LOWER SANTA CRUZ RIVER BASIN STUDY

SCIENCE SUMMARY OF CLIMATE AND SURFACE WATER MODELING

CENTER FOR CLIMATE ADAPTATION SCIENCE AND SOLUTIONS
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May 2022

Center for Climate Adaptation Science and Solutions

Arizona Institute for Resilient Environments and Societies

University of Arizona

Recommended Citation: Gupta, N., Jacobs, K., Halper, E., Bearup, L., Kennett, B., Wilson, W. (2022). *Lower Santa Cruz River Basin Study: Science Summary of Climate and Surface Water Modeling*. University of Arizona Center for Climate Adaptation Science and Solutions, Tucson, AZ, USA, 26 pp.

We are pleased to be able to share with you a science summary of Reclamation's Lower Santa Cruz River Basin Study's Hydroclimate Analysis (Technical Memorandum No ENV-2020-056) prepared by the University of Arizona's Center for Climate Adaptation Science and Solutions. The study area is identical to the boundaries of the Tucson Active Management Area.

The Lower Santa Cruz River Basin Study consisted of four major elements:

1. Projection of future supply and demand imbalances, including an analysis of the impacts of climate change
2. Evaluation of risks to infrastructure and other systems, including the environment
3. Development of adaptation strategies
4. Trade-off analysis of adaptation strategies.

In the coming months, we will be releasing the following additional materials from the Study:

1. Groundwater Modeling Technical Memorandum
2. Adaptation Strategy Technical Memorandum
3. Trade-off Analysis Technical Memorandum
4. Lower Santa Cruz River Basin Study Final Report

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1. DESCRIPTION AND PURPOSE

1.1. OVERVIEW

This Science Summary details the climate change and surface water modeling portion of the Lower Santa Cruz River (LSCR) Basin Study. The Study is a collaborative effort between the Bureau of Reclamation and six non-Federal groups, led by the Southern Arizona Water Users Association, that began in 2016 and is scheduled to conclude in 2022. The LSCR Basin Study area is identical to the Tucson Active Management Area as defined by the Arizona Department of Water Resources (Figure 1, black outline). More information about the Study can be found on its webpage at: https://www.usbr.gov/lc/phoenix/programs/lscrbasin/LSCRBStudy.html

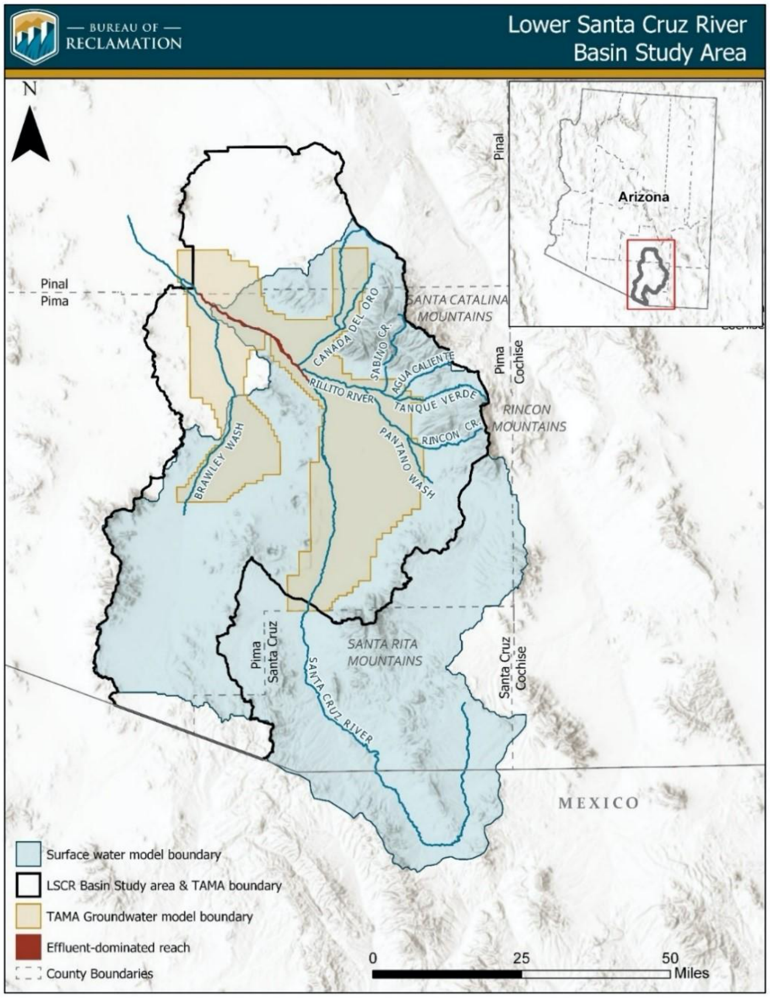

Figure 1 - Extent of Analyses for the LSCR Basin Study

This document serves as an accompaniment to Technical Memorandum No. ENV-2020-56, Lower Santa Cruz River Basin Hydroclimate Analysis, prepared by the Bureau of Reclamation[1].

This analysis is part of a larger effort to evaluate the impacts of climate change and growth on water supplies and demands in the LSCR Basin (Basin). Due to the multiple sources of water used in the Basin, a cascade of modeling efforts was required. The climate model outputs (primarily temperature and precipitation) served as inputs to the surface water model, which in turn provided input into a groundwater model. A separate model was used to project demands driven by population growth, and provided a complementary set of inputs to the same groundwater model.

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[1] https://www.usbr.gov/lc/phoenix/programs/lscrbasin/LSCRBS_Hydroclimate_2021.pdf

Results of surface and groundwater modeling were used to estimate changes in the Basin's future water supplies. The development and application of groundwater modeling efforts are addressed in a separate Groundwater Modeling Technical Memorandum currently in development.

The purpose of this summary is to provide an overview of water and climate conditions in the Basin and then to present the methods and results of the climate change and surface water analysis within this context. This includes the rationale behind the approach, the development of the climate scenarios, the selection and processing of climate projections and documentation of the climate and surface water modeling results.

1.2. BACKGROUND

In 2009, Congress enacted the Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act and established a climate change adaptation program. To implement the SECURE Water Act, the Department of Interior (DOI) established the Sustain and Manage America's Resources for Tomorrow Program (WaterSMART) in 2010. This program directed DOI to collaborate with States, Tribes, and local agencies to identify adaptive measures needed to address climate change and future water demands.

As part of DOI's WaterSMART strategy, the Bureau of Reclamation developed the Basin Studies program. These are collaborative studies that analyze the impacts of climate change and other factors on future water supplies and demands, identify risks and develop adaptation strategies at the river basin scale (Figure 2).

KEY STEPS IN THE LOWER SANTA CRUZ RIVER STUDY INCLUDE:

1. Developing projections of the basin's future water supply and demands, with consideration of climate change impacts
2. Analyzing how water delivery systems (e.g., infrastructure and operations) and riparian ecosystems will function under future conditions
3. Formulating structural and non-structural adaptation strategies to meet future demands for all water use sectors, including the environment
4. Conducting a tradeoff analysis of the strategies developed

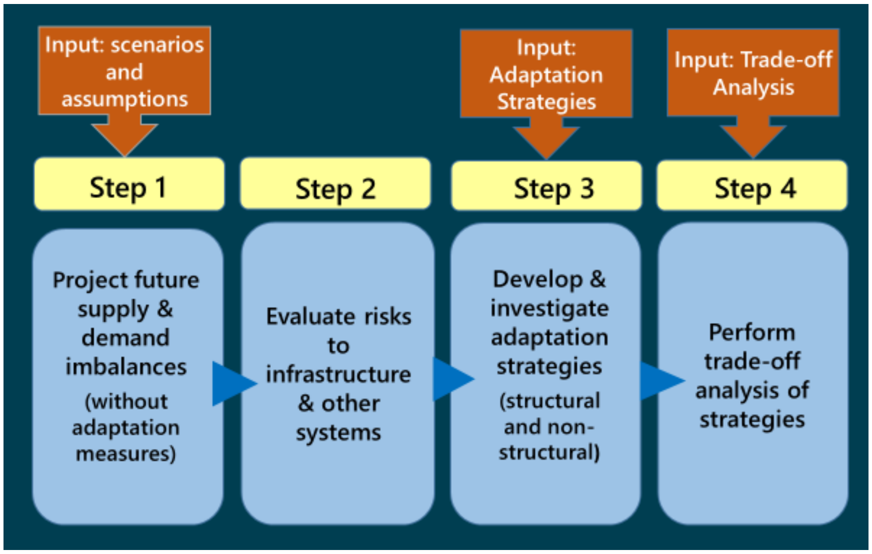

Figure 2 – The four components of a Reclamation Basin Study

Study management is coordinated by a "Core Team" which includes two Co-Study Managers, one representing the Bureau of Reclamation and the other representing the non-Federal cost-share partners. Major study decisions are made by a consensus of the Project Team, which consisted of representatives of the six cost-share partners: the Southern Arizona Water Users' Association, the Central Arizona Project, the Pima Association of Governments, the Arizona Department of Water Resources, the Cortaro-Marana Irrigation District, and the University of Arizona.

2. CLIMATE AND HYDROLOGY IN THE LSCR BASIN

The Lower Santa Cruz River Basin (Figure 1, black outline) is located in Arizona's Sonoran Desert at 32.2° N latitude, one of the hottest and driest regions in the United States (Garfin et al., 2013). The Basin sits within a stable high-pressure zone in which air from equatorial areas rises and cools, loses moisture, and descends and heats at approximately 30° latitude (Gelt et al., 1999). Areas at or near these latitudes are characterized by their semi-arid and arid climates. Annual temperatures at the Tucson International Airport average a minimum of 57.3 degrees Fahrenheit (°F) and a maximum of 84.0° F, with large seasonal and diurnal variability typical of mid-latitude steppe and desert climates (NOAA NCEI U.S. Climate Normals Quick Access).

The greater Tucson area, which is situated within the Basin, receives an average of approximately eleven inches of precipitation a year, which is distributed between a summer monsoon season and a winter rainy season

(Western Regional Climate Center, 2006). From mid-June to September, the North American Monsoon delivers high-intensity, localized, short-duration (typically less than an hour) precipitation events that provide approximately 52% of average rainfall (Gelt et al., 1999).

The majority of remaining rainfall is delivered from October through March. This time period includes the winter rainy season where the normally high-pressure cell that covers the American Southwest is weakened, allowing large, slow-moving storms to pass over the Basin. The winter rainy season is typified by heavy cloud cover and rainfall events of longer duration (hours to days), which are lower in intensity and cover a wider area than summer monsoon events (Gelt et al., 1999).

Basin-wide precipitation also varies widely across years, due to the study area's location between shifting mid-latitude and subtropical atmospheric circulation regimes, as well as its proximity to the Pacific Ocean, the Gulf of California, and the Gulf of Mexico. The local climate is also strongly influenced by the El Niño-Southern Oscillation and the Pacific Decadal Oscillation (Sheppard, et al., 2002).

Most reaches of the Santa Cruz River within the Basin do not have streamflow except following rainstorms. Rainfall events that generate runoff provide surface water flow to normally dry stretches of the Lower Santa Cruz River and its tributaries, supporting riparian (streamside) ecosystems before infiltrating and recharging the area's aquifers. The geology of the regional aquifers allows runoff to infiltrate relatively quickly and easily via river channel losses (e.g., Wilson et al., 1998). However, rainfall events are highly variable spatially and temporally, and are influenced by the landscape both in terms of topography and land cover (Garfin et al., 2013).

3. SUMMARY OF LSCR BASIN STUDY PROCESS

3.1. SCENARIO PLANNING

Scenario planning is a method for considering possible futures and illustrating conditions that may occur under specific assumptions. Scenarios are not forecasts, but they provide a structured and scientific means to evaluate the impacts of possible futures. This Study incorporates scenario planning to address the considerable uncertainty associated with future climate and population conditions. Project Team members developed climate scenarios as part of the Study process.

“Climate” refers to the typical weather of an area over a period of time. The Study uses the World Meteorological Organization standard of a 30-year period (WMO, 2017). Two future time periods were assessed: the period between 2020-2049, described as the “2030s” or “near future”, and the period between 2050 and 2079, described as the “2060s” or “far future”.

3.1. STUDY APPROACH

With support from researchers at the University of Arizona and the Bureau of Reclamation’s Technical Service Center (BOR TSC), the Project Team developed an approach tailored to the needs of the area’s water users. Key choices used to guide the development of scenarios are described below.

To better assess impacts to water supply reliability and the environment, the Project Team agreed to consider impacts to a **wide range of climate related risks**. By focusing on the range of risk, rather than on “middle of the road” scenarios, modeling could evaluate the impact of substantial stresses on water supply systems and riparian ecosystems. This approach provided information on the resilience of the area’s water supplies.

Partners developed two climate scenarios that encompassed the range of risks to the area’s water-using sectors, a **“worse-case” scenario** (severe but not impossible to adapt to) to a **“best-case” scenario** where less severe climate impacts could be responded to with a minimum amount of adaptation. These scenarios “bookended” the range of impacts to water users and served as a basis for future planning activities.

The Project Team also identified key climate metrics to evaluate under future conditions, due to their importance for water availability and demand. These metrics included changes in **frequency and intensity of extreme events** (precipitation and temperature), **monsoon timing** (onset and duration), and **dry season timing** (onset and duration).

Finally, the Project Team wanted to investigate how the **variability of precipitation and temperature** could change in the future. Changes in variability could impact riparian ecosystems. For instance, certain riparian trees require floods flows in order for their seeds to germinate. Changes in the frequency of floods that recharge the aquifer, as well as changes in the onset and demise of the high-demand dry season, could affect the ability of water providers to reliably serve their customers.

4. DEVELOPMENT OF CLIMATE CHANGE PROJECTIONS

4.1. EMISSIONS SCENARIOS

The Earth's energy balance is influenced by the emissions and concentrations of greenhouse gases (GHG) such as carbon dioxide, aerosols and other chemically active gases (USGCRP, 2018). There is great uncertainty about how much the climate will change in the future, although the direction of change is well understood in many cases. The pace and magnitude of change depends to a great extent on the rate at which humans emit GHG, take other actions that promote climate change, or manage the amount of carbon dioxide in the atmosphere. Future emissions will depend on worldwide economic, technological, demographic, policy-related, and institutional forces.

Standardized emissions scenarios called "Representative Concentration Pathways", or RCP's, have been used by the Intergovernmental Panel on Climate Change to illustrate future climate conditions under specified concentrations of GHGs, particularly carbon dioxide (Moss et al., 2010; van Vuuren et al., 2011). By using standardized RCPs as input to Global Climate Models, the model results can be compared to each other on an "apples to apples" basis.

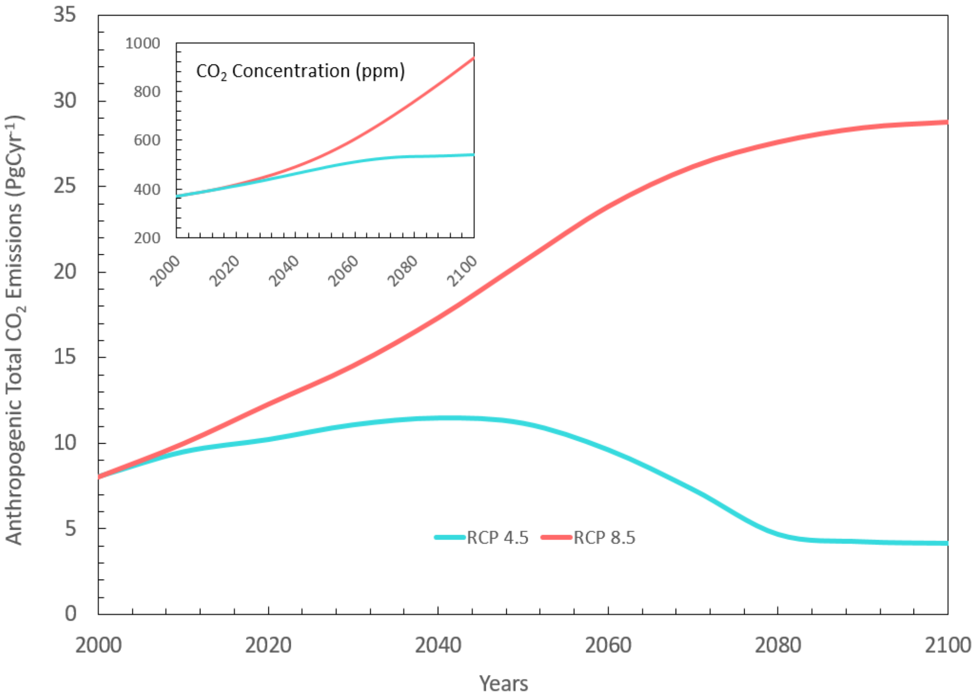

Figure 3 - CO_2 emissions and concentration projections through 2100 for RCP 4.5 and 8.5, as provided in the Intergovernmental Panel on Climate Change's Fifth Assessment Report

The RCP's provided a starting point for the development of the Study's climate scenarios. The "worse-case" scenario is based on the RCP 8.5 emissions scenario. This RCP is sometimes referred to as a "business as usual" scenario, since emissions continue to rise through 2100, although they begin to level off toward the end of the century. RCP 8.5 is not a definitive "worst" case, as it is clearly possible that emissions could increase faster than it projects.

A lower emission scenario, RCP 4.5, was chosen as a basis for the "best-case" scenario. The RCP 4.5 scenario is associated with lower global population growth and more technological innovation (USGCRP, 2018). Achieving the "best-case" RCP 4.5 will require significant reductions in emissions and/or some combination of carbon sequestration. These "best" and "worse" cases served as "bookends" for modeling the range of climate impacts to future water supplies and demands in the Basin.

4.2. DOWNSCALING OF GLOBAL CLIMATE PROJECTIONS

A Representative Concentration Pathway is an input to a Global Climate Model, or GCM. A GCM simulates global oceanic and atmospheric processes to produce gridded projections of temperature, precipitation and other climate variables (Figure 4B). However, the size of the grid cells created by a GCM is too coarse to perform the type of hydrologic modeling needed for this Study.

Downscaling is a process used to transform the GCM's low-resolution model grid cells to a spatial scale appropriate for a particular use, in this case, hydrologic modeling at the scale of the LSCR Basin. An example of a downscaled climate projection is shown in Figure 4A.

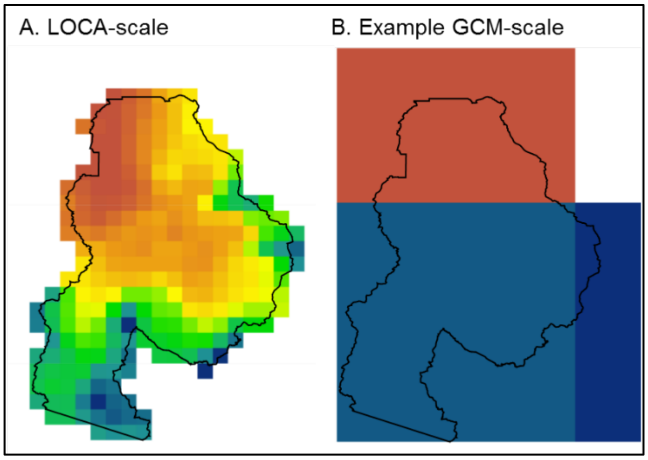

Figure 4. Approximate resolution of A) downscaled climate model and B) general circulation models (GCMs) that describe large-scale atmospheric processes (Reclamation, 2021).

Climate change studies often use “statistically downscaled” projections, which rely on relationships derived by comparing projections with historical data. Statistical downscaling uses a straightforward computational process, therefore statistically downscaled versions of many GCMs, run under a variety of emissions scenarios, are readily available for use.

The disadvantage of statistical downscaling methods is that they assume the historical relationships between climate variables will not change over time. However, as the climate changes, so do important aspects of natural processes, such as the amount of water that can be held by the atmosphere, rates of rainfall and snowfall, the amount of water discharged by rivers and the amount of water needed by plants. The changes in these processes may produce results outside the range of historical values (Milly et al., 2008).

Dynamical downscaling uses the output of Global Climate Models as input to a Regional-scale Climate Model, which produces gridded projections of climate variables at a finer spatial scale than a GCM. These models include regional topography and explicitly simulate physical processes in the atmosphere at a regional scale. Dynamically downscaled projections do not rely on historical data that may not accurately represent the conditions of an evolving climate.

The disadvantage of dynamical downscaling is that it requires a great deal of technical expertise and computing power, so it is a slow and expensive process. These factors limit the number of models and the emissions scenarios available for use in planning, as well as the spatial resolution of the downscaled projections.

In 2015, research led by Dr.’s Christopher Castro and Hsin-I Chang of University of Arizona (UA) compared the impact of downscaling techniques on flow projections for the Salt, Verde and Colorado Rivers. This work found that when using identical GCMs, dynamically downscaled projections of flows were significantly lower than those developed with a statistical downscaling method. Partners were concerned that using only statistically downscaled climate projections might underestimate the true level of risk to water supplies. Consistent with the goal of developing a “high-risk” scenario, they requested that the Study include a dynamically downscaled climate projection for the LSCR basin-wide surface hydrology modeling.

The Project Team reviewed the available dynamically downscaled climate projections developed by the University of Arizona and other groups. A key criterion for selecting a dynamically downscaled projection was an accurate representation of the timing of summer monsoon precipitation (Castro et al., 2012; Chang et al., 2015) since the onset and demise of seasons is so important for the area's hydrology.

After extensive testing, the Max Planck Institute Earth System Model (MPI), downscaled with the Regional Weather Regional and Forecasting Model (WRF) was selected to model the "worse-case" climate. In other words, the "worse-case" climate projections used the RCP 8.5 emissions scenario as input to the MPI model. The output of the MPI model was then run through the WRF model to produce the dynamically downscaled climate projections. A dynamically downscaled projection was not available for the "best-case", lower emissions RCP 4.5 scenario. Instead, an MPI projection run with RCP 4.5 that was statistically downscaled with the advanced LOCA (Locally Constructed Analog) method was selected.

4.3. USE OF A WEATHER GENERATOR

While the "best-case" and "worse-case" scenarios each provide one sequence of future precipitation and temperature, there are many other sequences that are equally likely to occur under the region's highly variable climate. To properly account for the variability of the regional climate and its resulting surface water flows, it was important to simulate the probability distribution of precipitation events and temperature at the daily level over a period of thirty years.

To accomplish this, staff at Reclamation's Technical Service Center developed a computer program called a "weather generator" specifically for the Study. The weather generator simulated the variability of precipitation and temperature in the region, including monsoonal and other seasonal dynamics.

The weather generator conceptualized the Study area's climate as having three seasons. Two of these were described in Section 2: a summer – fall monsoon season and a distinct winter wet season. Between the end of winter wet season and the next monsoon season is a period during which rainfall is extremely rare, the "arid fore-summer" (Figure 5).

For each season, the weather generator resampled the projected "best-case" and "worse-case" case time series of precipitation and temperature many times, while preserving key characteristics of the statistical distribution. This created a large group, or ensemble of plausible precipitation and temperature time series that simulated the variability of each season.

The Study investigated the possibility that in the future, seasons might begin and end at different times that they currently do. In order to perform this analysis, seasons were defined by their physical characteristics rather than by dates of the year. The changes in length and timing were then evaluated under the "best" and "worse" scenarios.

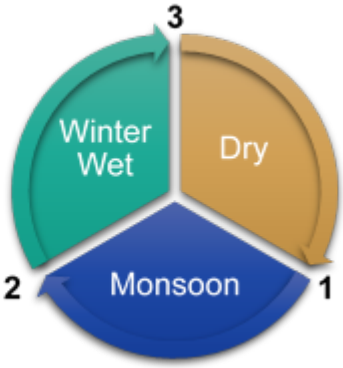

Figure 5 - Conceptual diagram of seasonality defined in weather generator used in the LSCRBS (BOR, 2021).

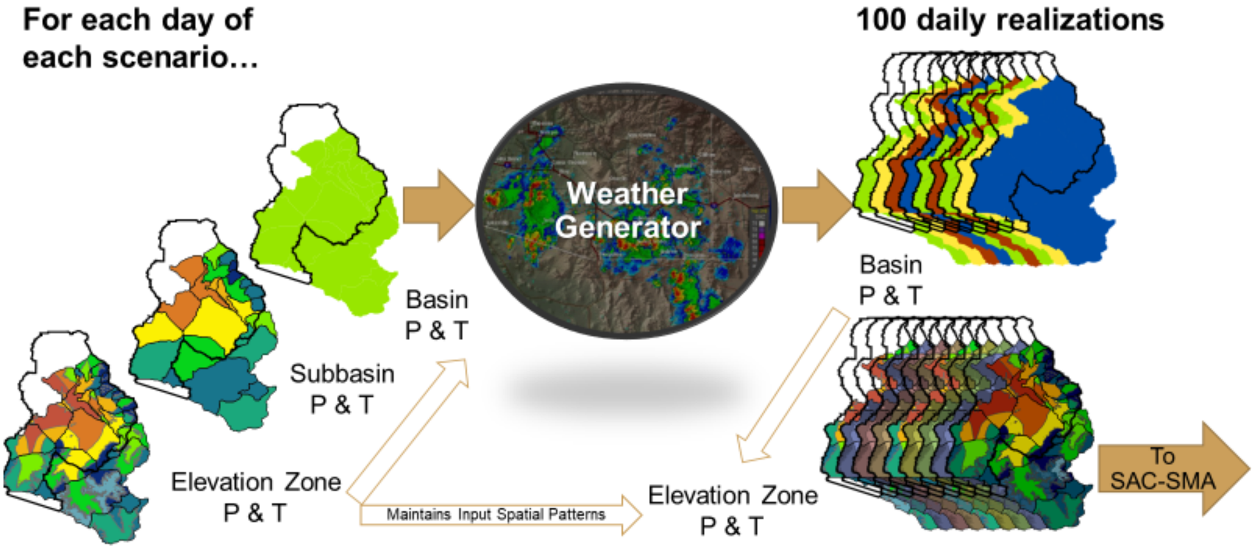

Figure 6 - Conceptual diagram of the daily weather generator developed by Reclamation TSC staff. P stands for precipitation, T stands for temperature. SAC-SMA is the Sacramento Soil Moisture Accounting model surface model.

4.4. SURFACE WATER PROJECTION DEVELOPMENT

The weather generator was designed to generate input for the surface water model deployed for the Study, the Sacramento Soil Moisture Accounting Model (Sac-SMA). The same 1970-1999 calibration data set, developed by the

National Weather Service’s Colorado River Forecast Center for flood forecasting, was used for the weather generator and the surface water model.

To examine the changes expected in surface water flows, Reclamation staff first used the “best-case” and “worse-case” climate models to simulate the precipitation and temperature of the historical calibration period, 1970 – 1999. The results compared favorably with the Sac-SMA calibration set for the same period.

Next, the “best-case” and “worse case” models’ simulation of the 1970 – 1999 time period, consisting of a single temperature and precipitation time series for each case, was run through the weather generator to create an “best” and “worse” ensemble, each containing 100 time series. Each of these ensembles were then run through the surface water model to produce stream flows and other surface water outputs for the 1970 -1999 period.

The “best-case” and “worse-case” projections for the near and far future 30-year period (2020 – 2049 and 2050-2079 respectively) were the processed in the same way. The single time series for each case was input into the weather generator to produce an ensemble of 100 temperature and precipitation time series for each period. The ensembles were then run through the surface water model to estimate resulting stream flows.

Finally, the change between the future periods and calibration period was developed by calculating the difference between ensembles of stream flows. For instance, the median change in stream flows between the period of 1970 – 1999 and 2020 – 2049 for the “worse-case” consists of the median of the differences of each of the stream flows between the 1970 – 1999 streamflow simulation and the 2020 – 2049 streamflow simulation.

4.5. SURFACE WATER MODELING

The Sac-SMA model simulates water movement through the soil while preserving the overall water balance. Mechanisms of water movement include surface runoff, infiltration, interflow[2], percolation, storage, evapotranspiration, and baseflow. The Sac-SMA hydrologic model is run in a lumped framework, meaning model parameters are averaged over elevation zones within sub-basins. Each sub-basin may include up to three elevation zones depending on the topography, vegetation, and snowpack patterns. The model used in this study has 26 sub-basins divided into a total of 59 elevation

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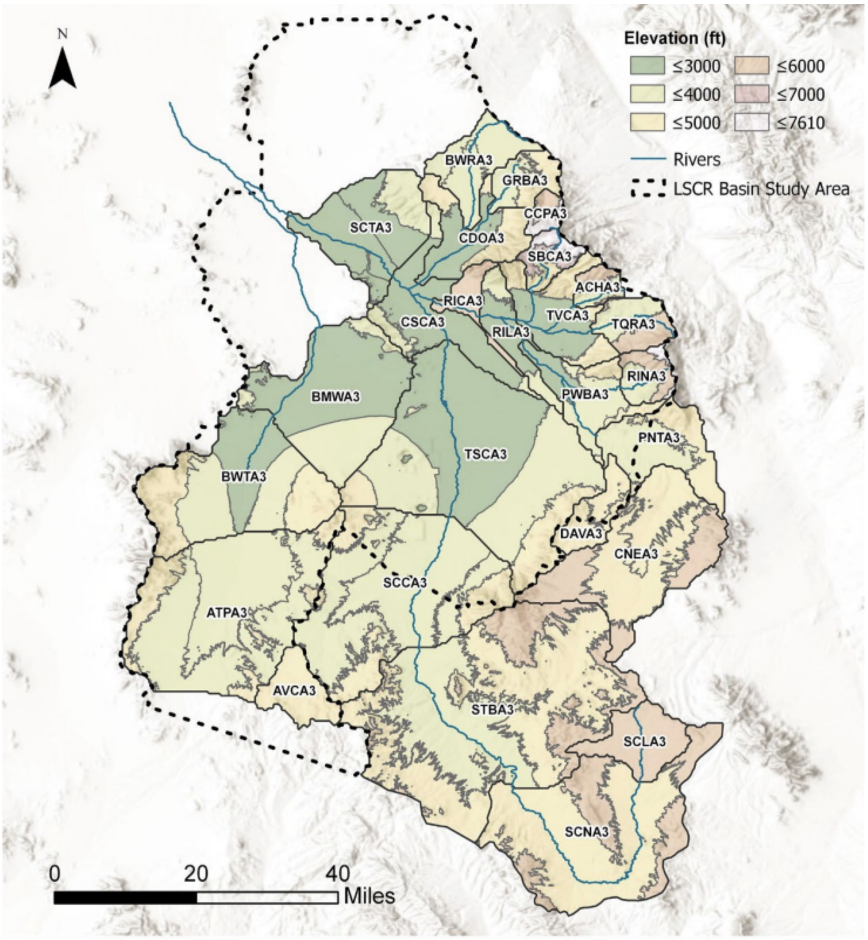
[2] Shallow subsurface flow that returns to the surface over relatively short distances

zones, where the average size of an elevation zone is 79 square miles (Figure 7).

The model used for this study contained a number of sub-basins outside the Tucson Active Management Area that directly generate runoff into the study area. The model did not include an area in the northwest of the study area that is sparsely populated and drains to the north (see figure below).



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

Figure 7 – Elevation zones (colored) across the subbasins (thin black line) delineated for the LSCR Basin within the Sac-SMA surface water model

5. CLIMATE AND SURFACE WATER MODELING RESULTS

5.1. TEMPERATURE CHANGE OVER THE SURFACE WATER MODEL BOUNDARY AREA

Modeling results indicate that seasonal and annual average temperatures will continue to increase under both the “best-case” and “worse-case” climate scenarios, with higher temperature increases observed in the “worse-case” (higher emissions) scenario, as expected (Table 1). This warming includes an increase in intensity in extreme temperature events such as heat waves. For the near future, the “best-case” projects that the highest increase in temperature will occur in the dry season; for the “worse-case” scenario, the highest temperature increase occurs in the monsoon season. For the far future period, both the “best-case” and “worse-case” project the greatest increases in temperature during the monsoon season.

	Best Case - 2030s “Near Future”	Best Case - 2060s “Far Future”	Worse Case - 2030s “Near Future”	Worse Case - 2060s “Far Future”
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 Temperature	1.88˚F	1.85˚F	2.45˚F	3.20˚F

Table 1. Summary of projected temperature changes from 1970 – 1999 30-year average

5.2. PRECIPITATION CHANGE OVER THE SURFACE WATER MODEL BOUNDARY AREA

Precipitation projections were more variable than temperature projections and are strongly influenced by emission scenario selection (Table 2).

Overall, the “best-case” scenario projects relatively minimal changes in precipitation (i.e. less than 1’’ change) while the “worse-case” scenario projects a general decrease of approximately 4 inches (a reduction of more than 30% of historical average rainfall) in total annual precipitation. Monsoon season rainfall is highly variable across sub-basins, which is challenging for modelers.

	Best Case 2030s: "Near Future"	Best Case 2060s: "Far Future"	Worse Case 2030s: "Near Future"	Worse Case 2060s: "Far Future"
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 Precipitation	-0.21"	0.57"	-2.25"	-2.38"

Table 2. Summary of projected precipitation changes from 30-year average.

With regards to extreme events, the best-case scenario projects a general increase in the magnitude of extreme events in the monsoon season, while the worse-case scenario projects more and larger individual extreme events.

5.3. SURFACE WATER MODEL RESULTS

Changes in streamflow were assessed using the Sac-SMA model, as described in Section 4.4. An abbreviated summary of results is included in the sections below. For detailed summary of results, refer to the LSCR Basin Study Hydroclimate Analysis, BOR Technical Memorandum No. ENV-2020-56.

Changes in monsoon and winter season streamflow are presented below as a fraction of the historical flow simulated by the model.

5.3.1. MONSOON SEASON STREAMFLOW

Changes in the total monsoon season streamflow result from changes in the length of the season, storm intensity, and frequency of storms. In the near future, the "best-case" scenario has a consistently longer monsoon season resulting in more total flow over this season (Figure 8). Streamflow decreases in some sub-basins in the far future, particularly in sub-basins that experience larger increases in no flow days.

Under the "worse-case" scenario, the near future appears to be a transition time with generally shorter, but highly variable, monsoon season length. The changes in monsoon seasonality result in high variability in monsoonal rainfall totals from year to year, with an overall decreased median streamflow.

In the far future, the longer monsoon season results in an apparent recovery of streamflow. However, streamflow events are less frequent and likely more extreme, consistent with the increase in individual large precipitation events projected under this scenario. Larger precipitation events can have a disproportionate effect on streamflow, since less water can infiltrate during large rainfall events. Therefore, small increases in monsoonal rainfall can result in increased streamflow when large runoff events occur.

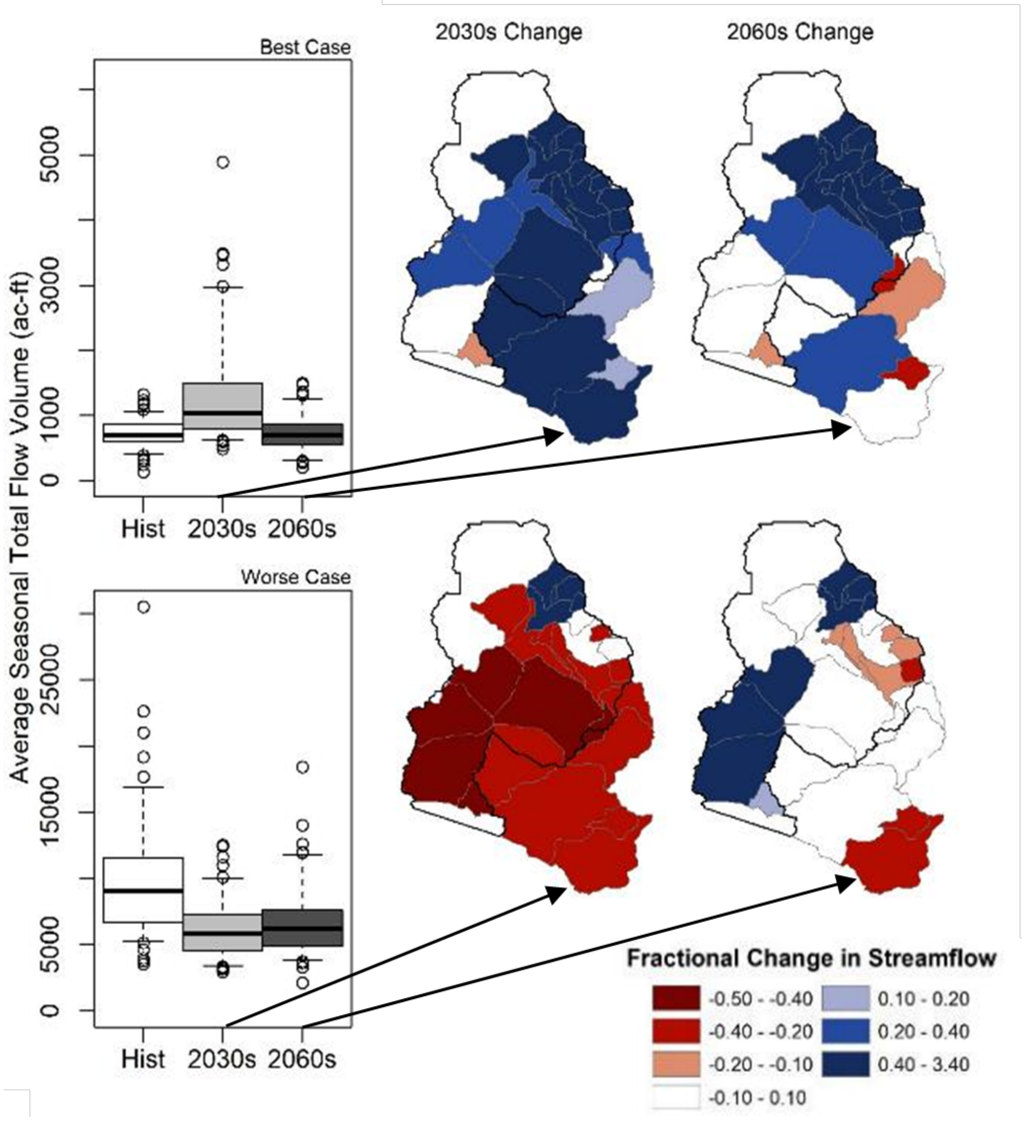


Figure 8 - Median of the ensemble 30-year average monsoon season total streamflow from the modeled historical period (tan) for each scenario, and projected change from historical (red for negative and blue for positive change respectively) in streamflow for the best- and worse-case climate scenarios.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

5.3.2. WINTER SEASON

The winter season is projected to shorten under both climate scenarios. In the best-case scenario, the large events get consistently larger into the future, compensating for the shortening of the winter season.

In the worse-case scenario, total winter precipitation is consistently lower in both future periods and this change in precipitation translates to less overall streamflow. In the near future, there is a relatively larger fractional decrease in streamflow due to a shorter season and lack of large precipitation events to compensate for the shortened season (Figure 9). In the far future, more extreme precipitation likely results in some streamflow recovery.

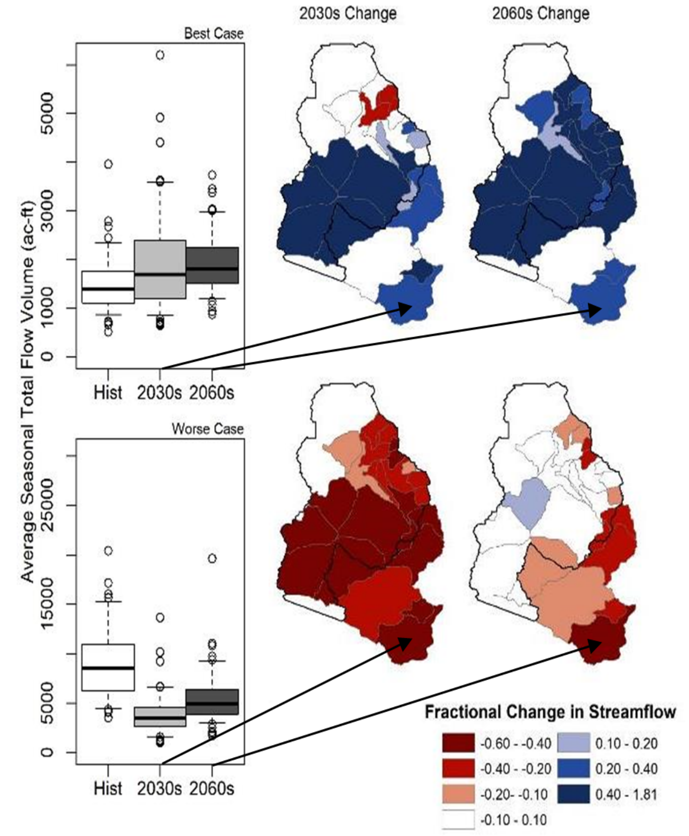


Figure 9 - Median of the ensemble 30-year average winter wet season total streamflow from the modeled historical period (tan) for each scenario, and projected change from historical (red for negative and blue for positive change respectively) in streamflow for the best- and worse-case climate scenarios. Note coverage is only over the areas identified as subbasins in Figure 7.

5.3.3. SOIL MOISTURE

Changes in soil moisture generally mirror changes in precipitation. For the best-case scenario, soil moisture generally increases in the fall and winter, particularly in the far future, and decreases in the far future monsoon season months of July and August.

The worse-case scenario is drier, however, with nearly all soil water zones indicating decreases in soil moisture in both the near and far future (Figure 10). The limited exceptions are the transition to the dry season in May and the fall months in the far future, which suggest wetter soils during these periods. These soil moisture increases tend to occur in the lower-elevation, drier portions of the basin where large percent changes may represent small actual increases in moisture, while the higher elevation and wetter sub-basins in the Santa Catalina and Rincon Mountains still decrease in soil moisture throughout the year.

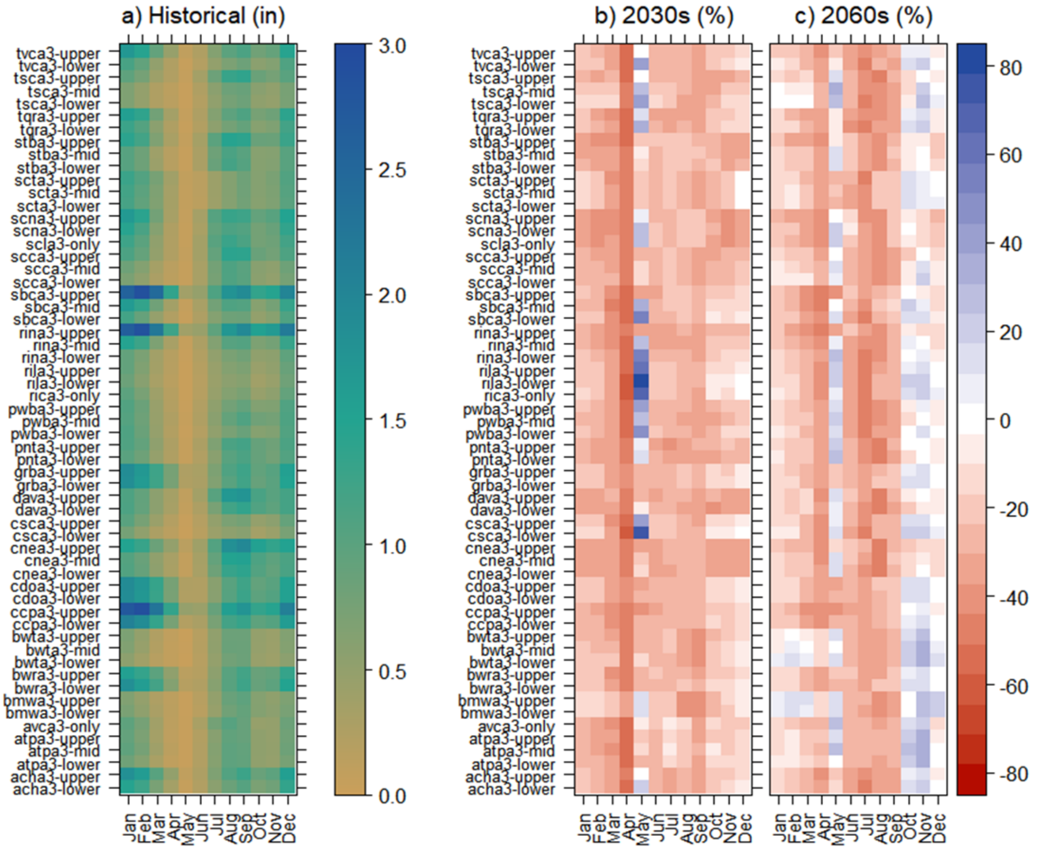


Figure 10 - Ensemble median, monthly average of the total tension water (sum of upper and lower soil zones) under the ***worse-case climate scenario*** *for: a) modeled historical tension water in inches, b) near future change, and c) far future change as a percent relative to the historical period. For soil moisture change, blue indicates an increase and red indicates a decrease. Results are presented for each elevation zone.*

6. SUMMARY

This Science Summary details a series of technical modeling efforts in which Project Team discussions guided the approach, design and application of the LSCR Basin Study. Key decisions made by the Project Team included the selection of climate scenarios, downscaling methods, and key climate metrics.

These decisions were guided by the larger goal to provide the most regionally relevant information on projected changes to surface and groundwater and to provide information that was useful for managing risk to important resources such as drinking water supply and riparian habitat health.

Increases in temperature are projected by all models that were evaluated. This is also consistent with observed and projected increases in temperature across almost all of the southwestern United States (Gonzalez et al., 2018).

Projections of rainfall are more complex and require specific context to evaluate. This is consistent with climate modeling across the globe, not a condition that is unique to this basin.

Overall, the “best-case” scenario projects relatively minimal changes in precipitation and smaller increases in temperature, a wetter and cooler climatology compared to the “worse-case” scenario. The latter projects decreases in total precipitation, larger increases in temperature, and increased extreme rainfall events. Projected decreases in precipitation under the worse-case scenario for both the monsoon and winter seasons generate concern with regards to “water supply, recharge, and environmental considerations” (BOR, 2021). Surface water modeling results indicate decreased soil moisture under both scenarios, and an increase of no-flow days in April, May, and August in the worse-case scenario.

This climate information was used as input to surface water and groundwater modeling efforts. The result of surface and groundwater modeling outputs were followed by identification of adaptation options to address future supply-demand imbalances in specific parts of the basin. These alternatives were evaluated by the Project Team in order to conduct a tradeoff analysis. These results are discussed in the forthcoming LSCR Basin Study Final Report.

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