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Groundwater Banking in Imperial Irrigation District: Planning for Future Water Scarcity on the Colorado River

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This Master's Project

Groundwater Banking in Imperial Irrigation District: Planning for Future Water Scarcity on the Colorado River

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Table of Contents

Figures and Tables

1.0 Introduction

Urban and rural economies throughout the southwestern United States and Mexico rely on surface water imported from the Colorado River. The Imperial Irrigation District (herein IID or District) has rights to use 3.1 million acre-feet[1] (MAF) per year of Colorado River Water (Regional Water Management Group 2013 and Imperial Irrigation District 2009). Of this water entitlement, IID uses 97 percent for agricultural production. In addition, IID supplies water to San Diego and Los Angeles urban areas.

The population reliant on Colorado River water is expected to rise from approximately 40 million people today, up to 76 million people over the next 50 years (Bureau of Reclamation 2012). Growth is anticipated both in urban areas including San Diego and Los Angeles, and within the area served directly by IID. Within IID, while demand for agricultural production is expected to remain constant, demand for water by municipal, commercial and industrial users is expected to increase (Regional Water Management Group 2013 and Imperial Irrigation District 2009).

IID maintains senior water entitlements for roughly 20 percent of the Colorado River flows. The rights were established almost a century ago, before populations grew significantly throughout the southwestern United States, and during decades when flows on the river were higher than historic averages (Reisner 1986). Moreover, models based on paleo data, and climate change models have predicted a decline in water flows on the Colorado River. Many climate change scenarios predict long-term droughts with deficits of up to 60 MAF (US Bureau of Reclamation 2012).

Over the past decades, court battles over water rights to the Colorado River have ensued. In addition, environmental policy has influenced controls of river flows to support ecosystems beneficially, in addition to providing water to support human populations. Given that IID utilizes a significant portion of its Colorado River entitlement for agricultural production, there is

[1] One acre-foot is defined as the volume of water required to cover one acre of land at a depth of 1 foot. 1 acre-foot equals approximately 1,233 cubic meters.

political and legal pressure for it to reduce its use in order to provide more water to support urban populations and ecosystems. As part of the Quantification Settlement Agreement (2003) for reducing reliance on Colorado River, the IID is required to transfer water to urban areas and for ecosystem restoration. The laws that allocate the Colorado River will be described in the Background of this report.

As recent policies require more water to be allocated for urban and ecosystem uses, the amount of agricultural production within the IID is not expected to decrease. IID relies almost entirely on Colorado River imports to support agricultural production, and does not have alternative water supplies. In the face of a potential reduction in river supplies, and an increase in demand for water, IID is exploring options to improve reliability of its water supply. One of the options is storing Colorado River water for future use. The IID Integrative Water Management Plan (2012) has identified a goal to diversify its regional water supply portfolio by developing groundwater storage and banking of Colorado River water. Specifically, IID intends to develop the capability to store any surplus water to which it is entitled (within its 3.1 MAF) in groundwater storage banks for later use. For any given year in which IID diverts less water than it is allocated, the unused surplus water is called an “underrun”.

In this report, I evaluate the question: ***Is the Imperial Irrigation District’s project to store “underruns” from their Colorado River entitlement economically and environmentally sustainable? How should their goals for water security be weighed against economic and environmental impacts?***

The development of groundwater banking projects in conjunction with increasing diversions of water from the Colorado River raises questions about economic and environmental sustainability. The definition and feasibility for groundwater banking projects in the IID are described in the Background section of this report. As described, groundwater banking within the IID region would require upfront costs for construction, and long-term costs associated with energy consumption, operation and maintenance. Furthermore the groundwater is typically salty and would require desalinization in order for it to be used beneficially. Impacts to ecosystems may also occur if more water is diverted from the Colorado River.

The IID Integrative Water Management Plan also includes strategies for reducing overall water demands within the district. One of the key strategies is programs that pay farmers to not use water through field fallowing, or by improving efficient irrigation practices. There are economic and environmental sustainability issues associated with these programs, too. For instance, the Salton Sea relies almost entirely on agricultural runoff to sustain its water levels.

As described in the Methodology section, this report compares groundwater banking projects that involve Colorado River inputs against alternative strategies that reduce demands. The methodology for evaluating impacts relies on the “soft path” approach for water policy decisions. This approach encourages water managers to first consider demand reductions before increasing water supply infrastructure. The methodology highlights key factors for IID to consider for evaluating groundwater banking projects to meet water security objectives.

The **Results and Discussion** section includes a description of how groundwater banking projects measure against alternatives in terms of economic and environmental sustainability factors. The analysis includes a cost comparison of groundwater banking projects for IID, in comparison to the strategies implemented if no groundwater banks are implemented. The environmental sustainability factors are discussed qualitatively, and from the perspective of identifying potential ecological resource impacts that IID should consider. The section also includes an analysis for how these strategies meet water security objectives.

Based on the analysis of economic factors, environmental sustainability factors and the ability to meet future water security needs, the analysis provides results for IID’s policy makers to consider when evaluating groundwater banking projects in the future.

2.0 Background

2.1 Regional Setting

Imperial Valley is in southeast Imperial County, California. The area is bounded on the north by Coachella Valley, the Salton Sea and Riverside County. To the south lies the U.S.-Mexico International Border. The Valley is bound on the east by the Chocolate Mountains, and on the west by the foothills of the Coastal Range mountains. The San Diego urban area lies west of the Coastal Range Mountains. The Colorado River and southwestern border of Arizona lie east of the region.

The Imperial Region is characterized as arid. Average precipitation is 2.5 inches per year in the central part of the region, and in the western mountains, the averages are 35 inches or more. Summertime temperatures often exceed 100 degrees Fahrenheit (Lawrence Livermore National Laboratory 2008).

The Colorado River supplies water to a population of 40 million people in seven states of the United States. 7.5 MAF each year is used for agricultural production on 5.5 million acres of land (Bureau of Reclamation 2012). Within IID, approximately 2.8 MAF of Colorado River has historically been used for agricultural production (IID 2012). In 2013, the gross value of agricultural production was $2,158,517,000. Of the crops produced, field crops such as alfalfa and lettuce comprised the largest area, approximately 332,727 acres. Fruit and nuts, vegetables and melons and seed and nursery crops were produced on approximately 197,200 acres of land (Imperial County 2013). Within IID, the population is 174,528 (IID 2012).

As shown in **Figure 1, Map of Colorado River Basin,** IID is located downstream of a series of key reservoirs and dams that supply water to region. Glenn Canyon Dam created Lake Powell, which controls flows going towards Lake Mead and the Hoover Dam. Both Lake Powell and Lake Mead are key components for controlling flows and diversion of the Colorado River. Lake Powell and Lake Mead can store up to 24.3 MAF and 26.2 MAF, respectively. Davis Dam, Parker Dam and Imperial Dam are south of Lake Mead. Davis Dam and Lake Mohave function to divert water to users in Nevada and Arizona. Parker Dam and Lake Havasu facilitate diversion of water to the Central Arizona Project and the Metropolitan Water District of Southern California. Further south, Imperial Dam diverts water to the Imperial Irrigation District and the Coachella Valley Water District to the west, as well as to other water users in Arizona to the east (Bureau of Reclamation 2007). The southernmost major dam on the Colorado River is the Morelos Diversion Dam, which is south of the U.S.-Mexico International Border. Water diverted from this dam supplies agricultural production in the Mexicali region, as well as the urban areas of Tijuana and Rosarito (Medellín-Azuara 2009).

The Salton Sea is another integral component of the IID drainage system. The Salton Sea was formed from a levee breach on the Colorado River in 1905 (California Department of Water Resources 2015). Water collected in the Salton Sea because the basin is the lowest point in the landscape, and is more than 230 feet below sea level. At the time of the levee breach, the basin was dry, though lakes historically did exist in the basin. In its current formation, Salton Sea is 350 square miles. The lake relies entirely on runoff from irrigation by IID farmers, as well as irrigation in Coachella Valley Water District (Cohen 2014). Historically, average flows from irrigation runoff to the Salton Sea were approximately 1.36 MAF per year (Scott et al. 2013).

Figure 1, Map of Colorado River Basin

Source: U.S. Department of the Interior, Bureau of Reclamation 2012

2.2 The Law of the River: IID's Legal Rights to Colorado River Water

The Colorado River Compact was signed in 1922 by the federal government and several states (excluding Arizona) to allocate the river's water. The states were divided politically into the "Upper Basin" and "Lower Basin" states, wherein the Upper Basin States were Colorado, Utah, Wyoming, and New Mexico and Lower Basin states were California, Arizona and Nevada. The Lower Basin states were those that received water diverted from the Colorado River below Lee Ferry, Arizona. Per the agreement, the Upper and Lower basins each had rights to 7.5 MAF (MAF). In addition, for any surplus of water supply over 15 MAF, the Lower Basin states were allowed to use up to one MAF for beneficial consumption. The remaining water was reserved for Mexico as a comity (Colorado River Compact 1922).

At the time the compact was signed, the Upper Basin states were not very populated in comparison with the Lower Basin states. The agreement was intended to protect the rights of the river such that the Upper Basin states could eventually be developed and use their allocated 7.5 MAF (U.S. Bureau of Reclamation 2008). Among the lower basin states, California was the only state that had the urban population and irrigation districts that could use the water immediately (Reisner 1986).

In 1928, the Boulder Canyon Project Act authorized construction of the Hoover Dam and divided the Lower Basin's 7.5 MAF of water in the following manner: California would be allocated 4.4 MAF, Arizona would be allocated 2.8 MAF, and Nevada would receive 0.3 MAF. The same act gave the Secretary of the Interior the authority to dictate flows, diversions, and beneficial uses of Colorado River water under the terms of the Colorado River Compact.

The State of California apportioned its rights from the Colorado River Compact, Boulder Canyon Project Act contract, and any other applicable entitlements to the seven water users, including agricultural and urban water suppliers. The California Seven Party Agreement was signed in 1931 and was intended to settle disputes among the irrigation districts and urban users in the state. The agricultural suppliers (Imperial Irrigation District, Palo Verde Irrigation District, the federal Yuma Project, and the Coachella Valley County Water District) were awarded their water first by the Secretary of the Interior (3.85 MAF). Next, the Metropolitan Water District of

Southern California and Los Angeles secured contracts for water amounting to approximately 0.55 MAF that would come out of California's 4.4 MAF basic allotment. Finally, the Metropolitan Water District of Southern California, the City of Los Angeles, and San Diego secured an additional 0.662 MAF for any unused apportionment or surplus (Boulder Canyon Project Agreement 1931). California was using almost the entire 1 MAF of surplus water allowed for Lower Basin states under the Colorado River Compact.

The *Arizona v. California* Supreme Court decisions in 1964 and 1979 defined IID's "present perfected rights" as rights specified prior to 1929 (the effective date of the Boulder Canyon Project Act). During years when less than 7.5 MAF of water are available for Lower Basin States, the Secretary of Interior gives priority based on present perfected rights, regardless of state boundaries. Since IID is among water users that "perfected" rights in 1901, it has priority over junior water rights holders who developed their rights after (Imperial Water Forum 2012). Per the Supreme Court decree, IID's perfected rights include 2.6 MAF of water from the main stem, or sufficient water to irrigate 424,125 acres and for related uses.

There were many other key findings from the *Arizona v. California* cases. Among them, the Supreme Court held that both interstate and intrastate distribution of water is controlled by federal law, not state prior appropriation law (Glennon and Kavkewitz 2013). In addition, federal claims (mostly Indian Reservations) were entitled to water necessary to satisfy future needs (MacDonnell 2013).

In 1968, congress approved the Colorado River Basin Project Act, which permitted construction of the Central Arizona Project, which provides 1.5 MAF of water from the Colorado River to central Arizona (U.S. Bureau of Reclamation 2000). Under the 1968 Colorado River Basin Project Act, in the event of water curtailments for Lower Basin States, pre-1968 users of Colorado River water diversions are senior to deliveries that have taken place after 1968. California will receive its 4.4 MAF before any water can be delivered to the Central Arizona Project. The Act also directed the Secretary of the Interior to institute water shortage criteria in the event that Lake Mead storage levels fall below an elevation of 1,075 feet. The Secretary adopted interim guidelines in 2006 (MacDonnell 2013).

Lake Mead levels were 1079.03 feet in April, 2015 (USBR 2015). Prior to 2015, the Secretary of the Interior has not required any curtailments to take place for the Lower Basin States. In light of the recent drought, curtailments could be required if Lake Mead elevations continue to decline.

As a result of the *Arizona v. California* Supreme Court decisions, California ultimately agreed to reduce its demand for Colorado River supplies to 4.4 MAF. In 2003, the California parties completed the Quantification Settlement Agreement 2003 in order to achieve this goal (MacDonnell 2013). These parties included IID, Metropolitan Water District of Southern California, Coachella Valley Water District, State of California, and U.S. Department of the Interior. Under the Quantification Settlement Agreement, IID must transfer 200,000 acre-feet per year to the San Diego County Water Authority for at least 45 years, with a potential to extend up to 75 years. IID will transfer 110,000 acre-feet per year to Metropolitan Water District of Southern California, and 103,000 acre-feet per year to Coachella Valley Water District. In addition to reducing California's reliance on Colorado River water, the Quantification Settlement Agreement also identified a plan to restore the Salton Sea (San Diego County Water Authority 2014).

Under the 2007 Colorado River Interim Guidelines for Lower Basin Shortages, the Secretary of the Interior determines if there is an 80 percent or higher likelihood that Lake Mead water levels will fall below 1,075 feet in the following year. The first stage of shortages on Lake Mead applies to the post-1968 users of the Colorado River, including Arizona, Nevada and Mexico. The maximum water curtailed under this phase is 1.8 MAF; Arizona would no longer divert any water from Lake Mead and Nevada and Mexico would reduce their diversions by a specified percentage. If shortages continue and the elevation of Lake Mead is at risk of declining to 1,000 feet, a second phase of reductions will apply to Lower Basin States in order to maintain elevations above 1,000 feet. At this stage, California water users, including IID, will be required to reduce diversions (USBR 2007).

2.3 U.S- Mexico Treaty of 1944

The U.S.-Mexico Treaty of 1944 establishes a minimum allocation of 1.5 MAF for Mexico. South of the U.S.-Mexico International Border, the Mexicali region relies on Colorado River water for agricultural production. Due to a variety of factors including runoff from up-stream agricultural users, and wastewater treatment plant effluent, Colorado River water is high in salt by the time it reaches Mexico (Carter et al. 2015). The 1973 Minute 242 limits the salinity of Colorado River deliveries to 115 parts per million (US Bureau of Reclamation 2012). The United States signed this treaty only after Mexicali farmers threatened international lawsuits related to the salinity levels damaging crops. The Bureau of Reclamation initiated development of drainage channels and other infrastructure to meet the salinity threshold, after the treaty was signed.

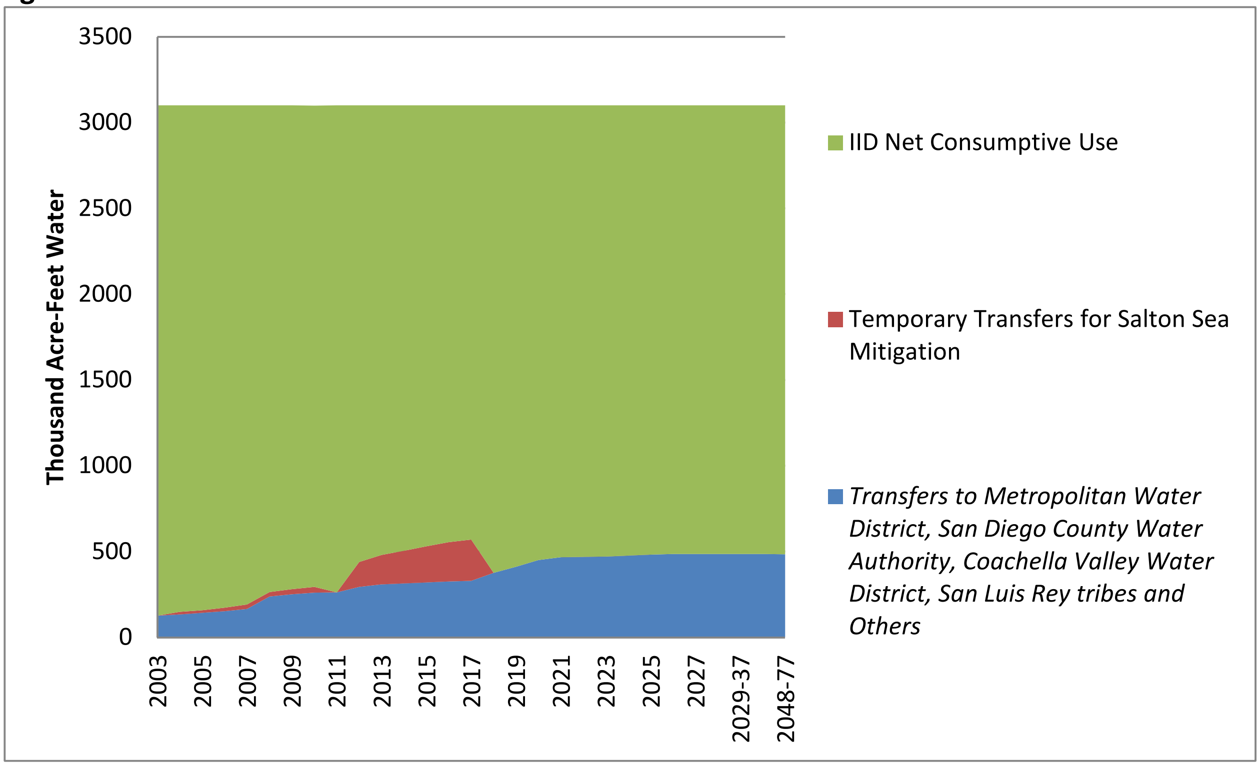
In addition to water quality concerns, Mexico also has raised concerns with the quantity of water delivered and ecological concerns in the Colorado River Delta. In 2012, the U.S. and Mexico signed Minute 319, which includes provisions for managing water deliveries and binational ecosystem enhancement (Carter et al. 2015). The agreement establishes a basis for policy in the U.S. to be established in order to support ecosystems across the international borders. While this agreement is expected to influence policy decisions for Colorado River allocation, it is not yet known how it could impact allocations of the river described above, or IID specifically.

2.4 Impact of the Quantification Settlement Agreement on IID

As shown in **Figure 2, IID Consumptive Use Allocated Under the 2003 Quantification Settlement Agreement**, IID maintains its entitlement of 3.1 MAF per year, though water is required to be diverted for beneficial uses such as Salton Sea Mitigation, other than by IID consumption alone. Assuming that California consumed 4.4 MAF of Colorado River water, IID was allowed to consume 2.97 MAF in 2003. This amount has been gradually decreasing since 2003, and will continue to decrease until 2017, during which IID can divert 2.7 MAF for net consumptive use. From 2003 to 2017, IID is sending water to the Salton Sea in order to mitigate for environmental impacts associated with reduced crop irrigation runoff (tailwater and operational spill). These impacts result partially from the improved irrigation efficiency under the Quantification Settlement Agreement. After 2017, IID will no longer be diverting water for

Salton Sea mitigation, but will be required to reduce its overall net consumptive use so water can be transferred for other beneficial uses. After 2026, IID's net consumption will be approximately 2.6 MAF.

Figure 2, IID Consumptive Use Allocated Under the 2003 Quantification Settlement Agreement



Source: Imperial Irrigation District. 2012. Imperial Integrated Regional Water Management Plan*. October. Prepared by GEI Consultants, Inc.*

The intent of the Quantification Settlement Agreement is to require IID to conserve water so that water can be transferred to other users in the area. **Figure 2, IID Consumptive Use Allocated under the 2003 Quantification Settlement Agreement**, highlights the incremental increase of water to be transferred to urban water districts such as the Metropolitan Water District of Southern California and the San Diego County Water Authority, as well as transfers to tribes and other users. The lining of the All American Canal is an example of a conservation measure in that water conveyed through the canal will no longer be lost due to seepage into groundwater.[2] As noted above, IID also implemented voluntary fallowing and crop efficiency programs. The voluntary fallowing program is temporary, and expires in 2018. IID supports the on-farm conservation practices by paying farmers directly for water conserved; it does not pay for the efficiency systems themselves. The program is funded by money generated by transferring conserved water to San Diego County Water Authority under the Quantification Settlement Agreement. The IID considered crop selection programs to oversee crop selection based on water use requirements. An example of a crop selection program would be to reduce irrigation associated with alfalfa, and replace with fewer but higher-value crops. Crop selection programs were rejected by IID. IID indicated that crop selection is driven by market conditions and that farmers are entitled to choose which crops to grow on their property (IID 2012).

Another issue for IID related to the Quantification Settlement Agreement is meeting increasing municipal, industrial and commercial demands for water within the IID region. Based on regional growth projections, growth in municipal and industrial areas is expected to increase demand for water. Geothermal and solar thermal industries are expected to develop in the region. Assuming that conservation measures are implemented in future residential, commercial and industrial practices, the municipal, industrial and commercial water demands within IID are expected to increase from 89,640 acre-feet to 255,235 acre-feet each year. Geothermal and solar thermal industries alone are expected to demand 144,000 acre-feet, assuming conservation (IID 2012).

While the IID has needed to reduce its overall demand for water per the Quantification Settlement Agreement and other agreements, IID still has senior rights to Colorado River (Imperial Water Forum 2012). The guidelines described in the 2007 Colorado River Interim Guidelines for Lower Basin Shortages would still be in effect during years of drought, so while Lake Mead elevations are above 1,000 feet, IID can continue diverting 3.1 MAF each year.

2.5 Water Security and Climate Change Impacts for Colorado River Users

[2] The lining of the All-American Canal was not without controversy. There are a number of Mexican farmers who relied on the groundwater from the seepage of the canal (Neir and Campana 2007).

Flow rates in the Colorado River depend on a number of factors, including evapotranspiration potential, snowpack levels, and runoff into various subbasins connecting to the Colorado River (Bureau of Reclamation 2012). The International Panel for Climate Change (IPCC) found robust evidence that increasing levels of anthropogenic greenhouse gas emissions will impact freshwater resources (IPCC 2014a). Warmer temperatures in western North American winters are expected to melt the snowpack earlier in the year, which changes the timing of hydraulic flows (IPCC 2014b). Most global climate model outputs suggest that a warmer climate will cause snowmelt to occur earlier in the hydrologic cycle, resulting in drier summer conditions. In addition, models predict more extreme weather events which lead to increased severity in floods and also increased severity for droughts (Dawadi and Sajjad 2012). The IPCC notes that arid and semi-arid regions in western United States and Mexico are projected to experience more drought conditions in the future (IPCC 2014b). Furthermore, current weather patterns suggest that the climate is already changing in the Colorado River Basin (Dawadi and Sajjad 2012).

In 2012, the Bureau of Reclamation completed a comprehensive study of the Colorado River water supplies and demands. In the study, the Bureau of Reclamation modeled future hydrologic regimes for the river based on several scenarios of future flows. The scenarios were based on: measured flow rates from the past 100 years; flow data from the paleo record based on tree ring studies, dating back approximately 1,250 years; and flow projections based on climate change predictions in general circulation models (GCM) models. Each scenario includes predictions for evapotranspiration potential, snowpack levels, and subsequent runoff into various subbasins connecting to the Colorado River (Bureau of Reclamation 2012).

From the years 1906 to 2007, the average flow rate at Lees Ferry, Arizona was 15 MAF. At its driest year (1977), the flows were 5.6 MAF at Lees Ferry, and at its peak year (1984), flows were 25.2 MAF. If the flows in the next century mimic observed flows from the past century, the average flows will continue to be approximately 15 MAF. According to models that include both observed and paleo data, the average flows are projected to be 14.7 to 14.9 MAF each year (Bureau of Reclamation 2012).

Temperatures for the entire river basin are expected to increase 1.3 degrees Celsius by 2025, 2.4 degrees Celsius by 2055, and 3.3 degrees Celsius by 2080. The Bureau of Reclamation incorporated predictions for temperature increase into 112 GCM models for the Colorado River Basin. Based on these models, the average flows at Lees Ferry, Arizona, will be approximately 13.7 MAF between the years 2011 and 2060. The median projected flow rate based on the 112 models for the same location and time period is 12.7 MAF. According to the paleo and GCM models, water deficits are likely to occur for longer than 15 years, resulting in deficits of up to 60 MAF (Bureau of Reclamation 2012).

As summarized above, the Bureau of Reclamation's Colorado River Basin Study found that the annual average flows on the Colorado River will likely be less than 15 MAF, which is the volume of water allocated under the Colorado River Compact (U.S. Bureau of Reclamation 2013). There will likely be insufficient supplies to meet demand throughout the basin in the future. The study also detailed and analyzed strategies for resolving the imbalances between supplies and demands. Moving forward, the Bureau and the seven Basin States have commenced with establishing work groups with key stakeholder information to further investigate how water demands by urban and agricultural users can be reduced (U.S. Bureau of Reclamation 2013).

2.6 Imperial Irrigation District Integrated Regional Water Management Plan

The Imperial Water Forum and Regional Water Management Group were established by the Imperial Irrigation District and Imperial County to prepare an Integrated Regional Water Management Plan (IRWMP). IRWMPs are intended to achieve the following goals: "increase regional self-reliance, reduce conflict, and manage water to concurrently achieve social, environmental, and economic objectives" (California Department of Water Resources 2015). IRWMPs are funded through a California Water Resources grant program. The Imperial Water Forum Charter identifies the goals for the IID region to: "identify water resources problems to be addressed, define IRWMP goals and objectives, review and develop water management strategies to resolve common issues related to the region's water supply, water quality, environmental stewardship, and flood management; and adopt an IRWMP to provide a roadmap for the future" (Imperial IRWMP Charter 2012). The first goal listed in the Imperial

IRWMP is to ensure water supplies meet the existing and future demands from agricultural, municipal, industrial, commercial and environmental users (Imperial Water Forum 2012*).* Furthermore, the IRWMP identifies the following objectives related to water supply.

> *"Optimize and sustain use of Colorado River entitlements through development of groundwater banking and storage projects. […]*
>
> *Integrate resources management strategies that diversify the regional water supply portfolio through projects such as desalination of brackish groundwater or drain water, reclaimed waste water, and stormwater reuse; or through coordinated land use and water management policies. […]*
>
> *Protect correlative groundwater rights and currently designated sole source aquifers from further overdraft, and optimize the use of other groundwater where feasible." (Imperial Water Forum 2012)*

IID has conducted a feasibility study for groundwater banking projects, including some that involve storage of Colorado River water. These projects are described in the next section.

2.7 Groundwater Banking

Definition of Groundwater Banking

Groundwater banking is the practice of storing water in underground aquifers for future extraction. The practice is also called "managed aquifer recharge". In addition, the term groundwater banking can be applied to the management and transactions involving groundwater storage and subsequent pumping. This paper uses the latter definition. Examples of groundwater banks will be described below.

The objective for groundwater banking is to store fresh water during years when surface water supplies are more plentiful, and extract groundwater during drought years. Groundwater banks are typically implemented in arid and semi arid regions where access to surface water supplies is limited and groundwater aquifers are prone to overdraft. Typically, groundwater banking involves an accounting system for water that is added to the aquifer during times of surplus for injecting freshwater supplies to the aquifer (either artificially through injection, or through infiltration), and water that is withdrawn (Maliva 2014).

Certain physical parameters are required for a groundwater bank to function. The aquifer needs to be clearly defined within a geographic area. The storage capacity and groundwater levels within the aquifer should also be measured. Lastly, the hydrologic layer that stores groundwater should be clearly defined (Maliva 2014).

Groundwater banks are not the same as water banks in that water banks facilitate transfers of water. However, groundwater banks are a key component of the water markets since they serve as a buffer during drought years. For instance, Arizona Water Banking Authority manages recharge and pumping of the groundwater aquifer as a mechanism to store water supplies for future scarcity (Megdal et al. 2014). The management of groundwater banks is an important component of a robust water market because establishing a price or cap of surface water without managing groundwater provides perverse incentives to deplete groundwater resources (Debaere et al 2014). Furthermore, based on analysis by Gao et al. (2014), the storage of water can lower the overall price of water during times of scarcity.

Groundwater Banking for IID: Storing "Underruns"

The IRWMP identifies groundwater storage and banking as IID's first priority to maximize its water supplies. Specifically, while IID carefully allocates water supplies to beneficial uses, the IID users occasionally demand less water than IID's full entitlement of water supplies. The amount of additional supply that the IID is entitled to but does not use is called an underrun (Imperial Water Forum 2012). The feasibility of the groundwater storage project is linked to the potential for IID to use less water than its 3.1 MAF entitlement. IID manages diversion of Colorado River water primarily based on contracts with individual farmers. Farmers request deliveries from IID, which in turn manages diversions of Colorado River water and delivery to individual farmers. IID manages its total diversion from the river to ensure that it has not exceeded contractual obligations to farmers or its overall entitlement for Colorado River. However, during some years, demand by farmers and other users is less than the entitled amount. For this reason, IID is exploring groundwater storage to maximize use of its water entitlement (Imperial Water Forum 2012).

Currently, when IID does not use its full entitlement of water for any given year, entities with junior Colorado River water rights are allowed to use the water, or the water is allowed to remain in the main stem of the Colorado River. This under-utilization of the IID entitlement is a main driver for establishing storage capacity.

Another driver for establishing a groundwater bank is that there are years when IID unintentionally uses more than its entitled amount of water supply. The system for IID to divert water from the main stem of Colorado River involves careful measurement of each diversion that are managed and verified by the Department of the Interior, Bureau of Reclamation. Frequently, more water is used than the water district is entitled to because the initial measurements differ from finalized data. For this reason, the overruns are considered unintentional. Historically, even though IID and other users of the Colorado River persistently exceeded their entitlement supplies, the Bureau of Reclamation lacked a policy for how the water should be returned to the Colorado River. Until recently, there were no penalties for inadvertent exceedances.

The Bureau of Reclamation adopted the Inadvertent Overrun and Payback Policy for the Lower Colorado River Basin in 2004 to define overruns and to establish a procedure for payback to the river when they do occur. Under the new policy, if an inadvertent overrun occurs that cannot be returned to the system within the same year, entitlement holders are required to pay in future years. The policy requires payback to begin in the year immediately following an overrun. Overrun payments are accomplished through “extraordinary conservation measures”. These extraordinary conservation measures require entitlement holders to forebear use of Colorado River water that are in addition to any existing conservation agreements. Under the policy, an entitlement holder is allowed to payback water by supplementing its Colorado River system water with water sources that are not hydrologically connected to the river. Groundwater banks and desalinization projects, like those proposed by IID, are examples of supplemental water sources. Another example of an extraordinary conservation measure is fallowing fields (USBR 2004). This measure would be valid for IID because its fallowing program that is required under existing conservation and transfer agreements is expected to expire in 2017.

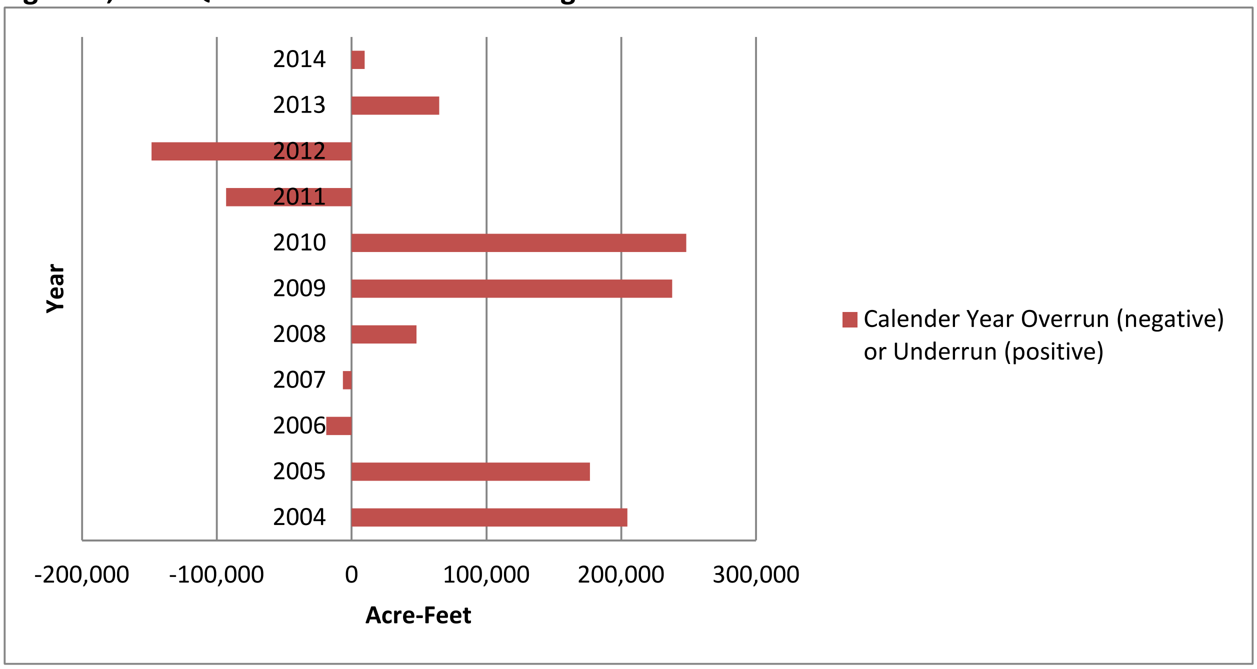
In order to evaluate how the new Inadvertent Overrun and Payback Policy for the Lower Colorado River Basin policy could impact future water supplies for IID, the District conducted a simulation of potential future overruns and underruns. The simulation is based on water use patterns by the District between 1987 and 1998. This period of time was selected because it represents relatively recent economic and cropping patterns and thus water demands. Weather patterns from 1925 to 1999 were compared against weather patterns between 1987 and 1998, and water demands were projected for the 1925 to 1999 period based on these weather patterns. According to historic demand compared to weather patterns, IID exceeded its 3.1 MAF entitlement 52 percent of the time. The average volume of each overrun was 113,866 acre-feet, and the median overrun was 101,984 acre-feet. The average volume for each underrun was 131,250.60 acre-feet, and the median was 106,104 acre-feet (IID 2012).

While historic averages are a good indicator of future overruns and underruns, the Quantification Settlement Agreement was not in effect between 1987 and 1998. After the Quantification Settlement Agreement was implemented in 2003, there have been changes to the amount of water demanded by agricultural and urban users, as various water demand efficiency programs were implemented. Since a key driver for overruns and underruns is related to diversions for agricultural production, the irrigation efficiency programs in effect after the Quantification Settlement Agreement could influence the overruns and underruns. In addition, cropping patterns tend to vary each year based on market conditions, which can change the amount of water demanded. For these reason, while the predictions of overruns and underruns above are useful, overrun and underrun data from after the Quantification Settlement Agreement are more relevant.

From the years 2004 to 2014, IID had underruns for 7 out of the 11 years. The water that IID did not use went to beneficial use by junior water rights holders, or remained in the main stem of the Colorado River. **Figure 3, Post Quantification Settlement Agreement Underruns and**

Overruns the IID shows the number of years during which IID used less water than it was entitled to use, and which years the allocated amount was exceeded.

Figure 3, Post Quantification Settlement Agreement Underruns and Overruns for IID



Source: U.S. Bureau of Reclamation. 2015b. "Lower Colorado River Water Accounting". <http://www.usbr.gov/lc/region/g4000/wtracct.html>

The practice of storing Colorado River water in groundwater aquifers is also not unprecedented. The State of Arizona established the Arizona Water Banking Authority in 1996 in order to maximize use of its 2.8 MAF of Colorado River water entitlement. Since Arizona does not have seniority for Colorado River supplies, in the event of a shortage on Lake Mead, it is required to significantly curtail use of river water. The water banking program has successfully stored 3.224 MAF of water and has almost secured enough supply to provide 100 years of water to residential users (Megdal et al. 2014). The usefulness and challenges of Arizona's groundwater storage program with respect to water security will be discussed further in the **Results and Discussion** section below.

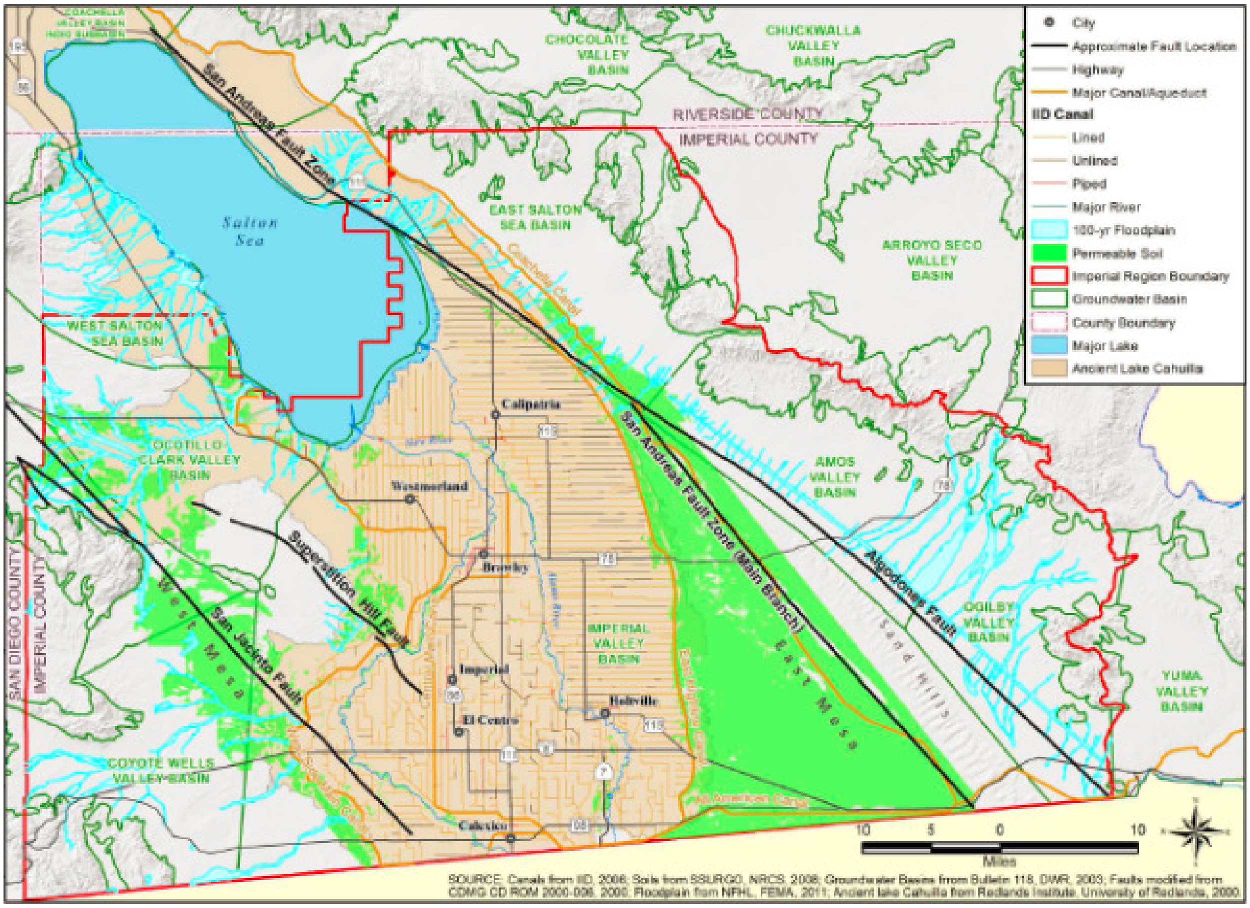
Feasibility for Groundwater Banking in IID

Studies in the Imperial Region have identified potential areas where groundwater production is feasible. Existing studies for groundwater availability identify groundwater quality, and determined if groundwater extraction can be sustained over time. Another important factor is determining if overlying soil is permeable enough for percolation to take place.

Within the Imperial Region, historically most groundwater production has taken place in shallow aquifers (up to 2,000 feet-deep). Deeper groundwater aquifers (approximately 2,000 to 20,000 feet in depth) are not typically used for groundwater production as water at this level is high in salinity and temperature. The salt content in the deep aquifers is typically from the mineral content of the soil itself and from the ancient seawater. For these reasons, groundwater production from deeper aquifers will not be discussed further (Lawrence Livermore National Laboratory 2008).

In the Imperial Region, most groundwater recharge is historically linked to seepage from unlined agricultural canals and from agricultural irrigation itself. Based on soil data for the Imperial Region, water recharge is feasible in the East Mesa, West Mesa and Imperial Valley areas. These areas are identified in **Figure 4, Groundwater Basins in IID.**

Figure 4, Groundwater Basins in IID



Source: Imperial Irrigation District. 2012. Imperial Integrated Regional Water Management Plan*. October. Prepared by GEI Consultants, Inc.*

The West Mesa is an area south and west of the Salton Sea, and includes several groundwater basins, including the Ocotillo/Coyote Wells Subbasin. The quality of water extracted from these Ocotillo/Coyote wells is considered good as the total dissolved solids concentrations are below 500 milligrams per Liter. However, extraction of groundwater from these wells currently exceeds the sustainable yield (Imperial Water Forum 2012). The West Mesa is recharged naturally from mountain runoff. The aquifer has been designated by the EPA as a Sole Source Aquifer (used for drinking water supplies without treatment) and EPA prohibits degrading the quality of such water.

The East Mesa groundwater basin currently contains water from the Colorado River that originally seeped from the All-American, Coachella and East Highline canals, before they were lined to prevent such seepage. The current water volume available in the basin is approximately 700,000 to 1,500,000 acre-feet, and it contains total dissolved solids between 500 and 1,000 milligrams per Liter. This level of total dissolved solids is considered reasonable for irrigating crops, though it is more brackish compared to imported water supplies from the Colorado River. Since the water available in East Mesa is primarily from historic seepage, long-term groundwater extraction would not be sustainable for this basin (Imperial Water Forum 2012). The East Mesa groundwater basin has capacity to hold up to one MAF (USBR, 1988; Imperial Water Forum 2012).

Future projects for this basin involve blending imported water from the Colorado River with the more-brackish groundwater. Since the blended water will be higher in salinity than typical Colorado River Water, IID would need to identify a beneficial use for the water for which this level of salinity is adequate. For agricultural applications, applying water with higher salinity content increases the volume of water required for crop production. For instance, if 1,000 acre-feet of water is applied containing salinity levels of 1000 ppm, the net supply is 932 acre-feet. If the same volume of water contains salinity levels of 3000 ppm, the net supply for crop production is 380 acre-feet (Imperial Water Forum 2012).

Groundwater in Imperial Valley is typically hot. Temperatures range from 180 to 300 degrees Fahrenheit. In order to desalinate water through reverse osmosis membranes, temperatures would need to be cooled to below 100 degrees Fahrenheit in order to avoid damage to the membranes (IID 2012).

IID conducted an evaluation of potential capital projects that could supplement its water supply, including pumping existing groundwater resources, utilizing tailwater runoff from irrigation, recycling water. Several projects incorporate storing Colorado River water in groundwater aquifers. For these projects, Colorado River water is conveyed from existing canals through conveyance canals to areas of recharge (Ryan and Shatz N.D.). From the recharge areas, water will be pumped from wells and conveyed back into the system for beneficial use (Imperial Water Forum 2012). IID proposed several projects that would blend brackish groundwater with Colorado River supply water to meet acceptable quality for beneficial users, and would not treat the water further. However, seventeen proposed alternatives would include reverse osmosis desalinization (IID 2012). This analysis will focus on a subset of projects proposed by IID. Specifically, the analysis focuses on projects that store Colorado River water and that incorporate desalinization.

IID sponsored a study to determine the technical feasibility for groundwater banking. In the study, weather data and crop patterns were used to predict the likelihood of future underruns and overruns. The study assumed an aquifer storage capacity of 1 MAF and assumed that initially, groundwater would need to be pumped out to make room for future storage of river water. Based on the weather data from 1925 to 1999, and crop data from 1982 to 1999, between 100,000 and 200,000 acre-feet of Colorado River water could be stored each year during which underruns occur. As explained above, water stored in groundwater banks may also be used for paying back inadvertent overruns. Combining the amount of existing groundwater, future inputs of Colorado River water, and future payback for overruns, the groundwater banking projects could result in annual yields from 19,000 to 55,000 acre-feet per year (Natural Resources Consulting Engineers, Inc. 2009). The analysis for this paper assumes that groundwater banking is technically feasible, as concluded in this IID-sponsored study.

2.8 Regulatory Background for Groundwater Management in IID

California State Laws for Groundwater

In the state of California, there are numerous laws governing groundwater. These laws will influence the future management of groundwater banks

Assembly Bill (AB) 3030 requires that local agencies create Groundwater Management Plans. State Bill (SB) 1938 requires the creation of Groundwater Management Plans if a public agency requests certain types of state funds. In addition, the Groundwater Management Act (AB 359) signed into law in 2011, requires identification of groundwater recharge areas in a groundwater management plan.

In 2009, California passed legislation requiring that the Department of Water Resources monitor groundwater elevations. Local agencies can voluntarily supply the groundwater elevation information to DWR, but DWR is required to monitor in the event that voluntary elevation monitoring is not completed at the local level.

In September 2014, Governor Brown signed three bills into law that aim to bring all high and medium risk groundwater basins to sustainable levels by 2040. SB 1168 (Fran Pavley) requires groundwater management plans to be created for all water agencies by 2020. The plans must be prepared and enforced by elected groundwater sustainability agencies.

AB 1739 (Dickinson) provides additional requirements for groundwater sustainable agencies established under SB 1168, including reporting requirements, groundwater extraction fees, and penalties for noncompliance. This legislation authorizes the state to develop interim plans, if the local agency is inadequately managing groundwater extractions such that yields are unsustainable (Mason 2014). The third bill, SB 1319 (Pavley), would provide additional authority to the state to designate groundwater basins as high and medium priority if groundwater extractions are impacting surface water levels, but would also delay state intervention until 2025.

3.0 Methodology

Historically, water managers have routinely turned to engineering solutions to convey freshwater to end users (Gleick 2002). Construction of the Hoover and Imperial Dams, and conveyance of Colorado River water to agricultural producers in IID are examples of this alternate "hard" path. The construction of this large infrastructure, in general, has resulted in significant damage to ecosystems and has increased the severity of floods and droughts (Gleick 2003; Dawadi and Ahmad 2013). Furthermore, water managers have erroneously equated increased supply of freshwater resources with overall water security (Gleick 2003).

The "soft path" is an approach for water managers to maximize the benefits of freshwater resources for end users, as an alternative to seeking large amounts of additional water supplies (Gleick 2003). The approach compels policy makers to incorporate economic feasibility, environmental sustainability and social responsibility in its decisions (Brooks and Holtz 2009). Brooks and Holtz (2009) created a framework for water managers to integrate a soft path approach into water policy. The methodologies below are based on this framework, incorporating unique circumstances for IID. The metrics used for the analysis are briefly described below, and summarized in **Table 1, Summary of Metrics used to Evaluate IID Groundwater Banking compared to Demand Reduction Alternatives**, located at the end of this section.

3.1 Evaluating Economic Value of Groundwater Banking Projects and Demand Reduction Programs

The first part of the economic evaluation will examine and compare the cost of groundwater banking projects for IID with the alternative scenarios that involve improving water use efficiency. Costs will be discussed from the perspective of IID.

As noted above, the IID IRWMP identifies twenty potential projects to supplement their water supply. Of these projects, seven projects include supplementing existing groundwater supplies with Colorado River underruns. Many of the projects that involve groundwater extraction without recharging the aquifer with Colorado River water were rejected due to potential overdrafts to the aquifer. Of the projects that include recharge with river water, there is variation in the amount of water produced annually, and in the intended beneficial use for the water. Costs associated with constructing these projects, including costs for operation and maintenance are included in the IID IRWMP and summarized below. Of the options considered, IID IRWMP also identifies storing its underrun water in a groundwater banking system in Coachella Valley, outside of its jurisdictional boundaries. The Coachella Valley artificial aquifer storage and recovery project has already been implemented, and conveyance facilities exist between IID and Coachella Valley.

A key incentive for setting up groundwater banking is to minimize overruns. IID is already implementing programs to reduce its overall water demands as a result of the Quantification Settlement Agreement. However, future demand reductions will also be expected to occur as a result of *unintentional* overruns. While overruns are not allowed, they have occurred and based on increasing demands projected by IID, they are likely to occur in the future. The Inadvertent Overrun Payback Policy requires implementation of extraordinary conservation measures. I will determine costs associated with these conservation measures as an alternative to implementing the groundwater banking projects.

In the second part of the economic evaluation, I will assess potential scarcity costs of water in IID if a groundwater banking project were implemented. This analysis will be based on an existing study of groundwater use in Southern California.

3.2 Evaluating Environmental Effects from Groundwater Banking Projects for IID

In this analysis, environmental impacts from groundwater storage and desalinization projects proposed for IID will be evaluated. In addition, impacts associated with incrementally increasing water diverted from the Colorado River will be discussed. The focus is to highlight both the direct impacts from implementing a groundwater banking project with desalinization, and to discuss potential indirect impacts related to river water.

If IID does not pursue water storage projects for Colorado River water underruns, the excess would remain in the river, or could be reallocated to junior water entitlement holders. This analysis assumes that underrun flows that are not captured for groundwater recharge would remain in the river. In addition, the analysis assumes that IID will reduce its demands for irrigation water as an alternative to increasing its supply in order to avoid overruns.

A number of environmental impacts have been associated with reducing the volume of water on the main stem of the Colorado River. This analysis will focus on impacts associated with changes in river flow down-stream of the Imperial Dam, even though the entire Colorado River ecosystem has already been substantially altered by all users of the river from the last century. Alternatively, if irrigated water demands are reduced, ecosystem impacts in the Salton Sea may occur. The discussion will acknowledge these impacts.

Groundwater banking projects in IID require desalinization, which has significant energy requirements. For this reason, it is important to discuss potential energy requirements from both groundwater banking and desalinization. The analysis will focus on energy related to the groundwater projects in addition to general energy requirements related to irrigated agricultural production.

Given political and environmental concerns related to salinity, this report will discuss water quality impact that would result directly and indirectly from IID's water management decisions. The evaluation will discuss water quality issues associated with reducing water flows to the Salton Sea, as well as water quality concerns south of the U.S- Mexico International Border.

3.3 Meeting Water Security Objectives

The approach for soft-path analyses is to evaluate all alternatives to increasing hard infrastructure, while still meeting water management objectives. In this discussion, I will compare the groundwater banking projects with the no-banking alternative with respect to meeting water security for IID.

Table 1, Summary of Metrics used to Evaluate IID Groundwater Banking compared to Demand Reduction Alternatives

Metric for Analysis	*Description*
Economic Viability	• Cost per acre-foot for IID • Scarcity costs of water for IID and Southern California region with groundwater banking
Environmental Sustainability	• Water quality for agricultural production end-users • Ecosystem impacts from adjusting instream flows • Ecosystem impacts from reducing irrigation water use • Energy demands from water use
Water Security	• Meeting water security objectives

4.0 Results and Discussion

4.1 Economic Evaluation

Costs to Implement Groundwater Banking Projects

Of the alternative water supply projects proposed by IID, the annual cost per acre-foot for projects involving Colorado River water storage ranged from $480 to $1,270. The locations and costs of groundwater storage projects in IID are shown in **Table 2, IID Groundwater Banking Project Alternatives**.

Table 2, IID Groundwater Banking Project Alternatives

Project Location	Cost per Acre-Foot[1,2]	Volume of Water Produced Annually (Thousand Acre-feet)	Beneficial Use for Water
Coachella Valley Water District (No Desalinization)[3]	**$ 266**	50	Agriculture, Municipal, Industrial and Commercial
East Brawley[3]	$ 480	25	Agriculture
East Mesa[3]	$ 513	25	Agriculture, Geothermal
Keystone[3]	$ 590	50	Agriculture
Keystone[3]	$ 625	50	Municipal, Industrial and Commercial
East Brawley[3]	$ 659	25	Municipal, Industrial and Commercial
Keystone[4]	$ 1,270	25	Agriculture

Source: Imperial Irrigation District. 2012. Imperial Integrated Regional Water Management Plan. October. Prepared by GEI Consultants, Inc.
1 Based on May 2009 price level, 4% interest rate, and a 30-year project life (IID 2012)
2 Assumes Storage of 15000 - 25000 Acre-Feet/Year
3 Assumes deep well injection for brine disposal.
4 Assumes evaporation ponds for brine disposal

The cost per acre-foot differs across projects for a variety of reasons. For example, evaporation ponds were costlier than deep well injection as a method for brine disposal. The end use of the water drives costs of treatment as well. Water that is used for agricultural irrigation, for instance, does not require as much treatment as water used for municipal supply. In addition, the high temperatures associated with groundwater in the East Mesa can damage the membranes used in the reverse osmosis process. Therefore, groundwater must be cooled prior to processing, which increases energy requirements, and therefore costs. Finally, IID considered costs of constructing and operating water distribution to various end users (IID 2012).

If groundwater banking occurred in a location off-site Coachella Valley Water District, IID estimated that the cost per acre-foot per year would be $266. The cost is subject to negotiations with CVWD (IID 2012). The reason for the reduced cost is that Coachella Valley Water District does not have high salinity in its groundwater and therefore, desalinization is not required. As highlighted in the lower cost for this alternative, desalinization of brackish groundwater is the main reason for higher costs of groundwater banking in IID.

The costs-benefit analysis of the groundwater storage projects conducted by IID was conceptual and could not account for certain risks associated with uncertain conditions. Risks that would increase costs include unpredictability in the hydrogeologic conditions, hindrances to well pumping (such as clogging in wells), and variability in the performance of the desalinization plants to meet water quality objectives (Maliva 2014). Another key risk for the groundwater banking success is the availability of Colorado River underrun water for storage. If underruns do not occur, the groundwater projects proposed would not be viable options as extraction would occur at higher rates than recharge. This would lead to overdraft of the groundwater basin, and would conflict with state and local laws governing groundwater extraction.

Costs for Reducing Demands

The groundwater banking projects proposed by IID are intended to supplement water supply to meet future projected demands. Specifically, given historic water use by agriculture and the projected increase in demand associated with municipal, industrial and commercial growth in IID, overruns are expected to occur. Under the Inadvertent Overrun and Payback Policy, IID is required to implement extraordinary conservation measures in order to compensate for overruns. Existing programs in IID that meet the definition of “extraordinary conservation measures” include land fallowing and the On-Farm Efficiency Conservation Plan. These programs each require voluntary participation by farmers to either fallow land or implement irrigation efficiency practices that reduce water us. The cost per acre-foot for the land fallowing program ranged from $60 per acre-foot in 2004 to $175 per acre-foot in 2015. For the On-Farm Efficiency Conservation Program, IID pays property owners up to $285 per acre-foot of water conserved. For both programs, the costs paid by IID to participants are established by the IID Board of Directors each year.

Fallowing Program

Based on the water budget for fallowing under the Quantification Settlement Agreement, IID is expected to save 1,500,000 acre-feet of water through the 2003-2017 period of time. Since implementation of the fallowing program in IID through 2015, 248,046 acres of fields have been fallowed, and $124.6 million has been paid by IID to participants. 1,479,311 acre-feet of water has been saved as a result of the program (IID 2014). 21,689 acres are left to save through completion of the program. Based on the 2015 payment rate of $175/acre-foot, payments from IID to participants are anticipated to be $3,795,575 from 2015 to 2017. The total amount paid to participants is projected to be $*128,395,575*.

The fallowing program also has direct and indirect economic impacts on the local economy while fields are taken out of production. As a result of negotiations from the Quantification Settlement Agreement, IID established a fund to mitigate for economic impacts from fallowing over the 15-year period. IID assigned a “Local Entity” to provide grants totaling $50 million to fund projects that promote the local economy. Based on the amount paid by IID to farmers to fallow fields, plus the cost to implement the mitigation program, the total cost per acre-foot of water saved under the fallowing program is $119.

After 2017, the mitigation water diversion to the Salton Sea will no longer be required under the Quantification Settlement Agreement. While IID does not currently plan to implement a fallowing program after the expiration date, given that fallowing is an option for water reduction as an extraordinary conservation measure, fallowing could be implemented in the future to mitigate for inadvertent overruns.

On-Farm Crop Efficiency Program

Agricultural productivity is not purely a function of the amount of water applied. While irrigation practices can be linked to the type of crop being produced, individual farmers can vary widely in water application. In short, while irrigation is required for crop production, overall agricultural productivity can remain constant while use of irrigation water decreases on average (Hanneman 2003).

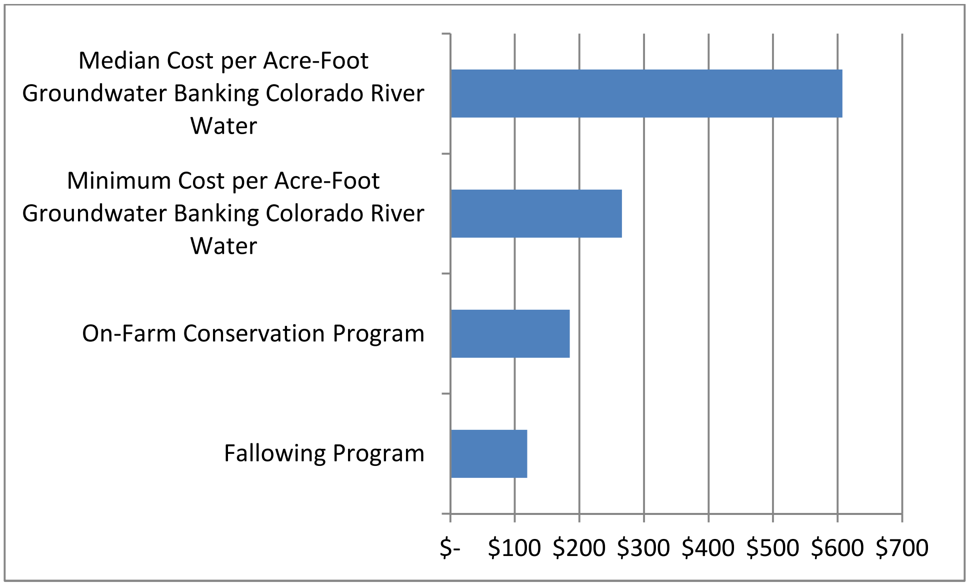
The On-Farm Crop Efficiency Program pays farmers to use water more efficiently through a range of acceptable measures. In order for farmers to qualify for the program, an irrigation efficiency measure must be applied to reduce water use without decreasing crop production. The efficiency is measured in the amount of tailwater (irrigation runoff) reduced, compared to historic irrigation runoff. Since crop productivity will remain constant while water use is reduced, there would be no direct changes to the local economy associated with the program.

Various conservation measures allowable under the program are described briefly below. Costs associated with these measures can vary, and would be implemented by the individual farmers, and not IID. To the extent these require investments by farmers in local labor and in physical improvements, the irrigation efficiency improvements could have a short-term positive impact on the local economy.

- Irrigation Scheduling is the practice of adjusting water orders and deliveries to maximize infiltration and decrease the amount of tailwater before irrigating. Event Management is the practice of managing orders after irrigation has begun to minimize water used.
- Tailwater Recovery Systems with Extended Delivery is a system that captures tailwater for reuse, and extends the timing for delivery to minimize the amount of excess tailwater released.
- Pressurized, Drip and Sprinkler Irrigation are irrigation systems intended to minimize evapotranspiration of water (IID 2013).

As shown in **Figure 5, Groundwater Supply Projects Compared to Demand Reduction Scenarios,** due to the costs associated with desalinization, the median cost per acre-foot is much higher than groundwater banking in Coachella Valley, where the groundwater is not brackish. Even considering the local economic burden of fallowing fields, the costs for IID to implement land fallowing to reduce water demands are significantly lower than the costs for a groundwater bank. Moreover, costs associated with improving irrigation efficiency are significantly less compared to the median price of groundwater banking with desalinization in IID.

Figure 5, Groundwater Supply Projects Compared to Demand Reduction Scenarios



Economic Benefits based on Previous Optimization Studies

While the local economy of Imperial County primarily relies on agricultural production, the value of agricultural production is small in comparison with other industries in California. The cost of water for agricultural users is typically significantly lower than costs for municipalities. This is because municipal users tend to have a higher willingness to pay for water compared to agricultural users (Culp et al. 2014). The following analysis addresses how groundwater storage projects effect costs for water during droughts, based on a regional economic analysis for Southern California.

Pulido-Velazquez et al. used an economic optimization model to evaluate the economic values for conjunctive uses of water, including groundwater banking, in southern California. The authors used the CALVIN hydroeconomic model, which incorporates predictions about the hydrologic cycle based on historic patterns of drought in California between 1922 and 1993. The model includes physical inputs to the system, including the major water supplies (Colorado River aqueduct, State Water Project aqueduct) and storage facilities. The baseline for the model incorporates urban and agricultural water demands and identifies constraints to water transfers including institutional, and physical.

The authors identified existing and potential groundwater storage locations throughout Southern California, including several potential groundwater storage locations along the Colorado River Aqueduct. The storage locations identified were groundwater basins in the Palo Verde Irrigation District, which is another senior [3] water rights holder for Colorado River water. The model results include projected annual scarcity costs for water users throughout southern California, total storage capacity for groundwater and surface supplies in the region, and the marginal value for expanding groundwater storage in the region (Pulido-Velazquez 2004).

Due to the reliability of supplies from the Colorado River, agricultural users in Southern California currently do not have high scarcity costs (Pulido-Velazquez 2004). The model assumed that transfers from agricultural to urban areas could occur without constraint. According to the Pulido-Velazquez (2004) model, if groundwater storage capacity increases throughout the region, there are overall economic benefits and water scarcity costs for the region would decrease overall. However, the study found that implementation of groundwater storage increased scarcity costs for agricultural users. Based on the above, even though the practice of groundwater storage increases overall economic efficiency for the southern California region, agricultural users who rely on Colorado River water would not benefit (Pulido-Velazquez 2004).

As noted above, one key constraint of the model is that it assumed unencumbered transfers from agricultural to urban areas. In reality, water transfers require physical conveyance capacity, evaluation for compliance with the California Environmental Quality Act, and are subject to legal barriers as well. Based on then the Pulido-Velazquez et al. (2004) study, assuming there is an open market allowing for trade between IID and urban areas of San Diego and Los Angeles, the IID's groundwater banking projects are unlikely to result in lower water

[3] Under the Seven-Party Agreement for Apportionments and Priorities, Palo Verde Irrigation District has first priority access to Colorado River water for irrigating 104,500 acres of land. It has seniority to Imperial Irrigation District, which has priority 3a.

scarcity costs for its farmers because the cost of water for them is already low. Even with the existing barriers to trade in place, water scarcity costs are unlikely to be affected by the groundwater banking projects because the volume of water that can be produced each year (19,000 acre-feet to 55,000 acre-feet) represents less than 2 percent of supply demanded by agriculture each year (2.8 MAF).

In general, the marginal willingness to pay for water is much higher for urban users than for agricultural users (Pulido-Velazquez et al. 2004). Therefore, IID would likely benefit more from reducing its water use for agricultural production and selling more water to the urban areas of San Diego and Los Angeles, rather than invest in groundwater banking projects that may not even reduce its scarcity costs.

4.2 Environmental Sustainability

The following section will discuss environmental impacts associated with the IID's groundwater banking projects. The analysis will first discuss water quality impacts that could result directly from the desalinization proposed by IID. Next, ecosystem resulting from diverting and storing Colorado River water underruns will be addressed. Thirdly, energy demands will be evaluated in terms of environmental impacts. These effects will be compared against demand reduction scenarios.

Water Quality

Colorado River water is already high in salinity by the time it has reached Imperial Dam. After water has reached Imperial Dam, upstream agricultural runoff has already contributed significant levels of salts. The groundwater banking projects that involve desalinization would be capable of treating water to meet the needs of end users. The availability of this technology could improve the quality of water sent to the IID distribution system. Furthermore, injection of freshwater from Colorado River has the potential to improve local aquifer water quality. Even though the aquifers contain brackish water, it is possible to store and recover fresh water supplies, depending on site specific conditions (Megdal et al. 2014). Brine would be injected in the deep subsurface aquifer that is already high in salinity and total dissolved solids. In short, the brine injected would not worsen the quality of water in the deep aquifer.

The availability of water storage from groundwater banking could enable IID to continue inefficient irrigation practices, to some extent. Under the current irrigation regime, water from IID is collected through the subsurface tailwater system and conveyed to the Salton Sea. The Salton Sea is fed entirely by irrigation runoff from IID and Coachella Valley Water District. As additional irrigation efficiency programs are implemented, less water will be conveyed to the Salton Sea. Furthermore, application of lower volumes of irrigation water results in less water to leach soil. This results in increased salinity for the lower volumes of water entering the tailwater system. High salinity tailwater contributes to hypersaline conditions in the Salton Sea, and leads to fish and bird kills (Carrillo-Guerrero et al. 2013).

Overall, since desalinization is a component of the groundwater banking projects in IID, and the supplemental supply would facilitate continuation of existing irrigation practices, the groundwater projects have positive impacts related to water quality. In contrast, reducing demand for water by implementing efficient agricultural practices will result in worsening already poor water quality in the Salton Sea.

Water Flow Ecosystem Impacts

Instream Flows

Instream flows are a critical component of the Colorado River ecosystem. Habitat for fish and wildlife is dependent on flow levels that are allowed to pass through the various diversions along the Colorado River. In the Colorado River, instream flow rights have been secured to benefit habitat for aquatic and riparian species. The Bureau of Reclamation implements the Lower Colorado River Multi-Species Conservation Program in order to protect habitat for federally endangered species within the lower basin of the Colorado River. The program establishes minimum flow rates for water flowing between each of the lower basin dams that can result from water transfers. The program provides metrics and thresholds for federal actions that could result in water diversions or other changes in water use that could impact federally endangered species (Bureau of Reclamation 2012). The Program does not govern aquatic and riparian habitat south of the U.S.-Mexico International Border.

Once water has flowed past Imperial Dam and crosses the border, water is diverted to Mexican users through the Morelos Diversion Dam. This is the point at which the 1.5 MAF allotment to Mexico is tracked. Historically, flows to support the Colorado River Delta, south of Morelos Dam were incidental to mismanagement of water supplies upstream, and were unintentional. While Mexico is allotted 1.5 MAF, much of the water that reaches the region is unmanaged. This water includes releases from upstream reservoirs from flood events, return flows from agricultural irrigation[4], and water that is diverted for irrigation, but are not applied to fields (Glenn et al. 2013). Furthermore, once water reaches Mexico, deliveries are made to supply agricultural production and urban supply from the Morelos Dam and surface flows do not always extend to the Gulf of California. Since 1960, there have been long periods (1960-1980, 1997-2010), where moderate to zero fresh water has reached the Gulf of California (Glenn et al. 2013).

The Colorado River Delta comprises the southern extent of the Colorado River, as it enters the Gulf of Mexico. The Delta is currently approximately 150,000 acres, and supports a range of riparian and wetland habitats of international significance (Wheeler et al. 2007). Specifically, the lower portion of the Colorado River Delta is part of a biosphere reserve, and a component of the UNESCO World Heritage Natural Property (Glenn et al. 2013). Currently, the volume of freshwater required to restore the Colorado River Delta ecosystem functions is unknown (Glenn et al. 2013). Wheeler et al. (2007) estimated that 50,000 acre-feet of instream flows would be needed to restore riparian habitat and wetlands. In addition, higher flow rates associated with floods amounting to 260,000 acre-feet, could also positively impact the ecosystem function of the delta (Wheeler et al. 2007). A pilot program was created by Minute 319 to provide supplemental water to support the Colorado River Delta ecosystem. As part of this pilot, 52,696 acre-feet of water would be sent on an annual basis as part of instream flows. In addition, 105,392 acre-feet will be released at one time to mimic flood flows. The program pilot is scheduled to begin in 2016 (Tarlock 2015).

[4] IID return flows do not reach the Colorado River and instead drain towards the Salton Sea.

The implementation of the groundwater banking projects by IID would incrementally increase its use of Colorado River water. IID would store 15,000 to 250,000 acre-feet each year during which underruns occur. This represents an increase in managed flows of Colorado River water, which has contributed to the decline of the Colorado River Delta in the past. The projects would take a similar volume of water out of the river as would be needed for the Colorado River Delta restoration pilot programs. This reduction in incidental flows would contribute to species declines south of Imperial Dam, and would contribute to the loss of Colorado River Delta ecosystems. The loss of delta ecosystem functionality includes losses to migratory bird habitat, marine fisheries, and multiple estuarine and marine species. The many unique attributes of the ecosystems supported by Colorado River flows will need to be considered by up-stream water managers.

Salton Sea

Since the Salton Sea relies solely on irrigation runoff, implementing irrigation efficiencies would contribute to the decline of Salton Sea water levels (Carrillo-Guerrero et al. 2013). In conjunction with reduced irrigation runoff, weather patterns under climate change scenarios are predicted to be hotter, and will result in more evapotranspiration of Salton Sea water. Decline of water levels in the Salton Sea is predicted to result in significant impacts from dust emissions. Particulate matter levels in the Salton Sea Air Basin are already poor, and are expected to worsen as more of the lakebed is exposed. Particulate matter is linked to human respiratory diseases, as well as a decline in agricultural production (Cohen 2014).

Based on these factors, implementation of groundwater banking projects that facilitate continuation of existing irrigation practices would be more beneficial for the Salton Sea, in comparison with the alternative of implementing demand efficiency projects.

Energy Demands

The groundwater banking projects conceived for IID would require significant amount of energy, most likely in the form of electricity. Energy is required to pump groundwater from wells, recharge water in an aquifer, distribute water, and supply the desalinization processes.

In general, the energy requirements for desalinization depend on the amount of salt removed from the water, and the temperature for source water.

Groundwater banking projects that utilize desalinization are brackish water desalination between 1,000 kilowatt hour per acre-foot (kWh/af) and 2,700 kWh/af (California Department of Water Resources 2013). Desalinization in Imperial Valley would also require groundwater cooling in order to avoid damaging the reverse osmosis membranes (IID 2012). The requirement to reduce temperatures would incrementally increase demands for electricity. In comparison with desalinization facilities, the energy requirements for standard drinking water treatment facilities range from 50 kWh/af to 650 kWh/af for treating drinking water (California Department of Water Resources 2013).

Energy requirements for groundwater pumping varies based on the depth of groundwater, and the efficiency of pumps (Cohen 2007). For groundwater that is shallower, pumping does not require as much energy as groundwater that is deeper below ground surface. In California, groundwater pumping ranges between 292 kwh/af and 740 kwh/af (Cohen 2007). In summary, the combination of recharging and pumping groundwater, cooling the water, and treating it in RO facilities will directly require more energy in compared to most treated water.

Overall, the energy required for reducing irrigation demands is much lower than energy required for groundwater recharge, pumps and desalinization. Water delivered from the Colorado River to California users requires less than 250 kWh/af on average. Improved irrigation efficiency often requires installation of new drip-irrigation devices and technologies that enable better irrigation scheduling. These new technologies can increase energy demands. However, with less water applied, overall energy demands for irrigation typically decreases (California Energy Commission 2005).

Energy intensity is closely linked to climate change because fossil fuels comprise a large proportion of energy supplies. IID energy supplies are typically hydroelectric, and geothermal, which do not emit high levels of greenhouse gases compared to burning fossil fuels like coal. However, to the extent that the electricity is part of an overall grid, energy intensity is important to evaluate. Moreover, given potential severe droughts associated with climate change, these impacts should be considered by IID.

4.3 Water Security

The security of IID's water supply lies in its legal entitlement to Colorado River Water. As described in the **Law of the River**, and under the most recent agreements (Quantification Settlement Agreement), IID is entitled to 20 percent of the entire Colorado River water allocation for the United States. The seniority of IID's water rights has been well established and upheld in multiple Supreme Court Cases. Nonetheless, there are external entities, such as tribes, who could challenge IIDs seniority for water rights. Furthermore, based on the Minute 319 and other negotiations between Non-Governmental Organizations, US and Mexico, environmental flows will be considered south of the border in the future, which are likely to influence policy decisions for water allocation upstream in the future.

IID is only required to reduce its intake during a severe drought, when Lake Mead levels are at risk of declining below 1,000 feet. Nonetheless, given mounting concern for water scarcity throughout the southwest, there is a chance that IID could be forced to reduce its water entitlement further in the future. As noted in the **Background** section above, climate change models predict a high likelihood for severe droughts lasting more than 15 years, with deficits up to 60 MAF.

IID worked with farmers and other stakeholders to create an Equitable Distribution Plan, which establishes how to fairly allocate water to farmers within IID when there are curtailments in place. However, with a severe drought such as one predicted above, there is a potential for severe restrictions to agricultural production, the volume of water provided by a groundwater bank would not assist farmers because there would not be enough water in storage. Even if the entire capacity of the groundwater basin could be used, comprising of 1 MAF, this would not be sufficient to sustain agricultural production for over 15 years.

As described in the **Background** above, the State of Arizona manages groundwater recharge in order to store Colorado River water entitlements. The Arizona Water Banking Authority banks approximately 50 percent of its 2.8 MAF entitlement of Colorado River water each year, and accounts for any extractions of the water. The Arizona Water Banking Authority exemplifies how groundwater banking can be used to meet water security needs because it was designed to meet supply requirements for a severe drought. However, Megdal et al. (2014) note that the success for the Arizona groundwater banking program relies on legislative support at the state level, as well as clearly identified groundwater entitlements. As noted in the **Background** section, California groundwater legislation has only recently been implemented, and the focus is on groundwater aquifers that are at risk for overdraft, and does not address managed aquifers.

IID's objective to "optimize and sustain use of Colorado River entitlements through development of groundwater banking and storage projects" supports an overall objective to improve its water security. In light of anticipated increasing demand for water in conjunction with climate change and potential for drought, groundwater aquifers present an opportunity to provide some storage capacity that IID currently lacks entirely. However, unlike the Arizona groundwater projects that are banking water for use during droughts, routine withdrawals from IID's groundwater banking projects would be expected. For a variety of physical requirements in IID and economic restrictions, once the desalinization facility is installed, it would need to be used routinely.

The groundwater banking projects for IID would most likely be planned to support agricultural production as the locations where they are most feasible are adjacent to distribution canals for irrigation. In that the groundwater banks would not provide sufficient supplies to support agricultural production during severe droughts, they do not meet water security objectives for IID. By comparison, the Arizona Water Banking project is designed to meet municipal demands during a severe drought, and is not intended to support agricultural production. Policy makers in the future will need to weigh the equitable use of water in the future, and determine if residential uses are more or less important than agricultural production.

With respect to meeting water security needs, reducing demand for irrigated water for IID would save as much water as the groundwater banks would supplement. The Equitable

Distribution Plan was established by IID in response to the Quantification Settlement Agreement, and the Inadvertent Overrun and Payback Policy. The Plan also highlights the potential for IID to significantly increase its water use efficiency to achieve similar agricultural production. However, under a severe drought scenario, even reducing water demands for agricultural production may not be sufficient for the current agricultural production in IID to continue.

5.0 Conclusion and Recommendations

In summary, the groundwater banking projects conceived by IID are costly, result in negative impacts related to energy demands, and potential negative ecological impacts related to instream flows. The alternative solution for IID in which agricultural water demands are reduced would be less costly up front, and would be less detrimental to the downstream Colorado River Delta. However, the indirect ecological impacts to the Salton Sea from reducing irrigation demands will contribute to cumulative long-term air quality impacts associated with loss of the Salton Sea.

There are constraints for developing groundwater banking projects within IID due to the high salinity and temperatures, among other factors evaluated in this paper. Alternatives outside IID could meet water security objectives while avoiding high energy and costs associated with the projects currently proposed. Specifically, Colorado River water could be stored in the Coachella Valley Water District groundwater bank, without requiring desalinization. Based on existing data, this alternative is less costly than most IID groundwater banking projects due to the lack of salinity constraints. On the other hand, as the groundwater banking project would still require incrementally increasing Colorado River water imports, the alternative would still contribute to adverse environmental impacts described in this report.

While IID did not identify this area for groundwater banking projects, the Ocotillo/Coyote Wells Subbasin area is currently pumped at unsustainable rates yet no surface water deliveries from the Colorado River are supplied to this area because it is far from the irrigated agricultural lands. This aquifer supplies drinking water supplies, and does not require desalinization. A number of recent laws are likely to inform IID's water management decisions regarding this basin. Specifically, the recent groundwater legislation requires management of unsustainable groundwater pumping and groundwater basins that are in overdraft will need to have a plan for how to restore the aquifers to sustainable levels. Given that the Ocotillo/Coyote Wells Subbasin is at risk, IID should prioritize groundwater management solutions in this area over the groundwater projects that require desalinization.

In the economic analysis in this report, I find that reducing demands for water is less costly when compared to groundwater banking projects. Future economic analysis could provide more in-depth analysis of groundwater banking projects, focusing on its role in the overall water market. For instance, with current physical and legal constraints, water trades that involve transferring water from IID to urban areas do not occur frequently. In addition, indirect and direct socioeconomic impacts to IID and to any users affected by IID's water use should be evaluated. Finally, future economic analyses should also incorporate the Colorado River Delta and Salton Sea ecosystem services that could be affected by water management decisions for IID. These recommendations could be incorporated in hydro-economic models to predict how water policy decisions influence the scarcity cost of water.

In that IID already has senior entitlements to Colorado River water, and uses roughly one third of the entire allocated supply for the United States, the incremental increase of water use from groundwater storage may not seem necessary. However, given potential long-term droughts projected under some of the hydrological models for Colorado River, groundwater banks are expected to provide much-needed water in times of scarcity. The issue lies in how water from the groundwater bank would be used during times of severe drought. Future policy analyses regarding groundwater storage projects should address short-term and long-term beneficial uses under various drought scenarios.

The IID's use of more Colorado River water than it currently uses highlights concerns related to the over-allocation of the river's supply. The analysis in this paper discusses how an incremental increase in withdrawing Colorado River water may result in ecosystem impacts downstream, in the Colorado River Delta in Mexico. These impacts should be evaluated further if IID proposes to bank Colorado River water. Furthermore, the recent treaty signed by the U.S. and Mexico highlights the need for the U.S. to consider how its use of the Colorado River results in ecosystem impacts in Mexico. IID and other U.S. water agencies should evaluate impacts to regions across the U.S.-Mexico border. Alternatively, while Salton Sea restoration plans have not been finalized, future policies may discourage efficient irrigation practices in order to sustain that ecosystem.

This report calls attention to the complicated nature of decisions related to future water supply and demand reduction projects for IID. The groundwater banking project requires a large up-front investment in infrastructure due to the necessity for both wells and desalinization. This "hard path" approach represents a technological solution to the water security problem. The soft path approach to water management suggests that water managers should explore how the needs of all users can be met without implementing large infrastructure projects. Note that the environmental sustainability metrics serve to evaluate groundwater banking projects for IID in general. For any individual project proposed, an in-depth analysis would capture direct and indirect environmental effects related to ecosystems, water demands and energy demands. In addition, a number of environmental factors that warrant further study include hydrological feasibility for groundwater banks, and water quality concerns related to disposal of brine water.

The intent of this study was to provide a framework for evaluating future groundwater banking projects in IID, as well as to determine if groundwater banking projects make sense for IID to implement. The soft-path approach to decision making requires water managers to evaluate alternatives to increasing water supplies and infrastructure. In this study, I compared groundwater banking with demand reductions from irrigation efficiency. While not discussed in this analysis, it should be noted that IID is exploring solutions other than groundwater storage. For instance, IID has evaluated recycling facilities to supply water for its municipal, commercial and industrial users. Future analyses should focus on how recycled water facilities could offset the potential increase in water demands related to the growth in municipal, commercial and industrial sectors, or even supplement water supplies to support agricultural production.

While not in the scope of this report, there are many important equity concerns related to farmers' water entitlements. Under a severe drought scenario when water imports were minimal, would the agricultural industry in IID persist, or would farmers attempt to relocate to other regions with more plentiful water supplies? Furthermore, even without scarcity, farmers use a significant portion of water supplies to grow food supplies, including crops that are exported to other states and countries. Meanwhile, urban areas receive a small portion of the overall water supply portfolio. In addition, questions about farmers' entitlement to water raise further questions about types of crops that farmers choose to grow, and how water policies could inform what food is grown by the agricultural industry. While there are no policies in place that govern crop selection in IID, more research could be done related to identifying crops that use less water and prohibiting production of thirstier crops. These questions warrant further exploration.

On the whole, due to the increased use of Colorado River water and the requirement to remove salt from the groundwater, IID's plans to implement groundwater banking projects are not favorable based on the metrics described in this report. I do not recommend that IID develop any projects that incrementally increase use of Colorado River water, or that involve desalinization.

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