

OPPORTUNITIES AND CHALLENGES FOR ARIZONA

The studies described above identify the potential imbalance between available water supplies and projected demands which could limit Arizona's future economic growth if no actions are taken. Consequently, the economic future of this State, and the region, is dependent on a resource for which legal and physical complexities need to be taken into consideration and addressed.

Complexities Affecting Long-Term Water Use and Planning

Arizona is characterized by widely diverse geographic regions, ranging from forested mountain areas to arid deserts. These areas have dissimilar climates and precipitation regimes, resulting in variability in, and accessibility to, surface water supplies. Arizona is also geologically complex, which impacts the availability, quality and accessibility of groundwater supplies. Areas of water demand are also unevenly distributed across the state. Central Arizona exhibits the highest concentration of urban/municipal uses and growth. Much of this use is located on retired irrigated farmlands. Agricultural irrigation is still significant, and is the most prevalent water use sector in the State. It continues to provide a significant benefit to Arizona's economy and serves as the foundation of the local economies in many regions of the State. Important industrial sectors, such as copper mining remain regionally significant water users and economic engines in isolated portions of the State. Portions of the State also remain popular winter-time destinations and golf courses are a prevalent and important economic use throughout the State.

Land Ownership

Arizona is also unique in its land ownership patterns. Less than 18 percent of the land within the State is under private ownership. State Trust Land comprises almost 13 percent of the land, with the remaining 69 percent in either federal or Indian ownership. This variability in land ownership adds additional complexity to the water supply challenges that must be met. These challenges range from the need to appropriately involve tribal entities to ensure that Indian water supplies, demands and water right claims are accurately understood and addressed, and ensuring that the mandates of federal lands are fulfilled. This ownership is also often fragmented, with federal, state, and private land holdings assembled in a "checkerboard" fashion that further complicates the development and execution of comprehensive land and water management strategies.

Additionally, there are possible limitations on the ability to construct and develop water transmission lines across federal and tribal lands. Because 69 percent of the land in Arizona is federally controlled, there is a strong likelihood that a federal nexus will exist, and the requirement for environmental compliance under the National Environmental Policy Act (NEPA) will be triggered. As water supplies are developed and water treatment and delivery infrastructure is designed, it will be important to consider the potential financial impacts of federal environmental compliance requirements. Those impacts could also result in a longer planning horizon to provide time to secure permits or other federal approvals. In most cases, environmental compliance processes include formal public input and the opportunity for third party legal action challenging the final decision of the federal agency issuing the permit or approval. This can increase the lead time for planning and constructing projects and may introduce additional levels of uncertainty in the outcome.

Experience with the planning, design, construction and operation of existing water projects shows that complying with federal requirements can add anywhere from several months to several years to a project. Some compliance programs that may be encountered whenever there is a federal nexus associated with a project include:

- 1) The National Environmental Policy Act of 1969 (NEPA). NEPA became effective on January 1, 1970. In simple terms, it requires that the federal government consider all environmental factors when making a decision on a major federal action. NEPA can result in projects incorporating mitigation measures that avoid, minimize or compensate for potential adverse environmental impacts. The federal agency taking the action is responsible for administering the Act.
- 2) The Endangered Species Act of 1973 (ESA). The ESA became law on December 28, 1973. Generally, the Act protects species from becoming extinct, by prohibiting the take of endangered or threatened species and adverse modification of a species critical habitat. Projects and actions that fall under the umbrella of the ESA may be required to minimize and mitigate negative impacts to species and their habitat to the maximum extent practicable. The ESA is administered by the US Fish and Wildlife Service and the National Oceanic and Atmospheric Administration.
- 3) Section 404 of the Clean Water Act (CWA). Section 404 of the CWA regulates the dredge and fill of materials into waters of the United States. The program to administer it was established in 1972. It is intended to protect aquatic resources and to avoid or lessen degradation of waters of the United States. The permitting process encourages avoidance of impacts and may require minimizing and mitigating impacts to the environment. The program is primarily administered by the US Army Corps of Engineers with additional oversight by the US Environmental Protection Agency.

Arizona Water Law

Another factor in the complexity of developing water supplies is the Arizona water law system under which groundwater and surface water are largely regulated under separate statutes and rules. While the groundwater management system primarily applies inside designated AMAs and INAs, the surface water system (except for Colorado River supplies) is administered statewide. Colorado River supplies are managed in cooperation with the State, but contracts for Colorado River water are initiated through the US Secretary of the Interior and administered by Reclamation. Reclaimed water use is managed under a completely different set of regulations and policies and was significantly influenced by case law³⁶. This legal complexity adds to the challenge of ensuring that adequate supplies exist to meet the demands across the state.

General Stream Adjudication

Adding to the legal complexities within the State are the on-going general stream adjudications of the Gila and Little Colorado river systems. General stream adjudications are judicial proceedings to determine or establish the extent and priority of water rights. Thousands of claimants and water users are joined in these judicial proceedings that will result in the Superior Court issuing a comprehensive

³⁶ Arizona Public Service Co. v. Long, discussed earlier

final decree of water rights for both river systems³⁷. The Gila River adjudication was initiated in 1974 when SRP filed a petition with Arizona State Land Department (ASLD³⁸), before the creation of ADWR, for the adjudication of the Upper Salt River. Thereafter, SRP, Phelps Dodge Corporation (Phelps Dodge), ASARCO and the Buckeye Irrigation Company filed petitions to adjudicate other watersheds within the Gila River Basin. The Gila River Adjudication includes much of the southern half of the state and covers the following seven watersheds: Upper Salt River, Upper and Lower Gila River, Verde River, Agua Fria River, Upper Santa Cruz River, and the San Pedro River.

The Little Colorado River Adjudication began in 1978 when Phelps Dodge filed a petition with the ASLD for the adjudication of water rights within the Little Colorado River system and source. The Little Colorado River Adjudication includes the northeastern part of the state and covers the following three watersheds: Silver Creek and the Upper and Lower Little Colorado River.

The general stream adjudications are comprehensive proceedings, evaluating water uses and claims by both State and federal entities. The State parties include municipalities, mines, utility companies, private water providers, water users' associations, conservation districts, irrigation districts, state agencies and individual water users that rely on water diverted from streams, lakes, springs, stored in reservoirs or stockponds, and withdrawn from wells. Within these proceedings, water rights are also being adjudicated for water uses on Indian reservations and federal lands including military installations, conservation areas, parks and forests, monuments, memorials, and wilderness areas. These water uses may include both surface (non-Colorado River) water and groundwater in certain instances. It is critical that the adjudication move forward in the near future to provide certainty regarding future water supply availability to the various water users throughout these watersheds, particularly during times of drought.

Outstanding Indian Water Rights Claims

While progress on the adjudication process has been complicated by the diversity of water users and the need to resolve preliminary legal issues, the State has made significant progress in reducing uncertainty through execution of Indian Settlements³⁹. However, there are still Indian claims that have yet to be addressed and completion of these settlements is essential to not only provide a secure water supply for tribal communities, but also to provide long-term certainty for all water users in Arizona (*see Table 1*).

³⁷ As of July 2013, there are 83,244 claims in the Gila River Adjudication and 14,522 claims in the Little Colorado River Adjudication.

³⁸ Upon its creation in 1980, ADWR assumed the role of administering surface water rights throughout the State. ASLD performed this function prior to ADWR's establishment.

³⁹ Discussed above in Section II Part III: Arizona's Historical Successes in Water Management, [Resolution of Tribal Water Rights](#).

Table 1. Outstanding Indian Water Rights Claims

Tribe	Potentially Affected Planning Area(s) *See Section 3
Havasupai Tribe	<i>Bill Williams, Verde, Western Plateau and Central Plateau</i>
Hualapai Tribe	<i>Bill Williams, Verde, Western Plateau and Central Plateau</i>
Hopi Tribe	<i>Navajo/Hopi, East Plateau, Central Plateau, Basin & Range AMAs, Colorado Mainstem – North, and Colorado Mainstem – South</i>
Kaibab Paiute Tribe	<i>Arizona Strip</i>
Navajo Nation	<i>Navajo/Hopi, East Plateau, Central Plateau, Basin & Range AMAs, Colorado Mainstem – North, and Colorado Mainstem – South</i>
Pasqua Yaqui Tribe	<i>Basin and Range AMAs</i>
San Carlos Apache Tribe (On-Reservation Gila River tributary claims)	<i>Basin & Range AMAs</i>
San Juan Southern Paiute	<i>Navajo-Hopi</i>
Tohono O’odham	<i>Basin & Range AMAs</i>
Tonto Apache Tribe	<i>Roosevelt and Basin & Range AMAs</i>
Yavapai Apache Nation	<i>Verde and Basin & Range AMAs</i>

Land Subsidence

Land subsidence occurs when groundwater has been withdrawn from certain types of aquifers, such as those containing fine-grained sediments, in excess of rates of replenishment. When groundwater is withdrawn from the open pore spaces between the soil particles, the sediments can collapse – causing a lowering of the land surface. In some systems, when large amounts of water are pumped, this can result in a permanent reduction in storage capacity of the local aquifer system. Uneven compaction of the soils overlying aquifer systems can lead to the formation of earth fissures (large cracks). Earth fissures typically form underground and can express themselves on the surface. The impacts of land subsidence include: damage to linear utilities and flood conveyance infrastructure; differential settling of building foundations; earth fissuring; and loss of aquifer storage capacity through compaction. The rate and magnitude of land subsidence is highly variable across the basins in the planning areas and are dependent upon geologic conditions and historical volumes of groundwater withdrawals.

Summary

The diversity, variability and complexity that are unique to Arizona make developing water supply strategies difficult. In some areas, water users have access only to surface water from rivers and streams. In others, they rely solely on groundwater. Other regions have access to both groundwater and surface water, which can be conjunctively managed to provide renewable and redundant supplies for the benefit of local water users. Some areas may have elaborate and far reaching water storage, transmission and delivery systems, while others have limited infrastructure and rely entirely on local wells. Some areas may have already experienced rapid growth and others have not. Some areas of the state have available water supplies in excess of projected demands. In others, the currently developed supplies may not be sufficient to meet projected future demands, although there may be locally available supplies that can be developed in volumes adequate to meet those needs. Absent development of supply acquisition and importation projects, some portions of this arid State will struggle to meet projected water demands with locally available supplies.

Water Supply Development Opportunities

Over the next 20 to 100 years, Arizona will need to identify and develop an additional 900,000 to 3.2 MAF of water supplies to meet its projected demands. While there may be local water supplies that have not yet been developed, water supply acquisition and/or augmentation will be required for some areas of the State to realize their growth potential. Examples of these potential supplies are:

- 1) Non-Indian Agricultural Priority CAP water;
- 2) Reclaimed water/water reuse for which there is not yet delivery or storage infrastructure constructed to put it to direct or indirect use;
- 3) Groundwater in storage;
- 4) Water supplies developed from revised watershed management practices;
- 5) Water supplies developed through weather modification;
- 6) Water supplies developed from large-scale or macro rainwater harvesting/stormwater capture; and
- 7) Direct importation or exchange of new water supplies developed outside of Arizona (e.g., ocean desalination).

1) Non-Indian Agricultural Priority CAP Water

The Arizona Water Settlements Act⁴⁰ (Settlements Act) was enacted on December 10, 2004. The Settlements Act ratified the Arizona Water Settlement Agreement (Agreement) between the United States, ADWR, and CAP and provided for the reallocation of 96,295 acre-feet of Non-Indian Agricultural Priority CAP water (NIA Priority CAP water) for municipal and industrial uses in the State of Arizona.

Both the Settlements Act and the Agreement required the US Secretary of the Interior (Secretary) to reallocate the 96,295 acre-feet of NIA Priority CAP water to ADWR “to be held under contract in trust for further allocation.”⁴¹ Both the Settlements Act and the Agreement also specified that the Director of ADWR shall submit a recommendation for reallocation to the Secretary, and that the Secretary shall carry out all necessary reviews of the proposed reallocation in accordance with applicable federal law⁴². The Agreement further provided that ADWR develop eligibility criteria and make the water available for reallocation “at periodic intervals, starting in 2010⁴³.” On August 22, 2006, the Secretary reallocated the 96,295 acre-feet of NIA Priority CAP water to ADWR acknowledging that “before the water may be further allocated the Director of ADWR shall submit to the Secretary of the Interior a recommendation for reallocation⁴⁴.”

The NIA Priority CAP water has a lower priority than Indian or Municipal and Industrial (M&I) Priority CAP water and is expected to have reduced availability, especially during times when Arizona’s supplies are affected by shortage operations on the Colorado River. ADWR’s analysis of the average availability of this 96,295 acre-feet of NIA Priority CAP water estimates that an average of about 64,000 acre-feet per year will be available over the next 100 years, assuming a moderate development schedule on the mainstem of the Colorado River. This availability is expected to reduce to an average of about 58,000

⁴⁰ Public Law 108-451

⁴¹ Settlements Act § 104(a)(2)(A); see also Agreement Paragraphs 3.1 and 9.3.1.

⁴² Settlements Act § 104(a)(2)(C); see also Agreement Paragraph 9.3.4. The Department has traditionally provided recommendations of allocations of CAP water to the Secretary, consistent with its authority in A.R.S. § 45-107.

⁴³ Agreement Paragraph 9.3.4.

⁴⁴ *Notice of Modification to the Secretary of the Interior’s Record of Decision, Publication of a Final Decision of CAP Water Reallocation*, 71 Fed. Reg. 50449, 50451 (Aug. 25, 2006).

acre-feet per year over the 100-year period after 2030 due to projected increases in use for all Colorado River water users. This means that over the next 100 years in some years this NIA water supply will be fully available, some years it will be partially available, and some years it will not be available at all. Recipients of this water will need alternate water supplies and the necessary infrastructure to use those alternate water supplies in order to meet future firm demands in years of reduced or no availability of this NIA Priority CAP water.

ADWR has divided the full reallocation volume of 96,295 acre-feet into three pools and the water will be reallocated in a tiered process, with phases starting in 2013, 2021 and, if there is any remaining water, in 2030. ADWR has initiated the reallocation process for the first pool, in the amount of 46,629 acre-feet of NIA Priority CAP water, within the three-county CAP service area (Maricopa, Pinal and Pima counties). The Director of ADWR will submit a recommendation for allocation of this volume to the Secretary by December 31, 2013. The second pool of NIA Priority CAP water (17,333 acre-feet) will be offered to water users inside of the three county CAP service area in 2021. The third pool of NIA Priority CAP water (17,333 acre-feet) will be offered to water users located outside of the three county CAP service area, also beginning in 2021.

2) Reclaimed Water/Water Reuse

Substantial volumes of reclaimed water are utilized today through underground storage and recovery and through direct use to non-potable uses such as landscaping and turf irrigation. ADWR has projected additional volumes of reclaimed water that can be generated by future populations⁴⁵. Along the Colorado River, water users can receive return flow credits for discharge of reclaimed water back to the River, allowing them to divert above their entitlement by the volume of return flows. The current volume of reclaimed water supplies available to meet demands is over 500,000 acre-feet. In 2035, the estimated volume of reclaimed water that can be generated is approximately 745,000 acre-feet. In 2060, the volume is estimated at approximately 935,000 acre-feet and in the year 2110 the volume is estimated to be approximately 1.3 MAF.

Reclaimed water supplies are potentially available to partially offset the projected imbalances throughout the State. Significant investments will need to be made to put this water to use and to overcome the public perception associated with direct potable reuse of this supply. By using this supply more effectively, the future imbalances can be reduced by nearly 50 percent to 155,000 acre-feet in 2035 and 1.9 MAF in 2110. In addition to reducing a community's possible water supply imbalance, expanding a community's sewer collection and treatment system to customers who are dependent on septic systems can also protect local water quality.

The volumes stated above are based on production from municipal wastewater systems. Other sources of water reuse include: 1) in home grey water reuse systems, which recycle water from uses such as washing machines and dishwashers for outdoor landscape watering or toilet flushing and 2) industrial wastewater.

⁴⁵ These projections were conservatively derived by holding the current percentage of the population that is connected to a sewer system in each groundwater basin constant and applying a constant reclaimed water generation factor to the projected population.

3) Groundwater

ADWR estimates that the groundwater currently in aquifer storage within the State to a depth of 1,000 to 1,200 feet below land surface (or bedrock, whichever is higher) is just over 1.2 billion acre-feet⁴⁶. If this groundwater were fully accessible and was utilized through 2110, without regard to the negative impacts of pumping that supply to those depths, the 100-year annual volume available would be 12.5 MAF. While at face value this would solve the water supply challenges facing Arizona, the available groundwater is not always located in the areas that have the greatest projected demands and depletion of this resource is not in the best interest of the State. For example, the adjusted estimated groundwater in aquifer storage in the Little Colorado Plateau Groundwater Basin is over 760 MAF (7.6 MAF annually for 100 years) while the projected demand in that basin in the year 2110 ranges from 300,000 to 400,000 acre-feet. Additionally, much of the groundwater basin underlays Indian reservation lands and is not likely available for off-Reservation uses.

In some areas of the State (e.g., Buckeye and Yuma), successful agricultural practices require leaching of salts from the soil profile and drainage of shallow groundwater to depths below crop root zones. This is accomplished through an extensive gravity drainage system and operation of dewatering wells, which discharge or dispose of this "brackish groundwater," typically to nearby rivers. Capture, treatment and direct use of this locally available resource can serve to augment local water supplies reducing demands on other groundwater supplies or can be transported to other areas as needed. Highly saline brine will be a by-product of the treatment required to reuse this supply. Development of a cost-effective brine disposal method will greatly enhance the viability of this supply augmentation alternative.

The potential for negative consequences associated with groundwater mining (withdrawing water from groundwater storage in excess of the rate of replenishment) is the primary reason for not relying on groundwater to meet all future water needs. These may include but are not limited to:

- Declining groundwater tables;
- Dewatering of certain areas of the basin;
- Declining well yields;
- Increased pumping depths and cost;
- Land subsidence and earth fissuring;
- Diminished water availability to water dependent natural resources; and
- Deterioration of water quality and the costs associated with treating that water.

Developing a regional analysis of the sustainable or optimal yield from Arizona's groundwater basins would provide water managers with information necessary to determine the long-term security associated with local reliance on groundwater supplies to meet current and projected water demands.

4) Watershed Management

Increasing water yields through vegetation management may be a viable option for water management for on-site or off-site uses. Vegetation management does not have to occur through extreme measures, such as clear-cutting (either wholesale clearing or type conversion), but can include strategies to decrease interception and evapotranspiration in upland areas outside of the riparian zone by reducing the numbers of trees and shrubs and replacing those species with plants that use less water, such as

⁴⁶ Arizona Department of Water Resources

native grasses. Existing soils, topography, precipitation and vegetation types are important elements in the effectiveness of this practice and will affect the timing and magnitude of potential water yields and required management practices essential to maintaining the benefits. Cost also must be weighed in determining whether to initiate and maintain such a program. The value of the water yield has to be compared to the other societal uses of the land. However, finding projects that have mutual benefits compatible with other natural resource objectives, such as increased livestock forage, recreational opportunities and reduced risks and costs of associated with wildfires may offset these costs.

Table 2. Compilation of Water Yield Data From Experiments in Arizona

(Source: *Water Yield Improvement by Vegetation Management*, Ffolliott and Thorud, 1977 & *Arizona Forest Resource Assessment- Arizona State Forestry Division*, 2013)

Vegetative Zone	Experimental Location	Water Yield Increase	Acreage of Traditional Forest Types in AZ	Studied Management Practice
Mixed Conifer Forests	Workman Creek – North Fork	No Change	450,221 acres	Removal of riparian vegetation
	Workman Creek – North Fork	0.10 ac-ft/ac/yr		Conversion of 1/3 rd of watershed, specifically moist-site vegetation immediately adjacent to stream channel
	Workman Creek – North Fork	0.45 ac-ft/ac/yr		Conversion of 1/3 rd of water watershed, specifically the dry-site vegetation immed.adjacent to the moist-site conversion.
	Workman Creek – South Fork	No Change		Individual tree selection cut
	Workman Creek – South Fork	0.50 ac-ft/ac/yr		Subsequent uniform thinning of areas dominated by Ponderosa pine, and after areas dominated by Douglas-fir and White fir were cleared
Ponderosa Pine Forests	West Fork of Castle Creek	0.05ac-ft/ac/yr	4,043,854 acres	Clearing 1/6 th of the overstory, with the remaining 5/6 ^{ths} subject to thinning treatment
	Beaver Creek	0.20 ac-ft/ac/yr		Clearing 1/3 rd of the forest overstory in uniform strips on Watershed 9 and irregular strips on Watershed 12
	Beaver Creek	0.15 ac-ft/ac/yr		Thinning of forestry overstory by group selection on Watershed 17
Pinyon-Juniper Woodlands	Beaver Creek	0.04ac-ft/ac/yr	13,420,572 acres	Aerial application of herbicides on Watershed 3
		Minimal increases		Mechanical conversion

Watershed management strategies have been explored and used in Arizona and across the West for decades to increase yields in localized settings. At a larger scale, Arizona’s forests are an integral part of the watershed management strategy in this State. The Tonto National Forest, which owes its existence to the construction of Roosevelt Dam, was created in 1905 to protect the watersheds of the Salt and

Verde Rivers and, according to its web site, continues to be a central focus of the Forest⁴⁷. Additionally, the Apache-Sitgreaves National Forests⁴⁸ include the health and restoration of the watersheds as one of their management concerns, and the Prescott National Forest⁴⁹ manages its watershed for the purpose of protecting the Agua Fria and Verde Rivers.

In the early 1960s, the Arizona Watershed Program was initiated to research integrated watershed management techniques for the purpose of increasing water yield. The program was a joint effort of the ASLD, working with the USDA Forest Service and other government agencies and cooperators. This effort was instrumental in many of the historic experimental research projects in Arizona, some exhibiting potentially promising results. The results of many of these projects were summarized in a report, *Water Yield Improvement by Vegetation Management* (Ffolliott and Thorud, 1977). The report presented the available information from experiments conducted in Arizona on water yield improvement for eight different vegetative zones. Those results are summarized above in Table 2.

ADWR recognizes that these studies are dated. New information is being developed through private and governmental organizations and should be part of the on-going analysis within Arizona to identify possible areas of focus. Combining efforts with other management initiatives (such as the Four Forest Restoration Initiative) may be a cost-effective way to advance this option and provide multiple benefits. The Four Forest Restoration Initiative (4FRI) is a collaborative effort to restore forest ecosystems on portions of four National Forests - Coconino, Kaibab, Apache-Sitgreaves, and Tonto - along the Mogollon Rim in northern Arizona. The vision of 4FRI is restored forest ecosystems that support natural fire regimes, functioning populations of native plants and animals, and forests that pose little threat of destructive wildfire to thriving forest communities, as well as support sustainable forest industries that strengthen local economies while conserving natural resources and aesthetic values⁵⁰. Future plans, through the 4FRI effort, for landscape scale restoration activities in Arizona's national forests have the potential to increase water yield and overall forest health.

Another area that may have promise for increasing water yields is Tamarisk removal⁵¹. Tamarisk, commonly known as salt cedar, is a non-native shrub or tree that was introduced into the US in the 19th Century. During the Great Depression in the 1930s, tamarisk was used as a tool to fight soil erosion in the Great Plains. Tamarisks are very prolific and displace native vegetation and animals, alter soil salinity, and increase fire frequency⁵². Tamarisk is an aggressive competitor for water supplies and often develops into monoculture stands, which can negatively impact native vegetative communities. In Arizona, Tamarisk has colonized into dense stands along many water courses, altering flow regimes and reducing downstream flows. Measures to control the growth of, or eradicate, tamarisk have been attempted for the purpose of reducing vegetative water consumption, improving habitat conditions, and improving river system function. Maintaining the benefits of these measures has proven difficult, but may have promise in selection regions of the State.

⁴⁷ <http://www.fs.usda.gov/tonto>

⁴⁸ <http://www.fs.usda.gov/asnf>

⁴⁹ <http://www.fs.usda.gov/prescott>

⁵⁰ <http://www.4fri.org/>

⁵¹ Other areas vegetation manipulation should also be explored, such as mesquite encroachment, but we are focusing on tamarisk in this report.

⁵² <http://www.nps.gov/grca/naturescience/exotic-tamarisk.htm>

The ability to employ watershed management practices is becoming significantly more constrained due, in part, to environmental concerns. Areas that appear to have potential for water yield improvement will also need to be evaluated not only for the vegetative, physiographic and climate potential but also social, institutional and economic factors.

5) Weather Modification

Weather modification (cloud seeding) is the application of scientific technology that can enhance a cloud's ability to produce precipitation. The technique was developed in the 1940's using small particles of dry ice and converting water droplets existing at temperatures lower than freezing (supercooled) to ice crystals. There are two types of projects that are being conducted today in parts of the US: 1) projects that increase snowpack (cold rain) and 2) projects that increase localized precipitation for range and croplands (warm rain).

The process is based on enhancing the natural formation of precipitation in the atmosphere. As wind pushes moist air over rising terrain, the rising air cools and water droplets are then formed through condensation, resulting in the formation of orographic clouds. The clouds consist of small droplets that, despite below-freezing temperatures, remain liquid. The water's purity and the lack of foreign particles in the atmosphere prevent the droplets from freezing, forming supercooled clouds. As temperatures decrease further, the droplets form ice crystals around small atmospheric particles such as dust (known as "condensation nuclei").

Cloud seeding introduces additional particles or nuclei into the atmosphere, causing more ice crystals to form. Silver iodide compounds and dry ice are the most common cloud seeding agents. Aircraft or ground-based generators are used to introduce the agents into the atmosphere. As the ice particles grow, they attract nearby water vapor and droplets, growing larger and heavier. These enlarged ice particles eventually fall as snow.

Cloud seeding experiments originally were focused largely on cumulus clouds, the most common, widely distributed cloud form, and the world's most important precipitation source. The short life span and instability of cumulus clouds complicated seeding operations. Orographic clouds, which form as air masses are forced over mountainous areas, are preferable for seeding as they typically last longer and are more predictable, allowing for more easily controlled weather modification experiments. Orographic clouds are the source of both rain and snow. In the mid-latitudes, nearly all precipitation begins as snow but, if it is much warmer than freezing below the cloud base, the snow melts and reaches the ground as rain. Freezing temperatures are required for crystallization to occur with the seeding material or agent. As a result, snow is the expected product of cloud seeding.

The West provides favorable conditions for weather modification as the mountainous terrain is generally favorable to the forming of orographic clouds. Additionally, it is an area of water scarcity, with the dependable flows of its natural streams typically fully appropriated. Therefore, the natural conditions and water supply needs suggest suitability for weather modification activities. With a large proportion of its area arid or semiarid, Arizona can be expected to benefit by weather modification, certainly to a greater extent than less arid states in the Nation.

SRP conducted some of the earliest cloud seeding operations in Arizona. During the 1950s, a time of drought in Arizona, SRP set up a series of ground-based seeders on its 13,000-square-mile watershed.

The operations relied on air masses to lift propane-burned silver iodide for seeding. SRP also contracted for aerial seeding during the 1950s and 1960s. These early efforts were suspended when drought conditions eased.

Reclamation released a study in 1974 that described the potential of weather modification to increase water resources in the region. The study estimated the average annual water augmentation potential in the Upper Colorado Basin to be about 1.4 MAF, with 300,000 acre-feet in the Lower Basin and 500,000 in adjacent basins. Most of the 300,000 acre-foot Lower-Basin yield would come from Arizona watersheds. The study found that an additional 300,000 acre-feet could be delivered to Arizona via the Central Arizona Project. The study estimated the cost of generating this new runoff to be about \$2 to \$5 per acre foot (1974 dollars- \$9.50 to \$23.75, adjusted to 2013 with CPI).

The Mogollon Rim, in central Arizona, has been identified as offering the greatest potential for in-state weather modification efforts⁵³. Stretching from northwest to southeast, the Rim forms a physical barrier that forces flowing air upward to cool, a situation favorable to orographic cloud development. According to the Arizona Water Resources Research Center, about 40 percent of the water for central and northern Arizona falls as winter precipitation over this area and drains north into the Little Colorado River and south to the Verde and Salt River systems. Thus, according to the Research Center, it provides an ideal opportunity for weather modification experimentation and research.

While studies continue, weather modification still remains somewhat scientifically uncertain and raises legal and public policy concerns in need of resolution, such as:

- How is it determined that precipitation was in fact the result of weather modification?
- How is the amount of new water to be quantified for credit and distribution?
- On what basis is the new water induced by weather modification to be allocated among water users?
- How can those who pay for the weather modification be assured that they will in fact receive their share of the new water?

Also not to be neglected are the possible unintended consequences resulting from weather modification (storm damage and flooding liability). Environmental studies would also be required to determine the effects of cloud seeding. Computer modeling is capable of contributing to this effort.

Weather modification may have potential to increase water supplies in Arizona. However, studies are needed to identify areas with potential, and practical public policies must be developed to address the legal and public policy concerns to benefit and protect Arizona water users and landowners.

6) Water Transfers

There are established laws, policies and procedures for transfers of groundwater, Colorado River water and in-state surface water. They are designed to protect local interests and other water users and water right holders in the system. These protections make water transfers difficult to execute and would likely limit their utility in addressing future water supply imbalances. In other

⁵³ <https://wrrc.arizona.edu/publications/arroyo-newsletter/weather-modification-water-resource-strategy-be-researched-tested-tri>

words, transfers that are possible *under existing law* may be a helpful limited tool to enhance water supplies under the right cooperative conditions, but it is clear this is not the mechanism for dealing with more comprehensive enhancement needs around the state.

Moving water from one area of Arizona to another has the potential to create controversies, especially if the area from which the water is being transferred has existing water uses and economies built on that water supply. However, such transfers have already been accomplished in limited cases and are subject to regulation aimed at protecting local economies and water users.

The Arizona State Legislature passed the Groundwater Transportation Act in 1991, prohibiting most transfers of groundwater. The law was passed in response to some of the larger cities in Maricopa and Pima counties purchasing large farms in other areas of the State to augment their water supplies. The restrictions imposed by the Transportation Act are intended to protect hydrologically distinct groundwater supplies and the economies in rural areas by ensuring the groundwater is not depleted in one groundwater basin to benefit another. The law does, however, recognize pre-existing investments in water transfers and allows for the following limited, exceptions to these restrictions, under specific statutory conditions that are unique to each exception:

- 1) Butler Valley Groundwater Basin to an initial AMA;
- 2) Harquahala Irrigation Non-Expansion Area to an initial AMA;
- 3) McMullen Valley Groundwater Basin to an adjacent initial AMA;
- 4) Big Chino Sub-Basin of the Verde River Groundwater Basin to an adjacent initial AMA;
- 5) Yuma Groundwater Basin;
- 6) Little Colorado River Plateau Groundwater Basin (under very limited conditions); and
- 7) Parker Groundwater Basin (under very limited conditions).

A transfer of a Colorado River water entitlement or allocation must be approved by the Secretary. State statute authorizes the Director of ADWR to consult, advise and cooperate with the Secretary in contracting for the delivery of water from the Colorado River⁵⁴. State statute also requires that a person proposing to transfer a Colorado River entitlement or allocation cooperate and obtain the advice of the Director of ADWR⁵⁵. ADWR has adopted a substantive policy statement that establishes the procedures that must be followed and criteria that must be met for the Director to recommend approval of a proposed Colorado River water transfer. Importantly, this process requires the input of stakeholders who may be impacted by these transfers. This input is designed to ensure that all impacts are evaluated prior to removing these water supplies from the region of origin and is an integral component of ADWR's Transfer Policy and, if conditions are met, its recommendation to the Secretary⁵⁶.

Transfers of in-state surface water (non-Colorado River water) are also allowed under specific conditions set forth in State statute⁵⁷. Generally, these types of transfers are limited to the same river system and do not involve trans-basin transfers. State law allows water to be transferred to another location on the river system but, depending on the type of use and location, the transferred supply may not retain the same water right priority date, which can limit its viability as a source for large-scale transfers.

⁵⁴ A.R.S. §45-107(A)

⁵⁵ A.R.S. §45-107(D)

⁵⁶ <http://www.azwater.gov/azdwr/Legal/LawsRulesPolicies/documents/CR7.pdf>

⁵⁷ A.R.S. §45-172

The role of water transfers for long-term water management strategies must be evaluated on a case-by-case basis. While certain transfers may have minimal impacts, others may not only impact local economies, but also operations of nearby and downstream irrigation districts, environmental and recreational needs, the operation of intra-state rivers for hydroelectric power, water quality, and international treaty obligations. Depending on the source of water, using transfers for long-term water supplies must take into account the long-term availability of the water supply that is subject to the transfer request, the reliance of the local area on that water supply, and the impacts to other water users in that system. In areas where the availability of the water to be transferred is limited, short-term and/or dry year options may be more suitable and beneficial to the communities.

There are established laws, policies and procedures for transfers of groundwater, Colorado River water and interstate surface water. They are designed to protect local interests and other water users and water right holders in the system. These protections make water right transfers difficult to execute and may limit their utility in addressing future water supply imbalances.

7) Large-Scale(Macro) Rainwater Harvesting/Stormwater Capture

The practice of rainwater harvesting dates back to the earliest days of civilization and refers to the technology for capturing, storing and using rainwater. This can be accomplished on a small-scale at a single residence, intercepting the precipitation that falls on impervious areas around the home or from rooftops and diverting it to cisterns or barrels for on-site uses such as landscape watering. In Arizona, rainwater harvesting is encouraged at the residential level as a water conservation best management practice and is a common, voluntarily employed, practice across the State. Some Arizona water providers offer incentives for their customers to invest in and utilize this technique. For example, Tucson Water has a program that will rebate qualifying residential rainwater harvesting systems costs up to a maximum of \$2,000⁵⁸.

Larger-scale techniques for the capture of rainwater or stormwater can be used for residential subdivisions, commercial developments, industrial sites, parking lots, roads and highways. While these types of projects can utilize commercially available equipment, they can also be accomplished through design of facilities and grading land surfaces to slow down flows and enhance infiltration into the aquifer, thereby creating the potential to enhance natural aquifer recharge. Large-scale stormwater capture and recharge is managed through ADEQ's Arizona Pollution Discharge Elimination System (AzPDES) permitting process and supports compliance with ADEQ's best management practices for stormwater management.

While, stormwater capture and infiltration enhancement projects exist in Arizona, proposals to obtain underground storage credits through ADWR's Underground Storage and Recovery Program have added a new dimension to this activity. Typically, rainwater or stormwater either infiltrates into the ground, ultimately replenishing local aquifers, or flows over the land surface to rivers, streams or other surface water management systems or impoundments. Water that infiltrates into the aquifer is considered a benefit to the aquifer, the environment, and all users in that system. Allowing individual entities to accrue underground storage credits for this water would require significant monitoring of localized storm events, accounting and administration. Additionally, there are concerns from some water rights

⁵⁸ For more information see <http://cms3.tucsonaz.gov/water/rwh-rebate>.

holders that inhibiting flows that otherwise would have entered the surface water system may reduce their water availability. To address these issues, the Arizona Legislature passed House Bill 2363 in 2012 establishing a Joint Legislative Study Committee on Macro-Harvested Water to evaluate the issues arising from the collection and recovery of large-scale harvested water. The process to evaluate these projects will be important in determining whether or not the projects can result in significantly enhancing water supplies beyond what is currently available for future uses, and whether those local benefits can be earmarked for specific parties. Pilot projects are currently being developed to analyze this activity in the Upper San Pedro Basin in Cochise County.

8) Importation of New Water Supplies

While Arizona has local options available to meet its near-term water supply challenges, there still may be a need to explore and acquire water supplies from outside of the State. Water supply augmentation from outside Arizona will be challenging and, most likely, more costly than the in-State options. In the public discussions following the release of the Basin Study, options for importation of water supplies were generally dismissed as less desirable than local conservation and reuse.

Unfortunately for Arizona, the significant strides that have already been made in the area of conservation and reuse have been ignored by external parties perhaps due to lack of understanding of the magnitude of Arizona's efforts. While Arizona has significant potential to reduce the future imbalances using reclaimed water, and to some extent the other options described above, there may remain an imbalance between future demands and available supplies that needs to be addressed. Given the long lead time that will be required, addressing this need cannot be pushed off into the future. Acquiring and developing imported water supplies could be an exponentially more difficult task than it was to bring Colorado River water to Central Arizona through authorization of the CAP, as the supplies will likely be derived from outside the State. Several other states are in the same, or nearly the same, position as Arizona, but do not share the challenge of having a significant portion of its entitlement as the junior priority on the Colorado River. If we take a wait-and-see approach to pursuing these options, we will certainly be at a disadvantage, as other states and municipal water suppliers are actively exploring similar options. If we are choosing to pursue economic expansion, for the future of Arizona, we must begin today to actively explore opportunities to expand our water supplies to meet those needs.

The pursuit of similar opportunities by entities outside of Arizona presents both potential competition and opportunities for cooperation. Arizona has and shall maintain its stalwart protection of our Colorado River supplies. We have been able to do that while maintaining a spirit of cooperation and collaboration with our fellow Basin States and representatives of Mexico. We continue to work to solidify those relationships and can expand on those relationships to explore importation opportunities from outside the State.

Options for importation of water supplies are limited because of the distance from the supplies and in some cases, the local demands on those supplies in the area of origin. Additionally, the cost-effectiveness of developing these options (acquiring, transmission, energy and maintenance) further limits the practical application of utilizing such supplies. Some of the importation alternatives identified in the Basin Study include trans-basin importation of Mississippi River water to the Lower Basin; importation of Missouri River water to the Upper Basin; and ocean desalination. Of all the options identified in the Basin Study, seawater desalination may be the most cost-effective and politically viable

importation option available to Arizona. Desalination refers to any of several processes that remove some amount of salt and other minerals from saline water to produce fresh water suitable for human consumption or irrigation.

The cost of desalinating sea water (including the infrastructure, energy and maintenance) is generally higher than obtaining fresh water from rivers or aquifers, reusing reclaimed water, or employing water conservation practices. Options for acquiring and delivering this supply vary based on the anticipated location of delivery within the State and the ability to develop agreements with neighboring states or Mexico. Table 3, below, identifies several desalinating options identified in the Basin Study. Obviously, among the Basin States, the state of California has access to the nearest US supply of ocean water. California is a partner in the Colorado River Basin and has significant needs for dependable water supplies into the future. Arizona can explore options for exchanging California's Colorado River water entitlement for use in Arizona for the construction and operation of desalination plants on the Pacific coast of California. This option is only likely to be possible if a mutually beneficial arrangement can be struck between Arizona and California. California already has access to large volumes of seawater and currently has no incentive to share its Colorado River entitlement. Thus, while monetary incentive may present an option, it is still uncertain if California would be a willing cooperator. Exploration of this option would require significant time and effort but, if viable, could provide a mechanism to address Arizona and Nevada's needs.

Table 3. Desalination Options Identified in the Colorado River Basin Supply and Demand Study

Option Type	Option Category	Representative Option	Estimated Cost (\$/AF)	Years Before Available	Potential Yield by 2035 (AFY)	Potential Yield by 2060 (AFY)
Increase Supply	Desalination	Gulf of California	2,100	20 - 30	200,000	1,200,000
		Pacific Ocean in California	1,850 – 2,100	20 - 25	200,000	600,000
		Pacific Ocean in Mexico	1,500	15	56,000	56,000
		Salton Sea Drainwater	1,000	15 – 25	200,000	500,000
		Groundwater in Southern California	750	10	20,000	20,000
		Groundwater near Yuma, AZ	600	10	100,000	100,000
		Subtotal				776,000

Source: Reclamation, 2012

Mexico is at the end of the Colorado River system and has an annual entitlement of 1.5 MAF. Two options are available for entering into an agreement for desalination with Mexico, but would require significant capital investment and negotiations through the State Department. First, capital investment in Mexico to construct a desalination plant for Mexico on either the Sea of Cortez or the Pacific Ocean could provide Arizona with an opportunity to exchange Mexico's Colorado River entitlement for desalinated ocean water. Depending on the volume and location of delivery, this option would also

require additional transmission capacity from the Colorado River to the location of use if the volume exchanged exceeds the current CAP canal capacity, as well as a source of energy to desalinate and deliver that supply to areas in Mexico. Secondly, cooperating with Mexico on the construction of a facility on the Sea of Cortez and directly transporting that water into Arizona (and along the pipeline route in Mexico) for use would provide water to an area of need. Both of these options would require significant capital investment for construction, energy development and transmission.

To provide a general sense of the cost for a desalination project, the San Diego County Water Authority has proposed construction of the 54 million gallons per day (MGD) Carlsbad Desalination Facility (approximately 60,000 acre-feet per year) and 10 miles of 54-inch transmission line. Capital costs for the project are approximately \$700 million. The annual operating costs for the facility are estimated at approximately \$50 million, with 50 percent of that cost for the energy production needed to operate the facility to produce and deliver drinking water. The cost to the ratepayers is (including capital repayment, operation and maintenance) is about \$2,329/acre-foot (\$7.14/1,000 gals)⁵⁹.

A more local study analyzed a desalination plant located on the Sea of Cortez, just northeast of the central part of Puerto Peñasco and delivery of the water above Imperial Dam, north of Yuma, Arizona⁶⁰. The study assumed that desalinated water conveyed to Imperial Dam could then be used to displace Colorado River water and exchanged to users in Arizona, and possibly other partnering states, which would then divert the additional Colorado River water through their existing, expanded, or new infrastructure (possibly requiring additional costs). A regional scenario that included a 1.07 Billion Gallon per Day (1.2 MAF) treatment facility and a 143-mile open canal conveyance structure was estimated to cost approximately \$1,183/acre-foot (\$3.63/1,000gallons), not including 500 MW energy production capacity requirement for this scenario. Replacing the open canal conveyance structure with a closed pipe system could provide more supply security but could also add as much as \$4.47/1000 gallons to the overall cost. In comparison, the current rate for M&I water delivered to Phoenix through the CAP canal is approximately \$0.45/1,000 gallons before treatment and approximately \$5.00/1,000 gallons after treatment, depending on location and treatment technology. It is interesting to note that the cost of that same volume of water from commercial bottled water is approximately \$12,736/1,000 gallons.

It is also important to note that an entity proposing a project in Mexico would need to consider supplying security to protect the project from possible terrorism, and would also need to consider environmental impacts, including disposal of the by-products of the desalination project, both of which could add to the cost.

⁵⁹ http://www.sdcwa.org/sites/default/files/files/board/2012_presentations/presentations_2012_06_14.pdf

⁶⁰ Investigation of Binational Desalination for the Benefit of Arizona, United States, and Sonora, Mexico – Final Report, June 5, 2009, HDR Engineering