BUREAU OF RECLAMATION

West Salt River Valley Basin Study

Economic and Trade-Off Analysis

Arizona, Lower Colorado Region

U.S. Department of the Interior

April 2021

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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.

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Abbreviations

ADWR – Arizona Department of Water Resources
AF – Acre-Feet
AMA – Active Management Area
AOT – Arizona Office of Tourism
ASP – Agricultural Settlement Pool
ASR – Annual Storage and Recovery
ASU – Arizona State University
AWS – Assured Water Supply
AWBA – Arizona Water Banking Authority
BT – Benefit Transfer
CAP – Central Arizona Project
CAP:SAM – Central Arizona Project Service-Area Model
CAGRD – Central Arizona Groundwater Replenishment District
CAWCD – Central Arizona Water Conservation District
CS – Consumer Surplus
CRSS – Colorado River Simulation System
GFR – Grandfathered Groundwater Right
GPCD – Gallons Per Capita Day
GPHUD – Gallons Per Housing Unit Per Day
GSF – Groundwater Savings Facility
GSP – Gross State Product
GW – Groundwater
HU – Housing Unit
ID – Irrigation District
IGFR – Irrigation Grandfathered Groundwater Right
MAF – Million Acre-Feet
MAG – Maricopa Association of Governments
MCDA – Multi-Criteria Decision Analysis
MMBtu – Million British Thermal Units
M&I – Municipal and Industrial
NASS – National Agricultural Statistics Service
NAICS – North American Industry Classification System
NPCCP – Non-Per Capita Conservation Program
PV – Present Value
PPHU – Population Per Housing Unit
OM&R – Operating, Maintenance, and Replacement
RP – Revealed Preference
RUVD – Recreation Use Values Database
SP – Stated Preference
SRP – Salt River Project
SW – Surface Water
USBR – U.S. Bureau of Reclamation
USF – Underground Storage Facility
WC – Water Company
WCDD – Water Conservation and Drainage District

WD – Water District
WSRV – West Salt River Valley
WVWA – West Valley Water Association

Executive Summary

The West Salt River Valley (WSRV) Basin Study is a collaborative effort between the U.S. Bureau of Reclamation (USBR), West Valley Water Association (WVWA), and other interested parties. The WVWA is a consortium of cities and water providers in the West Valley of central Arizona. The goal of the study is to evaluate regional water supply and demand under changing climate conditions and population growth, and to develop and evaluate adaptation strategies that ensure future sustainability of water resources within the West Valley area. The purpose of the *Economic and Trade-Off Analysis* is to compare adaptation strategies 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.

Water shortages have important implications for the price of renewable water and for dependence on groundwater, both of which influence welfare for water users. Strategies can also provide benefits for instream uses such as recreation, and there are additional impacts from adaptation strategies that are important to consider, such as social and environmental consequences. A trade-off analysis provides a 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 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 a 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.

For the analysis, attention is placed on municipal, industrial, agricultural, and recreational uses of renewable water supplies and non-renewable groundwater supplies in the study area. 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 the Central Arizona Project Service-Area Model (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 shortages and quantify welfare impacts from adaptation strategies intended to reduce shortages.

Several supply and demand scenarios are assessed for the period 2020-2060, each reflecting a different magnitude of 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. Strategies are compared based on their ability to decrease future water shortages while also considering several economic, financial, environmental, and social effects associated with each strategy. The trade-off analysis is used to compare adaptation strategies across multiple criteria simultaneously, identifying important trade-offs and highlighting the strengths and weaknesses of each strategy.

The project team decided to focus on 3 CAP:SAM scenarios, A, D, and F, capturing a range of potential future conditions. Scenario A represents "business as usual" in which the future follows closely to 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 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 the State's Assured Water Supply (AWS) rules which 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 get 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 since under Arizona's existing legal framework future demand must be met by directly using renewable supplies or offsetting groundwater use with renewable supplies. In 2060, the shortage volume for the region is expected to range from 114,071 AF (Scenario F) to 527,409 AF (Scenario D). The study area represents almost half of this shortage volume, ranging from 47,151 AF (Scenario F) to 263,687 (Scenario D). For the region, water shortages have already begun, and as a result, renewable water prices have been on the rise in recent years. Shortages at both the local and regional level influence price and welfare across the region, meaning adaptation strategies that are intended to address water shortages in the study area can have important implications for water users in the broader region.

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. To quantify adaptation strategy benefits associated with reducing water shortages, welfare effects are measured according to price impacts and subsequent changes in consumer welfare 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. Shortages in renewable supplies are primarily anticipated for municipal and industrial (M&I) users, while agricultural users are expected to continue to rely heavily on groundwater into the future. Nonetheless, many agricultural users also depend on renewable water purchased on the market, such as Salt River Project (SRP) water, Central Arizona Project (CAP) water, and effluent, meaning they could be affected by M&I shortages and market prices in the region.

The price end users pay for water, or the retail price, varies greatly depending on location and the type of end use. 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, meaning welfare effects and adaptation strategy benefits for water availability 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 market use between these sectors, incorporating unique demand and price assumptions for each.

Due to differences in the price of using different sources of raw water, welfare effects associated with future water shortages largely depend on the particular mix of water sources used by each water provider and irrigation district. The price of CAP and SRP raw water reflects the wholesale cost of provision, including both fixed (capital) and variable (delivery) costs, meaning the price differs depending on differences in the cost of provision. CAP water is generally more expensive since it has to be diverted a longer distance than SRP water, generating higher fixed and variable costs. Meanwhile, direct use of local surface water is one of the cheapest sources of raw water, along with groundwater which varies depending on depth to water and electricity prices. Effluent use can be relatively expensive depending on the level of treatment for wastewater to be reused, and for those providers that cannot meet AWS requirements for renewable supplies, groundwater pumping can be offset through the Central Arizona Groundwater Replenishment District (CAGRD), but this is an expensive option. Those relying on more expensive water sources will generally experience larger welfare effects associated with future water shortages, but even users who don't anticipate a shortage in their local area may be affected by shortages in the broader through price changes and subsequent welfare effects.

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 whom compete in the same market for renewable water supplies. The study area includes 13 water providers and 6 irrigation districts, and 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. Welfare effects are also considered for direct use of local surface water and groundwater, and for underground water storage, since direct use and storage are influenced by market shortages and may be affected by adaptation strategies. 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. 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.

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 elasticity of demand characterizes uncertainty in future price sensitivity for water users. Adverse price and welfare effects are largest with inelastic water demand under Scenario D, while effects are smallest with elastic water demand under Scenario F. Correspondingly, future water shortages are expected to increase renewable market prices anywhere from 2.5 to 34.5 percent annually. The change from year-to-year varies, differing based on annual water shortage volumes, and in general, price effects are smaller at the start of the study period and get larger toward the end due to population growth and more severe water shortages. 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 years with limited water availability the increase has been as much as 14 percent for M&I. Furthermore, with a CAP shortage expected to start in 2020, CAP's rate for M&I use jumps nearly 22 percent from 2019 to 2020, and the advisory rates imply a 5 percent annual change the following years. The price effects in this analysis are therefore consistent with recent wholesale price growth in the region, with a range that also reflects the possibility for more/less severe water shortages in the future.

Adaptation strategies that reduce water shortages in the region will lower adverse price effects and the upward trend of water prices across time. Furthermore, the earlier a strategy is implemented, the greater the effect on prices across the study period, since shortage reductions early on have a compounding effect on future prices. By measuring annual changes in prices and market welfare, the implementation time for an adaptation strategy is encompassed in the benefit estimate for reducing water shortages. The calculation therefore includes a volumetric and temporal component, which is important to not only capture differences in implementation time, but also the fact that some strategies don't provide a constant annual volume of water. For example, effluent availability is modeled as growing across the study period depending on population growth and water demand. In this assessment, the benefit for reducing water shortages is formally captured by the criterion *Water Availability and Reliability*, encompassing both the quantity of water provided as well as when that water is available to address shortages that vary in magnitude from year to year.

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 welfare values estimated in the economics literature and applying them to the area of interest. For this analysis, 19 different types of recreation are assessed by using an exhaustive list of studies from the literature that are applicable to the study area. Some forms of recreation depend directly on water, while others are indirectly influenced by water conditions. The results indicate that recreation generates around $1.56 billion ($2020) in welfare per year across the three counties analyzed, with an average of $386 per participant across all activities. 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. These estimates represent the annual welfare attributed to those adults partaking in recreational activities. There are however 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 not analyzed. Future welfare effects are calculated based on projected surface water conditions and population growth in CAP:SAM.

For M&I users, water shortages are expected to reduce welfare anywhere from $254 million (Scenario F) to $994 million (Scenario D) from 2020-2060, 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 each ones' raw water portfolio. A bit less than half of the welfare effects occur within the study area and the other half in the outside area. 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, absent adaptation efforts. This amounts to an average of $160 (Scenario F) to $448 (Scenario D) per cropped acre, with variation across irrigation districts again depending on each ones' raw water portfolio. Around two-thirds of welfare effects for irrigation occur outside the study area. For recreation, 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) to $69 (Scenario D) per recreation participant, with significant variation across activities depending on the importance of water. Roughly half of the welfare effects stem from water-based recreation, and around half of all welfare effects for recreation occur in the study area.

Across M&I, agricultural, and recreational water users in the central Arizona region, the estimates indicate that water shortages are expected to reduce welfare anywhere from $413 million (Scenario F) to $1.36 billion (Scenario D) across the 40-year study period, absent adaptation efforts. A bit under half (44 percent) of this welfare loss occurs in the study area, with the remainder in the outside area. This is used as a baseline to quantify adaptation strategy benefits for the criterion *Water Availability and Reliability*. Table ES-1 shows the estimated benefits under Scenario D conditions for each of the adaptation strategies considered in this analysis, with welfare effects separated by area.

Table ES-1 – 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.

These benefits capture the impact of reducing water shortages and keeping regional water prices down, benefiting water users. Although these estimates are at the wholesale level, it is fair to assume that welfare effects will largely get transferred to final consumers since water providers and irrigation districts often sell water at cost. These benefits are for the criterion *Water Availability and Reliability*, but it is also important to consider the costs associated with each strategy, and there are additional benefits to consider, such as impacts on the regional economy in terms of output, income, and employment.

A total of 10 evaluation criteria, defined as either a benefit criterion or a cost criterion, were chosen by the project team to capture a range of economic, financial, environmental, and social effects associated with each strategy. Strategies are evaluated relative to one another using a low-high scale to score and rank strategies for each criterion. Some criteria may be perceived as more important than others, so different weighting schemes are used to give additional preference 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 different weighting schemes, and no weighting scheme is considered "optimal." Instead, the results allow one to see how each strategy performs under different objectives and considerations.

Two criteria, *Water Availability and Reliability* and *Regional Economic Impact*, are first measured and assessed quantitively before getting converted to a low-high scale to compare impacts with other criteria that are scored qualitatively based on input from study partners. The benefits in Table ES-1 are therefore converted to a low-high (0-3) score for the trade-off analysis, as are the estimated regional economic impacts shown in Table ES-2. The remaining criteria are evaluated qualitatively, due in part to data and resource limitations, and in part to infeasibility with their measurement.

Table ES-2 – 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	$1,958.89	$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.

Conducting an original regional economic impact analysis was not feasible for this study, so the amounts in Table ES-2 are calculated based on the results of a recent IMPLAN analysis in the region. 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 USBR'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 and combine that with water quantity information for each adaptation strategy to quantify the criterion *Regional Economic Impact*. 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 as inputs and is 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 works as well as those self-employed, measured in job years, which is equivalent to one person having a full-time job for one year. 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.

To evaluate additional considerations, a survey is used to qualitatively score the remaining 8 criteria in 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.

Decimal places were permitted to allow for a continuous scoring scale and also encouraged to provide more precise scoring. Adding up criteria scores can help identify which strategies perform well overall under different weighting schemes, but the overall raw score masks trade-offs between criteria and doesn't illustrate the particular strengths and weaknesses of each strategy. To help illustrate strategy performance, Figure ES-1 shows the raw score for each strategy and criterion, rescaled so that at least one strategy receives the highest score possible for each criterion.

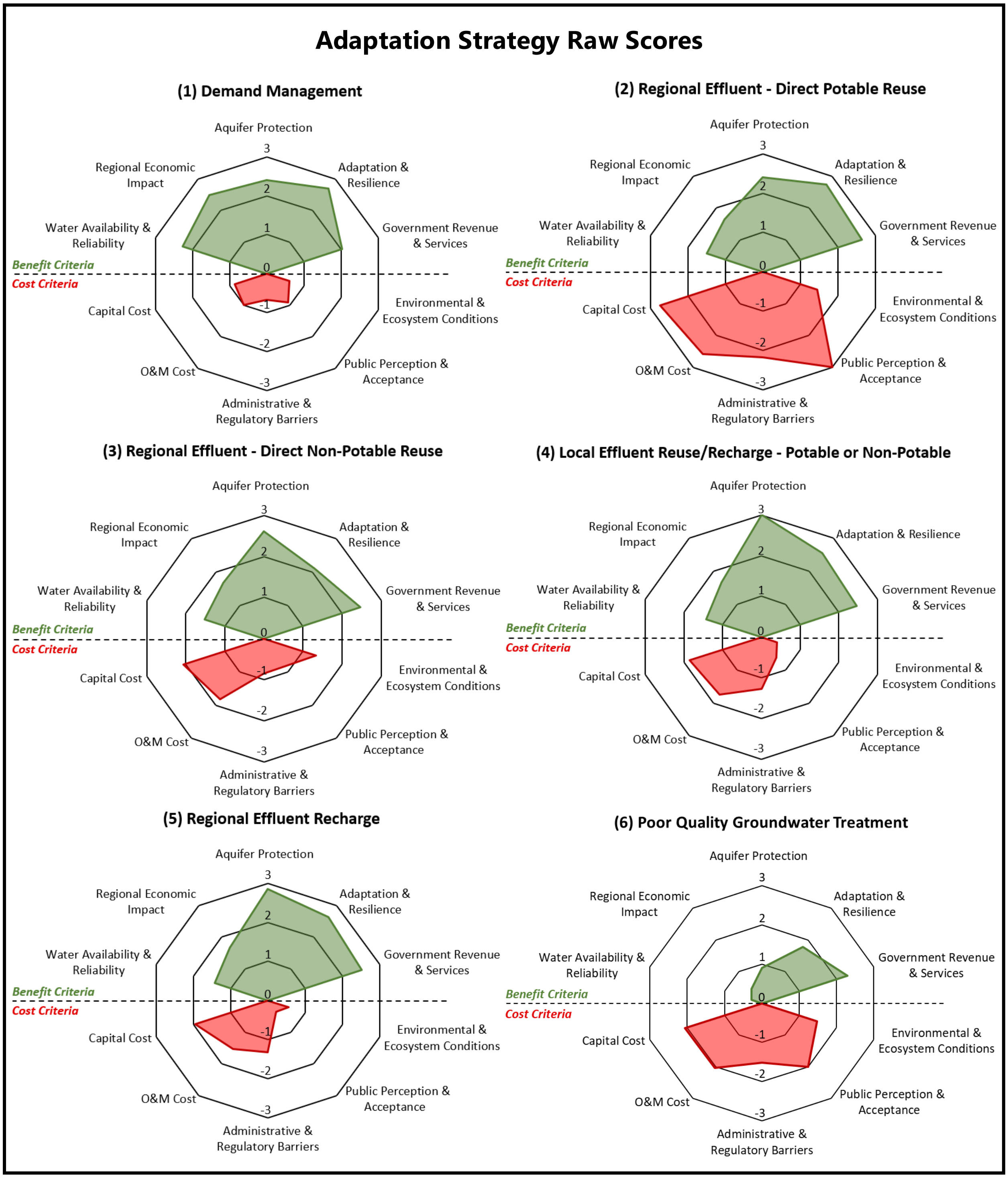

Figure ES-1 – Adaptation Strategy Raw Scores

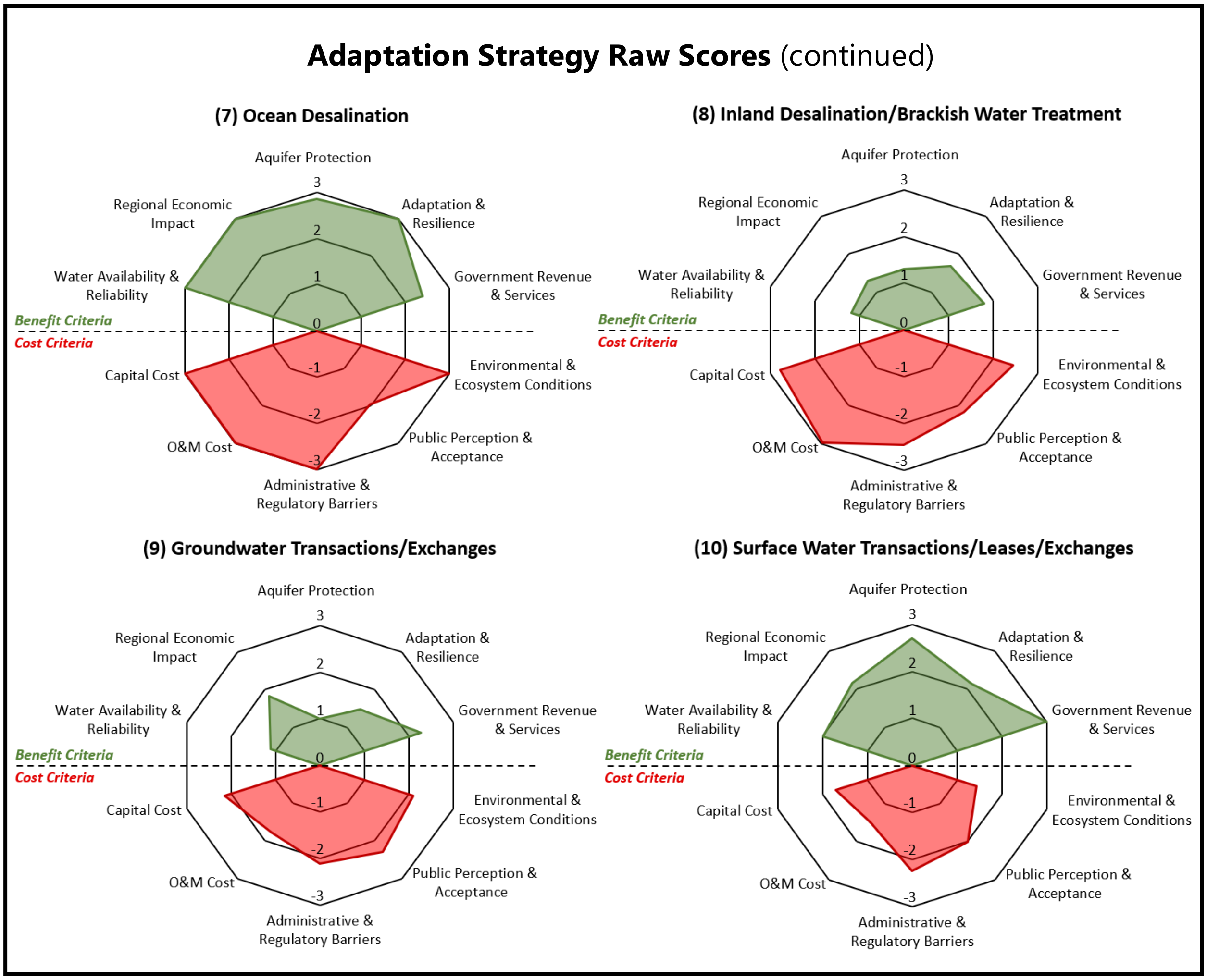

Figure ES-1 – Adaptation Strategy Raw Scores (continued)

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 a bit 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 region scale, is likely to be most efficient.

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 Impacts*, 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 to 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. The project team survey used for qualitatively scoring criteria was also used to ask about the importance that respondents placed on each evaluation criteria. These responses are utilized to generate a criteria weighting scheme that reflects the preferences of the basin study partners. Table ES-3 shows the criteria importance scores (0-3) from the team survey and the resulting weights associated with responses.

Table ES-3 – 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.

Scores are rescaled to ensure that at least one criterion receives the max score of 3 and the remining criteria retain their scores relative to one another. *Water Availability and Reliability* proved to be the most important criterion to the study partners and receives the greatest weight under the *Team Survey* weighting scheme. Meanwhile, *Government Revenue and Services* received the lowest importance score and is subsequently weighted at 35 percent of the importance of *Water Availability and Reliability*. The remaining criteria are weighted anywhere from 50-80 percent as important as *Water Availability and Reliability*. Several weighting schemes are tested to give additional weight to select criteria, one defined as *Economic and Financial*, one as *Environmental and Sustainability*, one as *Social and Administrative*, and one as the *Team Survey*. An overall rank is also provided. The raw scores previously shown indicate how strategies perform for each criterion, while the weighting schemes are used to highlight how strategies perform under different criteria groupings and criteria preferences. Table ES-4 shows how each strategy ranks under the different weighting schemes. As shown, there is variation across weighting schemes, helping to further highlight the strengths and weaknesses of each strategy.

Table ES-4 – Strategy Rank Under Different Weightings 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**
(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 is included three times in the overall rank.

While Table ES-4 shows how each strategy ranks relative to the others, it does not indicate the magnitude of differences between strategies and rankings. To examine the magnitude of differences between scores, Table ES-5 provides a normalized score for strategies under each weighting scheme, reported as a percentage of the highest-ranking strategy (i.e. 1st=100%). The cells are also colored 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 may be relatively small or quite large. 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. This provides additional information and helps further identify which strategies are suited to address future water shortages.

Table ES-5 – Score Magnitudes Under Different Weightings 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	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%	**42%**
(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 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% 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% 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% separating their overall performance. This means that their exists both demand-side and supply-side opportunities 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% of the top-scoring strategy. This strategy provides low benefits and comes with high costs, performing best under *Social and Administrative* considerations at 46% of the top-scoring strategy, and worst under *Economic and Financial* considerations at 34% of the top strategy. The strategy (9)*Groundwater Transactions/Exchanges* ranks 8th overall but scores relatively better at 54% of the top-performing strategy, with the best performance under *Social and Administrative* considerations at 57% of the top-scoring strategy, and worst under *Environment and Sustainability* considerations at 41% 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% 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% of the top-scoring strategy and ranking 6th. The strategy (6) *Poor Quality Groundwater Treatment* scored only 50% of the top strategy overall and ranked 9th, performing best under *Social and Administrative* considerations at 70% of the top strategy and worst under *Environment and Sustainability* considerations at 32% of the top strategy. Meanwhile, (7) *Ocean Desalination* was the opposite, performing the best under *Environment and Sustainability* considerations at 72% of the top strategy and worst under *Social and Administrative* considerations at 50% 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.

When 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 and central Arizona more broadly. 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 in this study helps to 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.

1.0 Introduction

The West Salt River Valley (WSRV) Basin Study is a collaborative effort between the U.S. Bureau of Reclamation (USBR), West Valley Water Association (WVWA), and other interested parties. The WVWA is a consortium of cities and water providers in the West Valley of central Arizona. The goal of the study is to evaluate regional water supply and demand under changing climate conditions and population growth, and to develop and evaluate adaptation strategies that ensure future sustainability of water resources within the West Valley area. The purpose of the *Economic and Trade-Off Analysis* is to compare adaptation strategies 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.

1.1 Overview of Economic and Trade-Off Analysis

This study embodies efforts from multiple water management agencies and organizations participating in a collaborative process to plan for future imbalances between regional water supply and demand. A key part of this effort is to evaluate adaptation strategies that are aimed at addressing water shortages in the study area. Water shortages have important implications for the price of renewable water and for dependence on groundwater, both of which influence welfare for water users. A key benefit of any adaptation strategy therefore stems from its ability to reduce water shortages and adverse effects on renewable water prices and groundwater aquifers. Strategies can also provide benefits for instream uses such as recreation, and there are additional impacts from adaptation strategies that are important to consider, such as social and environmental consequences. Some impacts can be quantified, while many can only be assessed qualitatively due to limited data and infeasibility with their measurement.

A trade-off analysis is an application of Multi-Criteria Decision Analysis (MCDA), which is a general framework for evaluating complex decision-making under multiple and often conflicting objectives. MCDA addresses trade-offs that occur when a decision leads to a desirable change in one or more objectives while simultaneously resulting in an 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 options.

Adaptation strategies come with several benefits and costs. 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 operation and maintenance. 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 associated with alternative strategies, some of which can be measured and quantified, and some of which can only be assessed qualitatively.

Attention is placed on municipal, industrial, agricultural, and recreational uses of renewable water supplies and non-renewable groundwater supplies in the study area. Welfare effects are 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 *Economic and Trade-Off Analysis* is to estimate the pre-adaptation welfare effects associated with expected 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. The pre-adaptation welfare effects are then utilized to measure welfare impacts from adaptation strategies. Several supply and demand scenarios are assessed, each reflecting a different magnitude of annual water shortages across time, absent any adaptation efforts. These scenarios serve as a baseline for comparing adaptation strategies. Strategies are compared based on their 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.

1.2 Steps for Economic and Trade-Off Analysis

The *Economic and Trade-Off Analysis* relies on existing data and is dependent on the outputs identified in previous parts of the 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, and the team was also surveyed to determine weights of importance for each criterion.

The first step in the *Economic and Trade-Off Analysis* is to quantify the pre-adaptation welfare effects associated with expected water shortages in the future. This requires projections of future water supply and demand in the region. For this study, the project team modeled future water supply and demand in the study area, as well as the central Arizona region more broadly, under various climate and population growth scenarios. This captures potential water shortages without adaptation efforts in place. The projections encompass groundwater and surface water conditions, which are both important for market and non-market uses. The scenarios also reflect different growth rates, spatial growth patterns, and assumptions of future water-use efficiency. Shortages are modeled annually from 2020-2060, serving as a baseline to quantify benefits associated with adaptation strategies.

The next step in the analysis 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 in order 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.

1.3 Adaptation Strategies

It is important to recognize the difference between an "adaptation" strategy and a "mitigation" strategy. For this study, attention is placed on adaptation strategies. Adaptation strategies are intended to reduce harmful effects from forces such as climate change and population growth, while a mitigation strategy is meant to directly reduce or prevent the driver itself. In other words, an adaptation strategy would address the harmful effects that stem from climate change and growth, while a mitigation strategy would directly target climate change and growth to prevent adverse effects to begin with. For example, a mitigation strategy might be to reduce greenhouse gas emissions to reduce future impacts associated with climate change, while an adaptation strategy might be to increase water-use efficiency to help cope with future impacts from climate change.

The strategies considered in this analysis fall primarily under adaptation strategies, as they are intended to address adverse effects stemming from climate change and population growth, not to directly reduce or prevent climate change or growth. A total of 10 adaptation strategies are evaluated in this analysis, with each consisting of several underlying components. For example, one strategy is targeted at demand management, which includes efficiency and conservation programs, low impact development, rainwater harvesting, reducing water loss, and "Smart Growth." Additional strategies encompass different forms of effluent use, poor quality groundwater treatment, desalination and brackish water treatment, and transactions, exchanges, and leases for both groundwater and surface water. These strategies are compared on a relative basis across several criteria of interest.

1.4 Criteria for Evaluating Adaptation Strategies

For this study, 10 different criteria are used to compare adaptation strategies. These criteria were selected by the project team and are intended to capture economic, financial, environmental, social effects associated with each strategy. Criteria are defined as either a benefit criterion or a cost criterion. Some criteria may be perceived as more important than others, so different weighting schemes are used to explicitly 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 different weighting schemes, and no weighting scheme is considered "optimal." Instead, the resulting rankings allow one to see how each strategy performs under different objectives and considerations. An overall rank is also provided, showing how strategies rank across all five weighting schemes together.

Of the criteria used to assess benefits and costs associated with adaptation strategies, only two criteria are measured quantitatively. The first is *Water Availability and Reliability* benefits (i.e. shortage reduction benefits), and the second is *Regional Economic Impact* (value-added, income, and employment). The remaining criteria are measured qualitatively, primarily due to data and resource limitations. These criteria mostly capture social, administrative, and environmental impacts. For the trade-off analysis, the quantified effects are converted to a relative scoring scale that is directly comparable with the qualitative scoring used for the other benefit and cost considerations. However, the quantified benefits on their own provide useful information that can assist with future decision-making and adaptation efforts in the region. For example, this assessment analyzes capital costs and operation, maintenance, and replacement (OM&R) costs on a qualitative and relative basis since the project team was not able to assign monetary costs for the adaptation strategies. That said, if in the future there is a desire to implement one of the strategies that performed well in this analysis, cost estimates could be generated and directly compared with the benefit estimates provided here to assess economic feasibility.

2.0 Study Area and Background[1]

The U.S. Census Bureau shows that Maricopa County, located in central Arizona and home to the city of Phoenix, is one of the fastest growing counties in the United States. In 2018, Maricopa County had a population over 4.4 million with 1.88% growth from the previous year.[2] The West Valley area is in the western portion of the Phoenix metropolitan area, along the Salt River and confluence with the Gila River. This is one of the fastest growing areas in central Arizona, consisting of several small to midsize cities and towns. Recognizing the need to manage finite groundwater resources, the 1980 Arizona Groundwater Code ("Groundwater Code") identified areas with a heavy reliance on mined groundwater as Active Management Areas (AMAs). Five AMAs were designated (Prescott, Phoenix, Pinal, Tucson, and Santa Cruz), all subject to numerous regulations enforced by the Arizona Department of Water Resources (ADWR). For this study, the study area is defined by the West Salt River Valley, Hassayampa, Rainbow Valley, and Lake Pleasant sub-basins of the Phoenix AMA.[3] These aquifers have been a source of groundwater for municipal, industrial, and agriculture uses for over 100 years. Historical overdraft has led to regulations and efforts to increase dependence on renewable water resources. Continuing to manage and develop renewable water supplies will be

[1] Much of the background information in this section comes from ADWR's *Phoenix AMA Fourth Management Plan* which can be found at: https://new.azwater.gov/ama/management-plan/fourth-management-plan.
[2] Historical population data for Maricopa County can be found at: https://worldpopulationreview.com/us-counties/az/maricopa-county-population/.
[3] The remaining sub-basins in the Phoenix AMA are Carefree, Fountain Hills, and East Salt River Valley.

important to reduce dependence on groundwater pumping and sustainably meet future water demand in the area.

2.1 Hydrology and Climate

The Phoenix AMA is characterized by broad, gently sloping alluvial plains separated by predominately north to northwest trending mountains. The Phoenix AMA covers 5,646 square miles and consists of seven groundwater sub-basins, four of which are the focus of this Study. Elevations within the AMA range from less than 800 feet above mean sea level near Gillespie Dam in the southwest part of the AMA, to over 6,000 feet above mean sea level in the Superstition Mountains in the eastern portion of the AMA. Flows of surface water from the Salt, Verde, Agua Fria, and Gila Rivers are stored in reservoirs for downstream users. Annual surface water flows vary greatly with weather patterns. In years of drought, insufficient surface water is often augmented by pumping additional groundwater. Since 1985, Colorado River water has been diverted to the area by the Central Arizona Project (CAP), providing a crucial source of renewable water supply.

Located primarily in subtropical desert, the climate of the Phoenix AMA is semi-arid. Long-term average temperature and precipitation are relatively uniform throughout the AMA due to the low topographic relief, and differences in elevation account for most variations. The region has hot summers and mild winters. Annual precipitation is limited, averaging 7-8 inches across the AMA, although higher elevations receive more rainfall. There are two distinct precipitation periods during the year, both of which are erratic and variable from year to year. In the summer months, tropical air from the Gulf of Mexico is carried by upper-level winds from the southeast, frequently resulting in thunderstorms. Winter precipitation is generally less intense but is more widespread and of longer duration than summer precipitation. Spring runoff from melting winter snow along mountains north and northeast of the AMA is collected by storage reservoirs to provide most of the local surface water.

All streams and washes within the Phoenix AMA are ephemeral, either naturally or due to upstream diversion. The Gila and Salt rivers have sustained flow in their lower reaches due to return flows from nearby agricultural areas and discharges from wastewater treatment facilities. Water is transported within the AMA by canals and pipelines from points of diversion, or from withdrawal to principal users. Groundwater withdrawn from wells, surface water diverted from rivers, and reclaimed water are all transported by canals and pipelines. Despite late summer rains, summer is the period of greatest evaporation potential and peak water demand for irrigation of landscapes, crops, and golf courses. During years of drought, less snowpack results in less runoff for water-storage systems along rivers, reducing surface water availability and increasing groundwater pumping.

2.2 Sub-Basin Conditions

This study focuses on potential future shortages in renewable water supplies and increased groundwater reliance in the WSRV, Hassayampa, Rainbow Valley, and Lake Pleasant sub-basins of the Phoenix AMA. The WSRV sub-basin is one of the largest sub-basins in the Phoenix AMA, covering 1,330 square miles. The sub-basin has several water users who do not have access to adequate renewable supplies and rely heavily on groundwater, including municipal water providers and irrigation districts, some of which have grandfathered rights to pump groundwater.

Groundwater pumping for agriculture in the WSRV sub-basin began in the late 1800s from irrigation wells along the Salt and Gila rivers. Increases in well-pumping capacity, expanding agriculture, and recently, urban development, have led to increased groundwater pumping. As a result, groundwater levels have declined significantly, and two large cones of depression have formed due to pumping. Historically, groundwater flowed westward from the WSRV sub-basin into the southern part of the Hassayampa sub-basin, but now much of the groundwater flows towards the cones of depression.

Groundwater historically flowed from the Rainbow Valley sub-basin into the WSRV sub-basin prior to development, but this no longer occurs because of groundwater pumping for agricultural irrigation. Pumping in the northern part of the Rainbow Valley sub-basin has caused groundwater to instead flow towards a cone of depression in that sub-basin. Meanwhile, in the Buckeye area, shallow groundwater conditions have caused waterlogging problems with detrimental effects on crops. Despite extensive groundwater pumping, waterlogging problems persist because of the high volume of treated reclaimed water discharged into the Salt River and because of high volumes of water applied for agricultural irrigation to manage elevated salt levels.

The Hassayampa sub-basin covers 1,200 square miles in the far western portion of the Phoenix AMA. In the lower Hassayampa area, extensive groundwater pumping for agricultural development began in the early 1950s. As a result of pumping, water levels have declined significantly in the agricultural areas of the sub-basin. This has resulted in two large cones of depression, one of which captures groundwater entering the southeastern part of the lower Hassayampa area from the WSRV sub-basin.

The Rainbow Valley Sub-basin covers approximately 420 square miles. Wells are concentrated in the northern part of the sub-basin, with very few wells in other parts. Groundwater historically entered the sub-basin from the Pinal AMA and groundwater from the southern part of the sub-basin generally flowed toward the northwest. Water levels began declining in the early 1950s with the commencement of intensive agricultural development in the northern part of the sub-basin. Pumping in the north has created a cone of depression and available information suggests that the regional aquifer in the Rainbow Valley sub-basin is not currently connected to adjacent sub-basins. Groundwater no longer flows into the sub-basin from the Pinal AMA because of groundwater pumping in that AMA.

The Lake Pleasant sub-basin is relatively small, covering 240 square miles in the northern part of the Phoenix AMA. Groundwater flow has remained relatively unchanged since minimal development has occurred in the sub-basin and the quantity of groundwater pumping has been relatively low. Groundwater is pumped by a handful of domestic wells and a few private companies. Long-term water level records are limited for the sub-basin, but available information suggests that water levels have been somewhat affected by groundwater pumping. Near the town of New River, areas have experienced declines and some domestic wells have gone dry.

The varied conditions and interconnectedness across sub-basins adds to the complexity of managing water resources in the study area. There exists wide variation in renewable supplies and groundwater supplies across AMAs, as well as across sub-basins and localized areas within each AMA. Water demand also varies spatially across sub-basins and AMAs, with several areas experiencing land subsidence and cones of depression due to extensive groundwater pumping. Limitations in localized infrastructure constrains access to renewable water supplies for some, making it difficult to reduce groundwater reliance and depletion in certain areas. Meanwhile, other areas exhibit water-logged conditions and generate unique challenges. Growing water demand across the region is expected to put further strain on water resources. Adaptation efforts are thus crucial to address anticipated imbalances between future water supply and demand.

2.3 Groundwater Supplies

Groundwater is generally considered non-renewable, at least to the extent that pumping is not offset through recharge, natural or artificial. Most groundwater supplies in the area are of acceptable quality for many purposes. However, human activity and natural processes have resulted in the degradation of groundwater quality in some areas, to the extent that the groundwater is unusable for direct consumption. The extent and type of contamination varies by location and land-use activities. Agriculture and development has afflicted the upper aquifers of several sub-basins with dissolved solids, nitrates, and other contaminants. Waterlogging downstream of Phoenix has required drainage pumping of groundwater with high concentrations of TDS. Pumping centers that provide potable water can also influence the migration of poor-quality water in many areas. Addressing low-quality groundwater issues therefore provides one means of improving water supplies in the study area.

Several types of water users, both existing and potential new users, may legally withdraw groundwater without replenishing or replacing that volume of water back into the aquifer (see Section 2.6 for more detail). Non-replenished groundwater pumping is permitted through use of grandfathered groundwater rights (GFRs), groundwater withdrawal permits, and exempt groundwater wells. An exempt well is one equipped to pump less than 35 gallons per minute, which ADWR has no regulatory authority over. Groundwater use that is not subject to replenishment requirements can contribute to overdraft when pumping exceeds recharge. Non-replenished groundwater use is expected to increase under the current regulatory framework and projections of future shortages in renewable water supplies across the region.

Although many municipal providers are required to replenish or offset groundwater pumping, the municipal sector is expected to grow, representing potential for increased groundwater demand. Agricultural and industrial users are currently not required to replenish or offset groundwater pumping, primarily due to the use of grandfathered rights. Groundwater management is further complicated by the fact that groundwater recharge often occurs in a different location than groundwater is withdrawn from, creating spatial heterogeneity in groundwater levels even when overall recharge offsets pumping. These factors pose challenges for managing aquifer health in the study area and preventing further decline of groundwater levels in certain areas. Beyond land subsidence, aquifer health, and environmental effects, declining groundwater levels also increase the cost of pumping and overdraft can generate future costs by reducing groundwater quality and availability. Improving the availability and reliability of renewable water supplies is therefore crucial for minimizing numerous costs associated with increased groundwater reliance.

2.4 Renewable Water Supplies

Renewable water supplies in the study area primarily come from surface water diverted through either the CAP or the Salt River Project (SRP). The remainder comes from local surface water supplies and effluent use. CAP and SRP are wholesale providers that help provide reliable water deliveries for municipal, industrial, and agricultural use. In-state surface water from the Salt and Verde rivers is delivered to the study area through SRP canals, while Colorado River water is delivered to Central Arizona through CAP canals. Beyond market and consumptive uses, these surface water systems provide instream benefits for non-market and non-consumptive uses, such as recreation and water-related ecosystem services.

Colorado River water is delivered to the study area through the CAP canal system. The CAP canal system stretches 336 miles and lifts the water more than 2,900 feet from Lake Havasu to its terminus south of Tucson. SRP water is delivered through a system of seven dams and reservoirs with approximately 131 miles of canals. Historically, CAP and SRP water was used heavily for agricultural irrigation, but now much of this water goes towards municipal use. People also use SRP canals and laterals for various recreational opportunities, such as walking, running, and bicycling, and the reservoirs also provide swimming, boating, fishing, camping, picnicking, and wildlife viewing opportunities. Managing water supplies is therefore not only important for market uses, but also for instream uses such as recreation.

Effluent, or reclaimed water from irrigation runoff, municipal drainage, and industrial use, also provides a crucial supply of renewable water. Wastewater treatment plants remove contaminants from wastewater and convert it into an effluent that can be returned to the water cycle with minimum impact on the environment, or directly reused. The industrial sector currently uses most of the reclaimed water that is directly reused. A portion of reclaimed water is stored for annual recovery or storage credits at underground storage facilities (USFs), also known as recharge facilities. The remainder of effluent is discharged into water bodies and the environment. Unused effluent represents a potential source of renewable water supply, through direct potable and non-potable reuse, as well as groundwater recharge. In the past, direct treated effluent utilization has been limited due to a lack of infrastructure, but as water treatment techniques improve and treated effluent becomes more accessible, it is expected that effluent use will increase, especially as ADWR encourages increased use across all sectors.

Future shortages in renewable supplies are anticipated in the study area as demand increases from population growth and water resources are limited by both legal restrictions and physical limitations. When the quantity demanded for renewable water exceeds the quantity supplied, the market price rises to reflect increased scarcity. A higher price in turn reduces welfare for users in the marketplace. When surface water conditions change, this can also impact non-market welfare for instream benefits such as recreation. Furthermore, increased groundwater reliance to offset shortages in renewable supplies can lead to land subsidence, aquifer degradation, adverse environmental effects, and increased costs associated with pumping and utilizing groundwater. Adaptation strategies that increase water supplies, or reduce demand, can help reduce these anticipated shortages and adverse effects. Without adaptation efforts, several welfare effects are expected for both market and non-market water users in the study area.

2.5 Sources of Water Demand

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 groundwater. This will have important implications for all water users in the study area, as well as communities across the Phoenix AMA and broader region which shares renewable water supplies and an interdependence between groundwater aquifers.

2.5.1 Municipal Use

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. Demand is composed of large and small municipal providers, with some providing treated water for drinking and others delivering untreated water for residential irrigation. Municipal demand has been increasing for decades, but 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 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 (see Section 2.6). However, not all groundwater pumping is subject to replenishment requirements, and pumping that is exempt from regulation is expected to increase over time. Municipal providers treat raw renewable water supplies at a water treatment facility and 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 underground storage/recharge and later recovery via permitted recovery wells. That said, 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. Regarding municipal demand, newer homes tend to use much less water than older homes. That said, 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. Declines in agricultural demand have helped keep overall water demand relatively stable in recent years. Unfortunately, although agricultural demand is expected to continue falling, future projections suggest that growth in municipal and industrial (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 the growth of M&I demand, as well as the availability of renewable supplies under changing climate conditions.

2.5.2 Industrial Use

The 1980 Groundwater Code defines industrial use as a non-irrigation use of water, not supplied by a city, town or private-water company, including animal industry use such as dairies and feedlots. 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 includes large turf-related facilities (greater than 10 acres), electric-power generation, dairies, feedlots, mines, and sand and gravel operations.

Industrial use is largely dependent on population growth and the economy. As such, water use in the industrial sector has been growing in the study area for decades. Groundwater demand in the industrial sector has fluctuated over time, but generally increased over the past few decades. Fortunately, industrial use of treated effluent also increased drastically over this period, helping to meet the growing industrial demand. The largest use of treated effluent in the industrial sector is in the power subsector. 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. 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. That said, 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 grandfathered rights are used to meet future water needs. Growing demand could also contribute to shortages in renewable supplies.

2.5.3 Agricultural Use

The agricultural sector is heavily dependent on groundwater and comprised of farms with two acres or more that were actively irrigated with groundwater from 1975 to 1980. Agricultural lands that used groundwater to irrigate crops during this time 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 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. Many irrigation districts utilize "in-lieu groundwater" by becoming permitted as Groundwater Savings Facilities (GSFs) and using renewable supplies (CAP water, effluent, and local surface water) in place of groundwater pumping. This is sometimes referred to as indirect recharge. Use of in-lieu groundwater is limited by IGFRs amounts, and the availability of renewable water is expected to decline for future agricultural use since GSFs often utilize excess supplies from M&I users.

Agricultural use represented the largest demand for water in the Phoenix AMA until 1999, when the municipal sector matched the agricultural sector. Since then, the municipal sector has been the dominant water-use sector. 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 decline is expected to be more than offset by 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 to use renewable supplies is higher than the cost to pump and use 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.

2.5.4 Tribal Use

Water demand for American Indian Tribes is composed of municipal, industrial, and agricultural demand on tribal land. The majority of 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 the state of Arizona and 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.[4] 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 than the urbanized areas within the study area.

2.5.5 Instream Use

The Salt, Verde, and Agua Fria rivers, and lakes and reservoirs along the rivers, are a key source for recreation and outdoor activities in the study area. Lakes and reservoirs provide swimming, boating, fishing, camping, picnicking, and wildlife viewing opportunities. Given that streams and washes in the study area are ephemeral, individuals frequently utilize water canals and laterals for various recreational opportunities. This includes walking, running, bicycling, and fishing. Managing surface water supplies is therefore not only important for providing reliable water for market uses, but also for instream uses such as recreation. Additional water related ecosystem services are also important to consider, which often depend on surface water conditions.

Ecosystem services are defined as benefits that humans get from the natural environment and properly functioning ecosystems, either directly or indirectly. This includes recreation, as well as water quality, water storage, fish and wildlife habitat, nutrient cycling, climate regulation, disaster mitigation, and many other benefits stemming from the natural environment that are typically "free of charge." Changes in surface water conditions and instream water availability can impact several forms of non-market benefits. Surface water for downstream users varies with the amount of water flowing into the watershed and reservoirs. This is largely dependent on upstream snowpack and driven by weather and climate conditions. Growing demand for renewable supplies can also influence surface water availability and non-market benefits.

2.6 Legal and Regulatory Setting

Water management is carried out by several entities in the study area, operating under a complex legal and regulatory framework. A detailed discussion of the legal setting is beyond the scope of this report, but this section covers some important features that are relevant for the *Economic and Trade-Off Analysis*. It is assumed that Arizona's existing legal and regulatory conditions remain in place throughout the

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

study period. 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.

ADWR was established to administer the provisions of the Groundwater Code, exercise jurisdiction over surface water, and represent Arizona on Colorado River issues. Meanwhile, the Arizona Department of Environmental Quality (ADEQ) regulates water quality. ADWR and ADEQ jointly participate in activities related to protecting groundwater quality. Several water management tools exist that limit use of groundwater and encourage use of renewable supplies. 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.

Under Arizona's AWS rules, many municipal providers must offset groundwater pumping with use of renewable supplies. The Central Arizona Groundwater Replenishment District (CAGRD), operated by CAP, helps property owners and water providers without access to sufficient renewable water supplies to demonstrate the required 100-year assured water supply. The CAGRD replenishes, recharges, or otherwise replaces groundwater that is pumped by its members. Any city, town, water company, subdivision, or homeowner's association located in Pima, Pinal, or Maricopa counties may join the CAGRD. That said, CAGRDs current portfolio of water supplies is limited and already near full utilization, meaning additional supplies are needed to support new membership. Furthermore, the price of renewable supplies through CAGRD is much higher than the price of directly using renewable supplies, which is reserved for those with priority water rights.

Agricultural and industrial users are not subject to the same 100-year assured water supply and groundwater replenishment obligations as municipal providers. However, agriculture is 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 make efforts to recycle water. To account for weather variations and other factors that may result in the use of more water in some years than others, ADWR determines compliance either through the operation of a flexibility account or through a three-year averaging method, depending on the type of use.

In addition to AWS rules, most municipal providers are regulated under the Total Gallons Per Capita per Day (GPCD) Program. The GPCD requirements are analogous to maximum annual water allotments, limiting the amount of water that may be used during a given year. The remaining municipal providers are regulated under the Non-Per Capita Conservation Program (NPCCP) and are required to comply with specific conservation measures instead of GPCD requirements. All municipal providers are required to meet an efficient lost and unaccounted-for water standard in their service areas. 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 from a treatment plant or stored underground and recovered is typically not counted when determining compliance with annual water allotments.

Artificial recharge is a means of storing available renewable water supplies for future use. The Recharge Program was established to allow those with excess renewable water supplies to store that water for recovery at a later time. Water can be directly stored at USFs or sent to irrigation districts permitted as a GSF to use in-lieu of groundwater (indirect recharge). In many cases, the Recharge Program requires a certain percentage of the recharged volume to be made non-recoverable in order 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 (ASR). Both short-term and long-term storage generally entails a fee, reflecting the fixed cost (capital) and variable cost (OM&R) associated with artificial groundwater recharge. Use of stored water then entails a standard water delivery fee.

The AWBA was established in 1996 to help mitigate impacts of 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 has been to improve the reliability of municipal CAP supplies during periods of extended drought on the Colorado River. AWBA's goal of increasing reliability ("firming") of municipal supplies is achieved by banking excess CAP water. However, the junior priority of Arizona's Colorado River water leaves the CAP supply susceptible. For example, conditions in neighboring states and future adjustments to Colorado River entitlements could affect the long-term availability of CAP water.

Effective water management requires effective enforcement. ADWR is given wide ranging enforcement authority in rules and statutes to ensure that all water users are contributing to the overall goal of the Groundwater Code. Rules and statutes allow the imposition of monetary penalties for violating either water use limitations or conservation requirements. That said, ADWR's philosophy is that the ability to correct management deficiencies and save groundwater is more important than collecting monetary penalties. Most of ADWR's regulatory efforts to date have therefore involved voluntary consent orders where the water user in violation agrees to adopt conservation measures, guarantee future compliance, or otherwise mitigate the impact of the violation in exchange for a waiver or reduction of the civil penalties.

3.0 Pre-Adaptation Supply and Demand

As part of the collaborative effort for the Study, CAP conducted supply and demand modeling under various scenarios of climate change and future growth. To do so, the Central Arizona Project Service-Area Model (CAP:SAM) was employed. CAP:SAM was used to project future water demands, along with the water supplies available to satisfy those demands, for each major water user in CAP's three-county service area (Maricopa, Pima, and Pinal counties). CAP:SAM produces projections for 80 public and private water utilities accounting for more than 99 percent of the demand in the municipal sector, 23 Agricultural Irrigation Districts and other Grandfathered Irrigation Rights, 12 Tribes and Tribal Districts, and over 20 other user categories including the CAGRD, Arizona Water Banking Authority (AWBA), and industrial users such as mines and power plants. Only a subset of these users are within the study area, but due to important regional interactions among water supply and demand, outputs for the study area are based on CAP:SAM runs that include the full three-county model.

The study area includes 13 water providers[5] and 6 irrigation districts[6] 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 *Economic and Trade-Off Analysis* uses projections for water providers to model M&I use as a single sector,[7] 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 outside the area, which together represent the central Arizona region. This is important since adaptation efforts in the study area can affect the broader region which relies on the same market for renewable water supplies and operates under the same legal and regulatory framework for water use.

Supply and demand modeling was conducted in CAP:SAM under 6 scenarios representing a wide range of potential future conditions, absent any adaptation efforts. These scenarios are differentiated based on the rate of population growth, the spatial distribution of growth, future water use efficiency, and several climate-related factors. A detailed discussion can be found in the CAP:SAM report for the WSRV Basin Study and the overall basin study report, while here only a brief overview is provided for CAP:SAM and the supply and demand scenarios. These scenarios provide information on the potential magnitude of future water shortages in both the study area and central Arizona region and serve as a pre-adaption baseline to measure welfare effects and compare adaptation strategies in terms of reducing water shortages.

3.1 CAP:SAM Model

CAP:SAM was developed by staff at CAP to help evaluate and plan for future water conditions. CAP:SAM projects water supply and demand for all major water users in CAP's service area and is intended to generate "what-if" scenarios. Since the geographic scope of CAP:SAM extends beyond the study area, the model captures the regional interdependency of both supply and demand, which then has sub-regional effects. The model simulates a wide range of future conditions, including variable rates and patterns of growth, shortage impacts, effluent reuse, aquifer recharge and recovery, and complex supply portfolio management decisions. The model accounts for numerous sources of water supply, and the major elements of Arizona's elaborate legal and regulatory framework that affect

[5] 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.
[6] Irrigation districts include; Adaman; Buckeye Water Conservation and Drainage District (WCDD); Maricopa Water District (WD); Roosevelt Irrigation District (ID); St. Johns Irrigation District (ID); and Salt River Project.
[7] Some industrial use is modeled in CAP:SAM at the AMA level. In particular, use that is not served by a municipal provider and instead comes from groundwater use through IGFRs and withdrawal permits. None of these users fall within the study area, but are included under the outside category.

the availability and accounting of those supplies. CAP:SAM relies on data that comes from CAP, the Arizona Department of Water Resources (ADWR), the Maricopa Association of Governments (MAG), and others, including information directly from study participants.

As a systems model, CAP:SAM generates different supply and demand conditions and models how water users might respond to changing conditions. CAP:SAM is therefore best understood as a regional planning tool. Many of the future responses are influenced by the set of laws, rules, rights, and practices that comprise water management in the region. Like any model, CAP:SAM simplifies phenomena that have many layers of additional complexity. For example, while CAP:SAM simultaneously simulates supply and demand for more than 100 entities, it does not model the distribution of those supplies and demands within an individual water provider or irrigation district. Exceptions include distinguishing between SRP on and off project demands, and the location of urbanizing agricultural land. In addition to complexity, future supplies and demands contain elements of irreducible uncertainty. Questions about the future hydrology and management of the Colorado River, the tastes and preferences of homeowners, and the pace and direction of technological change are but a few. CAP:SAM addresses these uncertainties by allowing the user to make assumptions about key factors, which in combination constitute a CAP:SAM scenario. Ultimately, CAP:SAM seeks to strike a balance between unmanageable complexity and unreasonable simplification.

The CAP:SAM model tracks the total legal and physical supply availability for several water supply types in each projection year. Supply categories include Effluent, SRP Water, CAP Water, Local Surface Water, and Groundwater, many of which are further divided into subcategories. The supply of LTSCs and Groundwater Allowances are also tracked, with debits and credits occurring through time. To model the CAP supply from the Colorado River, CAP:SAM allows the user to input an annual diversion supply for Arizona, demands from on-River users, total system losses, and the net storage to CAP's storage reservoir, Lake Pleasant. CAP:SAM can also utilize externally generated Colorado River supply scenarios from the Colorado River Simulation System (CRSS). For supplies that have multiple users, like CAP water, this model step calculates the aggregate supply available, prior to allocation by priority and individual user.

The "request" step of the model sets how much of each supply in an entity's portfolio will be available to satisfy demand, if necessary. In many cases, the "request" is set at the full volume of the supply that is legally available to that entity, but there are individual circumstances in which entitlement volumes are individually adjusted either by percentage, or by setting a limit to represent specific preferences or operational limitations. For instance, there are a few water providers that have entitlements to CAP water that they are not putting to use for legal or operational reasons. In those specific cases, the "request" for that supply is reduced. For requests for CAP supplies, in addition to entitlement by priority type, requests are further differentiated between water destined for a water treatment plant versus annual storage and recovery. CAP:SAM also contains individualized preferences for earning LTSCs after a provider's annual demand has been satisfied. The request portion of the model also includes deliveries to irrigation districts as in-lieu groundwater (indirect recharge), or to direct recharge projects. CAGRD membership is also modeled, assuming that supplies are limited by currently known CAGRD resources and that supplies are entirely allocated to the West Valley area. Finally, the request step simulates transfers, leases, exchanges, reallocations, and priority conversions. Only existing or currently proposed transactions are included.

In the final model step, information from each of the other steps is brought together and reconciled. For each projection year, CAP:SAM takes the demands for each entity and steps through each supply type in a defined sequence, incrementally satisfying the demand of each entity based on their request and their volume of unsatisfied demand. That sequence reflects observed historic behavior, which itself is largely based on utilizing lower cost supplies first. In order to account for groundwater storage arrangements, there is some iterative looping within CAP:SAM. As the model cycles through each of the supplies, credits and debits to CAP LTSCs and Groundwater Allowances are calculated.

In the process of fulfilling annual demands, CAP:SAM makes projections of effluent use. This effluent use includes non-potable reclaimed distribution (i.e., "purple pipe") and any recovered effluent that is indirectly satisfying potable demand (i.e., water that is physically groundwater, but legally effluent). CAP:SAM's effluent accounting does not reflect the total volume of effluent produced or potentially available to a water provider. Due to this limitation, separate calculations of effluent production were made (see *Groundwater Modeling Report*). In some cases, those calculations resulted in effluent volumes that were greater than what providers have identified plans for putting to use. This means that there is a volume of effluent that is available for more complete use. This "unaccounted for" volume is used to determine the annual volume available for adaptation strategies that utilize effluent. Several forms of effluent use are considered, including direct potable and non-potable reuse as well as groundwater recharge, considered at both a local and regional scale.

CAP:SAM does not attempt to simulate the SRP system in detail. Notably, the SRP supply available to each city is not differentiated between water originating from reservoirs versus from wells that is legally accounted for as surface water for AWS purposes. However, the physical distinction is obviously critical when evaluating impacts to the regional aquifer system, so in this Study, the proportion of SRP water that came from wells was separately estimated and then attributed to individual cells in the groundwater flow model. CAP:SAM accounts for other surface water in a manner similar to SRP water, using ADWR Annual Reporting data, along with specific data provided by individual users.

3.2 CAP:SAM Scenarios

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 3.1. 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 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.

Table 3.1 – Pre-Adaptation Supply and Demand Scenarios

Scenario	Name	Growth	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

Scenarios A, D, and F are considered the key scenarios. Scenario A (Baseline) is intended to represent "business as usual" while Scenario D (Dry and Rapid Outward Growth) and Scenario F (Slow and Compact Growth) represent the two extremes regarding growth and climate influences. These scenarios are incorporated in the economic and trade-off analysis by serving as the pre-adaptation baselines for comparing adaptation strategies in terms of addressing water shortages. Benefits are quantified for the criterion *Water Availability and Reliability* by analyzing water shortages with and without an adaptation strategy in place. A range of benefits are estimated by focusing on Scenarios A, D, and F.

Scenario A is intended to represent "business as usual" in which the future follows closely to the current rate and spatial distribution of growth and follows both observed and expected trends for water supply and demand. GPHUD rates continue to decline, with a maximum change of -15% and 200 GPHUD floor. Irrigation efficiencies gradually increase and shortages on the CAP system are simulated using the "Historic" climate series. No reductions in local surface water are simulated for Scenarios A and F, only Scenario D.

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 (HUs) 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 GPHUD, increased crop consumptive use, and deep CAP and local surface water shortages. This scenario is the most aggressive in terms of HU growth and climate impacts.

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" ethic, the scenario includes a more aggressive rate of decline in GPHUD, along with a larger maximum change and lower floor. It also includes higher irrigation efficiencies and greater preservation of existing agricultural land. That said, like Scenario A, this scenario uses the "Historic" climate series.

In addition to reduced availability of renewable supplies in the "Hot and Dry Climate" scenario, there are noticeable differences in the municipal and agricultural demands. For agriculture, the higher rates of evapotranspiration largely offset the effects of increased efficiency. Likewise, municipal demands are somewhat higher under this scenario because of a lower rate of GPHUD decline due to higher evapotranspiration affecting outdoor water use. The primary user-defined parameters used in the key CAP:SAM scenarios are shown in Table 3.2.

Table 3.2 – Primary CAP:SAM Modeling Parameters

Parameter	Scenario A	Scenario D	Scenario F
CAP Shortage	Frequent	Deep & Increasing	Frequent
Local Surface Water Reduction	None	Occasional	None
Growth Rate	Medium	High	Low
Growth Pattern	Baseline	Suburban Growth	Redevelopment
Existing GPHUD, Rate of Change	-0.5%	-0.3%	-0.7%
Existing GPHUD, Max Rate of Change	-15%	-15%	-20%
New GPHUD, Rate of Change	-0.1%	0%	-0.3%
New GPHUD, Max Rate of Change	-5%	-5%	-10%
Existing and New GPHUD, Min	200 GPHUD	220 GPHUD	150 GPHUD

Agriculture Efficiency, Rate of Change	0.1%	0.1%	0.2%
Agriculture Efficiency, Max	80%	80%	90%
Agriculture Develop on Crops	50%	70%	40%

All Scenarios assume 2045 CAP Buildup, Medium HU recovery, No crop type replacement, no reinvestment in underutilized agriculture, and max 20% AWBA firming for M&I.

3.3 Water Demand

Water demand is a complex phenomenon that is the result of literally millions of individual daily decisions. CAP:SAM takes a fairly simplistic aggregated approach to projecting water demand. As mentioned, demand is modeled for municipal and industrial use together and agricultural demand is captured by irrigation districts. To help differentiate the effects of observed long-term declines in water use from future growth-related trends, the model separately considers existing and new municipal demand. Existing municipal demand represents baseline water use, as reported to ADWR in the most recent Annual Report. New demand is simulated on the basis of HUs that are projected to be built in each water providers' service area. Demand includes the use from the housing unit itself as well as a fraction of the ancillary demands (e.g. new parks, commercial land uses, etc.).

CAP:SAM spatially distributes HUs among water providers based on a geographic reference projection of housing units by provider, by time. The geographic projections are based on growth modeling that incorporates a large number of factors, including demographic data from the U.S. Census, construction data, planned developments, land uses, employment patterns, and transportation infrastructure. To accommodate a variety of growth rates, while maintaining the integrity of the spatial growth pattern, CAP:SAM adjusts the timing of the reference projection to match the HUs generated by the model using the parameters specified by the user in the annual HU projection. In addition to dynamically adjusting the rate at which growth occurs, the model can incorporate alternative growth patterns. To implement this capability, CAP contracted with a consulting firm (Applied Economics) that developed a socioeconomic model for Maricopa, Pinal, and Pima counties.

Eight different growth scenarios were developed by varying key assumptions that affect the relative distribution of housing units. Some of the key factors included relative proximity to transportation infrastructure and existing development, how quickly planned but unbuilt development takes place, relative willingness to commute to employment centers, and land use capacity factors. For this Study, three of those spatial scenarios were used: "Baseline," which mirrors the officially adopted growth pattern by the Maricopa Association of Governments; "Outward Growth," which doubled the employment travel time factor and places a greater proportion of housing units in the western portion of the study Area; and "Compact" which halved the travel time and increased the housing capacity factor in the urban core by up to 20%, which places a greater proportion of the growth in the Phoenix area and portions of the metro area that are outside the study Area.

Because the footprint of irrigated agriculture cannot expand (other than on tribal lands), population growth can result in significant urbanization of agricultural land with a subsequent reduction in irrigation demand. As new housing units are projected, reduction in agriculture acreage is calculated based on the average density of surrounding urban uses. CAP:SAM also simulates agricultural demand based on a number of factors that affect agricultural use. These include crop mix by irrigation district, changes in efficiency, substitution of higher water use crops, and changes in consumptive use due to climate change.

The study area does not include tribal reservations, however, the use of tribal supplies (particularly CAP water) elsewhere in the CAP service area can affect the availability in the study area. To capture this, CAP:SAM runs include assumptions about tribal water use, including on-reservation use (predominantly irrigation), off-reservation storage, and off-reservation leasing. Leased tribal supplies are included in individual water provider portfolios.

Although this study focuses on the WSRV area, use and welfare in the surrounding region is also considered. This is important since all users in the region share the same sources of renewable supplies and operate under the same legal and regulatory framework. This means that a shortage in one location can affect users across the region. Of particular importance for the *Economic and Trade-Off Analysis*, this also means that adaptation strategies in the study area can impact users outside of the study area. Effects outside of the study area are captured by treating those users in CAP:SAM, but outside of the study area, as a collective user ("outside").

Table 3.3 provides the baseline population amounts used for each water provider, along with the number of HUs and the average population per housing unit (PPHU). These amounts are for 2010 and were generated via a GIS analysis using 2010 Census block data and water service areas. These amounts were used in CAP:SAM to model future municipal demand.

Table 3.3 – Population and Housing Units (2010)

Provider	Population	Housing Units	PPHU
Arizona WC White Tank	5,673	2,015	2.82
Avondale	75,841	26,856	2.82
Buckeye	36,966	12,708	2.91
El Mirage	29,824	10,690	2.79
EPCOR Agua Fria	5,673	2,015	2.82
EPCOR Sun City	51,926	36,208	1.43
EPCOR Sun City West	24,102	17,928	1.34
Glendale	225,613	88,843	2.54
Goodyear	40,590	15,113	2.69
Peoria	133,879	56,004	2.39
Phoenix	1,468,244	599,107	2.45
Surprise	53,241	20,440	2.60
Tolleson	6,547	2,170	3.02
Outside, All	2,698,631	1,212,709	2.23
Total	**4,940,878**	**2,141,570**	**2.31**

As shown, water providers in the study area supply water to nearly half of the population in the central Arizona region. Table 3.4 provides the CAP:SAM cropped acreage for irrigation districts in 2019, which highlights agricultural demand in the region. As shown, most agricultural use occurs outside of the study area.

Table 3.4 – Cropped Acreage (2019)

Irrigation District	Cropped Acres
Adaman	1,492
Buckeye WCDD	17,524
Maricopa WD	7,758
Roosevelt ID	24,104
St. Johns ID	1,253
Salt River Project	17,384
Outside, All	231,202
Total	**300,718**

Figure 3.1 shows the average annual water use amount for the region from 2015-2019, separated between M&I and agriculture use as well as between WSRV and Non-WSRV (outside) users. On average, the central Arizona region currently uses about 2.8 million AF (MAF) of water per year. As shown, the study area constitutes around one third of total water use in the region, with more water going towards M&I than agriculture. Agriculture in the outside area uses over one third of total water in the region, with the remainder going towards outside M&I. In general, it is expected that M&I use will grow while agricultural use declines across the study period, depending on the CAP:SAM scenario.

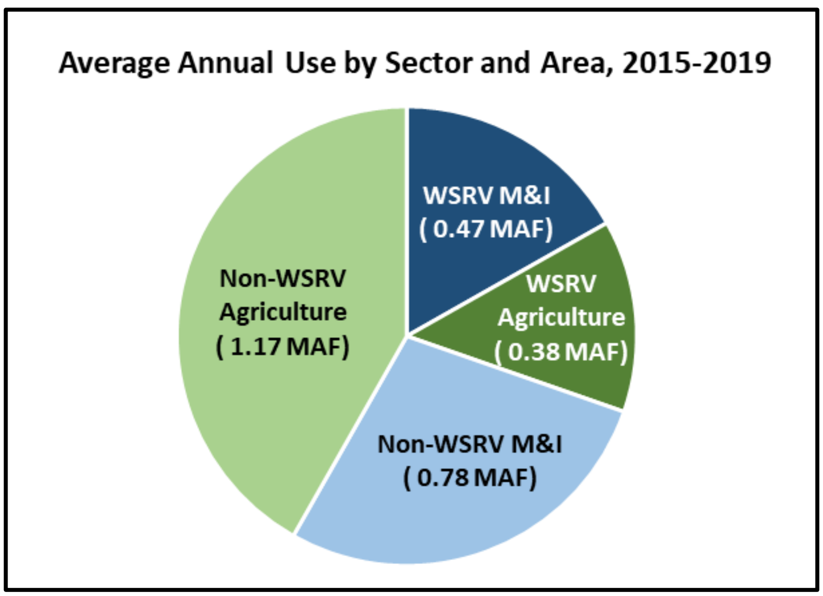

Figure 3.1 – Average Annual Use by Sector and Area, 2015-2019

3.4 Water Supply

Due to differences in the price of using different sources of raw water, welfare effects associated with future water shortages will largely depend on the particular mix of water sources used by each water provider and irrigation district. For example, even though many M&I providers utilize renewable supplies, the mix of raw water sources is unique to each user, and their future mix will likewise be unique. Those relying on more expensive water sources will generally experience larger welfare effects associated with future water shortages. Even users who don't anticipate a shortage in their local area will be affected by shortages in the broader region whenever they compete for the same scarce sources of renewable water supplies. This occurs through price changes and subsequent welfare effects which stem from water shortages in the regional market.

The mix of raw water sources used to meet M&I demand in the region differs from that used for agriculture, also differing between WSRV and Non-WSRV (outside) users. Figure 3.2 provides a breakdown of water use from 2015-2019 for the region's different sources of raw water. Water supplies are divided between groundwater and renewable supplies. Renewable supplies are further separated between CAP water, SRP water, local surface water, effluent, and use of CAGRD.[8] Renewable supplies mostly come from CAP and SRP water, but agricultural users in the study area also utilize a large amount of local surface water, and a growing population means that effluent use will likely grow in the future.[9] As shown, agricultural users depend heavily on groundwater, while M&I users primarily utilize renewable supplies. In general, the outside area depends more on groundwater than the study area, for both M&I and agricultural needs.

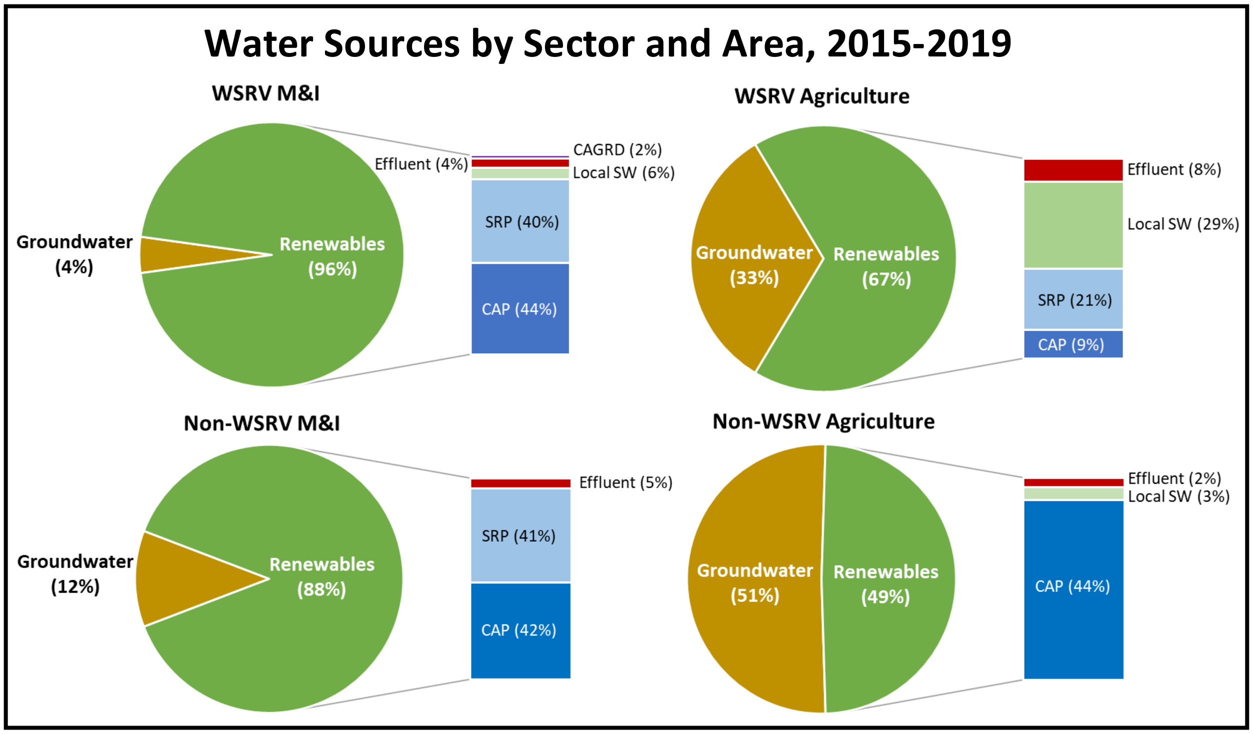

Figure 3.2 – Water Source by Sector and Area, 2015-2019

3.5 Future Water Shortages

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 the State's Assured Water Supply (AWS) rules and require offsetting replenishment. CAP:SAM treats this portion

[8] Use of CAGRD to offset groundwater pumping is shown under CAGRD rather than groundwater.

[9] In-lieu use for agriculture mostly comes from CAP water and effluent, but the exact split is unknown, so the team decided to assume that 90 percent is CAP water and the remainder is effluent. This is reflected in Figure 3.2.

of unmet demand as groundwater pumping that is subject to AWS rules, recognizing that it is yet to be determined how that pumping might get offset with renewable supplies in the future. For the *Economic and Trade-Off Analysis*, this unmet portion of demand is treated as the shortage amount for renewable supplies. This is appropriate, since future unmet demand must either use renewable supplies directly, or groundwater that is offset with renewable supplies under Arizona's existing legal framework.

Figure 3.3 shows the projected annual shortage volume for renewable supplies from 2020-2060 under CAP:SAM Scenarios A, D, and F.[10] 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 effects 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. In 2060, the shortage volume for the region is expected to range from 114,071 AF (Scenario F) to 527,409 AF (Scenario D). The study area represents almost half of this shortage volume, ranging from 47,151 AF (Scenario F) to 263,687 (Scenario D). For the region, water shortages have already begun. As a result, renewable water prices have been on the rise.

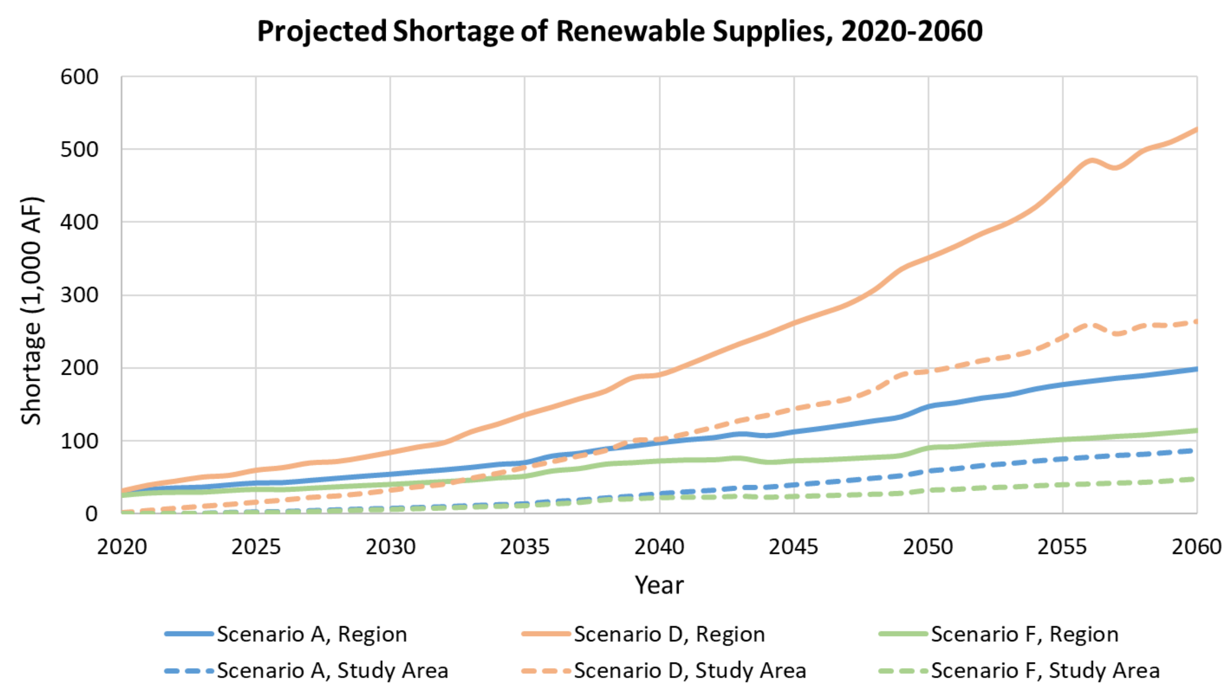

Figure 3.3 – Projected Shortage of Renewable Supplies, 2020-2060

4.0 Quantifying Welfare Effects from 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,

[10]Annual CAGRD use is subtracted from the annual shortage volume in each CAP:SAM scenario based on current CAGRD membership, current known renewable supplies, and projected changes in supplies under each scenario.

which subsequently leads to changes in welfare for water users. The demand for water represents the maximum willingness to pay (WTP) for water, which also reflects the marginal benefit derived from each unit of water. When users pay a price below their WTP, they gain welfare known as consumer surplus (CS). This measure of welfare is 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 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.

Welfare for wholesale water providers is not quantified in this analysis since the typical provider supplies water according to their average cost of provision. In other words, most wholesale providers operate on a break-even basis, meaning their total revenue equals their total cost and they do not generate economic profit. In this setting, changes in price do not affect provider welfare and instead reflect a change in the cost of meeting demand. If water prices are above or below average cost, adaptation strategies could affect welfare by altering economic profits or losses. These effects are outside the scope of this assessment, and it is assumed that wholesale providers continue to operate on a break-even basis so that market welfare effects only stem from changes in consumer welfare. That said, wholesale providers are encompassed in several components of the qualitative criteria, meaning impacts on provider welfare are ultimately incorporated in trade-off analysis, but not quantified like impacts on consumer welfare.

4.1 Measuring Welfare Effects

For many goods and services, the supply curve slopes upward, reflecting the fact that producers are able and willing to provide more of the good or service at higher prices. However, the supply of water in the study area is limited, due to physical availability as well as legal restrictions. Aggregate water supply for the region is therefore assumed to be fixed, or perfectly inelastic, which is reflected by a vertical supply curve. A perfectly inelastic supply is a reasonable assumption where the quantity of a good or service is relatively fixed, as with water availability in central Arizona. Under this framework, changes in CS can be measured using information on; (1) the size of shortage; (2) the price elasticity of demand; and (3) the price of raw water. Changes in CS can then be used to quantify adaptation strategy benefits from reducing water shortages.

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 put upward pressure on the price of renewable water bought and sold in the region. The left-hand graph in Figure 4.1 illustrates a shortage in the market for renewable supplies, which can result from a decline in supply, increase in demand, or a combination of both. Regardless of the cause, a shortage will put upward pressure on price and decrease CS, as depicted in the left-hand graph.

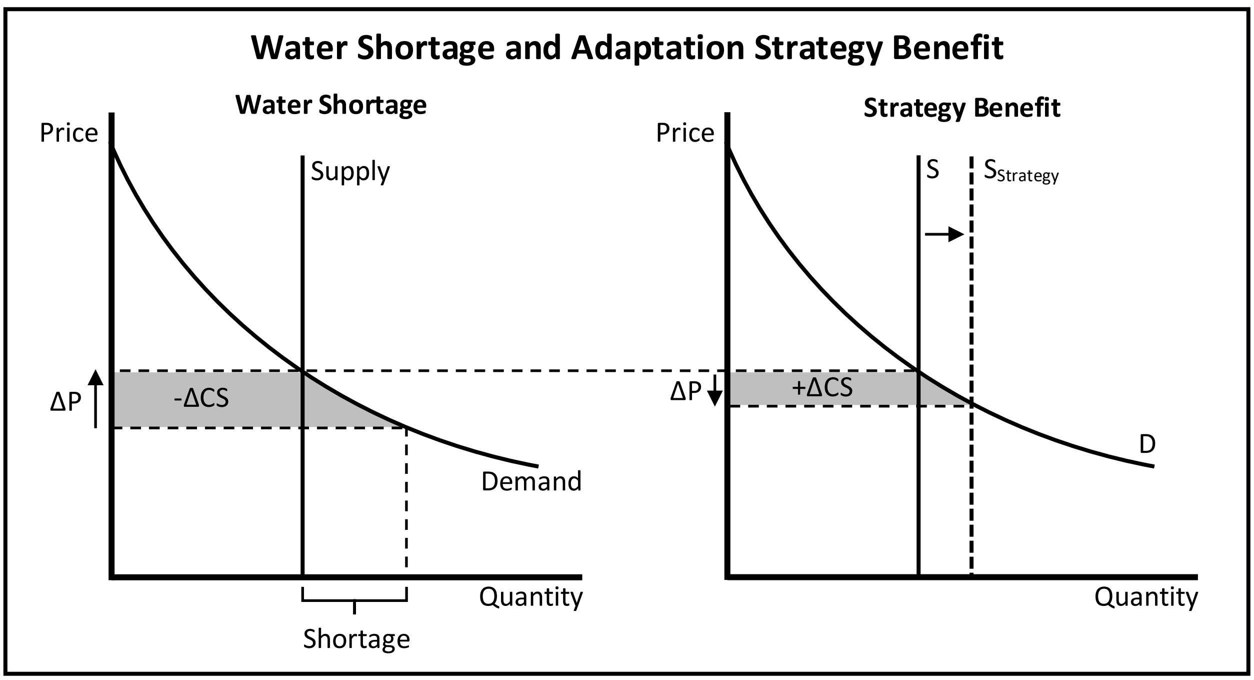

Figure 4.1 – Water Shortage and Adaptation Strategy Benefit

The left-hand graph reflects the pre-adaptation outcome where a shortage in marketed renewable water puts upward pressure on price and reduces CS. However, 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 from shortages and price effects in the market for renewable supplies, instead depending on the cost of withdrawal. Market shortages and prices nonetheless influence the amount of direct withdrawal, and changes in the availability of local supplies can conversely influence market demand in the region. It is therefore crucial to consider impacts for both wholesale market use and direct use in order to get a holistic picture of welfare effects for M&I and agricultural water users. Furthermore, underground storage is also important to capture, as storage is affected by shortages and influences future supply and use decisions.

Fortunately, CAP:SAM models these complex interactions for the region, providing the necessary quantity information to measure pre-adaptation welfare effects from water shortages while encompassing market use, direct use, and underground storage. 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. Including each of these components allows adaptation strategies to be modeled as reducing water shortages and improving welfare through market use, direct use, or a combination of both. Annual storage and future reserves can also be affected by strategies. For example, if a strategy provides more water than is necessary to close the shortage gap in a given year, additional water is modeled as storage that helps to mitigate future shortages. Considering welfare impacts on market use, direct use, and underground storage together, total pre-adaptation welfare effects are estimated annually for individual water providers and irrigation districts according to Equation 4.1, which is broken down in detail in Equations 4.2-4.4.

$$\Delta Total\ CS_t = \Delta Market\ CS_t + \Delta Direct\ CS_t + \Delta Storage\ CS_t \tag{4.1}$$

$$\Delta Market\ CS_t = -\sum_{j=1}^{J}\sum_{i=1}^{I}\left(\Delta P_{M_{it}}\right)(M_{ijt}) + 0.5\left(\Delta P_{M_{it}}\right)(Shortage_{M_{ijt}}) \tag{4.2}$$

$$\Delta Direct\ CS_t = -\sum_{j=1}^{J}\sum_{i=1}^{I}(\Delta P_{D_{it}})(D_{ijt}) + 0.5(\Delta P_{D_{it}})(\Delta D_{ijt}) \tag{4.3}$$

$$\Delta Storage\ CS_t = -\sum_{j=1}^{J}(\Delta P_{S_{it}})(S_{jt}) + 0.5(\Delta P_{S_{it}})(\Delta S_{jt}) \tag{4.4}$$

for

raw water sources $i = 1, \dots, I$
raw water users $j = 1, \dots, J$
year $t = 0, \dots, T$

where

M = amount of marketed renewable supply (AF)
$Shortage_M$ = shortage amount of marketed renewable supply (AF)
D = amount of direct water supply (AF)
S = amount of underground storage (AF)
P_M = price of marketed renewable supply (\$/AF)
P_D = price of direct water supply (\$/AF)
P_S = price of underground storage (\$/AF)

As shown, welfare effects are driven by prices and quantities of use. This framework captures the unique raw water portfolio of each water provider and irrigation district and measures changes across several types of source water with differing prices of use. Price changes for wholesale marketed renewable supplies are based on shortages at the aggregate level between regional supply and demand, which encompasses CAP:SAM's entire three-county area. This means that users not experiencing a shortage in their area can still be affected by price changes which stem from shortages in the broader region. This is measured by the first term in Equation 4.2 and captures the interdependence between users which compete in the regional market for renewable water. The annual percent change in price associated with a shortage is calculated for each marketed renewable source (i) according to Equation 4.5, where the price elasticity of demand (ε_D) and shortage amount are measured at a regional level.

$$\Delta P_{M\,it} = \left(\frac{Shortage_{M_{it}}}{M_{it} + Shortage_{M_{it}}}\right)\left(\frac{1}{\varepsilon_D}\right) \tag{4.5}$$

This equation states that price changes for market supplies are a function of market shortages, measured as a proportion of total market use, and the shape of regional water demand, which is defined by the price elasticity of demand. A long-run price elasticity of demand is used and assumed to remain fixed across the study period, chosen to represent demand for all water sources together. However, demand and price effects are separated between M&I and agricultural use, as discussed in the next section. The price of directly using groundwater and local surface water is independent from market shortages, so future prices are calculated separately from shortages and based on the expected cost of withdrawal. The price of groundwater is modeled as a function of energy prices and average depth to water for each user. The price of directly using groundwater is therefore unique to each user and varies across the region. The price of local surface water is assumed to be the same for each user. For underground water storage, price is again independent from market shortages, so future prices are calculated according to CAP future advisory rates, which trend closely with past CAP storage prices. Future prices are discussed in detail in the next section.

While market price is a function of regional supply and demand and shortages at the aggregate level, the mix of raw water is unique to each user. This means that welfare can vary for individual users based on regional water shortages and price changes, as well as changes in their chosen mix of water sources. As such, welfare effects are calculated at the individual user level and then aggregated for the region. The second term in Equation 4.2 captures welfare effects for those users experiencing a shortage in renewable supplies, which depends on their unique portfolio of water, their extent of shortage, and aggregate water prices. Note that Equation 4.2 represents a geometric approximation of the change in CS depicted by the shaded area in the left-hand graph of Figure 4.1. The first term in Equation 4.2 captures the shaded rectangle area shown, while the second term approximates the shaded triangle area assuming a linear hypotenuse (i.e. a linear demand between the new and old price). An approximation is required since the functional form of demand is unknown, meaning integration cannot be used to calculate CS areas. For incremental changes, this simplification has minimal influence on estimates of changes in CS. A similar geometric approximation is used for calculating changes in CS for direct use and storage as shown in equations 4.3 and 4.4, respectively.

As emphasized, future prices of direct use and storage are determined separately from water shortages and market prices. That said, these components are an important factor in welfare effects since water shortages influence the amount of direct use and storage, even if not affecting the price of use. Under the CAP:SAM projections, groundwater pumping is generally expected to increase for M&I users and decrease for agriculture, while underground storage is expected to decrease overall. This can have opposing effects on spending and welfare that are important to capture. For example, there may be a decline in welfare from increased groundwater pumping, but an increase in welfare from less spending on underground storage. However, less storage in one year means less is available to recover in future years, which can then affect future welfare. These interactions are encompassed in the estimation of welfare effects and benefits from adaptation strategies. As discussed later on, when a 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 keep in mind that changes in use 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. Equation 4.1 therefore represents 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. In short, the conditions modeled in CAP:SAM are reflected together in the calculation of welfare effects. Also recall that 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. As a whole, Equation 4.1 therefore measures pre-adaptation welfare changes for all M&I and agricultural water users in the region, encompassing numerous demand-side and supply-side effects and the use of marketed renewable supplies as well as local surface water supplies, groundwater supplies, and underground water storage.

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 and affect the amount of groundwater pumping and underground water storage, subsequently affecting welfare. The impact in the market for renewable supplies is shown in the right-hand graph of Figure 4.1. Increases in supply and decreases in demand (e.g. from conservation) are treated equivalently,[11] with both helping to reduce the gap between supply and demand and diminish the upward pressure on prices. This is done by treating all quantity changes as changes in the quantity supplied.[12] The resulting effect on CS for renewable water is depicted, reflecting the benefit of an adaptation strategy in terms of reducing water market shortages and price increases. Also considering welfare from direct use as well as storage, the overall change in welfare, or the benefit of a strategy, is measured by comparing annual welfare without the strategy in place to welfare when the strategy is in place. This is shown in Equation 4.6.

$$Strategy\ Benefit_t = \Delta Total\ CS_{With\ Strategy_t} - \Delta Total\ CS_{Without\ Strategy_t} \tag{4.6}$$

[11] In practice, there can be important differences between increases in supply and decreases in demand, but they are treated equivalently here since supply is assumed to be perfectly inelastic. In this setting, parallel shifts in demand do not affect CS, as the area below demand and above price is unchanged from demand shifts (the exception is if the shift is associated with changes in the price elasticity of demand, meaning the shift is not parallel). The benefit in this case stems from a lower cost of providing water and additional resources available for other purposes. That said, a decrease in demand also means that additional supplies are made available for other uses. For simplicity, as well as consistency in quantifying benefits across strategies, a decrease in the quantity demanded is modeled as an increase in the quantity supplied. This means that a strategy's benefit from reducing water shortages is the same regardless of whether from a supply-side or demand-side quantity effect.

[12] Note that only 1 of 10 strategies considered in this assessment targets demand reductions, while the remaining target increased supply.

The CAP:SAM model provides annual projections from 2020-2060, so to calculate benefits across the entire study period, annual benefits from Equation 4.6 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 according to Equation 4.7, which employs a classic exponential discounting method where the discount rate (*r*) reflects the 2020 Federal *Water Resources Planning* rate of 2.75%. Note that the study period is defined here as starting in 2020 (t=0).

$$PV = \sum_{t=0}^{40} \frac{Strategy\ Benefit_t}{(1+r)^t} \tag{4.7}$$

This framework captures welfare effects for shortages in renewable water bought and sold within the marketplace, as well as from changes in groundwater pumping, local surface water use, and underground water storage. That said, this only encompasses M&I use and agricultural use, or what is defined here as market use. There are however 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 this assessment, market use encompasses M&I and agricultural use, and 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 in order to compare welfare with and without an adaptation strategy in place. Equations 4.6 and 4.7 are therefore also used to calculate non-market benefits for recreation. A key distinction is that there is no price associated with non-market use and estimates for CS instead come from the economics literature (see Section 4.3). 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.

It is important to realize that there are potentially additional benefits from adaptation strategies, beyond water quantity impacts and reducing shortages. For example, increasing water supply and/or reducing water demand can have important effects on the regional economy in terms of output, income, and employment. It can also have significant impacts on aquifer health in terms of groundwater levels and land subsidence, which can have crucial long-term implications. These additional benefits are important to consider and are captured by assessing additional benefit criteria. Due to data limitations and the feasibility of trying to measure certain benefits quantitatively, a qualitative scoring method is used to capture effects that are not quantified. For this analysis, only the benefits of reducing water shortages (improving water availability and reliability) and regional economic impacts (output, income, and employment) are measured and assessed in quantitative terms.

Additional benefit considerations are measured and assessed qualitatively by having the project team score adaptation strategies, on a relative scale from low to high, for each of the chosen criteria. Several cost considerations are also assessed qualitatively, and the trade-off analysis provides a means for simultaneously comparing all benefit and cost considerations together. Further discussion can be found later in the report, while here the focus is on quantifying welfare changes from water shortages to then be used to measure *Water Availability and Reliability* benefits from adaptation strategies. To do so, the first step is to calculate pre-adaptation changes in welfare for both market and non-market use.

4.2 Market Use

For market use, attention is placed on raw water prices and regional supply and demand for M&I and agricultural water use. CAP and SRP are wholesale providers of water diverted from nearby river systems, providing most of the renewable water supplies used by water providers and irrigation districts in the central Arizona region. The price of CAP and SRP raw water reflects the wholesale cost of provision, including both fixed (capital) and variable (delivery) costs.[13] Although CAP and SRP are both wholesale providers, their price for raw water differs, reflecting differences in the cost of provision. SRP water is cheaper than CAP water since construction debt has already been paid off, SRP water is provided mostly by gravity while CAP water is pumped uphill over a long distance, and SRP subsidizes water rates using revenues from their electricity production.[14] Meanwhile, direct use of local surface water is one of the cheapest sources of raw water, while effluent use is often expensive due to the treatment necessary for wastewater to be reused.

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, effluent, and CAGRD use,[15] while groundwater is generally considered nonrenewable. Raw water is bought and sold 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, since direct use and storage are influenced by market shortages and may be affected by adaptation strategies.

The prices shown in Table 4.1 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 CPI-adjusted to 2020

[13] If focusing on the short-run, it would be appropriate to focus on variable cost. However, since this study has a long-run perspective, both fixed cost and variable cost components are considered when determining wholesale prices. This assessment therefore evaluates long-run regional supply and demand and wholesale water prices.

[14] All costs associated with wholesale provision are included so that each source of raw water is treated as being of similar quality and location. Subsidies are also included so that water rates reflect the actual prices that water users face.

[15] Using CAGRD is a way to meet AWS renewable requirements while continuing to use groundwater, and since CAGRD uses renewable supplies to replenish groundwater (usually CAP water), CAGRD use effectively represents renewable use for accounting purposes, since on the whole groundwater use is offset and renewable water is used.

using the index for the Phoenix area.[16] Prices are separated for M&I and agricultural use and used with separate estimates of price elasticity of demand. Only municipal users are subject to AWS rules and utilize CAGRD to comply with requirements. The following sections provide a detailed discussion on each wholesale price, highlighting the fixed cost and variable cost components that makeup wholesale market rates.

Table 4.1 – 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	$727.00	N/A[a]

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

To capture changes in direct use, the price of utilizing 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. The cost of underground storage is based on CAP's 2020 published rate and assumed to grow according to CAP's future advisory rates. Only municipal users are subject to AWS rules and utilize storage to comply with requirements. Table 4.2 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. The following sections provide a detailed discussion on each price, highlighting the assumptions used to predict future prices independently from market shortages.

Table 4.2 – 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 utilize storage to comply with requirements.

4.2.1 Price of CAP Water

The wholesale price of CAP water for M&I use encompasses a *Pumping Energy Rate* as well as *Fixed Operating, Maintenance, and Replacement* (OM&R) costs. These components cover the cost associated with water delivery as well as water delivery capital and debt, and for this assessment they are considered variable components since the amount paid varies with use. Meanwhile, M&I users with a long-term subcontract are also charged a *Capital Charge* to cover debt repayment on construction. This fee is paid on a subcontractor's full allocation, regardless of the amount of water delivered, and as such this is considered a fixed component in this analysis. Meanwhile, agricultural users pay a

[16] The Consumer Price Index (CPI) for the Phoenix area is published by the Bureau of Labor Statistics (BLS) and can be found at: https://www.bls.gov/cpi/regional-resources.htm.

subsidized price below the cost of providing CAP water. The price for CAP's Agricultural Settlement Pool (ASP) water only covers the *Pumping Energy Rate*, excluding *Fixed OM&R* and the *Capital Charge*. The price of CAP water used as in-lieu groundwater also generally reflects a similar rate. Agricultural use is often subsidized with the intent of encouraging the use of renewable supplies and keeping prices competitive with groundwater use, since agricultural users are not subject to the same renewable use requirements as municipal users.

The price difference for M&I use of CAP water versus agricultural use from the ASP is the result of several prior adjustments to CAP's financial structure and a complex history with setting rates for agricultural use. The specifics of this history are not particularly relevant here, but a few key details are worth mentioning.[17] The anticipated transition from an agricultural to an industrial economy was a key factor in how CAP water was originally allocated by the Secretary of the Interior in 1983. M&I and Tribal water users were allocated defined volumes based on projected future needs and were given priority over non-Tribal agricultural users. M&I and Tribal users were to pay CAP fixed OM&R costs based on water scheduled for delivery, while the agricultural users were to pay fixed OM&R for all water available to them each year, whether they took delivery or not. This provision for agricultural users was known as "take-or-pay."

M&I and Tribal demands for CAP water turned out to be significantly below original projections in the early 1990s, and as a result, the agricultural sector was expected to take much more water than they needed and pay the majority of CAP's fixed OM&R costs. This posed serious problems for agricultural users and threatened the basic CAP financial structure since roughly one-third of agricultural supply was not under subcontract, meaning nobody was obligated to pay that portion of CAP's fixed OM&R. Furthermore, those districts that had signed subcontracts were unable to afford the CAP water they were expected to take and pay for. This led to numerous efforts to identify solutions as it became apparent that initiation of repayment and enforcement of the take-or-pay provisions for agricultural users would pose serious problems.

The Central Arizona Water Conservation District (CAWCD) is a special purpose tax district known as a multi-county conservation district. It was formed for the purpose of contracting for the delivery of CAP water, repayment of CAP costs, and operation and maintenance of the CAP aqueduct. In 1993 it was recommended that CAWCD increase incentives for CAP use and adopt a policy that prices water to agricultural users at or below current groundwater costs.[18] As a result, CAP created the ASP which would be available to agricultural users at reduced prices. This led agricultural users to waive their rights to CAP water under long-term subcontracts in return for which CAWCD agreed to provide ASP water to the relinquishing subcontractors at energy-only rates through 2030, covering fixed OM&R costs from its reserves. The capital charge for long-term subcontracts was also eliminated under the agreement (previously set at $2 per AF). The ASP was sized at 400,000 AF initially, declining to 300,000 AF in 2017 and then to 225,000 AF in 2024 before it is set to expire in 2030. Agricultural users are therefore expected to experience declines in the ASP in 2024 and again in 2030. The ASP is modeled in CAP:SAM and changes are expected to lead to increased groundwater reliance for agricultural users. These anticipated changes are factored into the welfare estimates.

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[17] Details on the history of CAP's Agricultural Settlement Pool (ASP) and agricultural water rates come from CAP and can be found at: https://www.cap-az.com/departments/finance/agriculture.

[18] CAWCD also adopted an Agricultural Incentive Program in 2009, allowing ASP customers to further lower water rates by meeting specified goals. However, these incentives no longer existed as of 2018 due to growing scarcity.

In 2019, CAP published two rate schedules for 2020 with advisory rates for 2021-2024.[19] One schedule reflects a shortage of water starting in 2021 and the other reflects a shortage starting in 2020. There is a significant jump in M&I prices when the shortage starts, with a 21.6% increase year-over-year if the shortage starts in 2020 and a 20% increase if the shortage starts in 2021. This highlights the upward pressure that shortages have on price, as well as the effect of future expectations on present price decisions. That said, after the initial jump, the advisory rates are nearly identical in both rate schedules, growing a few percent year-over-year. Given that the CAP:SAM model shows a shortage occurring in 2020 for the region, the CAP rates for a shortage starting in 2020 are used and shown in Table 4.1. This means that the price jump for 2020 is included in pre-adaptation welfare calculations, which is important to ensure that projected prices are in line with CAP's advisory rates for 2021-2024.[20]

The price for M&I shown in Table 4.1 reflects the full wholesale cost of CAP provision, including both fixed and variable cost components. Table 4.3 provides a breakdown of these costs for 2020. The price shown for agriculture is for the ASP and encompasses only the cost of energy used for pumping, meaning the price is subsidized. Keep in mind that the ASP water is set to decline over time and expire in 2030. For in-lieu use of CAP water, the price of ASP water is also used. In reality, water for in-lieu use is often purchased on the spot market, but the negotiated prices are generally near the rate for ASP water, making it a reasonable proxy for the price of in-lieu use.

Table 4.3 - Breakdown of CAP Water Price ($2020)

Rate Component[a]	M&I	Agriculture
Fixed		
Capital Charge	$56.00 per AF	N/A
Variable		
Pumping Energy Rate	$58.00 per AF	$58.00 per AF
Fixed OM&R	$128.00 per AF	N/A
Total	**$242.00 per AF**	**$58.00 per AF[b]**

[a] The *Capital Charge* is paid on a subcontractor's full allocation, regardless of water delivered, while the other charges depend on use. This difference is used to distinguish between fixed and variable cost components.

[b] The price of CAP water for agricultural use is subsidized. Water from CAP's Agricultural Settlement Pool only encompasses the *Pumping Energy Rate*. The same price is assumed for in-lieu use.

4.2.2 Price of SRP Water

SRP water is reserved for members and commonly used for irrigation, in both residential and agricultural settings. The average wholesale price for SRP water is determined based on rates charged to directly use raw SRP water for residential use and agricultural use. These rates are heavily subsidized by SRP's electricity revenues, which has been the case historically, and is expected to be the case into the future. Although this subsidy is expected to be reduced over time, it is highly uncertain if, when, and how that might take place in the future, so for this analysis it is simply assumed that SRP rates will continue to be subsidized across the study period. SRP water rates are set as a function of one's land acreage, again encompassing fixed and variable cost components that reflect the wholesale cost

[19] CAP water rates for 2020 can be found at: https://www.cap-az.com/departments/finance/water-rates.

[20] An average price across recent years was also tested but resulted in projected prices that were well below CAP's advisory rates for 2020-2024. CAP's 2020 rate is therefore used for the start of the study period to model price effects from 2020-2060, and the 2020 price for other raw water sources is also used in order to remain consistent.

of provision.[21] The price for SRP water includes an *Annual Basic Charge* that helps pay for water storage and for the construction, operation, and maintenance of SRP facilities. This fee varies by land size and is charged regardless of whether water is delivered. SRP also charges a *Delivery Fee* which pays the administrative cost of servicing an account and varies slightly based on land size.

The *Annual Basic Charge* and *Delivery Fee* are the same for residential and agricultural use on a per acre basis and meant to cover the annual 2 AF per acre base allocation that all SRP users are entitled. For this analysis, these fees are considered the fixed cost components. That said, the effective price per AF paid by residential users differs from agricultural users due to differences in acreage and water use. Furthermore, M&I users generally do not pay the flat fee ($76.07) portion of the *Delivery Fee*, only the $0.38 per acre portion. Average lot size and cropped acreage are used to determine the average price of SRP water for M&I use and for agricultural use. Beyond the 2 AF per acre base allocation that users are entitled, additional fees are charged on use depending on whether use is classified as *Stored and Developed Water*, *Normal Flow Water*, *Pump Right Water*, or *Supplemental Supply*. For this assessment, these fees are considered the variable cost components. *Stored and Developed Water* is river water stored in the SRP reservoir system, and in 2020 costs the same as *Normal Flow Water*, which is river water that would have been available if there were no upstream reservoirs. If projected river flows are less than what is needed to satisfy total annual water allocation, *Pump Right Water* and *Supplemental Supply* is used to satisfy the deficit, generally coming from groundwater, which means that M&I users generally do not use these categories of water due to state restrictions on groundwater use.

The features of SRP rates make it challenging to determine a single price per AF for M&I and agricultural users in the region. That said, the average SRP user is examined by combing average SRP use in CAP:SAM with average land size to determine an average price per AF for SRP water. For M&I use, the average 2020 SRP use per SRP housing unit in CAP:SAM is used to get an average price. This amounted to 0.451 AF per SRP housing unit. For agricultural use, the average 2020 water use per cropped acre for farmers utilizing SRP water in CAP:SAM is used to get an average price. This amounted to 5.518 AF per cropped acre for farmers that utilize SRP water. Information on lot size is then needed to separate the average base allocation from additional use, as well as account for price differences based on land acreage. The average price is not very sensitive to the assumed acreage, but in general, assuming a larger acreage reduces the average price per AF under SRP's rate structure. For agricultural use, it is assumed that use beyond the base allocation is evenly divided between the different classifications that entail additional fees. For this assessment, a lot size of 0.175 acres (7,623 sqft) is assumed for residential use[22] and a farm size of 7.5 cropped acres is assumed for crop irrigation.[23] This results in the average price for M&I use and for agricultural use broken down in Table 4.4 and listed in Table 4.1.

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21 SRP water rates for 2020 can be found at: https://www.srpnet.com/water/irrigation/fees.aspx.

22 According to the *Phoenix Business Journal* (2015), the median residential lot size in Phoenix is 7,453 sqft and 7,803 sqft in Glendale: https://www.bizjournals.com/phoenix/blog/business/2015/07/which-community-has-the-biggest.html.

23 The National Agricultural Statistics Service (NASS) publishes the Agricultural Census containing data on farm size and harvested cropland by county. Looking at Maricopa, Pima, and Pinal counties together, NASS (2017) reports that the average harvested cropland per farm is about 413 acres. However, average farm size is heavily skewed by large outliers. NASS (2017) further reports that 31 percent of farms are between 1 and 9 acres in size and 22 percent of farms are between 10 and 49 acres in size, but farm size is generally much larger than cropped acreage. Looking at those 53 percent of farms between 1 and 49 acres in size, the average harvested cropland was 7.5 acres. This is used to reflect the cropped acreage for a typical farm. NASS data can be found at: https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Census_by_State/Arizona/index.php.

Table 4.4 – Breakdown of SRP Water Price ($2020)

Rate Component[a]	M&I	Agriculture
Fixed		
Annual Basic Charge	$37.91 per acre per year	$37.91 per acre per year
Delivery Fee	$0.38 per acre	$76.07 per year + $0.38 per acre
Variable		
Stored and Developed Water	$15.45 per AF	$15.45 per AF
Normal Flow Water	$15.45 per AF	$15.45 per AF
Pump Right Water	N/A	$46.00 per AF
Supplemental Supply	N/A	$46.00 per AF
Total	**$18.32 per AF[b]**	**$28.37 per AF[c]**

[a] The fixed components cover a 2 AF per acre base allocation that each SRP user is entitled. M&I users generally do not have to pay the $76.07 portion of the *Delivery Fee*, only the $0.38 per acre portion. The variable components only apply to water beyond the 2 AF per acre base allocation and M&I users typically do not use *Pump Right Water* or *Supplemental Supply*, which comes from groundwater.

[b] This is based on an average lot size of 0.175 acres and the CAP:SAM average 2020 use of 0.451 AF per SRP HU.

[c] This is based on an average farm size of 7.5 cropped acres and the CAP:SAM average 2020 use of 5.518 AF per cropped acre for farmers that utilize SRP water. Water use beyond the base allocation is assumed to be evenly divided between the four classifications of variable components.

4.2.3 Price of Effluent

Arizona is one of the few states that makes extensive use of reclaimed water, or effluent. In their *2017 Arizona Water and Wastewater Rates Report*,[24] the Environmental Finance Center surveyed drinking water and wastewater rates for 421 utilities across Arizona. Of those, 51 utilities supplied treated effluent. A key part of the report was to analyze rates for treated effluent that was resold to customers. They found that for-profit utilities usually sold reclaimed water at uniform rates that were significantly lower than potable water, but more expensive than other sources of raw water. The median charge was $308.58 per AF ($2020).[25] Municipalities tended to sell reclaimed water at higher prices than for-profit utilities, and sometimes had more complex rate structures that involved base charges and block-price structures. The median charge for effluent offered by municipalities was $631.34 per AF. For this analysis, it is assumed that M&I users get effluent from municipalities and that agricultural users get effluent from for-profit utilities, resulting in the prices shown in Table 4.1.

It is worth noting that these rates are consistent with the cost of treating wastewater according to a 2011 survey done by Industrial WaterWorld.[26] While not a representative sample, the magazine emailed subscribers across the country and received 175 responses across a wide range of industries, from utilities, manufacturing, government, chemicals, and food and beverage industries. For the cost of treating wastewater, they found a range of $478.79-$1,331.26 per AF with an average of $801.87 per AF. This suggests that utilities in Arizona may treat and sell effluent at lower rates than others across the country, which is consistent with the fact that Arizona has been developing effluent technologies and increasingly utilizing effluent. As effluent use continues to grow, it is expected that

[24] The full report is available at: https://old.azwifa.gov/waterrates/.
[25] The price of effluent is CPI-adjusted from 2017 to 2020 (first half) using the CPI for the Phoenix area.
[26] Details on the survey conducted by Industrial Water World can be found at: https://www.watertechonline.com/home/article/14170825/survey-examines-wastewater-treatment-costs.

treatment costs and subsequent resale prices will fall. However, water shortages and a growing demand for effluent could put upward pressure on resale prices.

4.2.4 Price of CAGRD

The use of CAGRD replenishment to offset groundwater pumping is an important means for M&I providers to comply with Arizona's Groundwater Code and meet renewable water requirements. CAP publishes rates for CAGRD use and the price is higher than direct use of renewable supplies, even effluent use. Nonetheless, CAGRD is an important tool for those M&I providers without adequate access to renewable supplies. Since CAGRD users pay for pumping groundwater as well as CAGRD fees to allow for pumping, both of these costs are factored into the welfare calculations. The price of CAGRD use encompasses a *Water and Replenishment Component, Administrative Component*, *Infrastructure and Water Rights Component*, and *Replenishment Reserve Charge*. Prices slightly differ by AMA, primarily due to differences in the *Water & Replenishment Component*, so rates for the Phoenix AMA are used here.

The *Water and Replenishment Component* covers the projected annual costs of satisfying replenishment obligations, including the purchase of LTSCs and the purchase and replenishment of water and effluent. The *Administrative Component* covers CAGRD administrative costs associated with the acquisition of infrastructure and water rights. These two components cover variable costs, while the remaining two cover fixed costs. The *Infrastructure and Water Rights Component* covers the cost to develop additional water supplies and cost to construct additional infrastructure. The *Replenishment Reserve Charge* covers costs associated with establishing a replenishment reserve of LTSCs as required under the Groundwater Code. These costs are broken out for 2020 in Table 4.5, reflecting the CAGRD price for M&I listed in Table 4.1.

Table 4.5 – Breakdown of CAGRDa Price ($2020)

Rate Component	M&I	Agriculture[b]
Fixed		
Infrastructure & Water Rights Component	$353.00 per AF	N/A
Replenishment Reserve Charge	$95.00 per AF	N/A
Variable		
Water & Replenishment Component	$238.00 per AF	N/A
Administrative Component	$41.00 per AF	N/A
Total	**$727.00 per AF**	**N/A**

[a] These amounts are for CAGRD use within the Phoenix AMA.

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

4.2.5 Price of Groundwater

The cost to utilize groundwater, or price of use, depends on water levels and the cost of energy used for pumping. The greater elevation one has to pump water, the more costly it is to pump that water to the surface. Users may also have different sources of energy used for pumping. Differences in depth to water (DTW) and energy used for pumping imply that each user experiences a unique price associated with groundwater use. For this analysis, energy prices and average DTW are used to determine the average price of use for each water provider and irrigation district in the study area.[27] The price of groundwater (P_{GW}) can be computed on an AF basis for each user (j) in year (t) according to Equation 4.8.

$$P_{GW_{jt}} = \theta(P_{E_t})(DTW_{jt}) \quad (4.8)$$

where

θ = amount of energy (MMBtu) required to lift 1 AF of water 1 ft in elevation
P_E = price of energy ($/MMBtu)
DTW = depth to water (ft)

This specification implies that the price of groundwater use has a one-to-one relationship with energy prices and with DTW, meaning that a 1 percent change in either increases the price of groundwater use by 1 percent, and that a 1 percent change in both increases price by 2 percent. In this calculation, θ is a constant that captures the amount of energy required to lift a unit of water, which differs across energy sources. Rogers and Alam (2006) provide measures of θ for electricity, natural gas, diesel, and propane. Most users in Arizona use electricity as their primary source of energy for groundwater pumping. Groundwater prices are therefore calculated for each user assuming that energy comes from electricity, which is also the cheapest of the energy sources, followed by natural gas, propane, and then diesel. The price of electricity comes from the U.S. Energy Information Administration (EIA) which publishes energy prices annually for Arizona.[28] The price of energy and current average DTW for each user is used to determine an average price for groundwater at the start of the study period that is unique to each user. Table 4.6 shows the average DTW and price calculated for each water provider and irrigation district, which results in the range of groundwater prices listed in Table 4.2.

Differences in price per AF shown in Table 4.6 stem from differences in DTW across users. Average DTW was calculated in GIS for each water provider based on service-area boundaries and DTW from the groundwater modeling done for the WSRV Basin Study. Users that partnered for the study were also given the opportunity to provide input on the average DTW in their area to improve the accuracy of estimates. Service area boundaries were not available for Arizona WC White Tank, EPCOR providers, or the outside area, but in general these areas are expected to have some of the greatest DTW, so a water level of 350ft is assumed for each. Average DTW was not available for irrigation districts, but in general DTW is much lower than in M&I areas due to irrigation districts doubling as groundwater recharge sites. A DTW of 50ft is therefore assumed for irrigation districts, while for Buckeye WCDD a DTW of 25ft is assumed due to waterlogging in the area, and a DTW of 100ft is assumed for outside irrigators since DTW is generally greater outside of the West Valley.

[27] The cost of installing a well pump is assumed to be a sunk cost and negligible, meaning the price of groundwater can be thought of as both a short-run and long-run price.
[28] The most recent energy prices available are for 2018, so the price of electricity is CPI-adjusted to 2020 (first half) using the CPI for the Phoenix area. Energy prices for Arizona can be found at: https://www.eia.gov/state/?sid=AZ.

Table 4.6 – Average DTW and Price of Groundwater by User ($2020)

Sector	User	DTW (ft)	Price per AF
M&I	*Arizona WC White Tank*	350.0	$61.55
	Avondale	79.1	$13.91
	Buckeye	101.6	$17.86
	El Mirage	223.8	$39.35
	EPCOR Agua Fria	350.0	$61.55
	EPCOR Sun City	350.0	$61.55
	EPCOR Sun City West	350.0	$61.55
	Glendale	250.0	$43.97
	Goodyear	272.0	$47.84
	Peoria	318.0	$55.92
	Phoenix	155.1	$27.28
	Surprise	265.4	$46.67
	Tolleson	92.5	$16.26
	Outside, All	350.0	$61.55
Agriculture	*Adaman*	50.0	$8.79
	Buckeye WCDD	25.0	$4.40
	Maricopa WD	50.0	$8.79
	Roosevelt ID	50.0	$8.79
	St. Johns ID	50.0	$8.79
	Salt River Project	50.0	$8.79
	Outside, All	100.0	$17.59

On average, M&I users pay more for groundwater than agricultural users due to a greater DTW, but some users do not currently use groundwater. Several users are only expected to use groundwater in the future in the event of shortages. For example, Phoenix does not currently rely on groundwater, but by 2060 they are expected to use some groundwater, with the volume varying across CAP:SAM scenarios. The price of groundwater use is assumed to be unaffected by future shortages in renewable supplies, so future prices are modeled independently and based on expected energy rates and changes in DTW. As discussed with the price for CAP water, the energy rate component is a key component driving CAP's wholesale price, and the only factor used to price ASP water. Recall that CAP includes advisory rates for 2021-2024 in their 2020 rate schedule. Looking at CAP's Pumping Energy Rate from 2020-2024, energy rates are expected to increase on average 1.29 percent annually, which is consistent with historical energy prices in Arizona published by the EIA. Looking at EIA's weighted average for total end-use energy price across all energy sources, the real price of energy in Arizona grew on average 1.52 percent from 1970-2018. That said, future energy prices may not coincide with past trends, which makes CAP's advisory rates a more appropriate proxy for future energy prices. An annual growth rate of 1.29 percent is therefore assumed for energy prices from 2020-2060 to model growth in the price of using groundwater.[29]

To capture varied future conditions represented in CAP:SAM Scenarios A, D, and F, the 1.29 percent annual growth is assumed to correspond with Scenario A and is adjusted (+0.5 and -0.5) for the other

[29] Assuming a constant annual growth rate for energy prices is a simplification since prices can vary significantly from year to year. That said, future variability is highly uncertain, and a constant rate is reasonable to use when measuring average changes across a long period of time, as done in this assessment.

scenarios. For Scenario D, rapid population growth and growing demand for all goods and services is assumed to drive energy prices up, while the opposite is assumed for Scenario F. Accordingly, an annual growth rate of 1.89 percent is assumed for Scenario D and a growth rate of 0.79 is assumed for Scenario F. This causes the price of using groundwater to vary across CAP:SAM scenarios based on growth, similar to market prices which reflect differing degrees of growth and water shortages. DTW is also assumed to change across the study period. However, it is unknown how much DTW might change for each user under each CAP:SAM scenario, so simplifying assumptions are used to capture likely effects on DTW from increased groundwater reliance. Across the study period, it is assumed that DTW increases 15 percent (0.375 percent per year) under Scenario D, 10 percent (0.25 percent per year) under Scenario A, and 5 percent (0.125 percent per year) under Scenario F. With expected changes in energy prices, this implies that the price of groundwater is modeled as growing on average 2.265 percent per year under Scenario D, 1.54 percent per year under Scenario A, and 0.915 percent under Scenario F. Adaptation strategies are assumed to not affect DTW across the study period, even if groundwater use might be affected. This is done to avoid adding uncertainty to the analysis but means that estimates may understate benefits for strategies that reduce groundwater use.

In this framework, adaptation strategies that reduce water shortages will help to reduce market prices for renewable water, but strategies will not influence the cost of directly using groundwater, which instead depends on energy rates and DTW. That said, strategies do affect welfare through changes in groundwater availability and the mix of raw water sources used by water providers and irrigation districts. The same applies for local surface water use and underground water storage, where the price of use is modeled independently from water shortages and adaptation strategies, but the amount of use is directly influenced by shortages and water volumes provided by strategies.

4.2.6 Price of Local Surface Water

Similar to groundwater, the cost of directly using local surface water is independent from water shortages in renewable supplies that are bought and sold in the regional market. The cost of directly utilizing local surface water, or the price of use, instead depends on the cost of diversion and storage. To capture the price of utilizing local surface water at the start of the study period, SRP's 2020 charge for *Normal Flow Water* is used. This reflects the price that SRP charges for river water that would have been available if there were no upstream reservoirs. In 2020, this is also the same amount that SRP charges for *Stored and Developed Water*, which is river water stored in the SRP reservoir system. It is assumed that this amount is a close proxy for the price of utilizing local surface water, which only a few users have rights for. It is assumed that M&I users pay the same amount to use local surface water as irrigation districts. For 2020, this amounts to $15.45 per AF as listed in Table 4.1 and shown in Table 4.4 under the variable rate component for SRP prices. Local surface water is therefore the cheapest source of raw water in the region.

As mentioned, the price of local surface water is independent from water market prices, instead depending on the cost of diversion and storage. For simplicity, the price of utilizing local surface water is assumed to remain constant across the study period. As before with groundwater, adaptation strategies that reduce water shortages have no influence on the cost of using local surface water in the future. However, strategies will affect welfare when there are changes in local surface water availability and the mix of raw water sources used by M&I providers and irrigation districts. Increasing local surface water availability reduces the use of more expensive renewable sources, which in turn are less expensive from a lower demand and reduced shortage in the marketplace.

4.2.7 Price of Underground Water Storage

Underground water storage can be done through CAP, SRP, or working directly with storage facilities. Underground storage is an important tool for M&I providers, used for both ASR purposes as well as LTSC's and long-term reliability. CAP publishes rates for underground water storage using their facilities, which varies slightly for the Phoenix versus Tucson AMA. For this study, the fee that CAP charges for underground water storage in the Phoenix AMA is assumed to reflect the typical price for underground storage in the region. The price reflects an *OM&R Charge* and *Capital Charge*, covering the variable cost and fixed cost components of storage. That said, the *Capital Charge* is not paid by municipal providers in the CAP service area, and it is intended to cover debt repayment and is therefore unique to the CAP system. Given this, the project team decided that CAP's *OM&R Charge* alone serves as the best proxy for the cost of underground storage in the region (CAP and non-CAP). Table 4.7 shows these costs in 2020, used to determine the storage fee shown in Table 4.1.

Table 4.7 – Breakdown of Underground Water Storage Price ($2020)

Rate Component	M&I	Agriculture[b]
Fixed		
Capital Charge	$15.00	N/A
Variable		
OM&R Charge	$13.00	N/A
Total	**$13.00***	**N/A**

[a] These amounts are for storage within the Phoenix AMA. Amounts slightly differ for the Tucson AMA.

[b] Only municipal users are subject to AWS rules and utilize storage to comply with requirements.

* Given that CAP's *Capital Charge* is intended to cover debt repayment unique to the CAP system, and municipal providers within the CAP service area are not required to pay this fee, only CAP's *OM&R Charge* is used for the total price for storage to serve as a better proxy for all the storage in the region (CAP and non-CAP).

It is important to account for storage when estimating welfare effects to capture changes in storage across the study period, which varies with water shortages, both in terms of the amount of storage and the use of stored water. Furthermore, when an adaptation strategy provides more water than is needed to close the shortage gap in a given year, it is assumed that excess water is stored and available to reduce future shortages (discussed in more detail in Section 5).The CAP:SAM projections include information on ASR amounts as well as credits and use of LTSCs for each M&I provider. The storage fee is applied to storage for both ASR and LTSC purposes in order to capture changes in expenditures on underground storage. The price of storage only reflects the cost of storing water underground. Once stored water is withdrawn for use, standard use rates apply, and the cost of pumping groundwater is also factored into the calculation (at the point of withdrawal, not storage/recharge). As with direct water use, the price of storage is largely independent from prices in the wholesale market for renewable supplies. To model future prices across the study period, the recent trend in CAP rates is used. From 2015-2019, the price of storage (*Capital Charge* and *OM&R Charge*) increased on average 1.76 percent per year, and CAP advisory rates imply an average increase of 1.75 percent annually from 2020-2024. The price of storage is therefore assumed to grow at 1.75 percent annually across the study period, with no difference across CAP:SAM scenarios. Historically, the *Capital Charge* has been relatively constant, while the *OM&R Charge* has varied over time.

4.2.8 Raw Water Expenditures for Market Use

To get an idea of the size of the regional water market, expenditures on raw water are shown below. Expenditures are shown for each user in the study area, along with the average per AF of water, which varies across users according to their unique raw water portfolio. Table 4.8 shows expenditures for M&I users, including average expenditure per housing unit, and Table 4.9 provides expenditures for agricultural users, including average expenditure per acre. These tables highlight variation across users in the study area and show spending on raw water at the start of the study period. The amounts shown represent expected expenditures for 2020 using CAP:SAM Scenario A water volumes, wholesale market prices from Table 4.1, and direct use prices from Table 4.2. Expenditures on water storage are not included, so that expenditures only reflect raw water use. M&I users in the region are expected to spend around $188 million on raw water in 2020, with around one-third of that occurring in the study area. Agricultural users are expected to spend around $44 million on raw water, also with about one-third of that occurring in the study area.

Table 4.8 – Expected 2020 Raw Water Expenditures for M&I Users

Provider	Total	Average Per AF	Average Per HU
Arizona WC White Tank	$0.78	$467.0	$290.4
Avondale	$3.12	$235.5	$113.0
Buckeye	$2.93	$300.8	$107.6
El Mirage	$2.24	$465.4	$202.4
EPCOR Agua Fria	$4.80	$226.3	$96.9
EPCOR Sun City	$1.86	$141.7	$51.9
EPCOR Sun City West	$1.00	$188.3	$55.6
Glendale	$10.67	$232.2	$114.5
Goodyear	$3.00	$263.0	$128.1
Peoria	$6.13	$182.6	$88.9
Phoenix	$33.81	$112.0	$53.3
Surprise	$3.18	$366.2	$129.9
Tolleson	$0.09	$20.8	$40.0
Outside, All	$114.09	$183.9	$78.4
Total	**$188.01**	**$171.1**	**$75.9**

Total expenditures are in millions ($2020) and reported amounts may not add to the total amount due to rounding. Expenditures on water storage are not included.

Table 4.9 – Expected 2020 Raw Water Expenditures for Agricultural Users

Irrigation District	Total	Average Per AF	Average Per Acre
Adaman	$0.05	$12.5	$36.8
Buckeye WCDD	$1.77	$13.7	$101.3
Maricopa WD	$1.44	$39.4	$188.2
Roosevelt ID	$8.80	$74.8	$367.5
St. Johns ID	$0.03	$8.9	$21.1
Salt River Project	$2.34	$31.8	$140.7
Outside, All	$29.82	$25.9	$129.7
Total	**$44.25**	**$29.2**	**$148.4**

Total expenditures are in millions ($2020) and reported amounts may not add to the total amount due to rounding.

4.2.9 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 (P) leads to a percent-change in the quantity demanded (Q_D). This is measured as a ratio, as shown in Equation 4.8. 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, which was previously shown in Equation 4.5. It is assumed that demand is isoelastic, meaning that price elasticity is constant across all parts of the demand curve.[30] 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.

$$\varepsilon_D = \frac{\%\Delta Q_D}{\%\Delta P} \tag{4.8}$$

The elasticity of demand is generally negative, reflecting that demand is downward-sloping due to an inverse relationship between price and the quantity demanded. This is known as the law of demand, which states that an increase in price will decrease quantity demanded, all else equal. Because elasticity is always negative, 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 more appropriate than a short-run elasticity. To remain consistent with CAP:SAM projections, water

[30] Price elasticity of demand can vary for several reasons. For example, 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 the CAP:SAM model does not permit for these differences to be captured, and modeling varied elasticities adds significant complexity with minimal value since this analysis is only intended to screen adaptation strategies. By assuming iso-elastic demand, this can be considered as focusing on a "typical water user" in the region.

demand is separated between M&I[31] and agricultural uses. This is important, as it captures the fact that M&I users and agricultural users may respond differently to changes in price. In many cases, agricultural users are less responsive than M&I users to price changes, but this can depend on several factors. The distinction between sectors is further necessary to capture benefits for adaptation strategies that don't only generate new water supplies, but also 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 economics literature has an extensive number of studies that measure the elasticity of demand for water. The overwhelming majority of this work has focused on residential water demand, with minimal attention on agricultural demand and very little research looking at commercial and industrial demand. Studies have also tended to focus on short-run estimates, with only a handful providing long-run estimates. For this analysis, the economics literature is reviewed to identify the most relevant estimates of long-run demand elasticities for M&I water use and agricultural water use in the study area. There have been several meta-analyses conducted that survey the economics literature, along with a handful of individual studies that examine residential and agricultural water demand in Arizona. These studies are reviewed to determine the most appropriate elasticities to use for M&I and agricultural uses. Few studies differentiate between wholesale demand and retail demand, so it is assumed that elasticities are applicable to wholesale water demand.[32]

There have been several meta-analyses that summarize and asses residential water demand elasticities from the literature. The earliest of these, Espey et al. (1997), reviewed 24 journal articles published between 1967 and 1993 encompassing 124 elasticity estimates. They found that 90% of the estimates were between 0 and 0.75, with an average short-run elasticity of 0.51 and a median of 0.38. Short-run elasticities were found to range from 0.03 to 2.23, while long-run elasticities were more elastic, ranging from 0.1 to 3.33 with a median of 0.64. A few years later, Dalhuisen et al. (2003) examined 64 studies and 314 estimates between 1963 and 2001. They found an average elasticity of 0.41 and a median elasticity of 0.35, with long-run estimates generally more elastic by 0.28. Worthington and Hoffman (2008) examined 37 studies from 1980 to 2006, many of which were outside of the United States. They found that price elasticity ranged from 0 to 0.5 in the short run, and 0.5 to 1 in the long run. The most recent meta-analysis of residential water demand, Sebri (2014), examined 100 studies encompassing 638 estimates from 2002-2012. They found an average price elasticity of 0.37 and a median elasticity of 0.29, with long-run elasticities that were more elastic by 0.2.

These meta-analyses highlight the extensive literature that has developed around estimating the price elasticity of residential water demand. These studies indicate that price elasticity is generally inelastic (between 0 and 1) and that long-run elasticities tend to be more elastic. That said, the estimates tend to vary across studies for several reasons, many of which are associated with conditions in the study location. The most relevant estimates are therefore those that are most applicable to the study area. There have been a handful of studies that estimate price elasticity for residential water demand in Arizona. However, many of these studies are outdated and utilize the same dataset to focus on the Tucson area. One exception, Klaiber et al. (2012) examined residential water demand in the Phoenix

[31] One could distinguish between municipal and industrial use, and further separate municipal use between residential and commercial use. However, these distinctions are not modeled in CAP:SAM since many providers supply water for various M&I uses. M&I use is therefore treated as one sector.

[32] In general, there is a direct relationship between retail demand and wholesale demand. Wholesale water demand reflects demand for raw water used as an input, sometimes referred to as "derived demand" since it is a direct function of final output and retail water demand (e.g. for potable water). It is therefore reasonable to assume that elasticity estimates are applicable to both wholesale and retail water demand.

metropolitan area, focusing on how price responsiveness varies with season and drought conditions. Another exception, Yoo et al. (2014), also estimated demand in Phoenix, expanding on methods used by Klaiber et al. (2012) to focus on water availability and climate change. The estimates from these recent studies are arguably the most applicable to the study area. That said, both of these studies focus on a single provider (Phoenix) and there are some limitations with their data and estimation methodology. It was therefore deemed most appropriate to determine an elasticity based on several studies that are relevant to the study area, rather than focusing on any single study and estimate.

Young (1973) was the first well-known study of residential water demand in Arizona. He examined water demand in Tucson from 1946-1971, finding a shift in demand around 1964. Elasticity of demand was estimated at about 0.63 during 1946-1964 and then 0.41 during 1965-1971, suggesting that demand became more inelastic across these periods. Agthe and Billings (1980) also examined residential water demand in Tucson, estimating short-run and long-run price elasticities for 1974-1980. They found that short-run price elasticity ranged from 0.18 to 0.36 and that long-run elasticity ranged from 0.27 to 0.5. Another study by these authors, Billings and Agthe (1980), relied on the same dataset but restricted the sample to 1974-1977 to examine increasing block rates. They found similar elasticity estimates as before. The 1974-1980 Tucson sample is used again in Agthe et. al (1986), where the authors utilize a different methodology for estimating the elasticity of demand. They found a short-run elasticity of 0.14 and a long-run elasticity of 0.62. The Tucson sample is used again in Agthe and Billings (1987), where the authors focus on the impact of income on the elasticity of demand. They found an elasticity of 0.56 for low income, 0.49 for middle income, 0.46 for upper-middle income, and 0.4 for high income, indicating that demand is more inelastic for those with higher income.

Even though most of these studies utilized the same dataset, the variation in elasticity estimates emphasizes the uncertainty that is inherent in modeling water demand. Estimates depend on several factors, from sample characteristics to modeling assumptions and methods. Arbues et al. (2003) examined differences in the specification of water demand models, assessing the selection of variables, the choice of functional form, the type of data, and the type of price specification. They found that price elasticity estimates varied both with modeling techniques and the type of data used (panel versus cross-sectional data and aggregated versus individual-level water use data). Unfortunately, most studies in Arizona have had to rely on the same dataset, highlighting the limited availability of data necessary to estimate the elasticity of demand in the study area.

Klaiber et al. (2012) utilized a different sample and a more recent methodology for estimating residential water demand. The authors focused on the Phoenix metropolitan area from 2000 to 2003, examining price responsiveness under changing seasonality and drought conditions. Unfortunately, the short time span of their sample limited the authors to only estimating short-run elasticities. They found that price responsiveness was reduced for summer months and when conditions are dry, and in winter months price responsiveness tended to be higher. They found an elasticity of 1.54 in the winter and 0.68 in the summer when conditions were normal. Meanwhile, elasticity fell to 1.17 in the winter and 0.3 in the summer when conditions were dry. The authors also found that larger users were uniformly less responsive to price across all seasons, regardless of weather conditions.

The estimates from Klaiber et al. (2012) are notably larger (more elastic) than past estimates, from both the Tucson area and economics literature more broadly. This could be due to Phoenix water users being more responsive to price changes than other areas, or due to water users becoming more responsive to price changes over time. It could also be due to the sample used, variables included, or modeling assumptions and methods. Realistically, it is likely that a combination of these factors are responsible for the larger estimates. That said, another recent study, Yoo et al. (2014), also estimated elasticities for the Phoenix area and likewise found elasticities that are considerably higher than reported elsewhere in the literature.

Yoo et al. (2014) utilized a similar methodology as Klaiber et al. (2012) but estimated both short-run and long-run elasticities by examining the city of Phoenix from 2000-2008. They found a short-run elasticity of 0.66 and a long-run elasticity of 1.55. Although larger than previous estimates, these estimates are somewhat consistent with Klaiber et al. (2012), at least their elasticity estimates for winter months. Yoo et al. (2014) also argue that their findings are consistent with other studies that have estimated residential water demand in a similar arid environment. Pint (1999) estimated water demand in California and found elasticity to range from 0.14 to 1.24 and Hewitt and Hanemann (1995) examined demand in Texas and found a range of 1.53 to 1.63. Yoo et al. (2014) also considered how elasticity changed at different levels of water use by estimating price elasticity at different quantiles of water use in their sample. Estimates at the 0.1, 0.25, 0.5, 0.75, and 0.9 quantiles of water use provided long-run elasticities of 2.399, 2.116, 1.697, 1.314, and 0.889, respectively. This indicates that low-water users are more price sensitive than high-water users, which is consistent with Klaiber et al. (2012).

All of these studies have focused on residential water demand, which is only one portion of municipal demand. Although residential demand constitutes the majority of municipal use, commercial use is also important, and may respond uniquely to price changes. By treating M&I as one sector, it is also important to consider how industrial use may respond to price changes. Unfortunately, there has been minimal work on commercial and industrial water demand, and no known estimates of elasticity near the study area. The few studies that exist do however suggest that demand elasticities are unique for commercial and industrial uses. Surveys of this literature are available in Renzetti (2002), Brosa (2004), and Worthington (2010).

One early study, Babin et al. (1982), estimated the elasticity of water demand for U.S. industries using state-level cross-sectional observations. The authors found prices elasticities to range broadly from 0 to 0.81. Later, Williams and Suh (1986) examined commercial use and found prices elasticities to range between 0.14 and 0.36, suggesting that demand is more inelastic than residential demand. When employing an aggregate analysis of residential, commercial, and industrial use, the authors found that price elasticities ranged from 0.44 to 0.74, which was more elastic than for residential use alone. These studies would seem to suggest that commercial use is the most inelastic, followed by residential use and then industrial use. However, more recent work has been mixed on this ordering.

Focusing on commercial demand, Schneider and Whitlatch (1991) found a short-run elasticity of 0.23 and a long-run elasticity of 0.92. The authors argued that these estimates were higher than for residential use and industrial use, meaning commercial users were the most price sensitive. This is opposite from what Williams and Suh (1986) had concluded for commercial use. Later work by Lynn et al. (1993) estimated elasticities by sub-sector, helping provide a potential explanation for this discrepancy. The authors found elasticity to range from 1.33 for department stores, 0.76 for grocery stores, 0.17 for restaurants, 0.12 to 0.24 for motels and hotels, and 0.48 for all other establishments. Like residential demand, these differences are likely in part linked with differences in use, with high-water users being less price sensitive than low-water users.

The range of elasticity estimates across these studies looking at residential, commercial, and industrial demand makes it difficult to determine a single long-run elasticity most appropriate to represent M&I water use in the region. Relying on a single elasticity clearly masks the variation in price sensitivity across uses and users, but a reasonable average can nevertheless serve to capture a "typical M&I water user" and quantify welfare effects for adaptation strategies in this analysis. Several elasticities are tested, highlighting the sensitivity of price effects and welfare estimates to the chosen elasticity of demand.

For this assessment, agricultural demand is separated from M&I demand. Past work suggests that agricultural users tend to be less price-sensitive than M&I users, which may be partly due to differences in use, as well as differences in price. One meta-analysis, Scheierling et al. (2006), examined 24 studies consisting of 73 estimates in the U.S. from 1963 to 2004. The mean price elasticity was 0.48, with a median of only 0.16. Elasticity estimates ranged from 0 to 1.97. Few studies estimated long-run elasticities, but the authors noted that long-run elasticities were generally more elastic, just as with other water uses. The authors also found that estimates may be more elastic if they are calculated at a higher irrigation water price, and more elastic in the presence of high-valued crops.

There have been several studies that examine irrigation water demand in western states, and a handful of studies that examine agricultural water demand in Arizona. Unfortunately, there have not been any elasticity estimates in recent years. Howe et al. (1971) estimated elasticities for Arizona, California, and Texas and found elasticities that broadly ranged from 0.09 to 1.86. When looking at Arizona, Colorado, and Kansas, Hexem and Heady (1978) found that price elasticity only ranged from 0.06 to 0.1, and Gisser et al. (1979) found a range of 0.08 to 0.12 when looking at Arizona, Colorado, New Mexico, and Utah. Heady et al. (1973) looked at 17 western states and found an average elasticity of only 0.15, while Frank and Beattie (1979) used a different modeling approach and found elasticity to range from 1.01 to 1.69. Meanwhile, Ogg and Gollehon (1989) looked at the western U.S. and found elasticities ranging from 0.07 to 0.26, and Moore et al. (1994) found a range of 0.03 to 0.1.

Focusing on Arizona only, Kelso et al. (1973) found elasticities ranging from 0 to 1.01, while Ayer and Hoyt (1981) found a range of 0.06 to 1.45. Although not in the study area, one of the most recent and rigorous studies, Hendricks and Peterson (2012), found an elasticity of 0.1 for irrigation water demand in Kansas. The broad range of elasticity estimates for agricultural demand, and the lack of recent estimates in and around the study area, make it difficult to determine a single measure of elasticity most applicable to agriculture use. As with M&I, several elasticities are therefore tested, highlighting the sensitivity of price and welfare estimates to the chosen elasticity. Table 4.10 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 from shortages in the market for renewable supplies.

Table 4.10 – 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%
1.5	4.92%	11.51%	3.36%
1	7.38%	17.26%	5.04%
0.5	14.76%	34.52%	10.09%

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,[33] but in some years (2009 and 2014) the increase has been as much as 14 percent for M&I. Also recall that with a CAP shortage expected to start in 2020, CAP's M&I rate jumps 22 percent from 2019 to 2020, and the advisory rates imply a 5 percent annual change the following years. The price effects in Table 4.10 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.

These price effects reflect average annual changes from 2020-2060, but depending on the scenario, the change from year-to-year varies, differing 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. The price effects in Table 4.10 represent pre-adaptation changes, meaning any future efforts to reduce water shortages in the region will lower adverse price effects and the upward trend of water prices across time. Furthermore, the earlier a strategy is implemented, the greater the effect on prices across the study period, since shortage reductions early on have a compounding effect on future prices.

By measuring annual changes in prices and market welfare (CS), the implementation time for an adaptation strategy is encompassed in the benefit estimate for reducing water shortages. The calculation therefore includes a volumetric and temporal component, which is important to not only capture differences in implementation time, but also the fact that some strategies don't provide a constant annual volume of water. For example, effluent availability is expected to grow across the study period as population grows, so strategies that utilize effluent provide a non-constant volume of water across time. 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 to address shortages that vary in magnitude from year to year.

The chosen 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 implementing a particular strategy, the elasticity of demand has important implications for estimating benefits.

Recent estimates from Klaiber et al (2012) and Yoo et al. (2014) suggest that 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). Although the chosen elasticity will not impact the trade-off analysis, it is important to keep in mind that the estimated welfare effects may be larger if future demand turns out to be more inelastic, and smaller if demand is more elastic.

[33] There is a decline in CAP's *Pumping Energy Rate* post-2019 that reflects the closure of the Navajo Generating Station. The energy component is expected to begin increasing again by 2023 according to CAP's advisory rates.

A more inelastic demand means that agricultural prices grow faster than M&I prices on a percentage basis, but keep in mind that prices are lower for agriculture, so this doesn't necessarily imply faster growth on a dollar basis. Also note that these price effects are only for the use of marketed renewable water supplies, while future prices for local surface water use and groundwater use are estimated separately, as discussed previously. Recall that the cost of local surface water use is assumed to grow between 0.79-1.89 percent per year and that the cost of groundwater use is assumed to grow between 0.915-2.265 percent per year. Although the cost of using marketed renewable supplies is therefore expected to grow faster than the cost of local surface water and groundwater use, both physical limitations and legal restrictions limit direct use. This means that most users will have to continue relying on marketed renewable supplies, regardless of higher prices, which is in turn part of the driving force behind rising prices to begin with.

4.3 Non-Market Use

Non-market use is quantified in this analysis according to changes in surface water 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 (RUVD)[34] is queried to identify all studies applicable to the study area. The list was last updated in 2016, so the U.S. Geological Survey's Benefit Transfer Toolkit[35] is used to identify studies potentially missing from the RUVD. Both lists identify studies based on the type of recreational activity and provide key information on the characteristics of the original study.

4.3.1 Valuing Recreation

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, so the search was broadened to Arizona plus other states, the West (as defined by the U.S. Census), and then the entire United States 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 are 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

[34] The RUVD is available at: http://recvaluation.forestry.oregonstate.edu/database.

[35] The Benefit Transfer Toolkit can be found at: https://sciencebase.usgs.gov/benefit-transfer/.

methods. Table 4.11 lists the 19 recreational activities analyzed, along with the number of studies and estimates used for BT, and the region where those studies were conducted. Appendix C[36] provides a list of all studies used to value recreation in this assessment, including the publication year and activities valued in each study (some studies estimate CS for multiple activities). Ultimately, 80 unique studies encompassing 317 CS estimates are used to value recreation, excluding 29 estimates that were flagged and not included. There were five activities where studies were available for a narrower region (denoted in the table), but the estimates were deemed unreliable, so a broader region was used. As discussed later on, some activities are combined, and snow sports are removed from the analysis.

Table 4.11 – Studies Used for Benefit Transfer and Valuing Recreation

Activity	Study Count[a]	Estimate Count	Region
Backpacking	1	1	AZ Plus
*Boating, Motorized**	7	19	West
Boating, Nonmotorized	2	5	AZ Only
Bicycling, Leisure	4	17	National
Bicycling, Mountain	5	11	West
Camping	2	23	AZ Only
Freshwater Fishing	14	38	AZ Only
*Hiking**	26	73	West
Horseback Riding	1	1	National
Hunting, Big Game	7	18	AZ Only
*Hunting, Small Game**	6	34	West
*Hunting, Waterfowl**	9	32	West
Picnicking	1	1	AZ Plus
Rock & Ice Climbing	2	16	West
Skiing, Cross-Country	1	2	West
*Skiing, Downhill**	4	8	West
Snowboarding	1	1	West
Swimming	4	8	West
Wildlife Viewing	7	9	AZ Only
Total	**80**	**317**	**N/A**

[a] Total study count is less than the sum of study counts across activities since some studies estimate values for more than one activity. See Appendix C for a list of all studies included.
* Studies are available for a narrower region, but the estimates are deemed unreliable, so a broader region is used.

Both the number of studies and number of estimates are provided in Table 4.11 since many studies offer multiple estimates, each reflecting different modeling assumptions. 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

[36] Appendix C also indicates whether a study used a stated preference (SP) or revealed preference (RP) method to estimate CS (note that these are broad categories, and that there are several estimation techniques that fall under each). In general, estimation with RP is preferable to SP, since RP uses observations of actual behavior, while SP uses hypothetical situations to obtain data and is prone to several potential biases. That said, SP has the advantage of being able to capture some forms of CS that cannot be measured using RP techniques and SP methods can often generate more detailed data than is available for RP methods. Some studies use a combination of both RP and SP methods, which has the potential to provide the most holistic picture of CS.

determining the median CS value across studies. Table 4.12 provides the median CS values used for this analysis, along with additional summary statistics. CS values reflect welfare per visitor day ($2020). The table highlights the variation in CS across activities as well as across studies. The RUVD reports values that are CPI-adjusted to 2016, so values are adjusted to 2020 (first half) using the CPI for the Phoenix area as done elsewhere. The average CS per visitor day is larger than the median value for many activities, implying that there is generally a positive skew in the distribution of estimates. This means that using the average would increase the estimated CS associated with recreation, but the estimate would then potentially be biased by outliers.

Table 4.12 – 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.

4.3.2 Recreation Visitation

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*.[37] The report provides visitation data for 2018 by recreational activity for each county in Arizona. The recreation categories used in Audubon (2019) are coarser then provided in the RUVD, so to make the CS estimates compatible with visitation data, estimates must be combined for certain activities.[38] For example, Audubon (2019) identified *Trail Sports* as one primary category of recreation, which consists of hiking, backpacking, climbing, and horseback riding. Meanwhile, the RUVD contains estimates for each of these individual forms of trail

[37] Report: https://www.audubon.org/sites/default/files/audubon_az_water-based_rec_economics_2019-04-08.pdf.

[38] Audubon (2019) didn't include off-roading with ATVs or 4x4 vehicles as a recreational activity, so it is excluded here, but CS values do exist in the RUVD. That said, motorized vehicles are generally not allowed near reservoirs or along canals, so water is likely to have minimal effects on welfare associated with off-road recreation in the area.

sports, meaning activities must be combined to calculate welfare for each category. In order to estimate CS values for Audubon's broad categories of recreation, the ratios shown in Table 4.13 are used to combine RUVD activities. These ratios were determined based on input from the project team. Note that Audubon provides nonzero estimates for the category *Snow Sports*, which encompasses cross-country, downhill, and telemark skiing, as well as snowboarding and snowshoeing. It was decided that this category is not relevant to the study area, and therefore *Snow Sports* is excluded from the analysis (assigned 0% in Table 4.13). This brings the final number of recreation categories to 8.

Table 4.13 – Weights Used to Combine Recreational Activities

Audubon Activity	RUVD Activity	Ratio Applied
Bicycling (cycling on paved road or off-road, skateboarding)	*Bicycling, Leisure* *Bicycling, Mountain*	70% 30%
Camping (RV campsite, tent campsite, or at a rustic lodge)	*Camping*	100%
Fishing (recreational fly and recreational non-fly)	*Freshwater Fishing*	100%
Hunting & Shooting (shotgun, rifle, or bow)	*Hunting, Big Game* *Hunting, Small Game* *Hunting, Waterfowl*	40% 40% 20%
Picnicking or Relaxing	*Picnicking*	100%
Snow Sports (cross-country, downhill, telemark, snowboarding, snowshoeing)	*Skiing, Cross-Country* *Skiing, Downhill* *Snowboarding*	0% 0% 0%
Trail Sports (day-hiking on trail, backpacking, climbing ice or rock, mountaineering, horseback riding, running)	*Backpacking* *Hiking* *Rock & Ice Climbing* *Horseback Riding*	5% 70% 5% 20%
Water Sports (swimming, canoeing, kayaking, rafting, paddle-boarding, boating)	*Boating, Motorized* *Boating, Nonmotorized* *Swimming*	60% 20% 20%
Wildlife Watching (viewing, feeding or photographing animals, bird watching)	*Wildlife Viewing*	100%

These weights were determined based on input from the project team. Although Audubon (2019) provides nonzero visitation estimates for Snow Sports, it was decided that this category should be excluded.

The visitation data from Audubon (2019) corresponds with county-level estimates. The study area falls inside Maricopa County, but does not span all of the county area. To isolate recreation in the study area, population data is used to separate visitation data. The population in the study area amounted to 58.7 percent of the population in Maricopa County in 2018. This ratio 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 in the outside category, 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 (AOT) is used. AOT provides information 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.[39]

In 2018, AOT reported that there was 23.2 million domestic overnight visitors to the Phoenix and Central Arizona Region, with 72 percent being non-residents. The average party size was 2.6 persons including adults and children, and 2.1 for adults only. Looking at the top activities done by visitors, 16 percent go swimming , 13 percent visit National and State parks, 12 percent go hiking or backpacking, and 2 percent go camping.[40] Since AOT defines the region as encompassing both Maricopa County and Pinal County, the county fraction of direct travel spending is used to separate and determine non-resident adult visitation by county. Visitation is then divided across recreation categories, with swimming attributed to *Water Sports*, hiking/backpacking attributed to *Trail Sports*, and camping attributed to *Camping*. Visitation to National and State parks is then distributed across the remaining categories based on the ratios observed for Arizona residents, which assumes that non-residents have similar preferences for recreational activities.

The same approach is used to estimate non-resident adult visitation for Pima County, which is part of what AOT defines as the Tucson and Southern Region. In 2018, AOT reported that there were 6.8 million domestic overnight visitors to the region, with 59 percent being non-residents. The average party size was 2.4 persons including adults and children, and 2 for adults only. Looking at the top activities done by visitors, AOT reported that 19 percent visit National and State parks, 16 percent go hiking or backpacking, 14 percent go swimming , and 7 percent go camping. Direct travel spending is again used to separate visitation across counties in the region, which includes Pima County as well as Cochise, Graham, Greenlee, and Santa Cruz counties.

AOT found that the average party stays 3.7 nights in the Phoenix and Central Arizona Region and 3.1 nights in the Tucson and Southern Region. Unfortunately, it is not known how many days visitors spend doing different activities or if they do multiple activities during their trip. To address this, it is assumed that there is only one visitor day per activity and per adult visitor, but that activities are then additive. For example, it may be that one spends 3 days in Arizona and goes camping, hiking, and swimming every day. Under this approach, one day is treated as camping, one day as hiking, and one day as swimming. On the other hand, if someone goes camping all 3 days, then this approach would assume only a single visitor day for camping. This approach may therefore understate non-resident visitation. However, it is unknown if visitors spend the entire day on a particular activity, and it is assumed that partaking in an activity represents a full visitor day. This means that this approach could also potentially overstate non-resident visitation. The possibility of understating visitation is therefore partially offset by the possibility of overstating visitation, and this approach is assumed to provide a reasonable estimate for non-resident visitation utilizing readily available data from AOT.

Table 4.14 provides recreation visitor days by activity and area for Arizona adult residents from Audubon (2019) and estimated for adult non-residents based on AOT information. Note that 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 different forms of recreation. Total visitor days, including Arizona residents and non-residents, is what 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

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[39] Visitation data from AOT can be found at: https://tourism.az.gov/visitation-profiles/.

[40] AOT only lists the top five activities, so the percent that go camping is based on the fraction of accommodation spending at campgrounds/trailer parks/RV parks.

visitor days spent in the study area. Around three-quarters of this corresponds with Arizona residents and the remaining quarter corresponds with non-residents that visit the state.

Table 4.14 – 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 AOT. Reported amounts may not add to total amounts due to rounding.

Table 4.14 reflects visitation for 2018 only. 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. Future visitation is therefore a function of population growth, which varies under the different CAP:SAM scenarios. To model changes in visitation across time, the number of visitor days is assumed to grow at the same rate as housing units under each scenario. Visitation is therefore modeled as growing the most under Scenario D with rapid and outward population growth, and least under Scenario F with slow and compact population growth. Note that population is projected to grow differently in the study area than in the outside area, so future visitation is calculated separately for each area.

4.3.3 Annual Welfare from Recreation

Annual welfare for recreation is determine by multiplying visitor days by CS per visitor day for each activity. Table 4.15 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 4.15 – 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
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 annual welfare attributed to those adults partaking in recreational activities. There are however 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 not analyzed. Table 4.15 therefore represents direct use benefits for those 18 and older partaking in recreational activities in the region, recognizing that there are additional benefits from recreation not included here.

4.3.4 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 don't 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 don't 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*. Table 6.8 provides the responses for the role of water in adding to enjoyment and Table 6.9 provides the responses for changes in visitation if one is not able to participate on or along water. These responses are used to generate elasticities that link surface water conditions to visitation (Visitation Elasticity) and welfare per visit (CS Per Visit Elasticity) for each activity. To do so, assumptions are made so that each response corresponds with a different elasticity, and the combination of responses is used to generate an elasticity for each activity. 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 elastic 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 don't 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 0 implies no response. For activities that don't 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 assume 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 0 (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 response categories for those recreational activities that indirectly depend on water. Tables 4.16 and 4.17 show the *Visitation Elasticity* and *CS Per Visit Elasticity* resulting from the question responses. These elasticities are used to link changes in surface water with changes in visitation and welfare per visit for each recreational activity. In general, the elasticity used for CS per visit is more elastic (responsive) than the elasticity used for visitation. Surface water conditions modeled in CAP:SAM are used to measure pre-adaption welfare effects. This is then compared with welfare and surface water conditions when an adaptation strategy is in place to quantify strategy benefits for each recreational activity in terms of surface water availability.

Table 4.16 – "How much does water add to your enjoyment?"

Activity	A Great Amount	A Moderate Amount	A Small Amount	Not at All	CS Per Visit Elasticity
Bicycling	28%	43%	22%	8%	**0.48**
Camping	53%	34%	11%	2%	**0.60**
*Fishing**	N/A	N/A	N/A	N/A	**1**
Hunting	43%	22%	28%	7%	**0.50**
Picnicking	55%	34%	8%	3%	**0.60**
Trail Sports	57%	19%	7%	16%	**0.55**
*Water Sports**	N/A	N/A	N/A	N/A	**1**
Wildlife Watching	48%	42%	8%	2%	**0.59**

This question was included in Audubon (2019) and the responses are used to generate CS Per Visit Elasticities that reflect the relationship between surface water and welfare per visit for each activity.
* The question was not asked for Fishing and Water Sports since they directly depend on water, so an elasticity of 1 is assumed for these categories.

Table 4.17 – "How much would activity participation decrease if not able to participate in or near water?"

Activity	A Great Amount	A Moderate Amount	A Small Amount	Not at All	Visitation Elasticity
Bicycling	21%	26%	20%	33%	**0.34**
Camping	29%	32%	22%	18%	**0.43**
*Fishing**	N/A	N/A	N/A	N/A	**1**
Hunting	30%	33%	30%	6%	**0.47**

Picnicking	21%	31%	29%	19%	**0.39**
Trail Sports	43%	21%	11%	25%	**0.34**
*Water Sports**	N/A	N/A	N/A	N/A	**1**
Wildlife Watching	15%	33%	30%	23%	**0.35**

This question was included in Audubon (2019) and the responses are used to generate Visitation Elasticities that reflect the relationship between surface water and visitor days for each activity.

* The question was not asked for Fishing and Water Sports since they directly depend on water, so an elasticity of 1 is assumed for these categories.

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 utilize water canals and laterals 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 area. Table 4.18 shows the average annual change in surface water availability and housing units under each CAP:SAM scenario and area. The change in surface water is the same for Scenario A and Scenario F since both reflect historic climate conditions.[41] 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.

Table 4.18 – Annual Change in Surface Water and Housing Units, 2020-2060

Variable	Scenario A		Scenario D		Scenario F	
	Study Area	Outside Area	Study Area	Outside Area	Study Area	Outside Area
Surface Water	-0.23%	-0.22%	-0.68%	-0.68%	-0.23%	-0.22%
Housing Units	1.90%	1.46%	2.69%	3.39%	1.58%	0.93%

Average annual changes are the same for Scenario A and Scenario F since both reflect historic climate conditions.

Table 4.18 shows the average annual change in conditions across the study period, but actual annual changes vary and are used to measure pre-adaptation welfare effects for recreation. For surface water, there is not necessarily a decline each year as the average might suggest, but instead severe declines in shortage years that cause the annual average to be negative across the study period. As a result, most

[41] There is a slight difference in surface water conditions between Scenario A and F, so surface water under Scenario A is used for both scenarios to ensure that they equivalently reflect historical climate conditions and that welfare differences only stem from differences in population growth and demand.

pre-adaptation declines in welfare occur during those shortage years, with minimal effects in other years. There are also some years with increases in surface water availability and welfare, especially following years with severe shortages.

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 from changes in surface water availability. Table 4.19 shows the estimated pre-adaptation change in visitor days and welfare per visit from 2020-2060 for each activity under each scenario using the elasticities from Tables 4.16 and 4.17. The change is calculated on an annual basis from changes in surface water availability and summed to derive a total pre-adaptation change that represents the average impact across the study period. Note that 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.

Table 4.19 – Impact of Surface Water Availability on Recreation, 2020-2060

Activity	Scenario A		Scenario D		Scenario F	
	Visitor Days	CS Per Visit	Visitor Days	CS Per Visit	Visitor Days	CS Per Visit
Bicycling	-3.2%	-4.5%	-2.7%	-6.2%	-3.2%	-4.5%
Camping	-4.0%	-5.5%	-4.9%	-9.9%	-4.0%	-5.5%
Fishing	-9.2%	-9.2%	-27.7%	-27.7%	-9.2%	-9.2%
Hunting	-4.4%	-4.7%	-5.7%	-6.8%	-4.4%	-4.7%
Picnicking	-3.6%	-5.6%	-3.7%	-10.1%	-3.6%	-5.6%
Trail Sports	-3.2%	-5.1%	-2.7%	-8.3%	-3.2%	-5.1%
Water Sports	-9.2%	-9.2%	-27.7%	-27.7%	-9.2%	-9.2%
Wildlife Watching	-3.3%	-5.5%	-3.0%	-9.7%	-3.3%	-5.5%
All Activities	**-5.0%**	**-6.1%**	**-10.2%**	**-13.2%**	**-5.0%**	**-6.1%**

These represent cumulative impacts per recreational participant from changes in surface water availability. Changes are the same for Scenario A and Scenario F since both reflect historic climate conditions.

Looking at the entire region and across all recreational activities together, recreation visitation is expected to decrease anywhere from 5 percent to 10 percent without adaptation efforts, and welfare per visit is expected to decrease anywhere from 6 percent to 13 percent. The impact is largest for those activities that depend on water and lowest for those that do not. The changes are again the same for Scenario A and Scenario F since both are based on historic climate conditions. These impact impacts will be reduced whenever an adaptation strategy improves surface water availability, even if that surface water ultimately goes towards market use.

4.4 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 covered in Section 4.1, annual changes in CS are then discounted (using the 2020 Federal *Water Resources Planning* rate of 2.75%) and summed across 2020-2060 to derive a single measure for pre-adaption changes in CS. 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 CS are estimated for wholesale market use (agriculture and M&I) and non-market use (recreation) under CAP:SAM Scenarios A, D, and F. For regional wholesale 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. Market calculations incorporate population growth under each CAP:SAM Scenario, so for symmetry, recreation visitation also grows with population.[42] Table 4.20 shows the cumulative pre-adaptation welfare effects for M&I users under each CAP:SAM Scenario, along with welfare effects 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 each ones' raw water portfolio. A bit less than half of the welfare effects occur within the study area and the remainder in the outside area.

Table 4.20 – 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, All	-$219.76	-$115.3	-$516.94	-$224.0	-$141.96	-$85.3
Total	**-$390.89**	**-$116.4**	**-$993.59**	**-$241.1**	**-$253.92**	**-$84.3**

Totals 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 4.21 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 each ones' raw water portfolio. Around two-thirds of welfare effects occur outside the study area.

[42] This approach assumes that the new population will have the same preferences for recreation as the existing population. Population growth is captured according to the annual growth in housing units under CAP:SAM Scenarios.

Table 4.21 – 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
Maricopa WD	-$1.67	-$289.7	-$5.03	-$834.5	-$1.47	-$224.7
Roosevelt ID	-$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
Salt River Project	-$2.46	-$240.6	-$7.26	-$625.5	-$1.73	-$165.9
Outside, 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**

Totals 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 4.22 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)[43] to $69 (Scenario D) per participant, with significant 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.

Table 4.22 – 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, 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**

Totals 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.

[43] 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.

Putting everything together, Table 4.23 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. A bit under half (44 percent) of this welfare loss occurs in the study area.

Table 4.23 – 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
	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.

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. For the trade-off analysis, the project team desired to focus on a single CAP:SAM Scenario, reducing the dimensionality and simplifying the analysis. The project team decided to focus on Scenario D, which embodies a "worst case" scenario with rapid population growth and hot and dry climate conditions. Since strategies are ultimately compared on a relative basis, the chosen scenario has minimal influence on the trade-off analysis and results, instead affecting primarily the magnitude of monetized effects. By focusing on Scenario D, the monetized benefit for *Water Availability and Reliability* will thus reflect a high-end estimate, at least in terms of the extent of water shortages.

5.0 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 quantitively 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 explicitly 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.

5.1 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, (1)*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 the *Future Water Management Goals, Objectives, and Adaptation Strategies* section of the basin study 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 Low Impact Development; 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 study 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 Yuma Desalting Plant and new infrastructure to utilize brackish water from the Buckeye Waterlogged Area, 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.

5.2 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.[44] Ultimately, five benefit and five cost criteria were selected. The scoring scale is defined as shown in Table 5.1, where scores indicate a relative ranking across the strategies considered.

Table 5.1 – 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* (value-added, income, and employment). 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

[44] Allowing some criteria to range from -3 to 3 while others can only go in one direction implicitly gives additional weight to some criteria. For example, suppose the impact captured by a criterion can only go in one direction, such as a cost ranging from -3 to 0. Meanwhile, suppose the impact for another criterion could conceivably go in either direction, reflecting either a beneficial or negative effect and thus scored from -3 to 3. In this case, the criterion that ranges from -3 to 3 would have the ability to influence the final score up to 6 points, while the criterion that goes in one direction can only impact the final score up to 3 points. Since strategies are compared on a relative basis, allowing the scoring scale to differ across criteria gives additional influence to those that have a larger scoring range. To avoid this issue, all criteria are categorized as either a cost or benefit consideration and therefore limited to having only a 3-point impact on final scores. If the effect measured by a criterion could conceivably be positive or negative, it is limited to a single direction based on the most likely impact across adaptation strategies.

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.

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 the 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.

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.

5.3 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 (1)*Demand Management*. Differences in implementation time are also captured, since a strategy with quicker 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.

Tables 5.2 and 5.3 show the information used to measure *Water Availability and Reliability* for each adaptation strategy. Table 5.2 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 5.3 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.[45] Information for the remaining strategies 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 5.2 – Potential Water Volume (AF) 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 100,000 AF.

[45] The CAP:SAM modeling 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.

Table 5.3 – Implementation Time 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 5.2 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 in 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 to prevent future price increases. To generate water volumes for adaptation strategies, split volumes between surface water and groundwater, and determine strategy implementation time, the project team had to rely on several simplifying assumptions. Table 5.4 lists some of the key assumptions underlying each adaptation strategy.

Table 5.4 – Key Assumptions for Adaptation Strategies

Strategy	Assumptions
(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 2060 this amounts to about 75,000 AF. • 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.
(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 per year for the study area. • Exchange goes through existing CAP canals.
(8) Inland Desalination/Brackish Water Treatment	• Volume of 35,000 AF based on Yuma Desalting Plant 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) and LTSCs from Harquahala basin (~2,000 AF). • Legal and regulatory barriers create enormous uncertainty for this strategy, so the volume is assumed to range widely from 0-82,000 AF and the midpoint of 41,000 AF 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 and the midpoint of 50,000 AF is used.

Putting everything together, adaptation strategy benefits for *Water Availability and Reliability* are estimated by comparing consumer welfare without/without a strategy in place, and annual benefits are combined into a single value by summing benefits across the 40-year study period. Keep in mind that these benefits are for raw water, encompassing municipal, industrial, agricultural, and recreational use. Table 5.5 shows the *Water Availability and Reliability* benefit in monetary terms for each strategy, separated between the study are and outside area.

Table 5.5 – 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.

Although these estimates are at the wholesale level, it is fair to assume that market welfare effects will largely get transferred to final consumers since water providers and irrigation districts often sell water at cost. Appendix B provides a breakdown of *Water Availability and Reliability* benefits for individual M&I providers, irrigation districts, and recreational activities in the study area, including 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 users' 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.

These benefit estimates provide important information that can be used to assess the economic feasibility of adaptation strategies, presuming that cost estimates could be generated for strategies of interest. Unfortunately, obtaining quantitative cost estimates was deemed infeasible for this study, so the trade-off analysis relies on all costs being measured qualitatively using a low-high scale. Quantifying costs to directly compare with quantified benefits is therefore the next-step in analyzing the economic feasibility of adaptation strategies and measuring net benefits. That said, 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 5.6 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 receiving a score of 3 with the remaining strategies scored 0-3 according to their relative magnitude of benefits.

Table 5.6 – 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.

5.4 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 utilized 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.[46] A series of IMPLAN input-output models were customized for each state and then combined into a single model that accounted for interactions between 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 USBR's 2012 *Colorado River Basin Water Supply and Demand Study*.[47] The results for Arizona are used in this analysis to derive an average impact per unit of water for value added, income, and employment and combine that with water quantity information for each adaptation strategy to measure *Regional Economic Impact*. Regional effects are generated by 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 measures 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

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[46] The ASU (2014) report is available at: https://businessforwater.org/wp-content/uploads/2016/12/PTF-Final-121814.pdf.

[47] The USBR (2012) study defines M&I use and agricultural use the same as done here and can be found at: http://www.usbr.gov/lc/region/programs/crbstudy.html.

demand in the state. GSP excludes the value of intermediate goods and services purchased as inputs 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 works 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 of time (typically one year). In ASU (2014) the 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.

There are some important caveats to point out with the regional economic impacts calculated for this analysis. First, input-output modeling, whether using IMPLAN or another model, is notoriously prone to overstate impacts since it is typical to assume fixed proportions in production and consumption, meaning non-substitutability is assumed.[48] As a consequence, a key assumption in ASU (2014) is that no other sources of water are available to compensate for the loss of CAP water, and substitution does not occur for production or consumption decisions as prices and quantities change in the economy. Although it is recognized that this may be unrealistic, this is a common assumption in input-out modeling for computational reasons, which can unfortunately result in inflated estimates.

Second, the estimates from ASU (2014) are associated with CAP water, which may have a greater impact on the economy than SRP and other local water resources which do not require large-scale diversion. By not distinguishing between water types for this assessment, the estimates for Colorado River water may overstate the impact of other raw water resources. Lastly, regional impact analysis typically includes estimation of direct, indirect, and induced impacts. Including indirect and induced impacts requires simplifying assumptions and the use of economic multipliers which are highly uncertain and may contribute to large estimates where the direct impact represents only a fraction of the total impact. Much of this uncertainty stems from the fact that there are several techniques to calculate regional multipliers from national multipliers, with no single preferred method and each resulting in different multipliers and thus estimated effects.

Although there are limitations, 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

[48] Allowing for substitutability requires complex modifications to traditional input-output modeling or can be accomplished through more advanced regional modeling known as Computable General Equilibrium (CGE) analysis. CGE models require significant resources and expertise to conduct but allow for substitutability by incorporating equations and parameters that reflect substitution for both consumption and production decisions.

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.[49] Table 5.7 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 5.7 – 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 for adaptation strategies and score strategies from low-high for this criterion. Table 5.8 shows the breakdown of impacts across sub-sectors, as defined by the North American Industry Classification System (NAICS). In general, impacts are largest for those sub-sectors that contribute the most to GSP, such as real estate, healthcare, finance, professional services, and retail trade. ASU (2014) does not provide direct, indirect, and induced effects for each sub-sector, so the amounts shown reflect the total impact including all three components. They also do not provide income effects by sub-sector, so the proportion of GSP is used to report approximated income effects for each sub-sector.[50]

Table 5.8 – Regional Economic Impact Per AF of Water by Sub-Sector

Sub-Sector	Value Added	Income	Employment
Accommodation and Food Services	$2,716.7	$1,582.8	0.04
Administrative and Waste Services	$3,240.8	$1,888.2	0.05
Agriculture, Forestry, Fishing, and Hunting	$340.1	$198.1	0.004
Arts, Entertainment, and Recreation	$884.2	$515.2	0.02
Construction	$956.2	$557.1	0.01
Educational Services	$1,452.4	$846.2	0.02
Finance and Insurance	$7,866.0	$4,582.8	0.07
Healthcare and Social Services	$9,270.3	$5,401.0	0.11
Information	$2,384.6	$1,389.3	0.02
Management of Companies	$1,052.3	$613.1	0.01
Manufacturing	$1,892.5	$1,102.6	0.02
Mining	$504.1	$293.7	0.003

[49] Section 3.3 notes that the central Arizona region used an annual average of 2.8 MAF of water from 2015-2019. For 2015 alone, total use was around 2.7 MAF. ASU (2014) used USBR (2012) projections predicting that the entire state of Arizona would use about 4.2 MAF in 2015, implying that the central Arizona region constitutes roughly two-thirds of water use in the state.

[50] This has no bearing on the analysis and is done only to report income effects by sub-sector in Table 5.10.

Other Services	$2,552.6	$1,487.2	0.04
Professional, Scientific and Technical Services	$5,713.4	$3,328.7	0.06
Public Administration and Other	$9,322.3	$5,431.4	0.10
Real Estate and Rental	$10,850.7	$6,321.8	0.07
Retail Trade	$5,677.4	$3,307.8	0.07
Transportation and Warehousing	$1,808.5	$1,053.6	0.02
Utilities	$1,856.5	$1,081.6	0.01
Wholesale Trade	$3,680.9	$2,144.6	0.03
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. Income effects were unavailable by sub-sector and approximated using the proportion of GSP for each sub-sector. Reported amounts may not add to total amounts due to rounding.

As shown, those sub-sectors that benefit the most from water in terms of output and income tend to also benefit the most in terms of employment. For the trade-off analysis, the total impact across all sub-sectors and indicators together is used to measure adaptation strategy impacts. The average annual water volume previously shown in Table 5.2 is combined with impacts per AF in Table 5.7 to determine 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 5.9 shows the estimated annual impact on value added (GSP) for each strategy, separated between direct, indirect, and induced effects. For reference, in 2019 Arizona's total GSP was about $321 billion.[51] Tables 5.10 and 5.11 show the annual impacts on income and employment, again separated between the underlying components.

Table 5.9 – Strategy Impact on Value Added

Strategy	Direct	Indirect	Induced
(1) Demand Management	$1,894.62	$510.27	$1,363.78
(2) Regional Effluent – Direct Potable Reuse	$1,246.32	$335.67	$897.12
(3) Regional Effluent – Direct Non-Potable Reuse	$1,272.79	$342.80	$916.18
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$1,258.51	$338.95	$905.89
(5) Regional Effluent Recharge	$1,258.51	$338.95	$905.89
(6) Poor Quality Groundwater Treatment	$344.90	$92.89	$248.27
(7) Ocean Desalination	$2,270.64	$611.54	$1,634.44
(8) Inland Desalination/Brackish Water Treatment	$984.79	$265.23	$708.87
(9) Groundwater Transactions/Exchanges	$1,395.50	$375.84	$1,004.50
(10) Surface Water Transactions/Leases/Exchanges	$1,633.76	$440.01	$1,176.00

Values are in millions ($2020). Value added is measured by annual GSP which represents the dollar value of all goods and services produced for final demand in the state.

[51] Historical GSP data is published by the Federal Reserve Bank: https://fred.stlouisfed.org/series/AZRGSP.

Table 5.10 – Strategy Impact on Income

Strategy	Direct	Indirect	Induced
(1) Demand Management	$1,139.30	$292.11	$764.29
(2) Regional Effluent – Direct Potable Reuse	$749.46	$192.15	$502.76
(3) Regional Effluent – Direct Non-Potable Reuse	$765.37	$196.24	$513.44
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$756.78	$194.03	$507.68
(5) Regional Effluent Recharge	$756.78	$194.03	$507.68
(6) Poor Quality Groundwater Treatment	$207.40	$53.18	$139.13
(7) Ocean Desalination	$1,365.41	$350.08	$915.97
(8) Inland Desalination/Brackish Water Treatment	$592.19	$151.83	$397.26
(9) Groundwater Transactions/Exchanges	$839.16	$215.15	$562.94
(10) Surface Water Transactions/Leases/Exchanges	$982.43	$251.89	$659.05

Values are in millions ($2020). Labor income reflects annual employee compensation (wages and benefits) and proprietor income.

Table 5.11 – Strategy Impact on Employment

Strategy	Direct	Indirect	Induced
(1) Demand Management	19,716	4,962	13,916
(2) Regional Effluent – Direct Potable Reuse	12,970	3,264	9,155
(3) Regional Effluent – Direct Non-Potable Reuse	13,245	3,333	9,349
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	13,096	3,296	9,244
(5) Regional Effluent Recharge	13,096	3,296	9,244
(6) Poor Quality Groundwater Treatment	3,589	903	2,533
(7) Ocean Desalination	23,629	5,947	16,678
(8) Inland Desalination/Brackish Water Treatment	10,248	2,579	7,234
(9) Groundwater Transactions/Exchanges	14,522	3,655	10,250
(10) Surface Water Transactions/Leases/Exchanges	17,001	4,279	12,000

Employment is measured in job years, which is equivalent to one person having a full-time job for one year.

Table 5.12 shows the total impact across all three economic indicators and Table 5.13 shows the resulting low-high (0-3) score assigned to each strategy for the *Regional Economic Impact* criterion.[52] The

[52] Any of the economic indicators, or a combination of all indicators, can be used to generate an identical relative score from 0 to 3 since amounts are calculated with linear effects per-unit of water using the same water volumes. This means that regional economic impacts are driven by the average annual quantity of water provided by each strategy across the study period, which is also a function implementation time.

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 5.12 – 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	$686.06	$399.71	7,026
(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 5.13 – 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 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.

5.5 Qualitative Criteria Scores

Beyond *Water Availability and Reliability* and *Regional Economic Impact*, which are quantified before being converted to a 3-point scale, there are additional criteria that are important to consider. To evaluate these additional considerations, a survey is used to qualitatively score the remaining 8 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 5.1. 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 also encouraged to provide more precise scoring. In total, 14 surveys were completed across 12 entities.[53] 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 utilized to generate a criteria weighting scheme that reflects the preferences of the study partners. Table 5.14 shows the raw scores for qualitative criteria generated from the survey responses.

Table 5.14 – 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.

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

[53] The entities that provided a completed survey were; Arizona WC; Avondale; Buckeye; Glendale; Goodyear; El Mirage; EPCOR; Peoria; Phoenix; Surprise; SRP; and USBR. Each entity is treated equally by averaging response scores from entities that completed more than one survey, ensuring that no entity has additional influence on the final scores.

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 5.14). 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 as 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.

To highlight uncertainty in scoring and variation across raw survey scores, Table 5.15 reports the standard deviation, showing how responses vary across strategies and criteria. Standard deviation is lower the closer responses are to the average response, meaning responses are more alike. A standard deviation of 0.5 for a particular criteria and strategy would mean that responses are generally within 0.5 points of the average response. A summation column is provided to show the sum of standard deviations across strategies and criteria, highlighting the overall response variation for each particular strategy and criterion. While not directly interpretable, a larger sum may indicate a degree of uncertainty, or possibly disagreement across respondents, while a lower sum of standard deviations implies more certainty and agreement across respondents. That said, some variation is to be expected. As shown, responses vary least for the criteria (6)*Capital Cost* and (7)*OM&R Cost*, and most for (3)*Aquifer Protection* and (4)*Adaptation and Resilience*. Looking at adaptation strategies, responses vary least for (4)*Local Effluent Reuse/Recharge - Potable or Non-Potable* and (5)*Regional Effluent Recharge*, and most for (6)*Poor Quality Groundwater Treatment* and (10)*Surface Water Transactions/Leases/Exchanges*.

Table 5.15 – Standard Deviation for Raw Scores

Strategy	Qualitative Criteria								
	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	Sum
(1)	0.95	0.92	0.90	0.75	0.62	0.60	0.56	0.90	**6.20**
(2)	1.13	0.90	0.86	0.62	0.77	0.83	1.00	0.63	**6.73**
(3)	0.80	1.00	0.45	0.56	0.81	0.71	0.64	0.67	**5.64**
(4)	0.64	0.63	0.72	0.64	0.46	0.83	0.77	0.44	**5.13**
(5)	0.64	0.74	0.62	0.69	0.60	0.94	0.45	0.50	**5.17**
(6)	0.97	0.77	0.63	0.77	0.80	1.00	1.16	0.99	**7.08**
(7)	1.15	0.89	1.07	0.29	0.45	0.40	0.90	0.78	**5.93**
(8)	1.00	0.90	0.72	0.40	0.39	0.45	0.87	1.02	**5.74**
(9)	0.96	0.78	0.67	0.73	0.71	0.75	0.95	0.90	**6.45**
(10)	1.06	0.83	0.70	1.09	0.80	0.76	1.04	0.72	**7.01**
Sum	**9.29**	**8.35**	**7.35**	**6.53**	**6.41**	**7.27**	**8.33**	**7.55**	

Standard deviation shows how survey responses (n=14) vary across strategies and criteria. The sum of standard deviations highlights the overall response variation across each strategy and criterion. A lower sum implies more certainty and agreement across respondents, meaning the responses are closer to the average response.

5.6 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 utilized to give additional weight to select criteria, 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 is a description of the different weighting schemes tested. Across the five weighting schemes, each criterion is included a total of three times.

All Criteria

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

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.

Environment and Sustainability

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

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.

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 necessarily considered "optimal." Instead, the results are intended to show how each strategy performs under different weighting schemes and considerations. That said, the weighting scheme that utilizes the survey of study partners to determine criteria importance is arguably the most appropriate weighting scheme to focus on, as it reflects the preferences of key water users and stakeholders in the study area. The other weighting schemes nevertheless help highlight how adaptation strategies perform under an alternative set of objectives, and an overall rank is also provided, showing how each strategy performs across all weighting schemes together. Table 5.16 shows the criteria importance scores (scored low-high from 0-3) from the project team survey and the resulting weights associated with the responses.

Table 5.16 – 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.

All but one entity assigned an importance score of 3 to the criterion *Water Availability and Reliability*. This means that this criterion is the most important to the study partners and receives the greatest weight under the team survey weighting scheme. Meanwhile, *Government Revenue and Services* received the lowest importance score and is subsequently weighted at 35 percent of the importance of *Water Availability and Reliability*. The remaining criteria are weighted anywhere from 50-80 percent as important as *Water Availability and Reliability*. Scores are rescaled to ensure that at least one criterion receives the max score of 3, and the remining criteria retain their relative scores to one another. As done elsewhere, this is accomplished by dividing each score by the max score and multiplying that ratio by 3.

Table 5.17 reports the standard deviation for the team survey on the importance of each criterion. These scores are explicitly intended to be subjective, reflecting preferences across the project team, so response variation is most appropriately interpreted as differences in preferences, rather than uncertainty or disagreement, as with qualitative criteria scores. In this case, a lower standard deviation indicates more homogenous preferences for a criterion, while a higher standard deviation implies more varied preferences. As shown, *Water Availability and Reliability* is considered the most important criterion and also had the lowest standard deviation, indicating that most of the project team shared this view. Meanwhile, *Public Perception and Acceptance* is deemed only half as important, but preferences on the importance are most varied, as indicated by the largest standard deviation.

Table 5.17 – Standard Deviation for Criteria Importance Scores

Criteria	Standard Deviation
(1) Water Availability & Reliability	0.27
(2) Regional Economic Impact	0.83
(3) Aquifer Protection	0.76
(4) Adaptation & Resilience	0.74
(5) Government Revenue & Services	0.68
(6) Capital Cost	0.67
(7) OM&R Cost	0.61
(8) Administrative & Regulatory Barriers	0.79
(9) Public Perception & Acceptance	0.95
(10) Environmental & Ecosystem Conditions	0.69

Standard deviation shows how survey responses (n=14) vary for criteria importance. A lower standard deviation implies more homogenous preferences across respondents for the relative importance of a criterion.

6.0 Trade-Off Analysis

A trade-off analysis is an application of Multi-Criteria Decision Analysis (MCDA), which is a general framework for evaluating complex decision-making under multiple and often conflicting objectives. MCDA addresses trade-offs that occur when a decision leads to a desirable change in one or more objectives while simultaneously resulting in an 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 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* (PR&G's). The PR&G's indicate that an analysis of alternatives under consideration needs to consider all benefits and costs and needs to 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 come with several benefits and costs. 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 operation and maintenance. 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 associated with alternative strategies, some of which can be measured and quantified, and some of which can only be assessed qualitatively.

6.1 Adaptation Strategy Raw Scores

Looking at the 10 adaptation strategies across the 10 evaluation 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 which puts equal weight on each criterion. As discussed in Section 5, all scores are rescaled to an equivalent 3-point scale to achieve equal weighting across criteria. Given that there are five benefit criteria and five cost criteria, this means that the highest score possible is 15 and the lowest score possible is -15. Meanwhile, a score of 0 represents a strategy with benefits that are exactly off-set by costs, at least when giving equal preference to each criterion. Table 6.1 shows the total raw score for each adaptation strategy, where a positive score indicates that benefits exceed costs and a negative score indicates that costs exceed benefits. The resulting strategy rank for the *All Criteria* weighting scheme is also shown.

Table 6.1 – Adaptation Strategy Raw Score and Rank

Strategy	Total Raw Score	Rank (*All Criteria*)
(1) Demand Management	7.86	**1st**
(2) Regional Effluent – Direct Potable Reuse	-1.03	**7th**
(3) Regional Effluent – Direct Non-Potable Reuse	3.49	**4th**
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	5.20	**3rd**
(5) Regional Effluent Recharge	5.39	**2nd**
(6) Poor Quality Groundwater Treatment	-3.42	**9th**
(7) Ocean Desalination	0.28	**6th**
(8) Inland Desalination/Brackish Water Treatment	-5.58	**10th**
(9) Groundwater Transactions/Exchanges	-2.71	**8th**
(10) Surface Water Transactions/Leases/Exchanges	3.09	**5th**

Total raw score and rank reflect the *All Criteria* weighting scheme which puts equal weight on each criterion. A positive score indicates that benefits exceed costs and a negative score indicates that costs exceed benefits.

As shown, (1)*Demand Management* received the highest raw score and ranked first under the *All Criteria* weighting scheme, followed by (5)*Regional Effluent Recharge*, (4)*Local Effluent Reuse/Recharge*, and (3)*Regional Effluent – Direct Non-Potable Reuse*, respectively. While these scores identify the strategies that perform best with equal weight put on each criterion, the overall raw score masks trade-offs between criteria and doesn't illustrate the particular strengths and weaknesses of each strategy. To evaluate how strategies perform across the different criteria, Figure 6.1 shows the raw score for each strategy and criterion. Keep in mind 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.

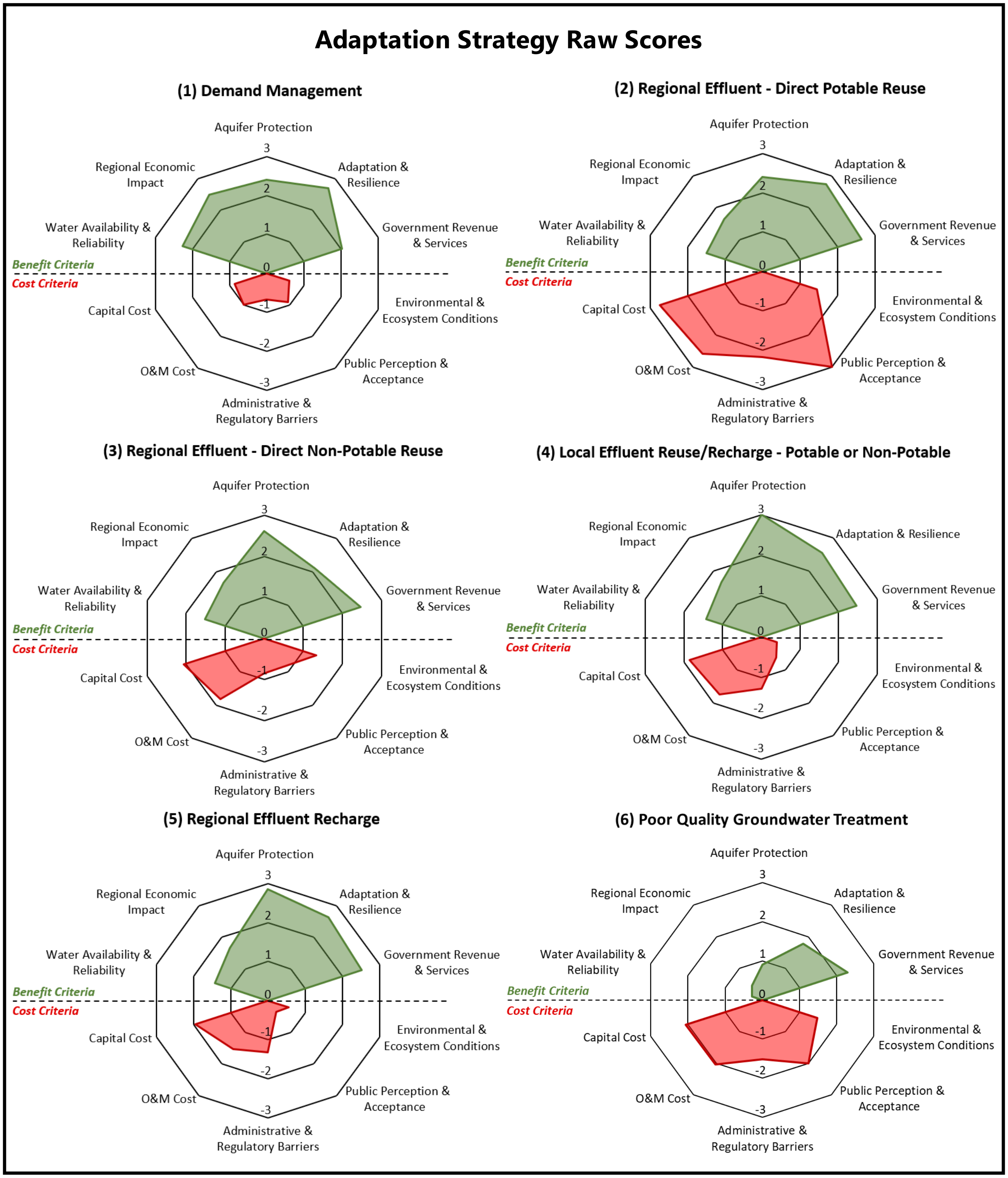

Figure 6.1 – Adaptation Strategy Raw Scores

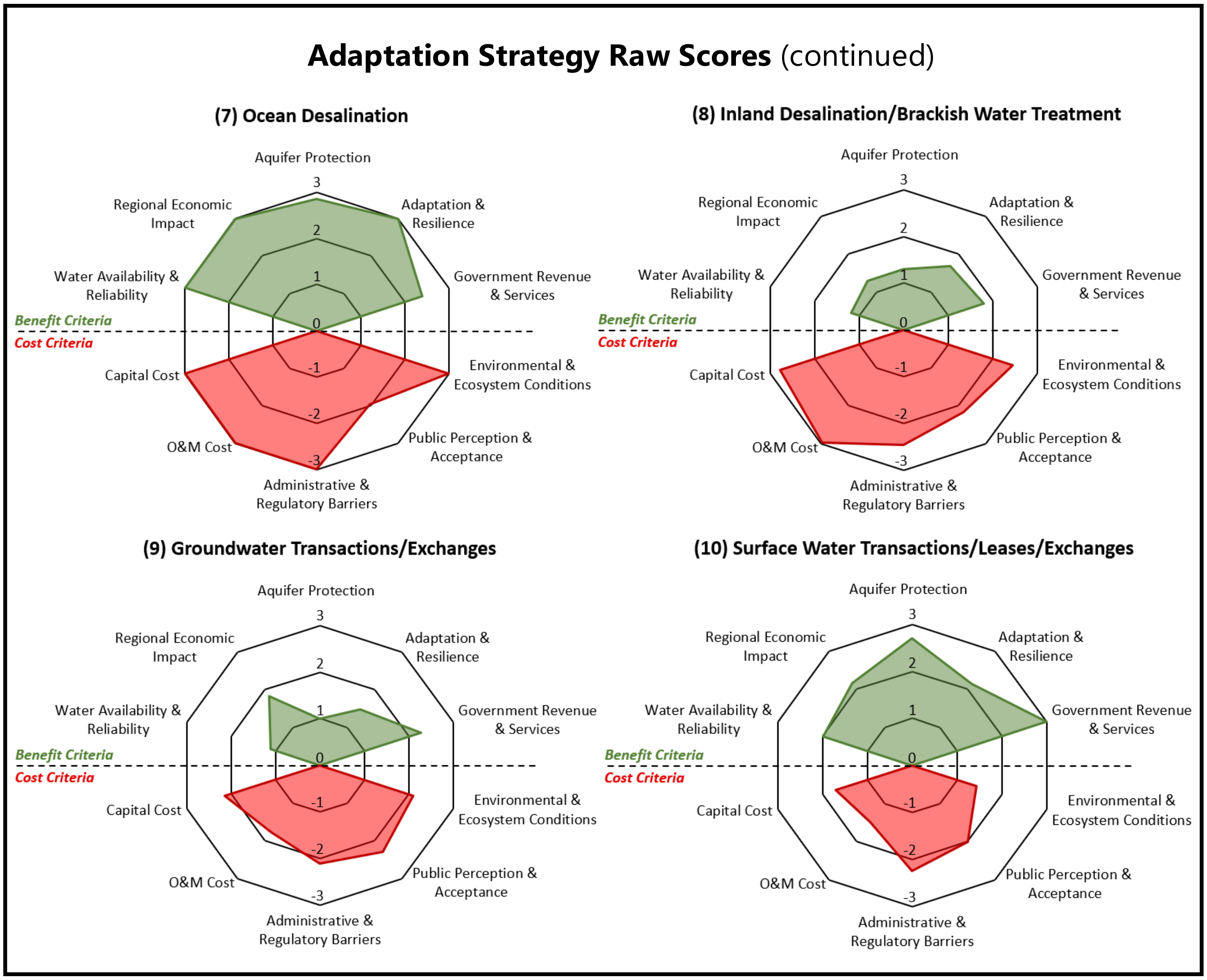

Figure 6.1 – Adaptation Strategy Raw Scores (continued)

Figure 6.1 illustrates the trade-offs underlying the raw scores for each strategy. Looking at (1)*Demand Management*, the results indicate that this strategy is overall the least-cost alternative, while also offering relatively large benefits along several dimensions. These features are why (1)*Demand Management* performs 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*. Figure 6.1 also highlights that these two strategies scored similarly, indicating that there are only minor differences between the two, which are primarily along cost considerations. In particular, *OM&R Cost* and *Public Perception and Acceptance* scores slightly worse for (4)*Local Effluent Reuse/Recharge*, while *Capital Cost* and *Environmental and Ecosystem Conditions* scores slightly worse for (5)*Regional Effluent Recharge*. 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 overall. Relative to the regional and local effluent recharge strategies, this strategy comes with lower *Administrative and Regulatory Barriers*, but greater costs for *Environmental and Ecosystem Condition*. Looking at benefits, this strategy also offers less *Aquifer Protection* and *Adaptation and Resilience*. The final effluent strategy, (2)*Regional Effluent – Direct Potable Reuse*, also offers several benefits but comes with greater costs than all other forms of effluent use. 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*, leading this strategy to rank 7th based on raw scores. 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 region scale, is likely to be most efficient. This assessment is limited to evaluating strategies independently, which avoids having a myriad of possible alternatives to compare but misses potential synergies between strategies. Future work could examine a combination of key strategies to provide additional information, and this study helps to identify those strategies worth further consideration.

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. Meanwhile, (8)*Inland Desalination/Brackish Water Treatment* provides similar benefits but comes with much higher costs. This strategy has a relatively high cost along all cost criteria considered, causing it to rank 10th and receive the lowest raw score. Notably, this strategy performs poorly in terms of *OM&R Cost* and *Capital Cost*, scoring slightly worse than (2)*Regional Effluent – Direct Potable Reuse* and only performing slightly better than (7)*Ocean Desalination* along these dimensions. However, (7)*Ocean Desalination* ultimately ranks 6th based on raw scores since it provides high benefits along all dimensions, even though it also comes with the highest *Capital Cost*, *OM&R Cost*, *Administrative and Regulatory Barriers*, and *Environmental and Ecosystem Conditions* of any strategy. In other words, this strategy 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 offering low benefits and coming with moderate costs. In particular, this strategy does little for *Aquifer Protection*, *Water Availability and Reliability*, and *Regional Economic Impact*, scoring similar to (6)*Poor Quality Groundwater Treatment* along these criteria, but coming with slightly higher costs. The final strategy, (10)*Surface Water Transactions/Leases/Exchanges*, ranks 5th among the strategies considered. This stems from relatively 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 to 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.

6.2 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 in only one possible weighting scheme, and it may not accurately represent trade-offs between the criteria of interest. In this section, different weighting schemes are used to examine how strategies perform under different objectives. Several weighting schemes are utilized to give additional weight to select criteria, one defined as *Economic and Financial*, one as *Environment and Sustainability*, and one as *Social and Administrative*. The final weighting scheme reflects 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, these preferences are not necessarily reflective of the public, so several weighting schemes are tested to highlight how strategies perform under alternative considerations and an overall rank is provided to identify which strategies perform best across all five weighting schemes together.

The raw scores previously shown in Figure 6.1 show how strategies perform for each criterion, while the weighting schemes are used to highlight how strategies perform under different criteria groupings and criteria preferences. Table 6.2 shows how each strategy ranks under the different weighting schemes. The overall ranking across all weighting schemes is identical to the *All Criteria* scheme which places equal weight on each criterion. This is not entirely surprising, since the overall rank gives equal preference to each of the weighting schemes, and given how the weighting schemes are defined, each criterion is included three times in the overall rank. That said, these rankings only differ slightly from the *Team Survey* weighting scheme, suggesting that the rankings are robust to equal weight placed on each criterion versus weights based on the preferences of study partners. There is however notable variation across the remaining weighting schemes which represent particular criteria groupings, with strategies such as (7)*Ocean Desalination* ranking 3rd for *Economic and Financial* considerations, but 7th for *Environment and Sustainability* and 9th for *Social and Administrative* considerations, leading the strategy to rank 6th overall. These weighting schemes help to further highlight strategy strengths and weaknesses along different dimensions.

Table 6.2 – Strategy Rank Under Different Weightings 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**
(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 is 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 6.2 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 6.3 provides a cardinal score for strategies under each weighting scheme, reported as a percentage of the highest-ranking strategy (i.e. 1st=100%). 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 6.3 – Score Magnitudes Under Different Weightings 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.

6.3 Discussion of Results

The results of the trade-off analysis show 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. A combination of effluent use, direct and indirect, potable and non-potable, and at a local scale and regional scale, is likely to be most efficient. 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 thus lower net benefit than the other alternatives considered.

The different weighting schemes that are tested highlight how strategies perform under different criteria groupings and criteria preferences. Recall that under the *All Criteria* scheme the top-performing strategies are (1)*Demand Management*, (5)*Regional Effluent Recharge*, (4)*Local Effluent Reuse/Recharge*, and (3) *Regional Effluent – Direct Non-Potable Reuse*, respectively. The results in Table 6.3 show that all of these strategies perform well, with only slight differences in score magnitudes across the effluent strategies. Direct non-potable effluent reuse performs worse than local and regional effluent recharge due to *Environment and Sustainability* considerations. Meanwhile, (1)*Demand Management* is the top performing strategy under several weighting schemes, and consistently scores at least 92% 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% of the top-scoring strategy. Similar to the other top-scoring strategies, this strategy scores fairly consistently across weighting schemes, implying that it performs well across all dimensions considered. 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% separating their overall performance. This means that their exists both demand-side and supply-side opportunities 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% of the top-scoring strategy. This strategy provides low benefits and comes with high costs, performing best under *Social and Administrative* considerations at 46% of the top-scoring strategy, and worst under *Economic and Financial* considerations at 34% of the top strategy. The strategy (9)*Groundwater Transactions/Exchanges* ranks 8th overall but scores relatively better at 53% of the top-performing strategy, with the best performance under *Social and Administrative* considerations at 57% of the top-scoring strategy, and worst under *Environment and Sustainability* considerations at 41% 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% 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% of the top-scoring strategy and ranking 6th. The strategy (6) *Poor Quality Groundwater Treatment* scored only 50% of the top strategy overall and ranked 9th, performing best under *Social and Administrative* considerations at 70% of the top strategy and worst under *Environment and Sustainability* considerations at 32% of the top strategy. Meanwhile, (7) *Ocean Desalination* was the opposite, performing the best under *Environment and Sustainability* considerations at 72% of the top strategy and worst under *Social and Administrative* considerations at 50% 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.

When considering all costs and benefits, a combination of supply-side and demand-side strategies is likely optimal for addressing future water shortages in the study area and central Arizona more broadly. 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 in this study helps to 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.

7.0 Conclusion and Opportunities

The WSRV Basin Study is a collaborative effort between USBR, WVWA, and several cities and water providers in the West Valley of central Arizona. The goal of the study is to evaluate regional water supply and demand under changing climate conditions and population growth, and to develop and evaluate adaptation strategies that ensure future sustainability of water resources within the West Valley area. The purpose of the *Economic and Trade-Off Analysis* is to compare adaptation strategies 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 cost and benefit criteria are used to compare 10 adaptation strategies. Evaluation criteria are analyzed under different combinations and weighting schemes to rank the performance of each adaptation strategy 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.

Several supply and demand scenarios from CAP:SAM are assessed for the period 2020-2060, each reflecting a different magnitude of annual water shortages across time, absent any adaptation efforts. These scenarios serve as a baseline for quantifying welfare effects from future water shortages and measuring and comparing adaptation strategy benefits for M&I, agricultural, and recreational water use in the study area and surrounding central Arizona region which shares many of the same water resources. Welfare effects for market use are based on changes in raw water prices in the regional wholesale market and impacts on recreation are based on surface water conditions in the area. This is the economic portion of the analysis. For the trade-off analysis, regional economic impacts are also quantified, measured according to effects on value added, income, and employment. Several additional benefit and cost criteria are evaluated qualitatively based on a scoring survey of study partners. This is used to capture various economic, financial, environmental, and social considerations that could not easily be quantified for the analysis. Several weighting schemes are tested to identify how strategies perform under different preferences for criteria importance. The results of the trade-off analysis identify important trade-offs and highlight the strengths and weaknesses of each adaptation strategy.

In general, the results show 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. A combination of effluent use, direct and indirect, potable and non-potable, and at a local scale and regional scale, is likely to be most efficient, but further examination is needed. 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. This means that these strategies may not be the best options to develop and implement first, but they should not necessarily be ruled out. Many of these strategies are worth looking at in greater detail, particularly in combinations where there could be potential synergies, or at least few trade-offs with combined implementation.

7.1 Limitations

The *Economic and Trade-Off Analysis* serves as a screening tool to help identify those strategies that are best suited to address future imbalances between water supply and demand. The analysis relies on existing data and is dependent on the outputs identified in previous parts of the 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 and limitations exist. One key limitation of this assessment is that strategies are evaluated independently. This avoids assessing countless strategy combinations and helps to keep the analysis more manageable, but also misses any 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, and the results from this analysis inform which strategies are worth further consideration.

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 is necessary to perform a traditional economic analysis that compares monetary costs and benefits to identify the alternative with the greatest net benefit. However, as made clear in this assessment, not only those costs and benefits which can be monetized are 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 life-cycle impacts of a strategy could prove to be different than the impact across 40 years. Also, when translating CAP:SAM outputs into welfare effects, water demand is assumed to be iso-elastic and water supply is assumed to be perfectly inelastic. These numerous assumptions could lead to inaccurate price and welfare effects and adjusting these parameters and assumptions could influence the results. Ideally, these simplifying assumptions should have minimal influence on the results of the trade-off analysis, in part because everything is compared purely on a relative basis, and because these assumptions only influence the measurement of 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 are important to consider whenever comparing monetized costs and benefits.

It is also worth noting that the price effects estimated in this analysis are only associated with water shortages, while there are other factors that could influence price, such as macroeconomic conditons and regulations. The price effects in this analysis should therefore not be thought of as projections of future water prices, but rather, the effects of water shortages on prices, all else equal. That said, these other sources of price changes are not relevant to this analysis since they are assumed to be unaffected by adaptation strategies and therefore do not have any bearing on the trade-off analysis. Lastly, this analysis uses a simplified approach to quantify *Regional Economic Impact*, calculating effects based on a recent IMPAN study looking at the importance of Colorado River water. Conducting an original regional impact analysis would be time and resource intensive but could provide a more accurate estimate of regional impacts across different strategies and types of raw water.

7.2 Future Opportunities

This study utilized readily available data and information to compare adaptation strategies aimed at reducing water shortages, highlighting the strengths and weaknesses of each strategy. The strategies that perform well in this analysis should be examined in greater detail, especially in combination with other strategies that might provide synergies. Future work would also benefit from quantifying some of the criteria measured qualitatively in this assessment, such as capital and OM&R costs, and examining the life-cycle of a strategy is preferable to a fixed time horizon. This would permit a traditional cost-benefit analysis and assessment of feasibility. Additional criteria could also be considered, and criterion such as *Environmental and Ecosystem Condition* could be sub-divided into multiple and more detailed criteria. 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. While this study provides a screening analysis for adaptation strategies, further examination of strategy feasibility is warranted in order to identify the optimal way to address future water shortages in the central Arizona region while considering strategy combinations and all potential costs and benefits.

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Appendix A – Studies Used in Benefit Transfer to Value Recreation

Study	Activity	Method
Adams et al. (1989)	Hunting, Small Game	SP
Adrangi (1982)	Skiing, Downhill	RP
Aiken (2009)	Freshwater Fishing; Hunting, Big Game; Wildlife Viewing	SP
Aiken & Rouche (2003)	Freshwater Fishing; Hunting, Big Game; Wildlife Viewing	SP
Anderson (2010)	Rock & Ice Climbing	RP
Bergstrom & Cordell (1991)	Bicycling, Leisure; Horseback Riding	RP
Betz et al. (2003)	Bicycling, Leisure	SP
Bhat et al. (1998)	Boating, Motorized	RP
Bishop et al. (1987)	Freshwater Fishing	SP
Bowker et al. (2004)	Bicycling, Leisure	RP
Bowker et al. (2009)	Backpacking; Hiking; Picnicking; Skiing, Downhill	RP
Brown & Hammack (1972)	Waterfowl Hunting	SP
Brown & Hay (1987)	Freshwater Fishing; Hunting, Big Game; Hunting, Waterfowl	SP
Brown & Plummer (1979)	Hiking; Hunting, Small Game	RP
Chakraborty & Keith (2000)	Bicylcing, Mountain	RP
Connelly & Brown (1988)	Wildlife Viewing	SP
Cooper & Loomis (1991)	Waterfowl Hunting	SP
Cooper & Loomis (1993)	Waterfowl Hunting	RP
Cory & Martin (1985)	Hunting, Big Game	SP
Crandall (1991)	Wildlife Viewing	RP
Duffield & Neher (1991)	Waterfowl Hunting	SP
Ekstrand (1994)	Rock Climbing	RP & SP
Englin & Moeltner (2004)	Skiing, Downhill; Snowboarding	RP
Englin & Shonkwiler (1995)	Hiking	RP
Englin et al. (2001)	Hiking	RP
Fadali & Shaw (1998)	Boating, Motorized	RP
Fix & Loomis (1998)	Bicycling, Mountain	RP & SP
Gornik et al. (2013)	Boating, Motorized	RP
Hackett (2000)	Hiking	RP
Hammer (2001)	Boating, Nonmotorized	RP
Hansen (1977)	Hunting, Small Game; Hunting, Waterfowl	SP
Harris (2010)	Freshwater Fishing	SP
Hausman et al. (1995)	Boating, Motorized; Hiking	RP
Hay (1988)	Freshwater Fishing; Hunting, Big Game; Hunting, Waterfowl	SP
Hay (1988)	Wildlife Viewing	SP
Hesseln et al. (2003)	Bicycling, Mountain; Hiking	RP
Hesseln et al. (2004)	Bicycling, Mountain; Hiking	RP
Hesseln et al. (2004)	Hiking	RP
Hilger (1998)	Hiking	RP
Keith et al. (1982)	Boating, Nonmotorized	SP

Keske & Loomis (2007)	Hiking	SP
Keske & Loomis (2008)	Hiking	SP
King & Hof (1985)	Freshwater Fishing	RP
King & Walka (1980)	Freshwater Fishing	RP
Loomis (1979)	Hiking	RP
Loomis & Keske (2009)	Hiking	RP
Loomis & Keske (2009)	Hiking	SP
Loomis & Keske (2012)	Hiking	SP
Loomis et al. (2001)	Bicycling, Mountain; Hiking	RP
Lutz et al. (2000)	Hiking	RP
Martin et al. (1974)	Freshwater Fishing; Hunting, Big Game; Hunting, Small Game; Hunting, Waterfowl	RP
McCollum et al. (1990)	Hiking; Picnicking; Swimming	RP
McKean et al. (2005)	Swimming	RP
Mendelsohn & Roberts (1982)	Hiking	RP
Miller (1983)	Freshwater Fishing	RP
Miller & Hay (1984)	Freshwater Fishing	RP
Moeltner (2003)	Hiking	RP
Morey (1985)	Skiing, Downhill	RP
Richards (1980)	Wildlife Viewing	RP
Richards et al. (1985)	Freshwater Fishing	RP
Richards et al. (1990)	Camping	RP & SP
Richer & Christensen (1999)	Hiking	SP
Rosenthal & Walsh (1986)	Hiking	SP
Shulstad & Stoevener (1978)	Hunting, Small Game	RP
Siderelis & Moore (1995)	Bicycling, Leisure; Hiking	RP
Smith & Kopp (1980)	Hiking	RP
Sorg & Nelson (1987)	Waterfowl Hunting	RP & SP
Starbuck et al. (2006)	Bicycling, Mountain	RP & SP
Sublette & Martin (1975)	Camping; Freshwater Fishing	RP & SP
Sutherland (1982)	Boating, Motorized	RP
Sutherland (1982)	Boating, Motorized	RP
Waddington et al. (1994)	Freshwater Fishing; Hunting, Big Game; Wildlife Viewing	SP
Walsh & Gilliam (1982)	Hiking	SP
Walsh & Olienyk (1981)	Hiking	SP
Walsh et al. (1982)	Hiking	RP
Walsh et al. (1984)	Hiking; Skiing, Cross-County	SP
Ward (1982)	Boating, Motorized; Swimming	RP
Wennergren (1965)	Boating, Motorized	RP
Williams (1994)	Boating, Motorized	RP & SP
Young et al. (1987)	Hunting, Small Game	SP

SP=Stated Preference, RP=Revealed Preference.

Appendix B – Water Availability and Reliability Benefits by User, 2020-2060

Adaptation Strategy	M&I Provider				
	Arizona WC White Tank	Avondale	Buckeye	El Mirage	EPCOR Agua Fria
(1) Demand Management	$4.92	$5.28	$32.24	$2.36	$4.68
(2) Regional Effluent – Direct Potable Reuse	$3.74	$3.60	$24.74	$1.45	$2.44
(3) Regional Effluent – Direct Non- Potable Reuse	$3.78	$3.68	$24.98	$1.49	$2.54
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$3.76	$3.64	$24.86	$1.47	$2.49
(5) Regional Effluent Recharge	$3.76	$3.64	$24.86	$1.47	$2.49
(6) Poor Quality Groundwater Treatment	$0.98	$0.95	$6.28	$0.44	$0.54
(7) Ocean Desalination	$6.32	$6.38	$42.69	$2.59	$5.56
(8) Inland Desalination/ Brackish Water Treatment	$2.89	$2.75	$19.04	$1.19	$1.61
(9) Groundwater Transactions/Exchanges	$3.65	$3.83	$23.88	$1.75	$2.98
(10) Surface Water Transactions/Leases/ Exchanges	$4.27	$4.46	$28.09	$2.01	$3.70

Values are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. These benefits are for CAP:SAM Scenario D.

Adaptation Strategy	**M&I Provider** (continued)				
	EPCOR Sun City	EPCOR Sun City West	Glendale	Goodyear	Peoria
(1) Demand Management	$1.18	$0.63	$10.58	$7.96	$8.80
(2) Regional Effluent – Direct Potable Reuse	$0.69	$0.33	$6.24	$5.62	$5.56
(3) Regional Effluent – Direct Non-Potable Reuse	$0.71	$0.35	$6.44	$5.71	$5.70
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$0.70	$0.34	$6.33	$5.66	$5.62
(5) Regional Effluent Recharge	$0.70	$0.34	$6.33	$5.66	$5.62
(6) Poor Quality Groundwater Treatment	$0.22	$0.12	$1.96	$1.47	$1.62
(7) Ocean Desalination	$1.23	$0.59	$11.42	$9.95	$10.03
(8) Inland Desalination/ Brackish Water Treatment	$0.58	$0.29	$5.23	$4.33	$4.51
(9) Groundwater Transactions/Exchanges	$0.87	$0.47	$7.87	$5.86	$6.52
(10) Surface Water Transactions/Leases/ Exchanges	$1.00	$0.54	$9.05	$6.90	$7.59

Values are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. These benefits are for CAP:SAM Scenario D.

Adaptation Strategy	**M&I Provider** (continued)			
	Phoenix	Surprise	Tolleson	Outside M&I, All
(1) Demand Management	$33.79	$11.48	$0.07	$126.36
(2) Regional Effluent – Direct Potable Reuse	$19.94	$8.47	$0.04	$77.78
(3) Regional Effluent – Direct Non-Potable Reuse	$20.59	$8.57	$0.04	$80.05
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$20.23	$8.52	$0.04	$78.79
(5) Regional Effluent Recharge	$20.23	$8.52	$0.04	$78.79
(6) Poor Quality Groundwater Treatment	$6.26	$2.09	$0.01	$23.44
(7) Ocean Desalination	$36.32	$15.16	$0.07	$139.37
(8) Inland Desalination/ Brackish Water Treatment	$16.81	$6.39	$0.03	$63.39
(9) Groundwater Transactions/Exchanges	$25.18	$8.34	$0.05	$93.19
(10) Surface Water Transactions/Leases/ Exchanges	$28.99	$9.87	$0.06	$107.34

Values are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. These benefits are for CAP:SAM Scenario D.

Adaptation Strategy	**Irrigation District**				
	Adaman*	Buckeye WCDD	Maricopa WD	Roosevelt ID	St. Johns ID*
(1) Demand Management	$0	$0.23	$1.44	$8.84	$0
(2) Regional Effluent – Direct Potable Reuse	$0	$0.12	$0.73	$5.01	$0
(3) Regional Effluent – Direct Non-Potable Reuse	$0	$0.13	$0.77	$5.19	$0
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$0	$0.13	$0.75	$5.09	$0
(5) Regional Effluent Recharge	$0	$0.13	$0.75	$5.09	$0
(6) Poor Quality Groundwater Treatment	$0	$0.04	$0.27	$1.65	$0
(7) Ocean Desalination	$0	$0.23	$1.31	$9.16	$0
(8) Inland Desalination/ Brackish Water Treatment	$0	$0.11	$0.66	$4.27	$0
(9) Groundwater Transactions/Exchanges	$0	$0.17	$1.08	$6.60	$0
(10) Surface Water Transactions/Leases/ Exchanges	$0	$0.19	$1.21	$7.54	$0

Values are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. These benefits are for CAP:SAM Scenario D.
*These users depend solely on direct use (groundwater and/or local surface water) and are not expected to experience a shortage during the study period, meaning they do not benefit from adaptation strategies.

Adaptation Strategy	Irrigation District (continued)		Recreational Activity	
	Salt River Project	Outside Irrigation, All	Bicycling	Camping
(1) Demand Management	$1.97	$17.63	$8.58	$0.41
(2) Regional Effluent – Direct Potable Reuse	$1.03	$8.78	$6.45	$0.31
(3) Regional Effluent – Direct Non-Potable Reuse	$1.07	$9.22	$6.47	$0.31
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$1.04	$8.98	$5.53	$0.26
(5) Regional Effluent Recharge	$1.04	$8.98	$5.53	$0.26
(6) Poor Quality Groundwater Treatment	$0.36	$3.45	$0	$0
(7) Ocean Desalination	$1.82	$14.63	$15.36	$0.73
(8) Inland Desalination/ Brackish Water Treatment	$0.88	$7.99	$4.13	$0.21
(9) Groundwater Transactions/Exchanges	$1.41	$13.83	$0	$0
(10) Surface Water Transactions/Leases/ Exchanges	$1.58	$15.68	$7.63	$0.37

Values are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. These benefits are for CAP:SAM Scenario D.

Adaptation Strategy	**Recreational Activity** (continued)				
	Fishing	Hunting and Shooting	Picnicking and Relaxing	Trail Sports	Water Sports
(1) Demand Management	$18.08	$0.97	$3.65	$9.74	$13.05
(2) Regional Effluent – Direct Potable Reuse	$12.97	$0.73	$2.73	$7.30	$9.36
(3) Regional Effluent – Direct Non-Potable Reuse	$13.03	$0.73	$2.74	$7.33	$9.40
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$11.07	$0.62	$2.34	$6.26	$7.99
(5) Regional Effluent Recharge	$11.07	$0.62	$2.34	$6.26	$7.99
(6) Poor Quality Groundwater Treatment	$0	$0	$0	$0	$0
(7) Ocean Desalination	$31.62	$1.73	$6.48	$17.37	$22.82
(8) Inland Desalination/ Brackish Water Treatment	$11.09	$0.48	$1.86	$4.83	$8.00
(9) Groundwater Transactions/Exchanges	$0	$0	$0	$0	$0
(10) Surface Water Transactions/Leases/ Exchanges	$16.88	$0.87	$3.28	$8.71	$12.18

Values are in millions ($2020) and discounted using the 2020 Federal *Water Resources Planning* rate of 2.75%. These benefits are for CAP:SAM Scenario D.

Adaptation Strategy	Recreational Activity (continued)		Grand Total
	Wildlife Watching	Outside Recreation, All	
(1) Demand Management	$9.32	$81.07	**$425.30**
(2) Regional Effluent – Direct Potable Reuse	$6.97	$57.42	**$280.53**
(3) Regional Effluent – Direct Non-Potable Reuse	$7.00	$57.83	**$285.84**
(4) Local Effluent Reuse/Recharge – Potable or Non-Potable	$5.98	$49.19	**$267.66**
(5) Regional Effluent Recharge	$5.98	$49.19	**$267.66**
(6) Poor Quality Groundwater Treatment	$0	$0	**$51.07**
(7) Ocean Desalination	$16.56	$134.20	**$561.67**
(8) Inland Desalination/ Brackish Water Treatment	$4.69	$42.59	**$220.82**
(9) Groundwater Transactions/Exchanges	$0	$0	**$207.53**
(10) Surface Water Transactions/Leases/ Exchanges	$8.35	$73.14	**$371.46**

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