West Salt River Valley Basin Study

Final Report

U.S. Department of the Interior **West Valley Water Association** **February 2023**

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The mission of the West Valley Water Association is to develop a cost effective, quality water supply; engage in water resource planning and management; and develop regional partnerships for water in the West Valley.

West Salt River Valley Basin Study

Final Report

February 2023

prepared by

Bureau of Reclamation
Lower Colorado Basin
Phoenix Area Office

West Valley Water Association

West Valley Water

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Acronyms and Abbreviations

A.A.C.	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
AF	acre-feet (1 AF = 43,560 cubic feet = 325,851 gallons)
AF/y	acre-feet per year
AMA	Active Management Area
AMWUA	Arizona Municipal Water Users Association
ARS	Arizona Revised Statutes
ASU	Arizona State University
AWBA	Arizona Water Banking Authority
AWS	Assured Water Supply
Basin Study	West Salt River Basin Study
BCSD	bias-correction and spatial downscaling
BT	benefit transfer
BWh	hot desert climate (in the Köppen climate classification system)
BWLA	Buckeye Waterlogged Area
CAGRD	Central Arizona Groundwater Replenishment District
CAP	Central Arizona Project
CAP:SAM	Central Arizona Project Service Area Model
CASS	Central Arizona Salinity Study
CAWCD	Central Arizona Water Conservation District
CAWS	Certificate of Assured Water Supply
CMIP Phases 3 & 5	Coupled Model Intercomparison Project Climate Projections
CPI	Consumer Price Index
CS	consumer surplus
D&S	Directives and Standards
DCP	Drought Contingency Pla
DPR	Direct Potable Reuse
EPA	United States Environmental Protection Agency
ESRV	East Salt River Valley
GDP	Gross Domestic Product
GFR	Grandfathered Rights
GIS	Geographic Information System
GMA	Groundwater Management Act (1980)
GPCD	gallons per capita per day
GPHUD	gallons per housing unit per day
GSF	Groundwater Savings Facility
GSP	Gross State Product
HD	hot-dry (climate)
HDe	ensemble informed hybrid delta method
HW	hot-wet (climate)
HUC6	six-digit Hydrologic Unit Code
HUC8	eight-digit Hydrologic Unit Code
ICS	Intentionally Created Surplus

ID	Irrigation District
IGFR	Irrigated Grandfathered Groundwater Rights
IMPLAN	Impact Analysis for Planning
INA	Irrigation Non-expansion Area
KAF	thousand acre-feet
LAU	Lower Alluvial Unit
LID	low impact development
LTSC	Long Term Storage Credits
M&I	Municipal and Industrial
MAF	million acre-feet
MAF/y	million acre-feet per year
MAU	Middle Alluvial Unit
MUSF	Managed Underground Storage Facilities
MWD	Maricopa Water District
NEPA	National Environmental Policy Act
NGO	Non-Governmental Organization
NIA	Non-Indian Agriculture
NIWR	Net irrigation water requirement
OM&R	Operations, Maintenance, and Replacement
PCE	tetrachloroethylene
P.L.	Public Law
RCP	Representative Concentration Pathways
Reclamation	United States Department of the Interior, Bureau of Reclamation
RID	Roosevelt Irrigation District
SAC-SMA	Sacramento Soil Moisture Accounting Algorithm
SROG	Sub Regional Operating Group
SRP	Salt River Project
SRV	Salt River Valley
TCE	trichloroethylene
TDS	total dissolved solids
TM	Technical Memorandum
UAU	Upper Alluvial Unit
U.S.	United States
USF	Underground Storage Facilities
USGS	United States Geological Survey
VIC	Variable Infiltration Capacity model
WaterSMART	Sustain and Manage America's Resources for Tomorrow program
WCDD	(Buckeye) Water Conservation and Drainage District
WESTCAPS	West Valley Central Arizona Project Subcontractors
WQARF	Arizona Water Quality Assurance Revolving Fund
WRDC	Water Resources Development Commission
WRRC	Water Resources Research Center (University of Arizona)
WSRV	West Salt River Valley
WSRVGFM	West Salt River Valley Groundwater Flow Model
WVWA	West Valley Water Association
WW	Warm-wet (climate)

WWTP	Wastewater Treatment Plant
YDP	Yuma Desalting Plant

Executive Summary

Introduction

The West Salt River Valley Basin Study was initiated by Reclamation and the West Valley Water Association (WVWA) to provide information to help guide future water-resource-management priorities and investment within the western Phoenix metropolitan area. The WVWA is an association of nine municipalities, three private water companies, two irrigation districts, the Salt River Project (SRP), and several interested parties dedicated to working together for a secure water future. The participants regularly shared data, organization plans, challenges, and ideas throughout the course of the study. The working relationships developed and expanded during the study are a foundation for avoiding conflict and enabling additional collaboration among WVWA members, Reclamation, and other interested parties.

The study was conducted to examine the challenges and opportunities related to water supply and demand imbalances within a portion of the Phoenix, Arizona, metropolitan area. This area is one of the most rapidly growing urban areas in the United States where water demand is expected to increase over time, and water supplies are finite. The study area is in the western portion of the Phoenix metropolitan area (Figure ES-1).

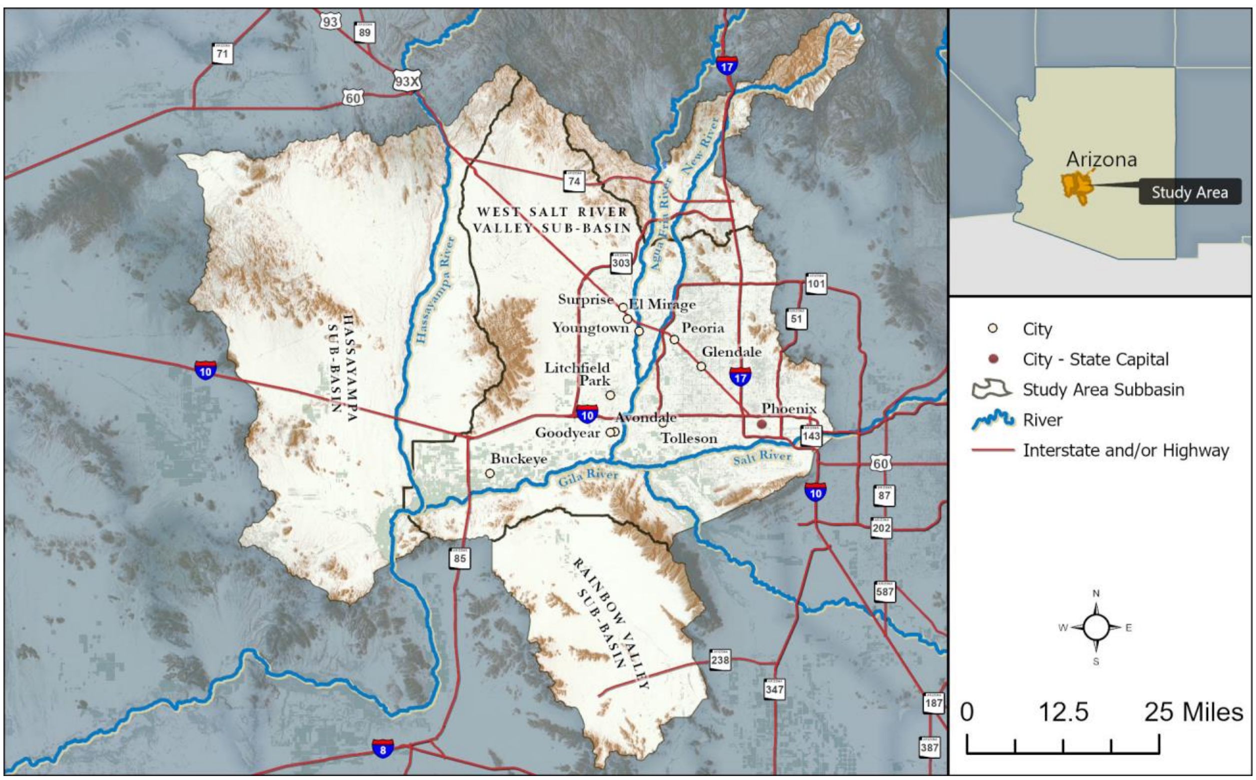

Figure ES-1: Study area

Anticipated challenges for the study area include potential impediments to maintaining reliable water supplies while meeting demand, regulatory requirements, and management goals. Supplies in the study area are groundwater, surface water, and treated wastewater (effluent).

Water supply challenges include the amount, location, management, and quality of groundwater; the current and future reliability of renewable surface water supplies (e.g., Colorado River water); and utilization of effluent. Climate change and drought impacts will likely exacerbate these pressures by altering temperature and precipitation patterns and amounts.

Water demand challenges relate to housing development, industrial growth, agriculture use and retirement, environmental uses, and demand management. The location and timing of demand, and supply availability, will impact infrastructure and operational needs and opportunities. This study follows Basin Study Program guidelines to describe and evaluate strategies to address these challenges.

Summary of Key Findings

- The study area will require additional renewable water supplies to meet growth projections. The amount of new water needed by 2060 in the study area is best expressed as a range because of uncertainty represented by the different scenarios evaluated in this study. The study area as a whole will have a new water supply need (shortage) of between about 47,000 and 260,000 acre-feet per year by the end of the study period in 2060, based on the climate change, supply and demand, and groundwater model analyses conducted as part of this study. The high estimate is based on a hot-dry climate with rapid outward growth.
- Climate change will increase demand and reduce supplies. Key scenarios evaluated in the study included potential reductions in Colorado River water to the Central Arizona Project and other surface water supplies (e.g., reduction to SRP supplies).
- All future supply and demand scenarios that were evaluated with a groundwater model show, to some extent, issues with increasing depths to water in the Hassayampa sub-basin, the north/northeast area of the study area, and in the Rainbow Valley sub-basin (Figure ES-2 and Figure ES-3, below). These areas are particularly vulnerable due to existing significant depths to water, or shallow bedrock, and proximity to the basin edge (basin geometry). Groundwater level impacts shown in the model simulations depend on the characteristics of the supply and demand scenarios. In general, higher growth rate scenarios correlate with greater pumping volumes and commensurate water level declines than in slow and moderate growth scenarios.
- Assessment of adaptation strategies (Table E-1), developed based on potential future need and a set of general goals, showed no single strategy completely bridges the projected gap between demand and supply for 2060 in the hot-dry rapid outward growth scenario (except perhaps *Ocean Desalination*). Therefore, a combination of strategies is required.
- Considering all costs and benefits, a combination of supply-side and demand-side strategies is likely to be optimal for addressing future water shortages in the study area.

- The highest-ranking strategies were *Demand Management* and *Effluent Reuse and Recharge* based on evaluation weighting schemes including economic & financial, environment & sustainability, and social & administrative (see Table ES-2, below).
- To meet the aquifer protection goal, increased use of renewable supplies is needed to offset groundwater pumping impacts.
- Water level impacts and supply shortages could be positively impacted by additional replenishment and full utilization of reclaimed water (effluent).
- With proper maintenance and replacement, infrastructure is currently working to meet demand. However, expansion, upgrades, and new infrastructure will be required in the future.
- The type, location, and extent of new infrastructure depends on factors such as growth patterns and supply sources.
- System interconnects and operation agreements will benefit multiple jurisdictions and provide for flexibility and reliability.
- Regional partnerships, such as the WVWA, are essential for responding to the water resource challenges in the study area.

Methodology and Results

The study approach aligned with the Basin Study Program objectives and study components. The primary tasks included:

- Climate change assessment: Quantifying potential effects of climate change on supplies and demands in the study area.
- Supply and demand analysis: Quantifying a range of potential future water supplies and demands.
- Planning scenario development: Developing a set of planning scenarios that incorporate the climate change and demand and supply results.
- Groundwater model: Constructing a numerical groundwater flow model and using it to investigate effects of the supply and demand scenarios, including a range of climate change effects.
- Description of imbalances: Using climate change, supply and demand, and groundwater model analyses to characterize the location and magnitude of potential future supply and demand imbalances.
- Adaptation strategies: Developing a set of adaptation strategies to reduce the potential imbalances identified in the study.
- Recharge Suitability model: Constructing a recharge suitability model to evaluate and rank potential locations within the study area that could be used for recharge facilities.

- Infrastructure review: Assessing existing and future infrastructure needs and operational opportunities.
- Economic & tradeoff analysis: Conducting an economic and tradeoff analysis to evaluate and rank the adaptation strategies.

The future supply and demand projections were for 2015-2060 and were created using the Central Arizona Water Conservation District's Central Arizona Project Service Area Model (CAP:SAM). The projections were based on the amount and location of growth and associated demand, and availability of various supplies. Reclamation's Technical Service Center (TSC) performed the technical evaluation of potential climate change effects on water availability in the study area. Using the CAP:SAM and TSC data, a set of planning scenarios was created covering a range of potential future conditions including population growth rates and geographic patterns, supply variability, and climate variability. The intent was to create a range of planning scenarios for this Basin Study; they are not predictions of the future.

The scenarios identified potential imbalances in themselves but were also used as input for evaluation with the groundwater flow model. The groundwater flow model was constructed by Matrix New World Engineering, Inc (Southwest Groundwater). It was used to establish baseline conditions, evaluate scenarios, and locate and quantify potential effects of scenarios of future conditions. The groundwater system for each scenario was evaluated, such as groundwater levels, aquifer drawdown amounts, aquifer recharge, and ability of current pumping centers to meet demands.

Based on the results of the models and evaluations, the study partners developed a set of strategies that could be used to adapt to the identified imbalances. The adaptation strategies were assessed, compared, and ranked through a tradeoff analysis performed by the TSC.

Each of the evaluated strategies was screened, at least in part, on its potential to meet planning goals and objectives, and to address future supply and demand imbalances in the study area. Each strategy was considered relative to the amount of water it could provide and other characteristics, such as relative cost; public perception; and environmental, legal, and institutional issues.

The following summarizes the findings for each major study task.

Climate Change Modeling

Climate change modeling for the study period indicates warmer mean annual basin-wide temperatures than the historical (1950-1999) value of 59.3 °F, ranging from an increase of 2.8 to 6.9 °F by 2060. This will result in higher evapotranspiration rates for agricultural crops and other vegetation. Changes in projected mean annual basin-wide precipitation range from -12.9 to +10.0 percent from the historical value of 15.9 inches. Climate modeling data also show that Arizona can expect more extreme weather patterns, bigger floods, and longer, more-severe droughts.

Supply and Demand Analysis

The study indicates the demand for water in the study area will increase over time, and without new supplies, imbalances between renewable supply and demand will also grow. Because of uncertainty represented by the different scenarios evaluated in this study, the amount of new water needed by 2060 is best expressed as a range. The study area providers, as a whole, will have a new water supply need (shortage) of between about 47,000 acre-feet and nearly 260,000 acre-feet per year by the end of the study period in 2060, based on the scenario assumptions. The high estimate for 2060 is based on a hot-dry climate with rapid outward growth with the imbalance growing over time. The low estimate is based on slow compact growth without climate change. The values are based on the CAP:SAM model scenarios and represent the amount of groundwater that would need to be replenished subject to Arizona's Assured and Adequate Water Program rules.

Multiple variables do not allow a direct comparison between the scenarios, but they do demonstrate that 1) hot, dry conditions coupled with aggressive growth lead to the greatest impacts to supplies; 2) historical climate trends, slower more compact growth, and more efficiency/conservation have less of an impact; and 3) growth management is imperative to extending supplies.

Groundwater Model

Groundwater model results show increased groundwater pumping to meet the 2060 demand will lead to water level declines. Those declines vary by location and the amount of pumping associated with each scenario. All scenarios showed an area of drawdown (relatively deep groundwater levels) in 2060 in the northern part of the WSRV, with the greatest amount of drawdown in the northeast part of the study area (Figure ES-2 and Figure ES-3). The hot-dry rapid growth scenario shows the greatest water level declines. The slow compact and average growth scenarios show moderate water level declines regionally and, in some areas, water level rises occurring in areas of large recharge facilities and the BWLA. Modeled hydrographs show accelerated groundwater level declines towards the end of the study period. The decline would likely continue if the model period was extended.

Areas with relatively deep groundwater levels at the end of the study period would result in increased operational costs and other negative effects. Concentrated, ongoing withdrawals from the study area basins have the potential to create problems, such as land subsidence and fissuring, infrastructure damage, declines in water quality, and increased pumping costs. This can be mitigated in several ways, such as identifying alternative water sources so that well pumping can be curtailed in areas with deep groundwater levels.

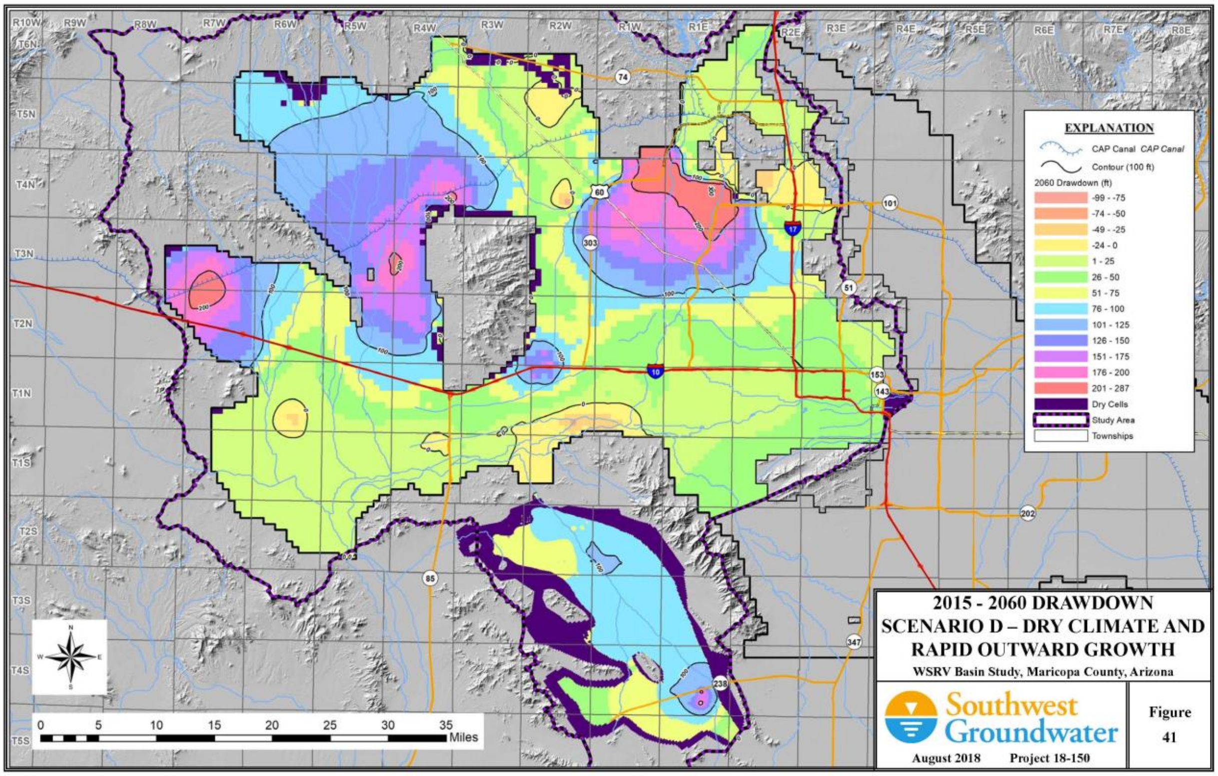

Figure ES-2: 2015-2060 Drawdown Scenario D - Dry Climate with Rapid Outward Growth

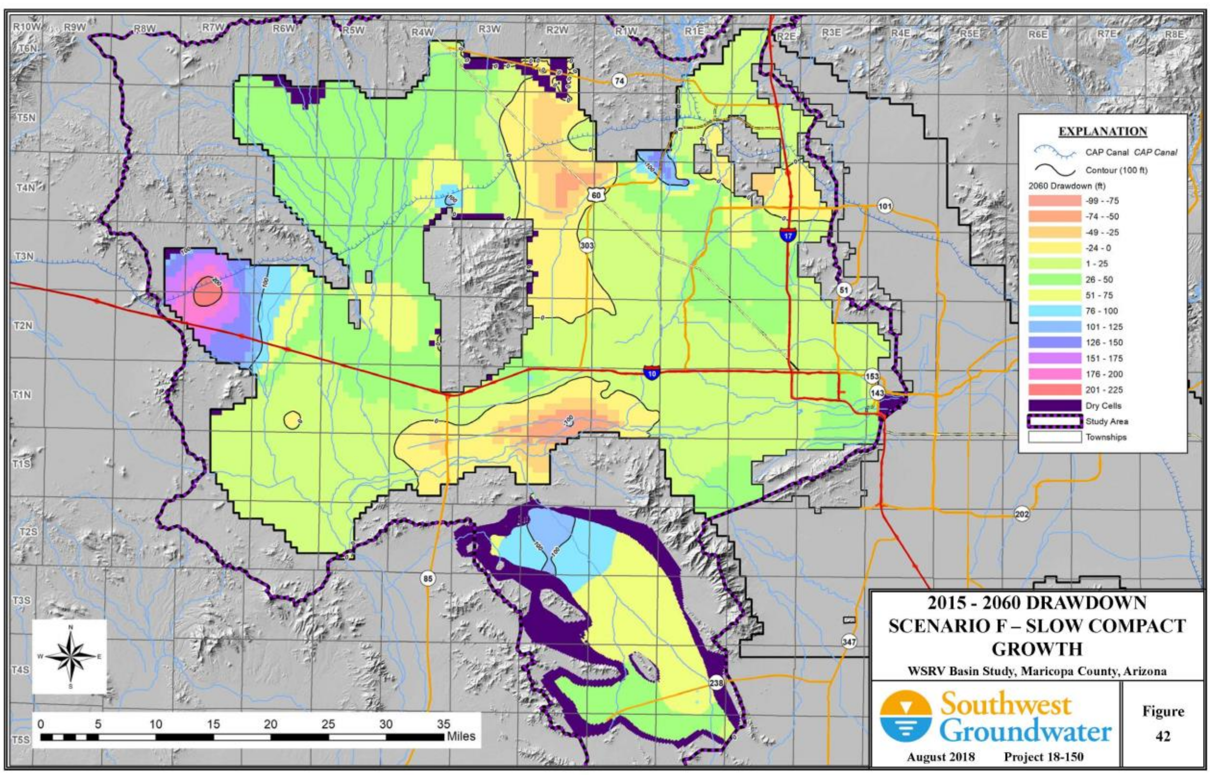

Figure ES-3: 2015-206 Drawdown Scenario F - Slow and Compact Growth

Adaptation Strategies

The study team characterized 21 adaptation strategies and grouped them into a smaller set of 10 final adaptation strategies for evaluation in an economic and trade-off analysis (Table E-1). Most of the strategies analyzed seek to address water shortages through supply-side improvements which increase the availability of water supplies. One exception, *Demand Management*, seeks to decrease the shortage gap through a combination of conservation and efficiency programs that reduce demand.

No single strategy, except perhaps *Ocean Desalination*, completely bridges the projected gap between demand and supply for 2060 in the hot-dry rapid outward growth scenario. Therefore, it appears that a combination of strategies is required to fully meet the projected 2060 demand. Considering all costs and benefits, a combination of supply-side and demand-side strategies is likely to be optimal for addressing future water shortages in the study area.

Increased use of renewable supplies is needed to offset groundwater pumping impacts. Without a renewable supply-based path going forward (individually or collectively), many West Valley water providers will continue to rely on the Central Arizona Groundwater Replenishment District (CAGRD) to replace the limited and variable non-renewable water that each provider pumps and delivers. While this poses challenges because of uncertainty associated with the sustainability of the CAGRD's ability to procure sufficient renewable supplies at affordable costs in the future, an even greater concern may be the reduction of groundwater quantity and quality within service areas.

Table E-1. Final Adaptation Strategies

Adaptation Strategy	Strategy Components
(1) Demand Management	• Efficiency/conservation programs • Low Impact Development (LID) and Stormwater Management (commercial/industrial scale) • Rainwater harvesting (residential scale) • Reducing water loss (M36 water audits) • Smart growth
(2) Regional Effluent – Direct Potable Reuse	• New infrastructure to treat and deliver effluent for direct potable reuse
(3) Regional Effluent - Direct Non-Potable Reuse (purple pipe)	• New infrastructure to treat and deliver effluent for non-potable reuse
(4) Local Effluent Reuse/Recharge Potable or Non-Potable	• Site specific wastewater treatment and reuse/recharge systems at or near the point of wastewater generation (e.g., systems in portions of communities, individual developments, industries)

Adaptation Strategy	Strategy Components
(5) Regional Effluent Recharge	• New Constructed Underground Storage (Recharge) Facilities (USF) • New Managed Underground Storage (Recharge) Facilities (MUSF) – include environmental flows
(6) Poor Quality Groundwater Treatment	• New infrastructure to deliver remediated groundwater (treatment facilities are in place)
(7) Ocean Desalination	• New infrastructure to desalinate and convey ocean water (e.g., pipeline from Sea of Cortez ocean desalination plant)
(8) Inland Desalination / Brackish Water Treatment	• New infrastructure to desalinate and convey water from inland sources (e.g., Yuma Desalting Plant) • New infrastructure to desalinate and deliver brackish groundwater (need a treatment facility) (e.g., BWLA, Yuma Mesa Mound, and Gila Bend Basin)
(9) Groundwater Transactions/ Exchanges	• New groundwater remarketers • Transactions with agricultural sector for infrastructure improvements that save groundwater • New interbasin groundwater transfers
(10) Surface Water Transactions/ Leases/ Exchanges	• New leases of surface water from Tribes • New surface water remarketers (e.g., private-sector water development companies) • New agricultural sector fallowing deals for surface water • New trade agreements with SRP or CAP for surface water

Infrastructure Analysis

All potential strategies to adapt to the projections of less water and more demand have infrastructure requirements, except for some forms of demand management (e.g., conservation).

With appropriate staffing, maintenance, and replacement, the existing water and power systems are currently working to meet demand, but over time, significant upgrades and new infrastructure will be required. However, existing infrastructure is not always meeting demand in a sustainable way. For example, as discussed in the Anticipated Future Challenges section of this report, there is presently a lack of surface water delivery infrastructure. While renewable supplies and groundwater pumping might be balanced on paper, this lack of infrastructure results in the unsustainable practice of groundwater recharge in one area and pumping in another i.e., hydrologic disconnect. Additionally, the types and locations of new or upgraded infrastructure are closely tied to the location of demand growth, the supply type, and supply source.

In addition to infrastructure, operational flexibility will be important to meet water management goals. Innovative operational methods, tailored agreements, and shared use of conveyance systems (e.g., interconnections, wheeling or transporting) between water providers can help balance resources and meet future demand.

Economic and Trade-Off Analyses

The economic and trade-off analysis of the adaptation strategies indicate that *Demand Management* performs well overall and proves to be the least-cost strategy considered, while also providing several relatively large benefits. Improving conservation and reducing water demand is therefore a sensible way to help reduce future water shortages and pressure on water resources.

Effluent use, especially recharge, also appears to be a practical way to address future water shortages in the study area. Surface water transactions and agreements could also be a viable way to help address shortages in the region, but the success of this strategy depends heavily on administrative and legal barriers as well as public perception and acceptance. Meanwhile, ocean desalination, poor quality groundwater treatment, groundwater transactions, and inland desalination/brackish water treatment all come with a relatively high cost and therefore lower net benefit than the other alternatives considered.

Ocean Desalination and *Demand Management* scored highest in the *Water Availability and Reliability* evaluation which is based on the volume of water provided by a strategy, the type of water provided, when that water becomes available, and if the water volume is constant or varies over time. However, water availability and reliability are not the only consideration in ranking strategies. Table ES-2 provides a cardinal score for strategies under each weighting scheme, reported as a percentage of the highest-ranking strategy (i.e., 1st=100 percent). These percentages indicate how strategies perform relative to one another while considering the magnitude of differences.

Demand Management is the overall top performing strategy and performs well along all dimensions. The top-performing effluent strategies also perform well overall, but they are distinguished by performing relatively worse along economic & financial considerations. The *Surface Water Transactions/Leases/Exchanges* strategy could also be a feasible way to help address future water shortages, overall ranking 5th and scoring 79 percent of the top-scoring strategy. Notably, this strategy performs well under economic & financial weighting schemes, but it does not perform well under social & administrative considerations. Overall, these results suggest that the top-five performing strategies represent viable alternatives, with a magnitude of only 21 percent separating their overall performance. This means that both demand-side and supply-side opportunities exist to help sustainably address future water shortages.

The results ultimately indicate that several strategies are worth studying in greater detail, especially in combinations where there could be potential synergies or few trade-offs associated with combined implementation.

Table ES-2. Adaptation Strategy Score Magnitudes Under Different Weighting Schemes

Strategy	All Criteria	Economic & Financial	Environment & Sustainability	Social & Administrative	Team Survey	Overall
(1) Demand Management	100%	100%	92%	94%	100%	100%
(2) Regional Effluent – Direct Potable Reuse	61%	45%	82%	51%	61%	62%
(3) Regional Effluent – Direct Non-Potable Reuse	81%	61%	79%	99%	79%	81%
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	88%	63%	100%	96%	86%	88%
(5) Regional Effluent Recharge	89%	64%	97%	100%	86%	89%
(6) Poor Quality Groundwater Treatment	62%	60%	51%	70%	59%	61%
(7) Ocean Desalination	67%	70%	72%	50%	71%	68%
(8) Inland Desalination/Brackish Water Treatment	41%	34%	43%	46%	41%	41%
(9) Groundwater Transactions/ Exchanges	54%	58%	41%	57%	51%	53%
(10) Surface Water Transactions/ Leases/Exchanges	79%	79%	79%	70%	78%	79%

Note: Scores are reported as a percentage of the highest-ranking strategy under each weighting scheme (i.e., 1st[t]=100 percent). This indicates how strategies perform relative to one another while considering the magnitude of differences. The cells are also colored from light to dark blue to visually show scoring magnitude, e.g., darker signifies a higher ranking while lighter ranks lower.

Next Steps

The study partners will continue to work together to meet the water supply needs identified in this study. Continued strategic planning and direct follow-on activities from this study will help focus and prioritize those efforts.

Potential follow-on activities related to this Basin Study include:

- Refinements and updates to the supply and demand scenarios.
- Examination of a wider range of scenarios.
- Further use of the groundwater model.
    - The groundwater model could be used evaluate additional scenarios, such as pre-adaptation scenarios or post-adaptation scenarios that incorporate estimates of water obtained through implementing adaptation strategies.
    - Scenarios that investigate changes in pumping and recharge locations could be useful for assessing questions about aquifer impacts.
    - Additional model runs with adaptation strategy scenarios would be useful for comparing pre- and post-adaptation conditions and assessing the effectiveness of the strategies.
    - Scenarios incorporating combinations of strategies could be evaluated.
    - The model simulation period could be extended beyond 2060.
- Refinement of the recharge suitability model to incorporate additional ranking criteria or to focus on specific geographic areas. For example, additional ranking and recharge suitability modeling tools criteria related to infrastructure locations and capabilities could be incorporated.
- Some of the adaptation strategies may benefit from assessment of recent or anticipated developments in technology, data, or policies. For example, Direct Potable Reuse could be evaluated for various locations in the study area. Water quality, regulations, and preliminary designs could be evaluated. A pilot project could be initiated.
- Other ongoing activities in the state and region should be closely monitored and may provide insight to adaptation strategy prioritization and implementation planning. For example, some strategies identified in this study will be affected by Colorado River management, regional surface water management (e.g., Verde River), Assured Water Supply designations in the Active Management Area, water transfers, cooperative water sharing agreements, and water reuse rulemaking.
- As priorities are refined, a more thorough infrastructure analysis would benefit the study partners. This could involve updating previous infrastructure studies conducted by WVWA with applicable results of this study.
- Preliminary or appraisal-level cost estimates for infrastructure associated with adaptation strategies would help study partners' planning activities.

- Address other strategies such as Integrated Stormwater Management. Large scale stormwater capture, redirection, and recharge may be a viable component to regional management.
- Expand the economic and trade-off analysis to consider different combinations of strategies. There are likely to be important trade-offs and synergies between strategies when strategies are combined. Analyzing a combination of strategies is an important next step in determining the optimal solution for addressing future water shortages.
- Further develop plans for implementing strategies or conducting pilot or demonstration projects.
- Continued follow-up on the demand management strategy is appropriate to consider as a high priority based on the findings of this study. This includes partnership opportunities with shared resources and unified messaging. It also includes evaluating and ranking demand management measures by estimating potential savings and assessing regional acceptance.
- Fully utilize opportunities to use Reclamation funding and expertise in water resource planning and implementation. Reclamation funding opportunities through the WaterSMART Program can be used to plan for and implement actions to improve water supply and/or quality, modernize infrastructure, and/or reduce water conflict for local governments and water providers. The WaterSMART grants that appear to be most applicable to the study area's needs are Small-Scale Water Efficiency Projects, Water Marketing Strategy Grants, Water and Energy Efficiency Grants, Title XVI Water Reclamation and Reuse Research Projects, Title XVI WIIN Water Reclamation and Reuse Projects, Water Conservation Field Services Program, and Drought Response Program. Reclamation staff can help study area water providers understand and navigate these programs and funding opportunities.
- Investigate other funding opportunities. Federal agencies, like the Environmental Protection Agency and U.S. Army Corps of Engineers offer a variety of grants or loans for water management. There are also programs and grants available through the State of Arizona, including the Arizona Department of Water Resources, Water Infrastructure Finance Authority of Arizona, and Arizona Department of Environmental Quality's Water Quality Assurance Revolving Fund.

Limitations

The quantities reported in this Basin Study are planning numbers based on assumptions made throughout this study. They are considered representative of the water supply challenges to which the WSRV water providers will need to adapt. Because strategies will be employed between now and 2060, the 2060 shortage amounts used in this study should not be construed as a prediction of the future.

Study participants recognize there is inherent uncertainty in projecting future water needs. Other planning scenarios could be created and evaluated. However, the takeaway point is not the exact value shown in each scenario, but rather that a significant amount of water will be needed, and water providers will be required to invest in maintaining existing supplies and developing new supplies over the study period.

Other limitations include:

- Reclaimed water was not utilized to its full extent in groundwater modeling.
- Only water currently secured by CAGRD was considered in the groundwater modeling.
- Projecting the acquisition of new CAGRD replenishment water was not included in the study. However, by law, CAGRD is required to replenish for all its members, including projected new members.
- Water level impacts/supply shortages would be positively impacted by additional CAGRD replenishment and full utilization of reclaimed water.
- In the groundwater model, only one growth model (rapid and outward) was used along with one projected climate change projection (hot and dry).
- The hot and dry climate change scenario included periods of CAP and SRP shortages; however, the shortages were based on planning assumptions for this study. They are not official CAWCD, SRP, or Reclamation projections.

1. Introduction

For decades, the Phoenix metropolitan area has been one of the most rapidly growing urban areas in the United States (U.S.). It is expected to remain so in the future. The current metropolitan area population is over four million and the U.S. Census Bureau estimates that it will exceed six million by 2030 (U.S. Census Bureau, 2020). The demand for water is also expected to increase to meet this growing population.

The West Salt River Valley (WSRV) is in the western portion of the Phoenix metropolitan area (Figure 1). The study area is the WSRV sub-basin and the adjacent groundwater sub-basins. The adjacent sub-basins – the Lower Hassayampa, Rainbow Valley, and a portion of Lake Pleasant – are hydrologically and politically connected to the WSRV. There is significant potential for growth in the study area due to vacant or agricultural land available for development.

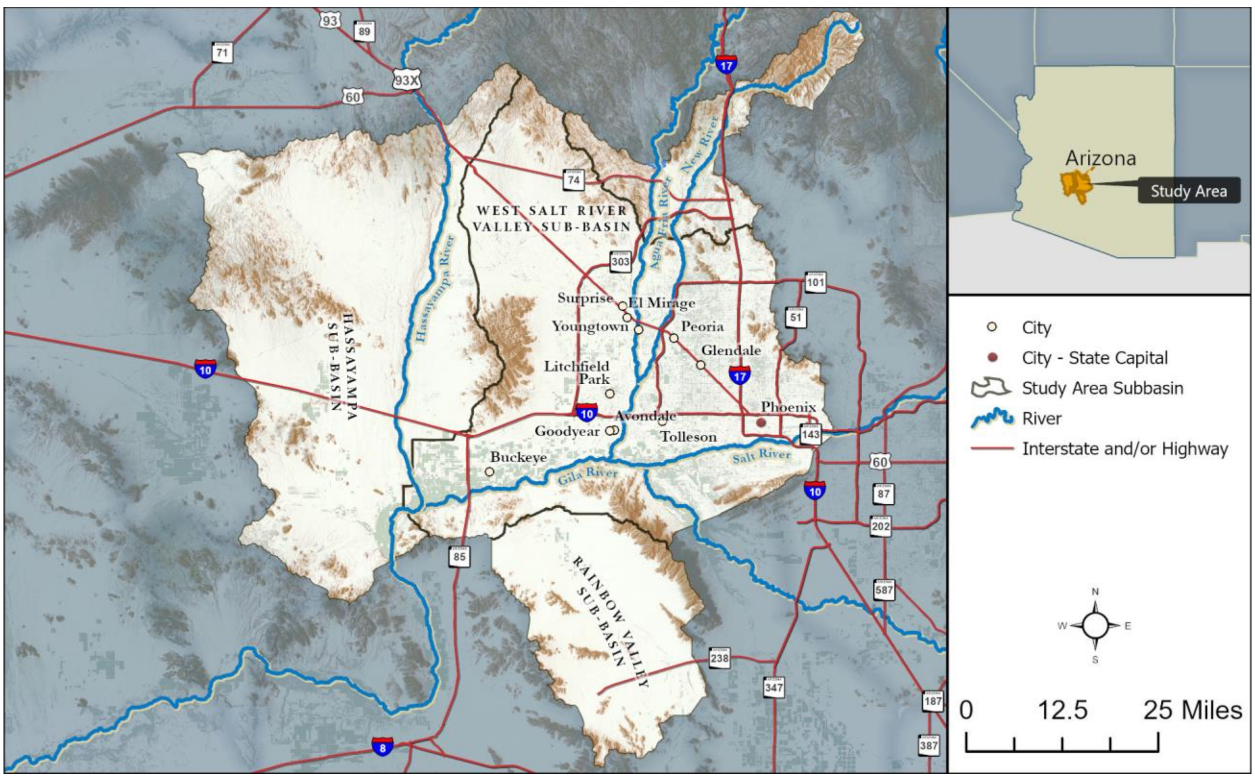

Figure 1. Location of the WSRV Basin study area including the West Salt River Valley sub-basin and surrounding sub-basins.

Because of limited supplies, the rapidly expanding population, and the hot, dry desert climate, water supply issues are a principal concern of the study area communities. Water resource managers in the area have been securing long-term supplies through a range of methods such as importation, water banking, demand management, and effluent use (Arizona Department of Water Resources, 2014). While past and current water management efforts are substantial, community leaders recognize that additional advanced planning, collaboration, and investment are needed to secure adequate water supplies into the future. These efforts will help sustain the excellent quality of life and thriving economies for which the area is known.

A secure water future in the study area depends upon solutions to both supply and demand challenges. Supply issues include the amount, location, management, and quality of groundwater; the current and future reliability of renewable surface water supplies; and utilization of effluent. Water demand issues relate to housing development, industrial growth, agriculture use and retirement, environmental uses, and demand management. Uncertainties associated with supply and demand, infrastructure needs, past groundwater modeling results, and a desire to compare and organize regional-scale solutions led to this Basin Study.

1.1 Purpose, Scope, and Objectives

The Memorandum of Agreement among the study partners (listed in Section 1.3) included a Plan of Study describing the purpose, scope, and objectives of the Basin Study (Appendix A).

The purpose of the WSRV Basin Study is to provide information that will help communities safeguard a secure water future in the study area. The information compiled in this report will assist community planners and leaders as they analyze and prioritize prospective action and investment.

The scope of this Basin Study includes four main components:

(1) Projections of future water supply and demand, considering specific impacts resulting from climate change;

(2) Analyses of how existing water and power infrastructure and operations will perform given current imbalances between water supply and demand and in the face of changing water realities due to climate change;

(3) Development of appropriate adaptation and mitigation strategies to meet current and future water demands; and

(4) A trade-off analysis of the mitigation strategies related to their ability to meet study objectives (Bureau of Reclamation, 2016).

The WSRV Basin Study objectives included formulation of regional-level scenarios of future water demands and supplies considering effects of growth patterns and climate change; a description of potential future supply and demand imbalances; an analysis of infrastructure and operations; an analysis of potential strategies to safely meet future demands; and development of model tools to inform the study and future planning efforts.

To achieve the study objectives, a set of future supply and demand projections were created using the Central Arizona Water Conservation District's Central Arizona Project Service Area Model (CAP:SAM). In addition, Reclamation's Technical Service Center (TSC) prepared a technical evaluation of potential climate change effects on water availability in the study area. The CAP:SAM and TSC climate change results were used to develop a set of future supply and demand scenarios.

To help locate and quantify potential future imbalances, the scenarios were used as input for a numerical groundwater flow model that was developed for the study. Based on an assessment of the model output, potential future supply and demand imbalances were identified. The study team then developed strategies to adapt to the potential imbalances shown by the scenarios and model runs. Adaptation strategies were assessed and compared through a trade-off analysis.

As part of the study, a Geographic Information System (GIS) model was developed by Reclamation to assess locations within the study area that may be suitable for aquifer recharge facilities. This model can be used as a tool to evaluate potential areas for recharging excess effluent or excess renewable surface water in wet climate years.

1.2 Study Authority

Basin Studies are conducted under the authority of the 2009 Omnibus Public Land Management Act (P.L. 111-11). Subtitle F of Title IX of P.L. 111-11, the SECURE Water Act, recognizes that adequate and safe supplies of water are fundamental to the health, economy, security, and ecology of the United States. It also recognizes that data gathering and research will help ensure sufficient quantities of water, and climate change poses a significant challenge to the protection and use of the water resources of the United States (SECURE Water Act, P.L. 111-11, Title IX, Subtitle F, 2009).

Section 9503 of the SECURE Water Act, which directed the U.S. Department of the Interior to develop a sustainable water management policy that considers the risks and associated impacts of climate change to water supplies as well as adaptation strategies to mitigate and minimize those impacts, authorizes Reclamation to coordinate and partner with others to ensure the use of best available science to assess specific risks to water supply. In 2010, the Secretary of the Interior established the WaterSMART (Sustain and Manage America's Resources for Tomorrow) program, an umbrella program with many components including the Basin Study Program, to implement various directives set forth in P.L. 111-11 (U.S. Department of the Interior, 2010). The Basin Study Program allows Reclamation to partner with tribal, State, regional, and local water managers in collaborative efforts to address basin-wide issues associated with water scarcity. Basin Studies are cost-shared studies to evaluate current and future water supply and demand imbalances and to identify adaptation strategies to reduce those imbalances.

In 2014, the West Valley Water Association (WVWA), formerly known as the West Valley Central Arizona Project Subcontractors (WESTCAPS), applied and was selected for a Basin Study to evaluate impacts from climate change within the study area and identify strategies that may support a more secure water supply in the future.

1.3 Study Partners

This study is a joint effort between Reclamation and the WVWA. The WVWA is a collaboration of municipal and private water providers in the study area, along with interested water agencies, working together for a future of secure, reliable, and resilient water supplies. Current WVWA member organizations include Arizona Water Company, EPCOR Water, Liberty Utilities, Salt River Project (SRP), Maricopa Water District (MWD), Buckeye Water Conservation and Drainage District, and the Cities of Avondale, Buckeye, El Mirage, Glendale, Goodyear, Peoria, Phoenix, Surprise, and Tolleson. Interested parties include Arizona Department of Water Resources (ADWR), Arizona Public Service (APS), Central Arizona Water Conservation District (CAWCD), Arizona State Land Department, Central Arizona Groundwater Replenishment District (CAGRD), and Flood Control District of Maricopa County (FCDMC) (West Valley Water Association, n.d.).

The mission of the WVWA is to develop a cost-effective, quality water supply, engage in water resource planning and management, and develop regional partnerships for water in the West Salt River Valley. Since the late 1990s, WVWA members have been evaluating the best methods to fully utilize their Colorado River water entitlements and coordinate water management planning.

The Reclamation Basin Study Program provided an opportunity for the WVWA members and Reclamation to jointly fund and use combined expertise to address water supply and demand issues related to WSRV communities and operations of the CAP and SRP systems, both of which are Reclamation projects. The WVWA members are Reclamation's primary partner for this Basin Study.

1.4 Study Approach

The Basin Study is composed of interrelated tasks to achieve the purpose, scope, and objectives. The Plan of Study and Memorandum of Agreement formed the basis for the study approach. Specialists and task teams were used to complete the study components. A technical consultant completed the groundwater modeling tasks, while Reclamation technical specialists conducted the climate change analysis, the recharge site suitability modeling, and the tradeoff analysis. CAWCD personnel performed the CAP Service Area Model of supply and demand. The infrastructure analysis was reviewed by a task team with input from water providers. The adaptation strategies were compiled by a task team with input from the study partners and interested parties.

The task teams consisted of combinations of study partner personnel, technical consultants, interested parties, and Reclamation staff (Phoenix Area Office and Denver TSC). The teams were established by, and reported to, the larger WVWA Planning Committee. Each team met as needed to accomplish the task objective. Workshops and regular meetings were conducted to gain insight, solicit input, and prepare and review documentation. Teams reviewed work scopes and products, assembled information, and conducted analyses. They also provided input to and review of the technical work products and documentation prepared by modeling experts and other specialists. The study partners reviewed the approach, results, and conclusions of each task throughout the course of the study. Where possible, values and assessments were based on quantified metrics. In areas where quantification was not possible, qualitative assessments were used.

Technical documentation of the methods and findings for the tasks are included as appendices to this report. Table 1 below lists the major tasks, objectives, and primary authors. The recognized modeling tools and methodologies used in this study are intended to be available for additional activities such as study refinement and further investigation of adaptation strategies.

Table 1. West Salt River Valley Basin Study Tasks

Task	Objective	Technical Documentation Author
Water Supply and Demand Projections. Develop scenarios of future conditions for evaluation with groundwater model.	Characterize existing conditions and develop scenarios of projected future water supply and demand within the study area. Use existing literature, stakeholder input, and analysis of projected water supply and demand using Central Arizona Project Service Area Model (CAP:SAM). Provide data sets for groundwater model.	CAP
Climate Change and Hydrologic Modeling	Use downscaled climate projections and hydrologic model simulations to evaluate potential climate change effects on future water supplies in the study area. Include results in groundwater modeling.	Reclamation Technical Services Center
Groundwater Model Development and Scenario Evaluation	Construct and use a numerical groundwater model to examine effects of future demand scenarios in and around the study area. Use to analyze potential impacts to the aquifers and form a basis for adaptation strategies. Provide tool for future use by study partners to evaluate other scenarios and effects of adaptation strategies.	Matrix New World Engineering (Southwest Groundwater Consultants)
Recharge Site Suitability Analysis	Develop GIS tool and evaluate the study area for potential recharge sites. Use a variety of weighted information such as land use, geology, and hydrology to screen the study area for potential recharge sites.	Reclamation Phoenix Area Office
Adaptation Strategy Identification and Description	Identify and describe a set of adaptation strategies to meet needs identified in supply and demand projections and groundwater model scenario runs.	WVWA Task Team
Infrastructure and Operations Analysis	Compile existing water and power infrastructure, and operational information for study area. General assessment of possible future needs.	Reclamation and Task Team

Task	Objective	Technical Documentation Author
Trade-Off Analysis and Opportunities	Compare potential future water supply system infrastructure and operations concepts using Trade-off Analysis and Economic Assessment.	Reclamation Technical Services Center

1.5 Collaboration and Outreach

The study partners used standard communication methods such as regular meetings and written updates to convey information over the course of the study. The Plan of Study and a study fact sheet were distributed to a wide variety of stakeholders identified early in the study. A Basin Study Advisory Group of interested parties was established and a kick-off meeting was held. The public was invited to attend meetings and participate in the study. An email list was assembled and used to inform study partners and interested parties of meetings and product-review opportunities over the course of the study.

The study partners held regular monthly WVWA Planning Committee meetings throughout the study and the task teams held regular meetings. Quarterly meetings were held with the WVWA Board of Directors where a Basin Study update was presented regularly. All the meetings were advertised and open to the public. Study materials and meeting agendas were posted to the WVWA website as they were developed throughout the study.

The consistent and dedicated collaboration among Reclamation, the study partners, and interested parties to complete this study is a testament to the focus and determination committed by the participants to prepare this region for a secure water future. The study participants regularly shared their data, organization plans, challenges, and opinions. Therefore, while not the primary focus of the study, the working relationships developed during this study are a positive outcome of the study.

1.6 Identification of Interrelated Activities

Many relevant water planning, monitoring, and regulatory activities have occurred within the region, and some are ongoing. These include studies, operational reports, data sets, and committee findings. The activities have provided estimates of future water demands, analyses of potential water management strategies, and legal and regulatory analyses. Relevant interrelated activities have been carried out by federal, state, and local governments and non-governmental organizations (NGOs). Study partners who have participated in or monitored these activities assisted in the Basin Study. While this basin study was largely conducted independently, both the completed and ongoing interrelated activities have helped greatly. The study partners are grateful for all the work that has been accomplished and the work that is ongoing.

Table 2 contains brief descriptions of significant interrelated activities and identifies key documentation. The list, while not exhaustive, demonstrates that much relevant work has occurred in and around the study area.

Table 2. WSRV Basin Study - Interrelated Activities

Activity	Description	Documentation
FEDERAL		
Colorado River Basin Study	Defined current and future imbalances in water supply and demand in the Colorado River Basin and the adjacent areas of the Basin States that receive Colorado River water for approximately the next 50 years. Developed and analyzed adaptation and mitigation strategies to resolve those imbalances.	2012 Final Study Reports https://www.usbr.gov/lc/region/programs/crbstudy.html
Lower Santa Cruz Basin Study and Eloy Maricopa Stanfield Basin Study	Conducting similar work to the WSRV Basin Study in nearby sub-basins, southwest of the WSRV study area. Linked through the CAP canal and have similar water resources issues. Because of the geographic proximity between the study areas, there are areas of overlap, such as interested parties, regulatory environment, climate, and adaptation strategies.	Ongoing https://www.usbr.gov/lc/phoenix/programs/lscrbasin/LSCRBStudy.htm Ongoing http://pinalpartnership.com/ems-basin-study
Colorado River Basin Drought Contingency Plans (DCP)	Designed to reduce risk of critical shortages on the Colorado River and impacts to Arizona water users.	Exhibit 1 to the Lower Basin Drought Contingency Plan Agreement – Lower Basin Drought Contingency Operations https://www.usbr.gov/dcp/
STATE		
Governor’s Water Augmentation, Innovation, and Conservation Council	Continues and expands upon work of the Governor's Water Initiative through the Council with a long-term focus on water augmentation, innovation, and conservation. Subcommittees include	Ongoing Annual Report 2019/2020 Long Term Water Augmentation Options for Arizona (2019 Carollo Report)

Activity	Description	Documentation
	desalination, long term water augmentation, and post-2025 AMAs.	https://new.azwater.gov/gwaicc
Active Management Area (AMA) Management Plans 5th Management Plan Workgroup	Stakeholder forum for the development of the 5th Management Plans, with a goal of working to assess existing conservation programs and to develop new management strategies for the fifth management period and beyond. Includes the "5th Management Plans Safe-Yield Technical Subgroup" that is assessing long-term balance and aquifer health in the AMAs.	4th and 5th Management Plans https://new.azwater.gov/5MP https://new.azwater.gov/sites/default/files/media/2020-09-30_SY_Subgroup.pdf
State's Water Resources Development Commission	Assessed the current and future water needs of Arizona.	WRDC Vol 1 https://new.azwater.gov/statewide-planning WRDC Vol 2 https://new.azwater.gov/statewide-planning
Arizona Water Initiative - Governor's Water Augmentation Council	Investigated long-term water augmentation strategies, additional water conservation opportunities, funding, and infrastructure needs to help secure water supplies for Arizona's future.	Meeting documentation and reporting on ADWR website. https://new.azwater.gov/water-initiative/governor-water-augmentation-council
ADWR State Monitoring (e.g., subsidence, water levels)	ADWR's Hydrology Division engages in a wide variety of data collection activities in support of public needs, including the Assured and Adequate Water Supply and Recharge Programs, Drought Monitoring Program, and well drilling and well impact assessments. The Hydrology Division also supports data collection in support of hydrologic studies such as groundwater	https://new.azwater.gov/hydrology/field-services/statewide-monitoring-program

Activity	Description	Documentation
	modeling and water budget development.	
Statewide Strategic Vision	Arizona's Strategic Vision for Water Supply Sustainability provides an analysis of water supply problems the State is facing and organizes the State into "solution-oriented Planning Areas."	Arizona's Next Century: A strategic vision for water supply sustainability. https://new.azwater.gov/statewide-planning
Arizona Re-consultation Committee (ARC)	Arizona steering committee for how the Colorado River system will be managed after 2026, when the 2007 Interim Guidelines expire.	Ongoing activity https://new.azwater.gov/arc
Universities: Arizona State University (ASU) – Kyl Center, University of Arizona – Water Resources Research Center (WRRC), & Northern Arizona University	The Kyl Center for Water Policy at Morrison Institute for Public Policy promotes research, analysis, collaboration, and dialogue to ensure sound water stewardship. For example, it has published reports and analysis of the Central Arizona Groundwater Replenishment District (CAGRD) and its role in Assured Water Supply and aquifer replenishment. The WRRC addresses key water policy and management issues, empowers informed decision-making, and enriches understanding through engagement, education, and applied research. These organizations have produced several useful reports and analyses.	https://science.asu.edu/kyl-center-water-policy https://morrisoninstitute.asu.edu/content/elusive-concept-assured-water-supply https://wrrc.arizona.edu/publications https://nau.edu/ses/water-management-policy-science/
OTHER		
Water Providers (cities, private companies, agricultural districts) e.g., WVWA, Arizona Municipal Water Users Association (AMWUA)	WVWA is working to develop a cost effective, quality water supply; engage in water resource planning and management; and develop regional partnerships for water in the West Valley. AMWUA comprehensively addresses water resource planning and policy at a	https://westcaps.org/ http://www.amwua.org/

Activity	Description	Documentation
	regional level. AMWUA staff and members, city managers, and elected officials work closely with one another and with water agencies and stakeholders to discuss complex issues and find innovative solutions to the challenges ahead.	
NGOs e.g., Lower Gila River Collaborative	The Lower Gila River Collaborative serves as an ongoing forum for collaboration, coordination, and outreach among local governments, the Gila River Indian Community, state agencies, NGOs, and the private sector.	www.lowergilariver.net
SRP	SRP actively works with stakeholders throughout Arizona to address concerns about water supplies, identify alternative supply options to meet demands, and collaborate on programs to resolve water resource conflicts.	https://www.srpnet.com/water/resource-management.aspx
CAWCD	CAWCD has planning functions relevant to this basin study, such as the CAP:SAM model and water supply reports. They also are responsible for managing the CAGRD.	https://www.cap-az.com/ https://www.cagrd.com/

2. Existing Conditions in the Study Area

2.1 Study Area Overview

Basin Studies address water resource issues within the boundaries of hydrologic basins as opposed to political or other physical boundaries. The study area includes the West Salt River Valley (WSRV) groundwater sub-basin and adjacent sub-basins in Maricopa County, Arizona. The WSRV groundwater sub-basin underlies the western half of the Phoenix metropolitan area and beyond. The area of the WSRV sub-basin is about 1,300 square miles, which is slightly larger than the land area of Rhode Island (Arizona Department of Water Resources, 2021b; U.S. Census Bureau, n.d.). The study area also includes three adjacent sub-basins—Lower Hassayampa, Lake Pleasant, and Rainbow Valley. The adjacent sub-basins are included in the study area due to their hydrologic and political connection to the WSRV.

The entire study area is approximately 3,000 square miles and contains eleven incorporated municipalities and several unincorporated communities (Figure 2). This area is one of the fastest growing and driest regions in the U.S. (U.S. Census Bureau, 2020). Extending across such a large space, the study area is very diverse with respect to development, containing both the urban core of the nation's fifth largest city as well as more than 100,000 acres of irrigated agricultural land and vast swaths of unaltered Sonoran Desert (Tannler, 2016; U.S. Census Bureau, 2019). The study area is expected to continue to add population at about 2.3 times the national annualized growth rate through 2055. Small-to-midsize cities and towns west of Phoenix, along with leapfrog developments in unincorporated Maricopa County, will eventually merge as the study area adds 1.2 million people by 2055 (Maricopa Association of Governments, 2019).

Historically, this region has relied on non-renewable groundwater along with surface water imported from wetter, higher elevation areas to the north and east (Salt River Project, 2021b). Overreliance on unsustainable groundwater resources led to the Arizona's passage of the 1980 Groundwater Management Act (GMA). The GMA regulated groundwater use in the fastest growing areas of the state, including the study area (Arizona Department of Water Resources, 2021a). Passage of the GMA and the arrival of additional renewable supplies in the mid-1980s, most notably from the Colorado River, significantly enhanced the sustainability of the study area's growth.

Forty years after the GMA, the study area's growth is and will continue to extend beyond the urban center of Phoenix. Areas of future growth generally have smaller surface water allotments and less direct access to renewable water supplies than communities closer to the urban core (Central Arizona Project, 2019; Salt River Project, 2021a). In order to maintain sustainability of the study area's water supplies, water managers must address the increasing reliance on finite groundwater. Adding to this challenge is the highly diverse and sometimes impaired quality of groundwater throughout the study area (U.S. Geological Survey, 2002).

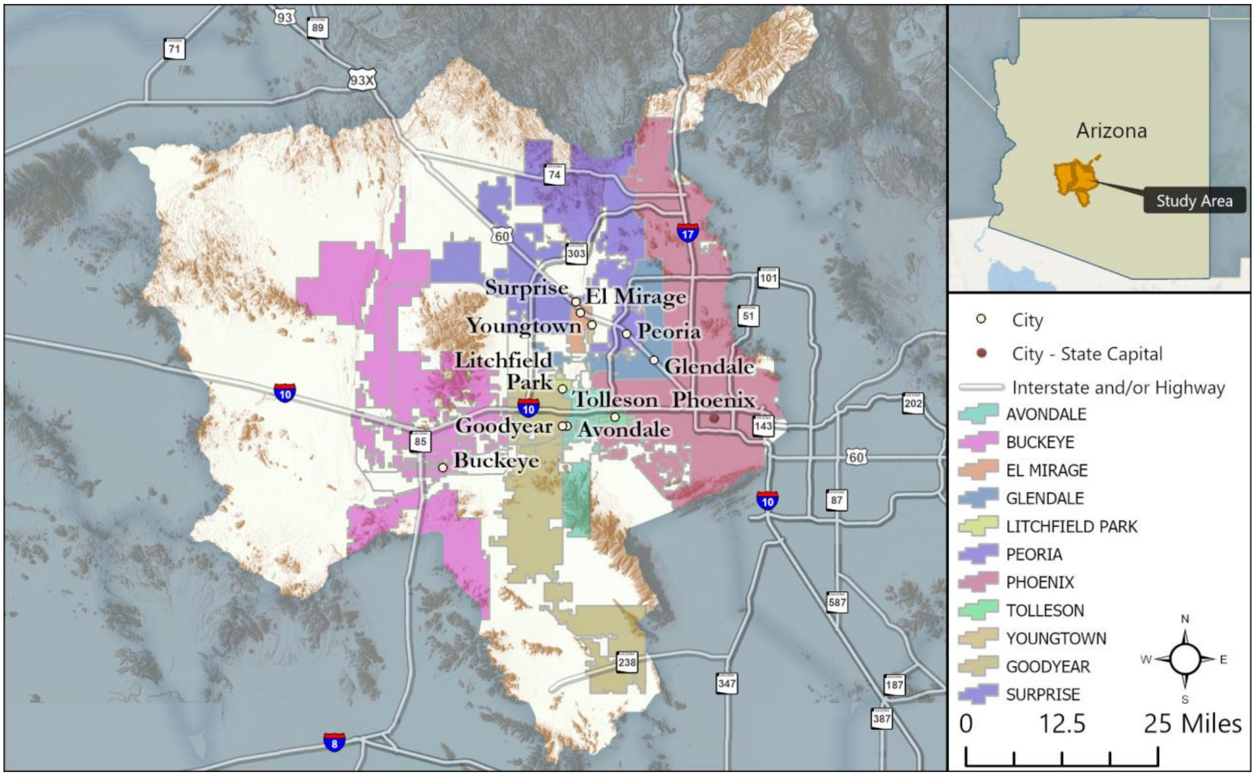

Figure 2. Municipalities in the West Salt River Valley and surrounding sub-basins

2.2 Physical Setting

The study area falls within the Sonoran Desert portion of the Basin and Range physiographic province of the Western U.S. (Arizona Department of Water Resources, 2010a; U.S. Geological Survey, 2002). Typical of this topography, the study area contains a gently sloping alluvium filled valley surrounded by mid-elevation mountain peaks ranging from 4,000 to 4,500 feet above mean sea level (Arizona Department of Water Resources, 2010a; U.S. Geological Survey, n.d. a). Elevation of the valley floor ranges from 2,600 feet north of Wittmann near the mountain front to 800 feet where the Gila River exits the sub-basin to the southwest at Powers Butte in Buckeye (U.S. Geological Survey, n.d. b). The center of the sub-basin, just east of Luke Air Force Base, has an elevation of approximately 1,075 feet. Significant stores of naturally occurring, but slowly replenishing, groundwater exist within aquifers in the sediment-filled valley (Gammage Jr., Stigler, Daugherty, Clark-Johnson, & Hart, 2011). Alluvium thickness, the depth from the surface to bedrock underlying the alluvium, ranges from hundreds of feet near the mountain front to over 11,200 feet near the center of the sub-basin (Cook, 2013).

The Köppen-Geiger climate classification system classifies the study area as a hot, arid desert (BWh) (Peel, Finlayson, & McMahon, 2007; Climate Change and Infectious Diseases Group, University of Veterinary Medicine Vienna, 2019). From 1981 – 2010, the Youngtown weather station (USC0002963), near the center of the study area, averaged 105 days per year with a maximum daily temperature of 100 ºF or higher (National Oceanic and Atmospheric Association National Centers for Environmental Information, n.d.). Annual precipitation averaged over the same period ranged from 8.03 inches at Phoenix Sky Harbor International Airport (USW0002) to 10.65 inches in

Wittmann (USC000294), generally corresponding to elevation (Western Regional Climate Center, n.d. a; Western Regional Climate Center, n.d. b). Most of this precipitation falls during the summer monsoon from July – September and the winter rainy season from December – March (Arizona Department of Water Resources, 2010a). Consistent with high temperatures and aridity, evaporation rates are high, estimated at 72.4 inches or 6.03 feet per year (Cooley, 1970).

Water flows into and out of the study area both above and below ground. There are four adjacent, hydrologically connected sub-basins that influence groundwater availability in the WSRV sub-basin. Thus, these surrounding sub-basins are included as part of the study area and in many of the models of this study (Bureau of Reclamation and WESTCAPS, 2014). The primary surface water features in the study area are the Gila, Salt, Hassayampa, and Agua Fria rivers and their tributaries (Figure 3). These rivers generally flow from north and east to south and west. With such little, intermittent precipitation, most of the surface water features are ephemeral unless fed by treated effluent (Arizona Department of Water Resources, 2010b).

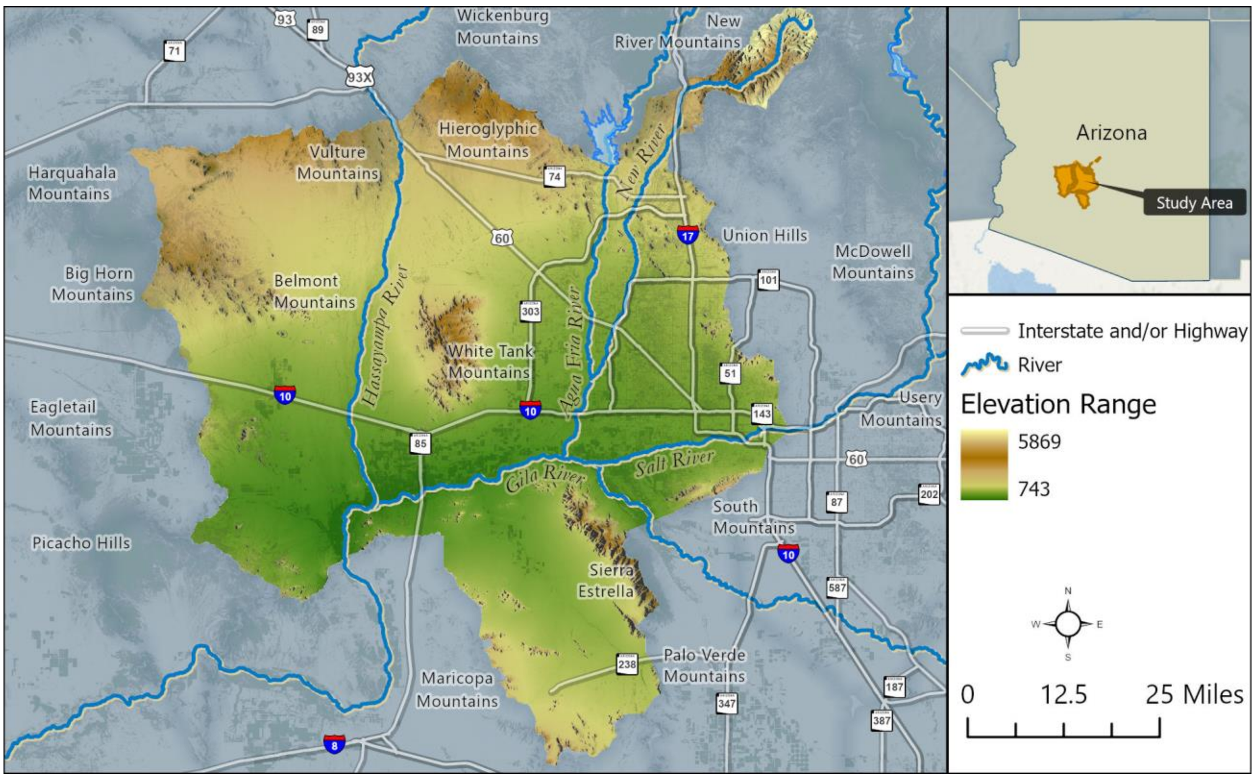

Figure 3. Physical geography of WSRV study area - rivers and topography

2.2.1 Surface Water Hydrology

The Gila River and its tributaries drain the WSRV groundwater sub-basin. The Gila arcs across the study area near its southern end, entering from the southeast and exiting to the southwest. The three major tributaries within the sub-basin are the Salt, the Agua Fria, and the Hassayampa rivers. The Salt River, the Gila's main tributary, originates in the mountains of eastern Arizona and drains an area of 13,700 square miles. The Salt enters the study area in the east and joins the Gila from the northeast at Monument Hill, adjacent to the Phoenix International Raceway. The Agua Fria River originates in the mountains of central Arizona near Prescott Valley, flowing south across the study area joining the Gila approximately three miles downstream of the Salt-Gila confluence

(U.S. Department of Agriculture Natural Resource Conservation Service and University of Arizona, Water Resources Research Center, 2007). A third major tributary, the Hassayampa River, enters at the southwestern edge of the WSRV (Arizona Department of Water Resources, 2010b). The Hassayampa's watershed drains the area west of the WSRV groundwater sub-basin.

Both the Salt and the Agua Fria rivers exhibit extreme flow variability. Since 1993, the Agua Fria has had annual flows as low as 2,000 acre-feet (AF) and as high as 466,000 AF, with a median of 21,000 AF (Central Arizona Project, 2020). Since 1913, the Salt River, including its Verde and Tonto River tributaries, has produced as little as 273,232 AF and as much as 4,238,610 AF, with a median of 880,477 AF (Volkmer, 2020). Because of the flow variability, both river systems have been dammed to protect against flooding and provide a stable water supply. Just north of the study area, the Agua Fria River is impounded by the New Waddell Dam, creating Lake Pleasant (1.1 million AF capacity) (Arizona Department of Water Resources, 2010b). The Salt River and its Verde tributary are regulated by six dams in the mountains east of the study area, having a total capacity of 2.3 million AF (Salt River Project, 2021b). Roosevelt, the largest of these dams, was dedicated in 1911 and was the first major project completed under the 1902 Reclamation Act (National Park Service, 2018). With the water from these rivers and dams completely subscribed for use, and with such little, intermittent precipitation, nearly all study area waterways, large and small, are considered ephemeral and are dry the majority of the year (U.S. Geological Survey, 2002). The exceptions to this are reaches of the lower Salt River and lower Gila River that are fed by effluent from wastewater treatment plants, return flow from agricultural irrigation, and areas where groundwater is very near the surface (e.g., Buckeye Waterlogged Area [BWLA]) (Arizona Department of Water Resources, 2010b; Arizona Department of Water Resources, 2015b).

Surface water supplies in the study area are all imported and highly developed. Multiple canal systems and associated laterals and ditches distribute surface water to urbanizing irrigation districts across the study area (Figure 4). These include:

Salt River Valley Water Users' Association (SRP) (Salt River Project, 2021a):

- Arizona Canal
- Grand Canal
- Western Canal

Maricopa County Municipal Water Conservation District No. 1 (MWD) (George Cairo Engineering, Inc., 2021):

- Beardsley Canal

Roosevelt Irrigation District (RID) (Roosevelt Irrigation District, 2021):

- RID Main Canal

Buckeye Water Conservation and Drainage District (WCDD): (Buckeye Water Conservation and Drainage District, 2021)

- Buckeye Canal

The only major surface water supply for the study area not originating from an in-state watershed is Colorado River water delivered via the CAP. The CAP begins at Lake Havasu along the border with California and pumps Colorado River water from west to east across the northern portion of the study area (Arizona Department of Water Resources, 2010b). Water from the CAP can be delivered across large swaths of the study area via interconnects with MWD's Beardsley Canal and SRP canals (e.g., CAP-SRP interconnect facility) (U.S. Geological Survey, 2002).

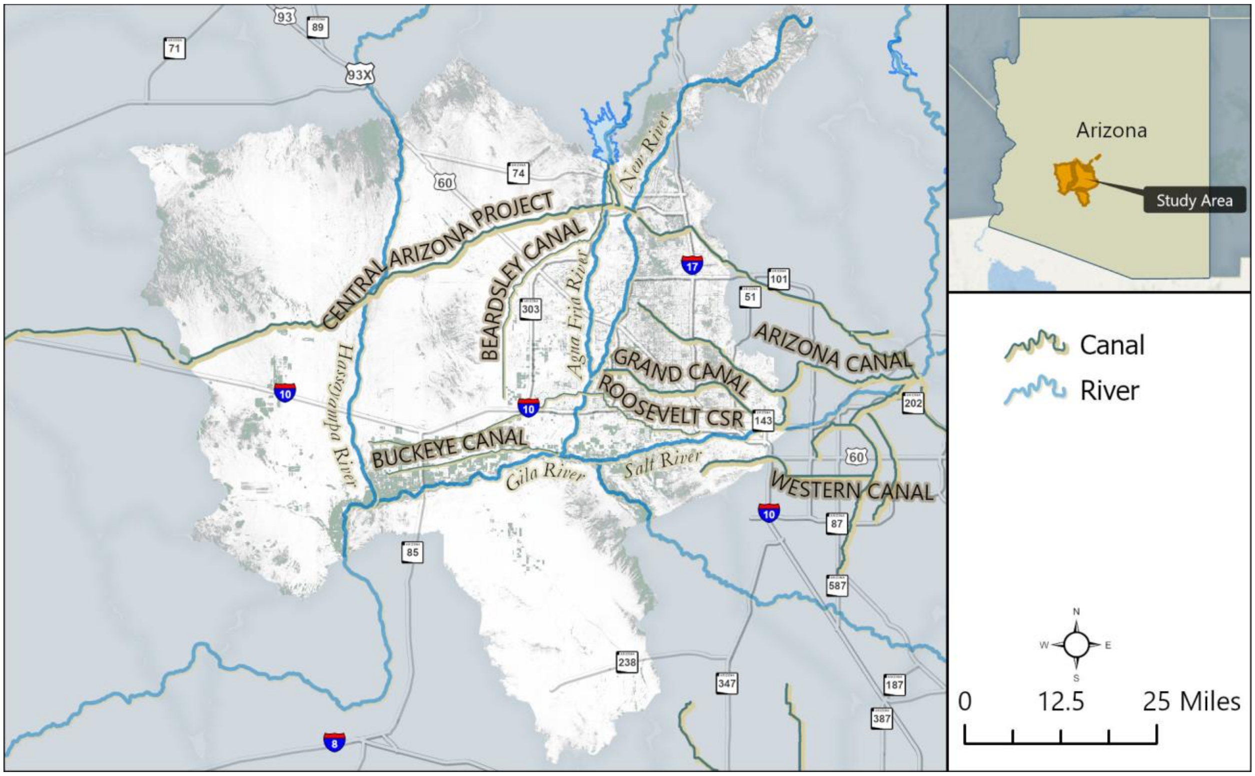

Figure 4. Rivers and major canals in the study area

2.2.2 Groundwater Hydrology (Hydrogeology)

The primary aquifers within the study are alluvium-filled structural troughs characteristic of the Basin and Range physiographic province (Figure 5). These basins contain thick deposits of sedimentary material underlain by less permeable bedrock. Large aquifers of varying water quality are within the basins. The maximum depth-to-bedrock in the WSRV sub-basin is estimated to range from 11,200 to 12,800 feet (Oppenheimer & Sumner, 1980). The depth to bedrock generally decreases, and the alluvium is thinner towards the mountain ranges.

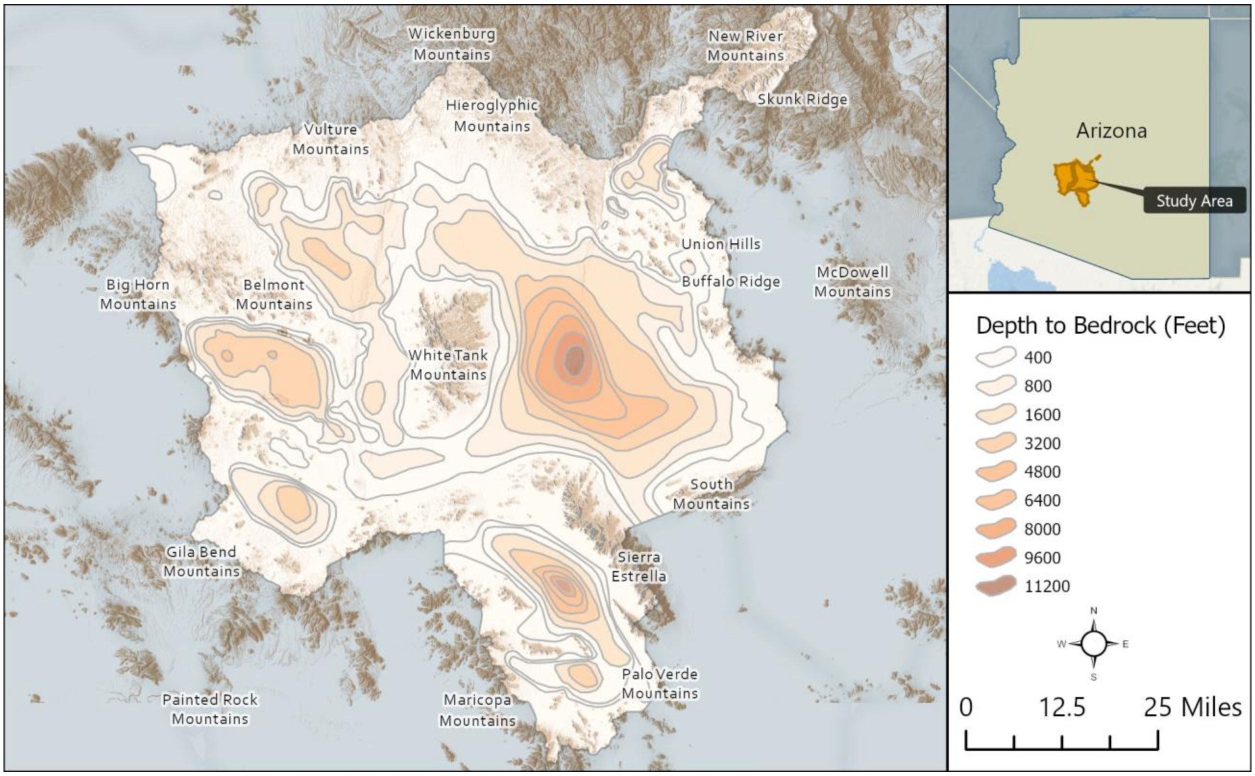

Figure 5. Basin thickness map (depth to bedrock)

The mountain ranges between alluvial basins are generally composed of impermeable bedrock, forming distinct hydrogeologic boundaries to the basins. These bounding mountain ranges consist of the Vulture, Hieroglyphic, and New River Mountains to the north; the Mazatzal, Usery, Superstition, and Dripping Springs Mountains to the east; the San Tan, Sacaton, South, Sierra Estrella, Maricopa, and Gila Bend Mountains to the south; and the Saddle and Belmont Mountains to the west. These ranges are predominantly comprised of Tertiary volcanic, and Precambrian granitoid and metamorphic rocks (Reynolds, 1988).

The groundwater system in the Phoenix Active Management Area (AMA) is dominated by regional pumping centers and incidental recharge caused by the infiltration of excess irrigation water, canal leakage, and occasional natural flooding events. Aquifer conditions in the region have also been influenced by artificial recharge. Changes in aquifer storage occur in response to pumping stresses and recharge. Before widespread irrigation was implemented, the primary source of recharge was the natural infiltration of streamflow. However, development of surface water delivery systems has greatly diminished the occurrence of surface flows within the AMA.

Groundwater in the study area occurs within the three hydro-stratigraphic units comprising the aquifer system. These units are designated by ADWR as the Upper Alluvial Unit (UAU), the Middle Alluvial Unit (MAU), and the Lower Alluvial Unit (LAU), although other investigations have devised other nomenclature for units comprising the aquifer system. These units were defined for the entire Salt River Valley area, not just the study area. The nomenclature and correlations described by each agency are presented in Table 3.

Table 3. Correlation between the ADWR Hydrogeological Units and the U.S. Geological Survey (USGS) and Reclamation Geologic Units

ADWR (1993)	USGS (1986/1989)	Reclamation (1976)
Upper Alluvial Unit (UAU)	Upper Unit	Upper Alluvial Unit
Upper Alluvial Unit (UAU)	Middle Unit	Upper Alluvial Unit
Middle Alluvial Unit (MAU)	Upper part of the Lower Unit	Middle Fine-Grained Unit
Lower Alluvial Unit (LAU)	Lower Part of the Lower Unit	Lower Conglomerate Unit

The stratigraphic divisions defined by ADWR are based on differences in the hydrologic and geologic characteristic of each unit, whereas the divisions defined by the USGS and Reclamation are based primarily on geologic variations of lithology. The WSRV Basin Study uses stratigraphic nomenclature defined by ADWR (Corkhill, Corell, Hill, & Carr, 1993). A brief summary of each hydro-stratigraphic unit, as well as the Luke Salt Dome, are provided below:

- Upper Alluvial Unit (UAU) – The UAU was deposited in an open, integrated stream system and consists of channel, terrace, floodplain, and alluvial fan deposits. Principal material sources for the deposition were derived principally from the Salt and Gila River drainages. During the time the UAU was deposited, the ancestral Salt River channel migrated across the southern portions of the Salt River Valley. Fine-grained deposits overlying coarse channel deposits were likely deposited by ephemeral streams and sheet flow associated with the ancestral channel (Laney & Hahn, 1986). The UAU generally consists of silt and sand, except near principal drainages and the margins of the basin where the deposits are predominantly sand and gravel.

- Middle Alluvial Unit (MAU) – MAU sediments were deposited in a closed, subsiding basin. Coarse-grained alluvial fans comprised mostly of sand and gravel were deposited near the basin margins, whereas in the central basin areas, deposits of fine-grained fluvial, playa, and evaporate materials accumulated. These deposits generally consist of silt and clay with some mudstones and interbedded sand and gravel.

- Lower Alluvial Unit (LAU) – LAU sediments were derived from the erosion of mountains surrounding the sub-basins and were deposited in a closed, subsiding basin. The unit is coarse-grained near the basin margins, comprised primarily of conglomerate and gravel deposits. These deposits become increasingly finer grained near the basin center, where thick deposits of mudstones and anhydrite occur in some locations.

- Luke Salt Dome – A massive evaporative deposit exists in the WSRV sub-basin profoundly affecting the occurrence and movement of groundwater. The deposit is estimated to be more than 3,500 feet thick; however, the total thickness is unknown. The Luke Salt Dome occurs within the LAU and is considered a hydrogeologic barrier to groundwater flow in the ADWR Salt River Valley groundwater flow model (Corkhill, Corell, Hill, & Carr, 1993). During the Miocene Epoch, about 10 to 15 million years ago, the salt body formed in a localized, closed structural basin as an evaporite deposit) (Shafiquallah, et al., 1980; Peirce, 1976). The age of the salt dome is based on an overlying volcanic flow that was age dated at

10 million years old (Shafiquallah, et al., 1980). Substantial groundwater pumping and water level declines caused land subsidence and fissuring in the area surrounding the Luke Salt Dome (Arizona Department of Water Resources, 2021d).

Historically, the UAU was the major water bearing unit in the AMA. However, continued use of this aquifer has dewatered much of it. Due to this pumping, vertical hydraulic gradients have developed in many areas. In the Salt River Valley, vertical hydraulic gradients exceeding 100 feet have been measured between the UAU and LAU in areas where significant dewatering of the UAU have occurred.

Predevelopment hydrogeologic conditions suggest that groundwater in the Phoenix AMA generally flowed west in the southern portion of the WSRV sub-basin. Groundwater flow direction in the WSRV sub-basin was originally along the Salt, Agua Fria, and Gila rivers into the Lower Hassayampa sub-basin. Arrows in Figure 6 show very generalized predevelopment groundwater flow directions in the study area. Since that time, the direction of groundwater flow has been artificially modified toward cones of depression near Luke Air Force Base and Deer Valley. Detailed pre- and post-development groundwater contour maps can be found in the groundwater modeling report prepared for this study as well as ADWR reports (e.g., Rascona, 2005; Corkhill, Corell, Hill, & Carr, 1993).

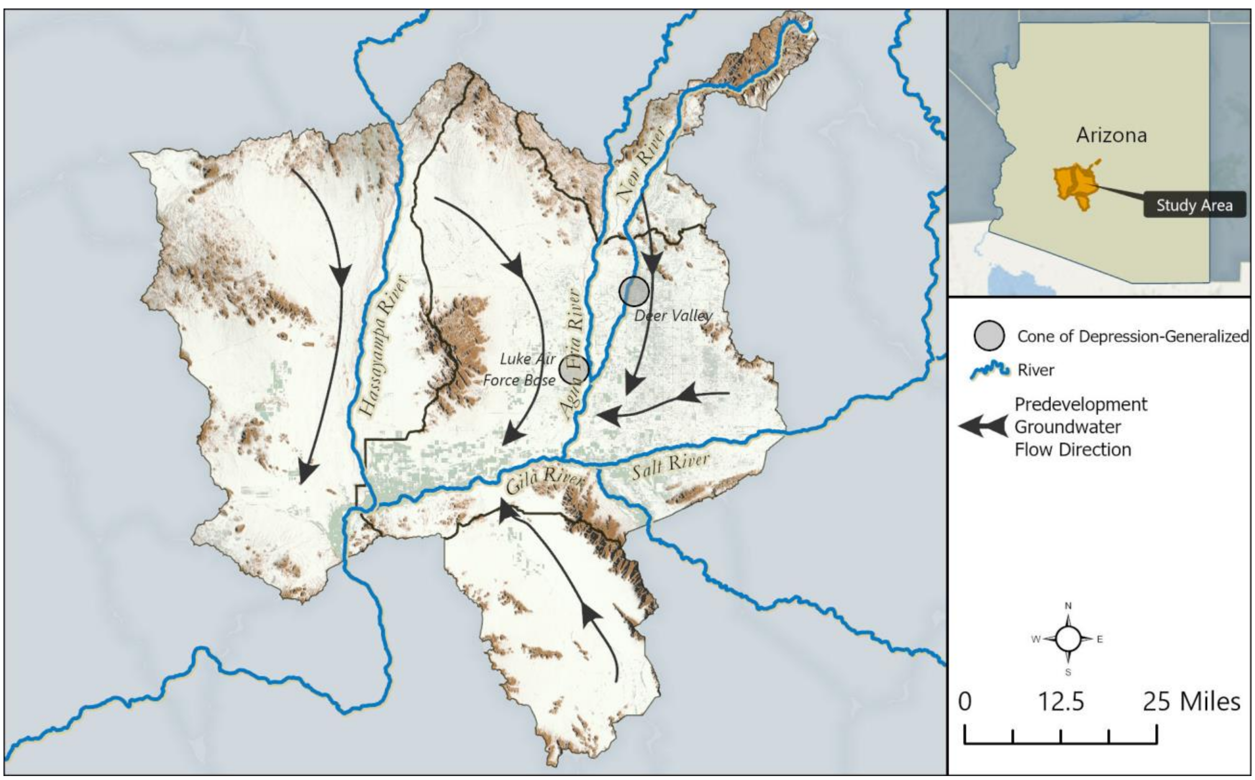

Figure 6. Generalized predevelopment groundwater flow direction and existing cones of depression

2.3 Legal and Regulatory Setting

Water management is carried out by several entities in the study area, operating under a complex legal and regulatory framework. Requirements for water users to rely substantially on renewable supplies is fundamental to understanding future demand needs and water shortages across the region. The Arizona Groundwater Code established management strategies to reduce groundwater withdrawal across AMAs. The general goal of the Groundwater Code is to achieve a long-term balance between the amount of groundwater pumping and the amount of natural and artificial recharge, referred to as a "safe-yield." Management strategies include conservation programs for all major water using sectors, as well as replacement of groundwater use with renewable water supplies. Management also includes assistance programs, enforcement provisions, and monitoring requirements. The Assured Water Supply (AWS) Program and the Underground Water Storage, Savings, and Replenishment (Recharge) Program are focused on the use of renewable water supplies and are key vehicles for ADWR's water management objectives.

Much of the groundwater pumped by municipal providers in Arizona's AMAs is subject to the state's AWS Program. The AWS rules require municipal providers to demonstrate a 100-year physical availability of water supplies for all new residential and commercial subdivisions, and the demand must be met primarily from renewable supplies. The AWS requirements allow for groundwater pumping to continue, but much of that pumping must be offset through recharge with renewable supplies. Only a certain declining volume of groundwater is allowed to be used and not replenished or offset. These groundwater allowances are intended to help municipal providers transition over time from groundwater to renewable supplies. Other temporary exemptions allow groundwater pumping during periods of drought e.g., ARS 45-134 (Arizona State Legislature, n.d.).

Agricultural and industrial users are not subject to the same 100-year assured water supply and groundwater replenishment obligations as municipal providers. However, agricultural users are subject to annual allotments, conservation measures, and a prohibition on bringing new land into production. Meanwhile, industrial users are subject to annual water allotments and conservation measurements. Conservation requirements aim to avoid waste and encourage efforts to recycle water. In addition to AWS rules, most municipal providers are regulated under the Total Gallons Per Capita Per Day (GPCD) Program. The remaining municipal providers are regulated under the Modified Non-Per Capita Conservation Program and are required to comply with specific conservation measures instead of GPCD requirements. All municipal providers are required to meet a lost and unaccounted-for water standard. Lost and unaccounted-for water includes line leakage, meter under-registration, evaporation or leakage from storage ponds or tanks, system and hydrant leaks or breaks, and illegal connections. To encourage effluent use, treated effluent used directly or stored underground and recovered is typically not counted when determining compliance with annual water conservation allotments.

Artificial recharge is a means of storing available renewable water supplies or effluent for future use. The Recharge Program was established to allow those with excess water supplies to store that water for recovery later. Water can be directly stored at an underground storage facility (USF) or sent to irrigation districts permitted as Groundwater Savings Facilities (GSFs) to use in-lieu of groundwater (indirect recharge). In many cases (except effluent), the Recharge Program requires a certain percentage of the recharged volume to be made non-recoverable to benefit the aquifer and contribute to the safe-yield goal. These non-recoverable volumes are called 'cuts' to the aquifer. The cuts apply to the storage of water for long-term storage credits (LTSCs), but do not apply to water that is stored and recovered within the same calendar year, known as annual storage and recovery.

The Arizona Water Banking Authority (AWBA) was established in 1996 to help mitigate impacts of future CAP shortages and store Arizona's unused entitlement of CAP water for later use. The AWBA's role has grown over time, but its largest responsibility is to improve the reliability of municipal CAP supplies during periods of extended drought on the Colorado River. The AWBA's goal of increasing reliability ('firming') of municipal supplies is achieved by banking excess CAP water. Recognizing that the junior priority of Arizona's Colorado River water leaves the CAP supply susceptible to the impacts of drought conditions and future adjustments to Colorado River entitlements, the AWBA is expected to have a significant role in addressing future CAP shortages.

2.4 History of Water Resources Development and Management Framework

Water resources in the WSRV Basin Study area were developed as an extension of early water supply projects for the Phoenix area that began well before statehood. These efforts were first begun by the federal government with passage of the 1902 National Reclamation Act for the construction of dams to support agricultural development in the West. With this and localized efforts by SRP, over 200,000 acres of private ranching and farmlands in the Phoenix area were pledged as collateral for the construction of Roosevelt Dam in 1903 (Arizona Department of Water Resources, 2014). Completion of Roosevelt Dam in 1911, the first of numerous dam construction projects, provided a reservoir storage capacity of nearly 1.4 million AF and a reliable delivery system (Figure 7).

Figure 7. Roosevelt Dam and reservoir on the Salt River (Reclamation photo)

Another dam of importance to the study area is the New Waddell Dam (Figure 8). Constructed between 1985 and 1994, it stores CAP Colorado River water and Agua Fria River runoff and provides flood protection by controlling river flows. The dam is north of the study area on the Agua Fria River about 35 miles above the Gila River confluence and located one-half mile downstream of the now submerged historic

Waddell Dam, which was built by the Maricopa Water District (MWD). The dam's reservoir, Lake Pleasant, also stores water for MWD irrigation (Bureau of Reclamation, n.d. b).

Figure 8. New Waddell Dam and Lake Pleasant view north from study area (Reclamation photo)

While central Arizona was utilizing the Salt River in the early 1900s, efforts were being made for future development of water resources from the Colorado River, culminating 50 years later, after a series of legal and political struggles, in the authorization of the Central Arizona Project Act in 1968 (Arizona Department of Water Resources, 2010a). The CAP was a shared dream of Arizonans for the anticipated future growth of the State and is now central Arizona's single largest resource for renewable water supplies (Central Arizona Project, 2016a). The CAP was designed and constructed by Reclamation to annually bring about 1.5 million AF of water from the Colorado River to central and southern Arizona. More than five million people, or more than 80 percent of the state's population, live in Maricopa, Pima, and Pinal counties, where CAP water is delivered. The CAP uses a 336 mile-long system of aqueducts, tunnels, pumping plants and pipelines to pump and lift Colorado River water nearly 2,400 feet to its final destination in Tucson (Figure 9). Turnouts from the CAP aqueduct provide connections to municipal water treatment plans to produce drinking water for cities, and to irrigation district canals for agricultural use. CAP water was first delivered and used in the AMA in 1985 and its use has steadily grown (Arizona Department of Water Resources, 1999).

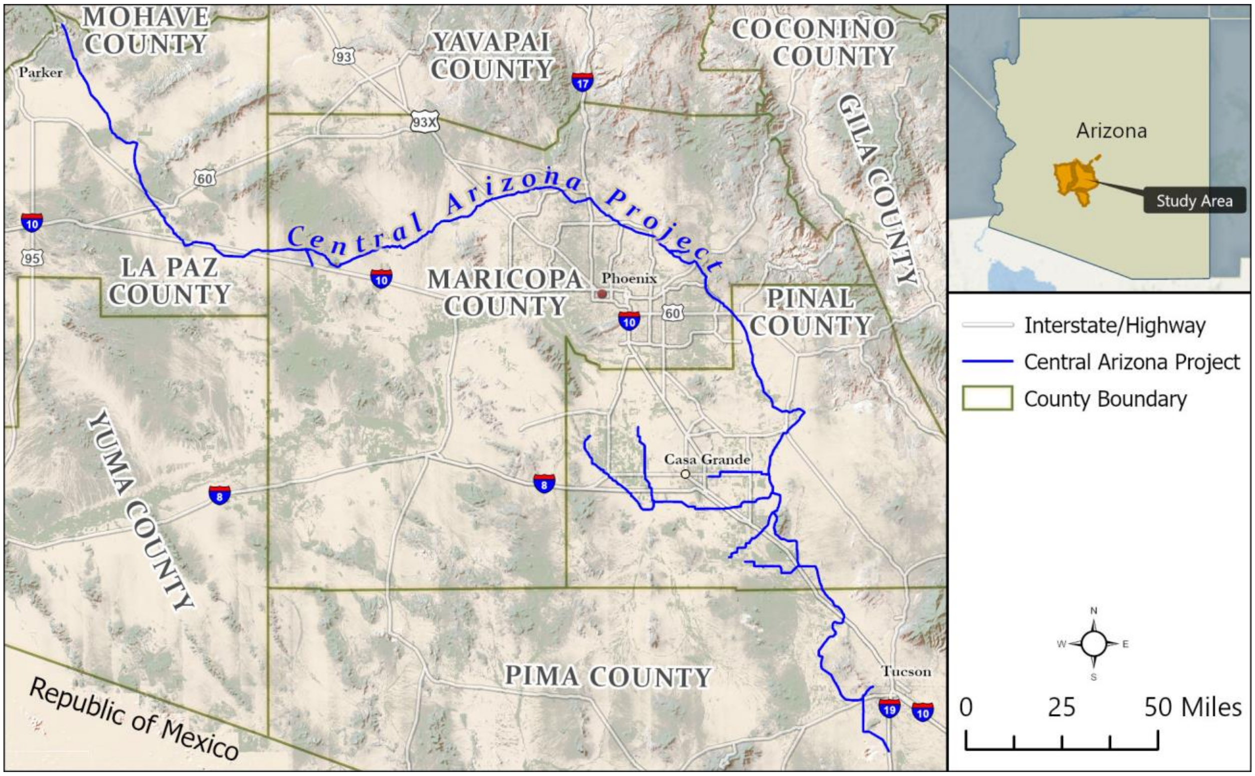

Figure 9. Central Arizona Project system map

Within Arizona, rights to CAP water were originally allocated in 1983 among Indian users, non-Indian municipal and industrial (M&I) users, and agricultural users who requested an allocation. Allocations for Indian and M&I users are fixed; however, allocations for agricultural users are calculated as a percentage of the remaining CAP water (Arizona Department of Water Resources, 1999). Contracts for the allocations are made with the CAWCD, which is also responsible for operating and maintaining CAP infrastructure and managing the repayment of the costs of CAP construction to the federal government. A good review of the CAP and its history can be found in Zuniga (2000).

CAP water allocated to study area cities are shown in Table 4. Current allocations range from 280 AF/y for Buckeye to 122,204 AF/y for the City of Phoenix. Tolleson is the only WVWA member in the West Valley that did not receive a CAP allocation. In addition, EPCOR has three allocations to serve separate areas within the study area, which includes the Agua Fria, Sun City, and Sun City West developments. EPCOR's total allocation is 17,654 AF/y. The City of Phoenix straddles both the WSRV and East Salt River Valley (ESRV) (not in study area) and its allocation is used for municipal uses in both groundwater sub-basins.

Table 4. Current CAP Water Allocations in the WSRV (AF/y)

WVWA CAP Subcontractor	2019 M&I Entitlement	Current Additional Assignments/Leases	TOTALS
Avondale	5,416	0	5,416
Buckeye	280	0	280
El Mirage	508	0	508
EPCOR Agua Fria	11,093	0	11,093
EPCOR Sun City	4,189	0	4,189
EPCOR Sun City West	2,372	0	2,372
Glendale	17,236	7,709	24,945
Goodyear	10,742	7,000	17,742
Peoria	25,236	7,000	32,236
Phoenix	122,204	67,678	189,882
Surprise	10,249	0	10,249
Totals	203,321	82,387	285,708

In addition to planning for the major SRP and CAP systems, additional water supply development began in 1922 when the City of Phoenix constructed wells in the floodplain aquifer of the Lower Verde River Valley and began withdrawing higher quality groundwater to supplement its surface water supplies from the SRP. After World War II, the Phoenix area rapidly grew in both population and spatial extent. During this time, numerous wells were constructed to provide reliable groundwater in areas where surface water supplies were unavailable due to large distances to major canals. Prolific aquifers throughout the Phoenix AMA were used to serve this growing need, but this extensive use caused major groundwater level declines throughout many areas of the AMA.

Arizona's groundwater supplies were managed through the courts until the Arizona Legislature adopted one of the most comprehensive groundwater management strategies in the U.S., the 1980 Groundwater Management Act. The GMA provides a framework intended to both protect existing groundwater water users and serve new uses with renewable supplies, thus preserving the groundwater supply for future shortages (Arizona Department of Water Resources, 2014). The GMA established a timeline for reduction and elimination of groundwater pumping in certain areas of the State, designating AMAs and Irrigation Non-Expansion Areas (INAs) to facilitate this process. Since adoption of the GMA and subsequent refinements to its mandatory water conservation requirements, Arizona has seen significant improvement in water use efficiencies (Arizona Department of Water Resources, 2010a). The AMAs have also seen a general overall benefit with rising water levels and decreasing subsidence in some areas.

Within this framework of federal, state, and regional water resource development efforts, the West Valley cities have grown using a portfolio of water supply sources that use the SRP and CAP systems, groundwater, and effluent. However, because some of these cities are located far from major delivery canal systems, they still find themselves primarily dependent on groundwater supplies to meet a sizable portion of their current water demand.

Effluent, or reclaimed water from wastewater treatment plants (WWTPs), is a growing supply in the West Valley that is typically used for landscape irrigation, agricultural irrigation, power generation, irrigating parks and schools, and artificial recharge into groundwater aquifers. ADWR defines effluent to be consistent to reclaimed water per A.S.R. §45-101 (Arizona Department of Water Resources, 2019). The largest direct user of reclaimed water (over approximately 70 thousand AF annually) is the Palo Verde Nuclear Generating Station, co-owned and operated by Arizona Public Service Company. The facility is located just west of the WSRV sub-basin in the Lower Hassayampa sub-basin (Figure 10). Additionally, part of the effluent from the cities of Glendale, Mesa, Phoenix, Scottsdale, Sun City, and Tempe is piped and treated at Phoenix's 91st Avenue WWTP. This facility accounts for most of the effluent produced in the AMA, averaging about 159 thousand AF/y since 1989 (Arizona Department of Water Resources, 1999). A portion of the reclaimed water is discharged into rivers and streams for groundwater recharge and storage. These operations often benefit the environment by providing habitat for wildlife and adding aesthetic and economic value to Arizona's landscape (Arizona Department of Water Resources, 2010a).

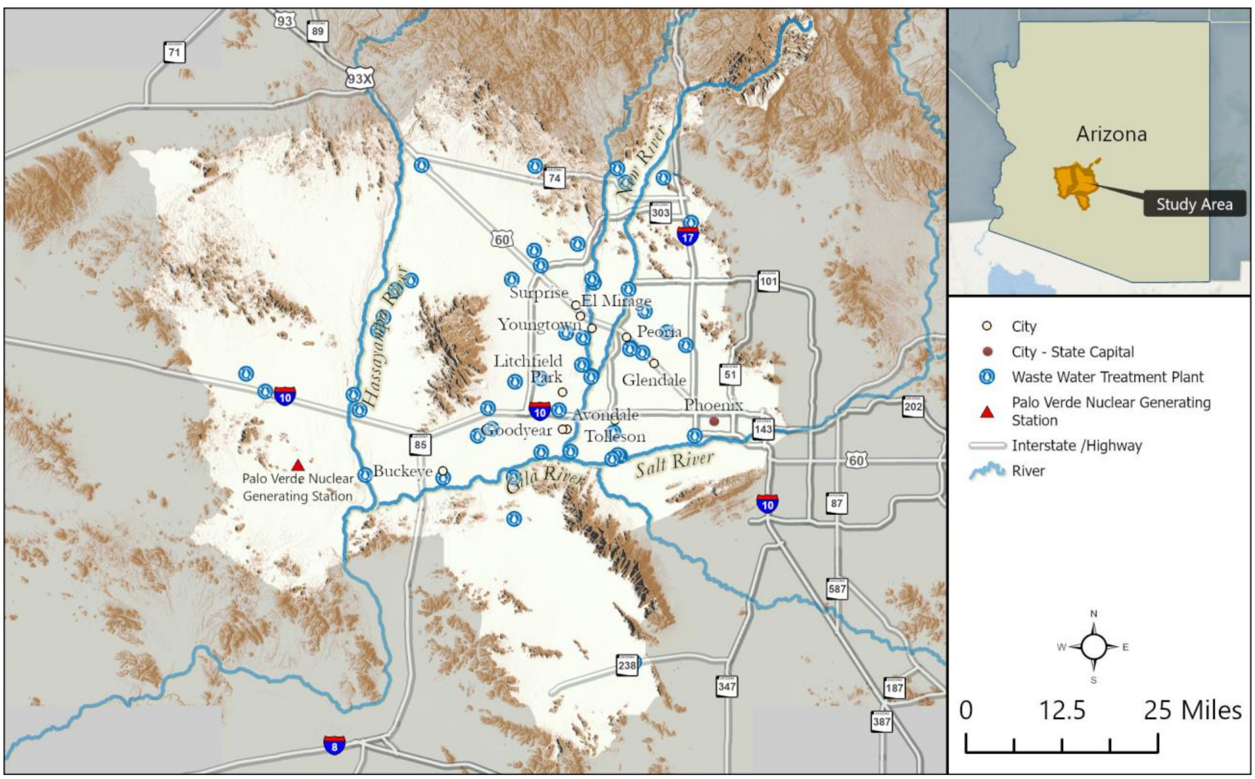

Figure 10. Location of wastewater treatment plants and the Palo Verde Nuclear Generating Station

The Arizona Department of Environmental Quality (ADEQ) is now undergoing a multiphase restructure and revision of its recycled water use rules to further utilize this resource for augmenting sustainable water supplies (Arizona Department of Environmental Quality, 2018). As part of this process, it is anticipated that its use will be expanded to include direct potable reuse (DPR) using advanced water treatment and other technologies to provide a new and reliable potable resource.

Previous achievements in water management and water supply development such as the SRP, CAP, GMA, and others have contributed greatly to supporting the state's phenomenal growth, its robust economy, attractive way of life, and protection of many of its natural resources. Arizona's future success is tied to management and development of current and new water supplies and associated infrastructure (Arizona Department of Water Resources, 2010a).

2.5 Overview of Water Supply and Demand

2.5.1 Water Supply Overview

The Phoenix metropolitan area, including the study area, generally relies on four primary water supply sources. The CAP, and to a lesser extent SRP, provide renewable surface water supplies to the area from different river systems. Groundwater wells and effluent provide additional supplies, which can be the principal sources of water for some communities in the study area due to distance to the CAP canal and other factors. The availability of a source is often governed by unique hydrologic, legal, and institutional circumstances. Wholesale providers such as the CAP and SRP, along with local municipal water providers (cities and private water companies), operate in the area to provide reliable water deliveries to industrial, commercial, and municipal water customers.

Approximately 1.5 million acre-feet per year (MAF/y) of Colorado River water can be conveyed through the CAP, which delivers the state's single largest renewable water supply. It serves about 80 of the state's population (Bureau of Reclamation, n.d. a; Central Arizona Project, 2016b).

The SRP is one of the state's largest water suppliers, providing more than 700 thousand AF/y annually to its customers. However, within the study area, only the cities of Phoenix, Peoria, Glendale, and Avondale have access to SRP water. The sources of SRP water are the Salt and Verde rivers, and about 250 groundwater wells. Those waters are delivered to customers across 375 square miles of the Phoenix metropolitan area, including portions of the ESRV and WSRV (Salt River Project, 2021c). Historically, SRP water was primarily used for agricultural irrigation. Now the vast majority of SRP's service area is urbanized and most of this water is now being served for municipal uses.

The mix of raw water sources used to meet M&I demand differs from that used for agriculture. Figure 11 provides a breakdown of water use from 2015-2019 for the different sources of raw water within the study area. Water supplies are divided between groundwater and renewable supplies. Renewable supplies are further separated among CAP water, SRP water, local surface water, effluent, and use of the Central Arizona Groundwater Replenishment District (CAGRD). To meet AWS criteria, groundwater pumping can be offset using CAGRD, generally from CAP supplies, so this is shown as a renewable source in Figure 11. Renewable supplies mostly come from CAP and SRP water, but agricultural users in the study area also use a large amount of local surface water, and growing population means that effluent use will likely grow in the future.[1] As shown, agricultural users depend heavily on groundwater, while M&I users primarily use renewable supplies.

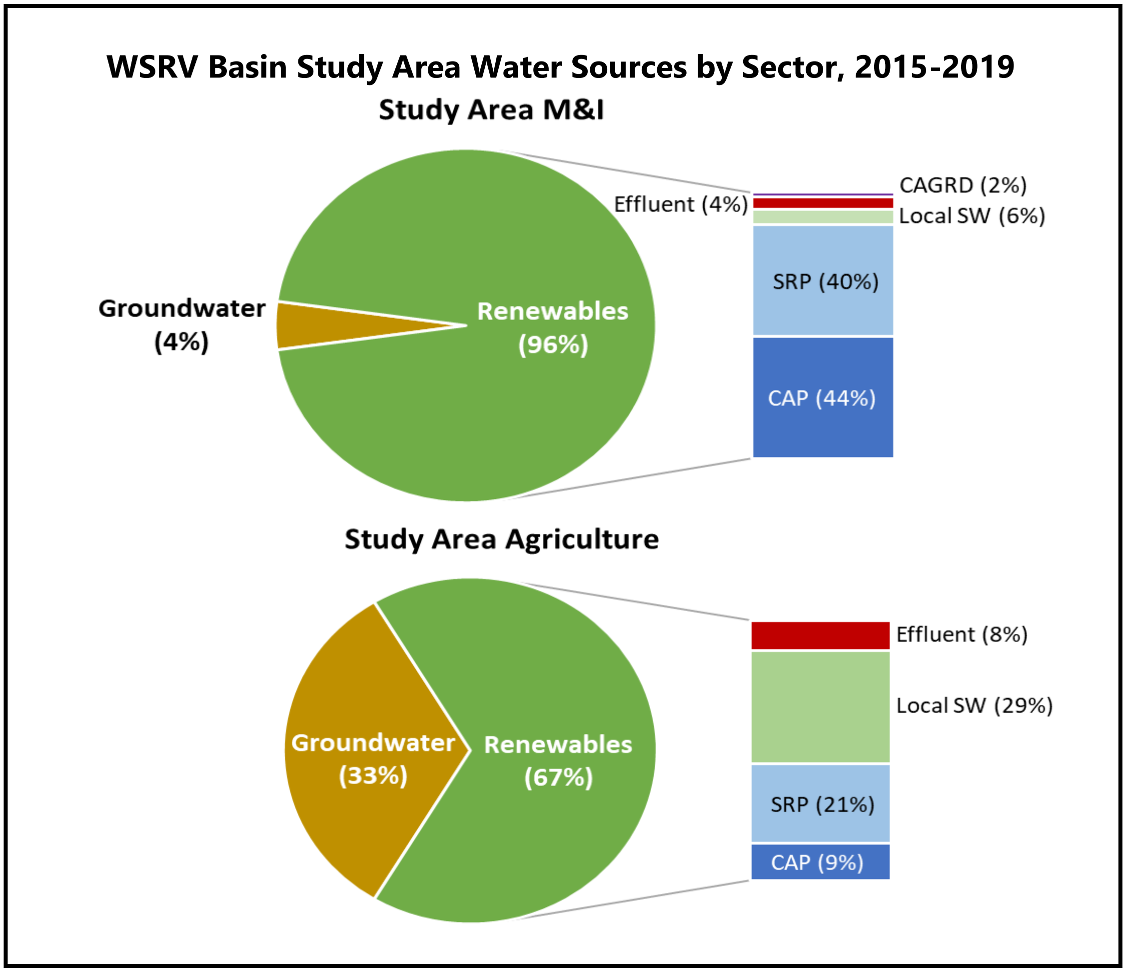

Figure 11. WSRV Basin study area water sources by sector, 2015-2019

2.5.2 Water Demand Overview

Demand within and surrounding the study area is a result of municipal, industrial, agricultural, tribal, and recreation uses. Several investigations have estimated and projected demand in the Phoenix area and the State of Arizona. An analysis completed by ADWR for the Basin and Range AMAs Planning Area (Phoenix, Pinal, and Tucson AMAs), which also includes the Basin Study area, showed that water demands in the Planning Area totaled nearly 3.7 MAF/y for municipal, industrial, and agricultural uses (Arizona Department of Water Resources, 2014). This is nearly 50 percent of the total water use in the state. Also, recent work by the state's Water Resources Development Commission (WRDC) and Reclamation's Colorado River Basin Study both concluded that between 2030 and 2060, Arizona will resume having a statewide imbalance between its water supplies and water demands. The WRDC determined that Arizona's population has grown from about 2.7 million in 1980 to 6.6 million in 2009. The population is projected to grow to about 8.5 million

[1] In-lieu use for agriculture mostly comes from CAP water and effluent, but the exact split is unknown, Figure 9 shows 90 percent as CAP water and 10 percent as effluent.

in 2035 and is expected to be about 11 million in 2060 (Arizona Commerce Authority, 2018). Concurrent with this growth, the state's water demand is expected to grow from a current level of 6.9 MAF/y to between 8.2 and 8.6 MAF/y by 2035 (Arizona Department of Water Resources, 2014). This is expected to further increase to between 8.6 and 9.1 MAF/y by 2060.

In 2010, ADWR conducted a Water Demand and Supply Assessment for 1985 to 2025 for the Phoenix AMA (Arizona Department of Water Resources, 2014). Their analysis indicated a shift in water demand from the agricultural sector to the municipal sector, which is comprised of both small and large municipal water providers (Figure 12). Between 1985 and 2017, demand from the municipal sector increased from 29 percent of the total Phoenix AMA water demand to about 48 percent of total demand (Arizona Department of Water Resources, 2019). Municipal demand has been increasing in the Phoenix AMA since 1985, peaking in 2007, which may be in part related to the past economic downturn. The industrial sector similarly had a small demand increase over the same period, from about four percent of the total Phoenix AMA demand to about eight percent. This contrasts with the agricultural demand reduction that has been observed over the same period. Demand in this sector has declined from 58 percent to 32 percent of total Phoenix AMA demand. Tribal demand, which is composed of municipal, industrial, and agricultural water uses, increased slightly from nine to about 12 percent over the same period, primarily due to increases in agricultural activity (Arizona Department of Water Resources, 2019).

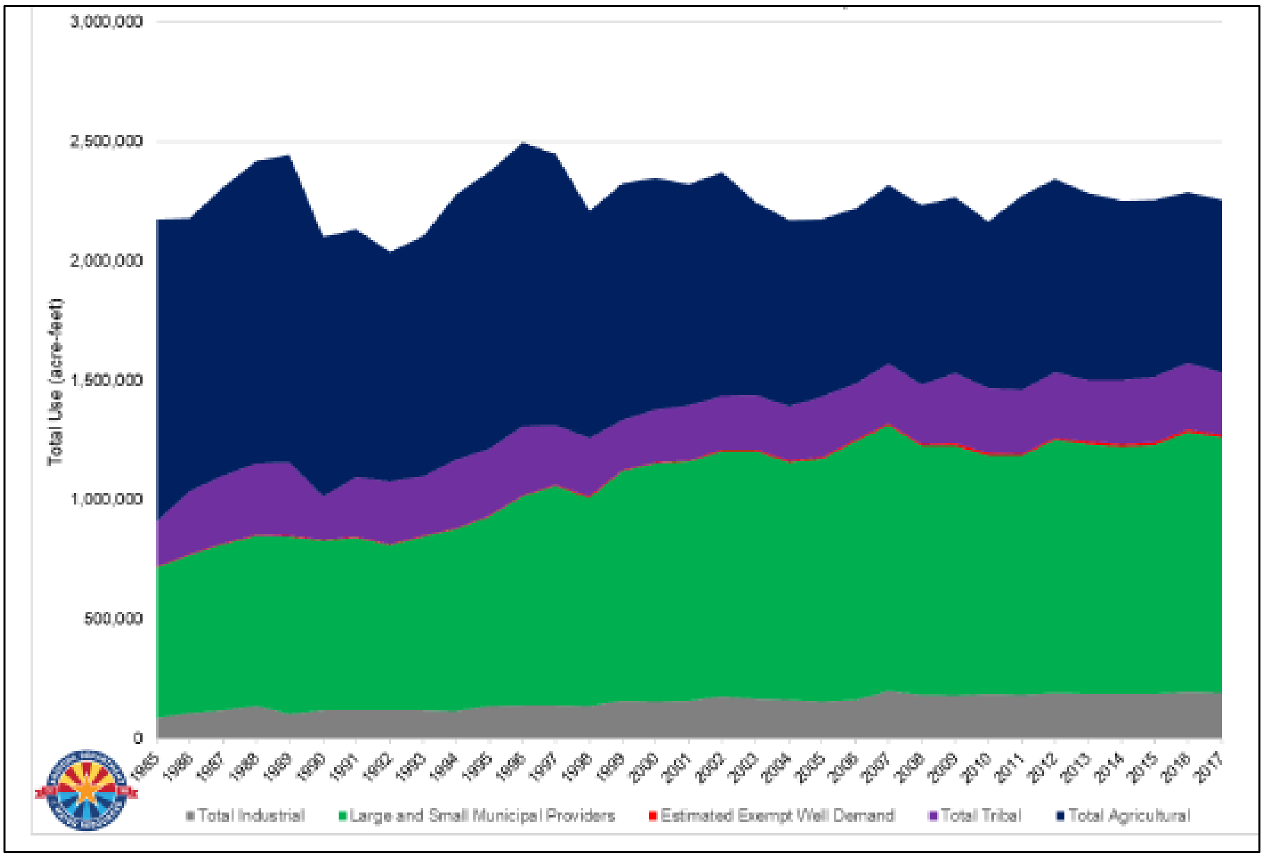

Figure 12. Phoenix AMA water demand by sector from 1985 to 2017

Market demand for water comes from municipal, industrial, agricultural, and tribal use. Non-market demand stems from instream benefits, such as recreational opportunities and water-related ecosystem services. Market demand often consists of consumptive use, while non-market demand is often non-consumptive in nature. Market demand is met using a combination of groundwater and renewable water supplies, while non-market demand primarily depends on surface water conditions. Future projections of water supply and demand in the study area predict that there will be shortages of renewable supplies and increased reliance on a diminishing groundwater supply. This will have important implications for water users in the WSRV area, as well as communities across the Phoenix AMA and the broader region that share renewable water supplies and an interdependence between groundwater aquifers.

2.5.2.1 *Municipal Demand*

Municipal water use includes water delivered for non-agricultural uses by a city, town, private water company, or irrigation district. This water goes towards residential, commercial, and any other non-agricultural use, such as construction and residential irrigation. Overall demand is composed of large and small municipal providers that provide treated water for drinking and some untreated water for residential irrigation. Municipal demand has been increasing for decades. However, over the last five years, municipalities have seen a decline on overall water use. This decline is linked to conservation efforts by the municipalities. Demand for groundwater has remained relatively constant over time as renewable supplies such as CAP water and treated effluent have been used to meet growing municipal demand. That said, continued population growth and limited water supplies are expected to lead to future shortages in renewable supplies and increased reliance on groundwater pumping.

Much of the groundwater pumped by the municipal sector, especially to serve new development, is subject to state laws that require the use of renewable supplies or recharge to offset groundwater pumping. However, not all groundwater pumping is subject to replenishment requirements. Municipal providers treat raw renewable water supplies at a water treatment facility, then deliver the water to customers using their potable distribution systems. However, some municipal providers do not have water treatment facilities. Providers lacking water treatment facilities can utilize renewable supplies through indirect recharge via underground storage/recharge and later recovery via permitted recovery wells. Nevertheless, several municipal providers remain dependent on groundwater as their sole source of supply. Some municipal providers deliver treated effluent for irrigation or for purposes such as dust control, while others store and recover treated effluent for use in their potable delivery system.

Fortunately, increased efficiency of use has been observed in all water-use sectors over time. In the municipal sector, newer homes tend to use much less water than older homes. A downward trend of gallons per housing unit per day (GPHUD) has been offset by a growing population, causing overall municipal demand to continue rising across time. The municipal sector is the dominant water-use sector in the Phoenix AMA, followed by agriculture, tribal, then industrial use (Arizona Department of Water Resources, 2019). Declines in agricultural demand have helped keep overall water demand relatively stable in recent years. Unfortunately, although agricultural demand is expected to continue to decrease, projections suggest that growth in M&I demand will outpace the decline in agricultural use. This is expected to cause overall demand for water to rise over time. The extent of future water shortages in the region therefore depends largely on M&I growth and overall demand, as well as the availability of renewable supplies under changing climate conditions.

2.5.2.2 *Industrial Demand*

The 1980 GMA defines industrial use as a non-irrigation use of water, not supplied by a city, town, or private-water company, including animal industry use. Thus, industrial use includes large turf-related facilities (greater than 10 acres), electric-power generation, dairies, feedlots, mines, and sand and gravel operations. In general, industrial users withdraw water from their own wells that are associated with grandfathered groundwater rights (GFRs) or withdrawal permits. Although industrial users are primarily dependent on groundwater, some use renewable supplies such as CAP water, local surface water, and treated effluent. Industrial use is largely dependent on population growth and the economy. As such, water use in the industrial sector has fluctuated over time but has generally been growing in the study area for decades. Fortunately, industrial use of treated effluent also increased significantly over this period, helping meet the growing industrial demand.

The power subsector is the largest user of treated effluent in the industrial sector. The electric power and turf subsectors (e.g., golf courses) have remained the dominant subsectors over time, comprising about 80 percent of total industrial demand in the Phoenix AMA (Arizona Department of Water Resources, 2019). The remaining demand is divided among sand and gravel operations, dairies, and other uses such as cooling and manufacturing. In some cases, industrial water users may acquire new groundwater withdrawal permits and may obtain, through purchase or lease, unused non-irrigation GFRs to pump groundwater. There is currently no regulatory or statutory authority to require industrial water users to convert to renewable supplies. However, some users may choose to do so voluntarily, and there are some incentives in place to encourage use of renewable supplies. Future industrial sector development will impact groundwater levels, particularly if unused GFRs are used to meet future water needs. Growing demand could also contribute to shortages in renewable supplies.

2.5.2.3 *Agricultural Demand*

The agricultural sector, comprised of farms with two acres or more that were actively irrigated with groundwater from 1975 to 1980, is heavily dependent on groundwater. Agricultural lands that used groundwater to irrigate crops during this period were issued an Irrigation Grandfathered Groundwater Right (IGFR) by ADWR. This groundwater use is not subject to replenishment requirements, but no new IGFRs may be created and the amount of land that may be irrigated in the region is limited to that which was historically irrigated. Existing IGFRs may be conveyed to a new owner, converted to a type-1 non-irrigation GFR, or extinguished for credits. Agricultural demand has been falling over time, with groundwater demand decreasing while the use of renewable supplies, such as CAP and SRP water, has been relatively stable (Arizona Department of Water Resources, 2019). Many irrigation districts utilize "in-lieu groundwater" by becoming permitted as Groundwater Savings Facilities (GSFs) and using renewable supplies (mostly CAP water and effluent) in place of groundwater pumping. This is sometimes referred to as indirect recharge.

Agricultural use represented the largest demand for water in the Phoenix AMA until 1999, when the municipal sector matched the agricultural sector, eventually becoming the dominant water-use sector (Arizona Department of Water Resources, 2019). Much of the decrease in agricultural water use can be attributed to urbanization of agricultural lands. Overall water demand is likely to decline for agriculture in the future, but the reduction is expected to be less than the increased demand for M&I uses. This could reduce the availability of renewable supplies and increase the region's reliance on groundwater. For many, the cost of using renewable supplies is higher than the cost of pumping and using groundwater, even as water levels decline. If existing IGFRs continue to be used, additional renewable water supplies and enhanced irrigation efficiency and management practices may be needed to meet future water demand.

2.5.2.4 *Tribal Demand*

Water demand for Tribes is composed of municipal, industrial, and agricultural demand on tribal land. Most of the demand is for agriculture use, with a portion going to municipal use. Tribal water use is exempt from state regulation but can nonetheless have impacts on aquifers in the region. There are 22 federally recognized tribes in Arizona of which 14 have either fully resolved or partially resolved CAP water right claims. Approximately 46 percent of the CAP water supply is expected to be permanently allocated to Arizona Indian tribes.[2] There are no tribal users directly located in the study area, but tribal use is included in the regional supply and demand projections due to linkages with regional water conditions. Furthermore, several municipal, industrial, and agricultural users rely on agreements with tribal users to lease and exchange water rights. Tribal demand is expected to remain relatively stable into the future, with less population growth for tribal communities than the urbanized areas within the study area.

2.5.2.5 *Recreation Demand*

The Salt, Verde, and Agua Fria rivers, and lakes and reservoirs along the rivers are key sources for recreation and outdoor activities in the greater Phoenix metropolitan area. These water bodies provide year-round swimming, boating, fishing, hiking, camping, picnicking, and wildlife viewing opportunities. Given that streams and washes in the study area are ephemeral, individuals also frequently use water canals and laterals for various recreational opportunities. This includes walking, running, bicycling, and fishing. Water demand for recreation is typically non-consumptive and difficult to measure, but recent efforts have begun to evaluate water demand for outdoor recreation in Arizona.

According to a 2019 Audubon report, *The Economic Contributions of Water-Related Outdoor Recreation in Arizona*, more than 1.5 million residents in Arizona take part in outdoor recreational activities on or along water in the state, which equates to a participation rate of 28 percent. Residents spent 48 million days recreating on or along the water in 2018. The report stated that the most popular activities were picnicking or relaxing (18.2 percent), trail-related activities (12.5 percent), fishing (10.7 percent), water sports (10.5 percent), and wildlife watching (10.4 percent). Audubon also found that for Maricopa County, residents spent 17 million days recreating, which generated an estimated $5.3 million in economic output, contributed $2.8 million to the state's $370 million total GDP, supported 43,600 jobs, provided $1.7 billion in household income, and generated $724 million in tax revenues (Federal Reserve Bank of St. Louis, 2020; Southwick Associates (for Audubon Arizona), 2019). Managing surface water supplies is therefore not only important for providing reliable water for market uses, but also for supporting instream uses such as recreation.

[2] Information on CAP tribal water use can be found at: https://www.cap-az.com/about-us/tribal-water.

2.6 Anticipated Future Challenges

As part of its analysis, this study considered the challenges to maintaining reliable water supplies into the future while meeting regulations and management goals. The anticipated challenges relate to escalating pressures on regional water supplies associated with continuing demand-growth in the Phoenix metropolitan area and throughout the Southwest. Climate change and drought impacts will likely exacerbate these pressures by altering temperature and precipitation patterns. The supply and demand analysis, climate change analysis, and the groundwater model scenario results completed as part of this study highlight these challenges. While this study provides some new insights and analyses, the challenges identified here are consistent with those identified in other planning efforts in the state and region.

To meet these challenges, ADWR, SRP, CAP, and many large and small municipal water providers have used methodical approaches to supply management and planning, infrastructure management, conservation, and drought preparation. These types of efforts will continue. Coordination of these efforts into a long-term effective strategy for the WVWA is a key challenge being addressed, in part, through this Basin Study.

This study does not address every potential challenge or potential solution such as forest management and watershed health, reservoir capacity management, weather modification, phreatophyte management, exempt well pumping (less than 35 gallons per minute), and pending Colorado River management negotiations. Many of the study partners are involved in these activities, and they will be considered in future management planning as appropriate.

The following sections outline some of the primary challenges that water resource planners are currently addressing and will continue to address in the future. Potential future conditions that will affect these challenges are further described in Section 4.

2.6.1 Water Availability

The overall water availability challenge is to meet a growing demand by finding new supplies, fully utilizing existing supplies, and planning for potential reduction to current supplies. Competition for additional supplies poses a challenge for the study partners. Not only does the West Valley anticipate increased demand over time, but other areas are experiencing growth as well, such as the adjacent East Valley. Therefore, collaboration among providers will be required to develop new and manage existing supplies for the benefit of all users.

A significant portion of the study partners' water supply comes from the Colorado River through the CAP. The Colorado River is managed and operated under numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines collectively known as the "Law of the River". This collection of documents apportions the water and regulates the use and management of the Colorado River among the seven basin states and Mexico (Bureau of Reclamation, n.d. c). The "Law of the River," associated guidelines, and operational rules related to Arizona are well documented in many reports issued by government agencies (e.g., ADWR, CAP, Reclamation).

A significant challenge to the study partners is potential reduction to the Colorado River supply delivered through the CAP canal. This is known as a Colorado River Shortage (Arizona Department of Water Resources, 2015a). Because the Colorado River supply helps reduce reliance on local groundwater sources, a shortage may increase groundwater use and impact aquifer conditions. This potential decrease in the existing supply exacerbates the challenge of finding additional supplies to meet new demands.

Drought and climate may also affect within-state surface water availability and create a similar supply challenge. The impacts of drought and aridification on the Colorado River and in-state watersheds are uncertain. However, if these influences result in reductions of local renewable water supplies, portions of historic supplies may need to be replaced *in addition to* those obtained for new development.

2.6.2 Aquifer (Groundwater) Management

Continued and increased groundwater use can lead to undesirable water level declines and associated land subsidence (Conway, 2015) which creates an aquifer management challenge for the study partners. Groundwater is and will remain an important non-renewable water supply in the study area. Maintaining groundwater levels and preventing overdraft, as well as associated land subsidence, is a primary objective of the study partners. Land subsidence is discussed in Section 2.6.3, below.

ADWR is the regulatory agency responsible for overseeing management of Arizona's finite groundwater resources in accordance with the 1980 GMA (Arizona Department of Water Resources, 2021a). ADWR also identifies and designates areas with heavy reliance on non-renewable groundwater as AMAs and creates Management Plans for each to help water providers achieve AMA goals (Arizona Department of Water Resources, 2019). The study area is within the Phoenix AMA and is subject to regulation pursuant to the GMA. In the Phoenix AMA, the primary management goal is safe-yield by the year 2025. Safe-yield is accomplished when no more groundwater is being withdrawn than is being replaced annually. Several management tools and programs are available to water providers in the AMA, such as limits on groundwater use, permitting and reporting, conservation requirements, and underground water storage through recharge (replenishment) (Arizona Department of Water Resources, 2016).

Notwithstanding the groundwater regulations and ADWR efforts, there are significant challenges associated with groundwater use and aquifer protection. For example, the disconnect between where pumping of recharge credits occurs and where recharge occurs can lead to local undesirable water level declines even while complying with regulatory requirements of an AMA-wide balance. Water managers would like to continue to use recharge to offset groundwater pumping as much as possible. As a result, a challenge for the study partners was to find new or expanded recharge sites that lessen the disconnect and associated undesirable localized-aquifer decline. One way to minimize this is through aquifer storage and recovery wells that both recharge and recover water in the same well.

Until West Valley providers can afford and acquire renewable water supplies to replace groundwater pumping, many will continue to rely on the CAGRD. The CAGRD uses groundwater to serve developments and to comply with the state's AWS regulations. The CAGRD then recharges renewable water, such as CAP supplies, in the amount of groundwater withdrawn. While this poses challenges because of near- and long-term uncertainty associated with the sustainability of the CAGRD model, an even greater concern may be the reduction of groundwater quantity and quality within service areas. Concentrated, ongoing withdrawals from the study area have the potential to create problems such as land subsidence and fissuring, infrastructure damage, declines in water quality, and increased pumping costs. This is especially true when CAGRD replenishment does not occur in the area of groundwater withdrawals.

2.6.3 Land Subsidence

A significant challenge to water providers in the Phoenix AMA is land subsidence due to water level decline in aquifers, and the resulting effects on infrastructure (e.g., broken pipes, change in grade) and the aquifer's lost ability to store water. Land subsidence is the lowering in elevation of land-surface levels, which is largely the result of groundwater extraction. Subsidence is caused by the collapse of open-pore spaces in subsurface aquifers, an unseen water-storage catastrophe in the making. Pore spaces can collapse when they are no longer supported by water pressure because that groundwater that once filled the pore spaces has been pumped to the surface. In general, the closure of these pore spaces and subsequent ground compaction cannot be undone, resulting in a permanent reduction in the aquifer's storage capacity (Arizona Department of Water Resources, 2021d; Arizona Department of Water Resources, 2019).

ADWR is the principal agency responsible for identifying and monitoring active land subsidence areas in Arizona. Effective September 21, 2006, A.R.S. 27-152.01(3) requires the Arizona Geological Survey to complete comprehensive mapping of earth fissures throughout Arizona and provide earth fissure map data to the Arizona State Land Department. This information is available online with other GIS map layers for public use (Arizona Department of Water Resources, 2021d).

Land subsidence first became apparent in the WSRV sub-basin in the 1950s following dramatic increases in groundwater pumping for agricultural irrigation beginning around 1940 (Schumann & O'Day, 1995; Cook, 2013). Between 1957 and 1992, the land under the intersection of West Olive Avenue and North Reems Road, near the geographic center of the study area, sunk by 18.2 feet (Arizona Department of Water Resources, 2019; Galloway, Jones, & Ingebritsen, 1999). ADWR has been monitoring one large subsidence area within the WSRV, called the West Valley Land Subsidence Feature (Arizona Department of Water Resources, 2021d). While subsidence rates have slowed with reduced groundwater pumping, the ground across a large swath of the study area is still sinking (Neeley, 2011). In addition to a permanent loss of aquifer capacity, subsidence can cause other potentially damaging changes.

When subsidence occurs across areas with different alluvium thicknesses, differential subsidence can occur when adjacent areas subside at different rates (Arizona Department of Water Resources, 2021d). For example, bedrock will not compress like the surrounding alluvium, causing differential subsidence. The differential subsidence occurs in areas where shallow bedrock rapidly changes to deep bedrock, thus creating a zone of differential change in surface elevation. These differential amounts of subsidence can cause tension to build in the alluvium layer, consequently forming an earth fissure. Geologists first documented earth fissures in the study area in 1959 just east of Luke Air Force Base (Cook, 2013). The Base sits on top of a massive salt deposit known as the Luke Salt Dome. The Salt Dome is roughly 500-1,000 feet below the surface just east of the Base, with increasing depths toward the edge of the deposit. Varying depths to the Salt Dome create different alluvium thicknesses and potential for subsidence-induced fissuring.

Subsidence and fissuring from excessive groundwater pumping in the study area have already led to millions of dollars in damages (Arizona Geological Survey (University of Arizona), n.d.). In 1992, a high-intensity storm overtopped the Dysart Drain flood control structure, causing $3 million in damages and costing $16 million to repair. Land subsidence changed the Drain's slope significantly, reducing its carrying capacity (Schumann & O'Day, 1995). More recently, engineers designed Arizona State Route 303L (Loop 303) to mitigate the impact of multiple Earth fissures that the roadway crosses near the Northern Avenue Parkway (Neeley, 2011).

While subsidence and fissuring in the study area have slowed significantly, they remain a major concern given the damage they can cause to infrastructure (Davis, 2018). If groundwater pumping to supply new development is not adequately or proximally replenished with renewable supplies, rates of subsidence and fissuring could increase again, potentially in new locations.

2.6.4 Water Quality

In addition to physical water-availability challenges, the study area has groundwater quality challenges. All community water systems are regulated under the Safe Drinking Water Act and treat water supplies to meet drinking water standards. In order to continue to meet water quality standards, managing water quality into the future will require continued monitoring and treatment. This challenge will increase as providers explore using poorer quality sources to meet the projected increased demand.

The quality of water for the surface water sources (SRP and CAP) supplying the WSRV are generally acceptable for agricultural purposes (Reeter & Remick, 1986). SRP water has been used for agriculture in the region since the 1900s. However, total dissolved solids (TDS) concentrations can be an issue for some municipal water providers and industrial users, especially those using CAP water in which TDS tends to be higher than in SRP water.[3]

Groundwater within the Phoenix AMA may have some areas where concentrations of nitrate, fluoride, chromium, and arsenic exceed state and/or federal drinking water standards. Also of concern are several organic chemicals derived from industrial sources, including tetrachloroethylene (PCE), trichloroethylene (TCE), perchlorate, and other chemicals (Towne & Jones, 2011; Arizona Department of Water Resources, 2010b).

TDS concentrations in groundwater can vary widely in the Phoenix AMA. Water quality is generally best along mountain fronts due to higher aquifer recharge from precipitation. TDS concentrations tend to increase towards the Salt and Gila rivers as water quality tends to degrade. Specific conductivity values for groundwater can vary widely depending on location (Reeter & Remick, 1986). Water quality issues can be worsened by water level decline because of a general decrease in water quality with depth. The WSRV has an area that has significant salt production, leaving a portion of the groundwater unusable for potable purposes. Some areas of the aquifer, such as the Buckeye Waterlogged Area, have poor quality water near the surface (Arizona Department of Water Resources, 2015b)

The magnitude of the salinity issue is unclear. Water providers in central Arizona decided to work together to assess the problem and develop regional strategies for managing it, if necessary. To accomplish this, the Central Arizona Salinity Study (CASS) was initiated in 2001 to examine the problems created by the importation of salts into central Arizona. CASS began through a

[3] TDS concentrations are a general measure of water quality, which can be determined from specific conductivity measurements of the water. TDS concentrations in milligrams per liter (mg/L) can be estimated by multiplying the measured specific conductivity (in microsiemens) by 0.60 (Reeter & Remick, 1986).

cooperative partnership between Reclamation and the Sub-Regional Operating Group (SROG), which is represented by the cities of Glendale, Mesa, Phoenix, Scottsdale, and Tempe. In addition, the cities of Chandler, Goodyear, Peoria, Surprise, and Tucson; the towns of Buckeye, Gilbert, and Oro Valley; and the water suppliers Arizona-American Water Company, Arizona Water Company, and Queen Creek Water Company joined the CASS and financially contribute to the ongoing effort.

2.6.5 Ability to Deliver Water

While the current infrastructure, with appropriate maintenance and replacement, is sufficient to deliver water to most existing users into the near future, additional infrastructure will be needed for new growth. However, existing infrastructure cannot adequately deliver existing surface water supplies to customers. As noted in Section 2.6.2, water providers have significant concerns about reliance on often unrealistic transport through the aquifers to connect recharge and recovery at a distance.

The location and amount of development, as well as the type and location of the water source, will need to be assessed to determine the infrastructure needs. The challenge will be to identify and plan for these needs in a timely and cost-effective way. Existing conveyance infrastructure likely will be the first choice for "new" water, but depending on the needs and location, it may not be enough. Additionally, it is likely to become increasingly difficult to fund and site new projects in ideal locations. Existing and planned land uses of higher economic value will compete with water-related projects. Yet, it will be important for storage, recovery, treatment, and conveyance mechanisms for projects to be near the point of use. This will require investment commitments and engineering solutions. Partnerships and mutually beneficial agreements have been advantageous in the past. In the future, new cooperative efforts will be desirable to maintain delivery of reliable supplies.

2.6.6 Managing with Uncertainty

Acknowledging and managing with uncertainty is a familiar challenge to water managers. The sources of uncertainty should be identified and quantified where possible. In particular, quantifying uncertainty in water resource planning can improve the reliability of the water management strategies chosen, reduce the cost of implementation, and help water supply managers adapt more effectively to unexpected changes in circumstances (e.g., a drought worse than the drought of record or a failure of an existing major water supply) (Singh, et al., 2010). Uncertainty in climate, water supply, demand, and reliability of management-strategy may impact managers' decisions. Additionally, the respective rates of growth, locational details, and economic conditions confronted by each utility are often difficult to predict with a high degree of certainty. New water markets, funding, legislation, and regulations may also constrain water providers. Better-informed decisions will be possible as certainty increases, but monetary and infrastructure investments generally need to be made ahead of growth so that economic opportunities can be seized. Therefore, water managers know they will need flexible and adaptive approaches. Risk-based decision approaches to cope with uncertainties will be required throughout the entire management process. Furthermore, while creating some certainty, rigid regulations can hinder the implementation of flexible and adaptive management (Hollermann & Evers, 2017).

2.6.7 Legal and Regulatory

In addition to physical availability of water, water managers will need to balance legal and regulatory frameworks at local, state, and federal levels. All strategies to address water resource needs must comply with applicable legal and regulatory frameworks. Water providers will work within existing policy constraints or identify and promulgate new policies. Legal and regulatory challenges center on changes to existing regulations and the adoption of new policies.

For example, the Colorado River water supply is currently managed under the Colorado River Drought Contingency Plans (DCP) that will expire in 2026 (Bureau of Reclamation, 2019). The DCP is a temporary measure that will be renegotiated, and a new set of guidelines will be implemented in 2026.

Additionally, a key element of the 1980 GMA was its series of "management plans" for groundwater users in the state's five Active Management Areas. These plans are designed to help users conserve groundwater and assist toward achieving their industry's AMA management goals, with the ultimate goal of reaching safe yield. Water providers in the Phoenix AMA are currently operating under the 4th Management Plan (for the period of 2010-2020) (Arizona Department of Water Resources, 2019) and the state is working on a new 5th Management Plan (Arizona Department of Water Resources, 2021). Also, the state reviews and is renewing several required Designations of Assured Water Supply which may impact the quantity of groundwater a provider may use (Arizona Department of Water Resources, 2021). It is conceivable that the state-imposed 1,000-foot maximum depth-to-water below land surface in select wells could be exceeded in some instances and thereby reduce the amount of available groundwater. This could jeopardize the validity of a utility's required Designation of Assured Water Supply. The results of these activities may create unexpected challenges to water providers in the West Valley.

Water rights adjudications in the Gila River basin and elsewhere in Arizona may have impacts to water users in the Phoenix AMA. General stream adjudications are judicial proceedings to determine the extent and priority of all water rights in an entire river system. Arizona is undertaking a general stream adjudication of both the Gila River and the Little Colorado River systems (The Judicial Branch of Arizona in Maricopa County, 2021). The results of the adjudication may impact water availability for users in the study area.

2.6.8 Fish and Wildlife Habitat

The Basin Study area is located within the Sonoran Desert, the most biologically diverse desert in the world, covering approximately 100 thousand square miles of the Southwest U.S., extending into northern Mexico (Maricopa County Parks and Recreation, 2019).

The WSRV lies at the confluence of five major waterways: the Gila, Salt, Verde, Hassayampa, and Agua Fria rivers. Together these rivers drain nearly one-half of the state's land area as they flow through Maricopa County in a general northeast to southwest direction (Arizona Game and Fish Department, 2012). An extensive system of washes drains into these major rivers and contributes to an interconnected network of habitat for wildlife. Riparian habitats along these corridors support many species designated at the state or federal level as threatened, endangered, or sensitive, including the bald eagle, Yuma clapper rail, and many species of native fish. These rivers and washes provide critical habitat and movement corridors for a large variety of desert wildlife including mule deer, javelina, bobcats, mountain lions, and many other smaller mammals, birds, reptiles, and amphibians. Overall, wildlife associated with Sonoran Desert biotic communities and riparian habitats in Arizona are some of the most diverse in the U.S. (Hoffmeister, 1986).

Desert washes provide important habitat for breeding and migratory bird species. Some of the river stretches are supplied by effluent water delivered from water treatment plants (e.g., Tres Rios restoration project) (City of Phoenix Water Services, 2021). Use of the effluent elsewhere will negatively affect the habitat. The challenge is to protect habitat while maximizing use of the water supply.

2.6.9 Collaboration

The West Valley water providers realize that growth in other parts of the region and state will create competition for new renewable supplies. The competition for water may result in increased costs and competition between suppliers for limited amounts of available water. Additionally, managing land development practices with water resource sustainability in mind is a challenge that may become more acute with diminished future supplies. In this context, cities, towns, and private water providers will need to collaboratively align water use and land use planning, and strategically manage water supplies.

The challenge is creating a shared vision and collaborative approaches that benefit all users. This includes cooperation among the partners, subsets of partners, or with partners outside of the study area. An additional challenge will be identifying and implementing collaborative opportunities. While study area cities currently have integrated planning, improved collaboration between land use planning, economic development, and water resource departments will likely become even more critical in the future.

3. Pre-Adaptation Scenario Planning Approach

To better characterize relevant problems and needs for the West Valley, a set of potential future conditions was developed and analyzed. Potential future conditions for this study are represented by a set of scenarios that include projections of population growth and water supply and demand, and results of a climate change analysis. Key scenarios were input to a numerical groundwater model and the model results were used to inform the discussion regarding adaptation needs, such as water supply volumes, demand distribution, and water system needs and opportunities.

The planning scenarios are not predictions of the future. This study recognizes that water providers will take water resource development and adaptive actions between now and the end of the study period in 2060. The future conditions described in this section are properly characterized as components of planning scenarios. Therefore, the main purpose of the scenarios is to define planning assumptions and provide a basis for modeling and defining the adaptation strategies. The pre-adaptation work was used to quantify a range of what the region may need to adapt to in the future.

Future conditions considered in this study include:

- Climate change effects on water supplies and demand
- Population growth patterns
- Water demand increases associated with the growth
- Water supply
    - Colorado River supplies delivered through the CAP
        - Law of the River (Colorado River Water Law)
        - Colorado River Drought Contingency Plans (DCPs)
        - Shortage sharing
    - Local and regional supplies
- Effects of future water demand on groundwater conditions and aquifer health
- Water delivery operations (infrastructure needs, collaboration)

The sections below summarize the climate change analysis, and supply and demand modeling using the Central Arizona Project Service Area Model (CAP:SAM), the numerical groundwater model development and use, and the GIS-based Recharge Site Suitability Model. Climate change modeling considered a range of changes to precipitation and temperature patterns and their effects on stream flow and evapotranspiration. The CAP:SAM quantified a range of growth and demand patterns, existing supplies, and potential shortages to the CAP and SRP deliveries to the study area. The groundwater model was developed to provide a tool to examine potential future conditions based on pumping patterns and recharge characteristics. The recharge site suitability model is a GIS tool developed to analyze the study area for potential locations for a recharge site. Detailed technical documentation for these analyses is provided in Appendices B, C, D, and E.

3.1 Climate Change Modeling

Climate change scenarios and models were used to evaluate potential impacts on water supply and demand. Climate may be generally described as average weather (e.g., temperature and precipitation), typically considered over decades as opposed to days or weeks. A climate model is a representation of the physical, chemical, and biological processes that affect the climate system. In the climate change analysis, climate data and land characteristics were input to a surface hydrology model to evaluate historical trends and projections of climate.

The climate change analysis performed for this Basin Study is consistent with past and recent climate change analyses conducted by Reclamation for other river basins and uses the best available data, methodologies, and processes. The *West Salt River Valley Basin Study Climate, Hydrology, and Demand Projections* technical memorandum (TM) is included in Appendix B. The TM documents the climate change scenarios, hydrologic projections of local surface water supply, hydroclimate datasets developed, and projections of agricultural water demand and describes in detail the process and methodologies used to simulate and project climate change for this Basin Study.

The results of the climate change analysis were combined with water user supply and demand projections (CAP:SAM, Section 3.2, below) to create a set of scenarios for evaluation by a groundwater flow model (Section 3.3, below).

3.1.1 Climate Change Modeling Methodology

Climate change scenarios for the WSRV Basin Study are based on downscaling global climate model projections available from the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP). Figure 13 depicts the generalized downscaling methodology used for this analysis. The hydrologic analyses were developed based on the CMIP Phase 5 (CMIP5) projections (World Climate Research Programme, 2021a). The CMIP Phase 3 (CMIP3) projections were used for the demand analysis (World Climate Research Programme, 2021b).

The climate change scenarios for both the hydrologic and demands analyses were developed using the ensemble informed hybrid delta (HDe) method described in Hamlet, et al., 2013. For this study, the future period, referred to as the 2060s, is defined by the 30-year range 2045-2074 for the hydrologic analysis and 2040-2069 for the demand analysis. The choice of these periods only reflects a representative planning period. The apparent inconsistency in the definitions of supply and demand periods arises from previous studies relevant to this Basin Study, specifically the Colorado River Basin Study (Bureau of Reclamation, 2012) and the Agricultural Water Demands Study (Bureau of Reclamation, 2015) that were leveraged for this study. The choice of the 2060s as the future was identified by the study partners as the planning horizon of interest.

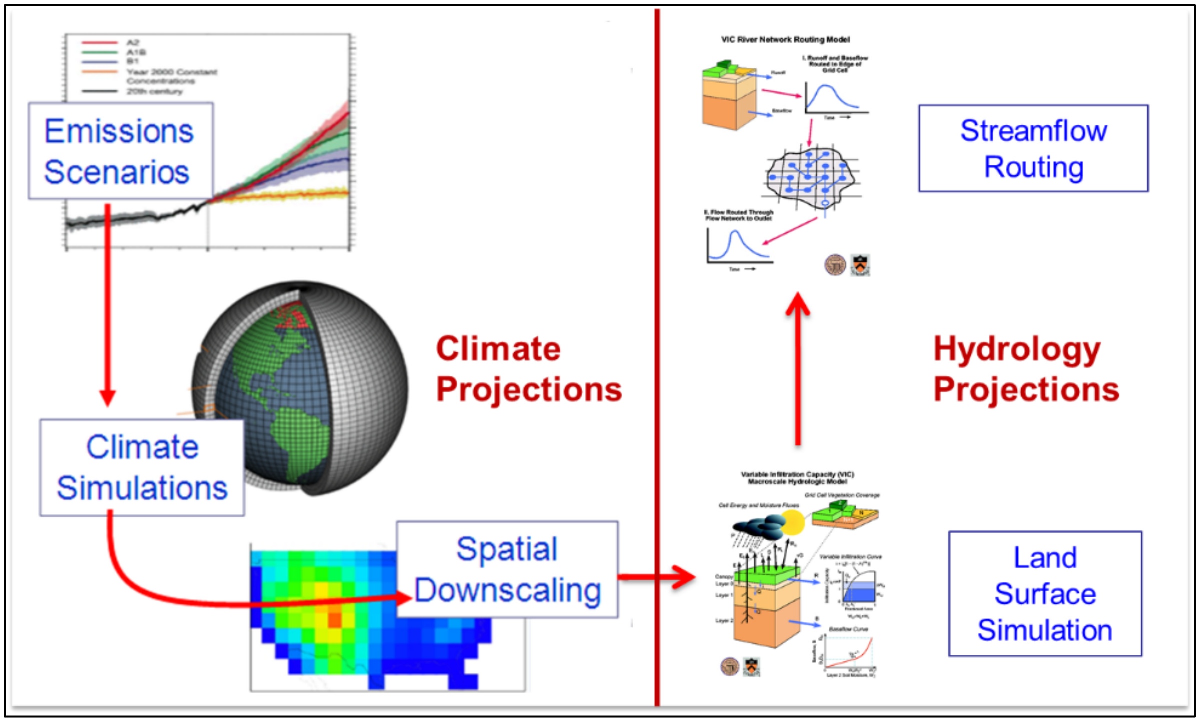

Figure 13. Climate change modeling downscaling methodology

The Variable Infiltration Capacity (VIC) surface water hydrologic model was used to generate five HDe hydrology scenarios based on the associated HDe climate change scenarios. Simulated routed streamflows were developed at 16 stream locations (Figure 14) for historical baseline conditions and the five HDe climate change scenarios. Additional simulations of climate change scenarios for three streamflow sites on the Salt, Verde, and Agua Fria rivers were made using a second hydrology model, the Sacramento Soil Moisture Accounting model (SAC-SMA), and results were compared with those from the VIC simulations. In addition, to support the groundwater modeling efforts for the Basin Study, transient streamflow change factors were calculated for all stream locations for use in the groundwater model simulations using the climate change scenarios.

Estimated agricultural irrigation demands under climate projections-based change scenarios for the study area are summarized from a previous study (Bureau of Reclamation, 2015) that includes estimated changes in crop irrigation demand in eight major river basins across the western U.S.

The hydrologic analysis was done at the six-digit Hydrologic Unit Code (HUC6) level and the results are presented and discussed for each HUC6 sub-basin within the study area. The region defined by the HUC6 with streams contributing to the study area water supply is shown in Figure 15. This includes the Salt, Verde, Agua Fria, Hassayampa, and Gila rivers as well as other smaller intermittent or ephemeral streams. The climate change study area is not identical to the study area of the Basin Study. Reference to the study area in the climate change analysis technical memorandum includes this HUC6 region because the water supply is dependent upon these streams.

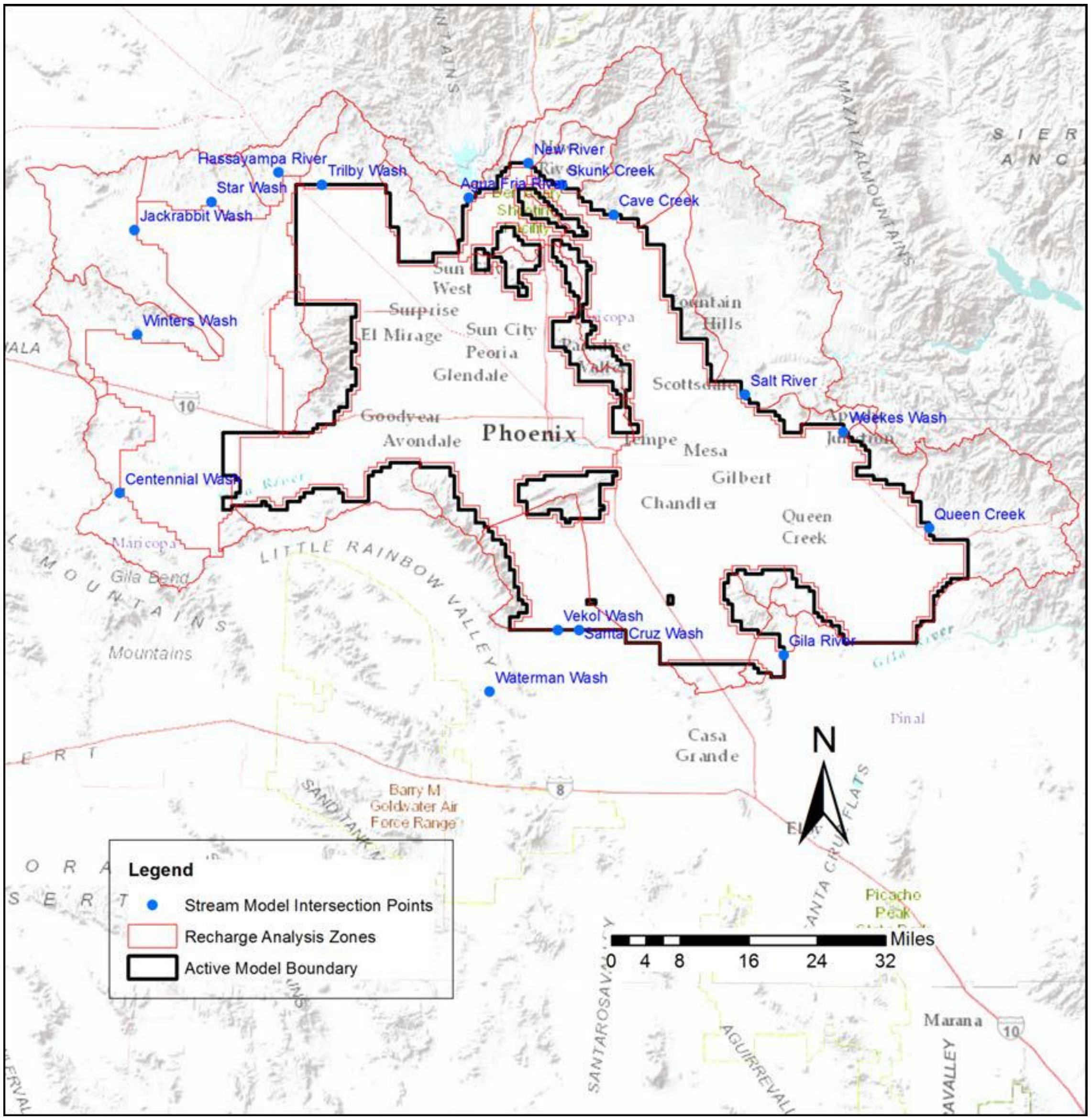

Figure 14. Map of the Salt River Valley including the study area showing stream intersection locations and recharge analysis zones for climate change analysis (blue). Note: Active model boundary in this figure is for Salt River Valley Groundwater Model and is not the study area.

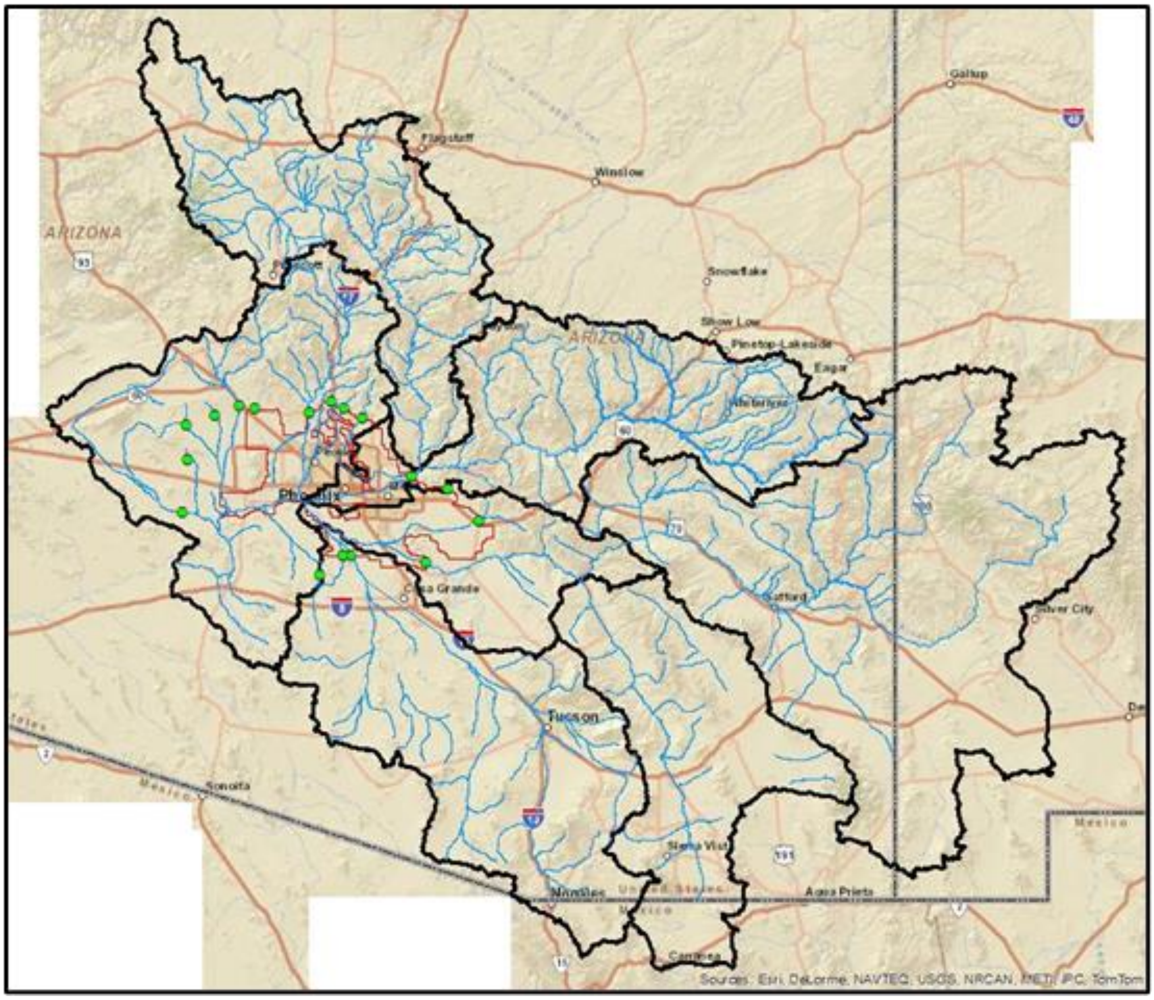

Figure 15. Map of HUC6 areas (black line) with streams contributing to the study area water supply. Stream locations (filled green circles) and the active groundwater model boundary (red line) are also shown.

3.1.2 Results of Climate Change Modeling

All five scenarios indicate warmer mean annual basin-wide temperatures than the historical (1950-1999) value of 59.3 °F, ranging from an increase of 2.8 to 6.9 °F. Changes in projected mean annual basin-wide precipitation range from -12.9 to +10.0 percent change from the historical value of 15.9 inches. Table 5 summarizes projected precipitation and temperature changes for these five scenarios.

Monthly streamflow results show, generally, the warm-wet (WW) scenario produces the largest streamflow in the winter and spring months with the hot-wet (HW) scenario producing the largest streamflows in the summer and early fall months. The smallest streamflows are usually seen in the hot-dry (HD) scenario. The baseline and central tendency streamflow results are similar. For a more detailed explanation of these results refer to the technical memorandum in Appendix B.

SAC-SMA streamflow simulations for the Agua Fria, Verde, and Salt rivers for five HDe hydrology scenarios were produced and compared with VIC simulation results to explore the effects of using different models and parameterizations on simulated streamflow results. In general, the shapes of the mean monthly streamflow traces are similar between the SAC-SMA and VIC results; however, the VIC streamflows have greater variability in most months compared to the SAC-SMA streamflows.

Estimated agricultural irrigation demands under climate change scenarios for the study area are summarized in the climate change report from a previous effort based on CMIP3 projections (Bureau of Reclamation, 2015). Results from this work for the eight-digit Hydrologic Unit Code (HUC8) sub-basins that fall within the Basin Study area are presented. In general, hotter drier climate increases agricultural irrigation demands.

Results from five HDe-based demand scenarios are presented in Table 5 using the 30-year range, 2045-2074, and the 50-year range, 1950-1999. All five scenarios indicate warmer mean annual basin wide temperatures than the historical value of 59.3 ºF, ranging from an increase of 2.8 to 6.9 °F. Changes in projected mean annual basin wide precipitation range from -12.9% to +10.0% from the historical value of 15.9 inches. Spatial differences in the distribution of projected percent change in net irrigation water requirement (NIWR) depth are a function of crop evapotranspiration and precipitation. Depending on the scenario, basin-wide average NIWR depth percent changes range from 3.2% to 22.0% with the central tendency future scenario basin-wide annual average estimate of 41.8 inches increasing 3.3 inches from the baseline value of 38.5 inches.

Table 5. Projected Change in Mean Annual Basin-wide Temperature and Precipitation for the Climate Change Scenarios Based on CMIP5 BCSD Projections; Historical Period, 1950-1999; Future Period, 2060s (30-year range, 2045-2074)

Historical, 1950-1999	Basin Mean Temperature (°F)	Basin Mean Precipitation (in)
Baseline	59.3	15.9
Climate Change Scenarios, 2060s (2045-2074)	**Projected Change in Basin Mean Temperature (°F)**	**Projected Change in Basin Mean Precipitation (%)**
Hot Dry (HD)	+ 6.9	- 12.9
Hot Wet (HW)	+ 6.6	+ 10.0
Central Tendency (CT)	+ 4.6	- 0.6
Warm Dry (WD)	+ 3.6	- 10.2
Warm Wet (WW)	+ 2.8	+ 8.8

3.2 Central Arizona Project – Service Area Model (CAP:SAM)

Water supply and demand for the study area was evaluated using CAP:SAM. The CAP:SAM was used to create a set of scenarios of future growth and demand. The scenarios were used in the numerical groundwater model. The CAP:SAM model runs and summary report were prepared by CAP staff with input from the study partners and interested parties. The full report is included as Appendix C (*West Salt River Valley Basin Study - Supply and Demand Modeling*).

Stakeholders in this Basin Study participated in a scenario development workshop hosted by CAWCD. The workshop combined an overview of the modeling capabilities of CAP:SAM with a traditional scenario planning process to identify key drivers of supply and demand and an initial matrix of factors. In keeping with the study's formal scope of work, the group agreed with the need to consider a range of climate conditions, as well as a desire to evaluate a range of future population growth outcomes. There was also discussion about the total scenarios and relative merits of having some scenarios in which only the climate factors were adjusted so that a pairwise comparison could be made.

The group reached an initial consensus to have six pre-adaptation scenarios (Table 6) that would include differences in the rate of population growth, spatial distribution of growth, relative rates of conservation, and a set of climate-related factors including the magnitude and frequency of shortage to the CAP, crop evapotranspiration, and surface water availability. Climate was classified into three categories: historic, hot and dry, and warm and wet.

Table 6. Pre-Adaptation Scenario Descriptions

Scenario ID	Name	Growth Pattern	Climate
A*	Baseline	Medium	Historic
B	Dry Baseline	Medium	Hot, Dry
C	Rapid Outward Growth	Rapid Outward	Historic
D*	Dry and Rapid Outward Growth	Rapid Outward	Hot, Dry
E	Wet and Rapid Outward Growth	Rapid Outward	Warm, Wet
F*	Slow and Compact Growth	Slow and Compact	Historic

Note: * indicates key scenario for groundwater model

A process of model validation and confidence-building was initiated in which each water provider was provided the specific supply and demand data, GIS shapefiles, and initial model results. Participants were requested to review the data for accuracy and reasonableness. The feedback received was used to make refinements to several individual assumptions. The same process was used to reach group consensus that CAP:SAM was a suitable tool to evaluate supply and demand in the study area.

3.2.1 CAP:SAM Modeling Methodology

The CAP:SAM simulates water demand by producing individual projections for 80 public and private water utilities in the CAP service area (Central Arizona Project, 2017). This model also includes the existing irrigation grandfathered rights, 23 agricultural irrigation districts, 12 Native American tribes and tribal districts, and over 20 other user categories including the CAGRD, AWBA, and industrial users such as mines and power plants. Only a subset of those users is within the study area. However, because there are interactions among supplies and demands, the demands for the Basin Study were extracted from the CAP:SAM model for the full three county model domain.

CAP:SAM is a complex model that performs hundreds of interrelated calculations within the GoldSim software environment (https://www.goldsim.com/web/home/). However, CAP:SAM's overall structure is organized into four conceptually basic steps: (1) project demands, (2) determine supplies, (3)request supplies, and (4) fulfill demands.

The D, Dry and Rapid Outward Growth, and F, Slow and Compact Growth, scenarios represent the two extremes in terms of growth and climate influences. The A, Baseline scenario represents a medium growth rate with historical climate conditions. All six of the pre-adaptation scenarios constrain the use of renewable supplies to those that are in-hand or part of existing plans. Scenarios A, D, and F are considered key scenarios and are discussed in detail in the CAP:SAM report.

The CAP:SAM scenarios included climate change effects on the Colorado River. These were represented in the scenarios as shortages to the CAP supply in some years. The shortages included in the CAP:SAM scenarios are not official shortage predictions and are only meant to serve as planning assumptions for this Basin Study.

The scenarios used in this study were developed as planning scenarios for the purposes of this study. While they are based on a range of estimates of growth and supply, they do not represent official Reclamation or water provider projections of future conditions.

3.2.2 Results of CAP:SAM Modeling

The rate and distribution of population growth has a large effect on demand, particularly in the western portion of the study area. As expected, the impact of differing growth assumptions is most apparent when comparing outward growth and compact growth. For instance, the number of projected housing units in Buckeye varies by a factor of nearly three between those scenarios. There is also a generally higher reliance on groundwater in the outward growth scenarios as more of the growth occurs in newer communities that have smaller and less diverse renewable supply portfolios. Much of that groundwater reliance would generate an Assured Water Supply requirement for replenishment, either by the CAGRD or the water provider. However, because CAGRD supplies were limited to supplies secured by CAGRD at the time of the model runs for this study, much of the new growth results in a net pumping stress.

The impact of shortages to the CAP supply are also evident in the model results, particularly shortages to the non-Indian agriculture (NIA) priority supply that several the West Valley cities hold. NIA priority is lower than Indian and M&I priority. Consequently, those entitlements are subject to more frequent reductions due to shortage. For water providers with NIA priority water, the availability of the supply is greatly diminished under the more aggressive shortage assumptions used in the Dry scenarios. Those CAP reductions, along with the surface water reductions, result in higher use of other supplies in the provider's portfolio to satisfy the remaining demand. Because of the sequence of supplies followed in the model, those other supplies (recovered CAP long-term storage credits, groundwater allowance, replenished groundwater, exempt groundwater [CAWS], and unknown) all result in pumping stresses.

Variations in the CAP supply availability are evident in the utilization of recharge facilities. In each scenario, there is a general modest upward trend in annual storage and recovery as existing supply portfolios are fully utilized, and a general downward trajectory to other recharge (i.e., accrual of long-term storage credits). However, there is a pronounced difference in the recharge activity between "Dry" and the other scenarios due to the availability of other excess. In the "Historic

Climate" trace there are periods with low or even zero supply reduction. In those periods, there is a significant amount of Other Excess CAP water available, which is presumed to be put to use by underground storage by either the AWBA or CAGRD. In the "Dry" climate trace, there is a period of relatively low reduction (200 KAF in the late 2020s), but deeper shortages for the remaining periods. Those shortages are deep enough that there is little, if any, excess CAP water available, so storage activity is suppressed.

In addition to reduced availability of renewable supplies in the "Dry" scenarios, there are noticeable differences in the municipal and agricultural demands. For agriculture, the higher rates of evapotranspiration associated with the Dry scenarios largely offset the effects of increased efficiency. Likewise, municipal demands are somewhat higher under the "Dry" scenarios because there is a lower rate of GPHUD decline due to higher evapotranspiration affecting outdoor water use.

3.2.2.1 *Future Supply and Demand*

The project team reached a consensus on modeling a total of six pre-adaptation scenarios for the period 2020-2060. These scenarios are shown in Table 6, above. All scenarios constrain the use of renewable supplies to those that are "in-hand", or part of existing plans. The scenarios differ in the rate of population growth, spatial distribution of growth, water use efficiency, and a set of climate-related factors including the magnitude and frequency of shortage to the CAP, crop evapotranspiration, and SRP and local surface water availability. Municipal demand varies among the scenarios, but generally trends downward per household to reflect observed long-term trends associated with improvements in water use efficiency and societal tastes and preferences. Agricultural demand is based on cropped acres, crop mix, consumptive use, and irrigation efficiency. Gradual improvements in agricultural efficiency are also included in all scenarios.

Scenarios A, D, and F were selected for evaluation. Scenario A represents a baseline condition ("business as usual"). Scenario D and Scenario F represent the two extremes regarding growth and climate influences. Scenario A follows closely the current rate and spatial distribution of growth and observed and expected trends for water supply and demand. Irrigation efficiencies gradually increase and shortages on the CAP system are simulated using the Historic climate series. Figure 16 shows supply and demand for M&I and agriculture in the study area from 2020-2060 under Scenario A. The shortage volume highlights the expected gap between supply and demand assuming no new water supplies are developed, and excess effluent is not used.

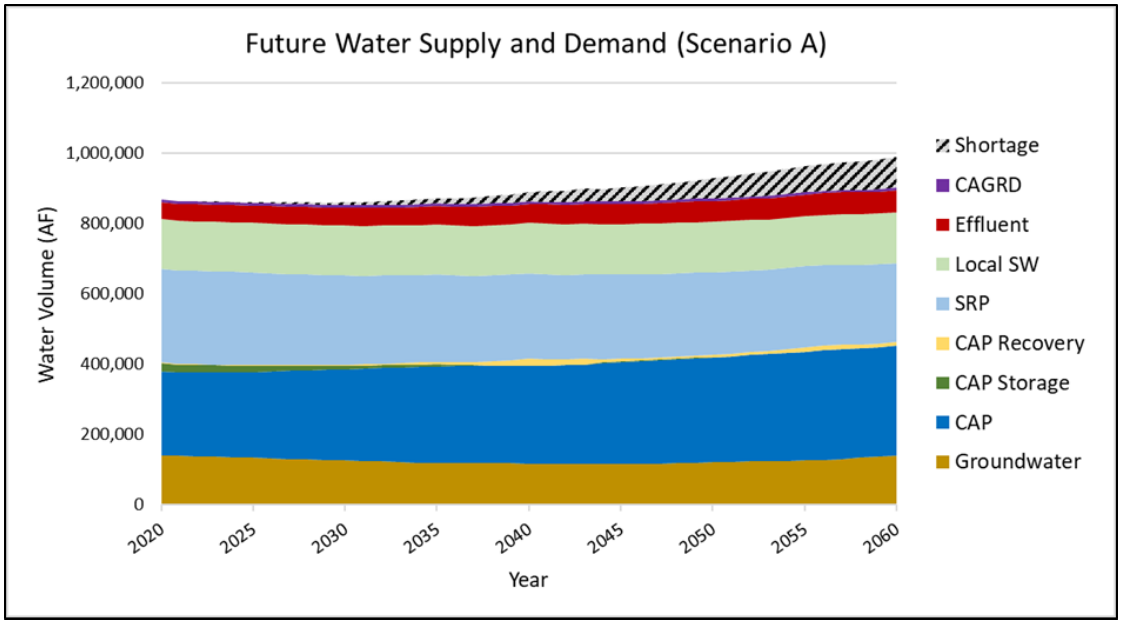

Figure 16. Scenario A (Baseline) future water supply and demand (CAP:SAM)

Scenario D simulates an aggressive rate of growth coupled with a regional growth pattern that is weighted more heavily towards suburban and exurban areas. A higher proportion of the housing units in agricultural areas are placed on active agricultural land compared to Scenario A. Furthermore, climate factors reflect a hotter, drier future. This includes lesser declines in municipal demand per household, increased crop consumptive use, and deep CAP and local surface water shortages. This scenario is the most aggressive in terms of population growth and climate impacts. Figure 17 shows future supply and demand for M&I and agriculture in the study area from 2020-2060 under Scenario D.

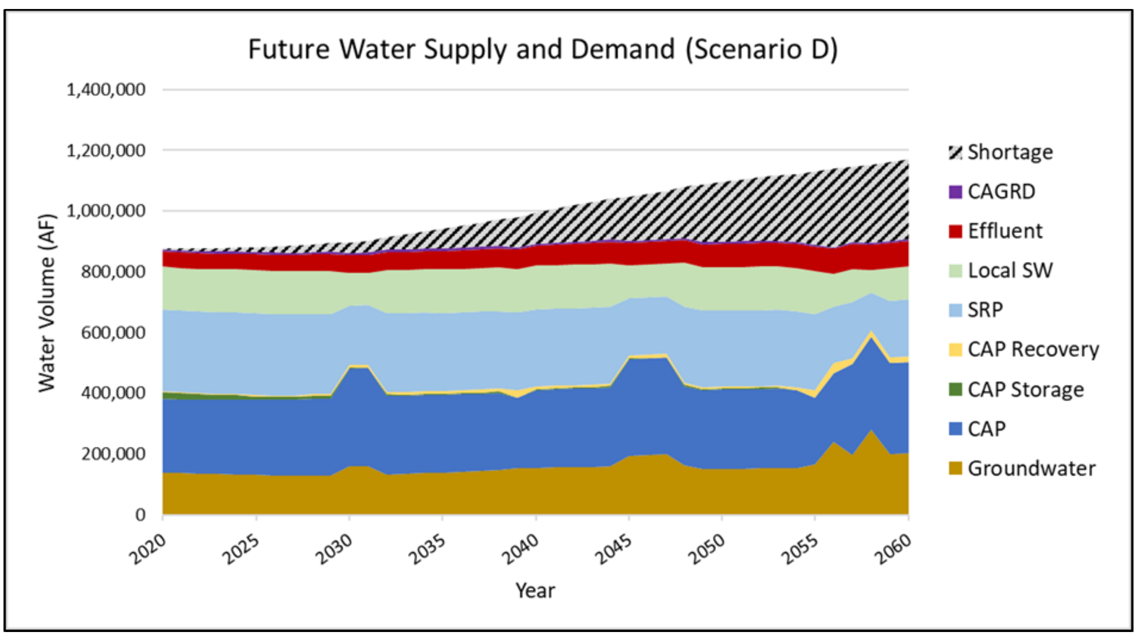

Figure 17. Scenario D (Dry and Rapid Outward Growth) future water supply and demand (CAP:SAM)

Scenario F simulates a less aggressive rate of growth than Scenario A and a spatial pattern of growth that places a greater proportion of housing units within the existing urban core. To reflect an associated new urbanism conservation ethic, the scenario includes a more aggressive rate of decline in GPHUD and a larger maximum reduction and lower minimum. It also includes higher irrigation efficiencies and greater preservation of existing agricultural land. Like Scenario A, this scenario uses the Historic Climate series. Figure 18 shows supply and demand for M&I and agriculture in the study area from 2020-2060 under Scenario F.

Figure 19 is a 2060 M&I supply utilization summary table for the three key scenarios evaluated in CAP:SAM.

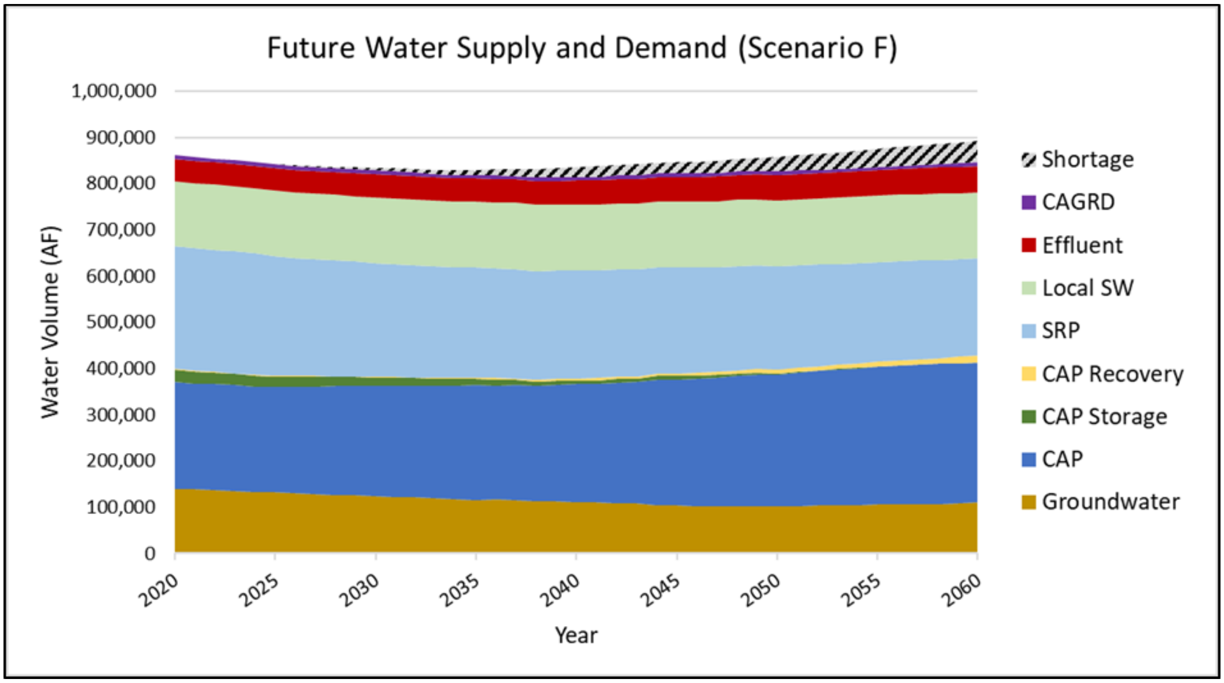

Figure 18. Scenario F (Slow and Compact Growth) future water supply and demand (CAP:SAM)

Supply Utilization Summary (in AF) for Key Scenarios, 2060

Scenario	Housing Units	Effluent	Surface	CAP	Groundwater (Subject to AWS) [1]	Groundwater (Exempt from AWS)	Total
A. Baseline	1.82 M	36,918	206,947	304,472	86,820	68,007	703,164
D. Dry, Rapid	2.23 M	56,238	166,398	294,127	263,687 [2]	97,025	877,476
F. Slow, Compact	1.68 M	30,817	193,237	309,649	47,151	45,635	626,489

[1] The majority of the "Groundwater (Subject to AWS)" value represents the volume of additional supplies needed in order to stay in compliance with AWS rules. This value was reduced by the CAGRD's available supply at the end of simulation (2060).

[2] Value includes 49,744 AF of "Unknown" water for Peoria in the Dry, Rapid scenario. The City's lack of a relationship with the CAGRD does not allow for the assumption that the CAGRD will acquire supplies to replenish on their behalf.

Figure 19. CAP:SAM 2060 supply utilization results for M&I

3.3 Numerical Groundwater Model

Reclamation contracted with PARS Environmental, Inc. for Southwest Groundwater Consultants (Matrix New-World) to produce a numerical groundwater model. The groundwater model combined and improved upon existing models. The focus of the groundwater modeling effort for this Basin Study was to assess groundwater conditions in the western portion of the Phoenix AMA under varying potential future stress scenarios. The area of the model assessed for this study includes the WSRV, Lake Pleasant, Lower Hassayampa, and Rainbow Valley sub-basins of the Phoenix AMA (Figure 20). However, to have a complete model of the Salt River Valley for future use, the model was constructed to also include the East Salt River Valley (ESRV). But the growth and demand scenarios assessed in this study did not include the ESRV because those communities were not part of this study. The ESRV was held constant for this study and results for the ESRV were not considered.

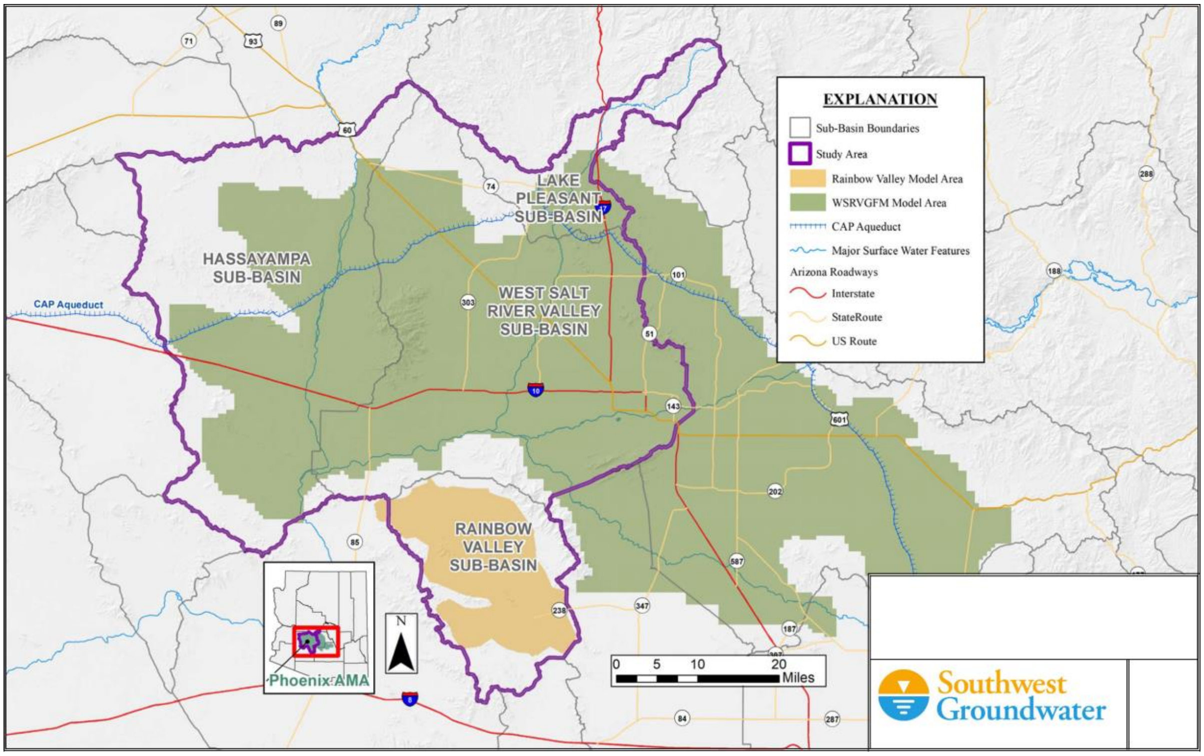

Figure 20. Groundwater model study area

3.3.1 Numerical Groundwater Modeling Methodology

The previously developed Salt River Valley Model (Freihoefer, Mason, Jahnke, Dubas, & Hutchinson, 2009) and Lower Hassayampa Sub-basin Model (Brown and Caldwell, 2006) provided the framework for the construction of a new model, the West Salt River Valley Groundwater Flow Model (WSRVGFM), which was developed to simulate conditions in the WSRV, Lower Hassayampa, and Lake Pleasant sub-basins. The Rainbow Valley Sub-basin Model (RVM) (Golder Associates Inc., 2010) provided the base model for simulating conditions in the Rainbow Valley sub-basin. Water supply wells of the West Valley water providers were used as pumping centers for the model runs in this study. Figure 21 shows the wells, the study area, and water provider boundaries.

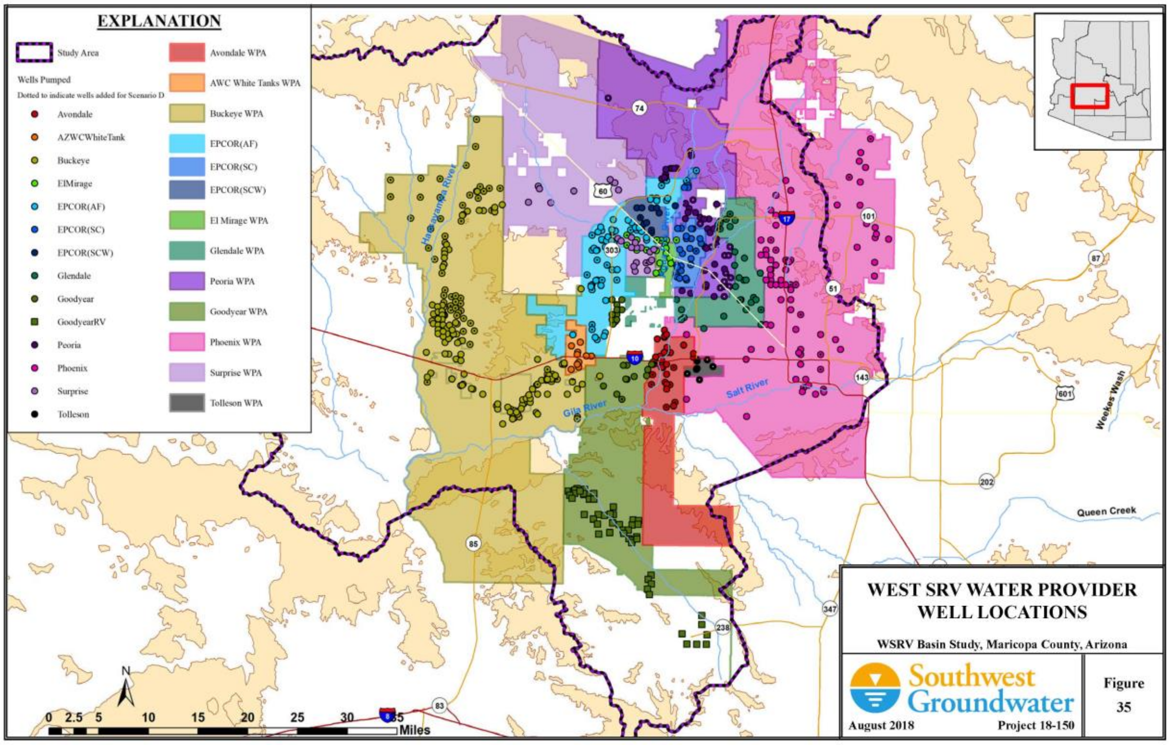

Figure 21. West Salt River Valley water provider well locations used in WSRVGFM

The groundwater model report, *West Salt River Valley Basin Study Groundwater Flow Modeling, Maricopa County, AZ* (Appendix D), presents results from the independently run WSRVGFM and the RVM. CAP provided supply and demand models that formed the basis for building the predictive groundwater model scenarios. The groundwater model development and use benefited greatly from the collaborative efforts of the study partners and interested parties, that provided a considerable amount of new data and valuable review and oversight.

The WSRVGFM was calibrated by adjusting model input parameters to achieve a satisfactory fit to head and flow targets. Hydraulic properties were varied during calibration using a pilot point-based parameterization method. Mountain front recharge, stream conductance, stream recharge, and evapotranspiration rates were also varied during model calibration. Calibration targets included predevelopment and transient (1983 to 2014) groundwater levels, and components of the conceptual predevelopment water budget. A regularized inverse modeling approach was applied using the PEST parameter estimation software.

Several common statistics for assessment of fit to simulated heads were applied. Calibration goals were established for statistics calculated specifically for the focus area. Water level observations were divided into three datasets for statistical analyses. One set of water level observations collected near 1900 were used to test the fit of the model to steady state conditions (Steady-state Wells). The transient model conditions (Transient Wells) were tested using data collected from 1983 through 2014. A third group of head targets (Underground Storage Facility [USF] Wells) represents groundwater levels measured at monitoring wells associated with artificial recharge projects throughout the study area. Model calibration statistics for the head targets are all within their goal criteria. Simulated flows at target locations are at or within their calibration goal of 25 percent of estimated flow rates.

The sensitivity analysis was conducted by varying horizontal hydraulic conductivity, vertical anisotropy, specific yield, specific storage, stream conductance, evapotranspiration rates, mountain front recharge rates, and agricultural recharge lag rates in each layer within the study area to assess model calibration and predicted drawdown through 2060. Results indicate that specific yield in all three layers, specific storage in layer two, and stream recharge all had a significant effect on drawdown impact, but an insignificant effect on model calibration.

Seven predictive water supply and demand scenarios were developed for the Basin Study. Some of the scenarios also include changes in demands and other model inputs due to possible climate changes. Four of the scenarios were simulated using the WSRVGFM and the RVM. These model scenarios incorporated differences in groundwater pumping and artificial recharge for major water users in the study area for scenarios selected to show the range of effects of various supply and demand and climate change projections. For these scenarios, the effects of climate change on pertinent hydrologic inputs to the system were accounted for by changing associated inputs to the groundwater flow model. The groundwater model addresses climate change effects on evapotranspiration and local streamflow using change factors defined by the climate change analysis. Table 7 shows the model scenarios included.

Table 7. Predictive Model Scenarios used in the Basin Study

ID	Name	Growth	Climate
A*	Baseline	Medium Growth	No Climate Change
B	Dry Baseline	Medium Growth	Hot, Dry
C	Rapid Outward Growth	Rapid Outward Growth	No Climate Change
D*	Dry and Rapid Outward Growth	Rapid Outward Growth	Hot, Dry
E	Wet and Rapid Outward Growth	Rapid Outward Growth	Warm, Wet
F*	Low Growth	Slow and Compact Growth	No Climate Change
G*	Business as Usual	No Growth	No Climate Change

Note: *Scenario simulated with the groundwater flow model.

3.3.2 Results of Numerical Groundwater Modeling

Review of the model results for each scenario indicated significant differences in the depth to groundwater over time in key locations in the study area. A more thorough discussion of the groundwater model and scenario results can be found in the model report (Appendix D). Figures 22-27 show results of the groundwater model scenario runs. Figures 22-24 show depth to water at the end of the study period (2060) and Figures 25-27 show drawdown over the study period. The figures show simulated changes in the water budget of the aquifer. For example, model results showing lower water levels over time indicate that increased groundwater extraction from the aquifer by wells exceeds additions to the aquifer by natural or artificial recharge.

All scenarios showed an area of relatively deep groundwater in 2060 and significant drawdown in the northern part of the study area, with the deepest water levels in the northeast part of the study area near the Hedgpeth Hills (Township 4 North, Range 1 East). In 2060, the depth to water exceeded 500 feet below land surface (ft bls) in Scenario A, 700 feet bls in Scenario D, and 450 ft bls in Scenario F for that area. In Scenario G, depth to water exceeded 500 ft bls in that area and a larger portion of the northeastern study area. Depth to water was at land surface at the Agua Fria USF in all the scenarios (Township 5 North, Range 1 East). Depth to water was close to land surface in all scenarios along the Gila River. Comparison of model results at the end of the simulation period in 2060 indicates that simulated groundwater levels are approximately 100 feet deeper in Scenario D than in Scenario A in three different model areas: one in the northeast portion of the study area near the Hedgpeth Hills, one between the Belmont Mountains and the White Tank Mountains, and a relatively smaller area just southeast of the White Tank Mountains. Drawdown in the western-most portion of the study area in all scenarios is related to less artificial recharge and resulting lowering of the groundwater mound at the Tonopah Desert Recharge Facility (Figures 25-27).

The purpose of the groundwater model is to assess the availability of groundwater resources for various projected demand scenarios so that participating entities can effectively make decisions on future water use. The model simulations described in the groundwater model report indicate possible aquifer responses to various scenarios considering possible growth and climate patterns. In general, scenarios indicate groundwater should be available in year 2060, but may reduce rapidly thereafter based on water level hydrographs (Figure 28). While it is difficult to project broad trends using these hydrographs, the simulations identify potential groundwater resource issues, specifically in Scenario D, in which groundwater level decline rates at the end of the simulation (2060) were more than five feet per year in several areas. Extending the simulation beyond 2060 would likely result in groundwater level declines in additional areas. Areas with relatively deep groundwater levels at the end of the model simulation would result in increased operational costs. Potential for subsidence in the basin may also increase with groundwater level declines. This can be mitigated in several ways, such as identifying alternative water sources so that well pumping can be curtailed in such areas. Based on the results of this modeling, it is evident that increased use of renewable supplies is needed to offset groundwater pumping impacts.

Additional investigation using the groundwater model could further explore additional scenarios such as effects of changing the distribution of groundwater pumping, longer simulation periods, and effects of various adaptation and mitigation strategies. Because reclaimed water was not utilized to its full extent in the groundwater modeling for this study, additional model runs could be used to examine reclaimed water use more fully. Only water currently secured by CAGRD was considered in the groundwater modeling and model runs could be set up to include assumptions about future new CAGRD water.

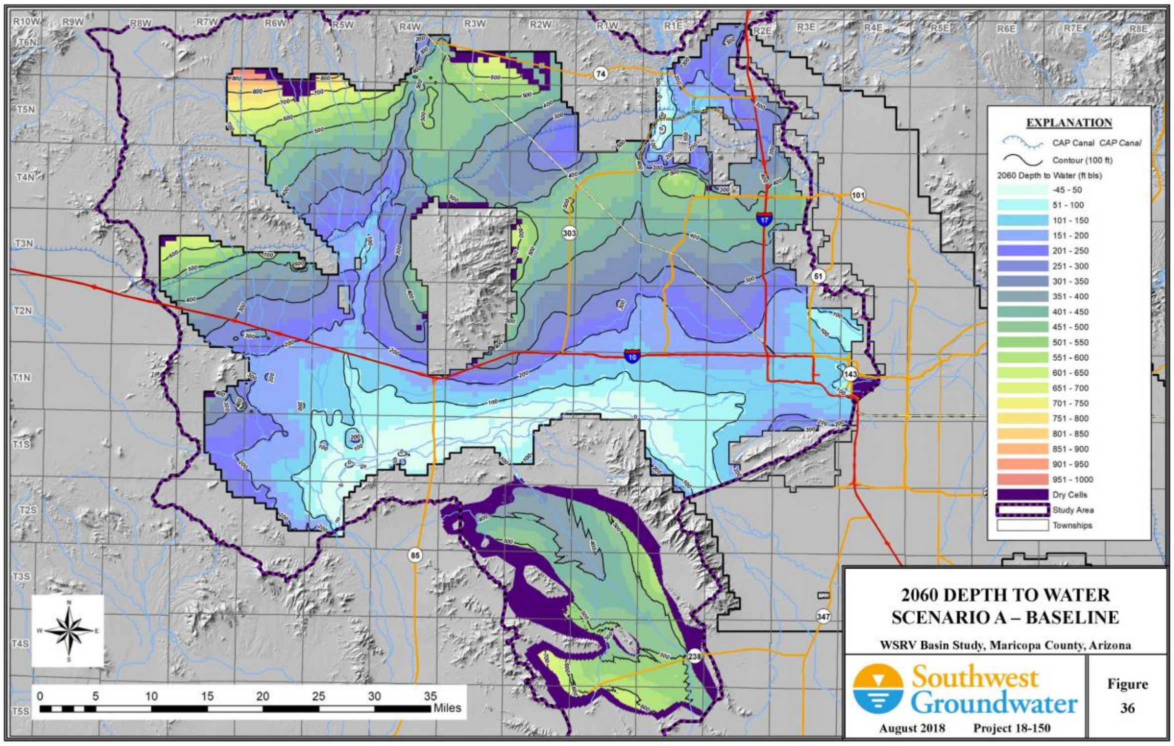

Figure 22. 2060 Depth to Water (feet below land surface), Scenario A, Baseline

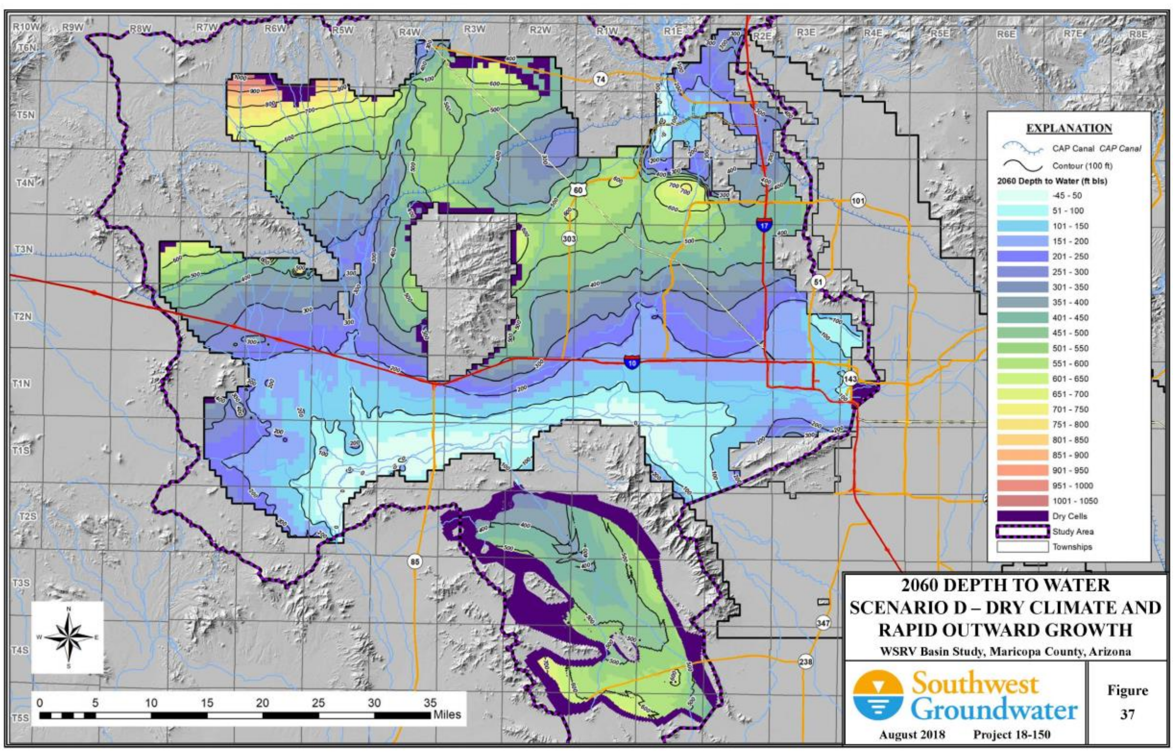

Figure 23. 2060 Depth to Water (feet below land surface), Scenario D, Dry Climate with Rapid Outward Growth

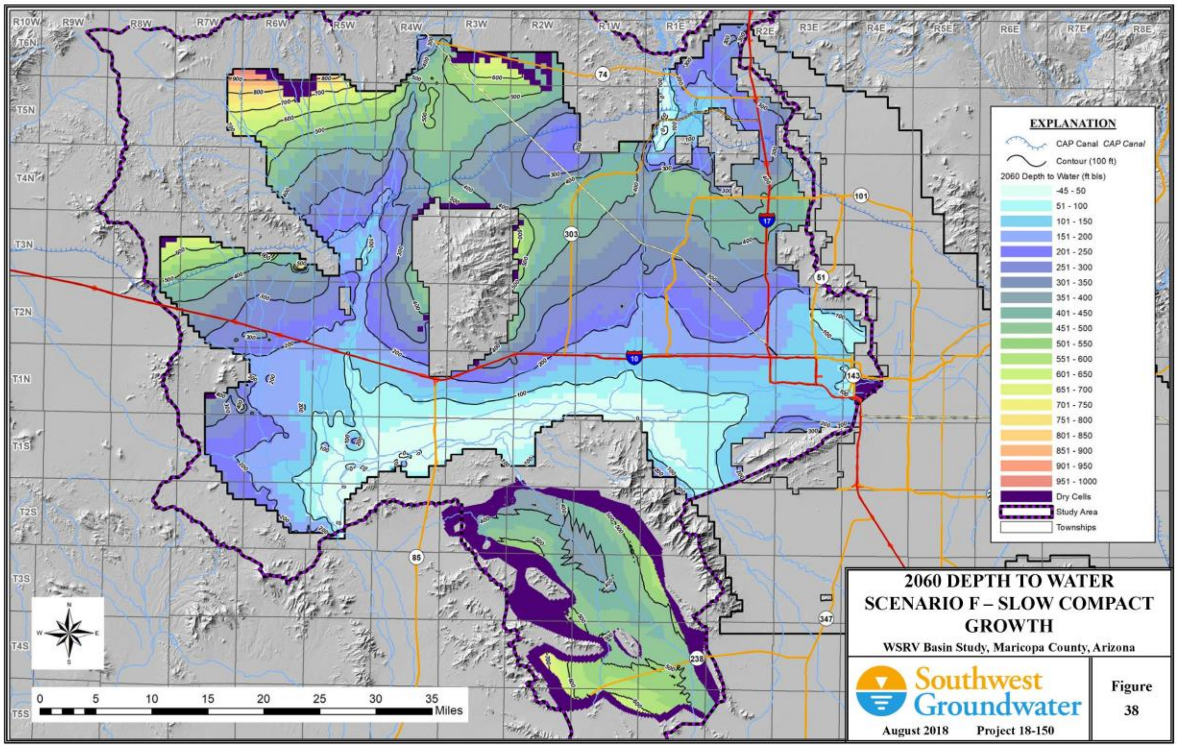

Figure 24. 2060 Depth to Water (feet below land surface), Scenario F, Slow Compact Growth

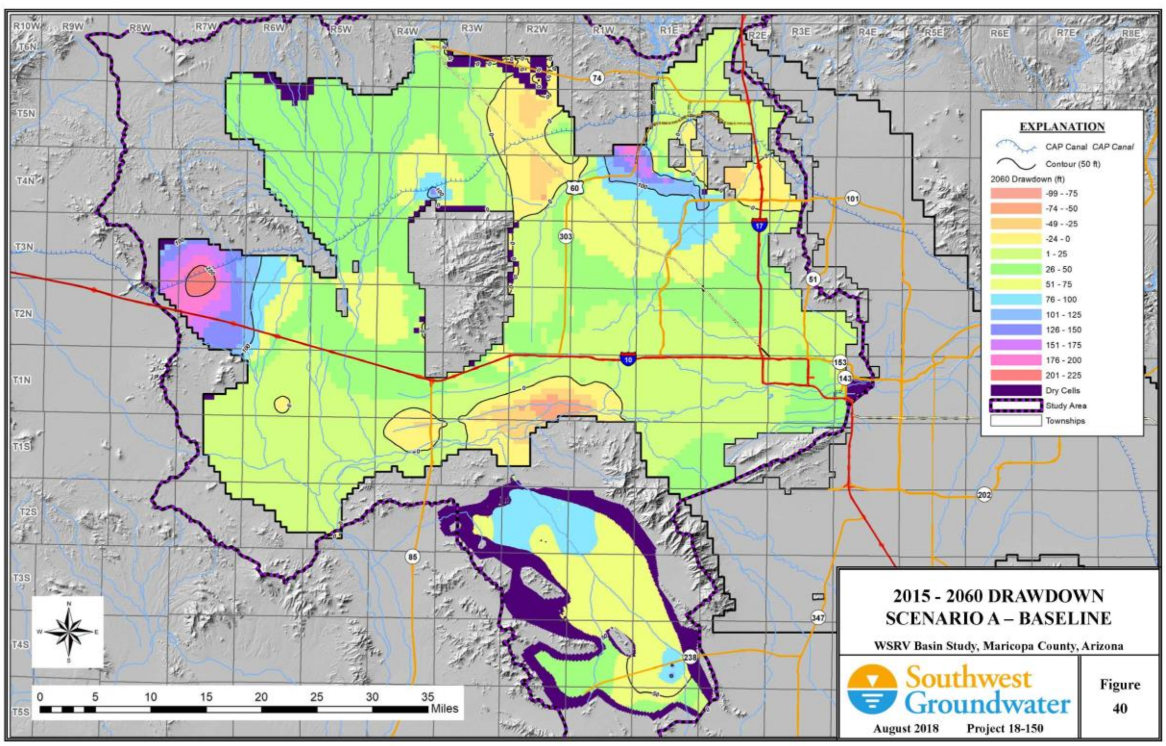

Figure 25. 2015-2060 Drawdown (feet), Scenario A, Baseline

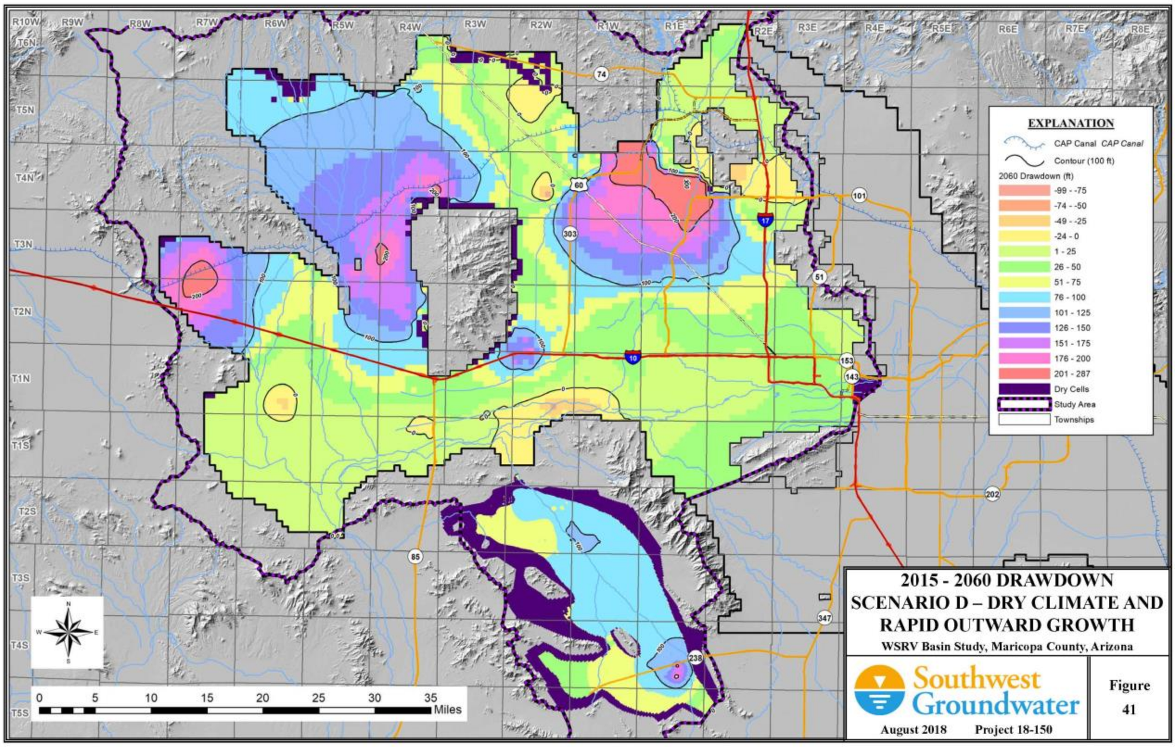

Figure 26. 2015-2060 Drawdown (feet), Scenario D, Dry Climate with Rapid Outward Growth

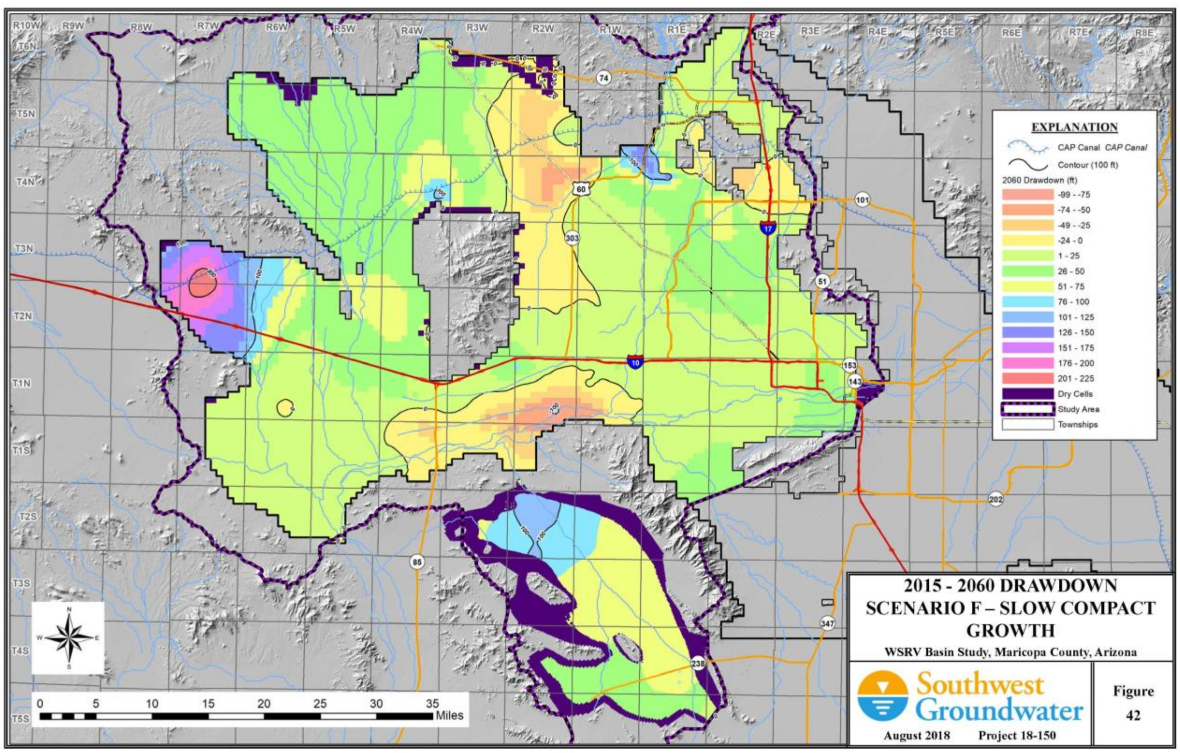

Figure 27. 2015-2060 Drawdown (feet), Scenario F, Slow and Compact Growth

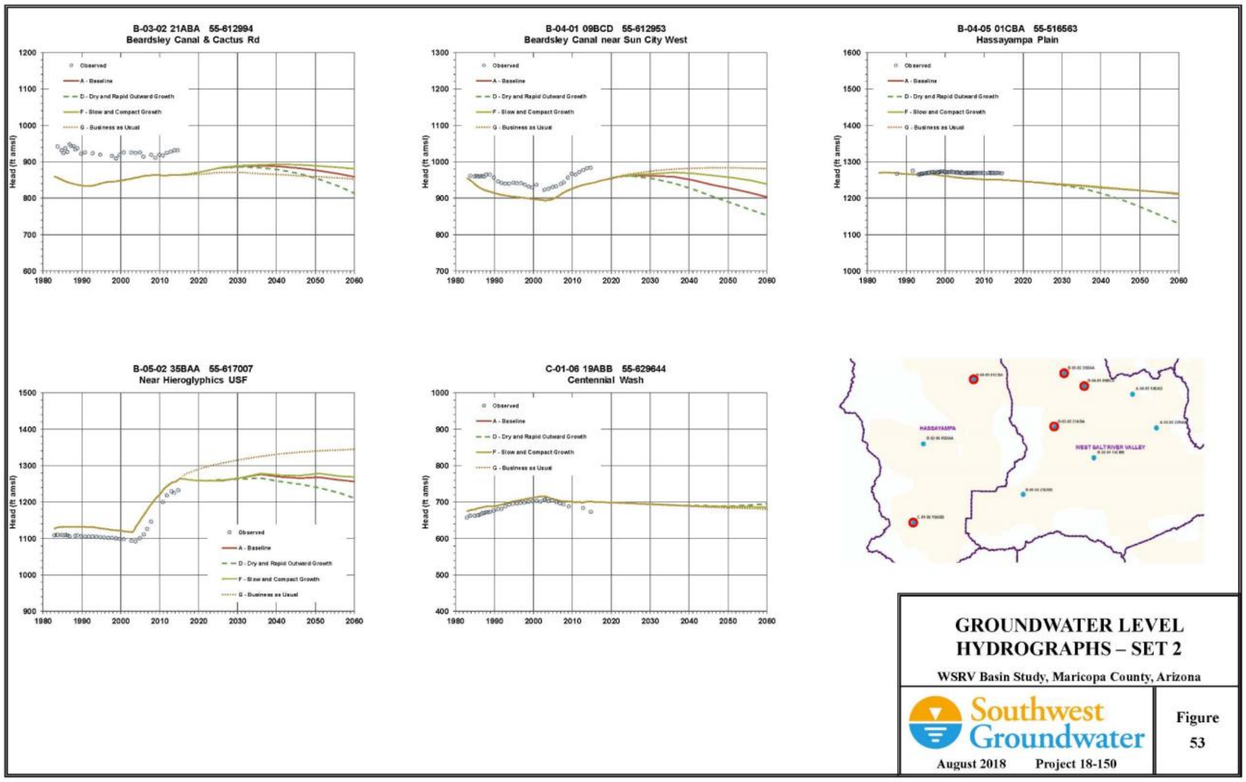

Figure 28. Groundwater Level - hydrographs for selected wells

3.4 Recharge Suitability Model

The goal of the recharge suitability model was to identify optimal locations for groundwater recharge in the WVWA area of interest. The analysis is at a high level and intended as a screening exercise. Proposals for specific sites would require additional site-specific data and feasibility analysis. For this model, the study partners were interviewed and met on multiple occasions to discuss the process and the data sets most important for siting a facility. Data sets for land use, hydrology (depth to water and horizontal conductivity), surface soils drainage class, and geology were considered important for this level of analysis. The data sets were weighted and combined into a GIS model for analysis. Appendix E contains the summary report *WVWA Groundwater Recharge GIS Suitability Analysis (GIS Weighted Analysis).*

Undeveloped land use areas, such as active and passive/restricted open space, golf courses, agricultural land, vacant land, and state trust land were considered most suitable and weighted highest. Developed lands were excluded (given zero weight). Hydrologic data consisted of depth to water and hydrologic conductivity. Areas with shallow water tables (less than 100 feet) were excluded; areas with depth to water greater than 400 feet were considered most suitable. Areas with water tables between 100 and 400 feet were intermediately weighted. Higher suitability was given to areas with well drained soils and higher conductivity. Geologic data were used to create a range of suitability weights. Hard rock (bedrock) was excluded and Quaternary aged (younger) alluvial material was weighted the highest. Other rock types were given intermediate weights.

Several criteria were considered important but too restrictive for this analysis and therefore not included. These include items such as areas with active land subsidence, mining operations, the Luke Salt Dome, power and infrastructure corridors, poor water quality areas, the BWLA, and terrain. Some of these, such as the Buckeye Waterlogged Area, which has shallow groundwater, were captured by other criteria. Land ownership was not a consideration for this analysis but would be an important consideration when further investigating sites.

This analysis primarily focused on recharge locations for spreading basins. There are opportunities such as aquifer storage and recovery wells for smaller recharge operations that this study did not identify. Figure 29 shows the results of the analysis. Other more detailed maps are in Appendix E. As expected, the suitable areas are generally flat-lying undeveloped areas with deep water tables and satisfactory geologic materials. While most of the results appear intuitively correct, some areas shown as suitable on this map may not be, such as western Rainbow Valley. Further analysis is required to refine the model and could include additional ranking criteria and changes to the current weighting scheme.

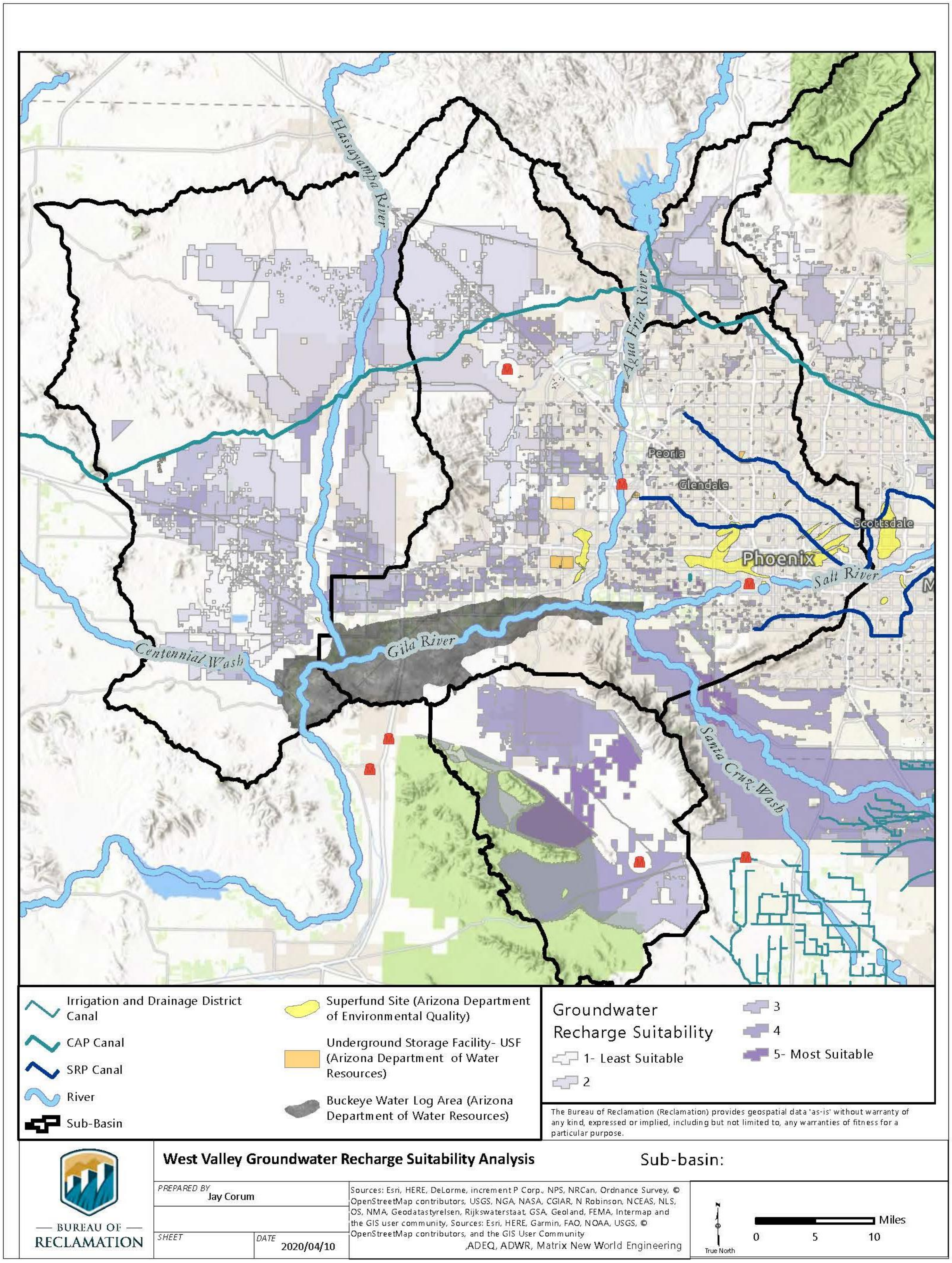

Figure 29. Map of study area with groundwater recharge suitability results

4. Future Water Management Goals, Objectives, and Adaptation Strategies

Adaptation strategies were developed to meet the needs identified in the climate change assessment, supply and demand analysis, and groundwater model scenario runs. Several stakeholder discussions about the findings were conducted at WVWA Planning Committee and other meetings. This section provides an account of the process and the adaptation strategies developed for a trade-off analysis. To help focus the adaptation strategies, the study partners chose to explicitly define some goals and objectives.

4.1 Goals and Objectives

Planning goals and objectives were based on the results of the climate change information, supply and demand assessment, groundwater modeling, and discussions with stakeholders. Goals are broad qualitative statements of what the study partners want to achieve in the study area. Objectives are more specific and quantitative in nature and formed a basis for adaptation strategy development. The goals and objectives were summarized to concisely express considerations for forming adaptation strategies. The goals and objectives in Table 8 are not everything the partners considered in evaluating strategies, but rather serve as a general screening tool. The adaptation strategies were evaluated, in part, on their ability to meet the objectives.

In general, the goals are focused on sustainable long-term water supplies and aquifer protection for a growing region. Despite uncertain future climatic, hydrologic, and economic conditions, municipalities and communities in the study area collectively hold aspirations of substantial commercial and population growth in the coming decades. To facilitate this regional development, existing renewable water supplies will need to be protected and sustained, and additional supplies will need to be identified, purchased, and operationalized.

The study partners additionally recognize that both short-term and long-term strategies such as continuation and expansion of current programs and activities are important, as is taking definitive steps towards planning and investing in long-term solutions. Another goal of this study is to identify strategies that can be applied on a regional basis in a collaborative manner. The objectives in Table 8 include clarification notes and references to future needs required to better quantify or refine each objective.

Table 8. Goals and Objectives for Future Adaptation in the West Salt River Valley

Goals	Objectives (and Notes)
Permanent Reliable Water Supply to meet 2060 demands	**Develop 250-300 KAF/y of new renewable supplies by 2060**. (Based on Hot/Dry, Rapid Outward Growth, Scenario D) Create "Water Development Projection" (Quantify the need that will phase-in over time until the total is met, i.e., all 250-300 KAF is not needed in the short-term)
Aquifer Protection "The aquifer in 2060 will look the same or better than it does currently."	**Allow less than 3 feet annual decline in water levels** (Further discussion is needed about amount and how this would be measured, e.g., over the AMA? In any location? Time averaged?) **Recharge (replenish) in areas of need** (i.e., not just a "paper water" exercise). (Also, must consider geologic constraints – use recharge suitability model.) **Have acceptable levels of subsidence** (i.e., zero feet of new subsidence; but recognize there is a lag time). **Work towards mitigation for all groundwater pumped** (i.e., in a one-to-one ratio. Discuss groundwater allowances. Identify regulation changes that may be needed.)
Enact both short- and long-term solutions	Short-term is about 5 years (e.g., includes some types of effluent use, poor quality water use, regional conservation). Long-term is longer than 5 years (e.g., ocean desalination, large scale DPR). (This requires further discussion but generally means starting or continuing the "obvious and easy" actions but continue/begin planning now for permanent water supplies such as ocean desalination and DPR.)
Apply Regional Solutions	Develop a water transportation network. Increase investment in planning and design. Create or support regional conservation messaging.

Other goals for the adaptation strategies expressed by the study partners but not annotated in Table 8 include, but are not limited to, protecting existing water rights; compatibility with all regulations, policies, and environmental laws; and actions that are within the reasonable control of the study partners.

4.2 Formulation of Adaptation Strategies

The purpose of the adaptive strategies is to identify and characterize water supplies and actions that may be used to meet future demands. The adaptation strategies were developed to inform the planning processes of the WVWA and interested parties. Consideration was given to results of the groundwater model scenario runs, climate change analysis, the supply and demand analysis, Reclamation and State of Arizona Colorado River planning and forecasting, SRP and CAP planning and forecasting, and an awareness of individual water provider conditions and concerns.

The study partners established a task team, composed of Reclamation staff and members of the WVWA Planning Committee, to develop a set of potential strategies that could contribute to achieving the planning goals and objectives. These strategies were reviewed and approved by the larger study group. The broad set of strategies was screened, ranked, and prioritized through an iterative process consisting of meetings, written communication, and informal surveys with the task team members, the Planning Committee, and stakeholders. Priority strategies were carried forward for more detailed description and examination. The final set of strategies was further grouped into a set of ten to facilitate the economic and trade-off analysis.

In general, priority was given to strategies that could be implemented at a regional level and could utilize regional cooperation and collaboration. Regional level strategies are typically multi-jurisdictional and involve, or are applicable to, more than one water provider. This regional focus is not meant to imply that local level projects implemented by individual communities are not important.

Each of the evaluated strategies was screened, at least in part, on its potential to meet the planning goals and objectives. Each strategy was considered relative to the amount of water it could provide and other characteristics, such as relative-cost, public perception, and environmental, legal and institutional issues. Because there is a clear distinction between short- and long-term strategies, a qualitative assessment of the time it may take to implement a strategy was also considered. The strategies were also qualitatively evaluated against four tests of viability - acceptability, effectiveness, efficiency, and completeness.

The descriptions and evaluations of the strategies are at a preliminary level and based on information existing at the time of the evaluation. As such, a more thorough appraisal- or feasibility-level investigation would be needed to understand the strategies more fully.

This study did not complete a detailed analysis of infrastructure improvement needs for each specific strategy; however, it was recognized that each strategy will have associated infrastructure needs. While potential infrastructure needs such as inter-connections, conveyance pipelines, well fields, and recharge sites were not explicitly defined, the need for general infrastructure improvements were considered for the strategies.

4.3 Adaptation Strategies Considered

The strategies that were initially carried forward were combined into four broad category groups: Conservation and Efficiency; Effluent; Poor Quality Water; and Transactions, Leases and Exchanges. A fifth category, "Status Quo" (CAGRD), was noted for comparative purposes as the existing situation for many future water supplies. Each group contained several more specific strategies, and a total of 21 strategies (Table 9) was initially brought forward. The study team has not deemed all entries on this list as viable or practical; it primarily provides a final set of strategies to be assessed in the economic and trade-off analysis (Section 6, below).

Table 9. Initial Adaptation Strategies

Adaptation Strategy Group	Initial Adaptation Strategy
Conservation and Efficiency	(1) Low Impact Development (LID)/Hybrid Stormwater Management (2) Efficiency Programs (3) Smart Growth (4) Demand Management (5) Non-revenue Water Loss (M-36) (6) Vegetation Management (tamarisk removal)
Effluent: Full use of effluent resources (recycled, reclaimed water)	(7) Recharge (e.g., centralized facilities) Direct recharge Indirect recharge (8) Direct Potable Reuse (DPR) (9) Direct Use of Non-potable Irrigation (turf and non-food crops) Industrial use (e.g., cooling at PVNGS)
Poor Quality Water	(10) Buckeye Water-logged Area (11) Other poor-quality water (e.g., contaminated water) (12) Ocean water desalination Sea of Cortez/Mexico California exchange (13) Yuma Desalting Plant (14) Yuma-Mesa Mound (15) Gila Bend Basin
Transactions, Leases, and Exchanges	(16) Indian Leases (17) Re-marketers (18) Irrigation right conversions to M&I (groundwater) (19) Agricultural sector deals (e.g., fallow programs, leases) (20) Agricultural infrastructure improvements and transactions for saved water
Status Quo	(21) Existing strategy: Central Arizona Groundwater Replenishment District (CAGRD)

4.4 Final Adaptation Strategies

The final adaptation strategies listed in Table 10 were developed based on feedback received on the initial strategies and discussions with the study partners and interested parties. They have been grouped in a way that helps facilitate an efficient economic and trade-off analysis. Descriptions are included in the sections below and each strategy is evaluated in Section 6.

Table 10. Final Adaptation Strategies

Adaptation Strategy	Strategy Components
(1) Demand Management	• Efficiency/conservation programs • LID and Stormwater Management (commercial/industrial scale) • Rainwater harvesting (residential scale) • Reducing water loss (M36 water audits) • Smart growth
(2) Regional Effluent – Direct Potable Reuse	• New infrastructure to treat and deliver effluent for direct potable reuse
(3) Regional Effluent - Direct Non-Potable Reuse (purple pipe)	• New infrastructure to treat and deliver effluent for non-potable reuse
(4) Local Effluent Reuse/Recharge Potable or Non-Potable	• Site specific wastewater treatment and reuse/recharge systems at or near the point of wastewater generation (e.g., systems in portions of communities, individual developments, industries)
(5) Regional Effluent Recharge	• New Constructed Underground Storage (Recharge) Facilities (USF) • New Managed Underground Storage (Recharge) Facilities (MUSF) – include environmental flows
(6) Poor Quality Groundwater Treatment	• New infrastructure to deliver remediated groundwater (treatment facilities are in place)
(7) Ocean Desalination	• New infrastructure to desalinate and convey ocean water (e.g., pipeline from Sea of Cortez ocean desalination plant)
(8) Inland Desalination / Brackish Water Treatment	• New infrastructure to desalinate and convey water from inland sources (e.g., Yuma Desalting Plant) • New infrastructure to desalinate and deliver brackish groundwater (need a treatment facility) (e.g., BWLA, Yuma Mesa Mound, and Gila Bend Basin)

Adaptation Strategy	Strategy Components
(9) Groundwater Transactions/ Exchanges	• New groundwater remarketers • Transactions with ag sector for infrastructure improvements that save groundwater • New interbasin groundwater transfers
(10) Surface Water Transactions/ Leases/ Exchanges	• New leases of surface water from Tribes • New surface water remarketers (e.g., private sector water development companies) • New agricultural sector fallowing deals for surface water • New trade agreements with SRP or CAP for surface water
(11) Additional CAGRD availability (not evaluated in tradeoff analyses)	• Increase the amount of CAGRD renewable water available beyond the volume modeled in CAPSAM (~10,000 AF)

4.4.1 Demand Management

The demand management strategy includes several sub-strategies (Table 10). In general, this category means expanding or implementing a variety of conservation and efficiency programs to better use existing supplies and minimize the need for new water supply development. Water conservation refers to decreasing the total amount of water use, whereas efficiency means conserving water by using available water-saving technology.

This strategy includes smart growth, which refers to planned economic and community development that attempts to reduce negative urban sprawl effects and adverse environmental conditions. For example, communities and developers can reduce runoff quantity, protect water quality, and conserve water by developing compactly, preserving ecologically critical open space, and using green infrastructure strategies (U.S. Environmental Protection Agency, 2021). Similarly, this strategy includes commercial, industrial, or municipal-scale low impact development (LID). LID refers to land planning and engineering design, systems, and practices that use or mimic natural processes that result in the infiltration, evapotranspiration, or use of stormwater to protect water quality and associated aquatic habitat. LID emphasizes conservation and use of on-site natural features (e.g., green infrastructure) (U.S. Environmental Protection Agency, 2020).

Efficiency programs are considered part of this strategy. For example, this strategy incorporates expanded public education programs, conservation-oriented building codes, expanded surveys and audits, promotion of high efficiency fixtures, and alternative rate structures. Agricultural conservation programs can be part of this strategy, such as increasing efficient irrigation practices and reducing conveyance losses (U.S. Department of Agriculture, n.d.).

The strategy also captures non-revenue water loss reduction programs. Non-revenue water loss is water that has been produced and is lost before it reaches the customer. Losses can be a result of leaks or the result of theft or meter inaccuracies. This is also known as unaccounted-for water and represents the difference between net production (the volume of water delivered into a network) and consumption (the volume of water that can be accounted for by legitimate consumption, whether metered or not).

Another strategy in this category is rainwater harvesting, the capture, diversion, and storage of rainwater for landscape irrigation and other uses. It can reduce the use of potable water for landscaping and can help reduce off-site flooding. It is a strategy that has been employed throughout Arizona and could be expanded (Tucson Water, 2013; Waterfall, 2004). Similarly, larger-scale integrated stormwater management practices are included in this strategy. While legal and regulatory constraints must be considered, opportunities may exist to utilize infrastructure for managing and directing flood/stormwater flows to recharge areas or to supplement existing uses. Large scale flood and stormwater management is an opportunity for multijurisdictional collaboration and use of FCDMC facilities and land.

The water providers in and around the study area already have local demand management programs and will continue to invest in promoting water conservation and efficiency. The study partners recognize these programs will likely continue; however, opportunities to collaborate and create regional standards and programs may be beneficial. For example, efforts to develop best practices and standardized conservation messaging in the Phoenix AMA, such as through AMWUA, could be leveraged for WVWA use.

4.4.2 Regional Effluent – Direct Potable Reuse

This strategy involves new infrastructure to treat and deliver effluent for direct potable reuse (DPR). In DPR, wastewater is put through an advanced treatment process to meet drinking water standards and served directly to customers as potable water. There are two forms of direct potable reuse. In the first form, advanced treated water is introduced into the raw water supply upstream of a drinking water treatment facility. In the second form, finished drinking water from an advanced water treatment facility permitted as a drinking water treatment facility is introduced directly into a potable water supply distribution system (WateReuse Research Foundation, 2015). This allows effluent to be distributed to customers after treatment, not stored in a natural buffer such as a water body or groundwater basin. Therefore, DPR avoids the need to recharge the effluent, extract it through pumping wells, and then further treat it prior to customer use. This may involve multi-provider (multijurisdictional) or single-provider facilities (U.S. Environmental Protection Agency, 2020).

Because DPR would supplement the potable drinking water supply, ADEQ revised the rules governing this activity and prepared a guidance framework (Arizona Department of Environmental Quality, 2018a; National Water Research Institute, 2018). These rules allow for DPR projects in the West Valley. However, according to the ADEQ Recycled Water Work Group's final report dated January 15, 2018, the existing rule A.A.C. R18-9-E701 could be improved by including additional clarification and details to help water providers plan and implement full-scale facilities (Arizona Department of Environmental Quality, 2018b).

A DPR pilot project in the West Valley would give insight to the needs, cost, and operation of a full-scale DPR facility. A regional full-scale DPR facility could be built to serve multiple municipalities in the West Valley. Because effluent is relatively resilient to drought impacts, DPR has potential to supplement the water supply of the West Valley.

4.4.3 Regional Effluent – Direct Non-Potable Reuse

This strategy includes new infrastructure to treat and deliver effluent for non-potable use. Direct non-potable reuse refers to recycled or reclaimed water that is not used for drinking but is safe to use directly for irrigation or industrial processes. This may involve multi-provider (multijurisdictional) or single provider facilities.

Under the direction of ADEQ, non-potable reuse is allowed for various irrigation and industrial uses (Arizona Department of Environmental Quality, 2018a). This also includes non-potable use in lakes and turf facilities. Because effluent is such a valuable asset, the use of non-potable effluent may be limited in the future in lieu of potable uses (e.g., DPR).

4.4.4 Local Effluent Reuse/Recharge – Potable or Non-Potable

Similar to but distinct from regional effluent reuse strategies, this strategy includes new wastewater treatment and reuse/recharge systems at or near the point of wastewater generation. For example, this localized strategy includes facilities in portions of communities for individual residential or commercial developments, or industrial sites. This strategy is smaller scale than a regional project and typically would involve only one water provider. While it does not fully meet the planning objective of regional solutions, it may be effective in helping meet the aquifer health objective in ways that a single large regional facility would not.

4.4.5 Regional Effluent Recharge

Regional effluent recharge refers to new multi-provider recharge facilities in locations where storage benefits current and future groundwater conditions, and where recovery is practical. Types of recharge facilities include new constructed underground storage facilities (USF) and new managed underground storage facilities (MUSF). A permit from ADWR allows the permit holder to operate a facility that stores water in an aquifer. Information regarding the criteria a facility must meet to be permitted is included in A.R.S. §45-811.01.

A constructed USF permit allows water to be stored in an aquifer by using some type of constructed device such as an injection well or percolation basin. A MUSF permit allows water to be discharged to a naturally water-transmissive area, such as a streambed that allows the water to percolate into the aquifer without the assistance of a constructed device (Arizona Department of Water Resources, 2021). Floodplains and flood control facilities are possible considerations for recharge sites and may offer opportunities to combine with integrated stormwater management planning.

Indirect potable reuse projects that recharge and recover highly treated effluent for potable uses have been implemented in the West Valley and will likely be expanded. The process is governed by ADWR and includes storage credits (Arizona Department of Water Resources, 2021)that can be recovered (through pumping wells) and used for various purposes. There are concerns that unless long-term storage credits created by recharge are withdrawn within the area of hydrologic impact of the recharge project, the aquifer may experience greater declines in the area of recovery. The ADWR helps guide the recovery of stored water to best minimize impacts to an aquifer.

4.4.6 Poor Quality Groundwater Treatment (Remedial Groundwater)

This strategy includes developing new infrastructure to deliver remediated groundwater. Groundwater remediation is the process used to clean polluted groundwater to a level that meets regulatory water quality limits for potable or non-potable use. Treatment would take place at existing treatment facilities; therefore, new treatment facilities are not included in this strategy.

Remedial groundwater consists of groundwater within the boundary of an Arizona Water Quality Assurance Revolving Fund (WQARF) site or federal Superfund site which must be treated to remove contaminants under a requirement by the ADEQ or U.S. Environmental Protection Agency (EPA). A.A.C. R12-15-729(F) allows up to a total of 65 thousand AF/y of remedial groundwater to be withdrawn from Arizona WQARF sites or federal Superfund sites within the Phoenix AMA until January 1, 2025 (State of Arizona, 2006). For reasons associated with current use and future need, it is assumed the January 1, 2025, expiration date for remedial groundwater will be extended. This water is exempt from the requirement to replenish excess groundwater use.

Remedial groundwater is not an additional water supply separate from the regional aquifer. However, the replenishment exemption encourages the beneficial use of water that might sometimes be treated and discharged without a beneficial use, due to the public perception that this water may not be safe to drink. The cost savings associated with the replenishment exemption can make it worthwhile for the municipal provider to beneficially use this water. There are West Valley municipal water providers that are not currently using remedial groundwater but have Arizona WQARF or EPA Superfund sites or contaminated groundwater plumes within their water service areas.

4.4.7 Ocean Desalination

The ocean desalination strategy involves new infrastructure to desalinate and convey ocean water, such as a binational desalination plant at the Sea of Cortez or a plant along the Pacific Ocean coast. It involves delivery of the treated ocean water or exchange with Colorado River water. Substantial attention has been given to ocean desalination in recent years due to its potential to supply large amounts of water. However, there are technological, cost, and environmental drawbacks (U.S. Geological Survey, n.d.).

Desalination typically uses reverse osmosis technology to remove minerals from seawater. Water from the ocean is pressurized and forced through semipermeable membranes. The membranes allow the smaller water molecules to pass through, leaving salt and other impurities to be discharged from the facility. Another desalination method is thermal, where water is boiled at high temperatures creating water vapor free of salt. The water vapor is then collected. Desalination is considered by some as one of the most promising solutions to the problem of freshwater scarcity. However, critics point out it comes with considerable economic and environmental costs. Research is ongoing and new technological breakthroughs may help to increase efficiency, reduce cost, and eliminate unwanted environmental impacts.

Desalination costs have reduced by 50 percent over the last 10 years and much work has been done to investigate the possibilities of desalination for Arizona water supplies, such as partnering with Mexico to increase water availability within the U.S. (Arizona State University, 2021) (Arizona Department of Water Resources, 2021). The basic concept would be to have the U.S. build a desalinization plant in Mexico and exchange the plant water for Mexico’s share of Colorado River water. Similar ideas about desalination plants in California are under consideration as well. However, there are many challenges to overcome to make ocean desalinization a reality for Arizona supplies. Some of these challenges include power supply, brine disposal, environmental impacts, long-term relationships with Mexico, infrastructure concerns, establishing treaties between Mexico and the U.S., and negotiating contracts with California.

4.4.8 Inland Desalination / Brackish Water Treatment

This strategy includes new infrastructure to pump, convey, and treat brackish groundwater or other inland source water with high salinity and deliver (or exchange) it to end users in the West Valley. This could be accomplished through reverse osmosis treatment facilities. Examples include upgrading and operating the Yuma Desalting Plant (YDP) and new infrastructure to utilize brackish water from the BWLA, Yuma Mesa Mound, or Gila Bend Basin.

4.4.8.1 *Yuma Desalting Plant*

Since its construction in 1992, the YDP has been maintained by Reclamation but not operated on a continuous basis due to operating costs and surplus or normal water supply conditions on the Colorado River (Reclamation, 2015). However, due to steady water demand increases and the effects of a prolonged drought over the entire Colorado River Basin, there has been renewed interest in operating the plant. It is estimated that if the plant could be run at full capacity as originally designed, it could save the U.S. up to 91,153 AF of Colorado River water per year that could be stored in Lake Mead. This could be a major boost to the Colorado River supply for the West Valley. However, the major hurdles for this project are cost and environmental issues. It is estimated that it would take over $25 million to upgrade and restart the plant with additional high annual operational costs. Environmental issues include diminished inflows at the Cienega de Santa Clara wetland which is part of Mexico's Upper Gulf of California and Colorado River Delta Biosphere Reserve.

4.4.8.2 *Buckeye Waterlogged Area*

The BWLA is an area of shallow water levels along and near the Gila River in the southwestern portion of the West Valley (Arizona Department of Water Resources, 2015b). Land use within the BWLA consists mainly of irrigated agricultural lands and the historic portion of the City of Buckeye. The Buckeye WCDD drainage wells discharge about 30 thousand AF of groundwater annually to help keep the water level at an adequate distance below the agricultural lands. Some of this water could be treated and beneficially used by municipal providers with service areas within the BWLA, such as Buckeye and Goodyear. Because the maximum volume is 30 thousand AF/y and some of the water will likely be used by irrigation districts within the BWLA, it is possible that less than 30 thousand AF/y will be available for use by local municipal water providers and industrial users. Due to existing uses, brine disposal issues, and infrastructure costs, this concept for treating and serving water from this area is highly unlikely except perhaps as a localized project.

4.4.8.3 *Yuma Mound Desalinization*

The YMM is a large subsurface groundwater mound near Yuma, Arizona that was formed by the infiltration of Colorado River water applied to the land as agricultural irrigation. The total YMM storage volume has been estimated by the USGS to be about 600 thousand AF or a sustainable pumping rate of 50 thousand AF/y (U.S. Geological Survey, 2006). This water, which is extremely saline, would most likely be treated at the YDP. There has been much opposition from the local agricultural community which feels strongly that the water should stay within the Yuma area. Environmental and legal challenges make this project appear non-viable for the West Valley.

4.4.8.4 *Gila Bend Basin*

The Gila Bend Basin is located just outside the WSRV Basin Study area and the Phoenix AMA. However, a portion of Buckeye is in the Gila Bend Basin. Most of the groundwater in the Gila Bend Basin is brackish and high in TDS concentrations (Brown and Caldwell, 2003). This high TDS groundwater is the primary water supply currently available to the portion of Buckeye that is in the Gila Bend Basin. Therefore, a portion of the brackish groundwater in the Gila Bend Basin is being considered as a potential water supply for Buckeye. Much of the groundwater pumped in the Gila Bend Basin is used for agricultural irrigation; other large water users within the Gila Bend Basin include the Lewis Prison Complex, the Town of Gila Bend, a solar power plant, and municipal landfills owned by Phoenix and Buckeye.

The long-term sustainability of the brackish groundwater within the Gila Bend Basin is currently uncertain because an up-to-date, basin-wide groundwater model and hydrologic study has not been completed for the Gila Bend Basin. More evaluation is needed to determine if this is a viable option.

4.4.9 Groundwater Transactions/Exchanges

This strategy involves water markets and transfers for groundwater, including the various forms of water transactions, such as buying and selling, short-term and long-term leasing, dry-year options, water banking, fallowing agreements, and exchanges. These transactions may occur among government entities, including tribal Nations, utilities, and various configurations of government agencies, private citizens and citizen groups, businesses, and NGOs (Eden & Murray, 2019; Glennon & Pearce, 2007).

Markets allow the price to be set at the intersection of supply and demand. Water markets may be desirable to mitigate apparent water scarcity resulting from inefficient allocation because they allow buyers with a higher value use for water to purchase or lease water from those with a lower value use. Transactions could occur with the agricultural sector or groundwater remarketing firms. This strategy includes mechanisms such as inter-basin groundwater transfers (e.g., water in the Harquahala groundwater basin [Vidler Water Company, 2021; Arizona Department of Water Resources, 2009]) and procurement of groundwater saved by agricultural infrastructure improvements.

Water transfers in Arizona have often been controversial, especially when they involve Colorado River entitlements or groundwater. It was the transportation of groundwater that led, in part, to the 1980 Groundwater Management Act. Later, in 1991, the Arizona Legislature barred the transportation of groundwater from most rural groundwater basins to the state's AMAs. Therefore, opportunities are limited to basins that presently have provisions allowing inter-basin transfers. In addition to sustainability issues, additional work is needed to understand how the water could be conveyed (e.g., through the CAP canal). This type of project would require well development, pumping, transmission, storage, treatment, and delivery, and the costs would be significant. The best approach for this type of transportation of water would be a regional project to share the costs.

There are opportunities to purchase groundwater extinguishment credits[4] which can be used to meet legal (but not physical) replenishment requirements on the open market. Estimated rates to purchase extinguishment credits are approximately $50 - $300/AF. However, these credits can only be used once, and eventually there will be none remaining in the Phoenix AMA. Therefore, extinguishment credits do not provide a long-term solution.

There are also opportunities to purchase long term storage credits (LTSCs) to meet legal (but not localized physical) replenishment requirements. Designated providers can purchase CAP LTSCs from other water providers. In the near-term, the cost to purchase CAP LTSCs may exceed the cost for the water provider to order and recharge an equal amount of CAP water to which the provider already has access. The water providers should continue to monitor the market and opportunities to purchase LTSCs in the Phoenix AMA such as, Gila River Water Storage formed to bring additional dependable, renewable water supplies to central Arizona from the Gila River Indian Community's CAP water resources (Salt River Project, n.d.).

4.4.10 Surface Water Transactions, Leases, and Exchanges

This strategy is like the previous; however, it relates to surface water or Colorado River water. It consists of market-based transactions, leases, and exchanges including new leases with Indian communities, new transactions with surface water remarketeers, agricultural sector fallowing deals, and trade agreements with SRP or CAP (Eden & Murray, 2019; Glennon & Pearce, 2007).

Water transfers in Arizona have often been controversial, especially when they involve Colorado River entitlements. However, the extended drought on the Colorado River and recent climate projections have led many water providers in the Phoenix AMA to develop plans to acquire additional water supplies through tribal water leases, re-marketing, groundwater transportation, intentionally created surplus fallowing, and severance and transfers.

A water market type of approach can match different users and providers based on specific needs. However, some transfers may not be considered a renewable (sustainable) resource. Therefore, each possibility will require additional investigation to determine if it meets the study partners' goals and objectives. Some examples that fit into this strategy are described below.

4.4.10.1 *CAP Lease or Non-Indian Agriculture (NIA) Acquisition*

To date, large-scale transfers of entitlements to use main stem Colorado River water for use in other parts of Arizona have been rare. When such transfers have occurred, they have been part of congressionally approved tribal settlements. Transferring a main stem Colorado River entitlement is subject to the dual oversight of the ADWR at the state level, and Reclamation at the federal level. Although the Secretary of the Interior and Reclamation ultimately oversee the allocation of Colorado River water, they have historically given significant deference to the recommendations of the ADWR Director in determining intrastate allocations.

[4] An extinguishment credit is created when an existing grandfathered groundwater right is extinguished pursuant to a process established by DWR in administrative rule. The credit reflects an amount of groundwater that may be withdrawn and pledged to a certificate or designation of assured water supply. The amount of the credit is based on a formula outlined in administrative rule for each AMA and provides for a gradual reduction of the amount of the credit based on the year of extinguishment (Arizona Administrative Code R12-15-723 and R12-15-725.01).

If available, WVWA providers could lease CAP water from an Indian community that holds an entitlement. This approach is common and many water providers in the Phoenix AMA have entered into 100-year lease agreements with various Indian communities, some as recently as 2016. The ADWR is expected to allocate a second block of NIA water as early as 2021.

In addition to ADWR's review, any transfer must be approved by Reclamation. To date, most transfers of Colorado River water that require the issuance of a new contract have been for relatively modest amounts and have taken a few months to process.

Transfers of Colorado River water that require use of the CAP canal to deliver the water will also require a wheeling agreement pursuant to the CAP System Use Agreement. Obtaining a wheeling contract will require the transferee to contribute funds towards system improvement projects that increase the operational capability of the canal to carry wheeled water. In addition, the transferee will be required to pay certain CAP annual costs, such as an equivalent fixed OM&R rate, pumping energy rate, and a capital charge equivalent. Furthermore, any introduction of wheeled water must be approved by Reclamation and undergo environmental review under the National Environmental Policy Act (NEPA).

4.4.10.2 *Intentionally Created Surplus and Water Transfers*

The *2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead* allows a Colorado River contractor to leave conserved water that meets certain criteria in Lake Mead for later delivery; this water is known as Intentionally Created Surplus or ICS. ICS thus allows a contractor to reduce usage at one location for delivery at another location. ICS is a type of transfer because it allows for the movement of water that would have been used at one location for use at another location, potentially for a different end use.

It is important to note that while the primary purpose of ICS is to increase supplies in the Colorado River system, it has the effect of facilitating water marketing and transfers. For example, one of the primary methods of creating Extraordinary Conservation ICS is through fallowing. This conserved water, stored as ICS in Lake Mead, could be available for several uses beyond agriculture. To date, CAWCD is the only Arizona contractor that has created ICS. How CAWCD will use its ICS is unknown at this time.

Using this framework and working with CAP, there is a potential to create a special class of ICS for sub-contractors. This would allow all sub-contractors to create their own ICS accounts to then work with others to create a market for trading.

4.4.10.3 *Market-Based Approach Considerations*

Parties to future water transfers may need to consider how the transaction will not only benefit the immediate parties, but also mitigate any material impacts to affected rural communities. In some cases, targeted local mitigation efforts may be a cost worth bearing in effectuating transfers. Transfers of water will be more likely to proceed if the parties to the transaction use creative arrangements that consider impacts to local communities.

There are many positive aspects to water transfers. For example, water transfers can provide a financial incentive for farmers to use water more efficiently. Or farmers could potentially lease or transfer conserved water while maintaining current agricultural operations. This financial incentive can only exist if the farmer can be assured that they will not forfeit conserved water under forfeiture laws. Unfortunately, this type of arrangement does not appear consistent with Arizona law, although other states have implemented these kinds of reforms.

One option is to change Arizona law to facilitate transfers of conserved water through a type of "water right escrow". Under this approach, a water user, such as a farmer, could lease or transfer conserved water without fear of forfeiture under "use it or lose it" water laws. Conserved water put in a water rights escrow would undergo an expedited and simplified sever and transfer process. This type of program could even set aside a percentage of the transferred water to go to in-stream water flows rights to protect downstream users, as has been done in other states. While such an approach is not without its challenges, it is a market-based concept that has the effect of encouraging conservation. This approach could also free-up water supplies toward resolution of junior claims in the General Stream Adjudication.

In addition to incentivizing conservation, the expanded use of responsible water transfers would open Arizona's water markets in ways that will facilitate flexible water management. Increased market-based efficiency in the use of water will ensure that water supplies are available for job-creating economic activities. Such flexibility could facilitate now-unforeseen water arrangements that address projected supply and demand issues.

4.4.11 Additional Central Arizona Groundwater Replenishment District (CAGRD) Availability

Created in 1993 as a mitigation tool for replenishing mined groundwater (Central Arizona Groundwater Replenishment District, 2021), the CAGRD is responsible for replenishing the aquifer to offset the members' excess groundwater pumping and is statutorily obligated to accept new members, provided they meet the membership requirements. The CAGRD allows development with no direct access to renewable water supplies or CAP sub-contract to comply with the AWS rules.

The CAGRD has two options for replenishing groundwater: 1) recharging surface water or effluent to the aquifer via a recharge facility, and 2) relinquishing LTSCs. LTSCs are accrued by entities either recharging surface water or effluent, or by agriculture taking excess CAP water in-lieu of pumping groundwater.

Every 10 years, the CAGRD must prepare a Plan of Operation, which requires ADWR approval. The plan must describe the water resources that will meet its replenishment obligation for the next 20 years and potential water resources for the following 80 years for both existing and prospective members. In the past, CAGRD has relied heavily on excess CAP water to meet its obligations. Continued below average runoff in the Colorado River basin, as well as sub-contractors taking more than or all their allocation, has resulted in dwindling access to excess CAP water. Other potential sources include tribal water leases, effluent, and imported groundwater. These same sources are being considered by other large water providers to meet future needs, putting them in direct competition with the CAGRD.

The most recent CAGRD Plan of Operation covering Maricopa, Pinal, and Pima counties was published in 2015 and looks out 20 years to 2034. The estimated replenishment obligation in the year 2034 for current and projected members is 86,900 AF/y. The replenishment obligation for the year 2114 for those same members is estimated at 113 thousand AF/y. Based on the current portfolio of 36,534 AF/y, CAGRD needs to acquire an additional 50,370 AF/y for existing and projected 2034 members through 2114. This does not address build-out projections in many West Valley cities.

CAGRD recently acquired the following replenishment water to meet obligations for the next 25 years:

1. 15,000 AF/y CAP Priority 4 Exchange with Gila River Indian Community
2. 18,185 AF/y Lower priority water Gila River Indian Community Lease
3. 445,375 AF LTSCs in Pinal and Phoenix AMAs from Gila River Water Storage

The ability of CAGRD to meet future obligations is uncertain, given that they are not required to demonstrate the full 100-year supply in their 20-year plan of operation. Even if replenishment supplies are available, future costs are likely to be significant or even prohibitive. The AWS rules and the CAGRD were intended to preserve groundwater supplies into the future; however, they will not guarantee the physical availability of a water supply. Replenishment may occur anywhere within the AMA and not necessarily where excess groundwater pumping is occurring, which could lead to severe localized groundwater level declines. The CAGRD also does not provide additional water for future growth. It can only assist communities who have a physically available supply to meet the AMA requirement to off-set pumping with renewable supplies. For those with limited availability to wet water, a tangible supply will be needed.

The high rate of growth and diminishing supplies available to the CAGRD may pose an overwhelming challenge to sound water management in the WSRV. Even though the CAGRD is required by law to replenish its members' excess groundwater pumping, reliance on the CAGRD to support continued growth may not be a sustainable strategy, as is documented in a recent publication from the Kyl Center (Ferris & Porter, 2019). The report cites the following as serious challenges for the CAGRD: (1) actual enrollment far exceeds expected enrollment, (2) availability and/or acquisition of water supplies will be difficult, and (3) the CAGRD financial model needs to be revised to address astronomical increases in cost. The report does have recommendations for the CAGRD's sustainability and more sound water management including: (1) more definitive accounting of replenishment obligations, (2) requiring replenishment in the same location as pumping occurs, (3) moratoriums on new and extended Analyses of Assured Water Supply until further accounting can be done, (4) financing review, and 5) the ability to deny membership.

Currently, the success of future WSRV growth is closely tied to the success of the CAGRD. It is important to understand the benefits and risks associated with this mechanism for supporting growth. Projecting the acquisition of new CAGRD replenishment water was not included in the study. Water level impacts/supply shortages would be positively impacted by additional CAGRD replenishment and full utilization of reclaimed water.

5. Infrastructure and Operations Assessment

The objective of the water and power infrastructure and operations analysis was to identify the types of infrastructure investment that could help meet future demands considering the analyses of this study. Those analyses indicate a high likelihood of new land development, demand growth, and supply reduction in the study area. All potential strategies to adapt to the projections of less water and more demand have infrastructure components except for some forms of demand management (e.g., conservation).

Infrastructure includes wells, treatment plants, storage facilities, conveyance systems, recharge facilities, stormwater systems, effluent or reclaimed water systems, monitoring systems, and the power network. With appropriate staffing, maintenance, and replacement, the existing water and power systems are currently working to meet demand, but over time, significant upgrades and new infrastructure will be required. However, existing infrastructure is not always meeting demand in a sustainable way. For example, as discussed in the Anticipated Future Challenges section of this report, there is presently lack of surface water delivery infrastructure that puts unsustainable pressure on regional aquifers. The types and locations of new or upgraded infrastructure are closely tied to the location of demand growth, the supply type, and supply source.

In addition to infrastructure, operational flexibility will be important to meet water management goals. Innovative operational methods, tailored agreements, and shared use of conveyance systems (e.g., interconnections, wheeling) among water providers can help balance resources and meet future demand.

Water providers in the study area are continually assessing their supplies and systems. Regular maintenance, replacement, and planning are part of existing and ongoing operations. While each water provider has unique issues and water portfolios, the many commonalities make possible a general assessment of existing systems and potential future infrastructure needs and operational opportunities. However, it was beyond the scope of this study to examine detailed infrastructure and power systems of each of the study partners.

5.1 Existing Water and Power Infrastructure

As outlined in this report, current water supplies primarily include surface water, groundwater, and effluent. The infrastructure systems used to deliver these supplies depends on the source. Key components include water supply storage (reservoirs and tanks), wells and pumps, pipes and canals, turnouts, treatment plants, potable water distribution systems, monitoring systems, booster pump stations, pressure reducing valve stations, wastewater collection systems, effluent distribution systems, and the power network.

5.1.1 Central Arizona Project

Colorado River water is delivered to the study area through the CAP aqueduct (Figure 30). The CAP is maintained and operated by CAWCD under contract with Reclamation. Colorado River water is pumped from Lake Havasu behind Parker Dam into a 336-mile CAP aqueduct that can convey about 1.6 MAF/y through a series of pumps that lifts water over 1,000 feet to the study area. The aqueduct also supplies water users outside of the study area and has a total lift of nearly 3,000 feet to the terminus south of the City of Tucson. If the CAP aqueduct was operated full-bore year-round, the capacity would be approximately 2.2 million acre-feet (Central Arizona Project, 2016a).

Figure 30. CAP aqueduct between Lake Havasu and Phoenix (Reclamation photo)

The average size of the CAP aqueduct at its beginning is 80 feet across the top and 24 feet across the bottom and the water is 16.5 feet deep (Figure 31). The oversized section of the concrete lined aqueduct, which acts as an internal reservoir system, is 160 feet across the top and 80 feet across the bottom. The CAP uses an integral storage reservoir at Lake Pleasant on the Agua Fria River on the northern edge of the study area. The CAP fills the lake in the winter, when demand and the price of electricity are low, and releases water from the lake in the summer, when demand and electricity prices are highest. Throughout the CAP system, there are 33 turnouts where water is diverted from CAP's canal to subcontractors' aqueducts and water treatment plants.

Figure 31. CAP canal southeast of Phoenix (Reclamation photo)

An extensive transmission system supplies power to the pumping plants (Figure 32) and check structures along the aqueduct (Zuniga, 2000). The CAP aqueduct system has 14 pumping plants (lift stations) used to lift the water up at key locations so it can then continue to flow by gravity. Pumping water uphill requires a great deal of power. For example, it takes six 60 thousand-horsepower pumps to lift the water nearly 825 feet out of Lake Havasu on the Colorado River into the first segment of the CAP canal. The average lift of other CAP pumping plants is 150 feet (Ferris K. , 2015). CAP is the largest single power user in Arizona using about 2.5 million megawatt-hours (MWh) each year. In the past, most of the power needed to move this water came from a single source, the Navajo Generating Station, which closed in 2019. Now, to manage its power needs, CAP has developed a diversified power portfolio, which includes a combination of long-term contracts and short-term market purchases (Central Arizona Project, 2016b).

Figure 32. Hassayampa Pumping Plant, one of the 14 pump stations on the CAP's 336 mile-long system (Reclamation photo)

5.1.2 Salt River Project

Salt and Verde River surface water is supplied to part of the study area through the SRP system. The SRP operates seven dams and lakes on the Salt and Verde rivers and over 130 miles of canals. SRP also maintains over 250 high-capacity wells, some of which are in the study area (Figure 33). Many of these wells can pump groundwater or recovered stored water into the canal system to supplement the surface water supplies. Water is conveyed through the canal and pipe systems by gravity where possible.

Several SRP dams produce electricity and SRP operates or participates in other major power plants and generating facilities in Arizona and throughout the Southwest. The SRP electric service area includes part of the study area. The remainder of the study area receives electricity from APS (Figure 34). These are the primary electrical networks that power the water infrastructure within the study area. Water treatment plants are required to maintain emergency backup power systems. Emergency power is also required for some groundwater wells, booster pump stations and pressure reducing valve stations.

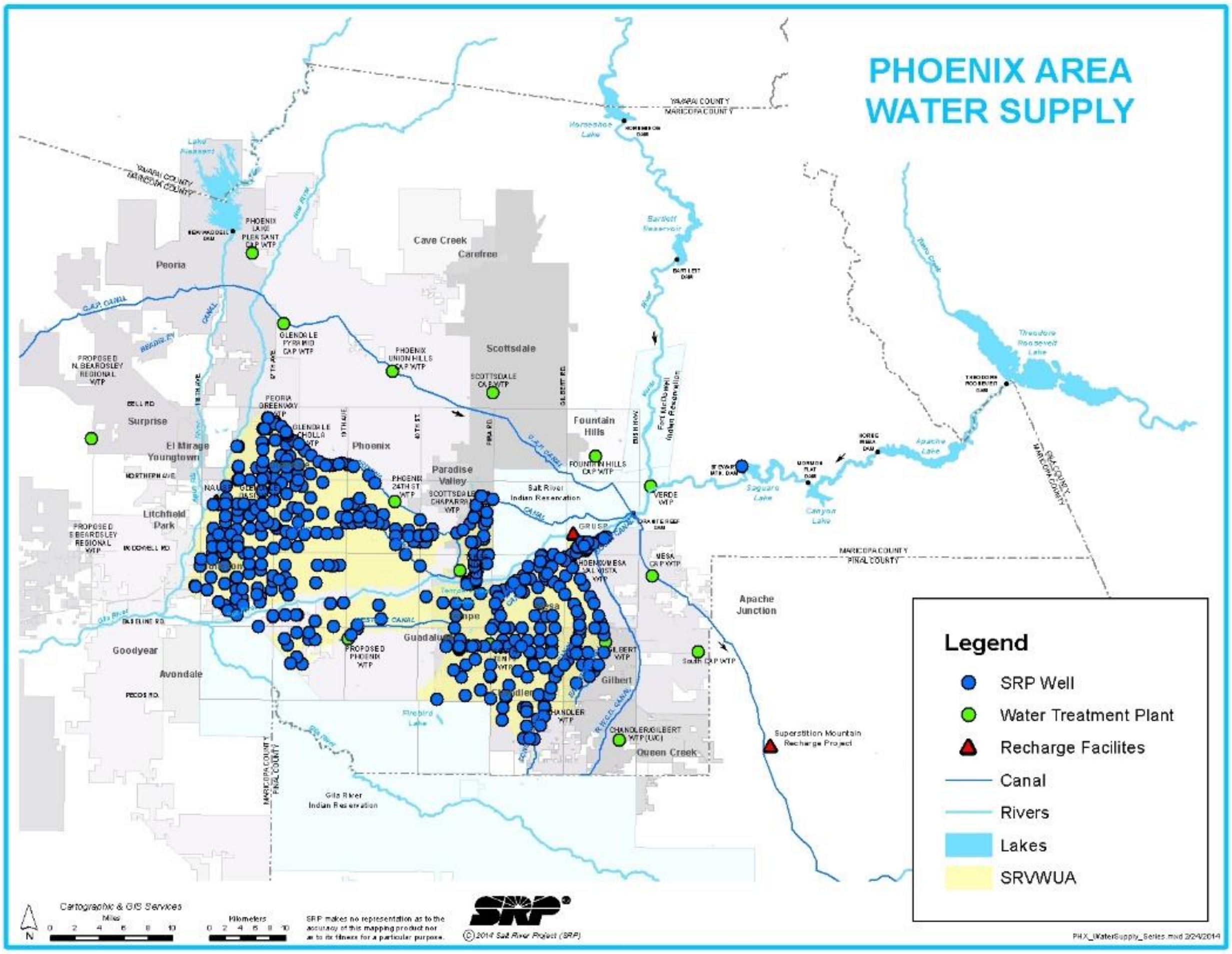

Figure 33. SRP system reservoirs, canals and wells. CAP canal is also shown along with a subset of water treatment plants and recharge facilities. The western portion of the SRP service area is in the study area.

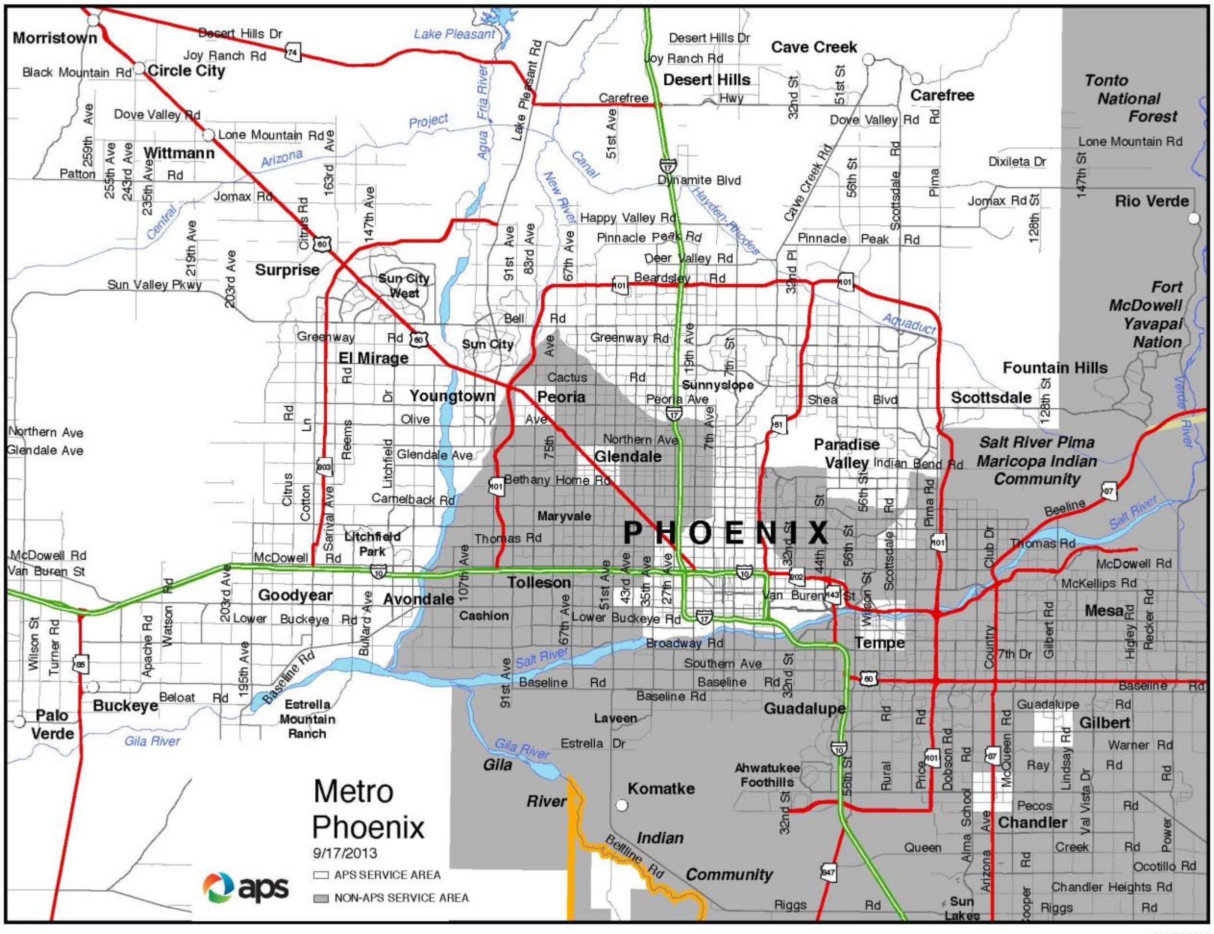

Figure 34. APS Metro Phoenix Electric Service Area (white) and SRP Electric Service Area (gray). The left half of this map includes the study area.

5.1.3 Groundwater and Surface Water Facilities

Groundwater is pumped from regional aquifers through wells. There are hundreds of high-capacity water supply wells in the study area. The existing pumping wells, used for groundwater modelling in this study, are shown in Figure 35. The supply wells and distribution systems are operated and maintained by the water providers. There are also many non-pumping observation wells in the study area that are used to monitor water levels and are vital to water management. Infrastructure for water supply wells includes the well itself, the well pump and pipes, and the power supply (and sometimes wellhead treatment for arsenic). The power requirement for groundwater extraction depends on the depth to water and the pump capacity.

Water from surface water sources is conveyed to water treatment plants where it is prepared for distribution to municipal and industrial users. There are 44 water treatment plants in the study area. Water treatment plants are used to treat the supply to meet or exceed state and federal water quality standards for the end use. The treatment plants are placed in strategic locations that take advantage of source proximity and elevation where possible. The treatment plants are operated and maintained by the water providers. Electrical power is required for treatment and distribution. Water and wastewater treatment plants are often the largest power users within public and private utilities.

The treated water is transported to the end user through complex distribution systems. The municipal and industrial distribution and collection systems consist of storage tanks, pipes, booster pumps, pressurization stations, and monitoring systems. There are hundreds of miles of canals and thousands of miles of distribution pipes in the study area. The City of Phoenix alone has over 7,000 miles of water mains throughout the city (City of Phoenix, n.d.).

Water that is used for purposes other than irrigation is often returned to wastewater treatment plants through wastewater collection systems. The wastewater is treated at the plants where it becomes reclaimed water available for direct or indirect reuse, such as landscape irrigation or aquifer recharge (Figure 36). Conveyance of this water to points of use is generally through systems similar to, but completely separate from, those used to deliver potable water. When not directed to recharge facilities, non-potable reclaimed water is distributed to golf courses, common areas, roadside landscaping, lakes, and park areas through a purple pipe system (Figure 38Figure 37).

Water used for agriculture is typically diverted from stream channels or pumped from wells into canals where it flows by gravity to turnouts and ditches accessed by end users. Some agricultural districts in the study area have rights to surface water from the Agua Fria River stored in Lake Pleasant and delivered by gravity flow through canals. For agricultural water providers, the infrastructure systems involve combinations of storage, wells, and canal/ditch conveyance networks. Water for agriculture does not go through a treatment process unless it is reclaimed water from a wastewater treatment plant. Reclaimed water used for agriculture must meet certain quality standards depending on how it will be used i.e., vegetables versus alfalfa.

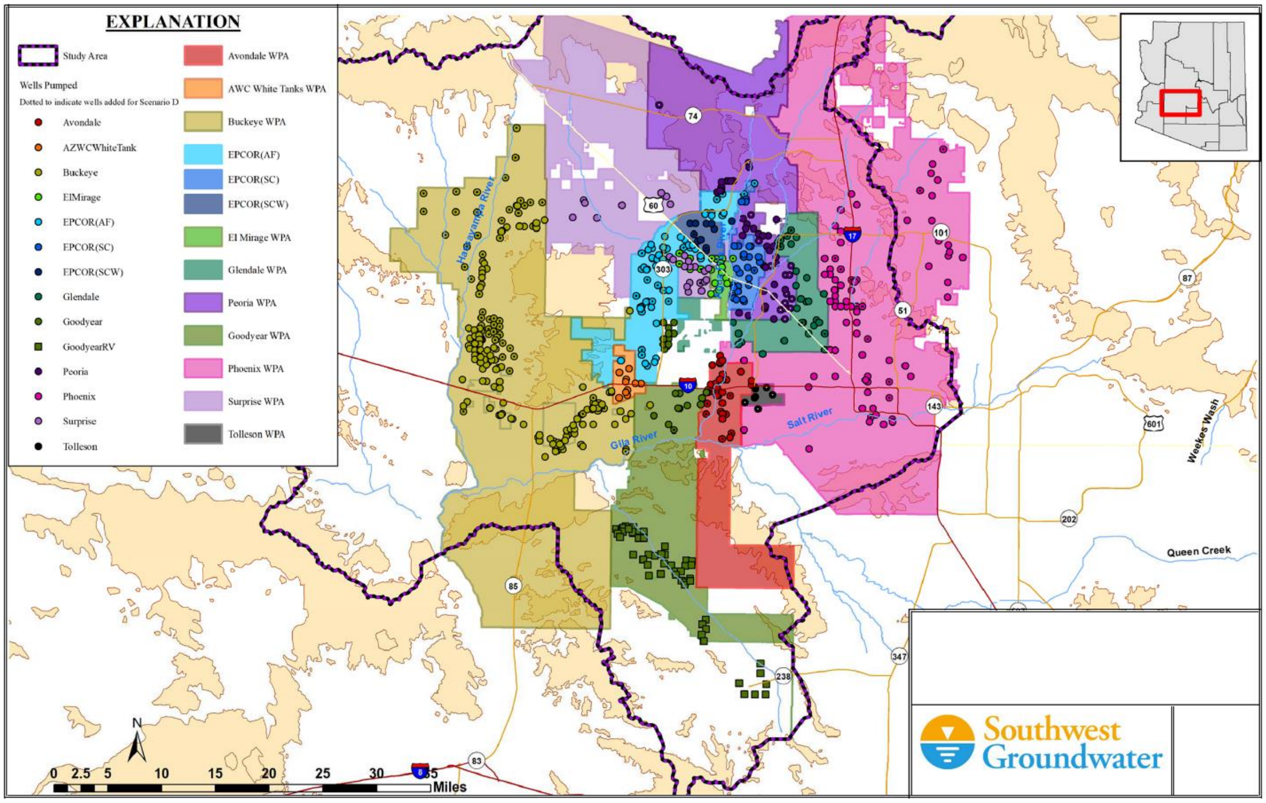

Figure 35. Pumping wells in study area used in the Basin Study groundwater model

Figure 36. The 91st Avenue Wastewater Treatment Plant, the largest of its kind in the entire Southwest region, is within the study area. (AMWUA photo)

Figure 37. Reclaimed water treatment and distribution site in the study area showing purple pipes. (City of Peoria photo)

5.1.4 Recharge Facilities

Artificial recharge and recovery are increasingly important for users in the study area. Recharge as a means of storing excess water is accomplished through an underground water storage, savings, and replenishment program and credit system regulated by the ADWR (Arizona Department of Water

Resources, 2021). A Constructed Underground Storage Facility Permit allows for water to be stored in an aquifer by using some type of constructed device, such as an injection well or percolation basin (Figure 38). A Managed Underground Storage Facility Permit allows for water to be discharged to a naturally water-transmissive area such as a dry streambed that allows the water to percolate into the aquifer without the assistance of a constructed device. A Recovery Well (RW) Permit allows the permit holder to recover water stored underground either on an annual basis or via long-term storage credits. Infrastructure like that discussed previously is required to convey water to the facilities, and to extract and convey water from the points of recovery.

Figure 38. Agua Fria Constructed Underground Storage Facility in the study area. (CAWCD photo)

5.2 Future Water and Power Infrastructure Needs

This study reveals increasing vulnerability in the study area due to supply reductions, increasing supply variability, and demand growth over time. All existing and new uses will remain dependent upon a finite water supply. Therefore, while regular maintenance and replacement is essential, expansion of existing or new infrastructure will be needed in the study area. The location and amount of development (demand growth), as well as the type and location of the water source, will impact specific infrastructure needs. All potential strategies to adapt to the projections of less water and more demand have infrastructure needs except for some forms of demand management (e.g., conservation, system optimization). Specific infrastructure components are unique to each adaptation strategy and require further investigation. Such components will be identified in future appraisal and feasibility investigations. However, because the adaptation strategies will include infrastructure components, a general discussion of these elements is warranted for this study.

5.2.1 Treatment Plants

Raw water from all sources must be treated prior to municipal use, and treatment plants will need to have appropriate capacities and be in optimal locations near sources and users. In many cases, expanded or new treatment plants will be similar to existing plants. However, if the source water quality is significantly different, or if a municipal provider is going to use a DPR strategy, for example, then a different treatment process and unique plant upgrades will be required.

Additionally, declining source water quality due to watershed fires and more intense storms is one of the primary drivers for investment in water treatment plants in the region. Current plants often cannot handle the lower quality water and need to be upgraded.

Investment in treatment plants will also likely be required to address chemicals and pathogens of emerging concern that threaten the safety of water. Emerging contaminants are chemicals, biological agents, and naturally occurring elements detected in the environment that may pose a potential or real threat to human health or the environment, but which generally are not currently regulated by the U.S. EPA or ADEQ ((Arizona Department of Environmental Quality, 2016).

Per and poly-fluoroalkyl substances (PFAS) are a group of man-made chemicals that are of concern in parts of the study area. Both chemicals are very persistent in the environment and in the human body (U.S. Environmental Protection Agency, 2021a). New plants or plant upgrades may need to add PFAS treatment technologies such as activated carbon, ion exchange resins, and high-pressure membranes, like nanofiltration or reverse osmosis. These technologies can be used in drinking water treatment facilities or smaller individual water systems.

Costs and operational feasibility will need to be weighed by the needs of the community. If existing wastewater treatment plants cannot be upgraded to meet the need, new plants will be needed. Locations will be selected based on available land, location to input sources, and distribution needs and opportunities. For example, it may be possible to locate a wastewater treatment plant near a recharge facility whereby the effluent from the plant can be recharged to offset aquifer impacts of pumping wells.

5.2.2 Groundwater Wells

With expanding population and new areas opened for growth, new groundwater wells will likely be required to meet demand and act as an emergency backup to surface water supplies. Infrastructure needs and costs for using groundwater will depend on location. Placement of new wells will be influenced by aquifer characteristics and proximity to infrastructure, such as conveyance and treatment plants. To meet goals and objectives for aquifer protection, water providers will avoid or not be permitted to put new wells in areas where excessive drawdown has occurred or is likely to occur. Land subsidence and associated land fissures can damage existing distribution systems and result in costly repairs and additional infrastructure needs, such as new lift stations, power stations, and costly redesigns.

The groundwater model developed for this study can help simulate or predict aquifer conditions and pumping effects, but specific site investigations will be required for groundwater infrastructure siting. Sites will be selected to avoid potential problems such as excessive drawdown, land subsidence, poor water quality, and high pumping and conveyance costs. Where possible, new wells will be in areas where water levels are high and water quality is good. Wells may also be located near recharge sites to recover stored (recharged) water. Well networks and interconnected systems may be expanded to allow for adaptive use of groundwater. Significant efforts are anticipated to site and permit new wells in the future.

5.2.3 Recharge Sites

Recharge of reclaimed water or excess surface water is necessary to meet the current and future water challenges in the study area. The process requires canal, pipe, and pump infrastructure to convey water from the source. It also needs the facilities to cause the recharge (e.g., basins), and the equipment required to monitor the process. Recharge sites must be in appropriate locations. Some recharge may rely on injection wells, while other recharge sites require large tracts of land suitable for constructing percolation basins. This study developed model tools that can be used to help locate suitable sites for future recharge facilities. Ideally, sites are near the source, and minimize infrastructure investment; however, a good recharge site involves other factors such as suitable geology, depth-to-water, and land use.

Many existing recharge facilities in the study area are a result of partnerships between entities. The study partners recognize that future regional recharge facilities will also likely be joint efforts. The shared goal to meet future challenges, and the positive working relationships among the study partners, will greatly benefit the ability to plan, design, construct, and operate new facilities.

5.2.4 Stormwater Management

Opportunities exist to integrate recharge projects with stormwater management practices, lands, and infrastructure. For example, flood control district lands along channels and behind flood control structures may be appropriate for recharge basins (Figure 39). Further investigation is needed to understand the potential synergies between regional stormwater management and recharge infrastructure.

Figure 39. View of impounded stormwater after monsoon shower looking north from the base of New River Dam (flood control structure) in Peoria, AZ (Reclamation photo)

5.2.5 Distribution and Collection Systems

Expansion of potable water distribution and wastewater collection networks will have similar components wherever they occur in the study area. As new development occurs, water providers will expand their distribution and collection systems as needed. In some cases, innovative interconnects between systems may create redundancy and backup capabilities helpful to face the supply and demand challenges. Continued proactive planning will be required to meet the challenges. Much can be anticipated based on current zoning and land ownership, but only as new developments move forward will specific new distribution and collection infrastructure be prioritized and constructed.

Additional raw water conveyance infrastructure to deliver surface water to WTPs, and then to the end user, will help protect aquifers by avoiding overreliance on recharge and recovery, particularly in disparate locations.

5.2.6 Agricultural Infrastructure

Agricultural water supply infrastructure is largely in place and working with appropriate OM&R. As shortages to traditional supplies occur, such as with CAP water, new infrastructure may be required. This may involve system interconnects for access to other sources, or additional groundwater wells and distribution systems. Operational agreements that identify exchange terms or temporary leases may be beneficial to adapt to future supply challenges.

Existing agricultural water users in the study area know irrigation water management is vital for water conservation. Some types of irrigation systems can be upgraded to increase irrigation efficiency. For example, switching from high or medium pressure drip sprinklers to low pressure systems can conserve water and reduce distribution costs (U.S. Department of Agriculture, National Resources Conservation Service, 2006). However, to avoid costly system failures, source water quality in the study area needs to be accounted for during planning upgrades or changes.

5.2.7 Operational Partnerships and Interconnects

Partnerships and mutually beneficial agreements are not new to Arizona. Yet, it is anticipated that new and innovative operational changes will be required to maintain delivery of reliable supplies in times of drought and supply shortages. With appropriate infrastructure, such as system interconnections, operational agreements can be arranged that allow water exchanges between entities. Arrangements that allow others to use existing infrastructure, can prevent the need for additional new infrastructure and provide flexibility in times of shortages. For example, the SRP to CAP Interconnection Facility (SCIF) could increase the use of existing infrastructure and provide water reliability benefits. McJunkin (2020) in an article titled, "The Value of Partnerships", provides a good summary explanation of the existing CAP to SRP interconnect facility (CSIF) and the proposed SCIF.

If the SCIF moves forward, it could allow water stored in SRP reservoirs to be transported to customers that have water treatments plants outside of SRP's water service area (Central Arizona Project, 2021).

Key findings regarding infrastructure and operations include:

- Infrastructure is a key component for managing supply reductions, supply variability, and increased demand.
- The types and locations of new or upgraded infrastructure are closely tied to the location of demand growth, the supply type, and supply source.

- Existing conveyance infrastructure likely will be the first choice for "new" water, but depending on the needs and location, it may not be enough.
- Maximizing the use of existing facilities affords the greatest return on investment.
- A lack of surface water delivery infrastructure today puts unsustainable pressure on regional aquifers.
- It is important for storage, recovery, treatment, and conveyance mechanisms for projects to be near the point of use and to each other.
- New groundwater wells will be sited with due consideration of aquifer protection goals.
- Upgrades to existing and construction of new treatment plants will occur. This may include DPR-capable systems in some places.
- Upgraded or new water treatment infrastructure will be required to properly treat poor quality water, such as source water with contaminants of emerging concern.
- Locations of new recharge infrastructure will be optimized (e.g., near existing infrastructure and rights of way, in geologically suitable locations that offset pumping drawdown effects).
- Opportunities will be investigated to coordinate with stormwater management and flood control efforts and locations.
- Expansion of the interconnected water network will provide operational flexibility and infrastructure cost savings.
- Partnerships will remain vital to meeting the water resource challenges.

6. Evaluation and Comparison of Adaptation Strategies, Economic and Trade-Off Analysis

The purpose of the *Economic and Trade-Off Analysis* is to compare the adaptation strategies developed by the study partners by considering the economic, financial, environmental, and social impacts of each strategy. Some effects are quantified and monetized, while others are evaluated qualitatively due to data limitations and infeasibility with their measurement. For this study, 10 evaluation criteria are analyzed to rank the performance of 10 different adaptation strategies across several considerations and trade-offs. This serves as a screening tool to help identify those strategies that are best suited to address future imbalances between water supply and demand in the study area.[5]

For the analysis, attention is placed on municipal, industrial, agricultural, and recreational uses of renewable water supplies and non-renewable groundwater supplies. Consumer welfare is assessed for the study area, as well as for the entire central Arizona region, which shares the same renewable water supplies and an interdependence between groundwater aquifers. The first step in the analysis is to estimate the pre-adaptation welfare effects associated with future water shortages. This includes price and welfare effects from shortages within the market for renewable water, costs associated with increased groundwater reliance, and effects on recreation due to surface water changes and instream water availability. Projections from CAP:SAM of water supply and demand in the central Arizona region (Maricopa County, Pinal County, and Pima County) are used to model pre-adaptation consumer welfare effects from future water shortage and quantify welfare impacts from adaptation strategies intended to reduce shortages.

Several pre-adaptation supply and demand scenarios are assessed for 2020-2060, each reflecting a different magnitude of annual water shortages across time, absent adaptation efforts. The projections encompass groundwater and surface water availability under varied climate conditions and water demand under varied growth rates, spatial growth patterns, and assumptions of future water-use efficiency. The model also accounts for the major elements of Arizona's elaborate legal and regulatory setting. These scenarios serve as a baseline for comparing adaptation strategies, which are assessed based on the ability to reduce future water shortages while also considering several economic, financial, environmental, and social effects associated with each strategy. A trade-off analysis is conducted to compare adaptation strategies across multiple criteria simultaneously, identifying important trade-offs and highlighting the strengths and weaknesses of each strategy.

6.1 Overview of Economic and Trade-Off Analysis

A trade-off analysis is an application of Multi-Criteria Decision Analysis, which is a general framework for evaluating complex decision-making under multiple and often conflicting objectives, where a decision may lead to a desirable change in one objective while simultaneously resulting in an

[5] Only a brief overview and the results of the *Economic and Trade-Off Analysis* are provided here. A full report containing the details of the analysis can be found in Appendix F.

undesirable change in another objective. Most multi-criteria problems have conflicting criteria and as a result, there is no unique solution that can optimize all criteria simultaneously. The purpose of the trade-off analysis is to evaluate quantifiable and non-quantifiable effects to score and rank alternative strategies. This involves developing evaluation criteria, assessing strategy impacts, weighting criteria for importance, and scoring alternative adaptation strategies.

The analysis relies on existing data and is dependent on the outputs identified in previous parts of this Basin Study to evaluate impacts and assess trade-offs associated with adaptation strategies. As a result, some areas of measurement and evaluation are limited, and several uncertainties exist. The study team started by developing numerous adaptation strategies and selecting several cost and benefit criteria to capture the economic, financial, environmental, and social impacts of each strategy. The team then provided key information necessary to score adaptation strategies across the chosen criteria. This included details on water quantity effects which are used to quantify *Water Availability and Reliability* benefits as well as *Regional Economic Impacts*. The team was also asked to provide qualitative information that could be used to compare strategies on a low-high relative scale for additional criteria of interest, such as environmental and social considerations. The team was also surveyed to determine weights of importance for each criterion.

The first step in the analysis is to quantify the pre-adaptation welfare effects associated with expected water shortages in the future. This is done using CAP:SAM projections of future water supply and demand in the study area, as well as in the central Arizona region more broadly, under various climate and population growth scenarios. This captures potential water shortages without adaptation efforts in place. The next step is to place monetary values on the quantifiable impacts of each strategy. This step is the economic portion of the analysis, where benefits are captured by improvements in consumer welfare. Economic benefits can be compared to project costs to evaluate economic feasibility. If benefits exceed costs, then a project is considered economically feasible and justified. Another type of analysis that is similar is a financial analysis, which is based on cash flows and is an evaluation of who pays the cost of a project. A trade-off analysis includes a broader range of impacts than a financial or economic analysis since the effects do not need to be translated into monetary terms to compare the impacts of alternatives.

In this assessment, only *Water Availability and Reliability* and *Regional Economic Impacts* are quantified, while additional criteria are analyzed qualitatively using a low-high relative scale. The final step in the analysis is to put all cost and benefit considerations on an equivalent scale in order to score and rank adaptation strategies on a relative basis across numerous considerations at once. This allows quantified effects to be directly compared with qualitative effects. The results provide a relative comparison of alternatives and identify the strengths and weaknesses of each adaptation strategy. Strategy scores are combined with several criteria weighting schemes to explore differing importance for the cost and benefit criteria and identify which strategies perform best under different objectives. This analysis provides crucial information to help inform water management in the study area and address anticipated gaps between future water supply and demand in the region.

6.2 Future Water Shortages

The project team decided to focus on three CAP:SAM scenarios (A, D, and F), capturing a range of potential future conditions and water shortages. Scenario A represents "business as usual," in which the future closely follows the current rate and spatial distribution of growth and follows both observed and expected trends for water supply and demand. Household water use continues to decline, and irrigation efficiencies gradually increase while shortages are simulated using historic climate conditions. Scenario D simulates an aggressive rate of growth coupled with a regional growth pattern that is weighted more heavily towards suburban and exurban areas. A higher proportion of the housing units in agricultural areas are placed on active agricultural land compared to Scenario A. Furthermore, climate factors reflect a hotter, drier future. This includes lesser declines in household water use, increased crop consumptive use, and large water shortages. This scenario reflects the most rapid population growth and adverse climate conditions. Scenario F is based on historic climate conditions, like Scenario A, but simulates a lower rate of growth and a spatial pattern of growth that places a greater proportion of housing units within the existing urban core rather than existing agricultural land. Scenario F also includes a more aggressive rate of decline in household water use and higher irrigation efficiencies.

Absent significant changes in renewable supplies, the study area will be heavily dependent on groundwater pumping to meet future demand. Much of that pumping will be subject to Arizona's AWS rules and require offsetting replenishment. CAP:SAM treats this portion of unmet demand as groundwater pumping that is subject to AWS rules, recognizing that it is yet to be determined how that pumping might be offset with renewable supplies in the future. For the *Economic and Trade-Off Analysis*, this unmet portion of demand is treated as the shortage volume for renewable supplies, which is appropriate under Arizona's existing legal framework where future demand must be met by directly using renewable supplies or offsetting groundwater use with renewable supplies. **Error! Reference source not found.** shows the projected shortage volume for renewable supplies from

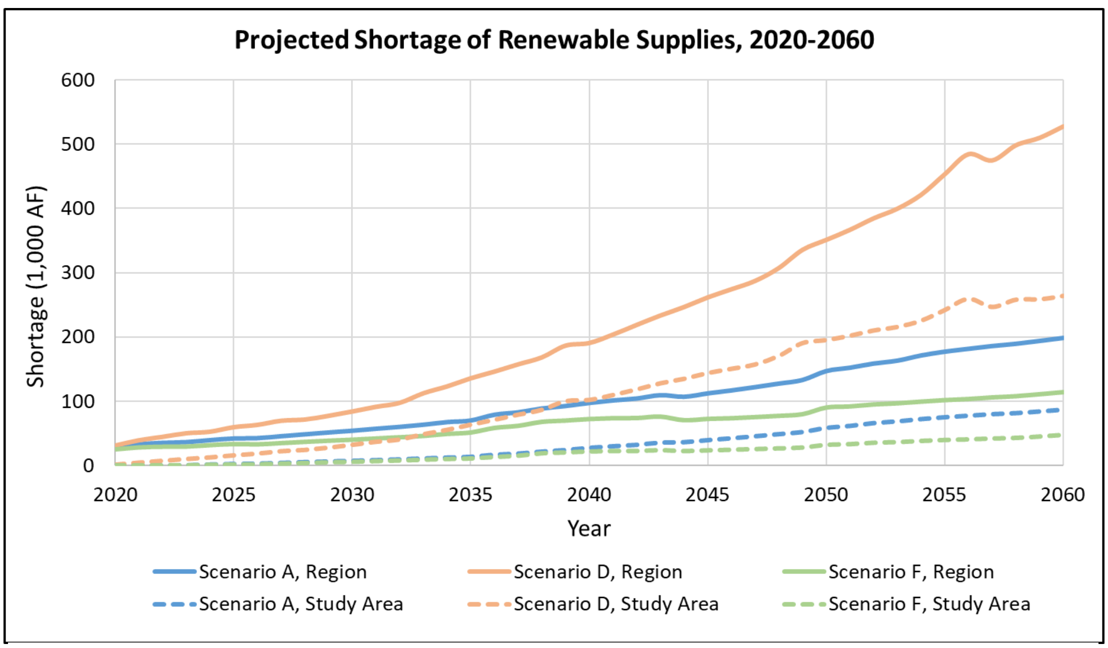

Figure 40. Projected shortage of renewable supplies, 2020-2060 (Note: 'Region' refers to the entire CAP Service Area)

2020-2060 under each CAP:SAM

scenario. The shortage amount is depicted for the entire region (CAP Service Area) as well as for the study area. Shortages at both the local and regional level influence price and welfare across the region. This means that adaptation strategies intended to address water shortages in the study area can have important implications for water users in the broader region.

6.3 Quantifying Welfare Effects from Water Shortages

A shortage is defined as a situation where the quantity demanded exceeds the quantity supplied at the market price. In other words, a shortage reflects a gap between supply and demand. When this happens for a good or service, such as renewable water, it puts upward pressure on market prices, which subsequently leads to changes in welfare for water users. The demand for water represents the maximum willingness to pay for water, which also reflects the marginal benefit derived from each unit of water. When users pay a price below their willingness to pay, they gain welfare known as consumer surplus (CS). This is a monetary measure of welfare calculated according to the area under the demand curve, above the price paid by consumers. This means that price changes affect consumer welfare, all else equal. To quantify adaptation strategy benefits associated with reducing water shortages, welfare effects are measured according to price impacts and subsequent changes in CS within the regional market. Impacts on direct use of local surface water and groundwater supplies are also measured, along with changes in underground water storage.

The price end users pay for water, or the retail price, varies greatly depending on location and the type of end use. For example, the price paid for potable water partly reflects the cost of water treatment and delivery to end users, generally resulting in a higher price than is paid for untreated irrigation water. In order to analyze various uses of water simultaneously, it is necessary to focus on water of similar quality and location, or wholesale demand and the price of raw water, rather than final water demand and retail prices. For this analysis, water shortages and price effects for marketed renewable supplies are assessed at the wholesale level based on regional supply and demand in central Arizona. This means that welfare effects and adaptation strategy benefits are also measured at the wholesale level. The supply and demand projections in CAP:SAM distinguish M&I use from agricultural use, so this analysis also separates use between these sectors, incorporating unique demand and price assumptions for each.

Shortages in renewable supplies are primarily anticipated for M&I users, while agricultural users are expected to continue to rely on groundwater into the future. Nonetheless, many agricultural users also depend on renewable water purchased on the market, such as SRP water, CAP water, and effluent, meaning they could be affected by M&I shortages and market prices in the region. Welfare effects from regional water shortages are estimated for individual M&I providers and irrigation districts within the study area, as well as for users in the broader region who share the same market for renewable water supplies. The “outside” area is defined here as the remainder of the central Arizona region, outside of the study area. The outside area welfare is included to capture adaptation strategy benefits that go beyond the study area, which can stem from reducing shortages in the study area and helping keep water prices down for all users in the regional market. Shortages are expected to vary from year to year, so annual welfare effects are summed across the study period to get a single benefit measure for adaptation strategies.

Shifts in supply and demand cause continual adjustments in price, reflecting either a market shortage (upward pressure on price) or a market surplus (downward pressure on price). Under the CAP:SAM projections, regional water demand is expected to grow significantly, and supply is expected to remain relatively fixed, with limited renewable water supplies and restrictions on groundwater pumping. This is expected to lead to growing water shortages over time and upward pressure on the price of renewable water bought and sold in the region. Adaptation strategies that increase the supply of water or reduce demand so that additional water is available for other uses, will reduce upward pressure on renewable prices. This will also affect the amount of groundwater pumping and underground water storage, subsequently affecting welfare. The overall change in welfare, or the benefit of a strategy, is measured by comparing annual welfare with and without the strategy in place. CAP:SAM provides annual projections from 2020-2060, so annual benefits are summed across the 40-year period. This is important since shortages are expected to vary from year to year, meaning that the benefit of a strategy also varies annually. Summing annual benefits across the study period also captures the additional benefit from strategies that can be implemented quicker, as they will subsequently generate benefits earlier on in the study period. The present value (*PV*) of benefits across the study period is calculated using the 2020 Federal *Water Resources Planning* discount rate of 2.75 percent.

Shortages will only affect prices for raw water bought and sold in the market, while the water portfolio for many users partly depends on direct groundwater and/or local surface water use. The price of direct use is independent of shortages and price effects in the market, instead depending on the cost of withdrawal. The price of groundwater is modeled as a function of future energy prices and average depth to water for each user, meaning the price is unique to each user and varies across the region. The price of local surface water is assumed to be the same for each user and remain constant across the study period. Underground storage is also important to consider as storage is affected by shortages and influences future supply and use decisions. Future prices for storage are modeled based on historic storage prices. When an adaptation strategy provides more water than is needed to avoid a shortage in a given year, excess water is modeled as being stored and available for mitigating future shortages, rather than allowing market prices to decline.

It is important to note that changes in use modeled in CAP:SAM reflect increased water use efficiency for both M&I and agricultural users, along with other features modeled in CAP:SAM. Water efficiency improvements result in increased welfare through lower use. Estimates therefore represent a net effect that includes improvements in water use efficiency, as well as changes in user preferences for different water sources. The extent of water shortage is largely a function of population growth and the spatial distribution of that growth, but the calculation of welfare also embodies supply-side effects from changes in water availability due to weather and climate factors. The conditions modeled in CAP:SAM are therefore reflected together in the calculation of welfare effects, and the current legal and regulatory setting is assumed to remain in place throughout the study period, serving as a constraint on regional water supply and demand.

In addition to M&I and agricultural use, or what is defined here as market uses of water, there are also non-market benefits of water that are important to consider, such as water-related ecosystem services. Ecosystem services are defined as benefits that humans get from the natural environment and properly functioning ecosystems, either directly or indirectly. This includes recreation, water quality, water storage, fish and wildlife habitat, nutrient cycling, climate regulation, disaster mitigation, and many other benefits stemming from the natural environment. Importantly, these goods and services are "free" in that beneficiaries typically do not pay a price, whether it is for consumptive or non-consumptive use. For non-market use, attention is placed on recreation and the role of water in providing welfare through several different types of recreation, either directly or indirectly. As with welfare effects for market use, welfare for recreation is quantified in terms of impacts on CS. Changes in CS are again measured annually and summed to compare welfare with and without an adaptation strategy in place. Data limitations for surface water conditions prevent other ecosystem services from being quantified in monetary terms for this assessment. However, ecosystem services, and environmental considerations more broadly, are incorporated in the trade-off analysis through qualitative criteria.

CAP:SAM provides the necessary quantity information to measure pre-adaptation welfare effects of water shortages, encompassing renewable market use, direct use, and underground storage, as well as changes in surface water which impact welfare for recreation. As with market use, welfare effects for direct use and storage are measured according to changes in CS, but instead of prices depending on water shortages, future prices are estimated separately. Changes in welfare for recreation are also assessed based on changes in CS, with changes in surface water used to estimate changes in visitation and welfare per visit for different types of recreation. Considering welfare impacts through all these avenues, total pre-adaptation welfare changes are estimated annually for individual water providers, individual irrigation districts, and individual recreation activities. Effects are separated between the study area and outside area, but ultimately summed across all water users in the region when assessing adaptation strategy benefits. Details on this process and the calculations used to measure welfare changes and adaptation strategy benefits can be found in the full *Economic and Trade-Off Analysis* report (Appendix F).

6.3.1 Welfare for Market Use

For market use, focus is placed on raw water prices and regional supply and demand for M&I and agricultural water use. Welfare effects from regional water shortages are estimated for individual M&I providers and irrigation districts within the study area, as well as for outside users in the broader region who share the same market and regulatory requirements for renewable water supplies. Price changes are based on shortages at the aggregate level between regional supply and demand, which encompasses CAP:SAM's entire three-county area. That said, the unique raw water portfolio of each water provider and irrigation district is captured along with differing prices across raw water sources. The study area encompasses 13 water providers[6] and six irrigation districts[7] in CAP's service area. The projections for water providers include residential demand as well as non-residential demand for commercial, industrial, and construction uses. As such, the analysis uses projections for water providers to model M&I use as a single sector, while projections for irrigation districts are used to model agricultural use.

Due to important market linkages between the study area and surrounding parts of the region, the analysis also includes welfare effects for users outside of the study area, treated as a single "outside" user. This is done by analyzing regional supply and demand and welfare effects for CAP:SAM's entire three-county region, distinguishing impacts in the study area from the outside area, which together represent the central Arizona region. Welfare effects are also considered for direct use of local surface water and groundwater, and for underground water storage, because direct use and storage are influenced by market shortages and may be affected by adaptation strategies. Whenever

[6] Water providers include Arizona Water Company (WC) White Tank, Avondale, Buckeye, El Mirage, EPCOR Agua Fria, EPCOR Sun City, EPCOR Sun City West, Glendale, Goodyear, Peoria, Phoenix, Surprise, and Tolleson.

[7] Irrigation districts include: Adaman, Buckeye WCDD, MWD, RID, St. Johns Irrigation District (ID), and SRP.

a strategy provides more water than is needed to close the shortage gap in a given year, it is assumed that surplus water is stored and used to mitigate shortages in future years.

Due to differences in the price of using different sources of raw water, welfare effects from future water shortages largely depend on the particular mix of water sources used by each water provider and irrigation district. Water users in the study area and surrounding region rely on six sources of raw water, each of which is considered a renewable source except for groundwater. In particular, renewable water comes from CAP water, SRP water, local surface water, and effluent, while groundwater is considered nonrenewable. For this analysis, use of the CAGRD is also considered renewable use, which is a way for municipal providers to meet AWS renewable requirements while continuing to use groundwater. Since CAGRD uses renewable supplies (usually CAP water) to replenish groundwater and offset pumping, CAGRD use effectively represents renewable use for accounting purposes. Raw water is purchased in the regional wholesale market, other than direct use from local surface water and groundwater. Each marketed source has a different wholesale price, generally reflecting the cost of provision, and price can vary for M&I use versus agricultural use, for reasons such as subsidies and incentives.

CAP:SAM projections of future water shortages and use by individual water providers and irrigation districts is combined with information on wholesale market prices to measure changes in consumer welfare. Welfare effects are also considered for direct use of local surface water and groundwater, and for underground water storage, because direct use and storage are influenced by market shortages and may be affected by adaptation strategies. The prices shown in Table 11 are used to represent the average wholesale price for each source of marketed renewable water at the start of the study period (2020). All prices are $2020 based on published 2020 rates, except for effluent, which is based on 2017 prices and adjusted to 2020 using the consumer price index (CPI) for the Phoenix area. Prices are separated between M&I and agricultural use and used with separate estimates of price elasticity of demand.

Table 11. Wholesale Market Prices ($2020 per AF)

Source	M&I	Agriculture
CAP Water	$242.00	$58.00
SRP Water	$18.32	$28.37
Effluent	$631.34	$308.58
CAGRD	$742.00	N/A[a]

[a] Only municipal users are subject to AWS rules and use CAGRD to comply with requirements.

To capture changes in direct use, the price of using local surface water and the price of pumping groundwater are determined for the start of the study period. The price of groundwater use depends on depth to water and energy prices. As such, average depth to water for each water provider and irrigation district is used to determine a unique price for each user. Future prices are then modeled as a function of expected energy rates and changes in depth to water. Table 12 shows the price of direct use and underground storage used for the start of the study period. A range is shown for groundwater use, representing the range across users, which varies based on depth to water.

Table 12. Price of Direct Use and Underground Storage ($2020 per AF)

Source	M&I	Agriculture
Groundwater[a]	$13.91-$61.55	$4.40-$17.59
Local Surface Water	$15.45	$15.45
Underground Storage	$13.00	N/A[b]

[a] The price of groundwater use is unique for each user and calculated based on average depth to water and 2018 energy rates which are CPI-adjusted to 2020.
[b] Only municipal users are subject to AWS rules and use storage to comply with requirements.

The full report for the *Economic and Trade-Off Analysis* provides a detailed discussion on each price shown in Table 11 and Table 12. For wholesale prices, the fixed cost and variable cost components that determine market rates are discussed, along with subsidies and features that influence the final price that water users pay. All costs associated with wholesale provision are included so that each source of raw water is treated as being of similar quality and location, and the price reflects a long-run value encompassing both fixed and variable cost components. Details are also provided on the price of direct use and underground storage, highlighting the assumptions used to predict future prices independently from shortages in renewable supplies. This includes information on depth to water and the cost of groundwater use for each user, which is informed by the groundwater modeling done for the study.

6.3.2 Linking Shortages to Market Welfare – Price Elasticity of Demand

Changes in CS are measured by combining information on projected water shortages modeled in CAP:SAM with price information for each source of raw water. To utilize price and quantity information, assumptions are needed for the own price elasticity of demand (ε_D) for water in the region. The own price elasticity of demand, or simply the elasticity of demand, measures the relationship between the price of water and quantity demanded. This captures the shape of the demand curve, reflecting how consumers alter their water use when price changes. More formally, it measures how a percent-change in price leads to a percent-change in the quantity demanded, measured as a ratio. For this assessment, the elasticity of demand is used to measure the relationship in the opposite direction, determining how quantity (a water shortage) affects price. It is assumed that demand is isoelastic, meaning that price elasticity is constant across all parts of the demand curve.[8] This allows the measure of elasticity to be applied across different levels of water use and across various wholesale prices for the different sources of raw water.

[8] Price elasticity of demand can vary for several reasons, such as at different levels of water use, at different prices, at different levels of income, and across different seasons. However, the level of detail provided by CAP:SAM does not permit for these differences to be captured, and modeling varied elasticities adds significant complexity with minimal

The elasticity of demand is generally negative, reflecting that demand is downward-sloping due to an inverse relationship between price and the quantity demanded. As such, it is common practice to take the absolute value for easier interpretation. An absolute value is therefore reported throughout this analysis. In this case, the elasticity of demand ranges from 0 to infinity. An elasticity of 0 implies no relationship between price and the quantity demanded. An elasticity of 1 (unit-elastic) implies that there is a one-to-one relationship, meaning a one-percent change in price corresponds with a one-percent change in the quantity demanded (and vice versa). An elasticity between 0 and 1 (inelastic) means the quantity demanded changes less than the percent-change in price. This is often the case for water demand, since water is a necessity with no close substitutes, meaning the quantity demanded is minimally influenced by changes in price. An elasticity greater than 1 (elastic) means the quantity demanded changes more than the percent-change in price. This reflects consumption that is more responsive to price changes, which is often associated with non-essential goods and services with several close substitutes.

The elasticity of demand tends to vary across time, with a more inelastic relationship between price and quantity in the short-run, and a more elastic relationship in the long-run. This is because in the long-run, consumers have more time to adjust their behavior and respond to changes in price. For example, there is more time for residential users to shift towards more efficient appliances, industrial users towards more efficient production, and agricultural users towards more efficient irrigation. Since this assessment is focused on long-term effects across a 40-year study period, a long-run elasticity is most appropriate. To remain consistent with CAP:SAM, water demand is separated between M&I and agricultural uses, which is also important to capture the fact that M&I users and agricultural users may respond differently to price changes. Agricultural users are often less responsive than M&I users to price changes, but this depends on several factors. The distinction between sectors is further necessary to capture benefits for adaptation strategies that shift water from one use to another. Benefits are typically generated when shifting water from low-value uses such as agriculture to high-value uses such as M&I.

The full report for the *Economic and Trade-Off Analysis* provides a survey of the economics literature on water demand, summarizing several meta-analyses and those studies most relevant to the study area. In general, the broad range of elasticity estimates, and the lack of recent estimates in and around the study area, make it difficult to determine a single measure of elasticity to adopt for M&I and agriculture. Several elasticities are therefore tested, highlighting the sensitivity of price and welfare estimates to the chosen elasticity. Table 13 shows the range of average annual changes in market prices for 2020-2060 under different price elasticities. These changes characterize the range of potential pre-adaptation price effects resulting from shortages in the market for renewable supplies.

Table 13. Average Annual Price Effects Under Different Elasticities, 2020-2060*

Price Elasticity (ε_D)	Scenario A	Scenario D	Scenario F
2	+3.69%	+8.63%	+2.52%

value since this analysis is only intended to screen adaptation strategies. By assuming isoelastic demand, this can be considered as focusing on a "typical water user" in the region.

1.5	+4.92%	+11.51%	+3.36%
1	+7.38%	+17.26%	+5.04%
0.5	+14.76%	+34.52%	+10.09%

Note: *These represent pre-adaption price changes associated with shortages in marketed renewable water supplies under different CAP:SAM scenarios and different assumptions for the price elasticity of demand.

The range of price effects across CAP:SAM scenarios represents uncertainty in future water shortages associated with population and climate conditions, while the range across price elasticities characterizes uncertainty in future price sensitivity for water users. Adverse price and welfare effects are largest with inelastic water demand (ε_D=0.5) under Scenario D, while effects are smallest with elastic water demand (ε_D=2) under Scenario F. Correspondingly, future water shortages could increase renewable market prices anywhere from 2.5 to 34.5 percent annually. For reference, CAP real prices have risen, on average, 5 percent per year for M&I and 4 percent per year for agriculture from 2008-2018, but in some years (2009 and 2014), the increase has been as much as 14 percent for M&I. With a CAP shortage expected to start in 2020,[9] CAP's M&I rate jumps 22 percent from 2019 to 2020, and the advisory rates indicate a 5 percent annual change the following years. The price effects in Table 13 are therefore consistent with recent price trends in the region, with a range that captures the possibility for more/less severe water shortages in the future.

The price effects in Table 13 reflect average annual pre-adaptation changes from 2020-2060, but depending on the scenario, the change from year-to-year varies, based on annual water shortage volumes. In general, price effects are smaller at the start of the study period and get larger toward the end of the period due to population growth and more severe water shortages. The annual variation in shortages and subsequent price changes are captured in the estimation of welfare effects. By measuring annual changes, the implementation time for an adaptation strategy is encompassed in the benefit estimate. The earlier a strategy is implemented, the greater the effect on prices across the study period since shortage reductions early on can have a compounding effect on future prices. The calculation therefore includes a volumetric and temporal component, which is important to not only capture differences in implementation time, but also demonstrate the fact that some strategies do not provide a constant annual volume of water. This is why the benefit estimate for reducing water shortages is formally defined as *Water Availability and Reliability*, since it encompasses both the quantity of water provided as well as when that water is available.

The elasticity of demand has important implications for measuring changes in price and CS in this framework. The more elastic demand is, the smaller the impact of shortages on price and the smaller the benefit from strategies that reduce water shortages. Conversely, price effects and subsequent changes in CS are larger the more inelastic demand is. Although the chosen elasticity has important implications for the magnitude of estimated welfare effects and benefits, it has minimal influence on the trade-off analysis itself. This is because benefits and adaptation strategies are compared purely on a relative basis, not absolute, and the relative ranking of strategies is unaffected by the chosen elasticity. However, if one is comparing the cost and benefit of

[9] In 2019, CAP published two rate schedules for 2020 with advisory rates for 2021-2024. One schedule reflects a shortage of water starting in 2021 and the other reflects a shortage starting in 2020 (used here).

implementing a particular strategy, the elasticity of demand has important implications for quantifying benefits. Recent estimates from Klaiber et al. (2012) and Yoo et al. (2014) suggest that long-run residential water demand in Phoenix is relatively elastic, while past studies looking at agricultural water demand in Arizona and elsewhere suggest that demand has historically been more inelastic for irrigation. To capture this difference, it is assumed that agricultural demand is slightly more inelastic than M&I demand in the study area. Welfare impacts and adaptation strategy benefits are estimated assuming M&I long-run demand is unit-elastic (ε_D=1) and agricultural long-run demand is slightly inelastic (ε_D=0.8).

6.3.3 Welfare for Non-Market Use

For non-market use of water, welfare is quantified according to changes in surface water availability and impacts on different forms of recreation. (Additional non-market benefits are evaluated qualitatively.) This is done using a benefit transfer (BT) approach, which involves taking CS values estimated in the economics literature and applying them to the area of interest. This is a well-accepted technique used by economists to value non-market goods and services, when conducting an original study is too time and resource intensive. In general, BT is most valid when values are transferred from study sites that reflect similar conditions to the area of interest. This is often accomplished by finding studies conducted in or nearby the area of interest. However, in some cases, there are no such estimates in the literature, so one must resort to using values from study areas that resemble the area of interest as closely as possible. Fortunately, several databases have been created that provide a comprehensive list of prior economic studies valuing recreation. For this analysis, Oregon State University's Recreation Use Values Database and the U.S. Geological Survey's Benefit Transfer Toolkit were queried to identify all studies applicable to the study area. Both lists identify studies based on the type of recreational activity and provide key information on the characteristics of the original study.

For this analysis, 19 types of recreation are assessed by using an exhaustive list of studies from the economics literature that are applicable to the study area. Studies were selected for each activity based on the study location and type of environment. Studies were first queried for Arizona only, but in some cases the results were insufficient. Therefore, the search was broadened to Arizona plus other states, the West (as defined by the U.S. Census Bureau), and then the entire U.S., as necessary. When available, studies that focused on Arizona were deemed the most appropriate, but in some cases, estimates were not available or were judged as not being reliable, so estimates from the broader regions were used. Several studies were flagged and not included, either because they were not applicable to the study area or because the CS estimate was unusually small or large. This was often associated with unique locations, such as particular wilderness areas or studies conducted long ago using outdated data or methods. Ultimately, 80 unique studies encompassing 317 CS estimates were used to value recreation, excluding 29 estimates that were flagged and not included. The full report for the *Economic and Trade-Off Analysis* provides details on the studies used for BT, including a list of all studies used to value recreation in this assessment.

The median CS value across the selected studies is used to measure welfare for each activity. The median is used instead of the average so that outliers do not influence the calculation of CS. When a study provided more than one estimate, the average was used so that no study was implicitly given greater influence when determining the median CS value across studies. Table 14 provides the median CS values used for the 19 recreation activities in this analysis, along with additional summary statistics across the studies used. CS values reflect welfare per visitor day adjusted to $2020 using the CPI for the Phoenix area. Table 14 also highlights the variation in CS across activities and across studies.

Table 14. Summary Statistics for CS per Visitor Day

Activity	Average	Median	Min	Max	Std. Dev.
Backpacking	$29.6	$29.6	$29.6	$29.6	N/A
Boating, Motorized	$41.2	$33.8	$9.6	$86.6	$25.7
Boating, Nonmotorized	$26.3	$26.3	$23.8	$28.7	$3.5
Bicycling, Leisure	$42.5	$38.1	$16.4	$82.1	$24.5
Bicycling, Mountain	$121.1	$96.1	$18.6	$226.4	$94.1
Camping	$24.8	$13.8	$10.2	$50.5	$22.3
Freshwater Fishing	$81.4	$82.1	$18.2	$125.1	$34.1
Hiking	$77.2	$53.8	$5.4	$222.4	$66.0
Horseback Riding	$26.7	$26.7	$26.7	$26.7	N/A
Hunting, Big Game	$93.9	$96.6	$29.5	$158.4	$50.7
Hunting, Small Game	$135.4	$142.8	$10.6	$259.3	$88.2
Hunting, Waterfowl	$72.2	$47.0	$7.9	$240.1	$53.4
Picnicking	$28.6	$28.6	$28.6	$28.6	N/A
Rock & Ice Climbing	$57.6	$57.6	$42.3	$72.8	$21.6
Skiing, Cross-Country	$40.4	$40.4	$40.4	$40.4	N/A
Skiing, Downhill	$80.6	$75.3	$14.6	$157.2	$72.0
Snowboarding	$61.9	$61.9	$61.9	$61.9	N/A
Swimming	$32.9	$30.2	$14.1	$55.0	$15.3
Wildlife Viewing	$93.4	$66.5	$40.3	$238.4	$69.5

Values are $2020. The median is used to measure welfare instead of the average so that outliers do not influence the calculation of CS.

To calculate welfare associated with recreation, CS estimates are combined with visitation data. Information on visitation by activity comes from Audubon (2019) from their report on *The Economic Contributions of Water-Related Outdoor Recreation in Arizona*. The report provides visitation data for 2018 by recreational activity for each county in Arizona. The recreation categories used in Audubon's report (2019) are coarser than provided in the Recreation Use Values Database and Benefit Transfer Toolkit. To make the CS estimates compatible with visitation data, estimates are combined for certain activities. For example, Audubon (2019) identified *Trail Sports* as one primary category of recreation, which consists of *Hiking*, *Backpacking*, *Rock Climbing*, and *Horseback Riding*. Meanwhile, estimates exist for each of these individual forms of trail sports, meaning activities must be combined to calculate welfare for Audubon's categories.

To estimate CS values for Audubon's broad categories of recreation, the project team provided ratios to use to combine individual activities. For example, the category *Water Sports* is split 60-20-20 percent across *Motorized Boating*, *Nonmotorized Boating*, and *Swimming*; the category *Trail Sports* is split 5-70-5-20 percent across *Backpacking*, *Hiking*, *Rock Climbing*, and *Horseback Riding*; and for categories such as *Fishing*, 100 percent is assigned to *Freshwater Fishing*; and for *Wildlife Watching*, 100 percent is assigned to *Wildlife Viewing*. The team also decided that the *Snow Sports* category was not relevant to the study area and snow-related activities are therefore excluded from the analysis.

The visitation data from Audubon (2019) corresponds with county-level estimates. The study area falls inside Maricopa County, but does not span all the county area. To isolate recreation in the study area, population data is used to separate visitation data. The population in the study area modeled in CAP:SAM amounted to 58.7 percent of the 2018 U.S. Census Bureau population for Maricopa County. This proportion is used to apply visitation data for Maricopa County to the study area, with the remaining amount assigned to the outside area. Visitation estimates for Pima County and Pinal County are also included under the outside area, meaning recreation is assessed for the same three counties modeled in CAP:SAM.

The data from Audubon (2019) only captures visitation for Arizona adult residents (age 18 and older). It therefore excludes visitation for non-residents as well as those under age 18. Reliable data is not available to measure welfare for those under age 18, so the benefits from recreation estimated here reflect only the welfare for those 18 and older. To estimate visitation for adult non-residents, information from the Arizona Office of Tourism is used to provide data on domestic overnight visitors to Arizona based on visitor studies by Longwoods and Tourism Economics. This includes the share of business versus leisure travelers, resident versus non-resident travelers, average party size, age, number of nights stayed, top activities, and travel expenditures.

Table 15 provides recreation visitor days in 2018 by activity and area for Arizona adult residents from Audubon (2019) and estimated for adult non-residents based on Arizona Office of Tourism information. Visitation is different from the number of participants, with the latter being much smaller since the typical participant spends several days recreating in a given year and some individuals may also participate in several forms of recreation. Total visitor days, including Arizona residents and non-residents, is used to assess welfare from recreation in the study area and outside area. In 2018, adult individuals spent over 31 million visitor days recreating in the region, with over 13 million visitor days spent in the study area. Around three-quarters of this corresponds with Arizona residents and the remaining quarter corresponds with non-residents who visit the state. These amounts are used as a baseline to estimate recreation visitation across the study period for each activity. As population grows, the number of recreation participants is expected to increase, so future visitation is assumed to grow according to each CAP:SAM scenario. Population is projected to grow differently in the study area than in the outside area, so future visitation is calculated separately for each area.

Table 15. Recreation Visitor Days (2018)

Activity	Study Area		Outside Area		Total
	Arizona Residents	Non-Residents	Arizona Residents	Non-Residents	
Bicycling	2,062,412	332,922	3,080,188	490,442	5,965,964
Camping	201,178	159,438	572,522	318,699	1,251,836
Fishing	1,276,026	205,981	1,542,474	229,149	3,253,630
Hunting	102,615	16,565	197,785	27,652	344,617
Picnicking	1,379,758	222,726	1,710,942	257,473	3,570,898
Trail Sports	1,936,360	956,625	2,827,140	1,194,178	6,914,303
Water Sports	1,507,630	1,275,499	1,658,770	1,389,721	5,831,620
Wildlife Watching	1,589,981	256,661	2,269,919	327,853	4,444,414
Total	10,055,960	3,426,416	13,859,740	4,235,167	31,577,282

Visitation data for Arizona residents comes from Audubon (2019) and visitation for non-residents is estimated using information from the Arizona Office of Tourism. Reported amounts may not add to total amounts due to rounding.

Annual welfare for recreation is determined by multiplying visitor days by CS per visitor day for each activity. Table 16 provides the annual welfare values by activity for the study area and outside area, including total welfare for the region and the average welfare per participant for each activity. The results indicate that recreation generates over $1.5 billion in welfare per year across the three counties analyzed, with an average of $386 per participant across all activities ($2020). In the study area, recreation generates about $666 million in welfare per year, with fishing and water sports together generating around $210 million per year. Note that welfare per participant is heavily influenced by differences in visitor days per participant in a given year. Those activities with a high number of visitor days per participant generate more welfare per participant, such as bicycling and fishing. Annual welfare per participant therefore varies much more than welfare per visitor day.

Table 16. Annual Welfare from Recreation

Activity	Study Area	Outside Area	Total	Per Participant
Bicycling	$133.00	$198.26	$331.26	$1,065.7
Camping	$4.97	$12.29	$17.26	$42.6
Fishing	$121.72	$145.50	$267.22	$542.3
Hunting	$12.53	$23.70	$36.23	$235.3
Picnicking	$45.84	$56.31	$102.15	$135.8

Activity	Study Area	Outside Area	Total	Per Participant
Trail Sports	$136.94	$190.36	$327.30	$435.8
Water Sports	$87.84	$96.22	$184.06	$298.3
Wildlife Watching	$122.79	$172.74	$295.53	$551.1
Total	$665.64	$895.37	$1,561.01	$386.2

Welfare is in millions ($2020), other than welfare per participant. Reported amounts may not add to total amounts due to rounding.

These estimates represent the direct use benefits attributed to adults partaking in recreational activities in the region. However, there are additional benefits associated with recreation, such as regional economic impacts on output, income, and employment. Regional economic impacts are addressed separately, but additional benefits from recreation, such as impacts on health and mental wellness, are outside of the scope of this analysis and were not analyzed.

6.3.4 Linking Surface Water Conditions to Welfare from Recreation

Different forms of recreation generate different amounts of welfare, with each uniquely influenced by water conditions. Fishing and water sports clearly depend on surface water, but it is not immediately obvious how welfare might be linked with water conditions when activities do not necessarily require water. For example, bicycling, camping, and trail sports do not require water, but the welfare generated by these activities is influenced by environmental factors such as water conditions. Fortunately, as part of the survey conducted by Audubon (2019), those partaking in recreational activities that do not require water were asked about the contribution of water to their welfare. In particular, visitors were asked "*How much does the presence of water add to your enjoyment of [activity]?*" and *"If you were not able to participate in [activity] on or along the water, how much would your total activity decrease?"* The responses from these two questions are used to estimate how visitation and welfare per visit might change from future changes in surface water conditions.

For these questions, individuals responded in categories of *A Great Amount*, *A Moderate Amount*, *A Small Amount*, or *Not at All*. These responses are used to generate elasticities that link surface water to visitation and welfare per visit for each activity. Assumptions are made so that each response corresponds with a different elasticity, and the combination of responses is used to generate elasticities. Questions regarding the role of water were not asked for *Fishing* and *Water Sports* since they directly depend on water, so it is assumed that there is an elasticity of 1 (1-to-1 relationship, or unit-elastic response) for these categories. This implies that a 1 percent decline in surface water corresponds with a 1 percent decline in visitation, as well as a 1 percent decline in welfare per visit. For activities that do not directly rely on water, more inelastic responses are assumed.

As with the price elasticity of demand, a higher elasticity implies a larger response, while an elasticity of zero implies no response. For activities that do not necessarily require water, it is assumed that there is an elasticity of 0.75 (1-to-0.75 relationship) for respondents stating that participation would decrease *A Great Amount* without the presence of water, and the same for those stating that water contributes *A Great Amount* to activity enjoyment. An elasticity of 0.5 (1-to-0.5 relationship) is assumed for those responding *A Moderate Amount* and an elasticity of 0.25 (1-to-0.25 relationship) is assumed for those responding *A Small Amount* for these questions. For those who responded *Not at All*, it is assumed that there is an elasticity of zero (no relationship) with surface water conditions. These assumptions imply a linear relationship between response categories, with a unit-elastic relationship for recreation categories that directly depend on water, and an elasticity change of 0.25 between the response categories for those recreational activities that indirectly depend on water.

Surface water conditions modeled in CAP:SAM are used to measure pre-adaption welfare effects, which is then compared with surface water availability and welfare when an adaptation strategy is in place to quantify strategy benefits for each recreational activity. In CAP:SAM, surface water conditions in the region are largely captured by SRP surface water availability as well as non-SRP local surface water availability. The combination of SRP and local surface water availability across both M&I and agriculture is therefore used to model pre-adaptation welfare effects under CAP:SAM Scenarios A, D, and F. This is appropriate, as the Salt River and local lakes and reservoirs are a key source for recreation and outdoor activities in the region. Lakes managed by SRP are regularly stocked with fish and are supplied with boat ramps for fishing and other water sports. These lakes and reservoirs provide swimming, boating, fishing, camping, picnicking, and wildlife viewing opportunities, and individuals frequently use water canals and laterals and their adjacent lands for various recreational opportunities, such as walking, running, bicycling, and fishing.

Surface water conditions impact benefits from recreation, and population influences the number of individuals participating in recreation. Projected changes in surface water availability and population from CAP:SAM are therefore used to measure pre-adaptation welfare effects for recreation. Surface water availability varies under each scenario, reflecting varied climate conditions and generally mirroring changes in CAP supplies from the Colorado River. As with population, surface water conditions differ for the study area and outside area, so changes are calculated separately for each. Population growth is important for measuring pre-adaptation welfare for recreation, but adaptation strategies do not influence population. This means that the benefit of a strategy for recreational activities stems only from changes in surface water availability.

Looking at the entire region and across all recreational activities together, recreation visitation is expected to decrease anywhere from 5 percent (Scenario F) to 10 percent (Scenario D) without adaptation efforts, and welfare per visit is expected to decrease anywhere from 6 percent (Scenario F) to 13 percent (Scenario D). The impact is largest for those activities that depend on water and lowest for those that do not. These effects correspond with impacts per recreational participant from changes in surface water availability, while overall visitor days and welfare from recreation grows according to population growth in each CAP:SAM scenario. The change in surface water is the same for Scenario A and Scenario F since both reflect historic climate conditions. Pre-adaption welfare effects for recreation therefore only differ between Scenarios A and F based on differences in population growth and demand, while welfare effects under Scenario D reflect the highest demand as well as hot and dry climate conditions that frequently affect surface water availability.

6.3.5 Pre-Adaptation Welfare Effects from Future Water Shortages

The projections generated by CAP:SAM model surface water and groundwater conditions on a yearly basis up to 2060. The projections include population and demand growth, which together with water availability determines the extent of water shortages across time. The size of shortage therefore varies from year to year, depending on the CAP:SAM scenario. This information is used to estimate changes in CS on an annual basis for the central Arizona region, focusing on the study area. As previously covered, annual changes are discounted using the 2020 Federal *Water Resources Planning* rate of 2.75 percent and summed across 2020-2060 to derive a single measure for pre-adaption changes in welfare. This represents a baseline for welfare effects before implementing adaptation strategies and is used to compare and score strategies in terms of *Water Availability and Reliability*.

Changes in welfare are estimated for wholesale market use (agriculture and M&I) and non-market use (recreation) under CAP:SAM Scenarios A, D, and F. For market use, welfare effects are calculated based on the extent of water shortage and subsequent changes in price and CS. For recreation, welfare effects are calculated based on projected surface water conditions and CS values from the economics literature. Market calculations incorporate population growth under each CAP:SAM scenario, so for symmetry, recreation visitation also grows with population. Table 17 shows the cumulative pre-adaptation welfare effects for M&I users under each CAP:SAM scenario, along with the effect per housing unit. Water shortages are expected to reduce welfare anywhere from $254 million (Scenario F) to $994 million (Scenario D) across the study period, absent adaptation efforts. This amounts to an average of $84 (Scenario F) to $241 (Scenario D) per housing unit, with variation across water providers depending on their raw water portfolio. Slightly less than half of the welfare effects occur within the study area and the remainder occur in the outside area.

Table 17. M&I Cumulative Welfare Effects, 2020-2060

Water Provider	Scenario A		Scenario D		Scenario F	
	Total	Per HU	Total	Per HU	Total	Per HU
Arizona WC White Tank	-$2.67	-$293.5	-$14.13	-$528.2	-$1.72	-$215.3
Avondale	-$7.25	- $146.3	-$20.87	-$315.4	-$4.25	-$108.3
Buckeye	-$16.13	-$165.8	-$100.82	-$345.7	-$10.87	-$121.9
El Mirage	-$4.27	-$295.8	-$8.90	-$654.5	-$2.53	-$203.6
EPCOR Agua Fria	-$8.86	-$107.3	-$21.15	-$169.2	-$5.65	-$78.4
EPCOR Sun City	-$2.48	-$63.3	-$4.85	-$117.6	-$1.68	-$45.0
EPCOR Sun City West	-$1.37	-$74.8	-$2.55	-$140.1	-$0.99	-$54.7
Glendale	-$18.37	-$170.7	-$43.35	-$389.0	-$13.39	-$119.8
Goodyear	-$11.50	-$182.9	-$31.36	-$349.6	-$6.50	-$145.9
Peoria	-$15.19	-$141.0	-$39.68	-$268.1	-$9.47	-$106.9
Phoenix	-$71.54	-$90.5	-$141.08	-$194.7	-$48.69	-$62.8
Surprise	-$11.38	-$182.5	-$47.65	-$383.4	-$6.11	-$133.5
Tolleson	-$0.13	-$44.7	-$0.25	-$84.7	-$0.09	-$30.6
Outside Area, All	-$219.76	-$115.3	-$516.94	-$224.0	-$141.96	-$85.3

Water Provider	Scenario A		Scenario D		Scenario F	
	Total	Per HU	Total	Per HU	Total	Per HU
Total	-$390.89	-$116.4	-$993.59	-$241.1	-$253.92	-$84.3

Total welfare effects are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. Reported amounts may not add to total amounts due to rounding.

Table 18 provides the cumulative pre-adaptation welfare effects for irrigation districts. Water shortages are expected to reduce welfare anywhere from $45 million (Scenario F) to $121 million (Scenario D) across the study period. This amounts to an average of $160 (Scenario F) to $448 (Scenario D) per cropped acre, with significant variation across irrigation districts depending on their raw water portfolio. Around two-thirds of welfare effects occur outside the study area.

Table 18. Agriculture Cumulative Welfare Effects, 2020-2060

Irrigation District	Scenario A		Scenario D		Scenario F	
	Total	Per Acre	Total	Per Acre	Total	Per Acre
Adaman	-$0.01	-$5.6	-$0.02	-$10.7	-$0.01	-$2.9
Buckeye WCDD	-$0.47	-$29.4	-$0.94	-$60.6	-$0.32	-$19.9
MWD	-$1.67	-$289.7	-$5.03	-$834.5	-$1.47	-$224.7
RID	-$16.10	-$796.0	-$34.99	-$1,796.3	-$11.34	-$539.4
St. Johns ID	-$8.50	-$8.1	-$13.16	-$13.3	-$0.01	-$4.5
SRP	-$2.46	-$240.6	-$7.26	-$625.5	-$1.73	-$165.9
Outside Area, All	-$44.44	-$206.6	-$72.42	-$338.0	-$29.89	-$133.9
Total	-$65.16	-$241.5	-$120.67	-$448.2	-$44.76	-$159.8

Total welfare effects are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. Reported amounts may not add to total amounts due to rounding.

Table 19 provides the cumulative pre-adaptation welfare effects for recreational activities, along with welfare effects per participant. Water shortages are expected to reduce welfare anywhere from $114 million (Scenario F) to $249 million (Scenario D) across the study period, absent adaptation efforts. This amounts to an average of $22 (Scenario A)[10] to $69 (Scenario D) per participant, with variation across activities depending on the importance of water. The largest welfare effects are tied with the two water-based activities, *Fishing* and *Water Sports*, though *Bicycling*, *Wildlife Watching*, and *Trail Sports* are also linked with significant welfare effects. Roughly half of the welfare effects stem from water-based recreation, with around half of all welfare effects occurring in the study area.

[10] Scenario A and Scenario F are both based on historic surface water conditions but differ in their projections of demand. This leads total welfare effects to be lowest in Scenario F, but welfare per participant is slightly less in Scenario A since the number of participants is greater from higher population growth.

Table 19. Recreation Cumulative Welfare Effects, 2020-2060

Activity	Scenario A		Scenario D		Scenario F	
	Total	Per Participant	Total	Per Participant	Total	Per Participant
Bicycling	-$8.07	-$47.2	-$8.66	-$82.4	-$7.78	-$47.7
Camping	-$0.38	-$1.9	-$0.53	-$4.1	-$0.36	-$1.9
Fishing	-$17.19	-$70.9	-$43.47	-$317.8	-$16.57	-$71.7
Hunting	-$0.89	-$15.6	-$1.14	-$34.5	-$0.86	-$15.8
Picnicking	-$3.34	-$7.7	-$4.59	-$16.0	-$3.21	-$7.8
Trail Sports	-$9.02	-$21.5	-$11.08	-$40.0	-$8.69	-$21.7
Water Sports	-$12.41	-$34.7	-$31.38	-$155.5	-$11.96	-$35.1
Wildlife Watching	-$8.55	-$30.4	-$11.34	-$59.7	-$8.24	-$30.7
Outside Area, All	-$61.77	-$18.1	-$136.41	-$64.2	-$56.76	-$18.9
Total	-$121.62	-$21.9	-$248.59	-$69.1	-$114.42	-$22.4

Total welfare effects are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. Reported amounts may not add to total amounts due to rounding.

Putting everything together, Table 20 shows the cumulative pre-adaptation welfare effects across M&I, agricultural, and recreational users in the central Arizona region. Effects are separated between the study area and outside area. Water shortages are expected to reduce welfare anywhere from $413 million (Scenario F) to $1.36 billion (Scenario D) across the study period, absent adaptation efforts. Slightly less than half (44 percent) of this welfare loss occurs in the study area. These pre-adaptation welfare changes highlight the magnitude of benefits that could potentially be provided by a strategy. For example, a strategy that exactly offsets the shortage volume in every year across the study period would have an estimated benefit equal to the pre-adaptation welfare effects shown. That said, the type of water provided, when it becomes available, and whether the volume varies across time also factor into the calculation of strategy benefits.

Table 20. Total Pre-Adaptation Welfare Effects by Area, 2020-2060

Use	Area	Scenario A	Scenario D	Scenario F
M&I	Study Area	-$171.13	-$476.64	-$111.95
	Outside Area	-$219.76	-$516.94	-$141.96

Use	Area	Scenario A	Scenario D	Scenario F
	Total	-$390.89	-$993.59	-$253.92
Agriculture	Study Area	-$20.72	-$48.25	-$14.89
	Outside Area	-$44.44	-$72.42	-$29.89
	Total	-$65.12	-$120.67	-$44.76
Recreation	Study Area	-$59.85	-$112.18	-$57.67
	Outside Area	-$61.77	-$136.41	-$56.76
	Total	-$121.62	-$248.59	-$114.42
All	Study Area	-$251.70	-$637.07	-$184.49
	Outside Area	-$325.97	-$725.77	-$228.61
	Total	-$577.67	-$1,362.84	-$413.10

Values are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. Reported amounts may not add to total amounts due to rounding.

6.4 Adaptation Strategies and Evaluation Criteria

For the trade-off analysis, 10 adaptation strategies are evaluated across 10 criteria to identify trade-offs and strengths and weaknesses of each strategy. Strategies were developed by the project team and selected to provide a range of alternatives aimed at reducing water shortages in the study area. Evaluation criteria, defined as either a benefit criterion or a cost criterion, were then chosen by the team to capture a range of economic, financial, environmental, and social effects associated with each strategy. Strategies consist of several components and are evaluated relative to one another using a low-high scale to score and rank strategies for each criterion. Two criteria, *Water Availability and Reliability* and *Regional Economic Impact*, are first assessed quantitatively before getting converted to a low-high scale to compare impacts with other criteria that are scored qualitatively based on input from study partners. This section describes each adaptation strategy and evaluation criterion and provides an overview of the process used to score strategies across criteria.

Some criteria may be more important than others, so different weighting schemes are used to give additional weight to certain criteria. Several weighting schemes are tested, one with additional emphasis placed on economic and financial considerations, one with emphasis on environmental and sustainability considerations, and one with emphasis on social and administrative considerations. Two other schemes are also tested, one with equal weight across all criteria, and another based on a survey identifying which criteria the study partners consider to be most important. Adaptation strategies are expected to perform differently under each weighting scheme, and no weighting scheme is considered "optimal." Instead, the results allow one to see how each strategy performs under different objectives and considerations. An overall rank is also provided, showing how strategies perform across all weighting schemes together.

6.4.1 Adaptation Strategies

Most of the 10 adaptation strategies analyzed seek to address water shortages through supply-side improvements which increase the availability of water supplies. One exception, *Demand Management*, seeks to decrease the shortage gap through a combination of conservation and efficiency programs that reduce demand. Below is a brief description for the strategies analyzed in the trade-off analysis. A detailed discussion on water management goals and objectives can be found in Section 4, *Future Water Management Goals, Objectives, and Adaptation Strategies,* of this report, along with details on the formulation and final selection of adaptation strategies. Each strategy is intended to reduce shortages in the study area, but this also benefits the broader region which participates in the same market for renewable water resources.

(1) Demand Management

Expanding or implementing a variety of conservation and efficiency programs. This includes "Smart Growth" (planned economic and community development that attempts to reduce urban sprawl and adverse environmental conditions); non-revenue water loss reduction (water that has been produced and is "lost" before it reaches the customer); residential-scale rainwater harvesting; commercial, industrial, or municipal-scale LID; efficiency programs (for example, expanded public education programs, conservation-oriented building codes, surveys and audits, high efficiency fixtures, alternative rate structures, etc.); and agricultural conservation programs (for example, increasing efficient irrigation practices and reductions to conveyance losses).

(2) Regional Effluent – Direct Potable Reuse

New infrastructure to treat and deliver effluent for direct potable use. Direct potable reuse is the process in which wastewater is put through an advanced treatment process and served as potable water directly to customers (i.e., distributed to customers after treatment, not stored in a natural water body or groundwater basin prior to extraction, further treatment, and use). This may involve multi-provider, multi-jurisdictional, or single-provider facilities.

(3) Regional Effluent – Direct Non-Potable Reuse

New infrastructure to treat and deliver effluent for non-potable use. Direct non-potable reuse refers to recycled or reclaimed water that is not used for drinking but is safe to use directly for irrigation or industrial processes. This may involve multi-provider, multi-jurisdictional, or single provider facilities.

(4) Local Effluent Reuse/Recharge – Potable or Non-Potable

New wastewater treatment and reuse/recharge systems at or near the point of wastewater generation (for example, facilities at portions of communities, individual residential and commercial developments, or industrial sites). This strategy is smaller in scale than a regional project and typically involves only one water provider.

(5) Regional Effluent Recharge

New multi-provider recharge facilities in appropriate locations (where underground storage benefits current and future groundwater conditions and where recovery is practical). Types of facilities include new constructed underground recharge facilities (percolation basins or injection wells) and new managed recharge facilities (discharge to naturally water-transmissive area, such as a streambed where recharge occurs).

(6) Poor Quality Groundwater Treatment

New infrastructure to deliver remediated groundwater. Treatment would take place at existing treatment facilities, and therefore, new treatment facilities are not included in this strategy. Groundwater remediation is the process used to clean polluted groundwater to a level that meets regulatory water quality limits for potable or non-potable use.

(7) Ocean Desalination

New infrastructure to desalinate and convey ocean water to the WSRV area. This involves delivery of treated water or exchange with Colorado River water (for example, through a bi-national desalination plant at the Sea of Cortez or Pacific Ocean coast).

(8) Inland Desalination/Brackish Water Treatment

New infrastructure to pump and treat brackish groundwater or other inland source water with high salinity and deliver (or exchange) it for end-use. Examples include upgrading and operating the YDP and new infrastructure to utilize brackish water from the BWLA, Yuma Mesa Mound, or Gila Bend Basin.

(9) Groundwater Transactions/Exchanges

Market-based transactions or exchanges of groundwater. Transactions could occur with the agricultural sector or groundwater remarketing firms. This strategy includes mechanisms such as inter-basin groundwater transfers (for example, with the Harquahala groundwater basin) and procurement of groundwater saved by agricultural infrastructure improvements.

(10) Surface Water Transactions/ Leases/ Exchanges

Market-based transactions, leases, or exchanges for surface water. This includes new leases with tribal users, new transactions with surface water remarketers, agriculture fallowing deals, and trade agreements for SRP or CAP water.

6.4.2 Criteria for Evaluating Adaptation Strategies

For this analysis, 10 criteria are used to compare adaptation strategies across several dimensions and identify important trade-offs between strategies. These criteria were selected by the project team and chosen to capture the economic, financial, environmental, and social impacts of each strategy. Criteria are defined as either a benefit criterion (scored 0 to 3) or a cost criterion (scored -3 to 0) to avoid some criteria from implicitly having additional weight in the final scores. This could happen, for example, if a criterion is able to range from -3 to 3 to indicate a negative or positive impact, which then means it has the ability to influence the final score up to 6 points instead of 3. All criteria are therefore limited to having a 3-point impact on the final score, which is important since criteria are compared on a relative basis in the analysis. Ultimately, five benefit and five cost criteria were selected. The scoring scale is defined as shown in Table 21, where scores indicate a relative ranking across the strategies considered.

Table 21. Criteria Scoring Scale

Criteria	Score
Benefit	3 = High
	2 = Moderate
	1 = Low
	0 = None
Cost	-1 = Low
	-2 = Moderate
	-3 = High

Of the criteria used to assess costs and benefits associated with adaptation strategies, only two criteria are measured quantitatively. The first is *Water Availability and Reliability* (i.e., shortage reduction benefits), and the second is *Regional Economic Impact* (income, employment, and value-added). The remaining criteria are evaluated qualitatively due to data limitations and infeasibility with their measurement. For the two quantified benefit criteria to be compared with other benefit and cost criteria that are scored on a qualitative basis, the estimated effects are ultimately converted to an equivalent 3-point low-high scale. In doing so, the quantified effects are converted to a relative scoring scale that is directly comparable with the qualitative scoring used for other benefit and cost considerations. This is necessary to compare adaptation strategies across all criteria simultaneously in the trade-off analysis. Below is a brief description of the benefit and cost criteria used to evaluate strategies, followed by a detailed discussion on the scoring methodology used for each criterion.

6.4.2.1 *Benefit Criteria*

(1) Water Availability and Reliability

Increased water availability from increasing supply or decreasing demand. Since shortages are expected to vary from year to year, this criterion also captures water reliability in terms of the number of years with/without a shortage when a strategy is in place. Differences in implementation time (the time needed to plan and implement a strategy) are also captured by this criterion, as a strategy with quicker implementation will yield more immediate effects.

(2) Regional Economic Impact

Increased income, employment, and the value of goods and services produced in the regional economy based on changes in water availability.

(3) Aquifer Protection

Improved aquifer condition in terms of water levels and potential land subsidence. This encompasses balancing groundwater withdrawal and recharge to achieve a safe yield, both locally and across the entire aquifer to address regional imbalances.

(4) Adaptation and Resilience

Contribution to the region's ability to adapt to, and recover from, adverse changes (for example, climate change, drought, weather, population growth, shifts in demands, etc.). This encompasses the ability to quickly respond and adjust to changes and sustainably meet water needs across time.

(5) Government Revenue and Services

Improved revenue, reduced expense, or improved delivery of government services at the federal, state, or local level. This is intended to capture indirect benefits of a strategy in terms of government revenue and services. For example, a strategy that promotes new development could help increase the tax base and local provision of government services. Or a strategy that improves infrastructure for water storage, delivery, or treatment could help reduce expenses currently faced by the government.

6.4.2.2 *Cost Criteria*

(6) Capital Cost

Upfront investment and expenses necessary to implement a strategy. This encompasses initial expenses for planning and design, as well as the purchase or rental of assets such as land and physical capital like buildings and equipment, which typically retain some recoverable value into the future.

(7) OM&R Cost

Ongoing expenses necessary to keep a strategy in place. This encompasses day-to-day costs for inputs such as labor and electricity which cannot be recovered in the future.

(8) Administrative and Regulatory Barriers

Potential hindrance to implementing a strategy due to administrative and regulatory requirements. This encompasses potential delays and uncertainty associated with conforming to existing policies and regulations, potential need for modification of regulations or new policies, as well as the administrative complexity associated with implementing a strategy.

(9) Public Perception and Acceptance

Potential hindrance to implementing a strategy due to public perception and acceptance and the need for education associated with a strategy. This encompasses how controversial a strategy may be, its potential impacts on community aesthetics and property values, and whether it disproportionately benefits or burdens a particular population (for example, having "environmental justice" implications).

(10) Environmental and Ecosystem Condition

Adverse impacts to environmental and ecosystem conditions. This encompasses water quality, riparian condition, pollution levels, habitat condition, fish and wildlife health, and overall ecosystem function and capacity to yield ecosystem services.

6.4.3 Water Availability and Reliability Score

One of the most important benefits of any adaptation strategy stems from its impact on future shortages, or *Water Availability and Reliability*. As discussed prior, strategy benefits for *Water Availability and Reliability* are determined using various outputs from CAP:SAM and the calculated pre-adaptation welfare effects. Annual benefits across market and non-market uses of water are summed from 2020-2060 to derive a single estimate. For the trade-off analysis, the project team decided to focus on CAP:SAM Scenario D, which is considered a "worst case" scenario. This means that the estimated benefits for *Water Availability and Reliability* also reflect conditions under Scenario D, such as the growth of population and magnitude of shortage. Benefits differ under Scenarios A and F, with lower benefits due to conditions of less severe and less frequent water shortages.

Water availability is captured by the water volume provided by a strategy, accounting for the type of water provided, and reliability is captured by year-to-year variation in shortages and the number of years without a shortage when a strategy is in place. If the additional water is not available at a constant rate across time, this is incorporated into the calculation. For example, effluent availability grows over time with population, as does the volume of water conserved under *Demand Management*. Differences in implementation time are also captured, since a strategy with more rapid implementation will yield more immediate effects on water quantity and generate more benefits across the study period. Benefits for *Water Availability and Reliability* are therefore measured based on the volume of water provided by a strategy, the type of water provided, when that water becomes available, and if the water volume is constant or varies over time.

Table 22 and Table 23 show the information used to measure *Water Availability and Reliability* for each adaptation strategy. Table 22 shows the potential water volume provided to the study area by each strategy, separated between surface water (SW) and groundwater (GW). Since volume grows across time for some strategies, the table includes the average annual volume provided by each strategy across the study period (SW and GW combined). This volume is a function of both water quantity and implementation time. Table 23 shows the range of implementation times assumed for each strategy, capturing when additional water is expected to become available for use. The midpoint implementation time is used for the trade-off analysis. Volumes are for 2060 under CAP:SAM Scenario D. For effluent strategies, the volume available for use is based on the "unaccounted for" effluent modeled under Scenario D.[11] Information for the remaining strategies

[11] The CAP:SAM assumes that both effluent availability and effluent use increase across time, meaning that a portion of increased effluent availability is already "built-in" to water use under the baseline calculations. This use was determined based on known plans for users to put future effluent to use. Because the baseline calculation already incorporates increased effluent use, the benefits estimated here for effluent strategies only capture the effluent volume that is not already planned to be put to use, or the "unaccounted for" effluent under CAP:SAM Scenario D.

was developed by the project team and chosen to reflect the expected outcomes for each strategy. For strategies that provide a growing volume of water across time, annual growth is modeled according to population growth under Scenario D.

Table 22. Potential Water Volume (AF/y) from Adaptation Strategies

Strategy	SW	GW	Annually	Annual Average
(1) Demand Management	60,000	15,000	Grows	50,912
(2) Regional Effluent – Direct Potable Reuse	47,213	20,234	Grows	33,491
(3) Regional Effluent – Direct Non-Potable Reuse	47,213	20,234	Grows	34,203
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	40,468	26,979	Grows	33,819
(5) Regional Effluent Recharge	40,468	26,979	Grows	33,819
(6) Poor Quality Groundwater Treatment	0	10,000	Constant	9,268
(7) Ocean Desalination	Entire Shortage*	0	Grows	61,017
(8) Inland Desalination/Brackish Water Treatment	35,000	0	Constant	26,463
(9) Groundwater Transactions/ Exchanges	0	41,000	Constant	37,500
(10) Surface Water Transactions/ Leases/Exchanges	50,000	0	Constant	43,902

Surface water (SW) and groundwater (GW) volumes are for 2060 under Scenario D and were determined by the project team to capture the potential volume of water provided to the study area under each strategy. Some strategies provide a growing volume of water across the study period, so the average annual volume (SW and GW combined) is reported, which is also a function of implementation time.

* Water volume is set equal to the annual shortage volume and capped at a max of 100 thousand AF.

Table 23. Implementation Time (years) for Adaptation Strategies

Strategy	Min	Max	Midpoint
(1) Demand Management	0	0	0
(2) Regional Effluent – Direct Potable Reuse	5	10	7.5
(3) Regional Effluent – Direct Non-Potable Reuse	2	5	3.5
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	2	10	6
(5) Regional Effluent Recharge	2	10	6
(6) Poor Quality Groundwater Treatment	1	5	3
(7) Ocean Desalination	10	20	15
(8) Inland Desalination/Brackish Water Treatment	10	10	10
(9) Groundwater Transactions/ Exchanges	2	5	3.5
(10) Surface Water Transactions/ Leases/Exchanges	0	10	5

Implementation time is measured in years and the range was determined by the project team to capture the expected time required to implement a strategy. The midpoint implementation time is used for the trade-off analysis.

Table 22 summarizes the water volume provided by each strategy, but in the actual estimation of benefits, annual changes in water volume are captured, which is important since the shortage volume also varies annually. Whenever a strategy provides more water than is needed to close the shortage gap in a given year, it is assumed that surplus water is stored and used to mitigate shortages in future years. An alternative would be to allow water prices to fall when there is a surplus, but this is not realistic or consistent with past trends. It is therefore assumed that adaptation strategies can only affect prices according to the magnitude of shortage, meaning that prices cannot fall over time, and instead only be prevented from rising due to a shortage. Any volume in excess of the shortage amount is assumed to go towards underground water storage and reducing shortages in future years, helping prevent future price increases. To generate water volumes for adaptation strategies, determine surface water and groundwater volumes, and determine strategy implementation time, the project team had to rely on several simplifying assumptions. Table 24 lists some of the key assumptions underlying each adaptation strategy.

Table 24. Key Assumptions for Adaptation Strategies

Strategy	Assumption(s)
(1) Demand Management	• Water volume assumes that around 60 percent of water use is for outdoor use and about 15 percent conservation is possible across the study period. For Scenario D this amounts to about 75,000 AF/y in 2060. • Additional conservation from indoor use is assumed to be minimal and not included. • Annual water volume grows according to population growth in Scenario D. • Water volume is split between groundwater and surface water based on 2020 CAP:SAM amounts (excluding effluent), which is about 80/20 percent surface water/groundwater.
(2) Regional Effluent – Direct Potable Reuse	• Annual water volume is based on the "unaccounted for" effluent modeled in CAP:SAM Scenario D. • Water volume grows according to population growth in Scenario D. • Water volume is split 70/30 percent surface water/groundwater.
(3) Regional Effluent – Direct Non-Potable Reuse	• Annual water volume is based on the "unaccounted for" effluent modeled in CAP:SAM Scenario D. • Water volume grows according to population growth in Scenario D. • Water volume is split 70/30 percent surface water/groundwater.
(4) Local Effluent Reuse/ Recharge – Potable or Non-Potable	• Annual water volume is based on the "unaccounted for" effluent modeled in CAP:SAM Scenario D. • Water volume grows according to population growth in Scenario D. • Water volume is split 60/40 percent surface water/groundwater.
(5) Regional Effluent Recharge	• Annual water volume is based on the "unaccounted for" effluent modeled in CAP:SAM Scenario D. • Water volume grows according to population growth in Scenario D. • Water volume is split 60/40 percent surface water/groundwater.

Strategy	Assumption(s)
(6) Poor Quality Groundwater Treatment	• Volume of 10,000 AF based on statewide exemption for 65,000 AF and expected availability in the study area (4,000 AF for Goodyear and 6,000 AF unidentified). • Exemption expires in 2025 and would need to be extended for this volume to be available.
(7) Ocean Desalination	• Annual water volume grows annually based on the size of expected shortage under Scenario D and is capped at a maximum of 100,000 AF/y for the study area. • Exchange goes through existing CAP canals.
(8) Inland Desalination/Brackish Water Treatment	• Volume of 35,000 AF/y based on YDP operating at one-third capacity, which is consistent with a 2010-2011 pilot run. • Considered surface water and a Colorado River exchange to conserve water at Lake Mead.
(9) Groundwater Transactions/ Exchanges	• Volume based on Water Asset Management (~80,000 AF/y) and LTSCs from Harquahala basin (~2,000 AF/y). • Legal and regulatory barriers create enormous uncertainty for this strategy, so the volume is assumed to range widely from 0-82,000 AF/y and the midpoint of 41,000 AF/y is used.
(10) Surface Water Transactions/ Leases/Exchanges	• Colorado River water transported via CAP canals. • Legal and regulatory barriers create enormous uncertainty for this strategy, so the volume is assumed to range widely from 0-100,000 AF/y and the midpoint of 50,000 AF/y is used.

Putting everything together, adaptation strategy benefits for *Water Availability and Reliability* are estimated by comparing consumer welfare with/without a strategy in place, and annual benefits are combined into a single value by summing benefits across the 40-year study period. It should be noted that these benefits are for raw water, encompassing municipal, industrial, agricultural, and recreational use. Table 25 shows the *Water Availability and Reliability* benefit in monetary terms for each strategy, separated between the study area and outside area. Although these estimates are at the wholesale level, it is fair to assume that market welfare effects will largely be transferred to final consumers since water providers and irrigation districts often sell water at cost. The full *Economic and Trade-Off Analysis* report provides a breakdown of *Water Availability and Reliability* benefits for individual M&I providers, irrigation districts, and recreational activities in the study area, as well as benefits for outside users. The benefit of each adaptation strategy is largely a function of groundwater and surface water impacts, and for market users, effects depend heavily on each user's unique raw water portfolio. In general, those that rely more on marketed renewable supplies benefit more from strategies that reduce shortages, while those that directly utilize surface water and groundwater are impacted less. For recreational activities, welfare effects depend on surface water changes and the importance of water for each particular activity.

Table 25. Water Availability and Reliability Benefit, 2020-2060

Strategy	Study Area	Outside Area	Total
(1) Demand Management	$200.24	$225.06	$425.30
(2) Regional Effluent – Direct Potable Reuse	$136.55	$143.98	$280.53
(3) Regional Effluent – Direct Non-Potable Reuse	$138.74	$147.10	$285.84
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$130.69	$136.96	$267.66
(5) Regional Effluent Recharge	$130.69	$136.96	$267.66
(6) Poor Quality Groundwater Treatment	$24.18	$26.89	$51.07
(7) Ocean Desalination	$273.47	$288.20	$561.67
(8) Inland Desalination/Brackish Water Treatment	$106.84	$113.97	$220.82
(9) Groundwater Transactions/ Exchanges	$100.51	$107.02	$207.53
(10) Surface Water Transactions/ Leases/Exchanges	$175.29	$196.17	$371.46

Values are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. These benefits are for Scenario D. Reported amounts may not add to total amounts due to rounding.

To conduct the trade-off analysis, quantified effects for *Water Availability and Reliability* must be comparable with qualitative criteria scored from low to high on a 3-point scale. To do so, benefits are converted to an equivalent 3-point scale, allowing for both quantitative and qualitative considerations to be assessed simultaneously and for strategies to be ranked on a relative basis, identifying important strengths and weaknesses across adaptation strategies. Table 26 shows the low-high (0-3) score assigned to each strategy for the *Water Availability and Reliability* criterion. These scores are calculated by dividing the quantified benefit for each strategy by the maximum benefit provided by any strategy, and then multiplying the resulting ratio by 3. This results in the highest performing strategy receive a score of 3 with the remaining strategies scored 0-3 according to their relative magnitude of benefits.

Table 26. Water Availability and Reliability Score

Strategy	Score
(1) Demand Management	2.27
(2) Regional Effluent – Direct Potable Reuse	1.50
(3) Regional Effluent – Direct Non-Potable Reuse	1.53
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	1.43
(5) Regional Effluent Recharge	1.43
(6) Poor Quality Groundwater Treatment	0.27
(7) Ocean Desalination	3
(8) Inland Desalination/Brackish Water Treatment	1.18
(9) Groundwater Transactions/ Exchanges	1.11
(10) Surface Water Transactions/ Leases/Exchanges	1.98

Quantified benefits are converted to a low-high (0-3) scale where the strategy with the highest quantified benefit receives a score of 3 and all strategies are scored relative to one another. These scores are for Scenario D.

6.4.4 Regional Economic Impact Score

Conducting an original regional economic impact analysis was not feasible for this study, so the results of a recent analysis are used to quantify impacts associated with the additional water provided by adaptation strategies. In 2014, researchers at the L. William Seidman Research Institute at Arizona State University (ASU) analyzed the economic importance of the Colorado River for seven states, one of which was Arizona. A series of IMPLAN (Impact Analysis for Planning) input-output models were customized for each state and then combined into a single model that accounted for interactions among states. The study estimated the economic impact of Colorado River water using historical water quantity data for M&I and agricultural users and water demand projections from Reclamation's 2012 *Colorado River Basin Water Supply and Demand Study*. The results for Arizona are used in this analysis to derive an average impact per unit of water for value added, income, and employment, which is then combined with water quantity information for each adaptation strategy to measure *Regional Economic Impact*. Regional effects are generated from the benefit of water availability and are therefore not additive. Quantified effects are converted to a low-high (0-3) scale to incorporate regional economic effects as a benefit criterion in the trade-off analysis.

In the ASU (2014) report, the authors measure regional economic impacts according to value added, labor income, and employment, so these factors are used here. Value added is measured by Gross State Product (GSP) which represents the dollar value of all goods and services produced for final demand in the state. GSP excludes the value of intermediate goods and services purchased and can be defined as the sum of employee compensation, proprietor income, property income, and indirect business taxes. Labor income encompasses employee compensation (wages and benefits) and proprietor income. Employment captures full- and part-time jobs, including wage and salary workers, as well as those self-employed. Employment is measured in job years, which is equivalent to one person having a full-time job for one year.

IMPLAN is widely used for economic assessments and provides detailed estimates for changes over a finite period (typically one year). The ASU (2014) researchers used IMPLAN to measure direct impacts, indirect impacts, and induced impacts associated with water availability. Direct effects capture production and employment impacts directly associated with the use of water, indirect effects capture the impacts on sectors that indirectly engage in production and employment as a result of the availability of water, and induced effects are associated with workers spending additional income in the economy. The authors measured impacts by assessing losses associated with the total non-availability of CAP water for one full year, noting that this is an unlikely scenario, but arguing that it is the best way to estimate the importance of Colorado River water. It is assumed that the loss per unit of water mirrors the gain per unit of water, so that estimates can be used in this analysis to quantify increases in water associated with adaptation strategies. Given data limitations, no distinction is made between the different types of source water, meaning the impact of CAP water is used for all sources.

Regional impact analysis is used to estimate the magnitude of economic effects associated with shocks to the regional economy, such as changes in water availability. The results from ASU (2014) are deemed sufficient to quantify *Regional Economic Impact* for adaptation strategies in this analysis. Given the linear nature of IMPLAN and input-output modeling in general, impacts are constant per unit of water, which allowed the authors to examine impacts for a percentage decline in water rather than total non-availability. In this analysis, the linearity allows for the average impact per unit of water to be multiplied by the average volume of water provided by each strategy to approximate regional economic impacts. This means that strategies which provide the most water will have the largest impact. Since ASU (2014) provides estimated impacts for the entire state of Arizona, a simple adjustment is made to focus on the central Arizona region based on the proportion of water used, which is roughly two-thirds of water use in the state. Table 27 provides the average annual impact per AF of water for the central Arizona region, distinguishing between impacts on value added, income, and employment, as well as direct, indirect, and induced effects. Dollar values are converted to $2020 using the CPI for the Phoenix area.

Table 27. Regional Economic Impact per AF of Water

Impact	Value Added	Income	Employment
Direct	$37,213.3	$22,377.6	0.39
Indirect	$10,022.5	$5,737.4	0.10
Induced	$26,786.7	$15,011.8	0.27
Total	$74,022.5	$43,126.8	0.76

Value added and income are $2020, and employment is measured in job years. These reflect estimated impacts for the central Arizona region. Reported amounts may not add to total amounts due to rounding.

These estimates are used to quantify regional economic impacts from additional water provided by adaptation strategies and score strategies from low-high for this criterion. For the trade-off analysis, the total impact is used to measure adaptation strategy impacts, encompassing direct, indirect, and induced impacts. The average annual water volume provided by a strategy is combined with the impact per AF to determine an average annual effect for each strategy across the study period. This accounts for differences in implementation time and recognizes that some strategies provide a growing water volume over time, with less volume in early years and more towards the end of the study period. This is necessary to compare strategies that provide a growing water volume with strategies that provide a constant annual volume across the study period. Table 28 shows the estimated total impact of each strategy across the three economic indicators.

Table 28. Regional Economic Impact

Strategy	Value Added	Income	Employment
(1) Demand Management	$3,768.67	$2,195.69	38,594
(2) Regional Effluent – Direct Potable Reuse	$2,479.11	$1,444.37	25,388
(3) Regional Effluent – Direct Non-Potable Reuse	$2,531.76	$1,475.05	25,927
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$2,503.35	$1,458.49	25,636
(5) Regional Effluent Recharge	$2,503.35	$1,458.49	25,636
(6) Poor Quality Groundwater Treatment	$3,087.28	$1,798.70	31,616
(7) Ocean Desalination	$4,516.63	$2,631.47	46,254
(8) Inland Desalination/Brackish Water Treatment	$1,958.90	$1,141.28	20,061
(9) Groundwater Transactions/ Exchanges	$2,775.85	$1,617.26	28,427
(10) Surface Water Transactions/ Leases/Exchanges	$3,249.77	$1,893.37	33,280

Value added and income are in millions ($2020), and employment is measured in job years. These represent total annual impacts across direct, indirect, and induced effects.

Table 29 shows the resulting low-high (0-3) score assigned to each strategy for the *Regional Economic Impact* criterion. The strategy with the greatest quantified impact is assigned a score of 3 while all other strategies are assigned a score from 0 to 3 according to their relative impacts. As before with *Water Availability and Reliability*, this is accomplished by dividing effects by the largest impact and multiplying that ratio by 3. The resulting scores range from 0-3 and are directly comparable with scores for *Water Availability and Reliability* as well as the remaining evaluation criteria scored qualitatively on an equivalent low-high (0-3) scale.

Table 29. Regional Economic Impact Score

Strategy	Score
(1) Demand Management	2.50
(2) Regional Effluent – Direct Potable Reuse	1.65
(3) Regional Effluent – Direct Non-Potable Reuse	1.68
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	1.66
(5) Regional Effluent Recharge	1.66
(6) Poor Quality Groundwater Treatment	0.46
(7) Ocean Desalination	3
(8) Inland Desalination/Brackish Water Treatment	1.30
(9) Groundwater Transactions/Exchanges	1.84
(10) Surface Water Transactions/Leases/Exchanges	2.16

Quantified benefits are converted to a low-high (0-3) scale where the strategy with the highest quantified benefit receives a score of 3 and all strategies are scored relative to one another. These scores are for Scenario D.

It is important to note that these regional impacts are associated with the additional water supply provided by each adaptation strategy. Regional economic impacts associated with expenditures on construction and planning to implement a strategy, and spending on OM&R from operation of the underlying components of a strategy, are not measured in this study. This would require cost estimates for capital and OM&R for each strategy, while this study only evaluated capital cost and OM&R cost qualitatively (low-high). In general, more expenditures (higher capital cost and OM&R cost) will result in larger regional impacts on labor, income, and output.

6.4.5 Qualitative Criteria Scores

Beyond *Water Availability and Reliability* and *Regional Economic Impact*, there are additional criteria that are important to consider. To evaluate these additional considerations, a survey is used to qualitatively score the remaining eight criteria for the trade-off analysis. For these criteria, a scoring survey was developed and all partners on the project team were asked to score strategy benefits and costs on a relative 3-point scale from low to high, as previously shown in Table 21. Irrigation districts were also asked for their input, even though many were not officially involved in the study. Decimal places were permitted to allow for a continuous scoring scale and were also encouraged to provide more precise scoring. In total, 14 surveys were completed across 12 entities and each entity is treated equally by averaging response scores from entities that completed more than one survey. The survey was also used to ask about the importance that respondents placed on each of the 10 evaluation criteria, scored low-high (0-3). These responses are used to generate a criteria weighting scheme that reflects the preferences of the study partners. Table 30 shows the raw scores for qualitative criteria generated from the survey responses.

Table 30. Qualitative Criteria Raw Scores

Strategy	Qualitative Criteria							
	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	2.00	2.29	1.42	-0.83	-0.92	-0.63	-0.74	-0.50
(2)	2.00	2.32	1.83	-2.67	-2.38	-2.02	-2.42	-1.19
(3)	2.18	1.78	1.71	-2.00	-1.67	-0.79	-0.68	-1.08
(4)	2.50	2.16	1.71	-1.80	-1.59	-1.19	-0.50	-0.33
(5)	2.38	2.24	1.75	-1.90	-1.40	-1.23	-0.29	-0.46
(6)	0.75	1.50	1.59	-2.00	-1.88	-1.42	-1.61	-1.21
(7)	2.38	2.54	1.67	-2.92	-2.75	-2.79	-1.58	-2.45
(8)	1.08	1.43	1.25	-2.71	-2.73	-2.29	-1.75	-2.00
(9)	0.83	1.25	1.58	-2.08	-1.63	-1.96	-1.84	-1.72
(10)	2.25	1.81	2.08	-1.67	-1.38	-2.08	-1.61	-1.17

Scores represent strategy benefits (scored 0 to 3) and strategy costs (scored 0 to -3) on a relative 3-point scale for qualitative criteria. Scores reflect the average across all survey responses (n=14), with all entities given equal weight.

Strategies: (1) Demand Management; (2) Regional Effluent DPR; (3) Regional effluent Direct non-Potable Reuse; (4) Local Effluent Reuse/Recharge; (5) Regional Effluent Recharge; (6) Poor Quality Groundwater; (7) Ocean Desalination; (8) Inland Desal Brackish Water; (9) Groundwater Transactions/Exchanges; (10) Surface Water Transactions/Leases/Exchanges

For the trade-off analysis, response scores are rescaled so that at least one strategy receives the max score possible for each criterion (3 for benefit criteria and -3 for cost criteria). The scores for all remaining strategies are then normalized relative to the max score possible. If this was not done, a strategy would only receive the max score of 3 (benefit) or -3 (cost) if every survey respondent assigned the same score for that strategy and criterion, which was not the case in any instance (i.e., there are no raw scores of 3 or -3 in Table 30). Rescaling all scores to an equivalent 3-point scale is done to ensure that certain criteria are not implicitly given additional influence on final scores, before explicitly weighting criteria for importance. Scores are rescaled with a similar approach used to translate quantified impacts for *Water Availability and Reliability* and *Regional Economic Impact* into a 3-point scale. In particular, raw benefit scores are divided by the maximum raw score received and the resulting ratio is then multiplied by 3. For cost criteria, raw scores are divided by the minimum raw score and the resulting ratio is multiplied by -3. This results in a 0 to 3 scale for benefit criteria and -3 to 0 scale for cost criteria where all strategy scores retain their relative magnitudes in relation to one another.

6.4.6 Criteria Weighting Schemes

Multi-objective optimization, which is at the heart of a trade-off analysis, requires weighting the objectives of interest, or in this case, the evaluation criteria. This weight reflects the importance of each criterion, which in turn determines how trade-offs between criteria are treated. A logical starting point is to assign equal weight to all criteria, which reflects one potential weighting scheme. However, some criteria are typically perceived as more important than others, so different weighting schemes are used to examine how strategies perform under different objectives. Several weighting schemes are tested, one with additional emphasis placed on economic and financial considerations, one with emphasis on environmental and sustainability considerations, and one with emphasis on social and administrative considerations. Two other schemes are also tested, one with equal weight across all criteria, and another based on a survey identifying which criteria the study partners consider to be most important. Below are descriptions of the different weighting schemes tested. Across the five weighting schemes, each criterion is included a total of three times.

6.4.6.1 *All Criteria*

Includes all 10 evaluation criteria with equal weight placed on each.

6.4.6.2 *Economic and Financial*

Includes the criteria: (1) *Water Availability and Reliability*, (2) *Regional Economic Impact*, (6) *Capital Cost*, and (7) *OM&R Cost*, with equal weight placed on each.

6.4.6.3 *Environment and Sustainability*

Includes the criteria: (3) *Aquifer Protection,* (4) *Adaptation and Resilience*, and (10) *Environmental & Ecosystem Condition*, with equal weight placed on each.

6.4.6.4 *Social and Administrative*

Includes the criteria: (5) *Government Revenue and Services*, (8) *Administrative and Regulatory Barriers,* and (9) *Public Perception and Acceptance*, with equal weight placed on each.

6.4.6.5 *Team Survey*

Includes all 10 evaluation criteria with each weighted according to survey responses for the relative importance of each criterion.

Adaptation strategies are expected to perform differently under different weighting schemes, and no weighting scheme is considered "optimal". Instead, the results are intended to show how each strategy performs under different weighting schemes and considerations. One weighting scheme is based on the preferences of study partners, which encompasses the key water users and stakeholders in the area. The other weighting schemes highlight how strategies perform under an alternative set of objectives.

Table 31 shows the criteria importance scores from the project team survey and the weights associated with the responses. Scores (low-high from 0-3) are rescaled to ensure that at least one criterion receives the max score of 3. The criterion *Water Availability and Reliability* proved to be the most important criterion, while *Government Revenue and Services* received the lowest importance score and is weighted as 35 percent as important. The remaining criteria are weighted anywhere from 50-80 percent as important as *Water Availability and Reliability*.

Table 31. Criteria Importance and Weight from Team Survey

Criteria Type	Criteria	Score	Weight
Benefit	(1) Water Availability & Reliability	3	100%
	(2) Regional Economic Impact	2.14	71.4%
	(3) Aquifer Protection	2.49	82.9%
	(4) Adaptation & Resilience	2.40	80.0%
	(5) Government Revenue & Services	1.05	35.0%
Cost	(6) Capital Cost	2.08	69.3%
	(7) OM&R Cost	1.80	60.0%
	(8) Administrative & Regulatory Barriers	2.14	71.4%
	(9) Public Perception & Acceptance	1.50	50.0%
	(10) Environmental & Ecosystem Conditions	1.86	62.1%

Scores represent the relative importance (scored 0 to 3) that respondents place on criteria. Scores reflect the average across all survey responses (n=14) and are rescaled to ensure that at least one criterion received the max score of 3.

6.5 Trade-Off Analysis

The purpose of the trade-off analysis is to compare adaptation strategies across multiple criteria simultaneously, identifying important trade-offs and highlighting the strengths and weaknesses of each strategy. The basic premise of a trade-off analysis is that there are benefits and costs other than traditional monetized benefits, and costs that are important and need to be considered when evaluating alternatives. The trade-off analysis methodology used here conforms with the Council on Environmental Quality's *Principles, Requirements, and Guidelines for Water and Land Related Resources Implementation Studies* which indicate that an analysis of alternatives under consideration needs to consider all benefits and costs and identify the alternative that maximizes public welfare. Public welfare includes environmental, economic, and social considerations, and can include monetary and non-monetary effects which may be quantified or unquantified.

Adaptation strategies can have several impacts. Economic effects include market and non-market benefits associated with reducing water shortages and the impact of a strategy on the regional economy in terms of output, income, and employment. Financial effects encompass the cost of implementing a strategy in terms of expenditures on planning, capital, and OM&R. Environmental effects reflect strategy impacts on natural resources and the environment. This encompasses water quality, riparian condition, pollution levels, habitat condition, fish and wildlife health, and overall ecosystem function. Social and administrative considerations for a strategy include public perception and acceptance, administrative and regulatory barriers, and government revenue and services. All of these reflect different forms of costs and benefits, some of which are measured and quantified, and some of which are assessed qualitatively.

6.5.1 Adaptation Strategy Raw Scores

Looking across strategies and criteria, the first step is to evaluate the raw scores for each strategy. Summing raw scores across criteria, the total score reflects the All Criteria weighting scheme with equal weight on each criterion. Looking at raw scores, (1) *Demand Management* received the highest score, followed by (5) *Regional Effluent Recharge*, (4) *Local Effluent Reuse/Recharge*, and (3) *Regional Effluent – Direct Non-Potable Reuse*, respectively. That said, the overall raw score masks trade-offs between criteria and does not illustrate the particular strengths and weaknesses of each strategy. To understand how strategies perform across the different criteria, Figure 41 shows the raw score for each strategy and each criterion. In Figure 41, a larger shaded green area corresponds to higher benefits and more red shading corresponds to higher costs. It should be noted that all scores are relative, with at least one strategy receiving a 3 (benefit) or -3 (cost) for each criterion, and the remaining strategies scored on a relative basis.

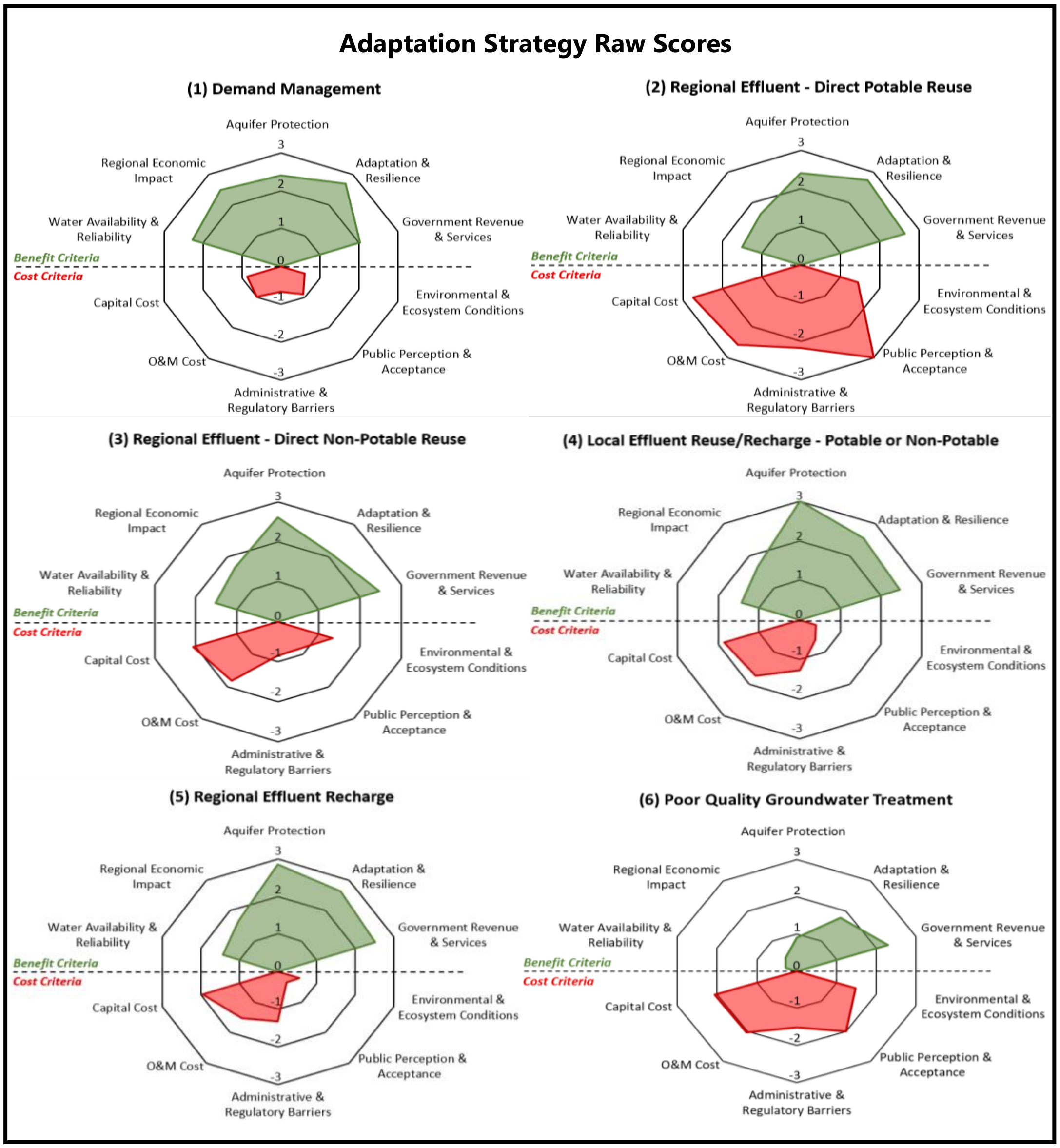

Figure 41. Adaptation Strategy Raw Scores

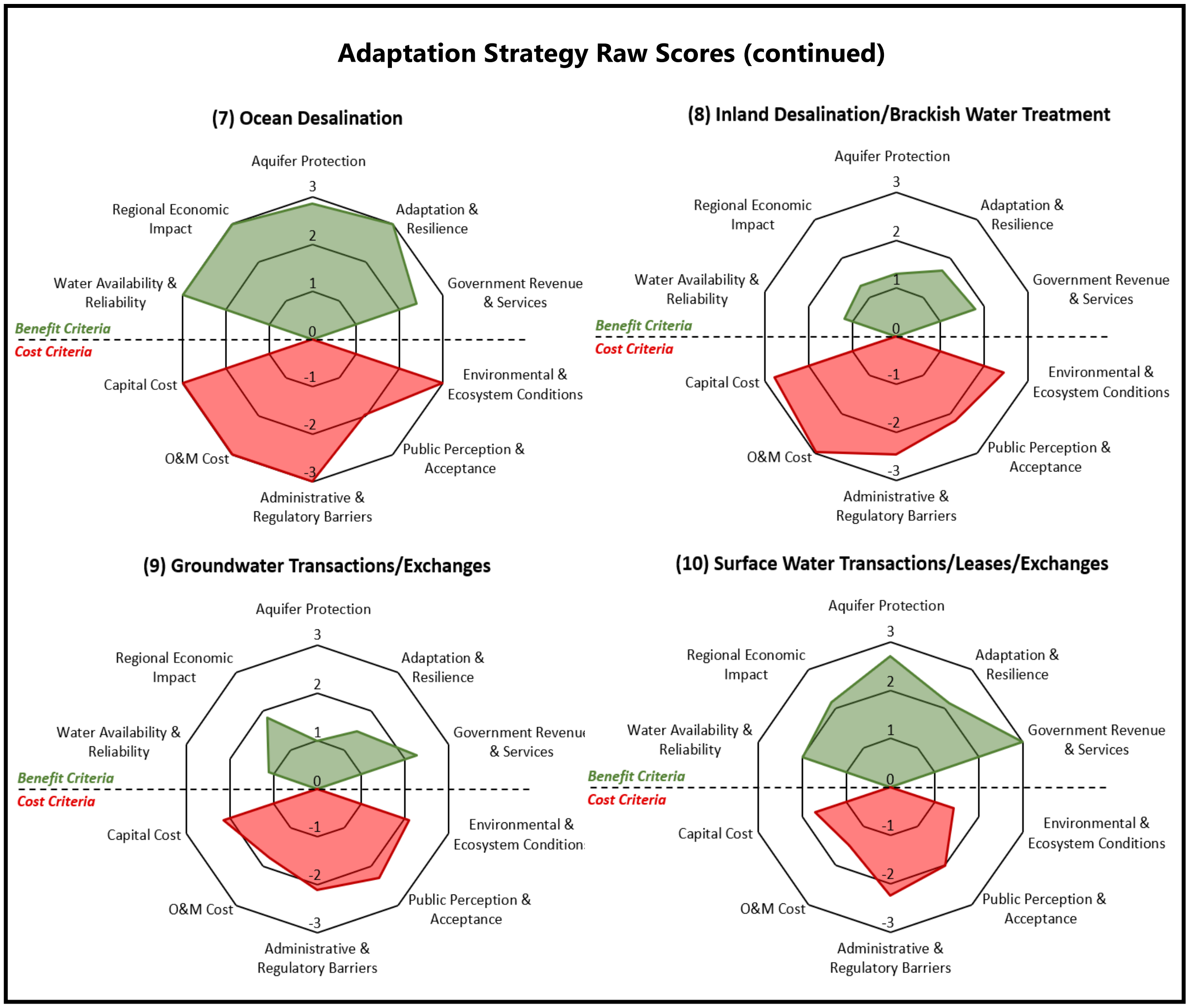

Figure 41 (continued)

The results indicate that (1) *Demand Management* is overall the least-cost alternative, while also offering relatively large benefits along several dimensions. These features lead this strategy to perform the best overall based on raw scores. The 2nd and 3rd ranking strategies, (5) *Regional Effluent Recharge* and (4) *Local Effluent Reuse/Recharge*, also have relatively low costs overall, but relatively higher *Capital Cost*, *OM&R Cost*, and *Administrative and Regulatory Barriers*. These two strategies scored similarly, indicating that there are only minor differences between the two, which are primarily along cost considerations. On the benefit side, relative to (1) *Demand Management*, these strategies perform better in terms of *Aquifer Protection* and *Government Revenue and Service*s, but worse in terms of *Water Availability and Reliability* and *Regional Economic Impact*.

Based on raw scores, (3) *Regional Effluent – Direct Non-Potable Reuse* ranks 4th with slightly lower benefit and higher cost than local and regional recharge. Meanwhile, the final effluent strategy, (2) *Regional Effluent – Direct Potable Reuse*, comes with greater costs than all other forms of effluent use, leading the strategy to rank 7th. This strategy scores the worst of any strategy for the criterion *Public Perception and Acceptance*, and is also associated with high *Capital Cost*, *OM&R Cost*, and *Administrative and Regulatory Barriers*. Based on these raw scores, effluent recharge, at a local or regional scale, appears to be a preferable strategy to direct effluent reuse, particularly for potable use. That said, a combination of effluent recharge and reuse, at a local and regional scale, is likely to be optimal.

Looking at the strategy (6) *Poor Quality Groundwater Treatment*, the costs are relatively moderate in all dimensions, and the benefits are relatively low. This strategy performs the worst of any in terms of *Aquifer Protection*, *Water Availability and Reliability*, and *Regional Economic Impact,* leading the strategy to rank 9th based on raw scores. Meanwhile, (8) *Inland Desalination/Brackish Water Treatment* provides similar benefits but comes with much higher costs, causing it to rank 10th based on raw scores. Notably, this strategy performs poorly in terms of *OM&R Cost* and *Capital Cost*, scoring only slightly better than (7) *Ocean Desalination* along these dimensions. However, (7) *Ocean Desalination* ultimately ranks 6th since it provides a high level of benefits, but also comes with a high degree of costs. The strategy (9) *Groundwater Transactions/Exchanges* ranks 8th based on raw scores, notably doing little for *Aquifer Protection*, *Water Availability and Reliability*, and *Regional Economic Impact* and coming with moderate costs. The final strategy, (10) *Surface Water Transactions/Leases/Exchanges*, ranks 5th among the strategies considered, due to moderate costs and several moderate to large benefits. This strategy is associated with relatively high *Administrative and Regulatory Barriers* but offers the most of any strategy in terms of *Government Revenue and Services*.

These raw scores help highlight the strengths and weaknesses of each strategy and the resulting rank shows how these strategies perform when equal weight is placed on each evaluation criteria (the *All Criteria* weighting scheme). That said, each criterion is not necessarily of equal importance, and strategies will perform differently depending on the particular objective and the emphasis placed on each criterion. To examine how strategies perform under different considerations, several criteria weighting schemes are tested.

6.5.2 Adaptation Strategy Performance Under Different Objectives

The trade-off analysis requires weighting evaluation criteria to capture the importance of each criterion, which in turn determines how trade-offs between criteria are treated. The previous section evaluated raw scores and the *All Criteria* weighting scheme, which assigns equal weight to all criteria. However, this is only one possible weighting scheme, and it may not accurately represent trade-offs between the criteria of interest. Several weighting schemes are therefore tested to examine how strategies perform under different objectives, one defined as economic and financial, one as environment and sustainability, and one as social and administrative. The final weighting scheme reflecting the importance that the study partners place on each criterion is tested, defined as the Team Survey weighting scheme. These weights are based on a survey asking project team members which criteria they consider to be most important, meaning it reflects the preferences of key water providers and stakeholders in the region. That said, several weighting schemes are tested to highlight how strategies perform under alternative considerations and an overall rank is also provided. Table 32 shows how each strategy ranks under each weighting scheme. The variation across weighting schemes helps to further highlight the strengths and weaknesses of each strategy.

Table 32. Strategy Rank Under Different Weighting Schemes

Strategy	All Criteria	Economic & Financial	Enviro. & Sustain.	Social & Admin.	Team Survey	Overall Rank
(1) Demand Management	1st	1st	3rd	4th	1st	1st
(2) Regional Effluent – Direct Potable Reuse	7th	8th	4th	8th	7th	7th

Strategy	All Criteria	Economic & Financial	Enviro. & Sustain.	Social & Admin.	Team Survey	Overall Rank
(3) Regional Effluent – Direct Non-Potable Reuse	4th	6th	6th	2nd	4th	4th
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	3rd	5th	1st	3rd	3rd	3rd
(5) Regional Effluent Recharge	2nd	4th	2nd	1st	2nd	2nd
(6) Poor Quality Groundwater Treatment	9th	10th	8th	5th	9th	9th
(7) Ocean Desalination	6th	3rd	7th	9th	6th	6th
(8) Inland Desalination/Brackish Water Treatment	10th	9th	9th	10th	10th	10th
(9) Groundwater Transactions/ Exchanges	8th	7th	10th	7th	8th	8th
(10) Surface Water Transactions/Leases/ Exchanges	5th	2nd	5th	6th	5th	5th

The overall rank gives equal preference to each of the weighting schemes, and given how the weighting schemes are defined, each criterion gets included three times in the overall rank.

An ordinal number, such as rank, only shows the relative position of strategies. Meanwhile, a cardinal number indicates magnitude and has a quantitative interpretation. While Table 32 shows how each strategy ranks relative to the others (ordinal score), it does not indicate the magnitude of differences between strategies and rankings (cardinal score). To examine the magnitude of differences between scores, Table 33 provides a cardinal score for strategies under each weighting scheme, reported as a percentage of the highest-ranking strategy (i.e., 1st =100 percent). The cells are also colored from light to dark blue to visually show magnitude. These percentages indicate how strategies perform relative to one another while considering the magnitude of differences. This is important since the difference between rankings is unlikely to be linear. As shown, those strategies that rank 2nd, 3rd, and 4th score rather closely across weighting schemes, while the difference is generally much greater between those strategies ranked 8th, 9th, and 10th. A cardinal score therefore provides more information than ordinal rankings and helps further identify which strategies are best suited to address future water shortages.

Table 33. Score Magnitudes Under Different Weighting Schemes

Strategy	All Criteria	Economic & Financial	Enviro. & Sustain.	Social & Admin.	Team Survey	Overall
(1) Demand Management	100%	100%	92%	94%	100%	100%
(2) Regional Effluent – Direct Potable Reuse	61%	45%	82%	51%	61%	62%
(3) Regional Effluent – Direct Non-Potable Reuse	81%	61%	79%	99%	79%	81%
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	88%	63%	100%	96%	86%	88%
(5) Regional Effluent Recharge	89%	64%	97%	100%	86%	89%
(6) Poor Quality Groundwater Treatment	51%	32%	51%	70%	46%	50%
(7) Ocean Desalination	67%	70%	72%	50%	71%	68%
(8) Inland Desalination/Brackish Water Treatment	41%	34%	43%	46%	41%	41%
(9) Groundwater Transactions/ Exchanges	54%	58%	41%	57%	51%	53%
(10) Surface Water Transactions/ Leases/Exchanges	79%	79%	79%	70%	78%	79%

Scores are reported as a percentage of the highest-ranking strategy under each weighting scheme (i.e., 1st=100%). This indicates how strategies perform relative to one another while considering the magnitude of differences. The cells are also colored from light to dark blue to visually show magnitude.

6.5.3 Discussion of Results

The results indicate that demand management performs well overall and proves to be the least-cost strategy considered, while also providing several relatively large benefits. Improving conservation and reducing water demand is therefore a sensible way to help reduce future water shortages and pressure on water resources. Effluent use, especially recharge, also appears to be a practical way to address future water shortages in the study area. Surface water transactions and agreements could also be a viable way to help address shortages in the region, but the success of this strategy depends heavily on administrative and legal barriers as well as public perception and acceptance. Meanwhile, ocean desalination, poor quality groundwater treatment, groundwater transactions, and inland desalination/brackish water treatment all come with a relatively high cost and therefore lower net benefit than the other alternatives considered.

The strategy (1) *Demand Management* is the top performing strategy under several weighting schemes, and consistently scores at least 92 percent of the top-scoring strategy under any weighting scheme. This indicates that demand management performs well along all dimensions. The top-performing effluent strategies also perform well overall, but they are distinguished by performing relatively worse along economic and financial considerations. Looking at (10) *Surface Water Transactions/Leases/Exchanges*, this strategy could also be a feasible way to help address future water shortages, overall ranking 5th and scoring 79 percent of the top-scoring strategy. Notably, this strategy performs well under economic and financial considerations, but it does not perform well under social and administrative considerations. Overall, these results suggest that the top-five performing strategies represent viable alternatives, with a magnitude of only 21 percent separating their overall performance. This means that both demand-side and supply-side opportunities exist to help sustainably address future water shortages.

Looking across those strategies that did not perform well, (8) *Inland Desalination/Brackish Water Treatment* did the worst with an overall score of 41 percent of the top-scoring strategy. This strategy provides low benefits and comes with high costs, performing best under social and administrative considerations at 46 percent of the top-scoring strategy, and worst under economic and financial considerations at 34 percent of the top strategy. The strategy (9) *Groundwater Transactions/Exchanges* ranks 9th overall but scores relatively better at 54 percent of the top-performing strategy, with the best performance under social and administrative considerations at 57 percent of the top-scoring strategy, and worst under *Environment and Sustainability* considerations at 41 percent of the top strategy. The one effluent strategy that did not perform well, (2) *Regional Effluent – Direct Potable Reuse*, ranks 7th overall and scores 61 percent of the top-performing strategy. When comparing direct potable and non-potable reuse, potable reuse performs notably worse along both economic and financial and social and administrative considerations.

The strategy (7) *Ocean Desalination* performed moderately overall, scoring 68 percent of the top-scoring strategy. The strategy (6) *Poor Quality Groundwater Treatment* scored only 50 percent of the top strategy overall, performing best under social and administrative considerations at 70 percent of the top strategy and worst under environment and sustainability considerations at 32 percent of the top strategy. Meanwhile, (7) *Ocean Desalination* was the opposite, performing the best under environment and sustainability considerations at 72 percent of the top strategy and worst under social and administrative considerations at 50 percent of the top strategy. This strategy performed much better than (6) *Poor Quality Groundwater Treatment* along economic and financial considerations. The lower-ranked strategies should therefore not be ruled out as alternatives, but they are unlikely to be optimal to develop and implement first. After other alternatives have been exhausted, or their marginal effectiveness diminished, these alternatives could be worth further consideration. The results ultimately indicate that several strategies are worth looking at in greater detail, especially in combinations where there could be potential synergies, or at least few trade-offs associated with combined implementation.

Considering all costs and benefits, a combination of supply-side and demand-side strategies is likely to be optimal for addressing future water shortages in the study area. Unfortunately, this analysis does not consider different combinations of strategies since it would exponentially increase the complexity and resource needs for the analysis. This does however offer an opportunity for future work to identify important trade-offs and synergies between strategies. For example, reducing water demand may reduce effluent availability, meaning that these strategies are not additive, and the outcome of their combined implementation is less than the sum of their individual performance. On the other hand, combing two effluent strategies may help reduce capital and OM&R costs, implying that their combined performance is greater than the sum of their individual performance. The trade-off analysis helps identify individual strategy strengths and weaknesses and determine which strategies perform well independently and are worth further consideration. Analyzing a combination of strategies is an important next step in determining the optimal solution for addressing future water shortages. It is unlikely that any one strategy alone is the best option, and there are likely to be important trade-offs and synergies when strategies are combined.

6.6 Limitations and Opportunities

The trade-off analysis relies on existing data and is dependent on the outputs identified in previous parts of the study to evaluate adaptation strategies. As a result, some areas of measurement and evaluation are limited, and several uncertainties and limitations exist. One key limitation of this assessment is that strategies are evaluated independently. This avoids assessing countless strategy combinations and keeps the analysis manageable, but also misses potential synergies or trade-offs associated with implementing strategies together. Since it is unlikely that any one strategy alone will be able to fully address future water shortages, it is important to understand which combination of strategies may be optimal. There is therefore an opportunity for future work to assess potential synergies and trade-offs with combined strategy implementation.

Another limitation of this analysis comes from the fact that many criteria are measured qualitatively through surveying study partners. This means that scores involve uncertainty and may not accurately reflect trade-offs. This approach is used for simplicity and to reduce the data, modeling, and overall resource needs for the analysis. However, future work would benefit from more objective and concrete measurement of cost and benefit criteria wherever possible, such as monetizing capital and OM&R costs. This would permit a traditional assessment of feasibility and an economic analysis that identifies the alternative with the greatest monetized net benefit. However, as made clear in this assessment, costs and benefits beyond those which can be monetized are also important to consider. As a consequence, future assessments will undoubtedly also have to rely on some criteria being evaluated qualitatively whenever all costs and benefits are to be considered.

Additional limitations stem from the simplifying assumptions used at various steps in the analysis. For example, the CAP:SAM projections of future water supply and demand rely on several assumptions for key model parameters, and this analysis relies on simplifying assumptions for modeling future water prices. The project team also relied on several assumptions when determining the water volume and implementation time for each strategy, sometimes providing a range that reflects uncertainty. The length of the study period is also an important factor, and the full life cycle impacts of a strategy could prove to be different than the impact across 40 years. That said, the assumptions used likely have minimal influence on the results of the trade-off analysis, in part because everything is compared on a relative basis, and in part because these assumptions only influence the two quantified criteria, *Water Availability and Reliability* and *Regional Economic Impact*. These assumptions nonetheless have important implications for the magnitude of monetized benefits, which is important to consider if comparing monetized costs and benefits.

The strategies that perform well in this analysis should be examined in greater detail, especially in combination with other strategies that might provide synergies. Additional criteria could also be considered, and criterion such as *Environmental and Ecosystem Condition* could be sub-divided into multiple and more detailed criteria such as water quality, fish and wildlife habitat, and riparian vegetation. Additional information could also be gathered regarding the importance of each criterion, beyond the preferences of the study team. Future work could also expand the accounting stance and scope to examine interactions that go beyond the central Arizona region, such as impacts on the Colorado River and other states that also rely on the river for renewable water supplies. This would of course require substantial resources and collaboration to properly account for and model interactions between states and key stakeholders. This study provides a screening analysis for adaptation strategies, but further examination of strategy feasibility is warranted in order to identify the optimal means to address future water shortages in the study area and central Arizona region, in particular, considering strategy combinations where synergies may exist.

7. Conclusions

7.1 Key Findings

- The study area will require additional new renewable water supplies to meet growth projections. The amount of new water needed by 2060 in the study area is best expressed as a range because of uncertainty represented by the different scenarios evaluated in this study. The study area as a whole will have a new water supply need (shortage) of between about 47,000 and 260,000 acre-feet per year by the end of the study period in 2060, based on the climate change, supply and demand, and groundwater model analyses conducted as part of this study. The high estimate is based on a hot-dry climate with rapid outward growth.
- Climate change will increase demand and reduce supplies. Key scenarios evaluated in the study included potential reductions in Colorado River water to the Central Arizona Project and other surface water supplies (e.g., reduction to SRP supplies).
- All future supply and demand scenarios that were evaluated with a groundwater model show, to some extent, issues with increasing depths to water in the Hassayampa sub-basin, the north/northeast area of the study area, and in the Rainbow Valley sub-basin (Figures 21-24). These areas are particularly vulnerable due to existing significant depths to water, or shallow bedrock, and proximity to the basin edge (basin geometry).
- The slow compact and average growth scenarios show moderate water level declines regionally and, in some areas, water level rises occurring in areas of large recharge facilities and the Buckeye Water Logged Area.
- Multiple variables in each scenario do not allow for a direct comparison between the scenarios except to say:
    - Hot, dry conditions, coupled with aggressive growth, incur the greatest impacts to supplies (i.e., the hot and dry climate change scenario included periods of CAP shortages).
    - Historical climate trends, slower more compact growth, and more efficiency/conservation have less of an impact.
    - Growth management is imperative to extending supplies.
- Assessment of adaptation strategies, developed based on potential future need and a set of general goals, showed no single strategy completely bridges the projected gap between demand and supply for 2060 in the hot-dry rapid outward growth scenario (except perhaps *Ocean Desalination*). Therefore, a combination of strategies is required.
- Considering all costs and benefits, a combination of supply-side and demand-side strategies is likely to be optimal for addressing future water shortages in the study area.
- The highest-ranking strategies were *Demand Management* and *Effluent Reuse and Recharge* based on evaluation weighting schemes including economic and financial, environment and sustainability, and social and administrative (Table 33, above).

- To meet the aquifer protection goal, increased use of renewable supplies is needed to offset groundwater pumping impacts.
- Water level impacts and supply shortages could be positively impacted by additional replenishment and full utilization of reclaimed water (effluent).
- With proper maintenance and replacement, infrastructure is currently working to meet demand; however, expansion, upgrades, and new infrastructure will be required in the future.
- The type, location, and extent of new infrastructure depends on factors such as growth patterns and supply sources.
- System interconnects and operation agreements will benefit multiple jurisdictions and provide for flexibility and reliability.
- Regional partnerships, such as the WVWA, are essential for responding to the water resource challenges in the study area.

7.2 Additional Findings

7.2.1 Climate Change Modeling

Climate change modeling for the study period indicates warmer mean annual basin-wide temperatures than the historical (1950-1999) value of 59.3°F, ranging from an increase of 2.8°F to 6.9°F. This will result in higher evapotranspiration rates for agricultural crops and other vegetation. Changes in projected mean annual basin-wide precipitation range from -12.9 to +10.0 percent from the historical value of 15.9 inches. Generally, the warm-wet (WW) scenario produces the largest streamflows in the winter and spring months with the hot-wet (HW) scenario producing the largest streamflows in the summer and early fall months. The smallest streamflows are usually seen in the hot-dry (HD) scenario. Climate modeling data also show that Arizona can expect more extreme weather patterns, bigger floods, and longer, more-severe droughts.

7.2.2 Supply and Demand Analysis

Unsurprisingly, the study indicates the demand for water in the study area will increase over time. Because of uncertainty represented by the different scenarios evaluated in this study, the amount of new water needed by 2060 is best expressed as a range. The study area providers as a whole will have a new water supply need (shortage) of between about 47 thousand and nearly 260 thousand AF/y by the end of the study period in 2060, based on the climate change, supply and demand, and groundwater model analyses conducted as part of this study. The high estimate is based on a hot-dry climate with rapid outward growth. It accumulates over the study period reaching the full amount in 2060 (Figure 17, Scenario D). The low estimate is based on slow compact growth without climate change (Figure 18, Scenario F). The values are based on the CAP:SAM model scenarios and represent the amount of groundwater that would need to be replenished subject to Arizona Assured Water Supply rules.

There are other ways to calculate these summary values based on the CAP:SAM results and the goals and objectives stated in this study. However, the general point being made is not the exact values, but rather that a significant amount of water will be needed, and water providers will require investment in managing existing and developing new supplies over the study period. The uncertainty in the needed water volume indicates that continued evaluation of new scenarios, updated projections, and assumptions is required moving forward. The quantities reported are planning numbers based on assumptions made throughout this study and they are representative of the water supply challenges to which the study area water providers will need to adapt. Because strategies will be employed between now and 2060, the 2060 shortage amounts used in this study should not be construed as a prediction of the future.

7.2.3 Groundwater Model

Groundwater model results show increased groundwater pumping to meet the 2060 demand will lead to water level declines. Those declines vary by location and the amount of pumping associated with each scenario. All scenarios showed an area of relatively deep groundwater in 2060 in the northern part of the WSRV, with the deepest water levels in the northeast near the Hedgpeth Hills (Township 4 North, Range 1 East; Figures 20-24). Modeled hydrographs show groundwater level declines will accelerate towards the end of the study period and beyond (Figure 28).

Areas with relatively deep groundwater levels at the end of the study period would result in increased operational costs and other negative effects. Concentrated, ongoing withdrawals from the study area basins have the potential to create problems, such as land subsidence and fissuring, infrastructure damage, declines in water quality, and increased pumping costs. This can be mitigated in several ways, such as identifying alternative water sources so that well pumping can be curtailed in areas with deep groundwater levels.

Increased use of renewable supplies is needed to offset groundwater pumping impacts. Without a renewable supply-based path going forward (individually or collectively), many study area water providers will continue to rely on the CAGRD to replace the limited and variable non-renewable water that each provider pumps and serves. While this poses challenges because of near- and long-term uncertainty associated with the sustainability of the CAGRD model, an even greater concern may be the reduction of groundwater quantity and quality within service areas.

7.2.4 Adaptation Strategies

To develop potential strategies for adapting to the challenges of increased demand and limited supplies, the study partners developed goals and objectives which prioritize permanent renewable supplies and aquifer protection (Table 8). Priority was also given to strategies that could be implemented at a regional level and utilize regional cooperation and collaboration. Regional level strategies are typically multi-jurisdictional and involve, or are applicable to, more than one water provider. This regional focus is not meant to imply that local level projects implemented by individual communities are not important.

The study team characterized 21 adaptation strategies that were grouped into 10 adaptation strategies for evaluation in an economic and trade-off analysis (Table 9 and Table 10). Each of the evaluated strategies was screened, at least in part, on its potential to meet the planning goals and objectives and its suitability to address future imbalances between water supply and demand in the

study area. Each strategy was considered relative to the amount of water it could provide and other characteristics, such as relative cost, public perception, and environmental, legal, and institutional issues.

Most of the 10 adaptation strategies analyzed seek to address water shortages through supply-side improvements which increase the availability of water supplies. One exception, *Demand Management*, seeks to decrease the shortage gap through a combination of conservation and efficiency programs that reduce demand.

No single strategy, except perhaps *Ocean Desalination*, completely provides all the new water supply needed for 2060 in the hot-dry rapid outward growth scenario. Therefore, it appears that a combination of strategies is required to fully meet the projected 2060 demand. Considering all costs and benefits, a combination of supply-side and demand-side strategies is likely to be optimal for addressing future water shortages in the study area.

7.2.5 Economic and Trade-Off Analyses

The economic and trade-off analysis of the adaptation strategies indicate that *Demand Management* performs well overall and proves to be the least-cost strategy considered, while also providing several relatively large benefits. Improving conservation and reducing water demand is therefore a sensible way to help reduce future water shortages and pressure on water resources.

Effluent use, especially recharge, also appears to be a practical way to address future water shortages in the study area. Surface water transactions and agreements could also be a viable way to help address shortages in the region, but the success of this strategy depends heavily on administrative and legal barriers as well as public perception and acceptance. Meanwhile, ocean desalination, poor quality groundwater treatment, groundwater transactions, and inland desalination/brackish water treatment all come with a relatively high cost and therefore lower net benefit than the other alternatives considered.

Ocean Desalination and *Demand Management* scored highest in the *Water Availability and Reliability* evaluation which is based on the volume of water provided by a strategy, the type of water provided, when that water becomes available, and if the water volume is constant or varies over time (Table 26). However, water availability and reliability are not the only consideration in ranking strategies. Table 33 provides a cardinal score for strategies under each weighting scheme, reported as a percentage of the highest-ranking strategy (i.e., 1st=100 percent). These percentages indicate how strategies perform relative to one another while considering the magnitude of differences.

The strategy *Demand Management* is the top performing strategy and performs well along all dimensions. The top-performing effluent strategies also perform well overall, but they are distinguished by performing relatively worse along economic and financial considerations. The *Surface Water Transactions/Leases/Exchanges* strategy could also be a feasible way to help address future water shortages, overall ranking 5th and scoring 79 percent of the top-scoring strategy. Notably, this strategy performs well under economic and financial considerations, but it does not perform well under social and administrative considerations. Overall, these results suggest that the top-five performing strategies represent viable alternatives, with a magnitude of only 21 percent separating their overall performance. This means that both demand-side and supply-side opportunities exist to help sustainably address future water shortages.

Strategies that did not perform as well include *Inland Desalination/Brackish Water Treatment* which provides low benefits and comes with high costs, performing best under social and administrative considerations at 46 percent of the top-scoring strategy, and worst under economic and financial considerations at 34 percent of the top strategy. The strategy *Groundwater Transactions/Exchanges* ranks 8th overall but scores relatively better at 53 percent of the top-performing strategy, with the best performance under social and administrative considerations at 57 percent of the top-scoring strategy, and worst under environment and sustainability considerations at 41 percent of the top strategy.

The one effluent strategy that did not perform well, *Regional Effluent – Direct Potable Reuse*, ranks 7th overall and scores 61 percent of the top-performing strategy. When comparing direct potable and non-potable reuse, potable reuse performs notably worse along both economic and financial and social and administrative considerations. The DPR rank is somewhat surprising, and the assumptions used should be investigated further.

The strategy (7) *Ocean Desalination* performed moderately overall, scoring 68 percent of the top-scoring strategy and ranking 6th. The strategy (6) *Poor Quality Groundwater Treatment* scored only 50 percent of the top strategy overall and ranked 9th, performing best under social and administrative considerations at 70 percent of the top strategy and worst under environment and sustainability considerations at 32 percent of the top strategy. Meanwhile, (7) *Ocean Desalination* was the opposite, performing the best under environment and sustainability considerations at 72 percent of the top strategy and worst under social and administrative considerations at 50 percent of the top strategy. Both of these strategies performed moderately along economic and financial considerations. The lower-ranked strategies should therefore not be ruled out as alternatives, but they are unlikely to be optimal to develop and implement first. After other alternatives have been exhausted, or their marginal effectiveness diminished, these alternatives could be worth further consideration.

The results ultimately indicate that several strategies are worth looking at in greater detail, especially in combinations where there could be potential synergies or few trade-offs associated with combined implementation.

Some study limitations include not using reclaimed water to its full extent and only considering water currently secured by CAGRD in the groundwater modeling. Projecting the acquisition of new CAGRD replenishment water was not included in the study. However, by law CAGRD is required to replenish for all its members including projected new members. Water level impacts/supply shortages would be positively impacted by additional CAGRD replenishment and full utilization of reclaimed water.

7.3 Next Steps and Future Considerations

The WVWA members will continue to work together and with various other partners to develop future water supplies to address the needs identified in this study. Strategic planning and further evaluation of this study and other interrelated activities will help focus those efforts.

Potential follow-on activities related to this Basin Study include refinements to the supply and demand scenarios, and further use of the groundwater and recharge suitability modeling tools. The purpose of additional work on the study components would be to increase understanding and confidence in the study results, adaptation strategy prioritization, and provide support for investment in water resource development activities.

7.3.1 New Demand and Supply Scenarios

While the scenarios used in this study were adequate to characterize the magnitude of water resource needs for the purposes of this study, it may be beneficial to examine a wider range of scenarios. Additionally, new growth and water supply projections and assessments are regularly produced for the study area and the larger region. These can be used to revise the scenarios and quantities reported in this study. The CAP:SAM could be used to create new supply and demand scenarios and update characterizations of the amount, location, and timing of the study area water supply needs.

7.3.2 Groundwater Model Refinement

The groundwater model could be used to evaluate additional scenarios, such as pre-adaptation scenarios or post-adaptation scenarios that incorporate estimates of water obtained through implementing adaptation strategies. Scenarios could include different uses of effluent or additional CAGRD replenishment. Scenarios that investigate changes in pumping and recharge locations could be useful for assessing questions about aquifer impacts. Additional model runs with adaptation strategy scenarios would be useful for comparing pre and post-adaptation conditions and assessing the effectiveness of the strategies. Also, scenarios incorporating combinations of strategies could be evaluated. In addition to other pre- and post-adaptation scenarios, the model simulation period could be extended beyond 2060.

7.3.3 Recharge Suitability Model Refinement

The recharge suitability model could incorporate additional ranking criteria or be refined to focus on specific geographic areas or general consideration of other criteria. For example, additional ranking criteria related to infrastructure locations and capabilities could be incorporated.

7.3.4 Adaptation Strategy Refinement

Some of the adaptation strategies may benefit from assessment of recent or anticipated developments in technology, data, or policies. Also, other ongoing activities in the state and region should be closely monitored and may provide insight to adaptation strategy prioritization and implementation planning. For example, some strategies identified in this study will be affected by Colorado River management, regional surface water management (e.g., Verde River), AWS designations in the AMA, water transfers, cooperative water sharing agreements, and water reuse rulemaking. The study partners, many of which are involved in the activities, could benefit from identifying and characterizing the activities in the context of the goals and water supply needs identified in this Basin Study.

Additional refinement could focus on design concepts and estimating costs for some of the strategies.

7.3.5 More Detailed Infrastructure Analysis

A more thorough infrastructure impact analysis would benefit the study partners. This could involve updating previous infrastructure studies conducted by WVWA with applicable results of this study. Identification and evaluation of more specific infrastructure needs associated with scenarios and strategies may help prioritize strategies. Additional groundwater model runs, and the recharge suitability model could help define potential areas of need and focus infrastructure assessments. Timely preliminary- or appraisal-level designs and cost estimates for infrastructure associated with adaptation strategies would help managers plan well ahead of the need.

Integrated Stormwater Management is a vital approach strategy that this study did not thoroughly address. Large scale stormwater capture and redirection is a potential alternative for direct/indirect recharge.

7.3.6 Expand Economic and Tradeoff Analysis

Because it is unlikely that any one strategy alone will solve all the issues, the economic and trade-off analysis could be expanded to consider different combinations of strategies. There are likely to be important trade-offs and synergies between strategies when strategies are combined. For example, reducing water demand may reduce effluent availability, meaning that these strategies are not additive, and the outcome of their combined implementation is less than the sum of their individual performance. On the other hand, combing two effluent strategies may help reduce capital and OM&R costs, implying that their combined performance is greater than the sum of their individual performance. Analyzing a combination of strategies is an important next step in determining the optimal solution for addressing future water shortages.

7.3.7 Conduct Appraisals, Pilots, and Demonstration Projects

The study partners understand that to meet the water supply needs of the future, definitive steps towards real projects with measurable benefits are required. These may include examining feasibility of fully implementing strategies or conducting pilot or demonstration projects. The specific strategy and project will be determined by partner interest, resources, and need.

7.3.8 Further Work on Demand Management Strategy

Continued follow-up on the demand management strategy is appropriate to consider as a high priority based on the findings of this study. This includes partnership opportunities with shared resources and unified messaging, such as AMWUA conservation messaging. Water providers in the study area are already conducting such programs. For example, some of the study area providers are participating in the Arizona Growing Water Smart program which provides opportunities for different city departments to work together toward better water management and planning. Additional steps could involve estimating which specific measures have the greatest potential savings, and then obtaining regional acceptance and demonstrated willingness to actively support such measures.

7.3.9 Identify and Utilize Funding Opportunities

Opportunities to use Reclamation funding and expertise in water resource planning and implementation could be useful for study area water providers. The Basin Study Program provides a way to conduct planning on a basin-wide scale to identify and evaluate adaptation strategies; however, it does not provide the means to construct or otherwise implement those strategies. Funding and expertise for construction/implementation may be provided under other programs.

Reclamation has funding opportunities through the WaterSMART Program for local governments and water providers to apply for 50/50 percent cost-share grants. The grants can be used to plan for and implement actions to improve water supply and/or quality, modernize infrastructure, and/or reduce water conflict. The WaterSMART grants that appear to be most applicable to the study area's needs are Small-Scale Water Efficiency Projects, Water Marketing Strategy Grants, Water and Energy Efficiency Grants, Title XVI Water Reclamation and Reuse Grants, Water Conservation Field Services Program, and Drought Response Program. Reclamation staff can help study area water providers understand and navigate these programs and funding opportunities.

Other federal agencies offer different types of grants or loans for water management, such as EPA and Army Corps of Engineers. There are also programs and grants available through the state of Arizona, including ADWR, Water Infrastructure Finance Authority of Arizona, and ADEQ's Water Quality Assurance Revolving Fund.

7.3.10 Continue Collaborative Efforts

Throughout this study, the participants regularly shared data, organization plans, challenges, and ideas. The working relationships developed and expanded during the study are a foundation for avoiding conflict and enabling additional collaboration among WVWA members, Reclamation, and other interested parties. In the future, as steps are taken to secure water to meet the growing demand, these relationships will be valuable assets. The study partners and interested parties can collaborate on prioritizing, further developing, and implementing strategies.

8. Disclaimer

This Basin Study is a technical assessment and does not provide recommendations or represent a statement of policy or position of Reclamation, the Department of the Interior, or the West Valley Water Association and interested parties. The Basin Study does not propose or address the feasibility of any specific project, program, or plan. Nothing in the study is intended, nor shall the study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the study represents a commitment for provision of local, State, or federal funds. All water volume and cost estimates included in this study are preliminary and intended only for comparative purposes.

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