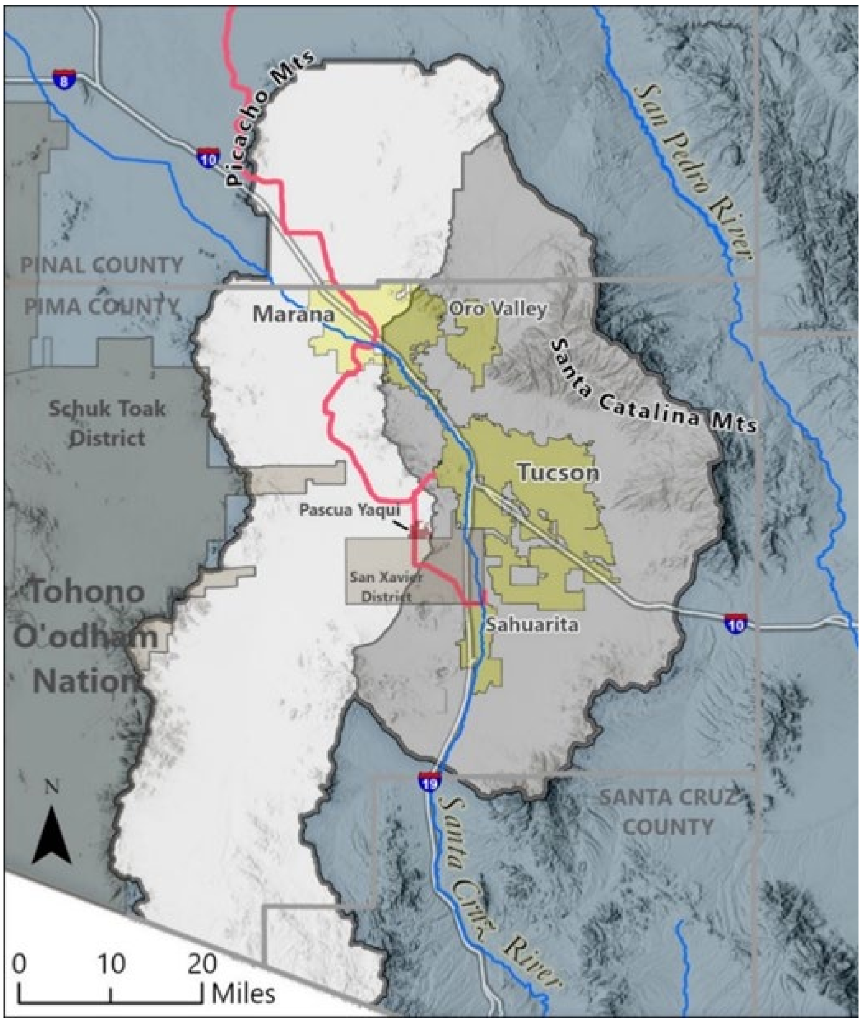
BUREAU OF RECLAMATION

Lower Santa Cruz River Basin Study

Executive Summary



U.S. Department of the Interior

May 2024

Mission Statements

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

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

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Acronyms

ADWR	Arizona Department of Water Resources
AMA	Active Management Area
AWS	Assured Water Supply
CAP	Central Arizona Project
CAP:SAM	Central Arizona Project Service Area Model
CAWCD	Central Arizona Water Conservation District
CBRFC	Colorado Basin River Forecast Center
GCM	Global Climate Model
LSCR	Lower Santa Cruz River
MPI-ESM-LR	Low Resolution Max Planck Institute Earth System Mode
NWRRDS	Northwest Recharge Recovery and Delivery System
RCP	Representative Concentration Pathway
RSD	Relative standard deviation
SAC-SMA	Sacramento Soil-Moisture Accounting

Introduction

The Bureau of Reclamation (Reclamation) joined with the Southern Arizona Water Users' Association and five other non-federal cost-share partners[1] (Study Partners) in 2016 to conduct the Lower Santa Cruz River Basin Study (LSCR Basin Study) in southern Arizona. The Study is the first direct assessment of climate impacts and municipal growth on the LSCR Basin's water supplies and demands. It engaged a wide variety of local stakeholders, including members of the public.

The Study Area, which is identical to the state-designated Tucson Active Management Area, is depicted in Figure ES-1. The climate is semi-arid at lower elevations, with annual precipitation ranging from 11 to 16 inches. In the mountains, precipitation can total as much as 30 inches per year (Arizona Department of Water Resources, 2016).

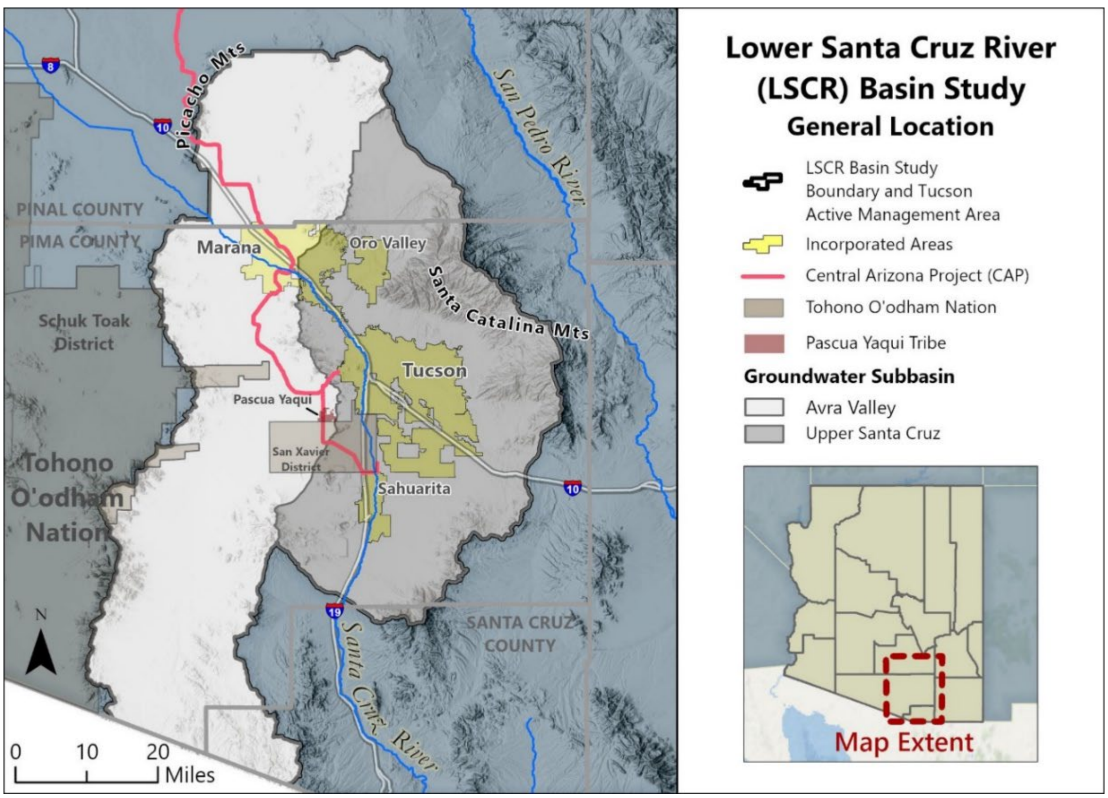


Figure ES-1. General location map for the Lower Santa Cruz River Basin Study.

[1] Cost-share partners include the Southern Arizona Water Users' Association, the Central Arizona Water Conservation District, the Arizona Department of Water Resources, the Pima Association of Governments, the University of Arizona, and the Cortaro-Marana Irrigation District.

From the development of the Tucson region in the 1800s through the 1990s, water users relied primarily on groundwater, which led to significant cones of depression around pumping sites. As shown in Figure ES-2, beginning in the 1990s, these drawdowns began to be offset by recharge of renewable Colorado River water transported via the Central Arizona Project (CAP), a 336-mile canal system that brings Colorado River water to Maricopa, Pinal, and Pima counties. However, local supply-demand imbalances in certain areas of the LSCR Basin have persisted due to a lack of delivery infrastructure for renewable supplies. Other challenges to a sustainable water supply for the Study Area include shortages to CAP deliveries, the growth of municipal and industrial demand, and a potential reduction in LSCR Basin-wide natural recharge due to climate impacts.

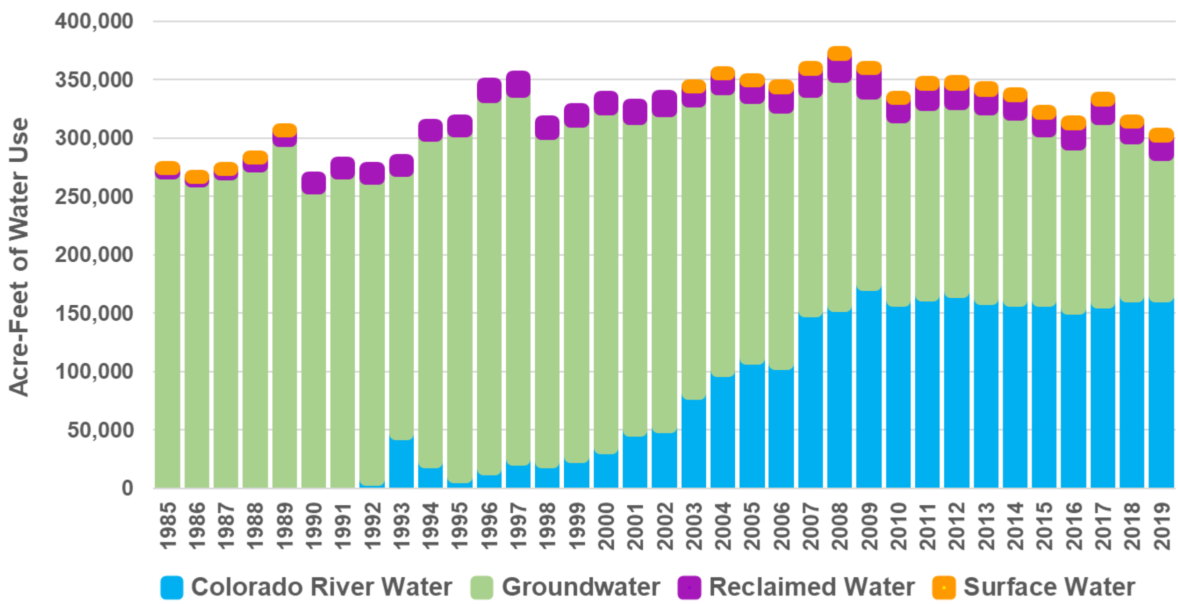


Figure ES-2. Water use by source in the Tucson Active Management Area, 1985-2019, accessed from AMA Data; Arizona Department of Water Resources (azwater.gov), March 28, 2022.

The Study had two key goals:

A) Identify where physical water resources were needed to mitigate supply-demand imbalances due to changes in climate and other factors.

B) Develop strategies to improve water reliability for the municipal, industrial, agricultural, and environmental sectors.

To this end, Reclamation and the Study Partners conducted a LSCR Basin-wide Hydroclimate (climate and surface water) Analysis, a Supply and Demand Analysis, and a Groundwater Modeling Analysis. Two stakeholder workshops were held to garner ideas for a wide range of adaptation strategies. Information regarding effectiveness, implementability, and cost were developed for a subset of these strategies and documented in the Adaptation Strategy Technical Memorandum. Finally, Reclamation and the Study Partners conducted an Economic and Trade-off Analysis of the adaptation strategies. All of these activities are documented in the LSCR Basin Study Final Report and the LSCR Basin Study Appendices.

Hydroclimate Analysis

Methodology

Climate Model Downscaling

Reclamation conducted a LSCR Basin Hydroclimate (climate and surface water) Analysis using advanced scientific products and methods, specifically, with the use of a dynamically downscaled climate projections and the development of a probabilistic weather generator. In this context, 'downscaling' refers to the process of enhancing the spatial resolution of a climate projection to include the detail necessary for running a hydrologic model. As shown in Figure ES-3, a projection from a Global Climate Model (GCM) with a spatial resolution of 1 degree latitude by 1 degree longitude can be downscaled to a spatial resolution of 6 kilometers by 6 kilometers in order to be used as input to a basin-scale hydrologic model.

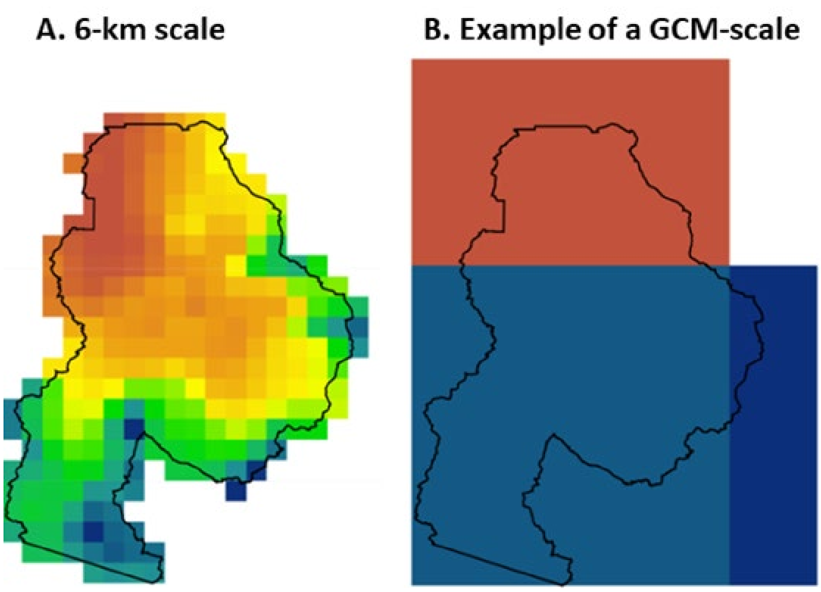


Figure ES-3. Example of resolutions from a downscaled projection (left) and a Global Climate Model projection prior to downscaling (right). These use the same Global Climate Model input.

Downscaling can be performed using relationships developed from historical data (statistical downscaling) or with the use of higher resolution, regional-scale atmospheric models (dynamical downscaling). Statistical downscaling is computationally straightforward, which allows the output of many different models, run under a variety of emissions scenarios, to be downscaled and used as hydrologic model inputs. On the other hand, statistical downscaling has the disadvantage on relying on historical observations to project the future (known as stationarity). Dynamical downscaling simulates the physical processes that take place at a higher resolution, regional scale within the atmosphere, but it is also computationally intensive, which limits the number of dynamically downscaled climate projections available to practitioners. Prior to this Basin Study, all Reclamation Basin Studies had employed statistically downscaled climate projections, but this Study used both statistically and dynamically downscaled projections.

Climate Scenario Selection

To simplify the analysis, Study Partners requested the development of two climate scenarios to represent the range of risk to water supplies in the LSCR Basin. To test the resilience of supplies and provide a conservative basis for adaptation planning, Partners requested a "high-risk" climate future in which water supplies would be put under significant stress. They chose to call this the "worse-case" scenario, to indicate that while this climate would pose significant water supply risks, more extreme levels of climate change were still possible. On the other end of the spectrum, they requested a "low-risk", or "best-case" climate future that would require a lower level of adaptation. In addition, for certain sections of the Study, a "current climate" scenario, using the past 30 years of temperature and precipitation, was included for comparison purposes.

Development of these two climate "futures" began with scenarios of worldwide greenhouse gas emissions. The Intergovernmental Panel on Climate Change 5th Assessment Report examined four emissions scenarios through the year 2100, termed Representative Concentration Pathways (RCPs) (depicted in Figure ES-4). RCP 2.6 would require stringent climate policies to limit emissions, while RCP 4.5 and RCP 6.0 are medium emission stabilization scenarios. RCP 8.5 is representative of the high range of non-climate policy scenarios (van Vuuren, et al., 2011). In consultation with the Study Partners and in alignment with the availability of GCM projections, the LSCR Basin Study used RCP 4.5 as its best-case, and RCP 8.5 as its worse-case future climate scenario.

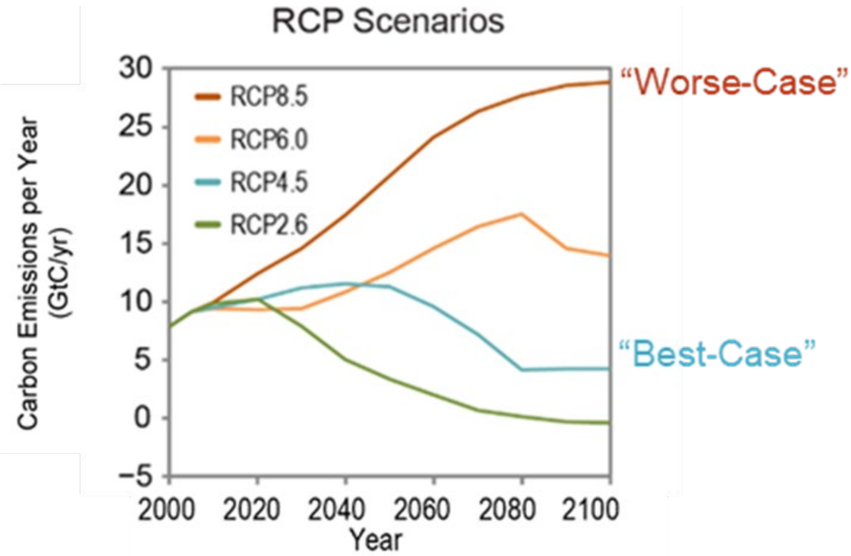


Figure ES-4. Annual carbon emissions (gigatons of carbon [GtC] per year) by RCP. Graphic adapted from Hayhoe, K. J. et al., 2017: Climate models, scenarios, and projections. In *Climate Science Special Report: Fourth National Climate Assessment*, Volume 1.

Incorporating a dynamically downscaled climate projection into the Study posed challenges. Due to the computationally intensiveness of dynamical downscaling, only a limited number of climate projections were available. In the end, a single dynamically downscaled projection, run under RCP 8.5, noted for its ability to reproduce the timing of the Basin's monsoon, was selected to represent the worse-case climate future. This selected projection was the Low Resolution Max Planck Earth System Model (MPI-ESM-LR), run downscaled using the Weather Research and Forecasting Model by researchers at the University of Arizona. However, no corresponding dynamically downscaled projection using RCP 4.5 was available. After extensive testing, a statistically downscaled version of the same climate model (MPI-ESM-LR downscaled with Locally Constructed Analogs) run under RCP 4.5, was selected to represent the best-case future climate.

Incorporating Variability with a Weather Generator

The southern Arizona climate is characterized by a high degree of annual and interannual variability (Sheppard, Comrie, Packin, Angersbach, & Hughes, 2002) and the Study Partners requested that this variability be incorporated into the Hydroclimate Analysis. This request led to the other major innovation in this Study, the use of a probabilistic weather generator.

A weather generator is a statistical model used to create many sequences of weather variables, such as precipitation and temperature, while maintaining selected statistical characteristics of an original data set. In this case, the weather generator was designed to reproduce the transition probabilities between wet and dry days for each of three "seasons": the monsoon, winter wet, or dry portions of the year.

The weather generator was used to produce groups, or ensembles, of 100 temperature and precipitation time-series for each of two 30-year periods. As a group, an ensemble of 100 time-series represented a plausible range of daily rainfall and temperature values at a time scale appropriate for use in a surface water model. Due to the highly seasonal nature of precipitation in this basin, the weather generator developed ensembles with distinct dry, monsoon and winter wet seasons (Figure ES-5).

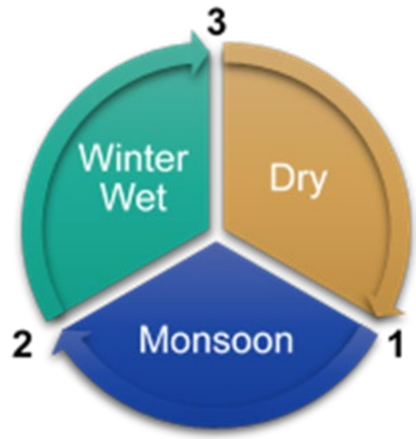


Figure ES-5. Conceptual diagram of the seasonal weather generator.

The Hydroclimate Analysis used the "Period Change" method, using standard World Meteorological Organization periods of thirty years described in Brekke et al., (2011). As the Study's climate projections extended through the year 2100, it was possible to develop results for two thirty-year periods: 2020 – 2049 and 2050 – 2079, as shown in the Figure ES-6.

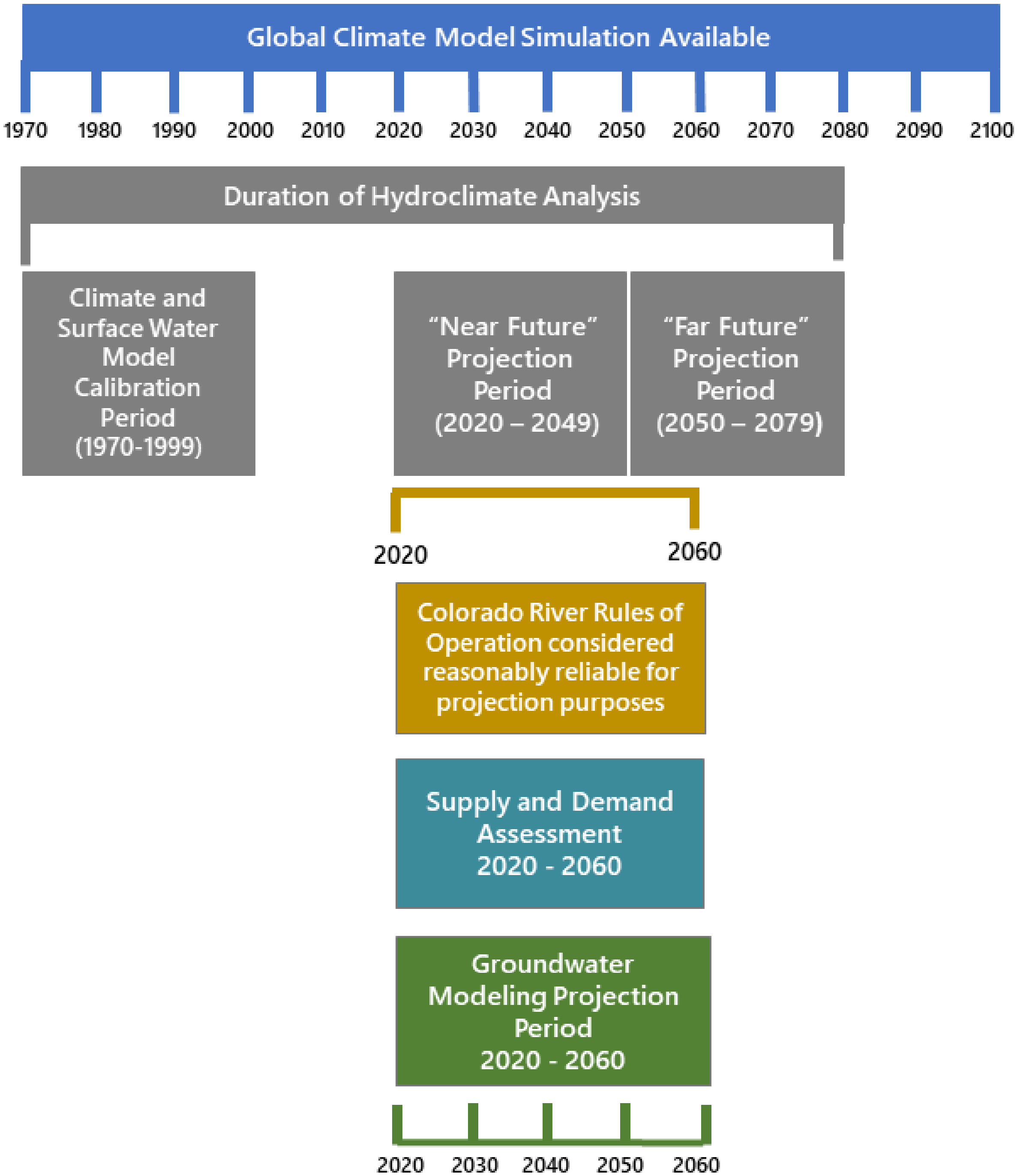


Figure ES-6. Diagram of time horizons for the LSCR Basin Study modeling analyses.

Surface Hydrology Model Selection

To simulate surface flows in the Study Area, Reclamation modelers selected the Sacramento Soil Moisture Accounting Model (Burnash, Ferral, & McGuire, 1973) which is used by the National Weather Service's Colorado Basin River Forecast Center (CBRFC). The model was calibrated for the period of 1970 – 1999. Thus, the Hydroclimate Analysis compared the weather-generated ensembles of projected temperature, precipitation, and streamflow for each of the two future periods with the historical period of 1970 – 1999. This analysis was performed for each of the two climate projections – the best-case based on the RCP 4.5 emissions scenario and the worse-case based on the RCP 8.5 emissions scenario.

Hydroclimate Analysis Results

Seasonal and Annual Average Changes

Consultation with the Study Partners led to the specific analyses and results developed from the Hydroclimate Analysis. Results included projected changes in seasonal average temperature and precipitation, changes in the time of onset and length of each season, as well as changes in variability and extreme values. A summary of results is shown in Table ES-1.

Findings included steadily increasing temperatures under both climate scenarios. For precipitation, the best-case projected relatively minimal change in seasonal precipitation; in the worse-case scenario, total precipitation decreased substantially in the monsoon and winter wet seasons. Precipitation was also projected to become increasingly variable.

Table ES-1. Summary of Climate Change Analysis Results, compared to 1970 – 1999 historic period

Statistic	Best-Case 2020-2049	Best-Case 2050-2079	Worse-Case 2020-2049	Worse-Case 2050-2079
Change in Total Annual Precipitation	0.32″	-0.85″	-4.34″	-3.90″
Change in Average Monsoon Precipitation	0.80″	-0.87″	-2.38″	-1.57″
Change in Average Winter Wet Precipitation	-0.21″	0.57″	-2.25″	-2.38″
Change in Average Dry Season Precipitation	-0.27″	-0.55″	0.28″	0.05″
Annual Precipitation RSD* compared to Historical: Best = 20.3%, Worse = 17.3%	21.6%	28.5%	18.9%	30.4%
Change in Average Annual Temperature	2.94°F	3.83°F	3.41°F	5.12°F
Change in Average Dry Season Temperature	2.59°F	2.31°F	3.44°F	3.34°F
Change in Average Monsoon Temperature	1.96°F	3.52°F	4.24°F	5.81°F
Change in Average Winter Wet Temperature	1.88°F	1.85°F	2.45°F	3.20°F

*Relative standard deviation (RSD) is calculated by normalizing the standard deviation to the mean of the 30-year period and presented as a percentage. RSD for temperature was < 2%.

Changes in Temperature and Precipitation Extremes

The use of the weather generator to produce ensembles of future temperature and precipitation time series allowed an analysis of changes in extreme values, here defined as the top ten (10) percent (%) of each distribution. Extreme temperatures increase consistently in every season, with the largest increases occurring in the dry and monsoon seasons, which are the spring and summer months when extreme temperatures pose the largest public health risk.

For this Study, extreme precipitation was defined as daily rainy-day precipitation that exceeds the 90th percentile in a season, from all the years within a weather-generated 30-year simulation. Detection of changes in extreme precipitation events from daily, gridded model outputs is challenging because monsoon events are often short but intense, occur over small areas, and are highly variable in time and space. Despite these limitations, both the weather-generated best-case and worse-case scenarios include changes in extreme precipitation events. Changes in the central tendency across the ensembles of extreme precipitation were not consistent, although increases in extreme precipitation during the winter wet period were suggested by the mean and the median statistics. The 95th percentile of storms consistently increased through time for the both the monsoon and winter seasons.

These results should be considered in the context of their technical constraints: statistical downscaling (best-case) is restricted in its ability to forecast events outside of the historical range, while dynamical downscaling is not.

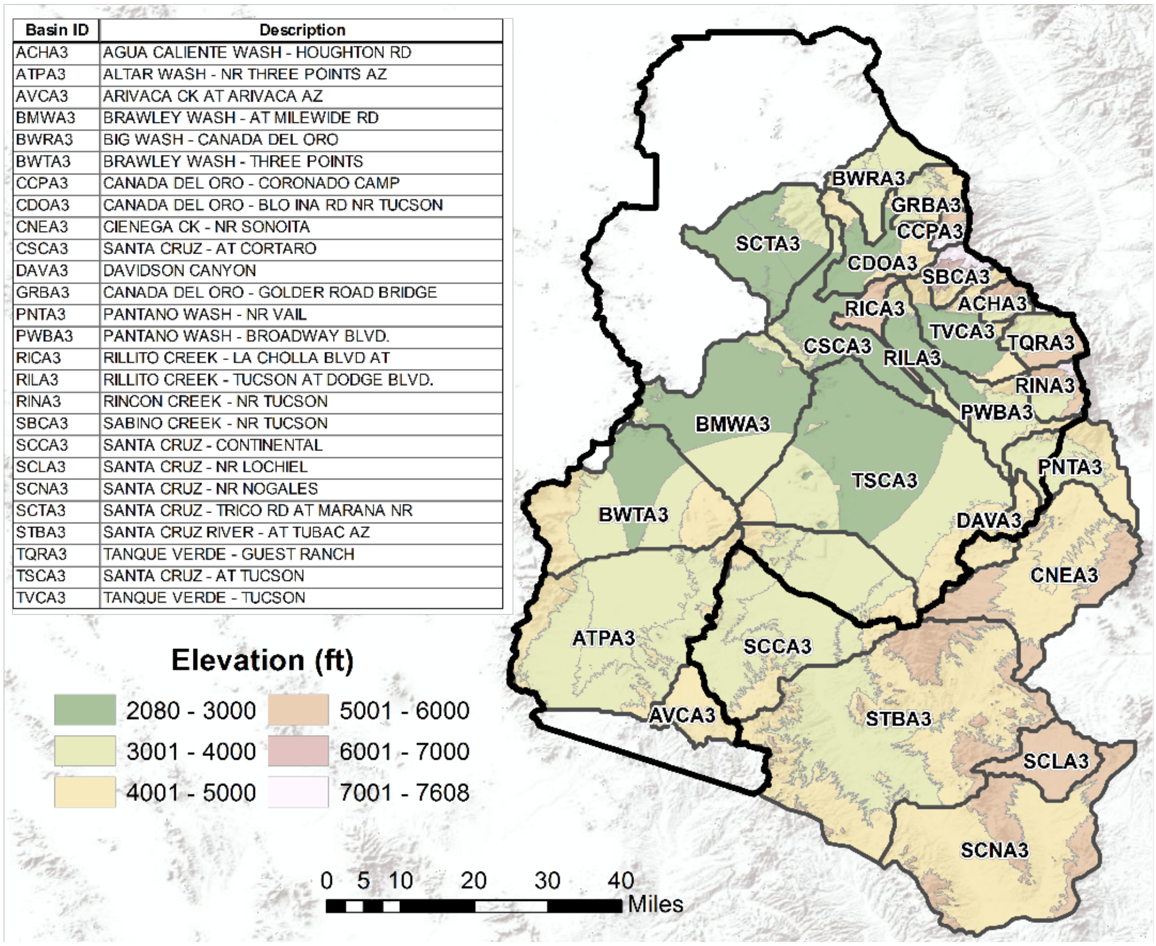
Change in Monsoon Onset Timing

Monsoon onset is an important climate feature both for vegetation health and for reducing the demand for outdoor landscape watering. For the best-case scenario, the median onset dates advance by two days for each future period, to July 3 for the 2020 – 2049 period, and July 1 for the 2050 – 2079 period. An earlier monsoon could offset the impacts of the projected rising temperatures and resulting water demands by vegetation. The worse-case scenario did not show a trend in monsoon onset date for the two future periods.

Changes in Streamflow

Development of the projected temperature and precipitation time-series ensembles provided the input for the next stage of the Hydroclimate Analysis: surface water modeling. As mentioned earlier, the Sacramento Soil-Moisture Accounting (SAC-SMA) model was selected for its performance in semi-arid areas, as well as for its calibration for the LSCR Basin and contributing watersheds by the National Weather Service's CBRFC.

In order to reflect the impact of climate on all the inflows to the LSCR Basin, results were developed for an area that contained the major upstream drainage basins. The northwest portion of the LSCR Basin was excluded from the Hydroclimate Analysis, as it drains out of the LSCR Basin further north into Pinal County. The outline of the surface water modeling area relative to the LSCR Basin boundaries is shown in Figure ES-7.



Basin ID	Description
ACHA3	AGUA CALIENTE WASH - HOUGHTON RD
ATPA3	ALTAR WASH - NR THREE POINTS AZ
AVCA3	ARIVACA CK AT ARIVACA AZ
BMWA3	BRAWLEY WASH - AT MILEWIDE RD
BWRA3	BIG WASH - CANADA DEL ORO
BWTA3	BRAWLEY WASH - THREE POINTS
CCPA3	CANADA DEL ORO - CORONADO CAMP
CDOA3	CANADA DEL ORO - BLO INA RD NR TUCSON
CNEA3	CIENEGA CK - NR SONOITA
CSCA3	SANTA CRUZ - AT CORTARO
DAVA3	DAVIDSON CANYON
GRBA3	CANADA DEL ORO - GOLDER ROAD BRIDGE
PNTA3	PANTANO WASH - NR VAIL
PWBA3	PANTANO WASH - BROADWAY BLVD.
RICA3	RILLITO CREEK - LA CHOLLA BLVD AT
RILA3	RILLITO CREEK - TUCSON AT DODGE BLVD.
RINA3	RINCON CREEK - NR TUCSON
SBCA3	SABINO CREEK - NR TUCSON
SCCA3	SANTA CRUZ - CONTINENTAL
SCLA3	SANTA CRUZ - NR LOCHIEL
SCNA3	SANTA CRUZ - NR NOGALES
SCTA3	SANTA CRUZ - TRICO RD AT MARANA NR
STBA3	SANTA CRUZ RIVER - AT TUBAC AZ
TQRA3	TANQUE VERDE - GUEST RANCH
TSCA3	SANTA CRUZ - AT TUCSON
TVCA3	TANQUE VERDE - TUCSON

Figure ES-7. Sac-SMA elevations by elevation zone for each labeled subbasin. The LSCR basin study area is shown using a thick black outline with subbasins outlined with a thinner black line. Elevation zones are not always continuous across a subbasin.

Surface water modeling results were developed for the dry, monsoon and winter wet seasons. Due to the importance of the monsoon rains for environmental and municipal water needs, these modeling results are presented below in Figure ES-8. Results for the dry and winter wet seasons are presented in the Hydroclimate Analysis Technical Memorandum.

Changes in the total monsoon season streamflow result from a combination of changes in the length of the season, storm intensity, and frequency of storms. In the 2020 – 2049 period, the best-case scenario had a consistently longer monsoon season resulting in more total flow. Streamflow decreased in some sub-basins in the 2050 – 2079 period, particularly in areas with more “no flow” days.

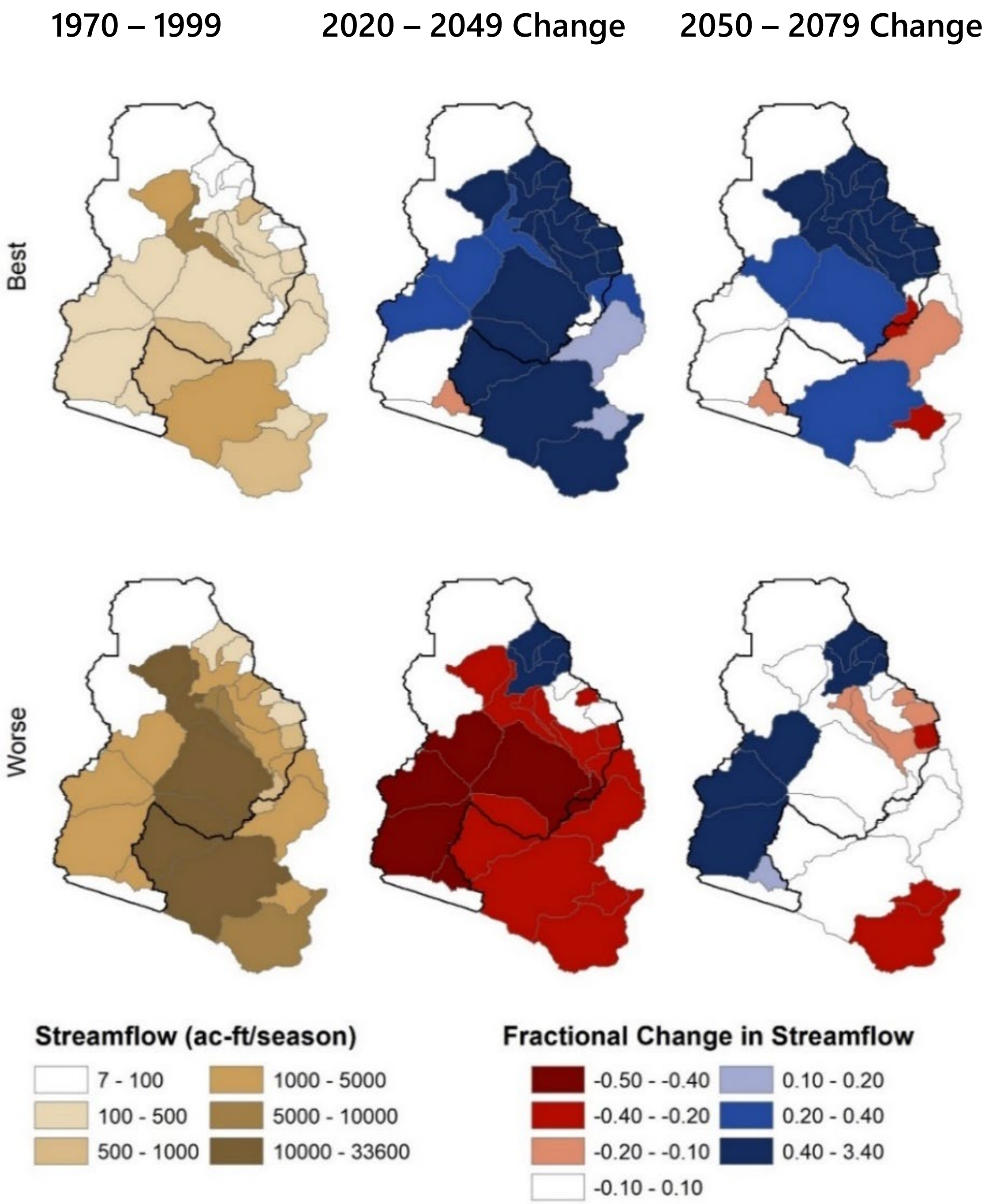


Figure ES-8. Median of the ensemble 30-year average monsoon season total streamflow from the modeled historical period (tan) for each scenario, and projected change from historical (red for negative and blue for positive change respectively), presented as a fraction of the simulated historical period streamflow for the best- and worse-case climate scenarios. Note coverage is only over the areas identified as subbasins in Figure ES-7.

Under the worse-case scenario, the 2020 – 2049 period had generally shorter, but highly variable, monsoon season length. The changes in monsoon seasonality resulted in high variability in monsoonal rainfall from year to year, with an overall decreased median streamflow. For the 2050 – 2079 period, the longer monsoon season resulted in an apparent recovery of streamflow. However, streamflow events were less frequent and likely more extreme, consistent with the projected increase in large precipitation events.

CAP:SAM Supply and Demand Assessment

While Reclamation Technical Service Center staff conducted the Hydroclimate Analysis, staff with the Central Arizona Water Conservation District (CAWCD), a key Study Partner, developed the Supply and Demand Assessment. The CAWCD operates the Central Arizona Project (CAP), the 336-mile canal system that brings Colorado River water to the CAP Service Area, which consists of Maricopa, Pinal, and Pima counties (Figure ES-9). The CAWCD's long-term contract obligations for Colorado River water total 1.415 million acre-feet annually (Central Arizona Project, 2022).

The Supply and Demand Assessment focused on human demands for water, as well as the volumes of CAP and reclaimed water available for recharge within the CAP Service Area. Most of the LSCR Basin is included in the CAP Service Area. The Assessment was developed using the CAWCD's state-of-the-art Central Arizona Project Service Area Model (CAP:SAM). CAP:SAM is not a hydrologic model; it projects demands for water using a range of assumptions regarding climatic, socio-economic, and behavioral factors through time. CAP:SAM also simulates the rules and policies that govern how water is managed within the Service Area.

CAP:SAM was used to project municipal, industrial, and agricultural (both tribal and non-tribal) demands for each water provider within the Study Area and then to forecast the most practical way to meet these demands given a provider's available resources. However, the Assessment focused on the municipal sector, as it represents the largest volume of water demand within the Study Area, and because its management is more complex than that for the agricultural and industrial sectors. A key question for the Study Partners was the impact of CAP shortages on municipal water providers' ability to meet projected demands.

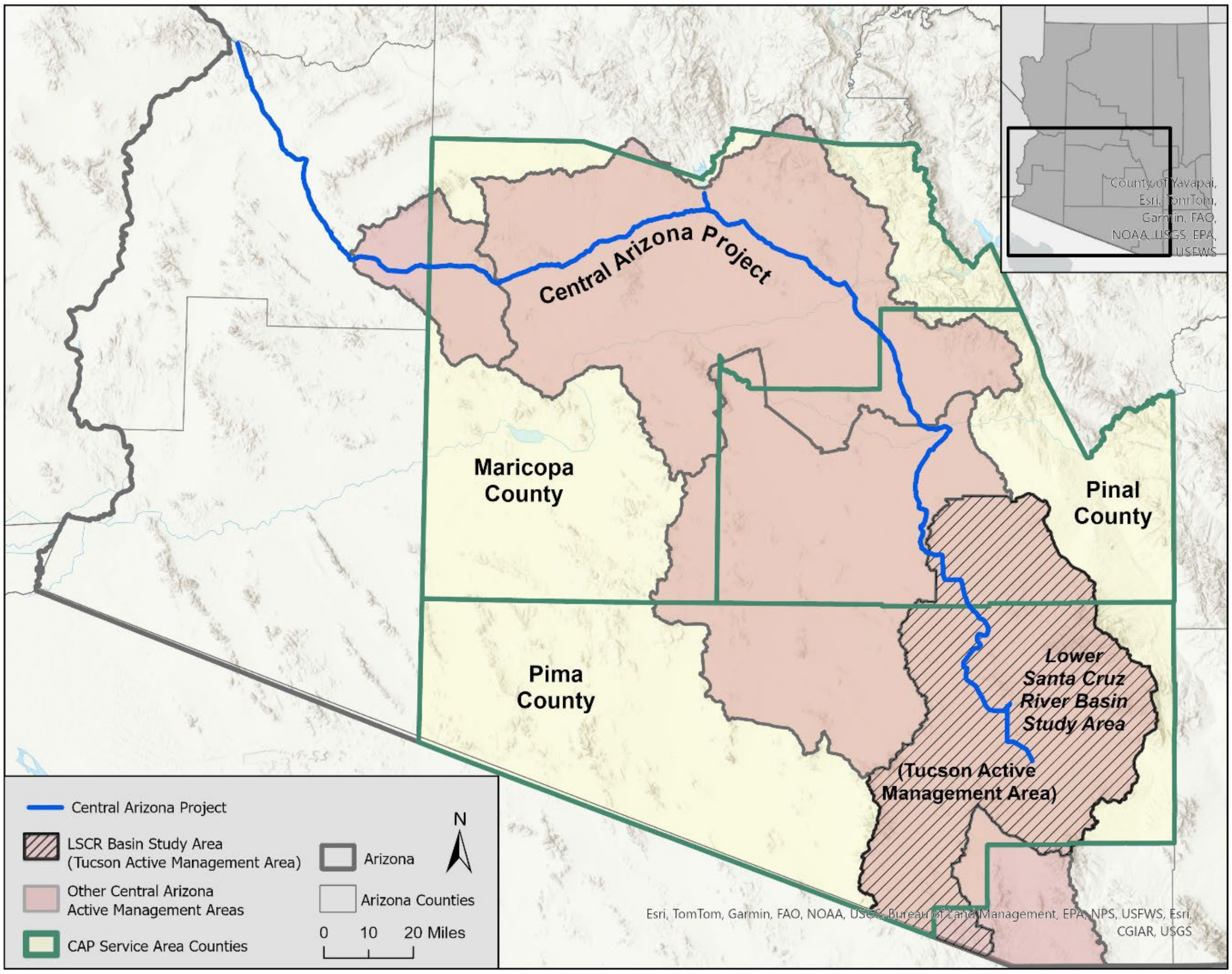


Figure ES-9. Central Arizona Project Service Area Counties, Central Arizona Active Management Areas, and Central Arizona Project Alignment.

Development of CAP:SAM Scenarios

CAP:SAM incorporates the influence of climate into municipal conservation rates, crop evapotranspiration, and the availability of CAP water due to shortages on the Colorado River. In this Study, the availability of CAP water was the most important of these factors. The volume of available CAP water is also highly dependent on the operating rules of the Colorado River, which have not yet been established past 2026. Recognizing the high levels of uncertainty regarding future Colorado River operations, Partners decided that it was reasonable to make CAP:SAM projections only through the year 2060. As a result, the Supply and Demand projections were generated from 2020 to 2060, as depicted in the lower portion of Figure ES-6.

To represent plausible sequences of future CAP shortages, expert CAWCD staff developed three representative traces, or shortage sequences, for the period from 2020 to 2060 (Figure ES-10). The traces were designed to align with the Study's three climate scenarios: current, best-case (based on RCP 4.5), and worse-case (based on RCP 8.5). The current climate trace is based on modeling of Colorado River operations under observed hydrology, the 2007 Colorado River Interim Guidelines, and the 2019 Drought Contingency Plan. The best-case and worse-case shortage traces reflect degrees of impacts for which there is general agreement among Global Climate Models: reduced average runoff and greater variability of precipitation (Seasholes, 2023).

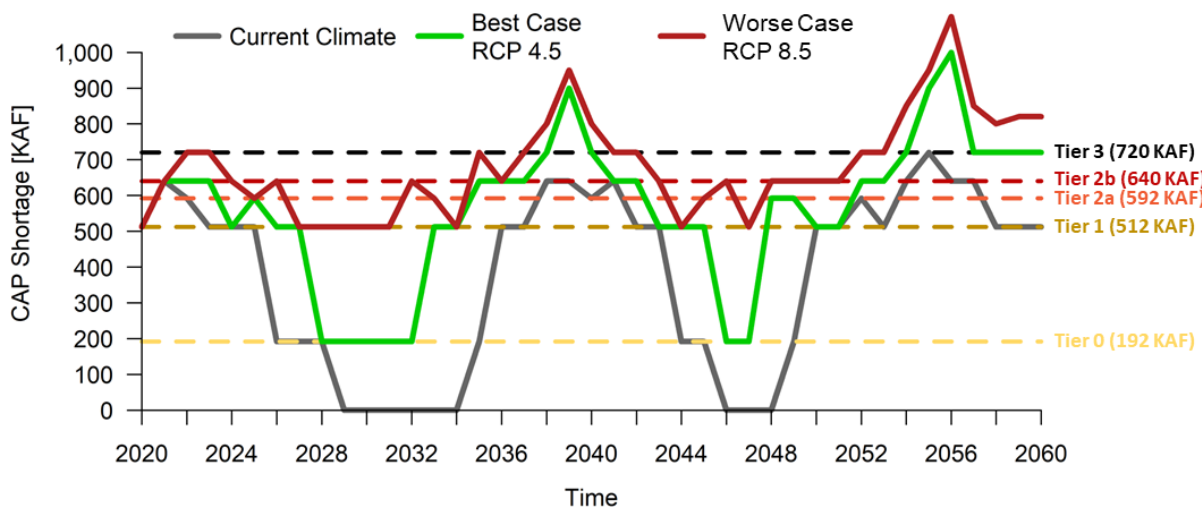


Figure ES-10. Representative CAP shortage sequences (traces) modeled using CAP:SAM, with reference levels of shortages under the 2019 Drought Contingency Plan denoted by dashed lines. Note that shortage volumes apply to the entire CAP system, not just the LSCR Basin Study Area.

CAP:SAM scenarios also include assumptions regarding the rate and type of municipal growth, depicted in Figure ES-11. Municipal growth can be slow, medium, or rapid, with each rate corresponding to a low, medium, or high rate of population growth as projected by the Arizona Office of Economic Opportunity. CAP:SAM also takes into account whether municipal growth is compact (primarily located in existing urban areas), official (reflecting the growth pattern used by the Pima Association of Governments), or outward (more housing in suburban and exurban areas). Outward growth leads to more housing in areas without direct access to the infrastructure that conveys renewable water supplies.

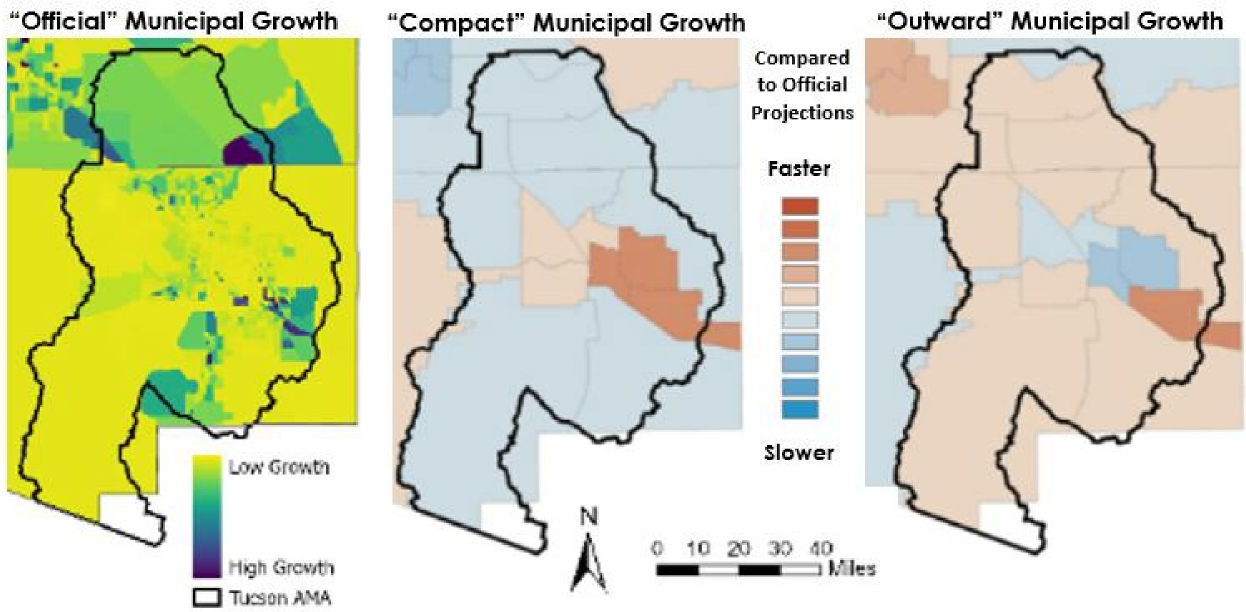


Figure ES-11. Official Housing Unit spatial pattern developed by the counties' Associations of Governments. Compact and Outward Growth alternative spatial patterns developed by Applied Economics. Study Area is outlined in black.

Six CAP:SAM scenarios were developed as part of the Supply and Demand Assessment (Figure ES-12). Each represents a plausible future condition for the region. While the matrix could generate nine pairs of climate and growth conditions, Study Partners suggested using six scenarios to simplify the analysis while maintaining useful pairwise comparisons.

As shown in Figure ES-12, Scenario A was considered the baseline condition, since it used the official growth projections developed by the Pima Association of Governments with no adjustments for climate change. The differences between Scenarios B versus D and C versus F could be attributed solely to the future level of climate change. Comparisons of Scenarios B versus C, as well D versus F, isolate the impacts of growth under constant climate conditions.

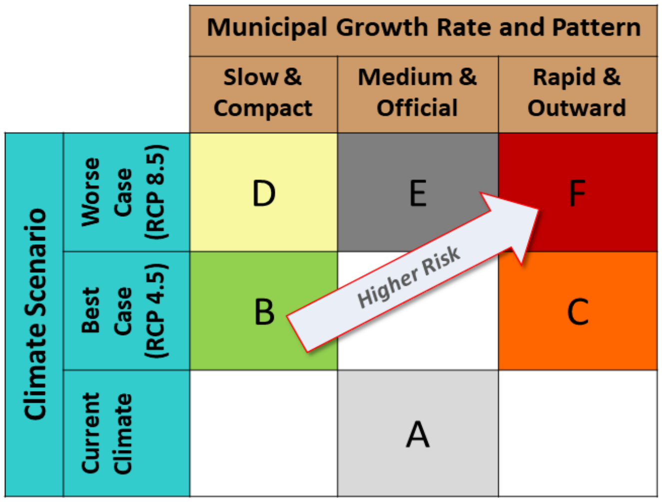


Figure ES-12. Matrix of Climate and Municipal Growth Scenarios for Supply and Demand Assessment.

Supply and Demand Assessment Results

The 1980 Arizona Groundwater Code established the Arizona Department of Water Resources (ADWR) and designated certain areas with heavy reliance on groundwater as Active Management Areas or AMAs. In 1995, ADWR adopted the Assured Water Supply (AWS) Program to preserve groundwater resources and promote long-term water supply planning within AMAs. New subdivisions within an AMA had to demonstrate that they would have a physical, legal, and continuously available water supply of sufficient quality for a 100-year period. In addition, water supply plans must be consistent with the AMA's management goal. For the Tucson AMA, the management goal is 'safe-yield', a long-term balance between groundwater withdrawal and recharge (natural and artificial) within the entire AMA (Silber-Coats & Eden, 2017).

If a provider has physical access to renewable supplies (CAP or reclaimed water), it can supply these to its customers to meet AWS requirements. Alternatively, municipal providers can pump groundwater to meet their demands, but groundwater pumped in excess of AWS limits must be replenished in state-certified facilities within the same AMA. Municipal providers also can also store excess renewable supplies in these facilities to be "recovered" to meet their future needs.

The Assessment estimated the amount of renewable water supplies each municipal provider would need to meet AWS requirements through 2060 under each CAP:SAM scenario. Results by scenario, totaled for all municipal providers in the Study Area, are presented in Table ES-2.

Table ES-2. Renewable water supplies (in acre-feet) needed to meet AWS requirements under each CAP:SAM scenario

Climate Scenario		Municipal Growth Rate and Pattern		
		Slow & Compact	Medium & Official	Rapid & Outward
Climate Scenario	Worse Case (RCP 8.5)	D	E	F
Climate Scenario	Best Case (RCP 4.5)	B		C
Climate Scenario	Current Climate		A	

Higher Risk

CAP:SAM Scenario	Acre-Feet Subject to AWS Rules in 2060 (single-year volume)	Acre-Feet Subject to AWS Rules 2020-2060 (cumulative volume)
A	12,700	330,100
B	8,800	231,000
C	34,400	517,400
D	9,500	250,600
E	14,300	368,400
F	38,100	570,000

Individual provider results are presented in the Supply and Demand Technical Memorandum. Depending on the scenario, some providers would be able to meet the entire volume of projected demand with their existing resources. Others would need to recover previously stored supplies to meet projected demands through 2060. For certain providers, projected demands would exceed existing resources, including their stored water, creating a need to acquire additional renewable supplies. As shown, the need for renewable supplies was greatest under the 'rapid, outward growth' scenarios.

Groundwater Modeling Analysis

Figure ES-13 presents a conceptual model of the Study's Groundwater Modeling Analysis that utilized ADWR's Tucson Active Management Area Regional Groundwater Flow Model. Each groundwater modeling scenario combined a projection of streamflow recharge and evapotranspiration developed in the Hydroclimate Analysis (represented in blue), with a CAP:SAM projection of municipal growth, water demand and the availability of CAP water (depicted in green). The Groundwater Modeling Analysis required that the CAP:SAM's projections of future water demands and recharge volumes, developed in the Supply and Demand Assessment, be translated into spatially explicit rates of pumping and recharge by expert Study Partners. Study Partners developed these input files for use in the groundwater model.

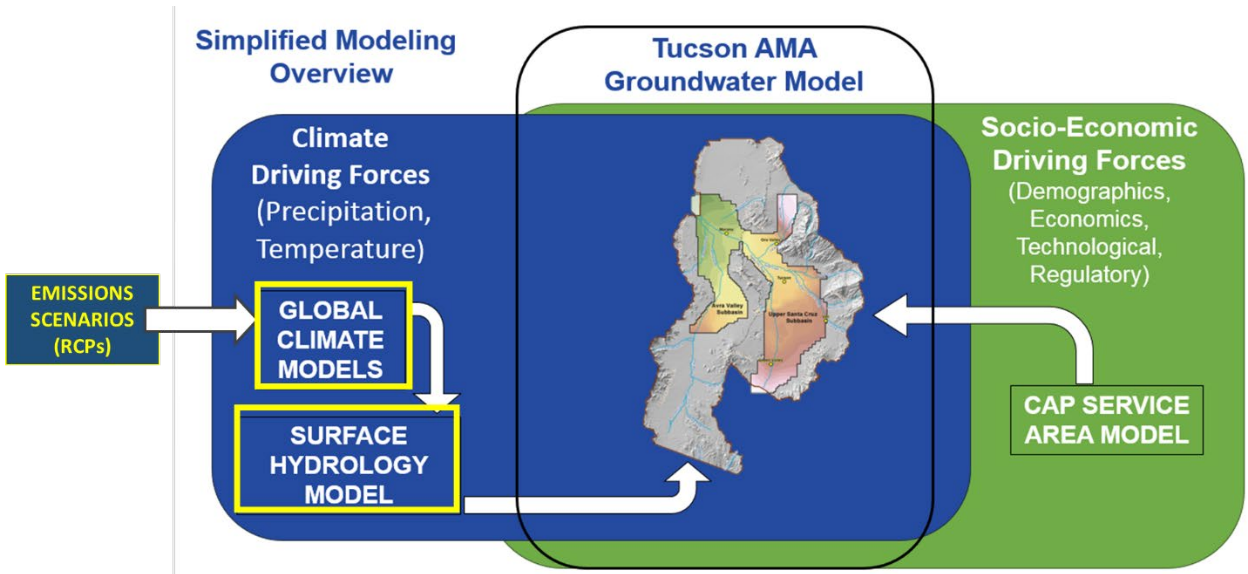


Figure ES-13. A simplified diagram of the models used in the LSCR Basin Study Groundwater Modeling Analysis.

Figure ES-14 shows the spatial domain of the ADWR Tucson Regional Groundwater Flow Model in yellow, relative to the LSCR Basin Study boundaries. Surface and groundwater generally flow from southeast to northwest, consistent with the change in elevation. The Basin's two metropolitan Water Reclamation Facilities, located along the Santa Cruz River northwest of Tucson, discharge some of their effluent to the River. The map also shows the CAP alignment, and large CAP and effluent recharge facilities within the LSCR Basin.

Municipal water providers within the LSCR Basin operate in a manner that complies with the Tucson Active Management Area goal of safe-yield. Tucson Water, the largest municipal provider in the Study Area, uses a "Storage and Recovery" approach to manage their supplies. Within Tucson Water facilities, basins infiltrate CAP water into the aquifer, where it mixes with native groundwater. Potable demand is met by recovering this mix and delivering it to customers. Pumping and recharge can be balanced because water is recharged and withdrawn within the same facilities.

The large size of these storage facilities, and the fact that the City of Tucson's CAP allocation exceeds its demands, allows Tucson Water to store the unused portion of their CAP entitlement for later use. These facilities also ensure water supplies can be delivered reliably during shortages on the CAP system (Megdal & Forrest, 2015).

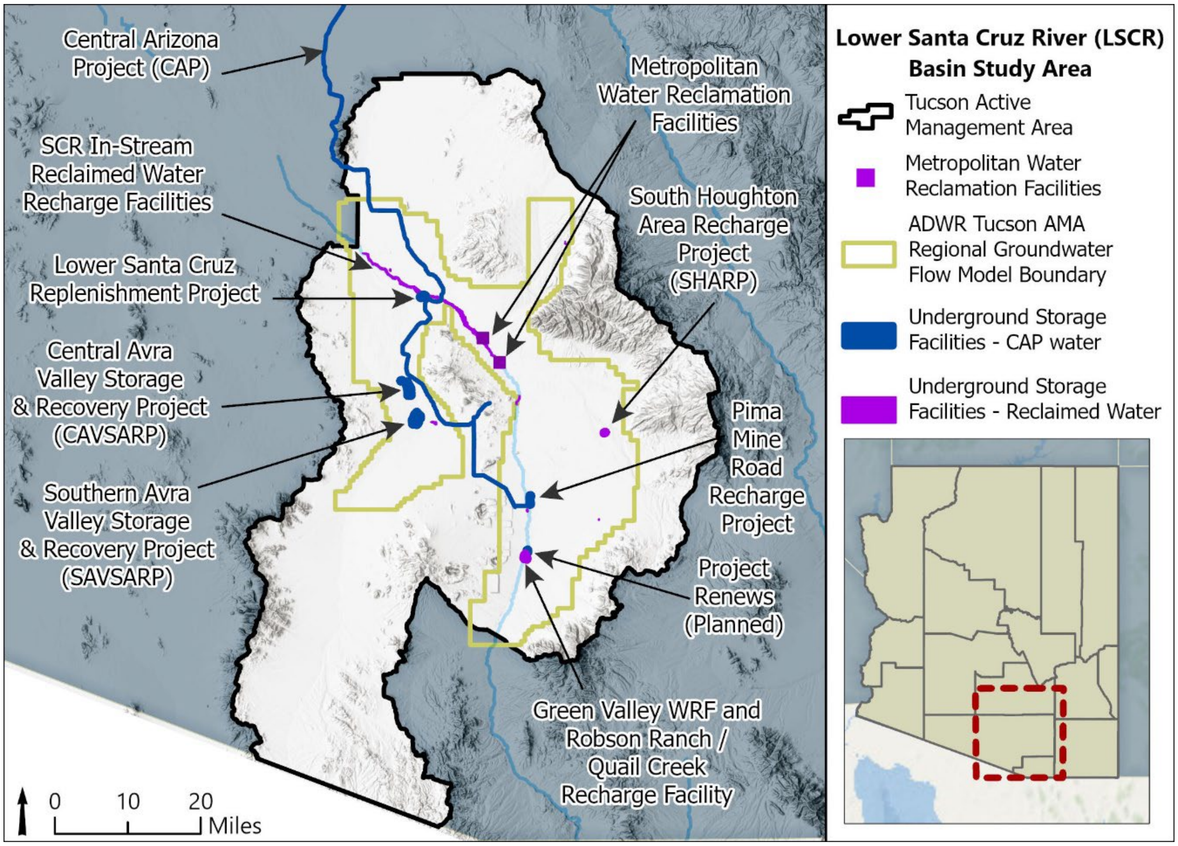


Figure ES-14. Map of ADWR's Regional Groundwater Flow Model of the Tucson Active Management Area domain, relative to the LSCR Basin boundaries, streams, and recharge facilities.

Municipal providers without access to these types of storage and recovery facilities can comply with AWS rules using another strategy. They are permitted to pump groundwater to serve their customers, but must offset withdrawals in excess of AWS limits by recharging an equal volume of renewable supplies (CAP or reclaimed water) in a state-certified facility within the same AMA. This type of recharge is also known as 'replenishment'. While this strategy is consistent with the Tucson AMA goal of safe-yield, it also creates localized drawdowns in areas where pumping is "disconnected" from recharge facilities (Silber-Coats & Eden, 2017). The impact of pumping groundwater in one location while recharging at a distant facility can be seen in the maps produced for the Groundwater Modeling Analysis.

Groundwater Modeling Analysis Results

Basin Level Results

Groundwater Modeling Analysis results, when generalized across the entire LSCR Basin, showed that the total volume of water stored has risen since substantial volumes of CAP water were introduced the mid-2000s. This storage will continue to increase through at least 2050 for all scenarios (Figure ES-15). Between 2050 and 2060, the results for the scenarios diverge. The LSCR Basin aquifer would continue to improve its overall water balance through 2060 under the scenarios that feature either slow and compact growth, or medium and official growth. Under the rapid and outward growth scenarios, storage begins to decline around 2050 (Scenarios C and F).

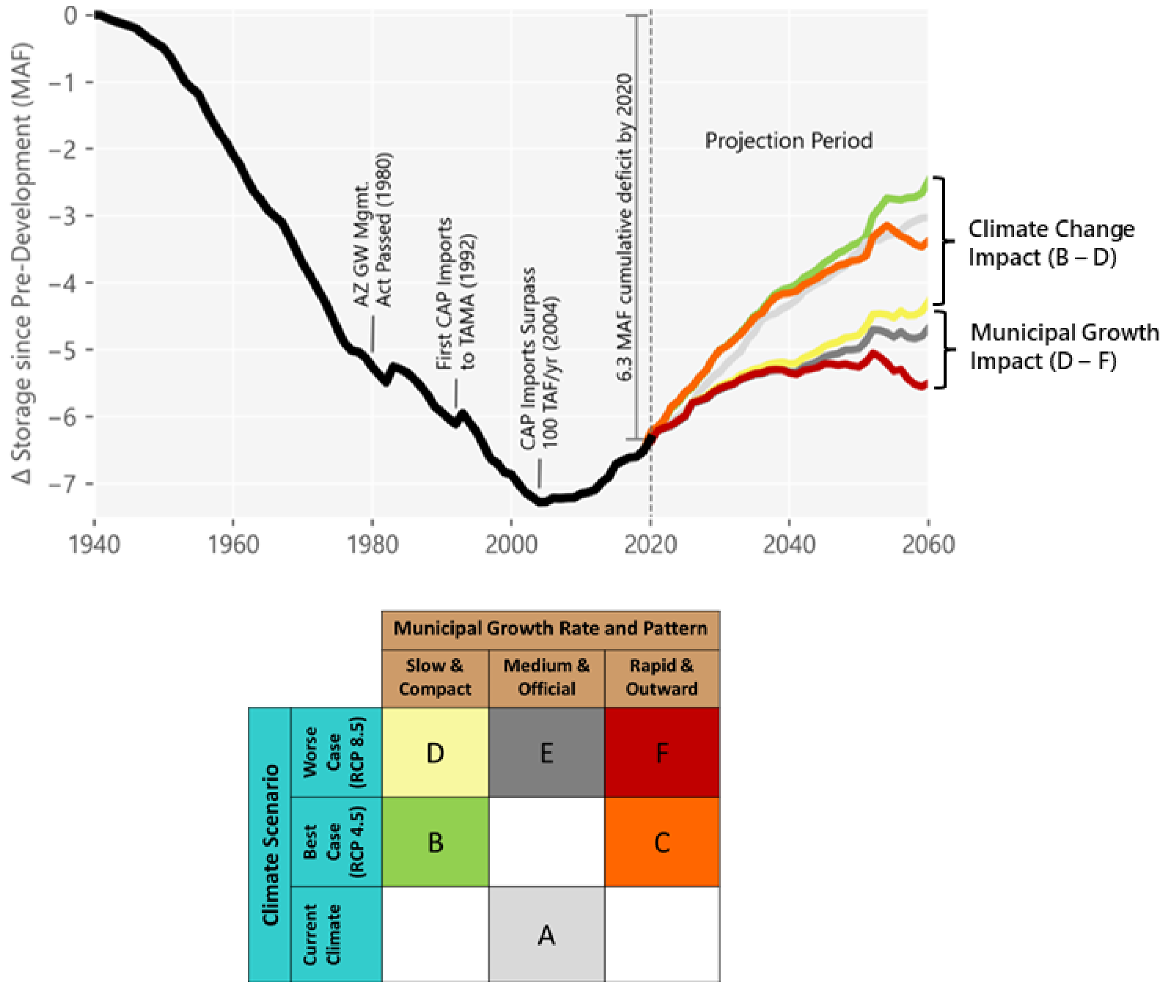


Figure ES-15. Simulated cumulative change in groundwater storage within the Study Area since pre-development (1940). Historical period is in black with results from scenarios branching out at the start of the projection period (2020).

Figure ES - 15 also depicts the relative impacts of municipal growth and climate change intensity on the overall groundwater balance. Scenarios D and F have the same degree of climate change, but in scenario D, municipal growth is slow and compact. In contrast, municipal growth in scenario F is rapid and outward. The distance between the lines representing scenarios D and F reflects the impact of the rate and type municipal growth on groundwater storage over time.

Similarly, scenarios D and B have the identical rate and type of municipal growth (slow and compact), but scenario D assumes a worse-case climate, while Scenario B uses a best-case climate. The distance between Scenario B's green line and Scenario D's yellow line reflects the impact of the Study's climate projections on aquifer storage.

By the end of the projection period, about 60% of the projected change in groundwater storage can be attributed to the influence of climate. This result highlights the strong impact of LSCR Basin-wide streamflow recharge on groundwater. The remaining 40% of the range between scenarios is due to the differences in the municipal growth rates and CAP shortages.

Spatially Distributed Results

Figure ES-16 depicts the spatial distribution of projected changes in water table elevations between 2020 and 2060 under each scenario. The color scale is the same across all panels, with blue areas indicating an increase in groundwater levels and red areas indicating a decrease.

All panels in Figure ES-16 show blue shading near and along the Santa Cruz River northwest of Tucson, indicating a rise in groundwater levels. This is a result of increased discharge of reclaimed water from the area's two metropolitan water reclamation facilities along the SCR as the population grows. More intense blue shading in the far-right portion of the model domain under scenarios B and C, compared to scenarios D, E, and F, indicate projected increases in streamflow in the Tanque Verde and Rillito Creek area under the best-case climate.

Figure ES-16 also shows concentrated changes in the groundwater levels in the lower left portion of the model domain. These areas were created by recharge of Central Arizona Project water at Tucson Water's CAVSARP and SAVSARP facilities. The blue dot at the far right of the model domain depicts the impact of the City of Tucson's South Houghton Area Recharge Project (SHARP), which recharges reclaimed water. The blue dots towards the bottom of the domain show the anticipated impact of one planned CAP recharge project (Project Renews) combined with the effects of two existing reclaimed water recharge projects (Green Valley Water Reclamation Facility and the Robson Ranch / Quail Creek Underground Storage Facility).

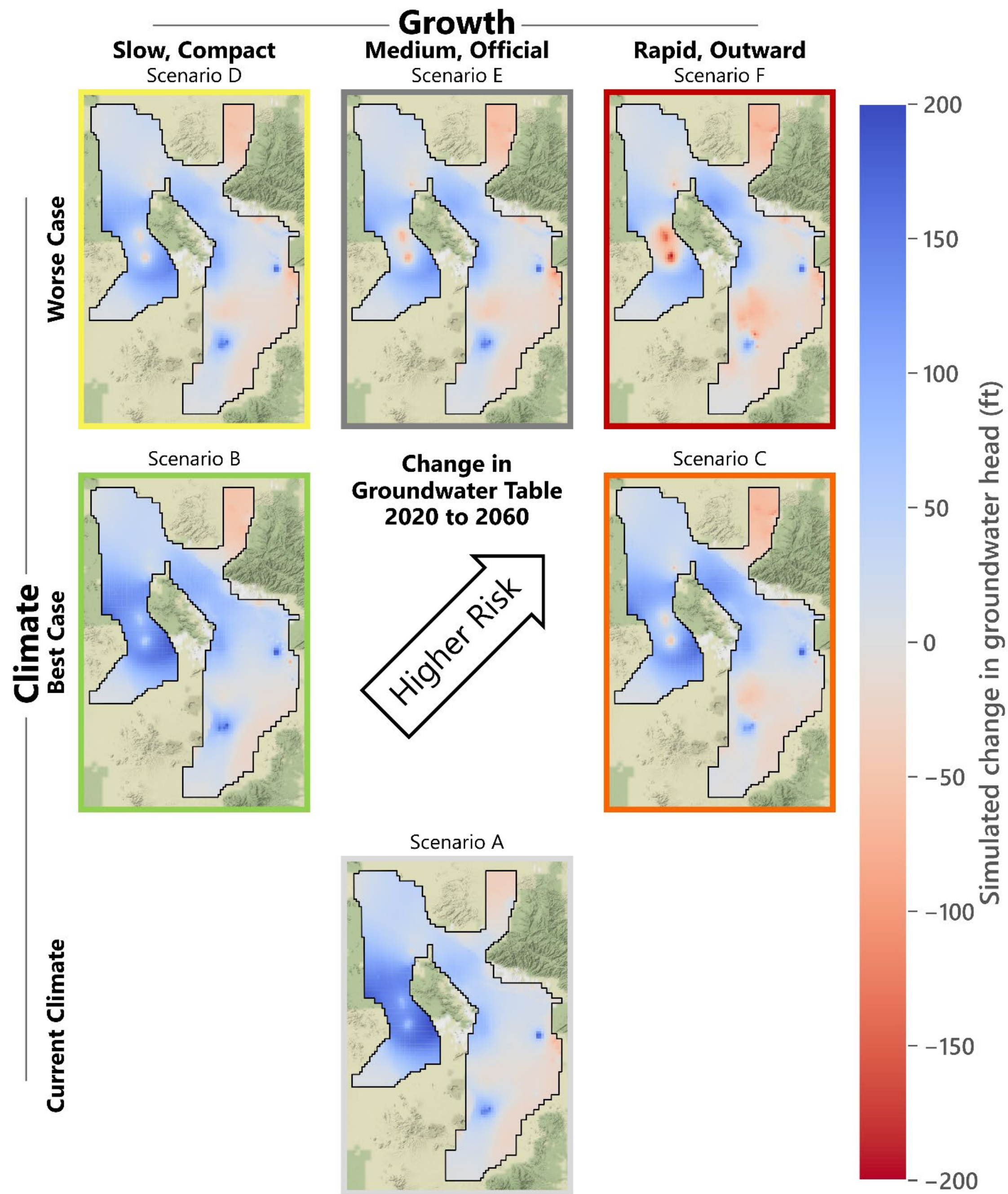


Figure ES-16. Change in simulated groundwater levels by model cell over the projection period (2020 -2060) for each groundwater modeling scenario. Color scale is shared among all maps.

Results demonstrate that while overall LSCR Basin aquifer storage has been increasing since the large-scale recharge of CAP water began, these changes have not been evenly distributed, which has created local supply-demand imbalances. In areas distant from recharge sites, groundwater levels are projected to fall, even under Scenario B, which has the lowest level of municipal growth and best-case future climate. These results guided Reclamation and the partners in the development of adaptation strategies. In addition to Basin-wide measures, specific strategies were conceived to address four areas of supply-demand imbalance, shown in Figure ES-17. These areas were labeled: Cañada del Oro / Saddlebrooke (CDO), Sabino Canyon / Tanque Verde (SC/TV), Southeast Tucson (SET), and Green Valley (GV).

Adaptation Strategies and Trade-off Analysis

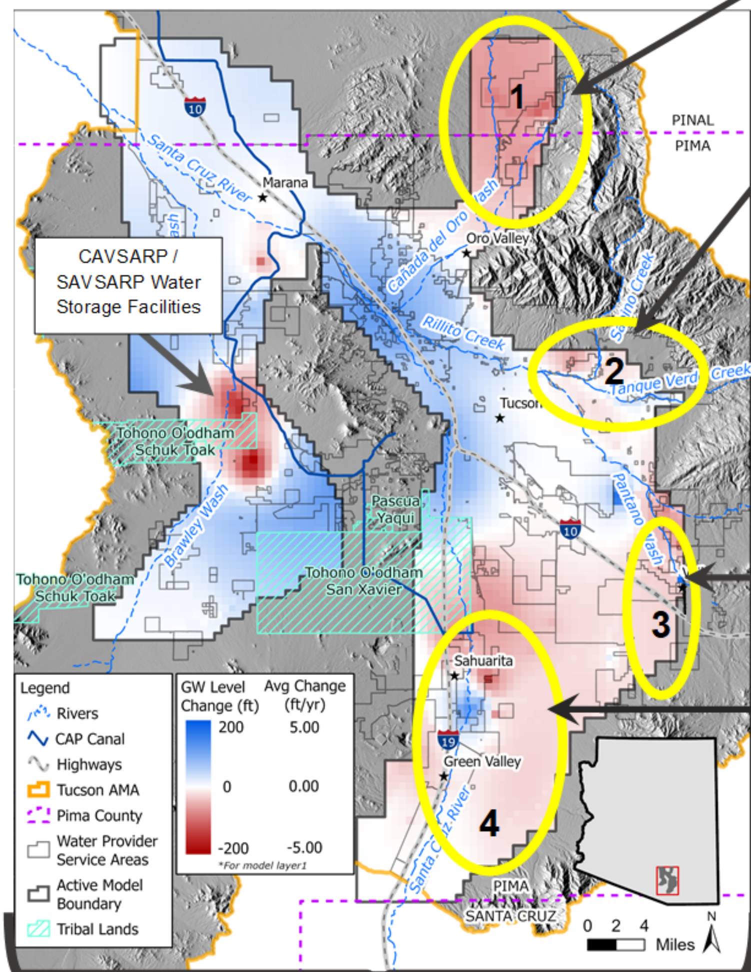
Concepts for adaptation strategies were elicited at two Stakeholder Workshops over the course of the Study. The workshops also solicited feedback on the evaluation criteria to be used in the Trade-off Analysis. A total of 15 adaptation strategies, shown in Figure ES-17, were developed for the Trade-off Analysis. Eleven of these specifically targeted areas of concern, while the rest could be applied region-wide. Strategies varied widely in the size of the local supply-demand imbalance they addressed, their capital costs, operations and maintenance costs, the benefits provided, and the barriers to implementation. More detail is provided in the Adaptation Strategies Descriptions document.

Most strategies involved transporting existing water resources within the LSCR Basin, rather than augmenting the total supply. Some strategies involved conveying CAP or reclaimed water to locations with falling groundwater levels, either for direct use or aquifer recharge. Other strategies involved locating new, sub-regional wastewater treatment plants with recharge facilities near these areas of concern. Still others involved wheeling (transport of one water provider's supplies through infrastructure belonging to another provider). In this case, Tucson Water would use its infrastructure to directly convey renewable supplies to municipal providers that are currently pumping groundwater and recharging elsewhere in the Basin. Reclamation engineers supplied cost information for some of these strategies, while others were provided by Partners.

Region-wide strategies encompassed a wide swath of concepts including utilizing stormwater, restoration of uplands within the Basin, and importation of desalinated water piped from Mexico's Sea of Cortez. Both the utilization of stormwater and the importation of desalinated water from Mexico would augment the total water supply. Partners provided the detailed descriptions and cost estimates associated with the regional strategies.

	Canada Del Oro Adaptation Strategies
CDO-1	Convey CAP water for in-stream recharge
CDO-2	Convey recycled water for in-stream recharge
CDO-3	Construct new regional wastewater reclamation plant with in-stream recharge

	Sabino Canyon / Tanque Verde Adaptation Strategies
SC/TV-1	Extend reclaimed water system to replace outdoor potable uses, support environmental needs
SC-TV-2	Replace municipal provider groundwater pumping with wheeled renewable supplies
SC/TV-3	Replace groundwater pumping by private wells with renewable supplies from municipal provider



	Southeast Tucson Adaptation Strategies
SET-1	Wheel renewable supplies to small providers without direct physical access to CAP
SET-2	Phased construction of regional wastewater reclamation facilities with recharge of recycled water

	Green Valley Adaptation Strategies
GV-1	Extend Farmers Investment Company (FICO) Groundwater Savings Facility
GV-2	In addition to GV-1, extend pipeline for environmental enhancement in agricultural off-season
GV-3	Construct new regional wastewater reclamation plant with in-stream recharge

	Regional Adaptation Strategies
REG-1	Site-based Stormwater Management using Low Impact Development Methods
REG-2	Large Stormwater Multi-purpose, Multi-use Basins and Channels
REG-3	Upland Restoration
REG-4	Desalination of Ocean Water with Pipeline from Sea of Cortez, Mexico

Figure ES-17. Projected groundwater level changes between 2020 and 2060 under Scenario F (worse-case), with areas of concern: 1. Cañada del Oro/Saddlebrooke (CDO), 2. Sabino Canyon/ Tanque Verde (SC/TV), 3. Southeast Tucson (SET), and 4. Green Valley (GV) and associated adaptation strategies.

Evaluation Criteria

Suggestions for evaluation criteria were solicited at the two Stakeholder Workshops. In general, the suggestions fell into three categories: Water for Society, Environmental Concerns, and Broader Considerations. The criteria were further refined in the Economic and Trade-off Analysis, resulting in the final evaluation criteria presented in Table ES-3. The Measurement column indicates whether the criterion was able to be monetized, or if it was evaluated using expert judgment on a point scale. Initially, all criteria were weighted equally, but Trade-off Analysis participants were given the opportunity to weigh specific evaluation criteria more heavily than others if they felt they were of greater importance.

Table ES-3. List of Final Evaluation Criteria for the Trade-off Analysis

Criterion	Description	Measurement	Directionality
(1) Water Supply Reliability Benefit	Benefit from reducing future shortages anticipated for the Study Area.	Monetized	Benefit
(2) Capital Cost	Cost of construction or implementation (upfront cost).	Monetized	Cost
(3) O&M Cost	Cost of operation and maintenance (ongoing cost).	Monetized	Cost
(4) Aquifer Benefit	Improvements in groundwater levels to reduce pumping costs, prevent subsidence, or improve general aquifer condition.	0 to 3	Benefit
(5) Quality of Life Benefit	Improvements in recreation, aesthetics, health, safety, heat island effect, or cultural resources.	0 to 3	Benefit
(6) Leverage Existing Resources	Utilizes or enhances existing investments or infrastructure.	0 to 3	Benefit
(7) Barriers to Implementation	Obstacles from public perception, regulations, administrative complexity, or physical limitations.	-3 to 0	Cost
(8) Riparian Impact	Changes to riparian habitat and conditions.	-3 to 3	Cost/Benefit
(9) Water Quality Impact	Changes in the chemical, physical, or biological characteristic of water resources.	-3 to 3	Cost/Benefit
(10) Flood Risk Impact	Changes in flood risk (probability or consequences).	-3 to 3	Cost/Benefit

The strategies were compared in three ways: within each area of concern, across all areas of concern, and across all strategies (this evaluation included the regional strategies). For example, only the strategies that pertained to a particular area of concern (for example, the Cañada del Oro) were compared to each other for the 'location rank'. The eleven strategies that pertained to one of the four areas of concern (excluding the regional strategies that were generally larger in scale) were compared to each other for the 'areas of concern rank', and all fifteen strategies, regardless of whether they targeted an area of concern or could apply regionally, were compared against each other for the 'overall rank' (Table ES-4).

Trade-off Analysis Results

The Trade-off Analysis results, shown in Table ES-4, demonstrated that most single strategies could not address all the LSCR Basin's adaptation needs, and those that could had significant costs and other serious obstacles. Most strategies provided a unique set of benefits and costs, suggesting that implementing a suite of local and regional strategies may be necessary to achieve a comprehensive adaptation plan across the Study Area.

Table ES-4. Adaptation Strategy Rankings. Color intensity indicates relative rank among strategies.

Adaptation Strategy	Strategy Type	Total Score	Normalized Score	Location Rank	Areas of Concern Rank	Overall Rank
CDO-1	Transport CAP supplies for in-stream recharge	4.13	0.75	**1st**	**3rd**	**6th**
CDO-2	Transport reclaimed water supplies for in-stream recharge	2.89	0.53	**3rd**	**9th**	**13th**
CDO-3	Construct regional water reclamation facility with in-stream recharge	2.96	0.54	**2nd**	**7th**	**10th**
SC/TV-1	Extend reclaimed system, support environmental needs	3.83	0.70	**3rd**	**5th**	**8th**
SC/TV-2	Wheel CAP supplies directly to replace municipal GW pumping	4.17	0.76	**1st**	**1st**	**4th**
SC/TV-3	Replace GW pumping by private wells with renewable municipal supplies	3.99	0.73	**2nd**	**4th**	**7th**
SET-1	Wheel CAP supplies to replace municipal GW pumping	4.15	0.76	**1st**	**2nd**	**5th**
SET-2	Construct regional water reclamation facility with in-stream recharge	2.30	0.42	**2nd**	**11th**	**15th**
GV-1	Substitute agricultural GW pumping with renewable supplies	3.33	0.61	**1st**	**6th**	**9th**

Adaptation Strategy	Strategy Type	Total Score	Normalized Score	Location Rank	Areas of Concern Rank	Overall Rank
GV-2	Extend agricultural water transport infrastructure, use for off-season environmental enhancement	2.95	0.54	**2nd**	**8th**	**11th**
GV-3	Construct regional water reclamation facility with in-stream recharge	2.64	0.48	**3rd**	**10th**	**14th**
REG-1	Site-based stormwater management using Low Impact Development	4.71	0.86	**2nd**	-	**2nd**
REG-2	Large stormwater multi-purpose basins and channels	4.43	0.81	**3rd**	-	**3rd**
REG-3	Upland restoration	5.48	1.00	**1st**	-	**1st**
REG-4	Desalination of ocean water with pipeline from Sea of Cortez, Mexico	2.91	0.53	**4th**	-	**12th**

Summary of Key Findings

Hydroclimate

- Projections of the Study Area's future climate indicate consistently higher temperatures and hotter extremes. Estimates of average temperature change for 2020 – 2049 range from 2.94°F to 3.41°F, rising to a range of 3.83°F to 5.12°F for 2050 – 2079. Precipitation is projected to become more variable, with less monsoon and winter precipitation under the worse-case scenario. Estimates of annual average declines under the worse-case scenario vary from -4.34" for the 2020 – 2049 period to -3.90" between 2050 and 2079.

- Less monsoon and winter precipitation translates to lower streamflows, more dry stream days, less stream recharge, and lower soil moisture. These changes will impact both human activities and natural ecosystems.

Supply and Demand

- Additional water supplies will be needed to meet the Study's projected 2060 demands under the Assured Water Supply rules. The cumulative volume needed to meet these demands between 2020 – 2060 ranged from 231,000 acre-feet for the slow, compact growth / best case climate scenario to 570,000 acre-feet under the rapid / outward, worse-case climate scenario. This disparity highlights the impacts of both municipal growth and climate on water supply and demand.

- Decreasing per capita municipal use and increasing water use efficiency will help extend providers' supplies.

- Some providers would be able to meet future demands by storing and recovering renewable water resources as they do today. Other providers would need to develop new facilities to recover stored water to meet their projected demands. Still other providers would only be able to meet projected demands by acquiring additional renewable supplies.

- Individual providers will experience different future supply shortage impacts; further details are available in the Supply and Demand Analysis Technical Memorandum.

Groundwater Modeling

- Overall, total aquifer storage in the LSCR Basin is increasing and continues to increase through 2050 under all the scenarios investigated in this Study. For the Study Area as a whole, underground storage of CAP and reclaimed water offer a substantial level of resilience to reduced streamflow recharge, growing water demand, and CAP shortages.

- Under Scenarios C and F (rapid / outward growth, high CAP shortage), total aquifer storage begins to decline around 2050.

- The effects of LSCR Basin-wide climate change are manifested earlier and had a greater impact on aquifer storage than municipal growth and CAP shortages (Figure ES-15).

- Due to a lack of delivery infrastructure, providers without physical access to renewable supplies often recharge at facilities located at a distance from their pumping sites. This "hydrologic disconnect" between areas of pumping and areas of recharge has led to the development of local supply-demand imbalances. Thus, some areas of the LSCR Basin are projected to have increasing groundwater levels while other areas are projected to decline (Figure ES-16).

- Modeling identified four "areas of concern" where groundwater levels are expected to decline under all scenarios, worsening existing local supply-demand imbalances. These areas, shown in Figure ES-17, were the focus of adaptation strategy development.

Adaptation Strategies

- Strategies fell into two categories:
  - Local supply-demand imbalances were addressed by transporting existing supplies within the LSCR Basin.
  - Regional solutions focused on either augmenting the water supply or improving overall watershed conditions.
- Example strategies addressing local supply-demand imbalances included:
  - Developing infrastructure to bring renewable supplies to pumping locations, either for direct delivery or recharge.
  - Siting new water reclamation facilities in a strategic manner to recharge reclaimed water near areas with declining groundwater levels, rather than using centralized facilities.
  - Promoting future growth within the service area boundaries of municipal providers with direct access to renewable water supplies.
- Regional Strategies included:
  - Collecting and utilizing stormwater. Stormwater harvesting has low barriers to implementation, but a high per-unit cost.
  - Importing desalinated water from the Sea of Cortez in Mexico. This strategy has high implementation barriers and high costs, but could also yield the largest volume of water of any single strategy considered in the Trade-off Analysis.
  - Upland restoration also received strong support from participants in the Trade-off Analysis. In this strategy, stormwater would be detained through natural channel design, and erosion/grade control techniques would be used to restore, protect, and enhance surface water resources. While this strategy did not generate additional water supplies, it was rated highly for many of the other criteria in the Trade-off Analysis.

Trade-Off Analysis

- Most individual strategies could not address all the LSCR Basin's adaptation needs, and those that could had serious obstacles.
- Most strategies provided a unique set of benefits and costs.
- A comprehensive adaptation plan would likely include multiple strategies to address local supply-demand imbalances and potentially augment the total water supply.

- Results also revealed strong support for projects that incorporate environmental benefits as well as meet human needs. Many of the adaptation strategies considered featured in-stream recharge of reclaimed water for ecosystem support.

Conclusions

Since the early 1990s, water users in the LSCR Basin have gone from depending almost exclusively on groundwater to a net gain in total water resources. The reasons for this change include a culture of conservation and efficiency, increasing reuse of reclaimed water and the ability to receive, deliver and store large volumes of Central Arizona Project water. For most of the 2020 – 2060 period modeled in this Study, the key water resources issue within the Basin is the presence of local, rather than overall, supply-demand imbalances. After 2050, rapid / outward growth scenarios predict a shift to declining storage, as demand outpaces available supplies, while the slow/compact and medium/ official growth scenarios still project increasing aquifer storage.

At an LSCR Basin-wide level, the large volume of CAP and reclaimed water stored underground provides a substantial buffer against future municipal water shortages. This resilience to shortages is a product of many years of planning and investment by municipal water providers. Individual providers' level of resilience depends on their current and projected demands, their available resources, and the degree of future shortages.

Decreasing per capita municipal use and increasing water use efficiency will help extend supplies. Still, some providers may need to develop new infrastructure to recover stored water in order to meet future demands. Still, others may need to acquire additional renewable supplies to maintain compliance with ADWR's Assured Water Supply Program requirements.

Study results show that land use policies and decisions matter – they affect total water use as well as local supply-demand imbalances. Linking municipal growth and physical access to renewable supplies can keep local supply-demand imbalances from worsening, avoid the pitfalls of excessive groundwater pumping, and help preserve the natural resources that rely on shallow groundwater. Conversely, new municipal development in areas without access to renewable water resources will exacerbate current local supply-demand imbalances or create new ones, worsening the hydrologic disconnect.

While municipal water providers in the Study Area have taken significant steps to ensure the reliability of their supplies, this Study's findings still underscore the need for timely and comprehensive climate adaptation. The LSCR Basin's semi-arid ecosystems have already been impacted by climate change. Many Southwest forests are converting to grassland or shrubland in response to changing climate conditions combined with high-intensity fires (United States Global Climate Research Program, 2023). These conversions extend to riparian areas which support a wide variety of plant and animal species on less than 2% of the Southwest's total land area (Baker, Ffolliott, DeBano, & Neary, 2004). Study results demonstrated that areas with natural surface water and shallow groundwater may become drier overall, as well as more variable in their moisture conditions. This is an appropriate time to start planning for protecting species by developing refugia and improving habitat, which can often be achieved in concert with projects that also have water management benefits.

Additional Investigations

Several additional analyses would complement this Study's findings. One such analysis is an investigation of projected changes to the LSCR Basin's mountain-front recharge rate. While the Study used the parameters developed for the ADWR Tucson Active Management Area Groundwater Model using the historic climate, climate change is expected to impact this critical recharge process.

The Study's surface water modeling could also be enhanced by including streamflow routing. At present, the surface water model only generates estimates of stream discharge for the watershed and the groundwater model uses a very simple method to calculate infiltration along a watercourse. Supplemental modeling efforts could evaluate the impacts of reduced water availability on riparian areas, including their plant and animal populations.

Additional adaptation strategies could be investigated, including projects that recover and use stored water to meet future demands. The adaptation strategies evaluated in this Study are just a sample of the ideas generated by participants in the Adaptation Strategy Workshops. A complete list of these ideas is provided in the Adaptation Strategy Workshop documentation.

The Economic and Trade-off analyses could be refined by more quantitative estimates of benefits, as well as by evaluating groups of adaptation strategies to identify an optimal combination. In addition, a more systematic development of strategies specifically intended to address supply-demand imbalances would make them easier to compare and evaluate.

Further refinement of the Study results could address specific concerns of individual water sectors, such as ensuring reliable supplies during periods of peak demand, preparing for the impact of increased heat on water resources and facilities, and maintaining biodiversity in areas projected to become hotter and potentially drier.

Next Steps

Strategies for Individual Providers

Water providers in the LSCR Basin Study area are already undertaking activities that address the need to maintain sustainable water supplies, such as promoting conservation and the use of alternative sources like stormwater. Many providers also support education programs to raise awareness of water resources issues. Water providers could expand these programs as a part of their adaptation efforts and target areas of local supply-demand imbalance.

Of particular note is Tucson Water's One Water 2100 Master Plan, a comprehensive, long-range plan that aims to protect the reliability and quality of Tucson's water supply through 2100. The Study has already provided climate information used to underpin the Plan (City of Tucson and HDR, 2021). The One Water approach values all types of water resources, recognizing the interconnectedness of the surface water and groundwater supply, recycled water, and rain and stormwater harvesting. The Plan guides Tucson Water's capital and financial planning, conservation practices, and provides information to support policy decisions.

Other examples of individual water providers' on-going adaptation measures include rebates for water efficient toilets and for graywater and rainwater harvesting systems, an online portal that alerts customers to high water use issues, free water use audits for homes and businesses, and the creation of a "Citizens' Water Academy".

Collaboration and Partnerships

LSCR Basin water providers have a long history of collaboration, including approaches akin to some of this Study's adaptation strategies. For example, Tucson Water has established "wheeling" agreements with the Metro Water District, the Towns of Oro Valley and Marana, the Vail Water Company, and the Pascua Yaqui Tribe. In this arrangement, Tucson Water takes delivery of some or all these providers' CAP allocations and recharges them in its facilities. When supplies are needed, water is delivered to these providers through Tucson Water's distribution system. These agreements provide a template for adaptation strategies where renewable supplies would be wheeled to providers near the Study's areas of concern.

Other collaborations involve transporting CAP water to points of use to reduce the need for groundwater pumping. One such project, still in the implementation stage, is the Northwest Recharge Recovery and Delivery System (NWRRDS), sponsored by the Metro Water District, the Town of Marana, and the Town of Oro Valley. The project will recover CAP water recharged in the Avra Valley Recharge Project and deliver it to the sponsors' service areas, reducing the need for groundwater pumping. By developing common infrastructure, the sponsors reduce the costs and minimize the permitting associated with building a project.

Most of the adaptation strategies examined in this Study are likely to require collaboration between water providers, and potentially other entities, with interests in a project. Since the Tucson Active Management Area's Fifth Management Plan requirements do not address local supply-demand imbalances, it is likely that projects will be motivated by other objectives, such as supply reliability in the case of the NWRRDS project.

Additionally in 2021, the Governor's Water Augmentation, Innovation and Conservation Council Post-2025 AMAs Committee recognized the "hydrologic disconnect" as an issue in most of the state's AMAs and suggested policy solutions. In 2023, the successor Governor's Water Policy Council Assured Water Supply Committee reiterated this concern and also proposed solutions. If these policies are adopted, they would provide a direct incentive for water providers to address the Study Area's local supply-demand imbalances.

Wider Implications of Study Findings

While water providers and the environment were the focus of this Study, the information generated in this Study is applicable to other many organizations. Projected changes in temperature and precipitation extremes are relevant to applications such as flood risk management, urban infrastructure design, and human health. Projected soil moisture and stream flows can help to inform land and wildlife management, ranching, and agriculture. Thus, this Study lays the groundwork for a wide range of adaptation activities to develop the resiliency necessary for a community to thrive in a changing climate.

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