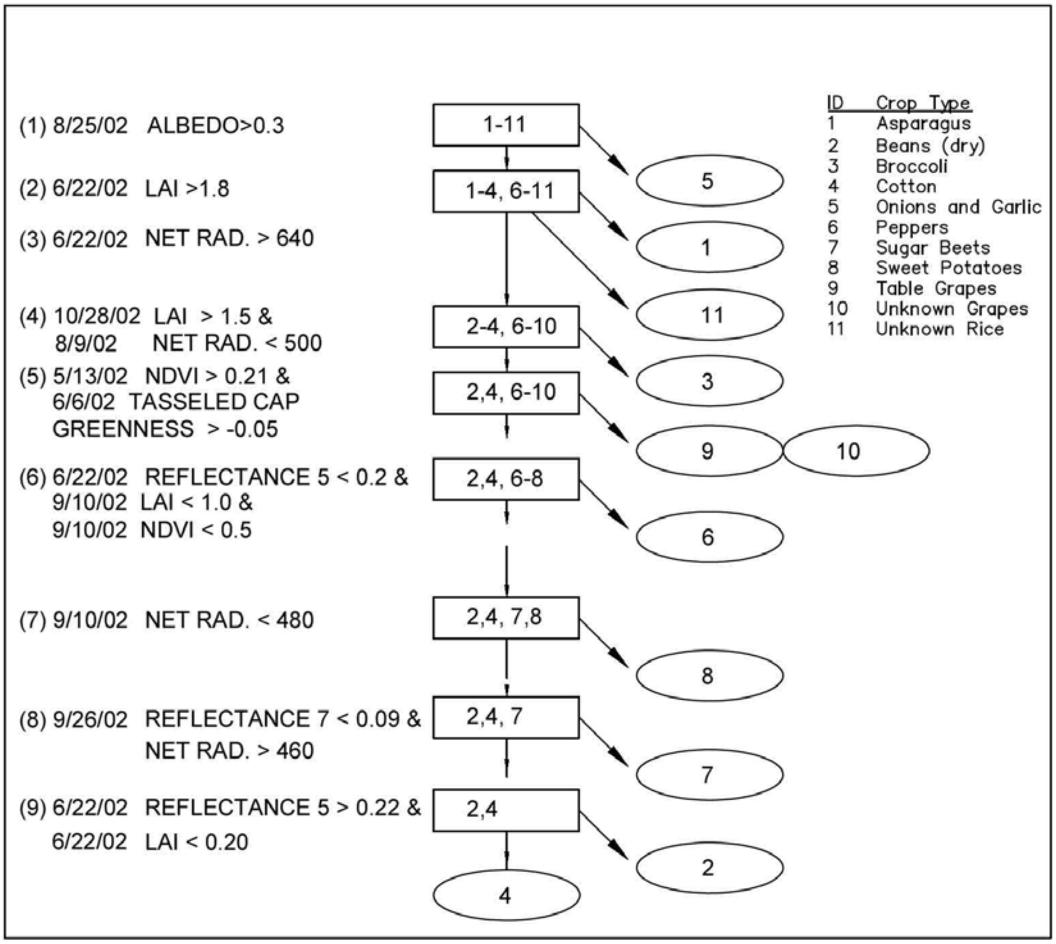

Figure 4. Merced 2002 Decision Tree Schematic

Future work will attempt to classify 42 DWR crop land types, including specific ground crops, fruits (orchards), and pastures with a similar methodology as presented in this paper. It is anticipated that a computer-assisted algorithm will be used to categorize the data into these land types for comparison. The authors intend to assess the accuracy of both of these models through comparisons with more recent data at sites surveyed by DWR.

CONCLUSIONS AND LIMITATIONS

A supervised hybrid DT was created using the initial 2002 data subset to discriminate 11 crop types from multi-temporal spectral data. Spectral overlap increased as the DT grew and it is hypothesized that the inclusion of a crop coefficient in the analysis may provide further discrimination between crop land types. Additionally, the authors intend to implement a computer-assisted classification tool to further discriminate the results and use as a comparison to the manual DT.

Currently, the 2001 data is being reviewed and analyzed in a similar manner to validate these findings and improve the classification methodology. Results of the project are on-going and should be finalized within the next few months. Shortcomings encountered thus far include the potential for classification inaccuracy associated with the large volume of training data (Pal and Mather 2003). The impact of present training data size and quality will also be considered as part of the ongoing work for this project.

ACKNOWLEDGEMENTS

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RECENT YEAR-END GROUNDWATER ELEVATION AND STORAGE CHANGES IN THE MESILLA SHALLOW ALLUVIUM AQUIFER WITHIN THE ELEPHANT BUTTE IRRIGATION DISTRICT

Erek H. Fuchs[1]

ABSTRACT

The surface water supply provided by Elephant Butte Reservoir of which the Elephant Butte Irrigation District (EBID) in south-central NM maintains a major interest has been severely impacted by drought conditions in recent years. The primary aquifer in the area, the Mesilla Bolson, has been deprived of recharge due to consecutive surface water allotment shortages. Increased groundwater pumping in the area in response to ongoing drought has compounded the problem. Data from the EBID's groundwater monitoring program were analyzed to reveal the spatial and annual variability of recent year-end (2009 through 2014) groundwater table elevation and net storage changes in the Mesilla shallow alluvium aquifer within the EBID. The cumulative average annual year-end decline in groundwater table elevations measured for this period was found to be 7.5 feet, indicating a 3.75% loss of the average available water column from the first 200 feet of saturated thickness. Linear regression analysis ($R^2 = 0.64$) suggests that a consistent EBID surface water allotment of at least 23.0 acre-inches per acre might stabilize an otherwise declining trend in average year-end shallow groundwater table elevations, and that at least 24.0 acre-inches per acre for at least five to six years is theoretically necessary to approximate recovery. These effects are likely buffered to some extent by a probable migration of groundwater down gradient into the Mesilla Valley from portions of the western extents of the greater Mesilla Basin. The calculated cumulative net loss in storage was estimated to be 172,418 acre-feet for this same timeframe. Regression analysis ($R^2 = 0.66$) suggests that a 36.0 acre-inch per acre allotment delivered to the EBID for five consecutive years might approximate recovery of aquifer storage. Net loss from storage is probably a better and more useful predictor of aquifer resilience.

INTRODUCTION

The Elephant Butte Irrigation District (EBID) and related water use community within the Lower Rio Grande of New Mexico has been experiencing ongoing drought conditions for much of the last decade. Figure 1 provides a generalized view of the area of interest, in this case concentrating on the Mesilla Valley since this area comprises the majority of the irrigated lands within the EBID.

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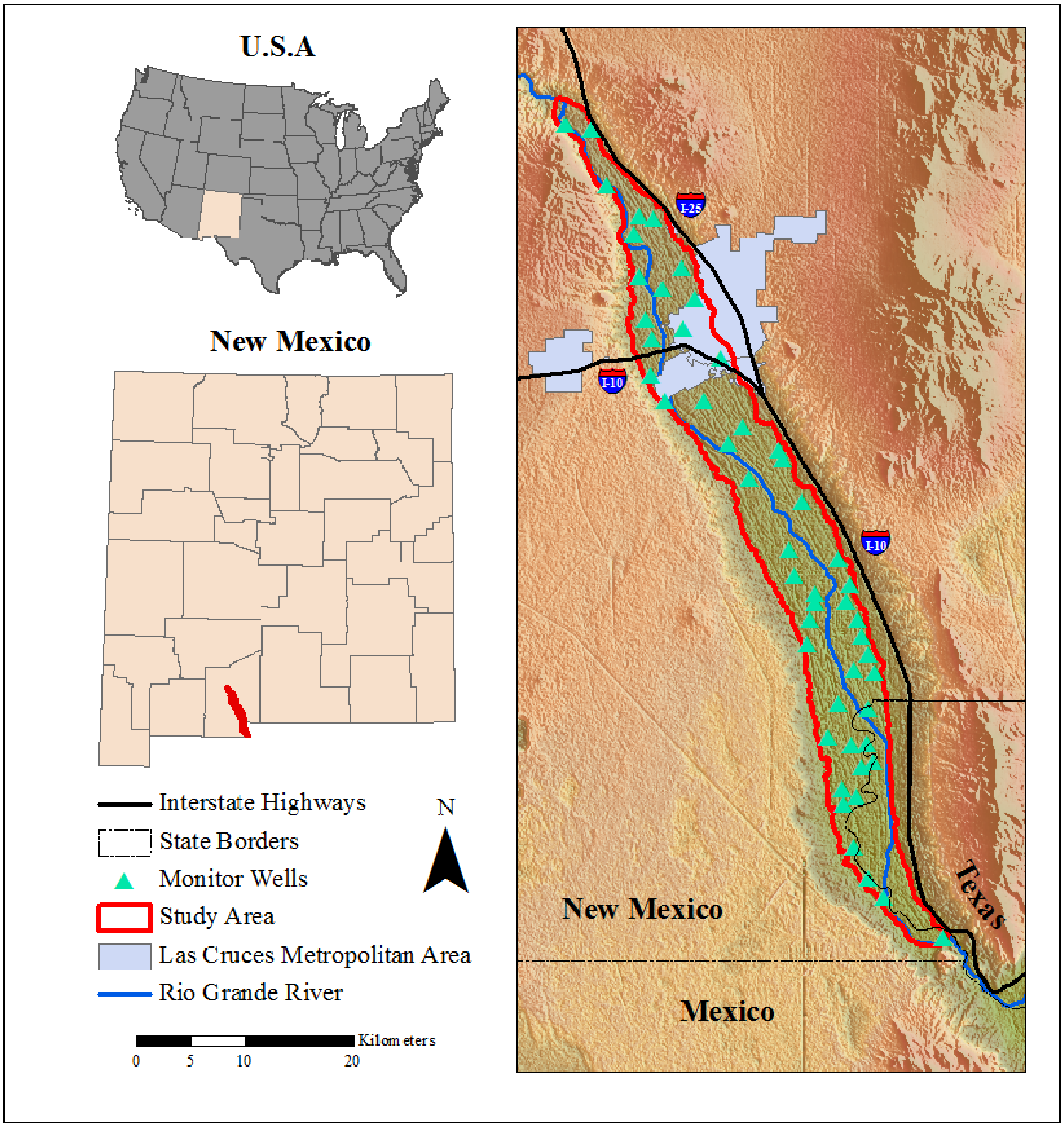

Figure 1. Generalized view of the area of interest and major features/boundaries of significance. Map courtesy of Dennis C. McCarville, EBID GIS Analyst.

The water supply provided by storage in Elephant Butte and Caballo Reservoirs, located in the upstream extent of the Lower Rio Grande Basin in southern New Mexico and a primary feature of the US Bureau of Reclamation Rio Grande Project has been reduced substantially due to ongoing drought. Elephant Butte Reservoir is the primary means of storage servicing the Rio Grande Project. Caballo Reservoir, located immediately adjacent and downstream, serves principally as a regulating feature for Rio Grande Project seasonal release. In a full supply year, irrigation releases from storage begin in March and end in September for a total volume of 790,000 acre-feet, reflecting a full EBID surface water allotment of 3.024 acre-feet (36.288 acre-inches) per irrigated acre for lands assessed to receive surface water within the EBID. In 2013, only 168,200 acre-feet were released between June 1 and July 21, reflecting the shortest release period in the history of the EBID and matching a record low surface water allotment of 3.5 acre-inches per irrigated acre not seen since 1964. Figure 2 is a photograph of Elephant Butte Reservoir taken in July of 2013. At this point, the reservoir had been drawn down to about four percent of its total capacity, the lowest in the history of the Rio Grande Project, and by this measure could be construed as the worst drought in the history of the Project. The volume of water in storage in Elephant Butte Reservoir at a given point in time might be a reasonable gauge of the status of drought for the Rio Grande corridor and the State of New Mexico.

Figure 2. Photograph of Elephant Butte Reservoir, July 2013 at approximately four percent of total (1,638,000 acre-feet) capacity. Photo courtesy of Dr. James P. King.

2014 showed a slight improvement in surface water available for release (7.5 acre-inches per irrigated acre EBID allotment), but still dramatically short of a full supply. 2015 has similarly seen some improvement (11.0 acre-inches per irrigated acre EBID allotment), and the presence of a strong El Niño climatic pattern recently formed could bring desperately needed additional moisture in the form of snowpack to the upland watersheds of northern New Mexico and southern Colorado whereupon spring snowmelt and runoff that traditionally feeds the headwaters and tributaries of the Rio Grande and ultimately downstream Elephant Butte Reservoir may occur. Still, it is entirely possible that a year or even a few years of relative relief in the near-term, should such relief occur and however welcome, may only reflect a respite in the context of drought conditions that could persist much longer.

The primary aquifer in the area upon which the great majority of the EBID overlies, known as the Mesilla Bolson, depends heavily on surface water for recharge in keeping with the basin-fill, mostly unconfined nature of the alluvium system, but recharge has been substantially reduced in recent years due to repeated surface water irrigation shortages. The situation is exacerbated by increased groundwater pumping for irrigation by farmers who are supplementing insufficient surface water allocations to meet seasonal crop requirements, and also by increased extraction for expanding municipal and industrial use in the area. It is therefore not surprising to find that groundwater table elevations within the Mesilla Valley have been in decline (Fuchs, 2014). However, the spatial and annual variations of these declines and particularly the net changes in groundwater from storage in recent years have not been revealed (or perhaps not understood) at a scale sufficient to help much with managerial and operational decisions, to inform other modeling efforts, or most significantly to make meaningful contributions to water policy discussions in the Lower Rio Grande. Consequently and perhaps as much a product of avoidable confusion, legal conflict concerning interstate water rights (Texas v. New Mexico and Colorado) is currently underway regarding this reach of the Rio Grande.

Scope of Study

Interactions between groundwater and surface water are a critical consideration for integrated, conjunctive river basin management, especially during periods of protracted drought conditions when relatively little surface water is available. Measuring these interactions is essential to any practical understanding and hope for managerial application, and has become painfully obvious in recent years within the EBID where farming interests, in response to protracted, severe drought conditions have been forced to rely almost exclusively on pumping groundwater for several consecutive years in order to meet crop requirements. This is not the first time that severe drought has challenged the ingenuity and resilience of the farming community within the EBID, and it is not expected to be the last. Integrated numeric modeling efforts currently underway that are specific to pertinent areas in the Lower Rio Grande, as well as several previous modeling contributions have substantially informed and helped to predict the interactions between surface water and groundwater in this area. Some of these works include Frenzel and Kaehler (1992), Hamilton and Maddock (1993), Lang (1995), Weedon and Maddock (1999), S.S. Papadopulus and Associates (2007), Schmid and Hanson (2009), Hanson et al. (2010), and certainly Knight (2015). The concentrated modeling efforts in the Lower Rio Grande for at least the last twenty years are probably as much a product of the richly litigious interstate history in this area (culminating in 2013 with the State of Texas filing a complaint in the US Supreme Court) as anything else. Otherwise, one might offer that if a river basin could be modeled to death, the Lower Rio Grande likely would have perished some time ago. Still, the predictive value of these excellent numeric modeling works that have tended to build upon one another with the most recent contribution by Knight (2015), and especially upon looking to the future rely largely on data observed from the past, therefore continued calibration based on current and ongoing actual field measurement and related research to better understand stresses to the system not seen before (at least not of the magnitude currently observed) is quite important. Accordingly, the theme of this study is that of a ‘back to the basics’ approach to characterize in quantitative and visual terms the response of the Mesilla shallow alluvium aquifer to ongoing stress in recent years using actual field measurements as adapted to a substantially simplified modeling framework. The present dynamic of changing climate, area demographics, cropping patterns, agronomic practices, population growth, regional politics and a host of other socio-economic considerations beyond the scope of this study are quite different than at any other time in the history of the Lower Rio Grande Basin and Rio Grande Project, therefore a different yet defensible, simplified approach to evaluating management alternatives in this reach of the Rio Grande could be useful. As a minimum, it might provide water managers and related makers of policy an easier and thus faster means by which to understand at a basic level the options going forward to allocate resources to address real water problems. This would seem to be particularly true where and when more fully developed, integrated numeric modeling platforms specific to a given river basin do not exist, or where they do exist (as such is the case in the Lower Rio Grande), perhaps how best to assure that field reconnaissance is maintained to support ongoing model calibration. The same or similar might be said for many other irrigation projects within river basins around the world where irrigated agriculture is considered important, if not critical to continuing to meet increasing societal demands for quality food and fiber. Attention to field-driven research, however time-consuming and relatively expensive (costs of personnel, measurement devices, instrumentation, etc.) but producing actual data to support an adaptive stochastic modeling framework should remain a priority for water scientists and managers. Such efforts are sure to further inform other ongoing modeling efforts, numeric or otherwise, and as noted by Yeh et al. (2015), we need to consider using stochastic subsurface hydrology principles for real-world problems.

The agricultural economy of the Lower Rio Grande in New Mexico is maintained almost exclusively by the membership of the EBID, which is the largest irrigation district in the state and remains a significant part of the overall economy in the region. Cash receipts from agricultural commodities in Doña Ana County where the majority of the EBID resides are consistently the first or second highest of all New Mexico counties (Skaggs, 1999). Fully aware of this and the fact that reliance on groundwater resources is at times necessary to survive drought conditions, the EBID does maintain a network of shallow monitoring wells situated along and throughout much of the Lower Rio Grande shallow alluvium aquifer and does routinely track and analyze groundwater table elevations in this reach of the Rio Grande (Fuchs, 2014). The objective of this work is specific to analysis of data available from the EBID to explore the spatial and annual variability of recent year-end (December 31) groundwater elevation and net storage changes in the Mesilla shallow alluvium aquifer within the EBID. This effort reflects a spatial modeling approach to show where changes have occurred and when on an annual basis in recent years (calendar year-end period of 2009 through the calendar year-end of 2014). Attempts also are made to correlate these changes with the annual surface water allotments made available to the EBID during this period by assuming a generalized mass-balance approach to characterize the response of the shallow aquifer system to ongoing stress (drought-induced extraction of groundwater). Mass-balance in this instance is simply taken to mean that evapotranspiration from irrigation use of water, while not estimated in this study, is the only (or by far the largest) net loss of water from the system, and that recharge of significance to the Mesilla alluvium aquifer is limited to annual release of surface water from Rio Grande Project reservoir storage.

Supporting Literature and Background

The surface waters of the Rio Grande and the groundwater of the shallow alluvium of the Mesilla aquifer in the Lower Rio Grande Basin are a highly-connected, essentially singular resource (Conover, 1954; Wilson et al., 1981; Frenzel and Kaehler, 1992; Winter et al., 1998; Turney, 1999; Hawley and Kennedy, 2004; and others). On average, the first two-hundred (200) feet of saturated thickness in the Mesilla Valley of the Lower Rio Grande may be taken as the shallow alluvium aquifer as defined by Frenzel and Kaehler (1992) as the first lithological layer for purposes of a groundwater model of this area. It should be noted that actually only about the first eighty (80) feet of this basin-fill material on average, with a mix of valley basalts is floodplain alluvium. This unit has a thick basal channel with sand and gravel overlain by finer grained, sand and clay floodplain deposits (King and Hawley, 1975) and is generally very permeable. Immediately below the floodplain alluvium begins the Upper Santa Fe Group, which interfaces with the surfaces of the youngest basin-fill deposits that predate initial entrenchment of the present Rio Grande valley in middle Pleistocene time (King et al., 1971). This unit contains alternating beds of sand to sand and gravel, and clay to sandy clay, and extends to depths of about 450 feet below the floodplain alluvium. The upper portions of this stratigraphic unit exhibit permeability very similar to the floodplain alluvium. Much deeper stratigraphic units with significant water-bearing potential in the Mesilla Valley do indeed exist as the Lower Santa Fe Group, however specific storage expected at depths greater than about 200 feet below ground surface and the likelihood of leaky-confined conditions at greater depths are beyond the scope of this study.

At the time (early-mid 1970's) that more concentrated field efforts were underway to better characterize the hydrogeology of the Mesilla Basin, the great majority of irrigation wells in the valley were found to have been completed from about 70 to 200 feet below ground surface (Wilson et al., 1981). Thus, most development of groundwater in the Mesilla Valley for irrigation historically had made use of both the floodplain alluvium and the underlying, upper portions of the Upper Santa Fe Group. This had followed a period of severe drought in the region that was unmistakable by 1951 and lasted throughout much of the 1960's, and actually well into the 1970's, notwithstanding a few average to above-average, relatively wet years during this otherwise multi-decadal dry period. During this period, thousands of irrigation and other wells were drilled in the Mesilla Valley in order to survive the drought, which indeed the family farming membership of the EBID mortgaged resources as necessary and successfully accomplished. Importantly, the State of New Mexico did not impose any regulatory hindrance on drilling wells of any sort for any purpose during this time (other than the requirement that well drilling be performed by drillers licensed to do so by the New Mexico State Engineer), and actually it was not until September 11, 1980 that the New Mexico State Engineer asserted his jurisdiction over groundwater resources in the Lower Rio Grande to require permitting. By this time, extensive groundwater development in the Mesilla Valley had long been established, or had been unmistakably initiated in the context of inchoate groundwater rights for purposes other than irrigation in keeping with New Mexico's Mendenhall Doctrine[2]. Regardless, the great majority of groundwater rights actually developed in the Mesilla Valley since at least the early 1950's were and

[2] Briefly, the significance of this historic decision as it is generally interpreted for administrative purposes is that so long as the water right in question, the works and use associated with which having been lawfully initiated prior to formal declaration by the State Engineer of the basin in question, is exercised in concert with the intent declared and done so with due diligence and in harmony with all applicable administrative conditions and/or statutory considerations (i.e., no willful waste, etc.), the opportunity to continue to develop the right within a reasonable period of time and associated priority are generally preserved. *State of New Mexico v. Mendenhall,* 68 N.M. 467, 362 P.2d 998 (1961).

are a supplemental source for irrigation purposes within the EBID. The period of 1979 to 2003 reflected a remarkable return of surface water back to the system with consistent, full surface water allotments available to the Rio Grande Project and the EBID for twenty-four consecutive years, however previously established groundwater rights for irrigation and the convenience of existing wells have continued to be used in varying amounts to this very day. Ready access to an additional source of water and established groundwater rights to supplement as necessary the uncertain availability of surface water in the Mesilla Valley led to the propagation of other, more profitable permanent crops such as pecans for which world-wide demand exists, but for which water requirements to effectively produce are necessarily greater than the mainstay of cotton that had otherwise dominated the area for many years prior. During this same timeframe (1979 to 2003) of relatively abundant surface water, the population in the Mesilla Valley more than doubled (US Census, 2010), and it continues to grow.

Since the maximum depths of most irrigation wells that had successfully survived the drought of the mid-twentieth century in the Mesilla Valley were found to be about 200 feet below ground surface, Frenzel and Kaehler (1992) apparently surmised that 200 feet could be taken to be the first lithological layer for purposes of groundwater modeling in the area. In practice, it is highly likely that enterprising farmers at the time these wells were originally being drilled (most in the early-mid 1950's) discovered that a cost for well drilling to well yield ratio was optimized by targeting well depths not to exceed about 200 feet below ground surface. Logic of this nature does make sense because the first 200 feet on average of saturated thickness in this unconfined, highly permeable, largely homogenous unit of the Mesilla aquifer is well known to exhibit a high hydraulic conductivity (i.e., 70-140 feet per day). Frenzel and Kaehler (1992) found that values of hydraulic conductivity estimated from specific capacities of irrigation wells were 200 or more feet per day in places. Well yields in excess of 3,000 gallons per minute from properly screened, 12 to 16-inch production casings running continuously for weeks at a time in the Mesilla Valley are not uncommon. In light of its tremendous productive potential and capacity, the shallow alluvium aquifer of the Mesilla Valley in the Lower Rio Grande has been readily developed to support irrigated agriculture, particularly as a drought contingency as encountered historically, and other uses as population in the area has grown exponentially since the early twentieth century.

The first 200 feet on average of saturated thickness of the Mesilla aquifer is also known for a relatively large specific yield. This of course compliments the average of high, sustained well yields for irrigation common in the Mesilla Valley. Conover (1954), Richardson et al. (1972), Lizarraga (1978), and Wilson et al. (1981) each independently reported a specific yield of at least 20 percent; 0.2, taken to be the storage coefficient in this unconfined unit of the aquifer. As noted by Conover (1954), the specific yield of an aquifer is difficult to determine accurately, either in the field or the laboratory. Driscoll's (1986) definition of specific yield is the ratio of the volume of water that a given body of rock or soil will yield by gravity to the volume of that mass. In an unconfined aquifer, this is virtually equal to the aquifer's storage coefficient, which Driscoll (1986) defines as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. A protracted discussion of the methods each of the authors noted above used to arrive at the average, estimated specific yield of the shallow alluvium aquifer in the Mesilla Valley is beyond the scope of this study, however in most instances data derived from well pump tests and resultant time-drawdown graphs are referred to. Accordingly, it is worth mentioning at least briefly one of the basic approaches typically used to estimate aquifer specific yield.

Data derived from properly conducted well pump tests (observation wells are properly located relative to pumping wells and the tests are conducted for sufficient duration) can be applied to the work of Cooper and Jacob (1946) whereby manipulation of the Theis (1941) nonequilibrium well equation, while using the zero-drawdown intercept of available time-drawdown graphs, renders the following equation:

$$S = \frac{0.3\ Tt_0}{r^2}$$

where

S = storage coefficient (dimensionless)

T = transmissivity, in gallons per day per foot

t_0 = intercept of the straight line at zero drawdown, in days

r = distance, in feet, from the pumped well to the observation well where the drawdown measurements were made

It is important to note that although the work of Cooper and Jacob (1946) has been successfully applied for many years in many parts of the world without significant error as a derivation of the work of Theis (1941), it is nevertheless still an analytical method operating with many assumptions. Among these assumptions are that the water-bearing formation is uniform in character (homogenous) and the hydraulic conductivity is the same in all directions (isotropic conditions), and that the formation is uniform in thickness. For the purposes of this study, these assumptions are reasonable. It is also important to consider that aquifer transmissivity, T, is an operative term in the estimation of aquifer storage here. Aquifer transmissivity is defined by Driscoll (1986) and others as the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. The unit width of aquifer may in this instance be taken to be the thickness of the stratigraphic unit under consideration, which in this study the saturated portion will be shown to have declined in recent years. If the aquifer thickness under consideration has declined, so too will the aquifer transmissivity have declined, and therefore well yields will tend to suffer.

Depending on the respective river stage and aquifer head, a river may entirely and persistently be gaining or losing, but may have reaches that are gaining and other reaches that are losing. Similarly, one reach can be gaining at one point in time and losing at another time (Winter et al., 1998; Woessner, 2000). The understanding of groundwater extractions interacting with surface water systems has been developed over many decades. Theis (1941) and Glover and Balmer (1954) were the first to consider the effects of a well on a nearby river. This was later refined by Hantush (1965) who included a semi-permeable barrier between the river and aquifer representing the riverbed, and Hunt (1999) who produced a solution to the case where the river is only partially penetrating the aquifer. These analytical solutions provide insights into river-aquifer interactions, but they are limited in their applicability as only a conceptual, idealized model of a river, aquifer and pumping well(s). Because of this relative simplicity, they cannot include the influences of varying recharge, variable transmissivity and other important hydraulic considerations that occur in reality (Rushton, 2002). Numerical methods, such as the popular US Geological Survey (USGS) modular finite-difference groundwater modeling code (MODFLOW), while having come a long way as evidenced by several of the excellent works cited previously (e.g., Hanson et al., 2010; Knight, 2015), are nevertheless not without significant limitations as well (Sophocleous, 2002; Kirkby, 2004; Burt et al., 2015). The fact that there can be substantial differences between field data and analytical or numerical models (Sophocleous, 2002; Kollet and Zlotnik, 2003; Kirkby, 2004; Burt et al., 2015) underscores the need for continued support for field-driven approaches where the hydrogeology of river basins is better understood and the impacts of management policy are better predicted (Mair and Fares, 2010; Tao et al., 2011; Burt et al., 2015). Acknowledging the inherent complexity exposed by the realities of heterogeneity, Yeh et al. (2015) offers the sobering, although arguably refreshing point that a lack of understanding persists regarding issues of scale related to observations, theories, and processes, and that this condition necessarily fosters an ongoing uncertainty in hydrogeologic science. This study does not attempt to address complexities of heterogeneity or anisotropic conditions given the observations and support found in the literature for the largely homogenous, uniform hydraulic properties of the Mesilla Valley floodplain alluvium that is the subject of this work.

Study Area

The Mesilla Basin itself encompasses a large area that extends well outside the bounds of the EBID, particularly on its western extent, however the focus of this study is within the bounds of the EBID which is essentially synonymous with the Rio Grande floodplain in the area. Figure 3 provides a generalized view of the major groundwater resources in the area, including the Mesilla Basin and the Rio Grande alluvium that is common to the basic boundaries of the EBID in the area. The Rio Grande alluvium is synonymous with the floodplain within the Mesilla Valley and is significant from a hydrologic perspective because groundwater pumping for irrigation and other purposes in the shallow alluvium of the Mesilla Valley tends to have essentially immediate effects on the surface water flows of the Rio Grande itself, but also readily observable effects on groundwater table elevations (Turney, 1999; S.S. Papadopulus and Associates, 2007; and others).

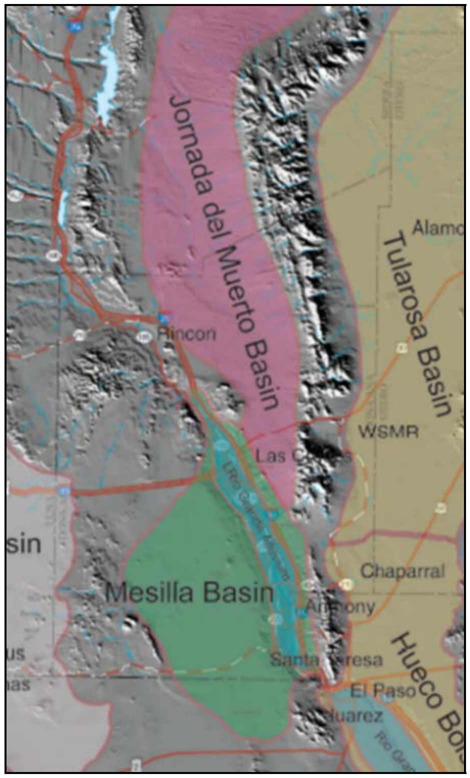

Figure 3. Area groundwater features, including the Rio Grande alluvium within the Mesilla Basin in southern NM. Adapted from: NMWRRI Technical Completion Report 332 (Hawley and Kennedy, 2004).

METHODS USED

A spatial modeling approach utilizing analytical tools available in a Geographic Information System (ArcGIS® v.10.2, Environmental Systems Research Institute, 2013) framework adapted specifically to the study area is used to show where and to what extent year-end groundwater elevation and storage changes in the Mesilla shallow alluvium aquifer within the EBID have occurred in recent years. Within the Mesilla Valley and within the EBID, the EBID maintains a network of forty-five (45) instrumented, shallow monitoring wells dedicated almost exclusively to tracking shallow groundwater level elevations in the area. Each monitoring well is completed to a depth of approximately forty (40) feet below ground surface. The bottom twenty (20) feet of each well is screened, however a blank sump of about ten (10) feet occupies the very bottom of each well. Figure 4 is a basic map showing the locations of the monitoring wells that are the subject of this study. These forty-five monitoring wells are located in a somewhat scattered, non-uniform, albeit convenient (in terms of access) fashion to provide a reasonably thorough representation of coverage throughout the Mesilla Valley. Completion of these monitoring wells as replacements of older monitoring wells exhibiting problems occurred in early-mid 2009. The existing monitoring well network that was installed by the US Bureau of Reclamation many decades ago as a facet of the Rio Grande Project within the EBID had largely outlived its usefulness years prior with wells in many instances long since dilapidated, too shallow, obstructed or otherwise beyond repair. Further, all of these old monitoring wells were without instrumentation of

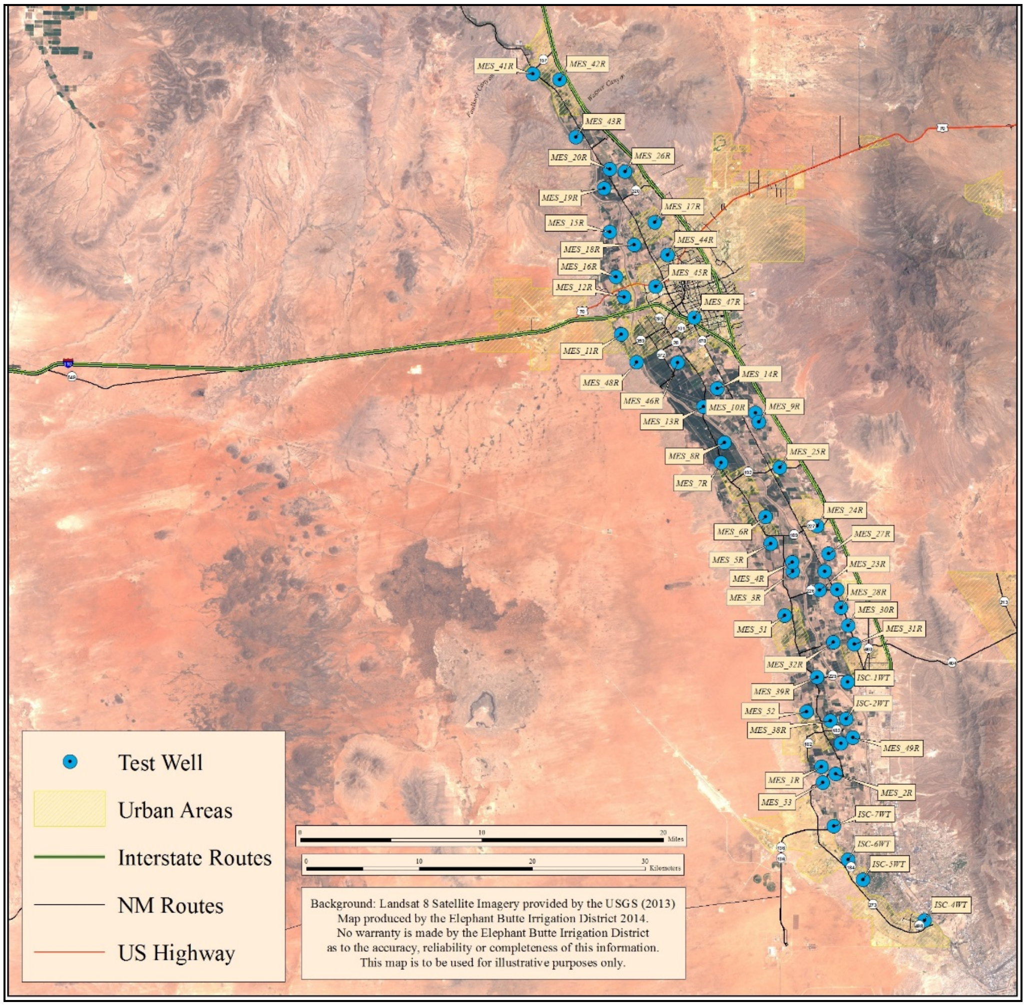

Figure 4. Test (monitoring) well locations within the Mesilla Valley of the ElephantButte Irrigation District (EBID). Depicted also in the southernmost extent of the Mesilla Valley are four monitoring wells (ISC-4WT through ISC-7WT) owned by the NM Interstate Stream Commission (ISC), but which the EBID manages. The ISC wells were not included in this study for the reason that the EBID does not have ownership of the data derived from these wells. Map courtesy of Dennis C. McCarville, EBID GIS Analyst.

any kind, and so data acquisition was strictly manual and dependent on the availability of qualified personnel to conduct measurements. Groundwater table elevation data from submersible pressure transducers (pneumatic bubbler sensors) situated at the bottom of the screen of each of the new monitoring wells and calibrated regularly as per manufacturer specification is recorded continuously (year-round) every thirty (30) minutes, temporarily stored in on-site data-logger storage devices maintained by EBID personnel, along with Remote Telemetry Units (RTUs) equipped with solar-charged batteries and sent via radio signal real-time to a central computing network. The data are monitored for quality assurance and control by professional staff of the EBID to produce the average daily groundwater level elevation at each monitoring well, and these data are stored within EBID's digital data archive. This real-time data and other real-time water resource data for EBID's collective monitoring program are available online and continuously via EBID's RTU Data Center website[3]. Quality assurance and control that is the subject of more concentrated analysis tends to occur quarterly and is focused mostly on data admitted to the EBID archive to assure that sensor anomalies, etc., as may occur from time to time are corrected. All groundwater elevation data used in this study were reviewed extensively, which was simplified somewhat in this case because the nature of this study is concerned only with the year-end (December 31) groundwater table elevations at each site. Annual year-end conditions are the focus of interest in this study for the reason that it has long been established (Wilson et al., 1981, and others) that irrigated agricultural extractions from the Mesilla shallow alluvium aquifer are by far (~80+ percent) the largest categorical use of groundwater in the region (the same or similar is true for irrigated agriculture throughout the western US, and many other river basins in arid to semi-arid climatic regimes across the globe; Sophocleous (2002)), and that year-end (late December, early January) is a period that reflects a time when irrigated agricultural pumping of groundwater is most likely minimal. At this time, groundwater table elevations between monitoring wells will tend not be influenced by the pumping effects of nearby irrigation wells since little or no irrigation is expected. Thus, potential for the elevation of the shallow alluvium Mesilla aquifer at each monitoring well location to have rebounded and/or reached a point of new relative equilibrium would have reached a maximum at this time, and it is at this time that comparison to the average groundwater table elevations measured for the day on the same date at each monitoring well for the year prior and for year after year thereafter (calendar year-end of 2009 through the calendar year-end of 2014) are compared. A spatial depiction of the accumulation of these groundwater elevation change summations is offered, along with an average groundwater table elevation decline in the Mesilla Valley for the duration of the study period.

It is presumed that for purposes of this study that each monitoring well location and the year-end groundwater table level elevation data associated with each monitoring well contributes equally to characterizing the collective response of the shallow alluvium aquifer within the Mesilla Valley to groundwater pumping in recent years. This is not to suggest that groundwater pumping effects in proximity to each monitoring well are in any way equitable in terms of induced hydraulic gradients and related drawdowns (obviously timing and rates of pumping vary considerably and are greater in some areas and less in others in response to particular crops grown, agronomic practices, aquifer properties, relative well capacities, etc.), but rather that all monitoring well locations and associated year-end groundwater level data are taken to be equally informative. If the purpose of this study were limited only to characterizing the year-end groundwater table elevation changes at or in immediate proximity to each monitoring well for the last several years, then a simple averaging approach such as the arithmetic mean method described by Fetter (1980) commonly used to determine the effective uniform depth of precipitation (in this study the effective uniform change in hydraulic head) would be explored. However, the monitoring well network maintained by the EBID is not uniform in spatial extent, and more importantly, a major purpose of this study is to characterize the net change in year-end shallow groundwater storage during the study period. To accomplish this, it is

[3] http://ebid.onerain.com/home.php

necessary to place spatial bounds on and around each monitoring well to reflect a relative 'area of influence' of each monitoring well location within the overall bounded area of the Mesilla Valley floodplain. The technique chosen for this study was the construction of Thiessen polygons (Thiessen, 1911) utilizing ArcGIS® spatial analysis software. This process is remarkably simple as largely automated with the spatial analysis features of ArcGIS®, particularly once a general area of interest (the floodplain within Mesilla Valley in this study) is mapped and GPS points of interest (the monitoring well locations in this study) are collectively loaded into the GIS with a common spatial coordinate system. Execution of the spatial analyst features of ArcGIS® specific to the Thiessen method (one of several analysis options available in ArcGIS®) automatically splits the general area of interest (the floodplain) into a number of individual polygons in keeping with the number of points of interest (the monitoring wells) identified. Each monitoring well then is contained by a polygon unique to that monitoring well and of unique spatial extent. The Thiessen method to adjust for non-uniform sampling point distribution uses a weighing factor for each sampling point (each monitoring well). The weighing factor is based on the size of the area within the drainage basin, in this case the floodplain alluvium within Mesilla Valley. The Thiessen method was chosen for this study because of its relative simplicity and the fact that it has been around for over one-hundred (100) years, and also ease of duplicity for potential adaptation elsewhere. It is not necessary to be a professional GIS analyst to deploy this method. Introductory coursework or training in GIS should in most cases suffice, however the robust spatial analysis features of ArcGIS® are probably among the most popular and perhaps easiest to learn of the current, commercially available computing software packages of this genre. Other spatial analysis methods, particularly a geostatistical approach known as Gaussian process regression (commonly referred to as Kriging) could very well be adapted to the purposes of this work. Recent efforts to this effect but elsewhere in New Mexico are underway as developed by Timmons et al. (2015). It is envisioned that this study may be expanded eventually to compare and collaborate with these efforts and other methods (i.e., isohyetal lines and other contouring approaches) since other areas in the Mesilla Basin apart from the Mesilla Valley do warrant attention. For example, expansion of the Thiessen polygon approach herein used, or alternatively Kriging to include the western extents of the Mesilla Basin may not be practical for the reason that the relative few monitoring wells that are situated throughout the West Mesa of the Mesilla Basin for which reliable groundwater elevation data for a number years exists (where it does exist) may be entirely too coarse to render meaningful results. This observation might serve a constructive argument for the need for a number of additional monitoring wells or nested piezometers in the western extents of the Mesilla Basin, or perhaps the deployment of other technology (e.g., gravity methods, etc.).

Methodology to estimate net change in the shallow alluvium aquifer storage at year-end for each year during the study period is computed as an expression of change in hydraulic head (measured change in shallow groundwater table elevation at year-end) relative to each individual monitoring well polygonal area and a storage coefficient assumed to be correct at each and every monitoring well location. As discussed previously, the storage coefficient supported in the literature for the shallow alluvium aquifer in the Mesilla Valley and adopted for this study is 0.2. It is possible that storage coefficients dropping to 0.1 or less might be encountered at depths near or somewhat below the stratigraphic surface of the Upper Santa Fe Group (Hawley et al., 2004), which on average would be expected to be encountered at about eighty (80) to ninety (90) feet below ground surface, however Conover (1954) reported storage coefficients in the most permeable parts of the floodplain alluvium as upwards of 0.25. Regardless, all of the monitoring wells maintained by the EBID are screened at depths no greater that about forty (40) feet below ground surface. Therefore, an assumed average storage coefficient of 0.2 is probably reasonable for the purposes of this study and indeed has been referenced and utilized by numerous groundwater modeling studies in the Lower Rio Grande as applicable to the shallow alluvium aquifer in the Mesilla Valley for at least the last thirty (30) years.

In keeping with the instruction of Fetter (1980) and others, net change in the shallow alluvium groundwater storage at each Thiessen polygon and associated monitoring well is simply expressed as:

$$\Delta V_w = SA\Delta h$$

where
ΔV_w = change in storage, in acre-feet
S = storage coefficient (dimensionless)
A = polygonal surface area within which the monitoring well is contained, in acres
Δh = change in head at the monitoring well, in feet

Summation of these products at each year-end from each monitoring well and associated polygonal area are offered as the estimated cumulative net change in storage from the Mesilla shallow alluvium aquifer for the calendar year-end period of 2009 (beginning of 2010) through the calendar year-end of 2014.

RESULTS

Theissen Polygons

As discussed previously, the Theissen-interpolated areas were initially defined with the aid of ArcGIS® spatial analysis mapping software. The polygons were thereafter preserved to reflect exactly the same polygonal geometry with respect to individual polygons and associated areas contained for each year for the duration of the study period. Each monitoring well location serves as the governing point of a respective Theissen polygon of which all polygons combined comprise the total area of the EBID occurring within the Mesilla Valley atop the Mesilla aquifer. This total area is calculated to be 108,777 acres, but only a part of this area (~70,000 acres on average) is in actual cultivation (regularly irrigated) during any given irrigation season and assessed to receive surface water from the works (canal system) of the EBID. The great majority (ninety (90+) percent)) of irrigated lands throughout the EBID receive a combination of surface water administered by and through the EBID and groundwater pumped from individually-owned, private wells to meet crop requirements. The average polygon area following the Theissen split in this exercise whereby all forty-five (45) EBID monitoring wells in the Mesilla Valley are included is 2,417.27 acres, but again not all of this land is actually irrigated. The largest Theissen polygon area created is 8,578.18 acres, and the smallest is 619.37 acres. A standard deviation of 1,415.29 acres from the mean was found. A standard deviation of this magnitude might suggest a source of error for the purposes of this study, not unlike discretization considerations common to numeric groundwater modeling efforts where the average model grid cell area is typically desired to be smaller rather than larger. Even so, smaller model grid cell areas for numeric modeling purposes are only as useful as is the availability and understanding of hydrogeologic field data specific to the area (Kirkby, 2004; Burt et al. 2015). In this respect, the relatively large standard deviation from the mean Theissen polygon area found in this study might serve an argument for the need for more monitoring wells and/or observation points in the study area. Regarding the polygonal geometry and related bounds of polygons created by the use of spatial analysis mapping software in this study, it is important to note that the software and related polygons created are in no way informed by the hydrology and other geophysical features of the system, other than the basic boundaries of the Mesilla Valley floodplain within which the polygons are created. The Theissen polygons in this instance are only a mathematical interpolation of the surface as governed by the boundaries of the floodplain and the locations of existing monitoring wells within the floodplain. This may be another source of error for the purposes of this study because adjusting the boundaries of individual polygons may in some instances better reflect the spatial distribution of effects to the shallow alluvium aquifer. An understanding of this could be useful from a managerial perspective as a basis for allocating limited resources to prioritize the locations and number of additional monitoring wells and/or observation points (e.g., scheduled deployment of gravity methods) in areas of particular interest or where data are relatively scarce.

Groundwater Elevation Changes

Table 1 provides a summary of the average annual year-end groundwater table elevation changes measured for the period December 31, 2009 through 2014 and the corresponding EBID surface water allotment for each year. The correlation of lower annual surface water allotments to lower year-end average groundwater elevations is unmistakable.

Table 1. Measured average annual year-end groundwater table elevation changes and the corresponding EBID surface water allotment for the period 2009 through 2014 in the Mesilla Valley shallow alluvium aquifer.

Year	Average year-end groundwater table elevation change (feet)	EBID surface water allotment (acre-inches per irrigated acre)
2009-2010	-0.153	24.0
2010-2011	-2.997	4.0
2011-2012	-1.212	10.0
2012-2013	-2.431	3.5
2013-2014	-0.688	7.5
Total:	-7.480	

It is interesting to note that although the EBID surface water allotment delivered during the 2011 irrigation season was 0.5-inches per irrigated acre greater than the allotment delivered during the 2013 irrigation season, the decline in the average groundwater elevation as measured at the end of 2011 was over a half-foot (18.9 percent) greater than that found at the end of 2013. The effects of ongoing drought would logically be prevalent here, but apparently aren't the primary cause for this unexpected finding. One possible explanation for this could be the existence of more groundwater pumping during the 2011 irrigation season by farmers in the Mesilla Valley responding to matters additional to and apart from an apparent shortfall of surface water to meet irrigation requirements in 2011.

Figure 5 is a map of the Theissen-interpolated areas projected to reflect the cumulative measured year-end groundwater table elevation change from within the Mesilla Valley of the EBID for the calendar year-end period of December 31, 2009 through the calendar year-end of 2014. Here it is seen where areas of potential concern may exist as of December 31, 2014.

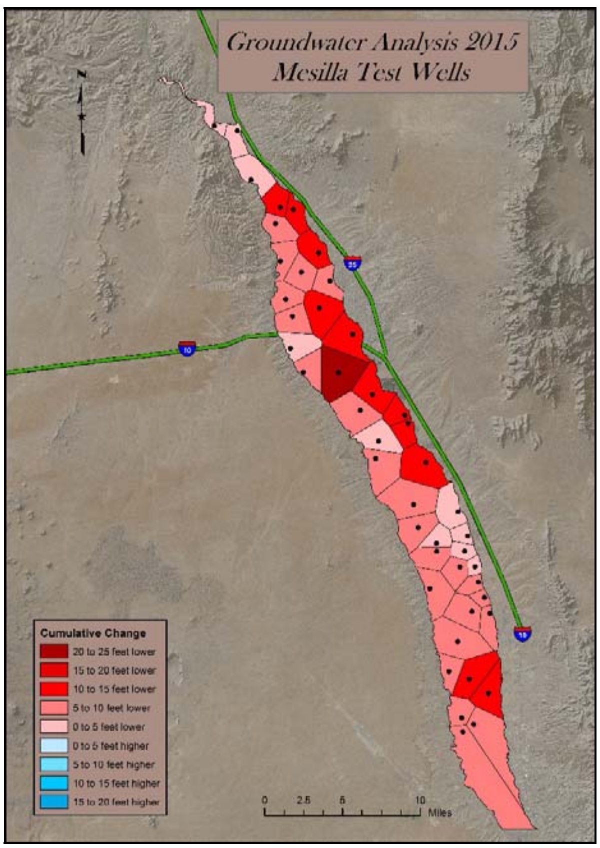

Figure 5. Cumulative year-end groundwater elevation change within the Mesilla Valley of the EBID, 2009 through 2014. Map courtesy of Dennis C. McCarville, EBID GIS Analyst.

The potential for greater groundwater pumping occurring in 2011 as compared to 2013 could be influenced by water policy activities at the time. Particularly and for purposes of water rights adjudication proceedings that remain underway in the Lower Rio Grande, the New Mexico State Engineer had in 2011 identified a deadline for farmers to submit evidence in 2012 for crop water requirements beyond an established, average threshold of 4.5 acre-feet per irrigated acre from both surface and groundwater sources, not to exceed 5.5 acre-feet per irrigated acre from all sources. Naturally, many farmers in the Mesilla Valley became very attentive to metering and reporting groundwater diversions in 2011, and it is possible that some amount of acreage that might have otherwise been fallowed in response to the shortage of surface water may have instead been kept in production during this time.

Groundwater Net Change in Storage

Table 2 provides a summary of the estimated annual net change in groundwater storage from the shallow alluvium aquifer within the Mesilla Valley for each year for the period December 31, 2009 through December 31, 2010. Similar to changes observed in groundwater table elevations during the study period, net change in storage calculated between the 2011 and 2013 irrigation seasons is interesting and not as expected relative to the EBID surface water allotment delivered during each of these respective years. As revealed in Table 1, a 12.5 percent greater surface water allotment (4.0 acre-inches per irrigated acre) was delivered during 2011 as compared to 2013 (3.5 acre-inches per irrigated acre), however calculated net change (loss) in storage is seen in Table 2 to be 14.6 percent more in 2011 than it was in 2013. Interesting also is that the 18.9 percent greater decline in average groundwater table elevation in 2011 relative to 2013 as revealed in Table 1 is 4.3 percent greater than the 14.6 percent difference in calculated net change (loss) in groundwater storage between these same two years as revealed in Table 2. This difference likely is not attributable to some amount of additional groundwater pumping occurring in 2011 in response to water rights adjudication affairs as discussed previously. One explanation might be that net change in groundwater storage better reflects the actual lateral movement and migration of groundwater at various depths responding to aquifer stress (pumping), whereas changes in groundwater table elevation in this unconfined, largely homogenous shallow alluvium system tend be limited mostly to vertical responses to recharge from surface water.

Table 2. Calculated annual net change in year-end storage for the period 2009 through 2014 in the Mesilla Valley shallow alluvium aquifer.

Year	Calculated net change in storage (acre-feet)
2009-2010	-3,499.245
2010-2011	-66,866.211
2011-2012	-28,061.513
2012-2013	-57,125.912
2013-2014	-16,865.253
Total:	-172,418.134

Figure 6 is a spatial depiction of the modeled (Theissen-interpolated) areas projected to reflect the cumulative calculated year-end net change in shallow alluvium aquifer storage from within the Mesilla Valley of the EBID for the calendar year-end period of

December 31, 2009 through the calendar year-end of 2014. As expected, here it is seen that storage of groundwater in the shallow alluvium aquifer throughout essentially all of the EBID has been reduced over the last five years as synonymous with ongoing drought conditions. There are a couple of areas, particularly one in the north-central part of the Mesilla Valley that may warrant managerial attention in the near future. By itself, this area reflects a calculated cumulative net loss from shallow alluvium aquifer storage of 19,968.532 acre-feet since the end of 2009 through the end of 2014. In sum, during this study period the floodplain alluvium aquifer within the Mesilla Valley appears to be losing an average of well over 34K acre-feet annually from storage. This is net loss that is forever gone in the absence of recharge.

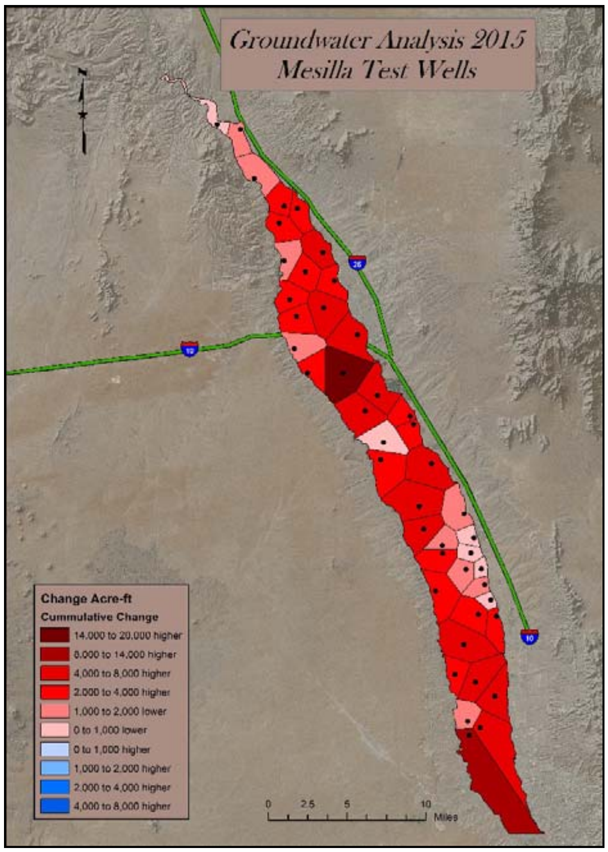

Figure 6. Cumulative year-end net change in shallow groundwater storage from within the Mesilla Valley of the EBID, 2009 through 2014. Map courtesy of Dennis C. McCarville, EBID GIS Analyst.

DISCUSSION

Interpretation of the results of this study may lead to several generalizations. As expected, areas within the study area corresponding to greater year-end net declines in shallow groundwater table elevations likewise reveal greater year-end net losses from shallow groundwater storage. Apart from the relatively minor, anomalous circumstance noted upon comparing EBID surface water allotments delivered during the irrigation seasons of 2011 and 2013, the trend of greater declines in year-end groundwater table elevations and greater year-end net losses from storage correlate closely with lower EBID surface water allotments. This fits with the generalized mass-balance assumption of this study in that the only true net loss of water from the system is taken to be evapotranspiration of which the great majority, while not estimated in this study, can be reasonably attributed to irrigation uses of water in the Mesilla Valley, and that the primary means of recharge to the aquifer is limited to annual surface water releases from reservoir storage. Table 1 shown previously and Figure 7 below reveals that the cumulative average annual year-end decline in groundwater elevations measured for the period 2009 through 2014 is 7.5 feet (average decline of 1.5 feet per year). While this might seem significant in light of the corresponding calculated cumulative net loss in storage from the shallow alluvium aquifer, estimated to be 172,418 acre-feet for this same timeframe, it is worth noting that the actual fresh (~ ≤ 1500 mg/L Total Dissolved Solids) water column available throughout the great majority of the Mesilla shallow groundwater aquifer is considerably greater as reported historically (King et al., 1971; King and Hawley, 1975). If the shallow groundwater interval (aka stratigraphic layer of the aquifer) is taken to be about 200 feet thick on average as reported by Frenzel and Kaehler (1992), then the 7.5 foot cumulative decline in groundwater elevations measured for this period accounts for an average 3.75% loss of available water column. At this rate and assuming nothing else changes, the shallow alluvium of the Mesilla aquifer might be expected to hold out for about another 133 years, but as Figure 7 also suggests (supported by Figures 5 and 6 as well), this likely will depend on where in the Mesilla Valley one is pumping from. This may reveal some other important managerial considerations moving into the future. For example, to the extent that salt accumulations in the shallow alluvium (not estimated or measured in this study) are found to persist in the absence of sufficient surface water to dilute and push these concentrations through the system, and particularly if these accumulations are found to become sodic, then a likely migration of these harmful water quality constituents drawn down to greater depths in the aquifer could present some serious, long term management problems.

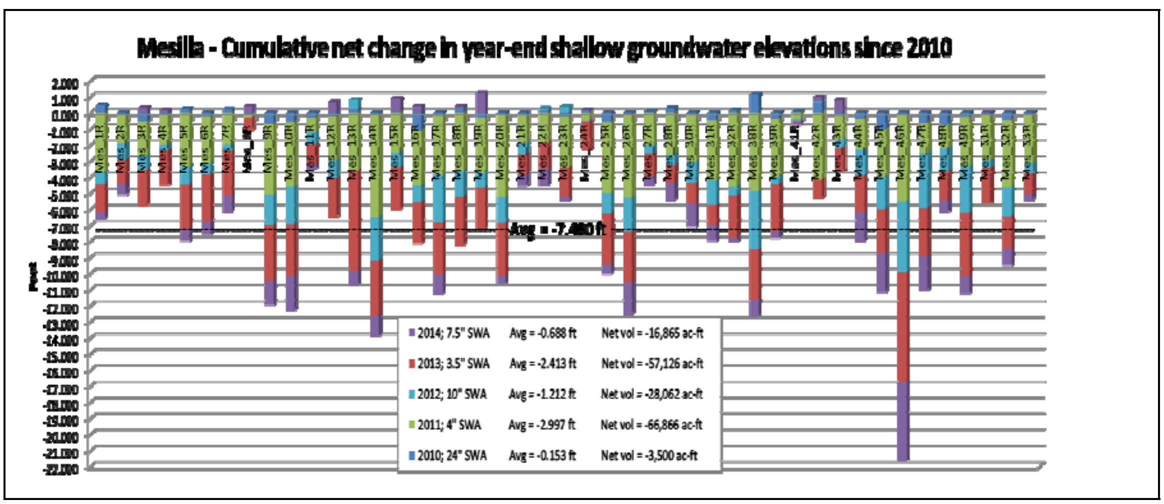

Figure 7. Cumulative year-end net change in shallow groundwater elevations at each monitoring site from within the Mesilla Valley of the EBID, 2009 (beginning of 2010) through 2014, including calculated net change in groundwater from storage for each year and the corresponding EBID surface water allotment (SWA) for each year.

Another consideration is that if 67% loss of water column otherwise available to a given irrigation well is taken to be the maximum permissible drawdown before the well is thereafter hydraulically uneconomical as defined by Driscoll (1986), then the average groundwater table decline reported here is subject to further scrutiny. If an average of 200 feet of saturated thickness is taken to be the limit of the shallow groundwater alluvium aquifer as suggested by Frenzel and Kaehler (1992), it can be seen that about 134 feet of fresh water column is available to be dewatered before irrigation and other wells in the area will likely need to be deepened beyond the shallow alluvium and into lower stratigraphic units of the aquifer. At this rate and assuming nothing else changes, it might be surmised that the shallow alluvium aquifer of the Mesilla Valley can go approximately another 89 years before depletion is imminent. The reality of course is that deeper wells have long since been sought (certainly within the last decade) by many irrigation (and other) interests in the Mesilla Valley as reduced well capacities as a consequence of lowering transmissivity on average has been observed. In this context, the average 7.5 foot cumulative decline in groundwater elevations measured over the five years found in this study could be conservatively construed to suggest that about 5.6% of the otherwise average available groundwater head in the Mesilla shallow alluvium aquifer has been lost. It may be further conservatively construed that the associated calculated cumulative average net change in groundwater from storage of 172,418 acre-feet during the same timeframe likewise reflects approximately 5.6% volumetric net loss (dewatering) of the Mesilla shallow aquifer. This suggests that groundwater otherwise in storage in just the shallow alluvium aquifer (first ~200 feet of saturated thickness) as limited only to the bounds of the Mesilla Valley would normally be about 3.1M acre-feet (172,418 acre-feet / .056). If the original suggested 3.75% volumetric net loss from storage is adopted, then storage in the shallow alluvium might normally be about 4.6M acre-feet (172,418 acre-feet /.0375). However arguably conservative, this notion of storage discrepancies raises an interesting specter because an unconfined, shallow aquifer taken to have an average depth of about 200 feet with contiguous spatial coverage of about 100,000 acres (approximate area encompassing the Mesilla Valley floodplain) and known to be largely homogenous with an assumed uniform specific yield of twenty (20) percent indicates shallow groundwater normally in storage of about 4.0M acre-feet (100,000 acres x 200 feet x 0.2). In the context of mass balance assumed for this study, there exists a storage discrepancy of about 1.0M acre-feet as dewatered from the Mesilla shallow alluvium aquifer in recent years. Accordingly, it may be logically surmised that groundwater at various depths from elsewhere within the Mesilla aquifer and/or Mesilla Basin is currently migrating along some series of hydraulic gradients to the Mesilla Valley to compensate and account for years of essentially unrestricted groundwater pumping in the Mesilla Valley to physically address this hydrologic discrepancy (i.e., fill a hydrologic 'hole'). Perhaps it is primarily for this reason that cumulative net declines in annual year-end groundwater elevations and also calculated net loss from storage are not found to be somewhat greater. The most likely area from which groundwater otherwise in storage that might serve this migration is probably from the west, well outside of the shallow alluvium of the Mesilla Valley and into the western extents of the Mesilla aquifer system (Mesilla Basin). This area, which indeed is substantial in spatial extent and depth, is shown previously in Figure 3. Depending on location, there are a number of faults at depth in the west-central and southwestern extents of the Mesilla

Basin (Hawley and Kennedy, 2004) that could in some instances impede or at least limit the subsurface flow potentially migrating to the Mesilla Valley, but otherwise there is no extensive subsurface barrier that separates the Mesilla Basin from the Mesilla Valley. Essentially, it is one large, regional groundwater resource. To the extent that western migration of groundwater from the Mesilla Basin to the Mesilla Valley is likely occurring is important and may reveal critical considerations regarding the potential development of groundwater resources (brackish at depth or otherwise) associated with the west and southwestern extents of the greater Mesilla Basin. This topic should be the focus of further research, particularly to better explore and more closely monitor what few wells do exist in the western extents of the Mesilla Basin and to install additional piezometers with nested sensors at depth, or perhaps the deployment of other technology (gravity methods, etc.).

While extraction of groundwater from the Mesilla shallow alluvium aquifer and beyond (i.e., from greater depths) can be expected to continue well into the future, much hope exists that the presence of a relatively strong El Niño climatic pattern that recently formed could bring desperately needed additional moisture in the form of snowpack to the upland watersheds of northern New Mexico and southern Colorado whereupon spring snowmelt and runoff that traditionally feeds the headwaters and tributaries of the Rio Grande, and ultimately downstream to Elephant Butte Reservoir, may occur. Figure 8 provides some insight based on the limited data that are the subject of this study into what surface water allotment conditions within the EBID will likely need to look like in order for aquifer recovery to be expected. Based on the five years of data herein reported, linear regression analysis renders a reasonably good fit ($R^2 = 0.64$) for purposes of forecasting.

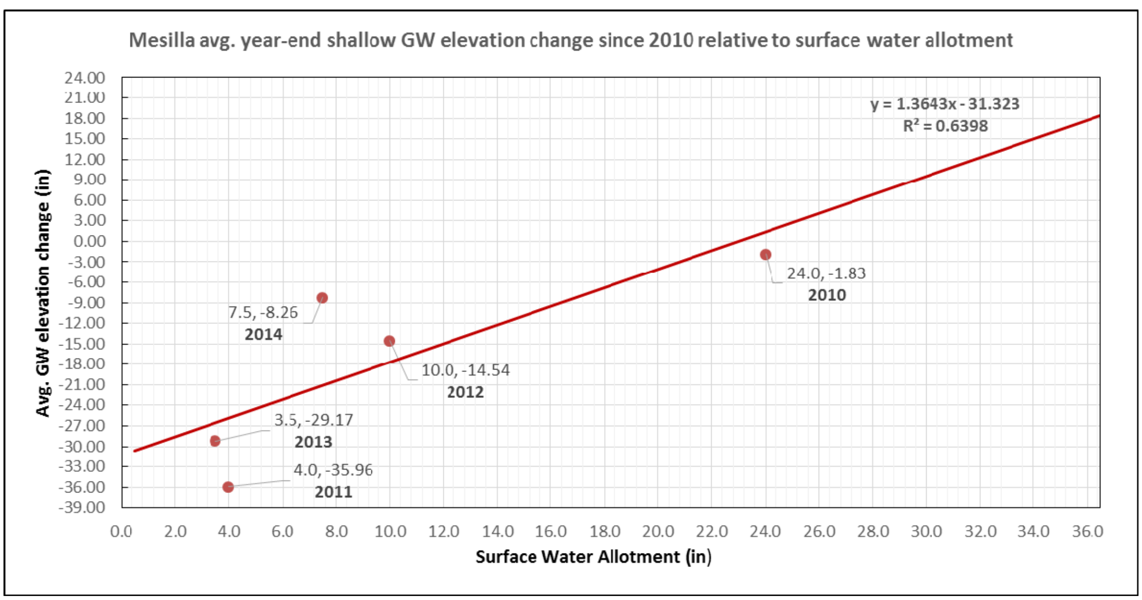

Figure 8. Regression analysis of the average year-end net change in shallow groundwater elevations from within the Mesilla Valley of the EBID, 2009 (beginning of 2010) through 2014 and the corresponding EBID surface water allotment for each year.

Particularly, the limited data analyzed suggests that an EBID surface water allotment of at least 23.0 acre-inches per acre will be necessary to stabilize an otherwise declining trend in average year-end groundwater table elevations, but will do essentially nothing to facilitate recovery of the aquifer since at this rate, 125 consecutive years of 23.0 acre-inch surface water allotments would theoretically be necessary to compensate for the average 7.5 foot cumulative decline in the groundwater table elevation measured to date. More interesting, and perhaps hopeful is that the regression analysis reported in Figure 8 supports the expectation that if the surface water allotment delivered to the EBID were increased just slightly, to 24.0 acre-inches (2.0 acre-feet per irrigated acre) and maintained as such for at least 5 to 6 consecutive years, then the cumulative average annual year-end decline in groundwater elevations measured for the year-end period of 2009 through 2014 would theoretically be reversed and the aquifer largely recovered, notwithstanding what surely will be a period of time necessary for otherwise established, downward hydraulic gradients to attenuate that simple regression analysis of this data cannot precisely predict. Still, a circumstance like this would put the shallow alluvium aquifer underlying the Mesilla Valley in a substantially improved stature to weather future drought, and it would mean that whatever rate of migration of groundwater that is likely moving from the western extents of the Mesilla Basin to the Mesilla Valley is markedly slowed and conserved for future severe drought contingencies and/or generations to come. It is possible that a single year or two of substantially improved surface flows in the Rio Grande as ultimately realized in the Mesilla Valley could significantly turn things around. For example, the regression analysis reported in Figure 8 suggests that a single year of just 28.5 acre-inches per irrigated acre (2.4 acre-feet per acre) delivered to the EBID could theoretically reverse the cumulative average annual year-end decline in groundwater table elevation measured for the year-end period of 2009 through 2014 and the aquifer be largely recovered, again notwithstanding what surely will be a period of time necessary for otherwise established, downward hydraulic gradients to attenuate.

Calculated average volumetric net changes in storage from the Mesilla shallow alluvium aquifer relative to the annual EBID surface water allotments for the timeframe that is this subject of this study tells a similar, albeit more conservative story because the assumptions at the outset of this study accept a generalized mass-balance condition such that evapotranspiration in the study area is the only true loss of water from the system and surface water is the primary means of recharge, but does not account for the migration of groundwater from any other source entering the system that has otherwise been suggested as likely and coming from the western extents of the Mesilla Basin. This is an important point and underscores a fundamental finding in this study, and that is that net changes in aquifer storage in the Mesilla Valley are probably a more useful indication of the system resilience than is strict attention to declines of the area groundwater table. This is because net changes in shallow aquifer storage as estimated by the methodology used in this study, while perhaps influenced by the migration of groundwater flows from the western extents of the Mesilla Basin to one degree or another, is nevertheless more representative of the lateral behavior of groundwater flows in the immediate area of each monitoring well location. It is likely that the migration of groundwater flows from the western extents of the Mesilla Basin into the Mesilla Valley are tending to buffer and thus more readily mask changes in the measured year-end groundwater table elevation since this measure is strictly a vertical account of the groundwater table.

Figure 9 is linear regression analysis of the average year-end net change in storage from the shallow groundwater alluvium aquifer relative to the annual EBID surface water allotment for the duration of this study. The analysis supports with reasonable confidence ($R^2 = 0.66$) the prospects of a full, 36.0 acre-inch per irrigated acre (3.0 acre-feet per acre) allotment delivered to the EBID for five consecutive years as theoretically capable of reversing the cumulative average annual year-end net loss from storage calculated for the period 2009 through 2014 and approximating aquifer recovery, again notwithstanding a period of time necessary for otherwise established, downward hydraulic gradients to attenuate.

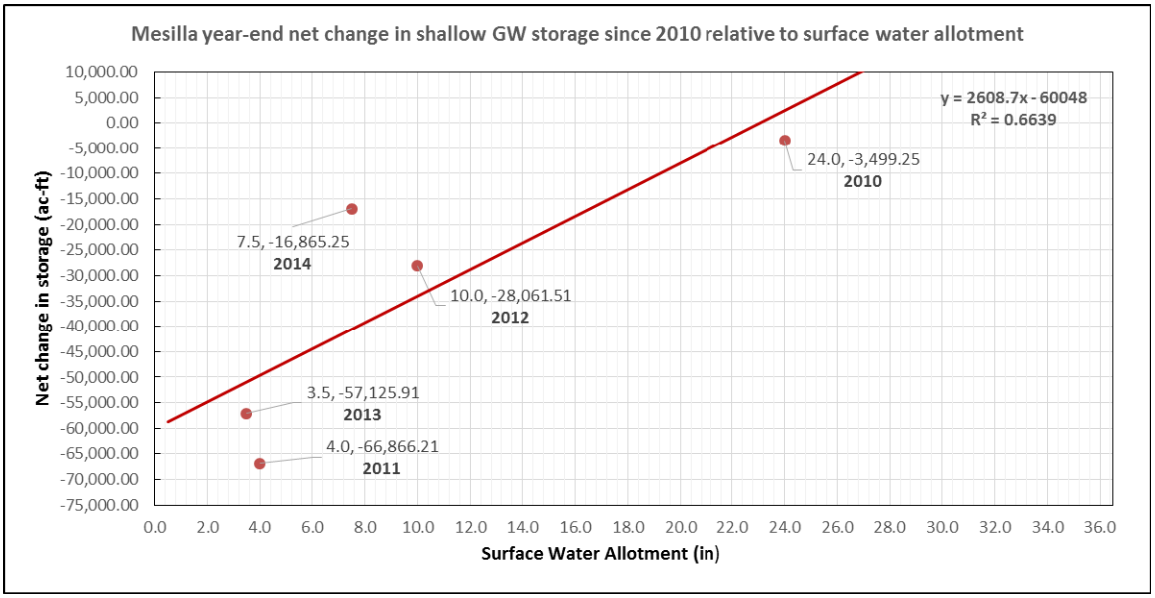

Figure 9. Regression analysis of average year-end net change in storage from the shallow groundwater alluvium aquifer from within the Mesilla Valley of the EBID, 2009 (beginning of 2010) through 2014 and the corresponding EBID surface water allotment for each year.

CONCLUSIONS

This study offers a substantially simplified approach to evaluating river basin and shallow aquifer interactions for practical management purposes that can be adapted to river basins and irrigation projects around the world where a recognized commitment to actual measurement and monitoring of water resources is embraced. This study shows that changes in groundwater table elevations, though most often approached with the limited utility of depth to water, and changes in aquifer storage are not the same things. Importantly, this study shows that changes in aquifer storage, otherwise aptly referred to as depletions of groundwater, are a more useful measure of aquifer resilience.

This study is not without shortcomings and gaps in important data that would otherwise inform this and related work, most notably actual well pumping on an annual basis from individual wells as metered and situated within the Theissen polygons herein depicted. The most comprehensive set of data reflecting annual groundwater pumping from within the Mesilla Valley and indeed the Lower Rio Grande Basin for about the last decade is maintained by the NM Office of the State Engineer (OSE). While available on a piece-meal basis online, efforts are underway to acquire a comprehensive set of pumping data from the OSE that has undergone a quality assurance and control protocol. It would be useful to further refine and perhaps rank the Theissen polygons herein described with additional weighing factors on the basis of actual groundwater pumping on a year-to-year basis, depth of wells, screened intervals, type of well (domestic v. irrigation) etc. Similarly, actual land in production, crop type, and fallowing practices on a spatial basis within each Theissen polygon would be useful. It is realized also that the number of monitoring wells and thus Theissen polygons available to characterize the spatial extent of the Mesilla Valley is a limitation (similar to the hope for ever-smaller cells within a discretization grid in the context of numeric modeling), and that the shallow nature of these wells prevents attempts with this methodology to characterize the aquifer response and established hydraulic gradients believed to exist at depth as result of many (hundreds) of irrigation and other wells that have been completed over about the last decade well below the 200-foot average depth below ground surface assumed for purposes of this study.

In any event, the results of this study are expected to be useful because the likelihood of a circumstance of some number of back-to-back, full surface water allotment years bringing recharge to the shallow alluvium aquifer in the Mesilla Valley is presently and quite understandably the subject of tremendous hope within the farming community of the Lower Rio Grande, and indeed with good cause given that the period of 1979 through 2002 was witness to exactly such a circumstance. Whether or not a similar 23-year period of full surface water allotments will revisit the Lower Rio Grande anytime soon is well beyond the scope of this study, but should not be dismissed as implausible, nor assumed likely. Meanwhile, it is clear that many years (decades) of continued, unrestricted pumping of the Mesilla shallow alluvium aquifer can be met with steady state conditions as long as wells are deepened as necessary (many already have been) and regardless of whether or not surface water available for release to serve the EBID is found to increase much in future years to facilitate recharge. However, it is important to understand that should this be so, then indeed a mining operation is in place that may prove to be unsustainable and/or may create essentially irreversible negative consequences eventually for the Mesilla Basin and the communities dependent on fresh groundwater resources in this area. To this end, attention to water quality, particularly salinity accumulating in the shallow alluvium of the Mesilla Valley should remain a priority. Further, ongoing monitoring efforts should be conducted with particular attention to quantifying net changes in aquifer storage and not limited to groundwater elevation and/or depth to water trends, and should be expanded to account for changes and hydraulic gradients occurring well below the shallow alluvium. This will necessitate a number of deeper monitoring wells in the Mesilla Valley, or perhaps the deployment of other technology (e.g., gravity methods). Also and apart from the subsurface below the groundwater table, seepage studies in immediate proximity to the Rio Grande that account for a genuine description of the vadose and infiltration of surface water flows from within the riverbed itself should also be pursued to generate actual field data for a more complete understanding of the system. Data of this nature can and should inform future modeling efforts.

The likely migration of groundwater at various depths from the western extents of the Mesilla Basin to the Mesilla Valley underway should be explored and quantified to better understand the location and persistence of hydraulic gradients, and efforts to model this should be paused for favor of a number of new, strategically placed nested piezometers with appropriate instrumentation to generate actual measured data. Gravity methods should similarly be deployed as a companion to new monitoring. Again, data of this nature can and should inform future modeling efforts. Potential development of groundwater resources in the western and/or southwestern extents of the Mesilla Basin, regardless of the depth and/or expected quality of groundwater anticipated to potentially be extracted from these locations should be conducted with particular attention to the monitoring suggestions herein offered. Such development interests, and those of the public, would be wise to invest in this knowledge now, not later. Meanwhile, the EBID is currently exploring ideas and developing administrative mechanisms by which depletions in the Mesilla Valley can be offset and effectively managed to approximate a hydrologic balance in the system by use of flexible market incentives to facilitate water rights transfers. Such efforts remain a work in progress.

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THE HISTORY AND HISTORICAL CONTEXT OF THE PIMA-MARICOPA IRRIGATION PROJECT (GILA RIVER INDIAN COMMUNITY)

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ABSTRACT

For more than 2,000 years the Gila River Indian Community parlayed fertile land, a steady surface water supply, and favorable physiographic conditions into an extraordinary agricultural economy along the Gila River. But the tribe's loss of independence with the advent of federal paternalism and upstream diversions disrupted the ability of tribal growers to cultivate the land and remain self-sufficient. While non-Indian growers around the reservation expanded their operations, tribal growers were left to navigate a labyrinth of administrative and legal obstacles that made productive use of the land a forlorn dream that only the most persistent realized. But with the Arizona Water Settlements Act of 2004 and with the Pima-Maricopa Irrigation Project constructing a new conveyance system, there has been a renewed interest in agriculture. While challenges rooted in century-old federal policies remain, the tribe has actively engaged in putting all of its settlement water to use, with Governor Stephen Roe Lewis proclaiming 2015 as the "Year of the Water Settlement." As part of this effort, the tribe has supported an agricultural entity to assist growers in reconnecting with their *himdag*. Understanding the historical context of the Community and federal administrative policies is essential to envisioning agricultural rejuvenation on the reservation. Mitigating and minimizing confiscatory federal policies and regulations is essential to attracting and supporting the next generation of tribal growers. This not only ensures the cultural and economic viability of agriculture on the reservation but also ensures the water settlement act is implemented as intended.

INTRODUCTION

On December 10, 2004, the Gila River Indian Community (Community) finalized its long-standing water rights settlement when President George W. Bush signed into law the Arizona Water Settlements Act (AWSA), restoring an average annual tribal water budget of 653,500 acre-feet.[2] This set into motion the means by which the Community seeks to restore its agrarian heritage and economic self-sufficiency.[3] Plans to develop 77,000 acres of agricultural land in a region of the country where similarly-situated land surrounding the reservation is rapidly being displaced by urbanization have been in place since 1985. Maricopa County on the northern boundary of the reservation has experienced a 66.7% decline in agricultural land (1,429,539 acres to 475,898 acres) since 1982, as developers convert some of the most productive farmland in the Southwest to

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[2] *The Arizona Water Settlements Act of 2004*, Public Law 108-360, 118 Stat. 3479.

[3] The Gila River Indian Community is home to two tribes: the Pima and the Maricopa. The Pima are the aboriginal occupants of the land while the Maricopa confederated with the Pima over two hundred years ago.

urban uses.[4] Although initiated later, a 51.1% decline (2,403,901 acres to 1,174,727 acres) has also occurred in Pinal County on the southern boundary of the reservation.[5] The upshot of this agrarian declension and the AWSA is that the Community is positioning itself to again serve as the breadbasket of Arizona, a position it has not enjoyed since the mid nineteenth century when water deprivation and environmental changes in the Gila watershed despoiled its agrarian-based economy.

For more than 2,000 years the tribe and its huhugam ancestors parlayed fertile land, a steady surface water supply, and favorable physiographic conditions into an extraordinary agricultural economy along the Gila River. But the tribe’s loss of independence with the advent of federal paternalism and administrative oversight 150 years ago disrupted their ability to cultivate the land and tribal grower’s struggled to gainfully use the land and remain self-sufficient. Depletion of meaningful control over the decision-making processes led to a dependent status by the tribe. While their non-Indian neighbors expanded their agricultural operations, tribal growers were left to navigate a labyrinth of administrative and legal obstacles that made productive use of the land a forlorn dream that only the most persistent realized.

THE PHYSICAL SETTING

The Gila River Indian Reservation (reservation) encompasses 371,792 acres in the middle Gila Valley, a seventy-two mile stretch of the Gila River in south-central Arizona. The valley has a low western gradient of 579 feet and is surrounded by the low-lying Sierra Estrella, Salt River, Santan, and Sacaton mountains. Fringing the mountains is a series of alluvial bajadas, below which are found the floodplains and terraces of the Gila River and its tributaries. The distal reaches of the valley consist of an expansive and fertile plain that has sustained irrigated agriculture for millennia.

Physiography, including climate and precipitation, has impacted cultural attitudes toward the land. The reservation receives a mean annual rainfall of 8.37 inches, although there is a slight moisture gradient from east to west. Precipitation is bimodal, being distributed in intense summer monsoons and gentle winter rains, with the spring months the driest. The entire middle Gila Valley is arid, with evapo-transpiration exceeding annual precipitation, necessitating supplemental water to yield adequate harvests.

Despite its aridity, groundwater beneath the valley can be found in most geologic strata, which are hydrologically connected and form one of the most robust aquifers in the state. The upper alluvial unit is the primary water-bearing strata with an average saturated depth of 400 feet. The geology of the middle alluvial unit (700-1,200’) serves to confine groundwater to the underlying aquifer. Extensive off-reservation groundwater mining in the Gila and Santa Cruz basins initiated severe environmental deprivation on reservation after the turn of the twentieth century, with groundwater over-drafting creating cones of

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[4] **United States Census of Agriculture, County Data, Arizona**, U.S. Department of Agriculture, National Agricultural Statistics Service (Washington DC: GPO, 2012), p. 226.
[5] Ibid.

depression that reversed the natural flow of groundwater. Such dewatering has adversely affected the water table and aggravated the surface flow of the Gila River.[6]

The principal geo-physical feature within the valley is the Gila River, which with its headwaters in western New Mexico, flows west-southwest and empties into the Colorado River near Yuma. The river encompasses a watershed of 63,000 square miles, with the Salt and Santa Cruz rivers, Queen Creek, and McClellan Wash all major on-reservation tributaries. The Gila River no longer flows except for ephemeral storm flows.[7]

ABORIGINAL TITLE

The reservation is part of a larger geographic loci legally classified as Indian Country, a definition that includes residual sovereignty and jurisdiction, enabling the Community to exercise cultural, political, economic, and property rights outside state interference.[8] The **United States Code** defines Indian Country as:

> (a) all land within the limits of any Indian reservation under the jurisdiction of the United States Government, notwithstanding the issuance of any patent, and, underlying rights-of-way running through the reservation, (b) all dependent Indian communities within the borders of the United States whether within the original or subsequently acquired territory thereof, and whether within or without the limits of a state, and (c) all Indian allotments, the Indian titles to which have not been extinguished, including rights-of-way through the same.[9]

Indian Country, therefore, is land to which aboriginal title has not been extinguished and over which tribal and federal law applies to the exclusion of state statutes.[10]

Reservation land that has not been divided in severalty is owned by the tribe and held as communal land for all tribal members. If such land is trust land, it is owned by the tribe but the fee is held by the federal government. Tribal fee lands, however, are not subject to the federal trust and the United States has no fiduciary responsibility over such lands. There are advantages to tribal ownership of trust land, including the fact that it is better protected due to continuity and singularity of ownership. Lands divided in severalty are fractionated via heirship while tribal lands are retained in larger blocks, making management of such land more easily accomplished.

Communally-owned lands can be leased by tribal members, although such tribal members do not own any particular parcel of this land. The Community has enacted

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[6] Aspect Consulting, **Gila River Indian Community Groundwater Analysis Component**, Prepared for the Pima-Maricopa Irrigation Project, project #990042-004-05, November 15, 2005.
[7] On August 31, 2015, the Community initiated its first Managed Aquifer Recharge facility, restoring a 5-mile section of the Gila River, while at the same time recharging CAP water for future use.
[8] See for instance, McClanahan v. Arizona State Tax Commission, 411 **US Reporter** 164 (1973).
[9] 18 **United States Code** §1151.
[10] This is true except in cases where federal law has conferred such authority, such as Public Law 280 (1953).

ordinances providing for land assignments and the leasing of agricultural and grazing units of tribal land. Since the land is owned by the Community, the tribe conveys a legal grant or license to a tribal (or non-tribal) member to utilize the land. Tribal and non-tribal lessees can seek leases, with such proposals reviewed by the Pima Agency (Bureau of Indian Affairs) as part of the federal trust responsibility.[11] Federal administrative control over tribal land restricts alienation, in some cases even if the land is not in federal trust.[12] Moreover, tribal lands face restrictions against alienation by state foreclosure for tax or mortgage obligations. The practical effect of this is that the tribe is precluded from mortgaging its lands, which can hinder economic development.[13]

Federal statutes (or for some tribes, treaty provisions) have caused the distribution of tribal land in severalty. By the 1880s, a national consensus coalesced around a universal and mandatory allotment policy and on February 8, 1887, Congress enacted into law the General Allotment Act.[14] This act set into motion a framework for allotting the reservation into a patchwork of ten acre individually-owned allotments. Across the West, "surplus" lands remaining after severalty was completed were opened to non-Indian settlement. Between 1887 and 1934, 118 reservations were allotted, with forty-four opened to homestead entry. Some 38,000,000 acres of tribal land was ceded to the United States, with an additional 22,000,000 acres declared "surplus" and opened to non-Indian settlement. Another 23,000,000 acres of fee patented land was forfeited through sale or foreclosure and an additional 3,400,000 acres of heirship land was alienated. The tribal land base in the United States was reduced from 138,000,000 acres to fewer than 52,000,000.[15]

Unlike fee lands, trust land requires secretarial approval before it can be leased since the secretary acts in a fiduciary capacity on behalf of trustee. A federal statute of August 9, 1955, authorizes the secretary to approve leases of Indian land for "public, religious, educational, recreational, residential or business purposes, including the development or utilization of natural resources in connection with operations under such leases, for

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[11] Home sites are governed by the Gila River Indian Community Code, Title 21, Chapter 1. The Gila River code has no current provisions governing non-member leases (as it is handled by the BIA), although it is a matter of policy that the tribal council approves tribal leases. The council does not approve of leases that impact the rights of allottees until it has been shown that such land uses will not adversely affect the allottee or the tribe.

[12] See Alonzo v. United States, 249 **F.2d** 189 (1957), which dealt with Pueblo land in New Mexico held in fee by the tribes. This application of law does not hold true when allotted land is owned in fee and is not held in trust.

[13] This was partially overcome by the Indian Financing Act of 1974 (88 Stat. 74, 25 **United States Code** Chapter 17, §§1461-1469), which established a revolving loan fund to be utilized by tribes and created a mortgage insurance program for privately secured tribal loans.

[14] 24 Stat. 388, codified at 25 **United States Code** §331-334. Sections 331-333 (sections 1-3 of the allotment act) were repealed in November 2000 by Public Law 106-462 (Indian Land Consolidation Act, 114 Stat. 2007). Section 334 remains in effect and relates primarily to allotments to Indians not residing on reservations.

[15] Janet McDonnell, **The Dispossession of the American Indians, 1887-1934**, (Bloomington, Indiana: University of Indiana Press, 1991), p. 121.

grazing purposes."[16] Federal regulations authorize leases of ten years for irrigated agriculture on allotted and tribal lands.[17]

The secretary can promulgate leases when the allotments are owned by minor children, when tribal members have granted such authorization in writing, where adults are *non compos mentis*, or in cases where the whereabouts of the landowner(s) is unknown.[18] Absent secretarial authority, the owners of a majority interest in an allotment can request the secretary to approve any lease, although there are a myriad of regulations governing such leases. The secretary can also authorize and grant rights-of-way through all trust land.[19] In general, a majority of the landowners must consent to such action unless the whereabouts of some landowners is unknown and a majority of the known landowners have consented, the heirs or devisees of a deceased landowner have not yet been determined, or the secretary believes the right-of-way will cause no substantial injury to the land or landowner, or there are so many owners that the secretary finds it impractical to obtain their consent and the grant of easement causes no substantial injury to the land or landowner. In all cases, just compensation must be provided.[20]

Outside of Indian Country the most fundamental form of land ownership is fee simple title, which grants the owner control over his property subject to local zoning and regulatory restrictions. In Indian Country, whether or not a parcel of land is held in fee determines who has jurisdiction. While most land in Indian Country is trust land owned by tribal members or the tribe, there are fee patented lands. If fee lands are owned by an Indian or a tribe within the exterior boundary of a reservation it <u>*may*</u> be under tribal zoning authority but it is otherwise subject to state and local tax laws.[21] If a non-Indian acquires the fee to land within the exterior boundary of the reservation, the land is subject to county and state jurisdiction.[22]

Since some reservations have checkerboard lands, the federal courts have attempted to clarify jurisdiction on parcels the tribe or tribal members have reacquired. Most tribes in the Southwest—including the Gila River Indian Community—were not opened to sale or

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[16] 25 **United States Code** §§415-415d.
[17] 25 **United States Code** §§394-395 and §§402-403. Section 394 governs allotted lands and §403 governs tribal lands. The maximum lease is generally twenty-five years, although grazing leases are limited to ten years. Generally, leases for non-agricultural purposes can be renewed for a maximum of twenty-five years, although §416 allows some leases up to forty years if the land requires a "substantial investment" to make the improvements necessary to farm. Section 395 limits agricultural leases to five years maximum if the landowner is incapacitated.
[18] 25 **Code of Federal Regulations** 162.209 (2005).
[19] 25 **United States Code** §§323-328.
[20] 25 **United States Code** §324.
[21] 25 **United States Code** Chapter 9, §348. In 1998 the Supreme Court held that certain Indian land was intended to be subject to state and local taxation. See <u>Cass County v. Leech Lake Band of Chippewa Indians</u> 524 **US Reporter** 103 (1998). But in 2005, a federal district court in Michigan held that the state could not tax fee lands owned by individual Indians or the tribe because there was no explicit law purporting to allow such measures. See <u>Keweenaw Bay Indian Community v. Naftaly</u> **WL** 1307789 (Western District of Michigan), June 1, 2005.
[22] The only limitation is if the non-Indian use of the land affects the ability of the tribe to govern itself. See <u>Montana v. United States</u> 450 **US Reporter** 544 (1981).

homesteading after allotment. In the Pacific Northwest, the Mountain West, and the Great Plains the demand for opening reservations was much more pronounced, resulting not only in land severalty but also in the opening of "surplus" land to entry by non-Indians who took possession of such land in fee. In some cases, a majority of a reservation came under non-Indian ownership. With this checkerboard pattern of ownership, disputes were inevitable. In some instances, the courts upheld the jurisdiction of the tribes and in other cases it has recognized controlling legislation as having diminished tribal authority.[23]

IRRIGATION HISTORY AT GILA RIVER

The Community has utilized informal irrigation districts since time immemorial. Historically, tribal growers in specific villages organized districts around a given canal with each grower expected to provide annual maintenance services in exchange for irrigation water.[24] While there were no O&M assessments per se, a portion of each grower's crops was given to the individuals who managed each ditch and each grower used only what water he needed. The excess water was returned to the river to be used by the next downstream village and its growers.

But this informal, communal system of irrigation changed dramatically after land severalty. While plans were made to allot in severalty the reservation in 1906, it was not until 1910 that Superintendent J. B. Alexander proposed ten-acre allotments for the reservation, and this after the U.S. Indian Irrigation Service advocated for 5-acre allotments.[25] Concerns over availability of water (due to upstream diversions in the post 1870s era) to make the land irrigable postponed allotment and it was not until 1914, after the Army Corps of Engineers determined the feasibility of upstream San Carlos dam, that the first allotments were made. By the end of 1916, 4,886 allotments were made, although no trust patents were issued pending confirmation of water rights.[26] Non-

[23] South Dakota v. Yankton Sioux Tribe, 522 **US Reporter** 329 (1998). Of the 430,405 acres on the Yankton Sioux Reservation, 262,325 were allotted and 168,080 were opened to homesteading. Of the original reservation, just 30,000 allotted acres and 6,000 tribal acres remained in Indian ownership in 1998. Brendale v. Confederated Tribes of Yakima, 492 **US Reporter** 408 (1989). Having said this, tribes can limit non-Indian utilization of such fee land if the use of the land is harmful or restricts the self-governing ability of the tribe. Even in cases when a tribe reacquires former reservation land it *may* be subject to *ad valorem* taxation by the state. In Cass County v. Leech Lake Band of Chippewa Indians 524 **US Reporter** 103 (1998), the Court ruled that original trust allotments issued on the reservation were intended to eventually subject the land to taxation and alienation. The Nelson Act, 25 Stat. 642, provided for the "complete cession and relinquishment" of the ceded lands. The Leech Lake Reservation is 588,684 acres in size although less than 27,000 acres is owned by the tribe or individual tribal members. But see Keweenaw Bay Indian Community v. Naftaly, **WL** 1307789, in which the federal district court for Western Michigan ruled the state had no authority to collect taxes on fee land owned by the Keweenaw Bay Chippewa or its members. The Chippewa would not have ceded over 7,000,000 acres to the United States, the Court held, "knowing they could lose the land they kept as a reservation the following year, due to non-payment of taxes."

[24] W. W. Hill, *Notes on Pima Land Law and Tenure*, **American Anthropologist** 38 (1936).

[25] *Conserving the Rights of the Pima Indians Arizona, Letters and Petitions with Reference to Conserving the Rights of the Pima Indians of Arizona to the Lands of their Reservation and the Necessary Water Supply for Irrigation*, House Document 521, 62nd Congress, 2nd Session (Washington, DC; 1912), p. 17.

[26] The allotment process was completed by 1920, with the first trust patent issued to Antonio B. Juan on June 25, 1921. "Pima Original Allotments (1914-1921), A-0349," in the Arizona State Museum Archives,

contiguous secondary allotments for grazing purposes were prepared and made between 1917 and 1920, by which time 4,894 tribal members received two ten-acre allotments, one irrigable "A" allotment and one grazing "B" allotment. All of these parcels are trust allotments, with title to the land held by the United States Government on behalf of the allottees. The surplus lands were retained by the tribe as communally-owned land and are also held in trust by the United States. When severalty ended at Gila River, there were 97,392 acres allotted, representing 26% of the total reservation land base but 67% of the available irrigable land. These lands have historically outpaced tribal lands in agricultural leases by a 20:1 ratio.

Some 274,400 acres of the reservation remain in tribal ownership, which includes most land away from the river and its fertile flood plains. Some of this land has been irrigated, with much of the 16,000 acre tribally-operated Gila River Farms (GRF) situated on such land. A P-MIP land survey indicates large blocks of tribal and allotted land could be farmed with moderate land preparation.[27] The largest blocks of these lands are in the central and western portion of the reservation where surface water has not traditionally been available, although the Pima-Maricopa Irrigation Project is constructing a distribution system to irrigate these and other lands.

Tribal lands—due to their communal ownership and subjection to tribal council control—represent the greatest opportunity for modern farm management. Allotted land, while generally the better of the two land types, represents a more difficult challenge due to its highly fractionated nature and, more recently, due to a proliferation of houses being constructed on the land. Some large agricultural units in recent years have become so fractionated that they have made the consent process difficult; in some instances, land has gone out of production, even though the superintendent of the Pima Agency is empowered to approve of leases when 51% of the ownership interests have consented. In the case of tribal land, the tribal council grants consent via tribal resolution, although in either case the Pima Agency is required as trustee to collect and distribute lease payments.[28]

Until the mid-1860s, tribal growers made uncontested use of the waters of the Gila River; after 1866, however, emigrants arrived and settled upstream of the reservation, established in 1859 by act of Congress. As more settlers arrived, additional water was diverted. By the 1870s shortages became acute and, by 1880, the forty years of famine

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Tucson, Arizona. See *Annual Statistical Report, Narrative Section,* (hereafter *Annual Report*) Pima Agency, Sacaton, Arizona, dated 1922, in "Superintendents Annual Narrative and Statistical Reports, 1907-1938," Record Group 75, Records of the Bureau of Indian Affairs, Microcopy 1011, roll 104-105, Statistical Section, pp. 6-7. There were actually 5,176 Pima, Papago and Maricopa who were allotted, 282 of whom did not receive a trust patent. There were an estimated 824 members (270 children and 554 adults) that had yet to be allotted in 1922. Some of these were removed from the allotment schedule due to dual enrollment, death, or other eligibility requirements. The 1921 annual report of the Commissioner of Indian Affairs noted that there were 4,869 allotments approved.

[27] There are 69,287 acres of class one land; 57,742 acres of class two land; 50,419 acres of class three land, for a total arable land base of 177,448 acres.

[28] 25 **United States Code** §324. The Bureau of Indian Affairs cannot collect money from leases on fee lands.

began. Although the United States authorized the construction of a series of small on-reservation irrigation projects after 1905, it was not until the approval of the San Carlos Project Act (and Coolidge Dam) in 1924 that it appeared a sufficient flow of water would return to the reservation. Hailed as the "Savior of the Pima," Coolidge Dam and the San Carlos Irrigation Project (SCIP) were far from the successes envisioned, as insufficient water, an inefficient delivery system, land fractionation, administrative delays in the leasing process, and lack of financing vexed growers. Having decreed rights for 210,000 acre-feet of Gila River water for 50,546 acres of land, tribal growers struggled to cultivate 35,000 SCIP acres, with just 21,000 decreed acres in production today.

At the beginning of the twentieth century, the Bureau of Indian Affairs promoted subsistence farming on the reservation. While such farming was not new, many tribal growers had previously engaged in commercial agriculture and marketed their crops to outside markets in Prescott, Tucson, and Sonora, Mexico.[29] By the 1930s, the Bureau of Indian Affairs largely excluded tribal growers from the planning and management needed to expand their operations. While the SCIP was intended to deliver water to all of the decreed lands, the earthen-constructed irrigation system was never concrete-lined and never completed, restraining agricultural development within the reservation. By the 1940s, the Bureau of Indian Affairs' promotion of subsistence farming was at odds with modern agriculture and the increased mass production of specialized cash crops for a national market. Moreover, while the Community had immemorial rights to the waters of the Gila River, federal administrative control restricted the agricultural development of the Community and its ability to put to use or call for such decreed water. While District Farmer Associations were formed across the reservation, the lack of credit, insufficient water, and paternalistic BIA policies discouraged agricultural expansion. Continued upstream diversions only compounded matters.

In the midst of these paternalist policies, the tribal council initiated an agricultural enterprise in 1951 by assuming control over the then-Pima Agency-operated Pima Community Farm, which was established by the Agency in 1937. By the latter 1940s, the tribal council requested that the Bureau of Indian Affairs allow the tribe to farm a section of land within the SCIP for the purpose of demonstrating to federal officials that the tribe was capable of farming without federal oversight. BIA denied these requests until early 1951, when the Agency notified tribal Governor David Johnson that the entire 10,311 acre farm would be turned over to the Community. To manage the farm, the Community turned to Sam Thomas, a University of Arizona-educated tribal leader and grower.

Thomas managed the Pima Community Farm for seventeen years, with 2,500 acres put into cultivation that first year. In 1953, the acreage increased to 5,000, but drought limited the acreage to 3,000 acres by 1956. The Community continued to centralize and expand what would later be renamed Gila River Farms (GRF) on tribal lands in the south-central portion of the reservation. In 1968, the Community hired Jack Palmer as farm manager and directed him to operate GRF as a for-profit, for-export enterprise, transitioning the tribe into large-scale agricultural production. As opposed to the

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[29] David H. DeJong, **Stealing the Gila: The Pima Agricultural Economy and Water Deprivation, 1848-1921** (Tucson: University of Arizona Press, 2009), pp. 41-56.

production of crops for local consumption, the newly renamed Gila River Farms engaged in modern agribusiness by marketing its crops world-wide, with Pima Gold citrus sold in Asia and durum wheat marketed in Europe.

Pooling Gila River and ground water, GRF initially irrigated 8,000 acres, but quickly grew to be one of the largest farming operations in Arizona. By the 1990s, GRF was vertically integrated with a cotton gin, grain storage facilities, chemical operations, mechanic shops, and a Construction Branch. The Community spent millions of dollars on farm improvements, increasing irrigation efficiencies (with laser leveling in the 1980s), raising crop yields (some of the highest in the Southwest), expanding acreage (to over 16,000 acres), and providing year-round employment for tribal members.

But GRF is not the only agribusiness operation within the Community. In the early 1960s, when many non-tribal lessees were leaving the reservation due to insufficient water, tribal member Harlan Bohnee began Harlan Bohnee Farm. Bohnee intended to lease and irrigate 40 acres, but when the Pima Agency pointed out there were numerous parcels available, he began leasing them. Within a year, Bohnee was cultivating 1,000 acres and quickly expanded to nearly 2,000 acres north of the Gila River. In 1982, Bohnee formed Stotonic Farm as a joint farming operation with Ramona Farms.

In 1974, Ramona and Terry Button established Ramona Farms on Ramona's mother's ten acre allotment. Learning to farm from her father, Ramona's desire was to grow traditional foods to improve tribal health. By the 1980s, Ramona Farms was cultivating 6,000 acres within the reservation, as well as 1,600 acres off reservation near Picacho. In the 1990s, Ramona Farms added another section of land off-reservation near Maricopa-Stanfield to its farming operations. In part because of leasing challenges and obstacles, Ramona Farms currently cultivates 3,500 acres within the reservation, in addition to 600 acres off reservation. In 2006, Bohnee Farms and Ramona Farms merged to form the Button-Bohnee Farming Partnership, which improved farming efficiencies by consolidating operations, allowing for better crop rotation and greater convenience in allocating scarce water, resources, equipment, and manpower.

While other growers operate within the Community, the Button-Bohnee Farms Partnership and Gila River Farms remain the largest growers on the reservation. An increasing number of tribal growers are cultivating traditional crops, such as Pima Corn, Bafv (tepary beans), White Sonora Wheat, Pima Club Wheat, Ga'ivsa, and Garbanzo Beans. While these crops are more costly to produce, they are healthier for consumers. They also enable tribal growers to diversify crops, enabling them to care for the land while at the same time preserving the Community's agrarian *himdag.*

Notwithstanding these developments, the trend between the mid 1980s and the early 2000s was downward due to water shortages (leading to a moratorium on new agricultural lands in 1985), fractionation of land, and troublesome leasing requirements. In the middle of this trend, the Community created the Pima-Maricopa Irrigation Project to develop and construct a modern irrigation water delivery system. The genesis of P-MIP dated to the early 1970s, when the Bureau of Reclamation considered options for providing Central Arizona Project (CAP) water to the Community, as a direct result of tribal claims against the United States and various state parties for the loss of water over the past century.

In October 1992 the Community and the secretary consummated a water delivery contract for 173,100 acre-feet of CAP water, with the tribe agreeing to a common-use irrigation delivery system, meaning all of the Community's water resources—CAP, Gila River, groundwater, and others—would flow in a single delivery system to and throughout the reservation. At that time, the project to deliver the CAP water was called the Central Arizona Project Indian Distribution Division, or the CAP-IDD. The Community was informed by Reclamation in 1992 that it would take the CAP-IDD eight to ten years to complete the NEPA work before construction could begin. This was unacceptable to the Community and it began looking at alternatives. To hasten the process, the Community proposed using cooperative agreements with Reclamation to conduct the work. This would allow the Community to begin the NEPA work and planning immediately. These cooperative agreements, first signed in 1993, allowed funding to begin flowing into the Community to hire consultants and the first staff to plan the delivery system. Despite some funding, Reclamation remained in control of the decision-making process.

The Community desired to assume responsibility for the planning, designing, and construction of the delivery system. In October 1995, the tribal council adopted resolution GR-43-95 and secured control of Reclamation's functions for the Gila River portion of the CAP-IDD. This was done under the authority of the Indian Self-Governance Act (PL 93-638 as amended) and, with the consummation of an agreement with the U. S. Department of Interior the Community took over all responsibilities for the irrigation delivery system, renaming the CAP –IDD the Pima-Maricopa Irrigation Project.[30]

The tribal council further directed P-MIP in 1995 to adopt alternative four of the P-MIP Programmatic Environmental Impact Statement. This meant that the Council directed P-MIP to construct the main stem delivery system along the selected route, which included some 200 miles of backbone canals and pipelines. That same year, the Community entered into its first annual funding agreement with Reclamation, becoming the first tribal nation in the United States to put an irrigation project under Indian self-governance.

Using its own engineers and four architectural and engineering firms, P-MIP began simultaneous planning in four areas of the reservation, including Blackwater, Santan, Memorial, and the Westside. P-MIP then set a goal of commencing construction in 1998, a goal that was realized when P-MIP had a groundbreaking ceremony for the Memorial pipeline in September of that year. That same year the Community and Reclamation signed the "Record of Decision," which outlined how P-MIP intended to construct the system and deliver the 173,100 acre-feet of contracted CAP water using revenue available under the Master Repayment Contract. Since 1998, P-MIP has constructed over 107 miles of the irrigation delivery system, completed a Comprehensive Water

[30] Tribal Self-Governance Act of 1994, PL-103-413 (October 25, 1994).

Management Plan, and conducted a land classification of more than 190,000 irrigable acres.

With the AWSA becoming enforceable in 2007, and as P-MIP constructed more of the irrigation system, there has been a renewed interest in agriculture by tribal growers, with a score of farming operations commencing or expanding production. Global Native, a Community-member agribusiness operation has developed over 2,500 acres since 2010 and seeks to add 5,000 additional acres within five years. Most tribal growers have taken advantage of the USDA's Environmental Quality Incentive Program to improve or expand their farming operations, with additional assistance provided by the Gila River Indian Irrigation and Drainage District, a Community subdivision charged with operating and maintaining the delivery system. By 2015, more than three dozen tribal growers cultivated over 35,000 acres.

Challenges remain, however, with several obstacles facing the Community, each of which is linked to federal land policies of a century ago. Land severalty had a deleterious impact on the traditional process of enculturating successive generations of tribal growers with the skills needed to cultivate the land. With the AWSA, P-MIP construction, and a rapidly declining agricultural land base surrounding the reservation, the tribe is positioning itself to revive its agricultural economy. But unlike the national trend, which is moving toward consolidated land holdings, the Community is moving toward more fractionated land holdings and smaller individual land ownership interests. While some tribal members desire to farm small tracts of land, or would like to irrigate pasture lands, the reality of twenty-first century agricultural economics is that most of the reservation farmland needs to be tied to large-scaled agriculture.[31]

While not alone in Indian Country, the Community is becoming increasingly fractionated due to land severalty laws. Compounding the matter is that many tribal members do not prepare wills in the event of their death. Consequently, if a landowner dies intestate, each surviving heir receives an equal share in the land, although none owns any particular piece of land since the interests are undivided. When this factor is multiplied by four or five generations, one can easily see how hundreds of landowners jointly own a ten-acre parcel. As land fractionation increases, management of the land becomes more challenging and keeping it in production more evasive since a majority interest must consent to any land use proposal.

Because of land fractionation, it is increasingly difficult for tribal growers to obtain and preserve large units of agricultural land. Challenge number one is to reverse fractionation of trust parcels. This is especially a challenge at Gila River because original allotments were ten acres and represented the best agricultural land and the majority of SCIP decreed land. While there are instances where individual landowners still own ten-acre allotments, this is by far the exception. The Pima Agency recently listed 121,136

[31] **Comprehensive Agricultural Development Plan**, Prepared for the Pima-Maricopa Irrigation Project, Department of Land and Water, Gila River Indian Community (Mesa, Arizona: EcoPlan Associates, Inc., June 2001). **Cash Flow Analysis: Pima-Maricopa Irrigation Project, Gila River Indian Community**, Prepared for U.S. Bureau of Reclamation, September 1997, pp. 4-6.

individual shares in allotments owned by tribal members. Nearly two-thirds of these were less than a two percent interest, meaning there are 80,283 shares that are less than a fifth of an acre.[32] In many cases, a single landowner owns an undivided interest in as little as 5/31,000[ths] (seventy square feet) of a ten-acre parcel.

Fractionation of land creates a sense of futility in leasing or utilizing allotted land for all but the most persistent. While it is possible to lease an allotment with dozens or even hundreds of landowners, it is difficult, especially since all landowners do not live on the reservation or may not concur with the proposed land use. For highly fractionated parcels there is yet another disincentive: annual lease payments to all but the largest ownership interests are minimal. With landowners having little financial incentive to lease the land, the land can quickly go fallow. Not surprisingly, there is a direct correlation between land fractionation and acres in production. As land becomes more fractionated, the likelihood of it being in production decreases.

The federal government has initiated a land consolidation project on the reservation with the federal government purchasing from willing sellers all two percent or fewer interests in the land and restoring it to tribal ownership.[33] Some of the funding comes from the Cobell settlement with additional funds from specific acts of Congress. While some members have sold to the tribe (or sold their interests to other landowners within the same allotment) many have refused, fearing the loss of their land regardless of its fractionated interest. As land fractionation increases, the leasing of the land becomes more of an administrative challenge. As trust lands are divided and subdivided they become increasingly difficult to administer and manage, making them more likely to go out of production.

Another challenge, therefore, is to simplify the leasing process to ensure the sustainability of agriculture. Unlike elsewhere in the United States, individual tribal landowners whose lands are held in trust on the reservation have no authority to lease the land on their own volition. This results from the federal trust relationship that requires the secretary of the Interior or his designee to approve of all leases. This is handled at the Agency level, with the superintendent responsible for lease approval. Furthermore, the approval process is cumbersome since the Agency requires an appraisal of the land before it will approve of a lease, even though there is no statutory or regulatory requirement for this.[34] The appraisal process often creates a situation "where rates are [subjectively] set by the appraisals themselves," establishing an artificial market with the result growers find rental rates

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[32] Of the 8,283 total landowners, 6,900 (83%) own interests smaller than two percent. "Concept Proposal to Buy Out/Consolidate Extremely Fractionated Lands," dated September 16, 2002, P-MIP (in author's file).
[33] See Indian Land Consolidation Act of 1983, 96 Stat. 2517 as amended 114 Stat. 1992 (2000) and codified at 25 **United States Code** §2201-2219. The two percent escheatment rule (interests of less than 2% of an allotment reverting to tribal ownership without compensation to the heir) was declared unconstitutional in Hodel v. Irving 481 **US Reporter** 704 (1987) and Babbitt, et al v. Youpee et al 519 **US Reporter** 234 (1997).
[34] See 25 **Code of Federal Regulations** §162.222. The Pima Agency requires appraisals using 52 **BIAM Supplement: Real Estate Appraisals** (Bureau of Indian Affairs, April 16, 1970) as its basis.

cutting into their profit margin.[35] This is especially troublesome when lessees must invest in on-farm development in order to make the land productive.

In some instances where land lies idle, infrastructure is vandalized and the land deteriorates, making it less likely that a grower is willing to make the necessary investments to bring the land and infrastructure to a productive state. The fact that the Pima Agency administratively limits leases to ten years further reduces the attractiveness of leases since growers may not be able to amortize costs.[36] This added uncertainty not only discourages grower investments but it also penalizes landowners who depend on lease income for part of their living. Added to this the Pima Agency does not always enforce lease provisions requiring landowners to maintain the land and its improvements. While the agency superintendent has the authority in some circumstances to signoff leases on behalf of a landowner, he must follow strict federal guidelines. The practical effect of this is that it is difficult, and at times impossible, to consolidate small fractionated parcels of land to establish a stable and economically-viable farming unit. Even if the owner of a small fractionated parcel of land seeks to utilize the land for growing crops, his divided interest might be too small to enable him to do so.

The existing lease process is a primary cause for trust land going out of production. The ten-year lease policy, the complicated leasing process, and untimely administrative delays in approving leases mean it is difficult for growers to make the investments necessary for land improvements. If the land and its improvements are allowed to degrade at the end of a lease, the land may be abandoned, adding to land lying fallow. As land deteriorates, efficiency and productivity are decreased. Poor productivity restricts financing, which leads to further deterioration and lost productivity. The end result is the reservation loses valuable and productive land resources and it does not gain an economic or cultural benefit from putting the water to use.

Another challenge is the perception financial institutions have that lending on the reservation is risky. This limits access to funding that tribal growers' need for the development of agricultural land on the reservation. Generally, agricultural lenders follow clearly defined criteria and guidelines when evaluating loan packages for growers. "Permanence of the operation and land tenure rank high on that list. If there is a perception of delays in continuing or obtaining leases of land to be farmed, this situation is viewed as negative and the loan proposal is downgraded."[37] Because of its trust status, it is difficult to use reservation trust land—tribal or allotted—as collateral, placing tribal growers in a special lending category that requires higher debt-to-equity ratios for approval.[38] This places tribal growers at a distinct disadvantage.

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[35] **Comprehensive Agricultural Development Plan**, 20.

[36] 25 **Code of Federal Regulations** §162.229 provides for leases to be ten years unless substantial improvements must be made to the land in which case the lease can be as long as twenty-five years.

[37] **Comprehensive Agricultural Development Plan** 2001, p. 24.

[38] **Providing Financial Services to Native Americans in Indian Country** (Native American Working Group: Office of the Comptroller of the Currency, July 1997). 25 **United States Code** 483a.

In the past, lenders to tribal growers have required a lien on a grower's crop as security for the operating loans; today, lenders may require a 25% margin for most crops and 50% for sensitive crops, such as produce. The greater the perceived risks, the greater the percentage of margin required. This strikes directly at tribal growers since land fractionation and leasing challenges multiply the perceived risks. The result is lenders require increasingly larger margins, driving tribal growers out of the market.[39]

Intermediate and long-term capital is even more challenging to acquire since growers must demonstrate that their cash-flow requirements can meet the demands of the lender. Since these loans are larger, they are typically collateral-based. With no land to serve as collateral, lenders have only assignments of leases as security, which encumber the lender with liabilities that become less attractive as the lease term decreases, something that does not occur when land is collateralized. Thus, lenders require additional assets to reduce their risk. In addition, lenders require from prospective borrowers a prior history of growing crops to establish credibility. Since many tribal growers have been out of the market for some time or are new, they face an additional hurdle. This is also true of qualifying for EQIP funds under the USDA.

Despite lending challenges, there are financing options including loans, grants, or loan/grant combinations. Capital can be secured via federally-backed loans from the Natural Resources Conservation Service/Natural Resource Conservation District, Rural Development program, the American Indian credit program of the Farm Services Agency, and guaranteed loans from the Bureau of Indian Affairs. In recent years financing has been available from the Community through its Pima Leasing Development Corporation, which lends money to growers to commence or expand operations. Growers can also secure grants from various federal sources, including the U.S. Department of Agriculture/Natural Resources Conservation Service

THE FUTURE

As P-MIP completes more of the infrastructure, growers have pressed the tribal government to do more. Governor Stephen Roe Lewis, elected to office in November 2014, took office on January 1, 2015, and immediately proclaimed 2015 as the "Year of the Water Settlement." Under Governor Lewis' leadership, the tribe is setting up an agricultural development entity to support growers.

Agricultural development on the scale of 77,000 acres—with the primary focus o the decreed SCIP acres—will require the leasing of both tribal and allotted lands. But this development cannot occur without properly supported growers and a stream-lined process for leasing land. To ensure that the Community's water is put to beneficial use, the Governor's initiative targets all growers, but emphasizes new and young tribal growers. The Pima-Maricopa Irrigation Project, the Gila River Indian Irrigation and Drainage District (the operating entity), the Governor's office, the tribal council, and legal counsel are working in concert to support and encourage the methodical development of agriculture on the reservation. While such market-based decisions are commonly made by growers

[39] **Providing Financial Services to Native Americans in Indian Country**, p. 2

outside the reservation, the reservation culture and environment require a different paradigm.

Today, the Community has a hard-earned water settlement that has restored an annual water budget of 653,500 acre-feet. The AWSA provided funding for P-MIP to rehabilitate the San Carlos Irrigation Project and provided funds to buy down the cost of CAP water for tribal growers.[40] These funds are in addition to the revenue provided under the provisions of the Community's Master Repayment Contract to construct the P-MIP irrigation delivery system.[41]

Understanding the historical context of P-MIP and the Community is crucial to envisioning the agricultural expansion on the reservation. Mitigating and minimizing confiscatory federal acts and regulations is essential to attracting and supporting tribal growers to cultivate the land. This not only ensures the cultural and economic viability of agriculture on the reservation but it will also ensure the AWSA is implemented as intended. This in turn will provide opportunities for food and fiber crops to be cultivated by tribal growers that will benefit the Community, the region, and off-set the loss of more than two million acres of farmland in Pinal and Maricopa counties.

While much of Indian Country remains dependent on federal dollars to maintain social and economic programs for their people, the Community has begun moving away from this paradigm through its own economic development. It has exercised its inherent sovereignty and flexed its political muscle in the water world with astonishing results.[42] While there is much room for improvement, the Community has been resolute in spirit and has led by example, creating an environment of optimism for the future.

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[40] The Community pays only the energy pump charge to get CAP water to the reservation; it does not pay the annual OM&R charges.

[41] *Master Contract Between the United States and the Gila River Indian Community for Repayment of Construction Costs and Operation, Maintenance, and Replacement of a Water Distribution System,* Contract No. 6-07-30-W0345, date July 20, 1998.

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