RECLAMATION

Managing Water in the West

Truckee Basin Study

BASIN STUDY REPORT
EXECUTIVE SUMMARY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TMWA

PCWA
water • energy • stewardship

Truckee River Flood Management Authority

TAHOE REGIONAL PLANNING AGENCY

December 2015

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to 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.

RECLAMATION
Managing Water in the West

Truckee Basin Study
Basin Study Report

August 2015

U.S. Department of the Interior
Bureau of Reclamation

In Partnership with:

TRUCKEE MEADOWS WATER AUTHORITY

TAHOE REGIONAL PLANNING AGENCY

TRUCKEE RIVER FLOOD MANAGEMENT AUTHORITY

PLACER COUNTY WATER AGENCY

Disclaimer

The Truckee Basin Study was funded jointly by the Bureau of Reclamation (Reclamation) and Placer County Water Agency, Tahoe Regional Planning Agency, Truckee Meadows Water Authority, and Truckee River Flood Management Authority, and is a collaborative product of the study participants as identified in Chapter 1 of this report. The purpose of the study is to assess current and future water supply and demand in the Truckee River Basin and adjacent areas that receive water from the basin, and to identify a range of potential strategies to address any projected imbalances. The study is a technical assessment and does not provide recommendations or represent a statement of policy or position of the Bureau of Reclamation, the Department of the Interior, or the funding partners (i.e. Placer County Water Agency, Tahoe Regional Planning Agency, Truckee Meadows Water Authority, and Truckee River Flood Management Authority). The study does not propose or address the feasibility of any specific project, program or plan. Nothing in the study is intended, nor shall the study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the study represents a commitment for provision of Federal funds. All cost estimates included in this study are preliminary and intended only for comparative purposes.

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Executive Summary

Introduction

The Truckee River Basin (Truckee Basin) provides a compelling demonstration for how changes in a region's climate could influence both environmental and human water uses. This relatively small Basin includes every form of water use and every type of water user that exists in the Western United States, including: tribal lands and trusts; irrigated agriculture; municipalities and industry; mining and geothermal energy exploration; Federal water projects; hydropower generation; lake, stream, and reservoir recreation; and restoration efforts for diminished wetlands and endangered aquatic species. Correspondingly, this diversity of water uses has made the Truckee Basin home to a wide variety of water resources conflicts.

Despite these conflicts, communities in the Truckee Basin have actively managed and adapted to water scarcity for as long as the arid region has been inhabited. Management activities include a number of significant water resource facilities, built through both Federal and local investment over the past century-and-a-half. In parallel with the construction of these facilities, regulations to govern their use have been promulgated in response to demands and to provide the flexibility to deal with highly variable weather patterns.

Like many basins in the West, water management practices in the Truckee Basin, including diversion regulations, have been developed through a century of infrastructure improvements followed by decades of litigation. But unlike most basins, the closed hydrologic condition of the Truckee Basin creates a zero-sum game for water. The Truckee River has never had surplus water: each drop from its headwaters at Lake Tahoe to its terminus at Pyramid Lake is fully appropriated and serves important human uses and ecological functions. As a result, even small changes in future conditions (e.g., increases in demand or changes in climate) are perceptible and potentially contentious.

The U.S. Department of the Interior (Interior), Bureau of Reclamation (Reclamation), has initiated a series of studies through the WaterSMART Basin Study Program to assess the range of potential effects of future climate change on a number of basins in the Western U.S., each in partnership with local agencies. The Truckee Basin Study (Basin Study) was conducted by Reclamation in partnership with four non-Federal cost-share partners: Placer County Water Agency (PCWA), Tahoe Regional Planning Agency (TRPA), Truckee Meadows Water Authority (TMWA), and Truckee River Flood Management Authority (TRFMA).

Authorization

The Basin Study Program, as part of Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program, addresses twenty-first century water supply challenges such as increased competition for limited water supplies and climate change. The Federal SECURE Water Act of 2009 and Secretarial Order 3297 established the WaterSMART Program, which authorizes Federal water and science agencies to work with State and local water managers to pursue and protect sustainable water supplies and plan for future climate change by providing leadership and technical assistance on the efficient use of water.

Purpose and Objectives

The Basin Study and Basin Study Report (Report) are intended to assist water management agencies in incorporating of future risks (e.g., water shortages) into their management, decision processes, and investment considerations. This Report identifies and describes future risks to Truckee Basin water resources and contains evaluations of selected options for addressing the related supply-demand imbalances. Further, as the first basin-wide climate change study focused on the resources of the Truckee River, it provides a foundation for future investigations by identifying key vulnerabilities and presents options for more detailed investigations. Decisions by local communities to move forward with one or more of the options or suggestions for additional study presented in the Report will likely require further evaluation and cooperation at multiple levels.

Study Area and Setting

The study area for the Truckee Basin Study, shown in Figure ES-1, includes both the Truckee River and Carson River basins. The Carson River Basin is included in the study area to represent how both basins are interconnected via the Truckee Canal and the export of Truckee River water to the Newlands Project.

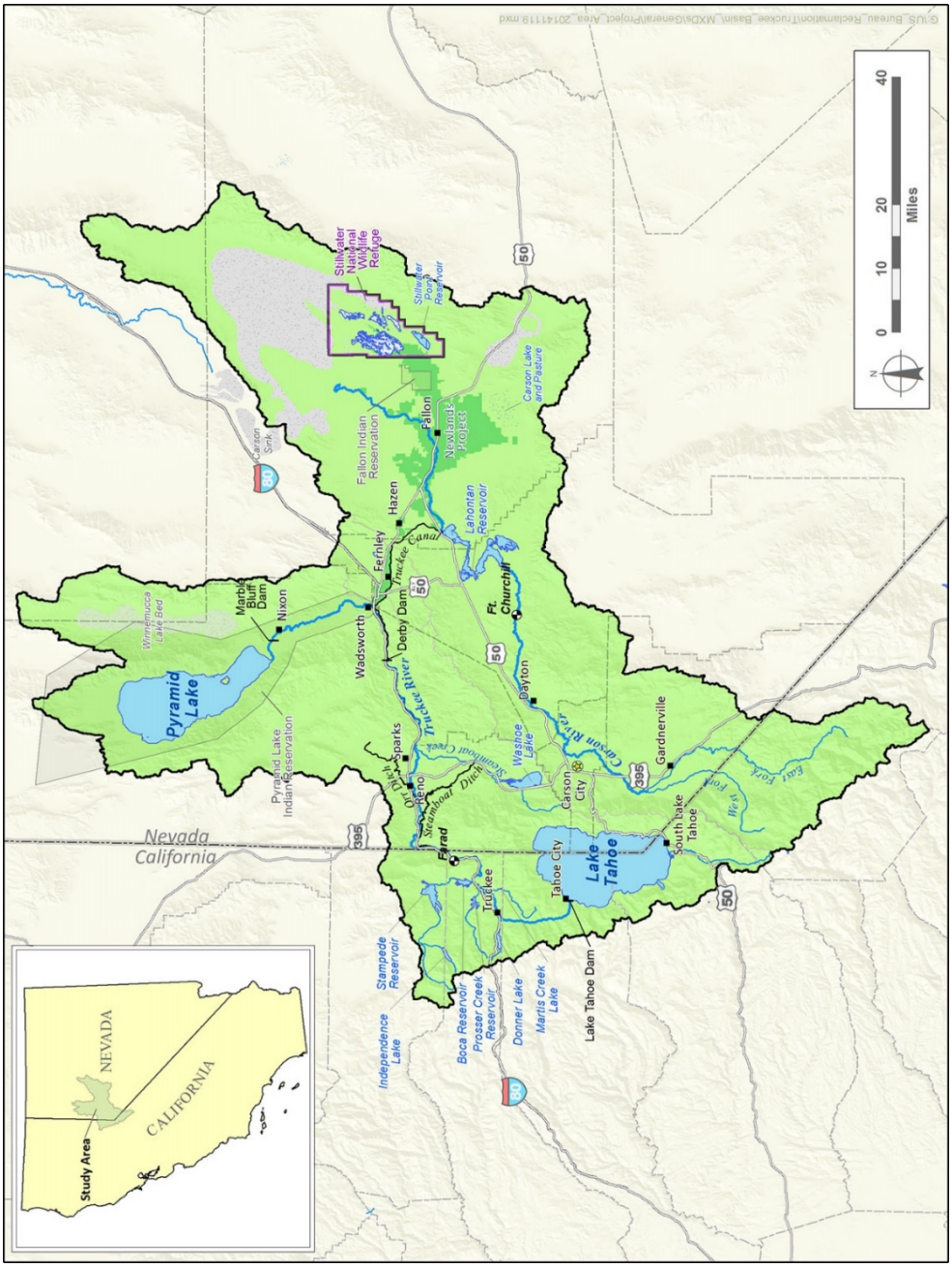


Figure E1-1. Study Area for the Truckee Basin Study

Study Management Structure

The Basin Study was managed cooperatively by Reclamation and its four non-Federal cost-share partners – PCWA, TRPA, TMWA, and TRFMA – as shown in Figure ES-2. Each of the partner agencies represented a valued and often unique perspective for water management in the Truckee Basin. PCWA's interests included surface and groundwater management in the Martis Valley Basin, located to the north of Lake Tahoe near Truckee, California. TRPA, formed under a bi-state compact between Nevada and California, is vitally involved in the protection of Lake Tahoe's water quality and preserving the lake's famous clarity. TMWA, as the largest water purveyor in northwestern Nevada, is the utility responsible for providing water and wastewater service to the Reno-Sparks metropolitan area. TRFMA was created by a number of the local governments in northwestern Nevada to plan and construct flood improvements for the Truckee River following the devastating Truckee River flood of 1997.

Figure ES-2. Organizational Structure for the Truckee Basin Study

Scenario Planning and Supporting Information

This Basin Study is intended to assist Truckee Basin water users and other stakeholders by (1) identifying the range of potential future risks and vulnerabilities to the Truckee Basin's water resources, and (2) evaluating the ability of different actions to maintain the existing balance between supplies and demands into the future. To achieve this, the Basin Study developed comparisons between current and potential future conditions through a scenario planning approach.

Scenario Planning Approach

On a day-to-day basis, water resource managers must balance water supply and demand under complex rules and uncertain conditions across the Truckee Basin's entire geographic area. When looking to plan for the future, managers must consider how investments made today could influence their ability to manage both current and future challenges. Scenario planning offers multiple benefits for water resources planning, as it allows for the development of flexible, long-term plans and making decisions where future conditions are uncertain. Development and analysis of scenarios is a way of systematically characterizing and combining different variables, events, conditions, or trends to reveal future problems or challenges and to design potential responses. The central purpose of scenario development shifts away from predicting the most likely future condition – as occurs in many Federal, State, or local planning processes – and instead focuses on understanding the full range of possibilities for how future conditions may look.

The Basin Study and this Report characterize the drivers that influence the current and future reliability of Truckee Basin water resources through the use of three "components" in each scenario. These components are illustrated in Figure ES-3.

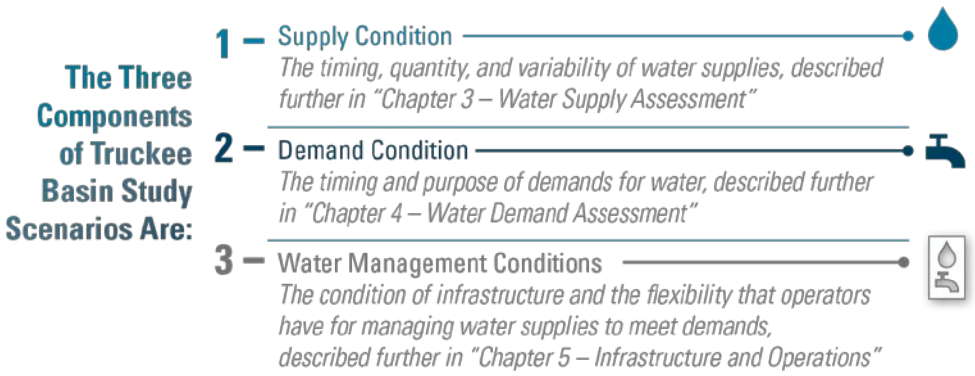


Figure ES-3. Components of Basin Study Scenarios

Reference Scenario

The Truckee Basin Study includes a "Reference" scenario, which is assembled from the combination of Reference conditions for all three scenario components, as shown in Figure ES-4. There is only one Reference scenario, as there is only one current condition for each of the scenario components.

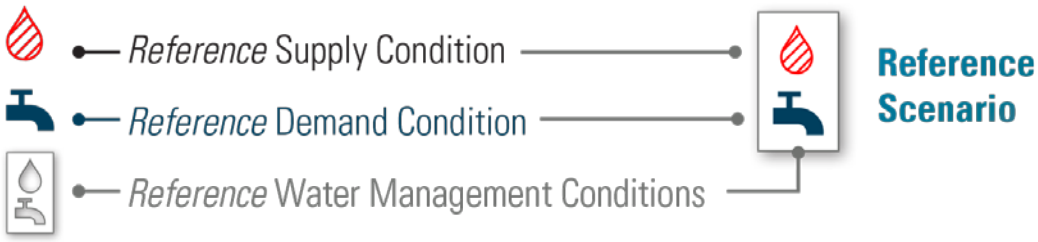


Figure ES-4. Construction of the Reference Scenario

The Reference scenario serves as an important point of comparison for Basin Study analyses, as it represents the level of water supply reliability that could be expected among water users in the Truckee Basin under the current (or baseline) conditions in the Basin, absent climate change.

Without-Action Scenarios

The Without-Action scenarios are assembled from the combination of all future supply and demand conditions with the Reference water management condition. These scenarios show how the future could look under a range of different changes in demand and supply if the water management conditions (such as infrastructure, operations, or policies) remain unchanged. Figure ES-5 demonstrates the make-up of the ten Without-Action scenarios. Each Without-Action scenario is the result of combining one of the five future supply conditions developed for the Basin Study, one of the two future demand conditions developed for the Basin Study, and the single Reference water management condition. Each of the ten Without-Action scenarios is considered to be equally possible in the future.

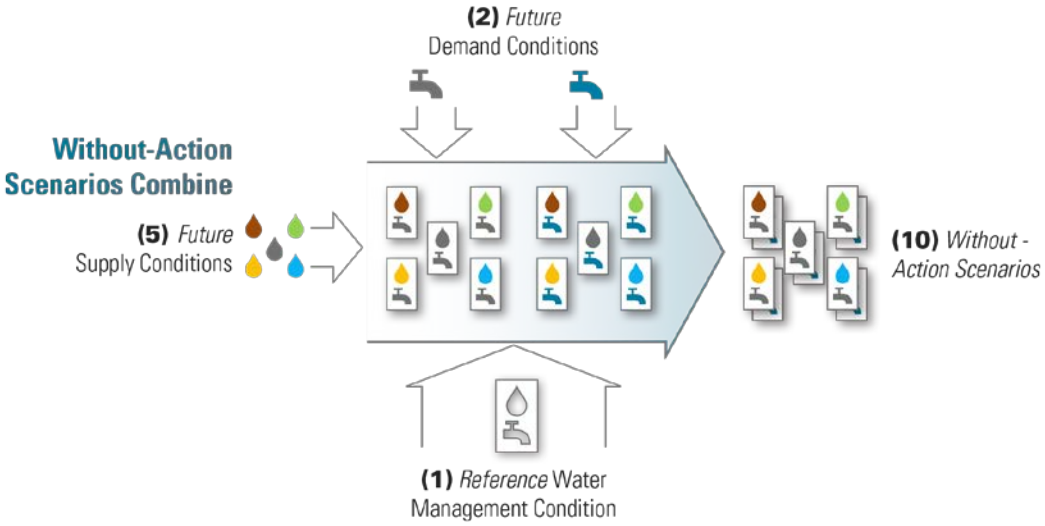


Figure ES-5. Construction of Without-Action Scenarios

Option Scenarios

Option scenarios are assembled from combination of all future water supply and demand conditions with a selected number of future water management conditions, each representing one of the "options" (changes to infrastructure, operations, or policies) evaluated in the Basin Study. Figure ES-6 demonstrates the make-up of the ten Option scenarios that result from the evaluation of any single option.

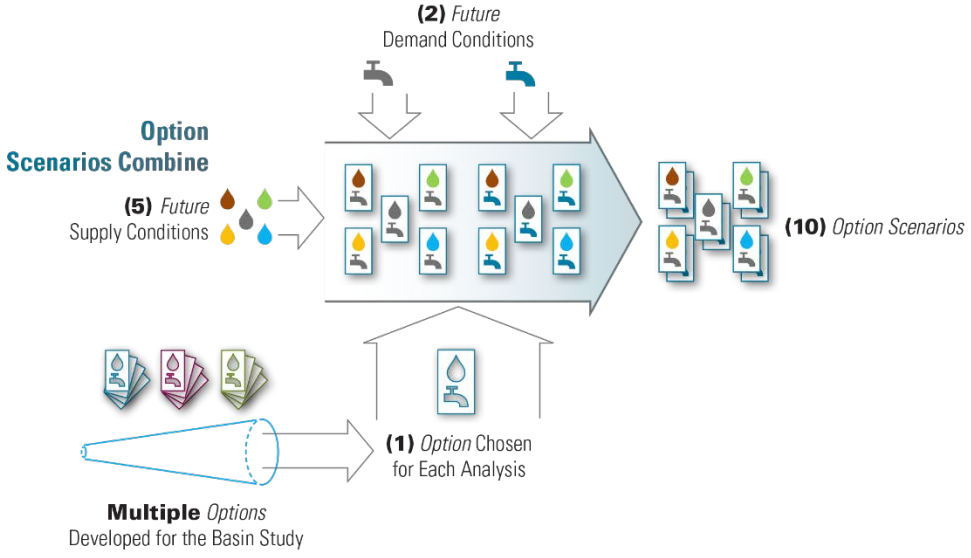


Figure ES-6. Construction of Option Scenarios

Water User Communities

The Basin Study incorporated the use of five distinct "water user communities" to respond to geographic and other variations in water use and water resources concerns throughout the Basin:

- Lake Tahoe Basin
- Truckee River Basin in California
- Truckee Meadows
- Pyramid Lake
- Newlands Project

The water user communities are geographically similar and may rely on some common characteristics or features, such as diversion facilities, land uses, or economic drivers. Not all types of water use in each community are the same; most include a blend of municipal and industrial (M&I) and at least one other type of use. Where the Report presents information grouped by water user community, it also highlights the distinct needs and effects for each type of use within the community. The geographic locations described in the Report for each community are very general and defined by preexisting land-use, ownership, or hydrologic boundaries.

Water Supply Assessment

The Basin Study's water supply assessment considered a range of variables that factor into the Truckee Basin's water supply, surface runoff and hydrologic processes, such as snow accumulation and melt, surface water evaporation, and groundwater recharge, as well as the overriding climatic conditions that shape these processes in the Truckee Basin.

Winter snowfall and spring runoff, which have been strong drivers of hydrologic processes in the northern Sierra Nevada, are a defining characteristic of the Truckee Basin's recorded (i.e., historical) hydrology. Historically, the majority of Truckee River inflows are generated during the spring runoff season (April to July) as the snowpack in the Sierra Nevada melts, and approximately 90 percent of the total inflows to the Truckee River occur upstream from the USGS stream gage at Farad (Interior and California 2008). The climate of the Truckee Basin is characterized by cycles of flood and drought, with precipitation and runoff varying widely from year to year. Runoff patterns and variability have driven streamflow, lake levels, evaporation, and groundwater recharge, all of which underpin the design of current water management practices and infrastructure in the Truckee Basin. Thus, the availability of water to be captured, stored, and managed to meet demand in the Truckee Basin is largely related to annual weather conditions and overall climate.

Areas in the mountains surrounding Lake Tahoe receive well over 70 inches of precipitation annually, whereas areas in Nevada receive less than 15 inches on average (Figure ES-7). The lower regions around the Carson River are especially dry, receiving on average less than 5 inches of precipitation each year. The average annual temperature ranges from 58 to 80 degrees Fahrenheit (Figure ES-8). Temperatures are generally cooler in high elevation areas in the Sierra Nevada and Truckee Basin, whereas the lower elevation areas (Carson Sink, Pyramid Lake) are generally warmer.

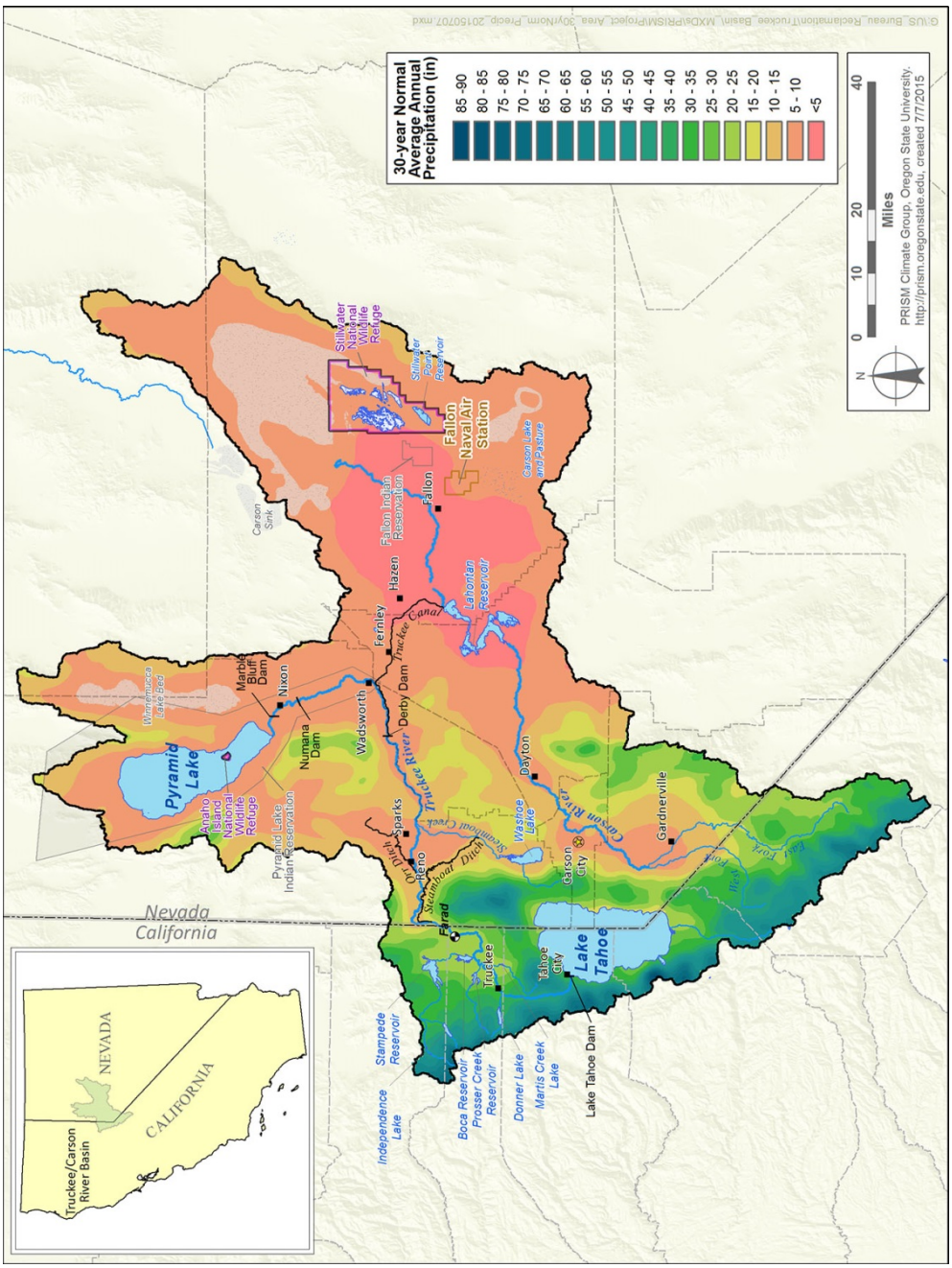


Figure ES-7. Average Annual Precipitation in the Truckee Basin (1981-2010)

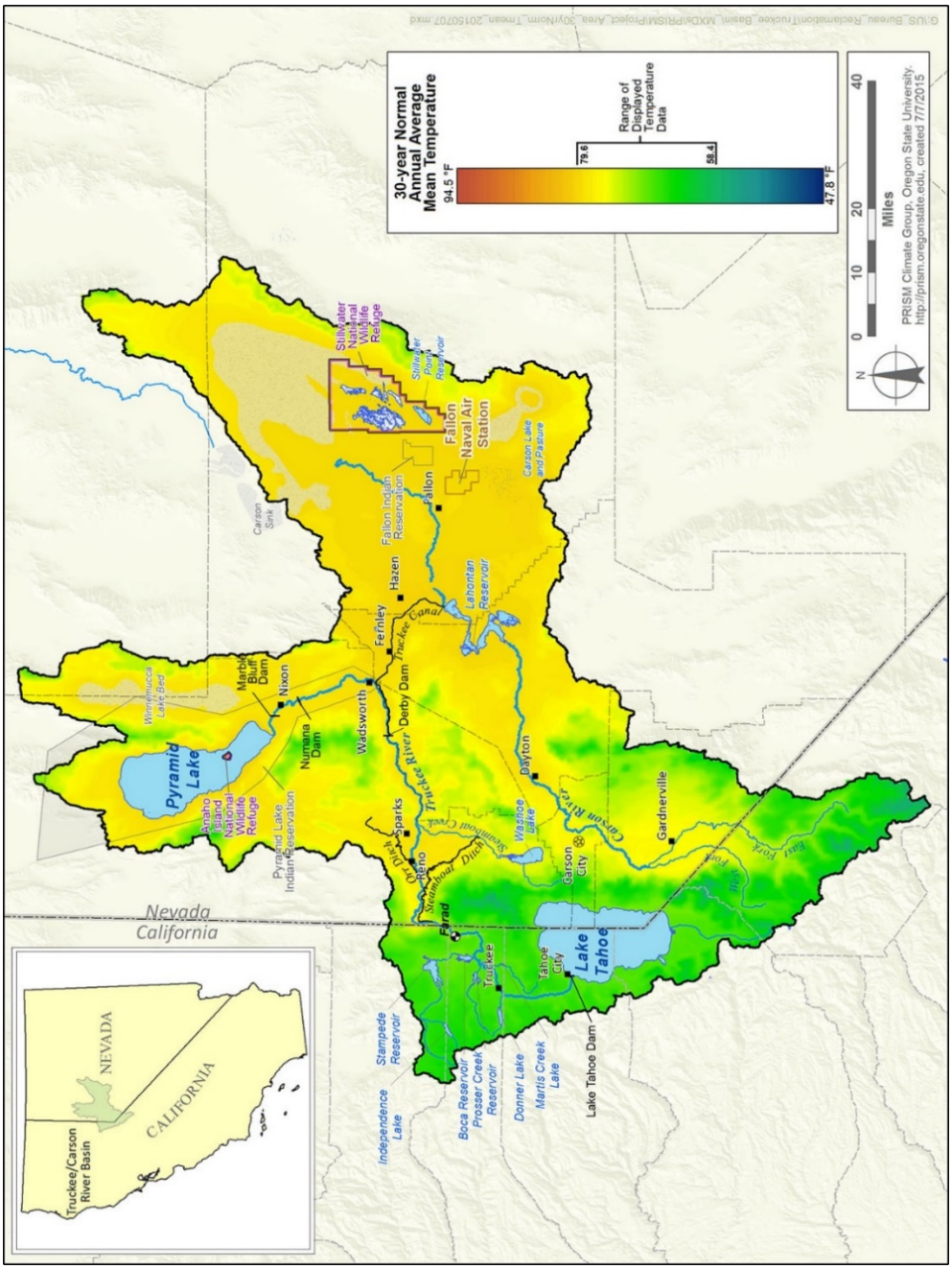


Figure ES-8. Average Annual Temperature in the Truckee Basin (1981-2010)

The water supply assessment included developing a Historical supply condition (based on gage data), the Reference supply condition (based on simulations), and five future supply conditions (also based on simulations) used throughout the Basin Study scenarios. Figure ES-9 depicts the relationship of these supply conditions to one another in terms of the Basin Study planning timeline.

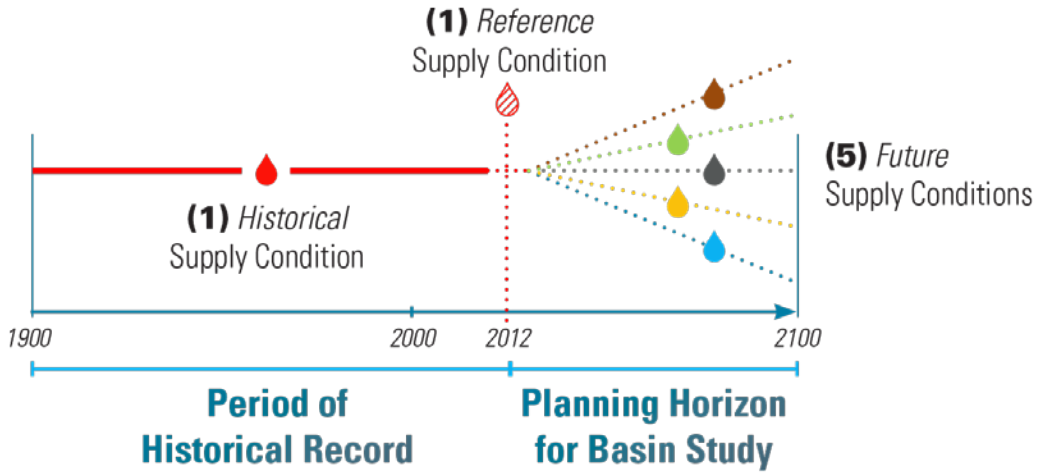


Figure ES-9. Supply Conditions Used in Basin Study Scenarios

The Historical supply condition is based on stream gage records for the Truckee Basin dating back to 1901, which have been used in several previous studies in the Basin, including the *Truckee River Operating Agreement* (TROA) *Environmental Impact Statement* (EIS)/*Environmental Impact Report* (EIR) (Interior and California 2008) and the Newlands Project Planning Study (Reclamation 2013).

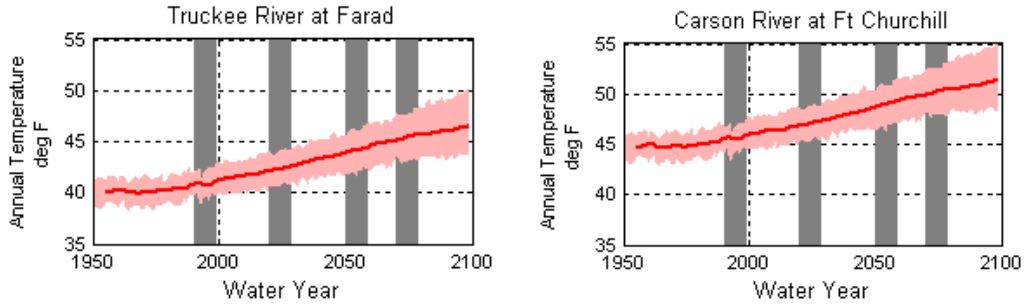
The Reference and five future supply conditions are based on hydrologic simulations of the Truckee Basin that use meteorological data (i.e., precipitation and temperature) to drive hydrologic processes (i.e., infiltration, runoff, and evapotranspiration). The Reference condition is intended to represent a "current" or baseline supply condition, and is simulated from historical meteorological conditions. Future conditions are also simulated, and use projected meteorological conditions that are based on different projected changes in climate.

Methods for Simulating Current and Future Supply

Assessing how climate change affects the hydrology of the Truckee Basin is a key step in determining the future water supply reliability of the Truckee Basin. The assessment conducted for the Basin Study included developing five climate "ensembles" (groups of climate projections) specifically for the Truckee Basin, and then applying each ensemble to models that simulate the effect of climate on hydrology in the Truckee Basin (i.e., snow accumulation and melt, surface runoff, and lake evaporation). A sixth climate condition, the Reference supply condition, was developed concurrent with the five ensembles to represent current supply

conditions without climate change; as with other Reference conditions developed for the Basin Study, the Reference supply condition provided a baseline for comparison with potential future conditions.

The primary source of uncertainty for assessing future water supply in the Truckee Basin is the large range of potential future climatic conditions that could occur over the coming century. Projections for the Truckee Basin climate include a range of potential changes in both the volume of annual precipitation and the seasonal temperature conditions. For example, the mean average annual temperature in the Truckee Basin above Farad is anticipated to increase by up to 5 to 6 degrees Fahrenheit by the end of the twenty-first century (Figure ES-10) (Reclamation 2011a, 2011b). A similar range of temperature changes is projected for the Carson River Basin above Fort Churchill, Nevada.



Source: SECURE Water Act Report (*Reclamation 2011a)*

Figure ES-10. Range of Mean Average Annual Temperatures Projected for the Truckee and Carson Basins Through 2100

The same climate projections also suggest that annual precipitation in the Truckee and Carson basins may decrease slightly by the end of the twenty-first century.

The Basin Study considered these uncertainties by surveying projections from multiple climate models, similar to the approach used in reports by the Intergovernmental Panel on Climate Change (IPCC) and in Reclamation's *SECURE Water Act Report* (IPCC 2007a, Reclamation 2011b). This approach simplifies the analysis while maintaining the uncertainty associated with selecting which climatic conditions are likely for the Truckee Basin. To simplify the use of all 112 climate projections, yet still capture a meaningful range of future climate uncertainty, a Hybrid Delta ensemble approach was used to develop five statistically relevant climate ensembles that represent a central tendency and outer bound variations in temperature and precipitation. All of the future climate ensembles include an increase in temperature, from a more moderate increase ("Warmer") to a more severe increase ("Hotter"), and either an increase ("Wetter") or decrease ("Drier") in precipitation. The central tendency ensemble represents a condition somewhat similar to an "average" of all future climate projections. The use of the ensembles is to represent, with a limited number of projections, the range of uncertainty in the full range of projections.

Development of Future Hydrology and Lake Evaporation

Through WWCRA, Reclamation has conducted assessments of future climate change implications for snowpack and natural hydrology for many Western river basins identified in the SECURE Water Act. The purpose of these assessments was to assemble a comprehensive and consistent understanding of risk across each of the basins.

The approach for the Truckee Basin Study considered applying the hydrology data developed through WWCRA for the Truckee and Carson basins. However, in *West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections* (Reclamation 2011b), Reclamation suggested that water managers in basins with a small geographic size relative to the spatial scale of the WWCRA model should carefully consider the use of the WWCRA data sets in future planning and studies (Reclamation 2011b). Reclamation also suggested that assessing climate change impacts on smaller water users and their operations may require using a model that also operates at a smaller spatial scale. Preliminary assessments of the WWCRA data revealed that the hydrology for many of the important reservoirs in the Truckee Basin had been represented within a combined watershed, creating a compressed picture of climate change's effects at the various reservoirs and for the different water users in the Truckee Basin. An alternative to the WWCRA model, which had been developed in coordination with the Basin Study non-Federal cost share partners, was available for use and had a spatial resolution that had been tailored to address the relatively small geographic scale of the Truckee Basin's important watersheds. This tool, the Precipitation Runoff Modeling System (PRMS), was found to provide an adequate simulation of monthly and annual runoff that is commensurate with the performance of the hydrology models developed through WWCRA in other larger basins.

The Basin Study developed models using PRMS for three sub-basin watersheds (Lake Tahoe, Martis, and Little Truckee) above Farad, California, which represents 90 percent of contributing surface runoff in the Truckee Basin. These models also included a simplified representation of groundwater. For areas downstream from Farad, regression equations were used to correlate flows on the Truckee River system to flows anticipated in the lower portions of the Truckee Basin and to inflows into Lahontan Reservoir.

Figure ES-11 shows the spatial coverage of the three models developed using PRMS, which separately consider the watersheds contributing to Lake Tahoe (red), Martis Valley (beige), and the Little Truckee River and sidewater downstream from the Town of Truckee (green).

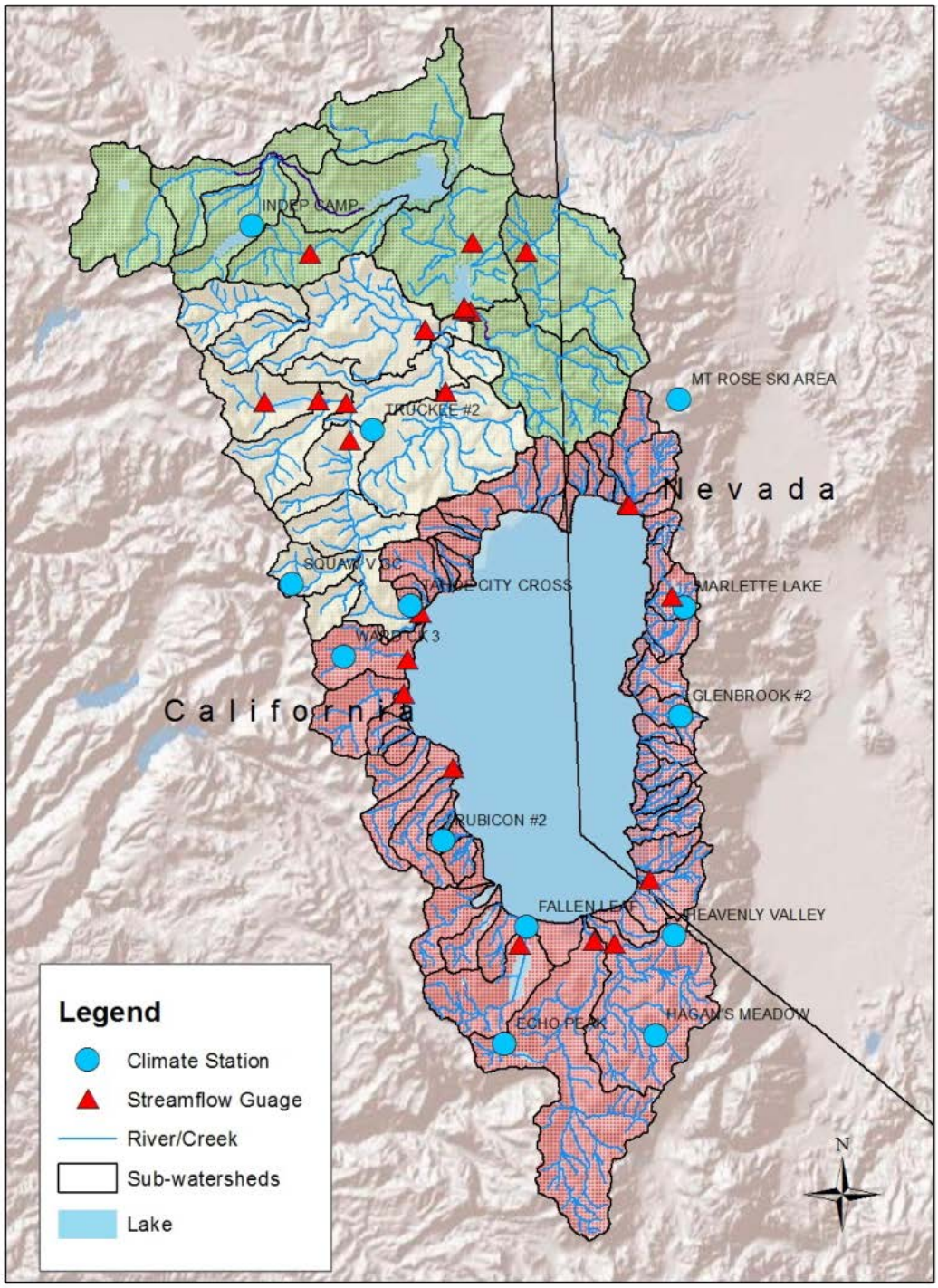


Figure ES-11. The Truckee Basin, Including the Tahoe Watershed, Martis Watershed, and Little Truckee Watershed

Comparison of Supply Conditions

Surface runoff of precipitation is the primary source of water supply in the Truckee Basin; changes in the quantity of precipitation would have a direct

influence on water supply availability. Historically, releases of water from Lake Tahoe Dam are the source of approximately 30 percent of the flow in the Truckee River near the California-Nevada stateline. Forty percent of the river's flow is contributed by regulated releases from other Federal and non-Federal reservoirs located in California, and the remaining 30 percent of the river's flow derives from uncontrolled runoff or streams. The existing infrastructure and water policies in the Truckee Basin were built to manage this historical distribution and range of water supply.

Changes in temperature would have complex and potentially significant effects on water supply. Increases in temperature, which occur in all future climate ensembles, would change the period during which snowpack melts and runs off into lakes, reservoirs, and streams. In general, reservoirs store surface water inflow in the spring (April to June) and release it in the summer and early fall, primarily to meet demands in Nevada. Even with the increased precipitation that occurs in some climate ensembles, snowmelt and runoff will occur earlier and potentially result in less water available in reservoirs during the spring and summer. Temperature increases could also cause more precipitation to fall as rain and cause snowpack to melt sooner and faster. Under these future conditions, the Truckee Basin's current storage capacity and operations may not be suited to manage the water supply. The following subsections describe how potential future changes in temperature would affect snowpack cover, hydrology inflows timing, and lake evaporation.

For example, as snowpack and snowmelt patterns change with increasing temperatures through the end of the century, more runoff shifts toward earlier months with higher precipitation. The first plot in Figure ES-12 (showing average flows for 2012 through 2039) demonstrates slight increase in winter runoff, and corresponding reductions in peak spring and summer runoff. The most prominent shifts are observable in the end-of-century hydrographs (2070 through 2099), which have peak runoff under the Central Tendency ensemble in March, and peak runoff in February for hotter ensembles. The average hydrographs of the mid-century period (2040 through 2069) demonstrates a period of transition in the peak outflow month from May/June to winter months.

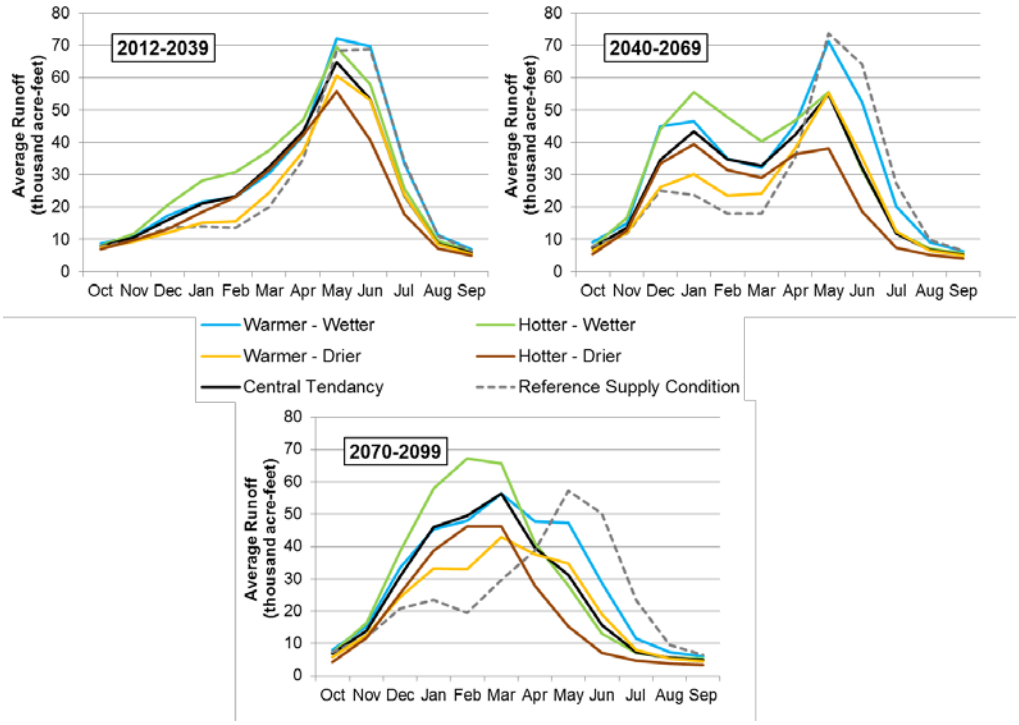


Figure ES-12. Monthly Average Runoff in Lake Tahoe Basin for Water Years 2012 – 2039, 2040 – 2069, and 2070 – 2099

Water Demand Assessment

The Basin Study's demand assessment considered the range of current and potential future diverted and in-river water uses in the Truckee Basin. The Truckee Basin's water rights are highly regulated and its water is fully appropriated by local communities, tribes, the states of California and Nevada, and the Federal government.

As with other aspects of the Basin Study, uncertainty about future conditions also exists related to demand. The rates of regional economic growth, conservation efforts, shifting social preferences, and other factors that cannot be firmly predicted will all affect future water demand in the Truckee Basin. Identification of a single set of future demands is thus both difficult and unwise, and the Basin Study instead employed a process to determine a range of current and future water demand for the Truckee Basin. This process relied on a development of three stakeholder-informed storylines that capture lower-growth and higher-growth economic trajectories and their associated effects on water demand in the Truckee Basin. As with the water supply assessment, this method preserves a full range of potential future conditions regarding how, and how much, water will be used in the Truckee Basin in the future.

All demand conditions were developed using data or input from water users throughout the Truckee Basin. Figure ES-13 depicts the relationship of these three demand conditions to one another, in terms of a timeline that includes the Basin Study's period of historical records and planning horizon.

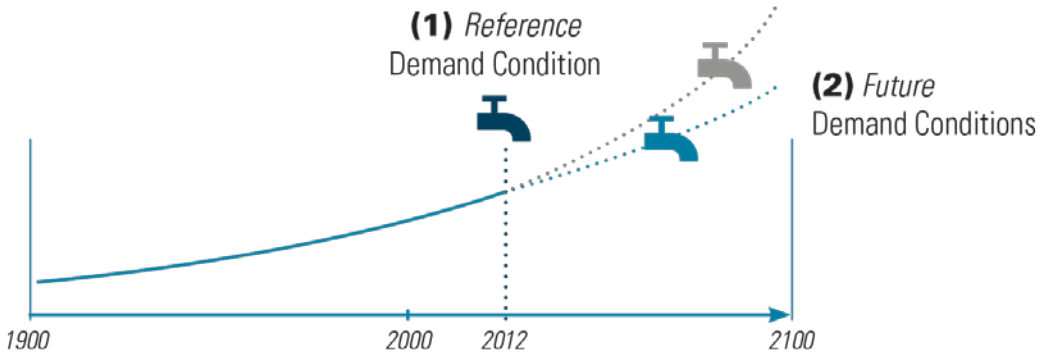


Figure ES-13. Demand Conditions Used in Basin Study Scenarios

The "Reference" demand condition is assembled from records of water use from 2012, the year the Basin Study began. It represents a snapshot in time of "current" water demand, and thus includes no future regional economic growth.

Through the use of previous studies and reports and input from Truckee Basin water users and stakeholders, the Basin Study developed two storylines to bracket the range of potential future water use in the Truckee Basin based largely on economic growth, one of the driving forces of human demands for water.

- **Existing Trends:** The primary factor affecting water use in this storyline is a persistently slow regional economy. The character and rate of change in water demand are similar to changes experienced in northwest Nevada and many parts of the Western U.S. during the recent economic recession, which began around 2007. Generally, development and water use are depressed and this storyline represents a lower bound for future water use within the Truckee Basin.

- **Robust Economy:** The primary factor affecting water use in this storyline is a robust and vibrant regional economy. The character and rate of change in water demand are similar to changes experienced in the early 2000s, before the economic recession. Generally, development and water use was accelerated during this period and this storyline represents an upper bound for future water use within the Truckee Basin.

These storylines were used to develop the corresponding future demand conditions used in the Basin Study scenarios, as shown in Figure ES-13. Table ES-1 compares the different factors identified to drive water demand in the Truckee Basin under both future demand storylines.

Table ES-1. Comparison of Driving Factors for Demand Storylines

Driving Factor	Existing Trends Storyline	Robust Economy Storyline
Population and Land Use	Population growth **does not change** from 2012 rates; urban areas reach full use of water rights between **2050 and 2100**; expansion of urban populations absorbs agricultural lands in the Truckee Meadows.	Population growth **increases** from 2012 rates; urban areas reach full use of water rights between **2040 and 2070**; expansion of urban populations absorbs agricultural lands in the Truckee Meadows.
Agriculture	Irrigated cropland decreases in areas of substantial urban development and natural resource restoration by encroachment and water right transfers. Limited changes occur to agricultural practices and crops.	Same as Existing Trends, **but increased economic activity increases demand for regional agricultural products and, in turn, increases competition for Newlands Project water rights**.
Industry and Commerce	In the California portion of the Basin, the economy remains primarily dependent on recreation and tourism. In the Nevada portion, the economy continues to be based on commercial and industrial development. The Newlands Project-area economy continues to be primarily agricultural.	In the California portion of the Basin, the economy remains primarily dependent on recreation and tourism. **Expansive growth is driven by industrial expansion in Nevada, and urban growth is accompanied by increased development.** The Newlands Project area economy continues to be primarily agricultural.
Institutional and Political	TROA is implemented and administered by the signatory parties. Lower Truckee River water users continue attempts to protect water quality and endangered species on the lower Truckee River.	Same as Existing Trends.
Natural Systems	Global climate change has affected natural systems. Air temperatures increase and precipitation patterns become more variable. Increased air temperatures provide for longer summers and earlier spring conditions, lengthening the growing season and increasing irrigation demands, as well as increasing the inflow required to maintain lake elevations due to increases in evaporation losses. Mountain snowpack recedes significantly toward the end of the century, resulting in earlier peak river flows, which could affect riparian, wetland and aquatic systems.	Same as Existing Trends.

Key:
TROA = Truckee River Operating Agreement

Figure ES-14 shows a comparison of the changes in consumptive demand through the end of the twenty-first century for both future demand storylines and different water user communities.

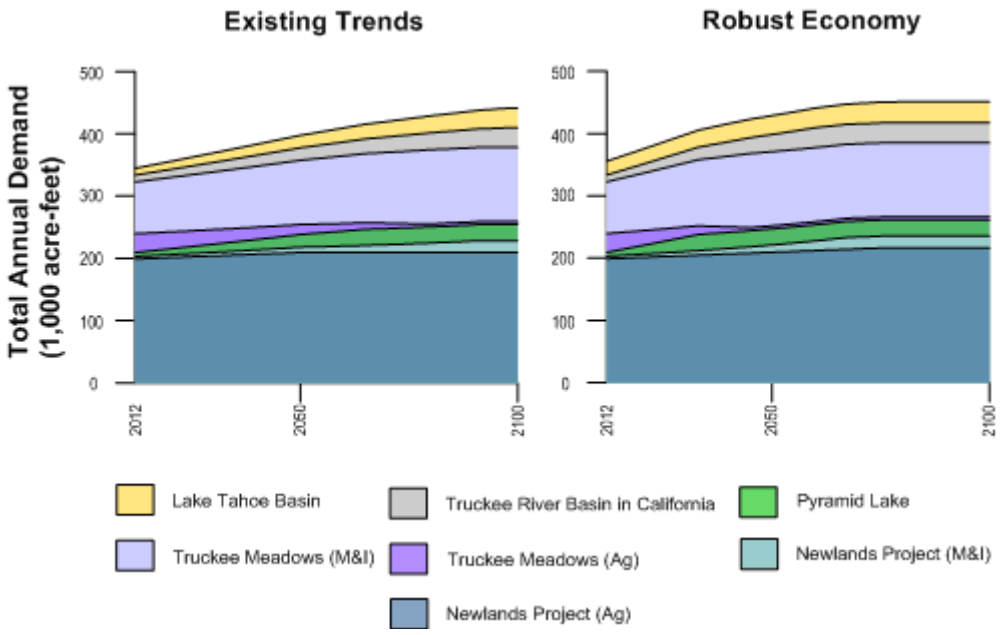


Figure ES-14. Total Truckee Basin Water Demand Under Future Storylines

Overall, the water user communities reach their full use of water rights in the future sooner under the Robust Economy storyline than the Existing Trends storyline, but by century's end, total annual water demand in the Truckee Basin only differs between the storylines by about 25,000 acre-feet. This is due to the highly planned and regulated nature of water rights in the Truckee Basin – most water rights are currently being exercised or are planned to be exercised fully by water users.

The changes in agricultural water use are also consistent with Table ES-1, wherein agricultural land and water rights in the Truckee Meadows area and in the Newlands Project experience different outcomes based on distinct local economic drivers and preferences. Under both storylines, the majority of Truckee Meadows agricultural water rights are transferred to TMWA to serve growing M&I demands associated with increased industrial and urban development that also absorbs Truckee Meadows agricultural land. In the Newlands Project, however, the Robust Economy storyline results in a higher agricultural demand due to increased demand for local agricultural products that leads to currently unused Newlands Project water rights to be approved and activated by the Nevada State Engineer (Reclamation 2013).

Effects of Climate Change on Future Demand

Human demands are not the only demands for water likely to change in the future. The added complexity of a changing climate also increases demands of ecosystems and crops. Although the Basin Study noted these changes in demand, they are not quantified as part of the demand assessment, which is constrained by the exercise of existing rights in the Truckee Basin rather than by all demands that

are possible. Nonetheless, changes in ecosystem and crop demands were factored into the Basin Study's reliability and vulnerability assessments.

The demands of different Truckee Basin ecosystems and how species may react to climate-driven changes in supply are not well understood. Changes in ambient temperatures and shifts in streamflow could alter the timing of breeding patterns of listed aquatic species. Although in the future these species may be able to adapt to such shifts (as they do now), the current regulatory and operational conditions of supplies maintained for these species may not be well suited for additional demands or changes in timing of flow. Specifically, any impacts on Pyramid Lake elevations have the potential to affect the passage of cui-ui and Lahontan cutthroat trout for spawning, and also the quality of lake habitat for these listed species.

Similar to agriculture demands, climate changes may also affect water demand for native vegetation that support migratory birds using Lahontan Valley wetlands and other lakes, as well as riparian and meadow areas along the Truckee and Carson rivers as resting points on the Pacific Flyway. Increased water demands could result from earlier plant growth and greater water requirements for each acre of managed wetland. Bird migration patterns may also be affected by global climate changes across the entire migratory flyway, and shifts in arrival at Lahontan Valley wetlands may not match available food supplies.

Changes in climate are also likely to increase overall crop demand. Crop water demand is a function of evapotranspiration, which is the amount of water transpired by the crop from the soil plus the amount that evaporates from the plant and surrounding soil surfaces. Crops need to be irrigated with enough water to meet the crop water demand that cannot be met with local precipitation. Future changes in climate (including maximum and minimum temperature, solar radiation, wind speed, humidity, and precipitation) will influence agricultural water use by changing crop water demands and irrigation requirements to meet them. Higher year-round temperatures can increase evapotranspiration rates that, unless offset by increased local precipitation, would require additional irrigation. Higher temperatures would also prolong the growing season, which changes the seasonal demand for water for crops that mature earlier in time and, in turn, increases the volume and duration of irrigation water deliveries needed for every farm. Decreases in local precipitation would increase irrigation requirements to meet crop water demand.

Water Management Conditions

"Water management conditions" describe a set of structural and non-structural tools water managers use to manage supply in the Truckee Basin to meet demand. This includes, but is not limited to, infrastructure (such as reservoirs and canals), institutional or regulatory requirements (such as water rights structures or protections for listed species), and operational rules and practices (such as TROA or flood management rules). As with other Reference conditions in the Basin

Study, the Reference water management condition is based on the current approach to water management throughout the Truckee Basin and can be considered a "baseline."

A set of potential future changes in the Truckee Basin's water management condition, or "options," were also identified for evaluation in the Basin Study through engagement with water users and stakeholders. The Basin Study options are structural or non-structural actions that would depart from the Reference water management condition to address future vulnerabilities by changing sources of supply, managing demands, or adjusting institutional arrangements, regulations, or policies. Figure ES-15 depicts the Reference water management condition and how it may change through implementation of one or more options to address future vulnerabilities.

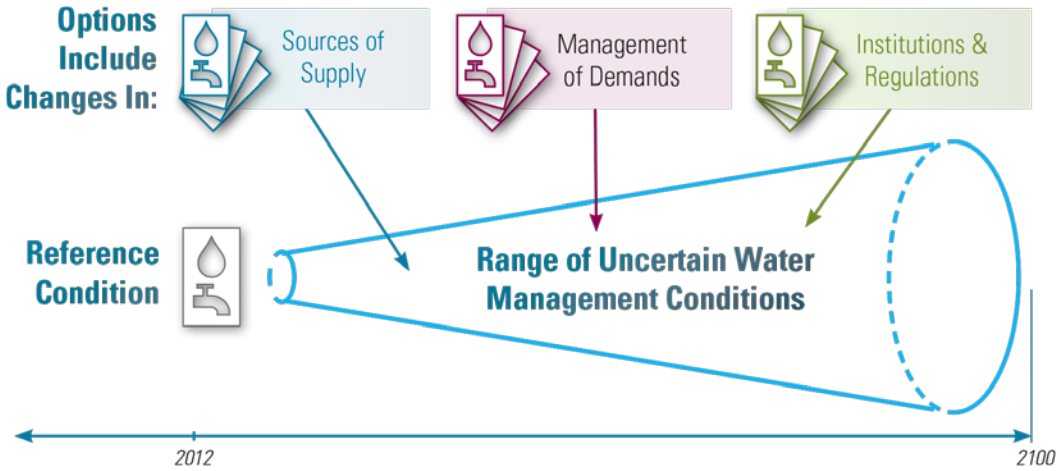


Figure ES-15. Options Shape Water Management Conditions Used in Truckee Basin Study Scenarios

The current infrastructure and facilities identified in the Reference water management condition include:

- Reservoirs and lakes: Lake Tahoe, Donner Lake, Martis Creek Lake, Independence Lake, Prosser Creek Reservoir, Stampede Reservoir, Boca Reservoir, and Lahontan Reservoir
- Truckee Canal
- Municipal diversion facilities for TMWA, the City of Fernley, and others
- Hydroelectric generation facilities of Reclamation, TMWA, and TCID
- Marble Dam and Fishway

The current operations, institutions, and regulations included as part of the Reference water management condition include:

- *Truckee River General Electric* Decree
- Truckee River Agreement
- *Orr Ditch* and Alpine decrees
- Interstate Agreements
- TROA
- Flood control operations
- Newlands Project OCAP and Truckee Canal safety restrictions
- Fish flow regimes for the Truckee River and Pyramid Lake

Risk and Reliability Assessment

One of the Basin Study's key objectives is the identification of challenges facing water user communities in the Truckee Basin. The risk and reliability assessment identifies these challenges guided by the question, "How well might existing infrastructure, institutional setting, and regulatory regimes, if unchanged, perform when attempting to meet future demands with future water supplies?" Answering this question includes two steps: (1) uncovering vulnerabilities, or the factors that could cause imbalances in basin-wide water supplies and demands; and (2) assessing reliability, or the features of future performance that are specific to individual water users.

The Basin Study risk and reliability assessments are built on comparisons between the Reference scenario or condition and several future Without-Action scenarios or conditions. Basin-wide vulnerabilities consider the ability to manage infrastructure and meet key objectives in the Truckee Basin under the full range of future supply and demand conditions. The water user reliability assessment documents how changes in future conditions affect each Truckee Basin water user community and the water-related conditions and resources that they identified as most important to them. This assessment is based on characterizations of risk and reliability informed by input from water users that was obtained during a workshop and through individual discussions with Basin Study partners and stakeholders.

Basin-wide Vulnerabilities

Projected future conditions in the Truckee Basin vary widely. Generally, the largest vulnerabilities in the Truckee Basin stem from uncertainties in future

supplies (i.e., future rates of precipitation and temperatures). In comparison to the uncertainty in future climatic conditions, the Truckee Basin appears to have minor sensitivity to increases in future demands. Often, the variability in future conditions that stem from uncertainty in the demand condition (i.e., Robust Economy and Existing Trends storylines) is imperceptible in comparison with the uncertainty in supply conditions. Although the difference in water use between the two future demand conditions is small when compared to uncertainties in future supplies, the Robust Economy demand condition for the scenario comparisons captures the greatest extent of vulnerabilities due changes in future demand.

Uncertainty in Water Supply

Uncertainty in the climate causes the greatest variability among projections for the future. Uncertainty in the climate includes a range of potential future conditions for both temperatures (Warmer, Hotter, or Central Tendency) and precipitation (Wetter, Drier, or Central Tendency). The linkages between climate and water supply are complex and are influenced by the unique geography of the Truckee River Basin.

Pyramid Lake's surface elevation provides a telling story about the influence of climate on Truckee Basin water supplies, especially relative to the influence of anticipated changes in human demand. Figure ES-16 presents the water surface elevations at Pyramid Lake from 2012 through the end of the century. Elevations are shown for eighteen scenarios that represent each combination of current and future supplies and demands. The spread in elevations among scenarios illustrates the relative uncertainty and relative importance among the different supply and demand scenario components. As the terminal point of the Truckee River, the lake and its elevation reflect the balance among the availability of water supplies, the high rate of evaporative losses experienced in the basin, and diversions to meet human demand. A gaining lake indicates that precipitation in the Truckee Basin is greater than losses from evaporation and diversions; a losing lake reflects that evaporation and diversion losses are greater. The broadest spread in elevations shown in Figure ES-16 arises between future climate conditions; the changes in elevation resulting from various future demand conditions is relatively smaller.

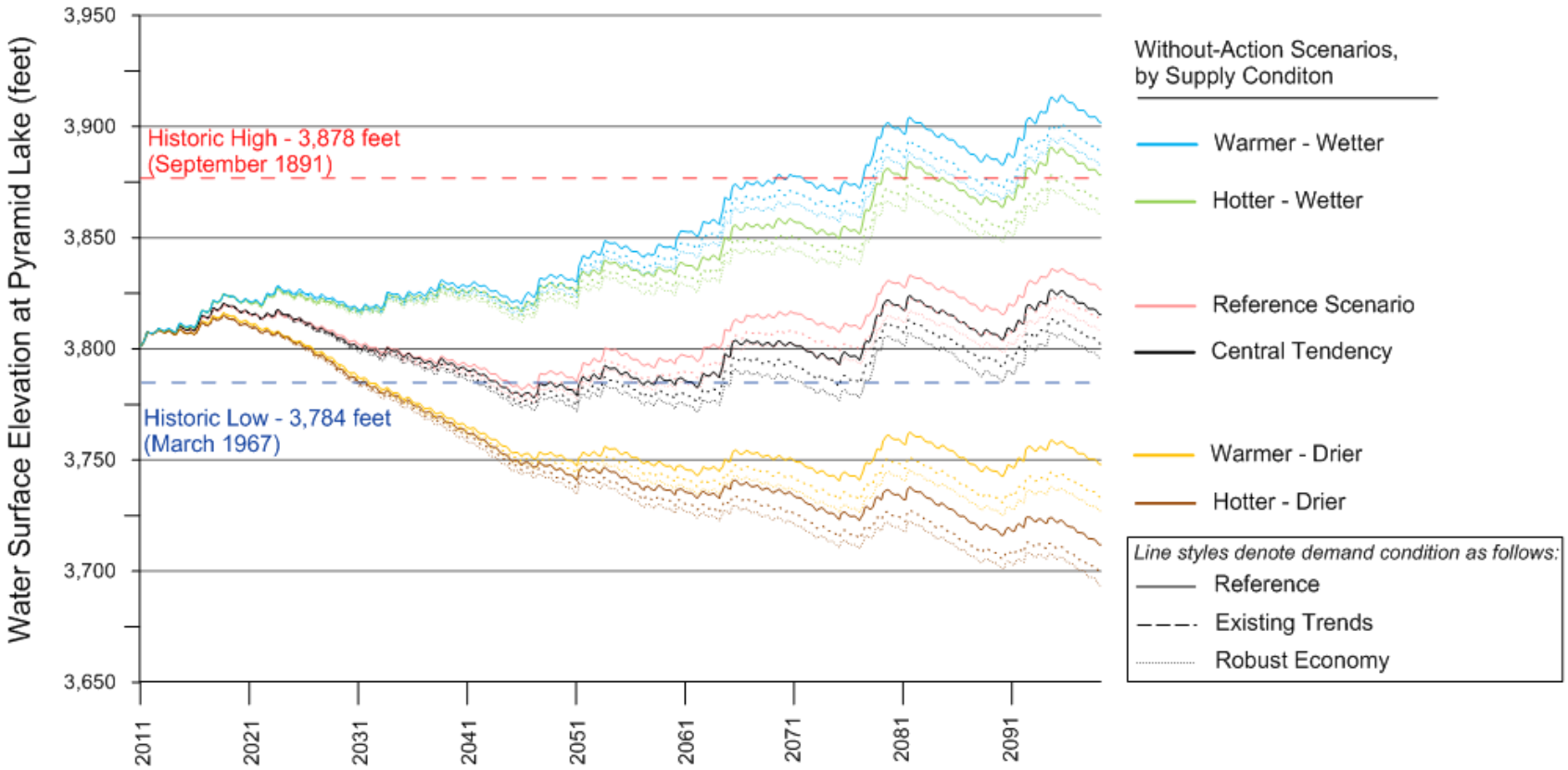


Figure ES-16. Projected Future Water Surface Elevations at Pyramid Lake Under Different Scenarios

Figure ES-16 illustrates several points that resonate throughout the Basin Study findings:

1. **A wide range of uncertainty exists for Truckee Basin supplies.** At Pyramid Lake, the eighteen scenarios diverge to span a difference in elevation of more than 200 feet by the end of the century. The outer bounds are defined by the divergence between wetter and drier scenarios. The outer bound conditions provide a remarkably different level of supply than the Reference scenario, which is demonstrated by end-of-century lake elevations that fall outside of historical ranges. Lake elevations under the Central Tendency appear similar to those under the Reference scenario; however, the Central Tendency is only the median among simulated climatic conditions and all future scenarios are considered equally possible.

2. **Increases in temperature will reduce water supplies.** While changes in precipitation remain highly uncertain, consensus exists in the expectation for the regional climate to warm. Warming temperatures will increase evaporation at all Truckee Basin lakes and reservoirs, most notably at Tahoe and Pyramid lakes because of their vast surface area. The effects of this are shown by Pyramid Lake elevations: hotter scenarios end the century with lake levels that are 20 to 30 feet lower than their warmer scenario counterparts.

3. **In comparison to the uncertainty in future supplies, the uncertainty in water demands is insignificant.** The relative significance of uncertainty can be observed through comparisons of scenarios with differences only in future precipitation, temperature, or demand: differences in demand affect end-of-century lake elevations by approximately 6 feet, temperatures by 28 feet, and precipitation by 161 feet. In part, the small divergence in demand reflects the extensive care and planning that has been conducted in the Truckee Basin to manage water rights and uses. This planning includes limits on water use that would be reached by the end of the century in either of the Basin Study's future demand storylines. Given the small contribution that future changes in demand have on the overall uncertainty in Truckee Basin water supplies, water users and local communities may see a benefit in focusing their future planning and investment efforts on actions to improve supply or to provide increased resiliency and flexibility for managing climatic uncertainty rather than demand.

4. **Maintaining the historical balance between supply and demand may not be possible if the climate departs significantly from historical conditions, even with exceptional changes in human behavior.** In comparison to the future demand conditions, scenarios where demand is held constant at 2012 levels produce approximately 16-foot higher elevations at Pyramid Lake for all future supply conditions. By inference,

this is the maximum potential supply that could be generated if water demands were managed so as not to increase over the coming century. This is an important consideration, particularly for drier conditions where the Pyramid Lake levels drop by up to 100 feet below the Reference scenario by the end of the century. Under these conditions, measures to maintain Pyramid Lake elevations by curtailing upstream demands would be insufficient.

Water Management Challenges

Increases in temperature and reductions in snow accumulation can cause a phenomenon referred to as a "seasonality shift," where peak runoff and flows occur earlier in the season than they have, historically. Seasonality shifts can complicate the ability of existing reservoirs to refill, which reduces the frequency that downstream demands and in-stream regulatory requirements are met in the Truckee Basin.

The net effect of the seasonality shifts is a greater reliance on reservoir storages after April and through the end of the summer. This reduces carry over storages, which is apparent at the beginning and end of each Without-Action scenario in the example provided. To protect against high flow events, reservoir elevations are kept lower through the early spring under current operating criteria. Truckee River reservoirs begin refilling around April 15, which aligns with historical snowmelt patterns. With the seasonality changes, peak runoff moves earlier in time, and the ability to meet full pool storages after April will be reduced. Figure ES-17 demonstrates how the shifted timing of inflows, in combination with the current flood management curves, perform for an example year (2082). In the top plot, reservoirs refill by June for both the Reference scenario and for a scenario that combines Reference supply conditions and Robust Economy demand conditions. The effect of future supply conditions are more apparent in the bottom portion of the plot, where the Without-Action scenarios begin refilling in January and follow the flood management curve until water demands exceed inflows between April and May.

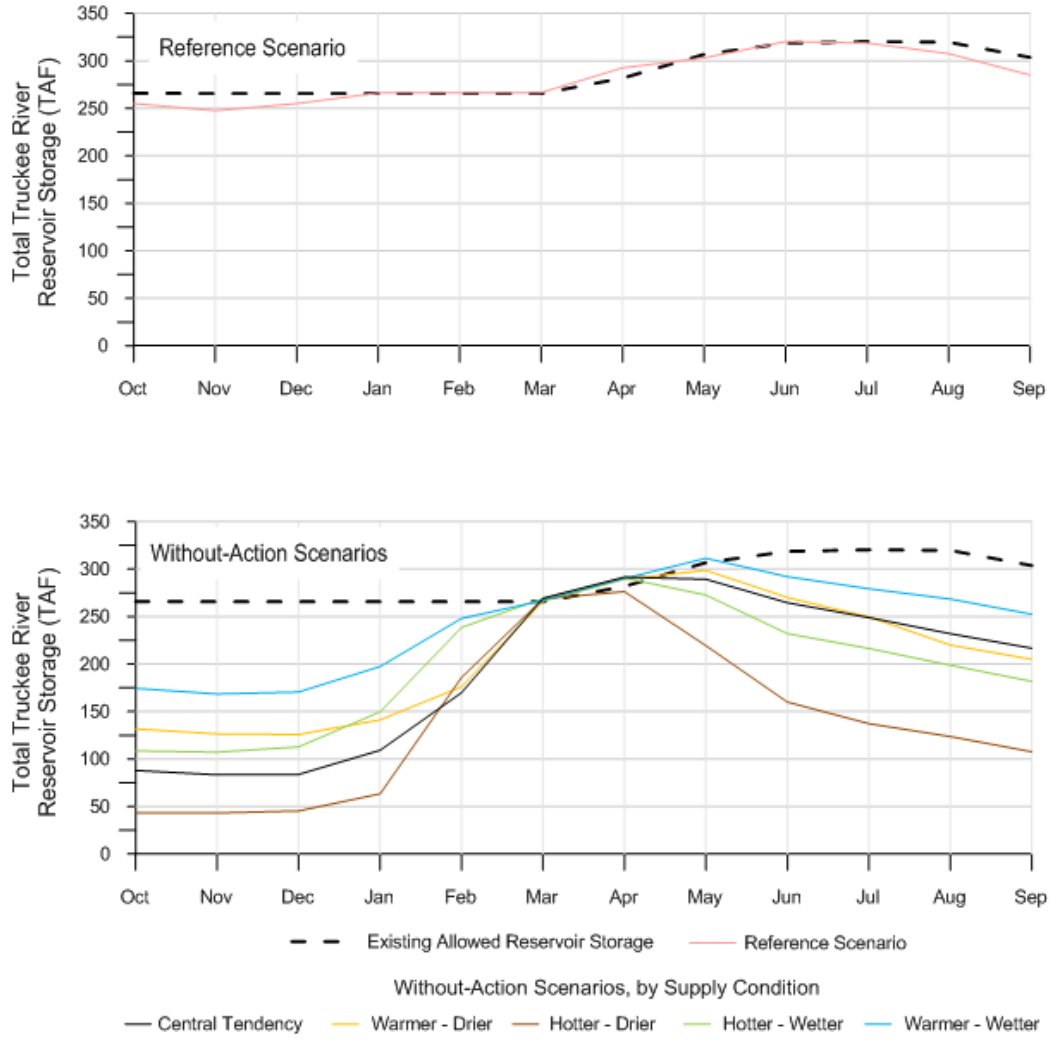


Figure ES-17. Comparison of Truckee River Reservoirs to Refill for Year 2082

Extreme Events

Drought and prolonged periods with low flows occur in all Without-Action scenarios, but are exacerbated in drier conditions. Similarly, the potential for flooding exists in all scenarios and would be more difficult to manage under wetter scenarios. In a separate but related effort to the Basin Study (included as Appendix E to the Report), Reclamation assessed the potential changes in flood frequency that could occur in the Truckee Basin under future conditions. This analysis found an increased probability of a one-day flood exceeding 37,600 cfs, which is the maximum flow recorded in the Truckee River at Reno during the January 1997 flood considered to be the Truckee Basin's largest flood on record. The analysis also found an increased likelihood for a flood of any magnitude occurring – in other words, the Truckee Basin may experience more floods like the 1997 flood, but would also experience more floods considered "less extreme." For years 2000 to 2050, the likelihood of a flood event with flows from 20,000 cfs to 40,000 cfs increases between 10 percent and 20 percent from the historical

likelihood for such a flood; for years 2050 to 2099, the likelihood for such a flood increases by 30 percent to 50 percent.

Influence of Climate Change on Water Demands

Changes in the Truckee Basin climate and hydrology have the potential to stimulate changes in the timing, quantity, and/or quality of water demands for water users in the Truckee Basin.

For example, crop water requirements are anticipated to increase as higher temperatures increase evapotranspiration rates and extend the growing season for alfalfa into the spring (Table ES-2). Alfalfa is the predominant crop grown on irrigated lands in the Newlands Project, which represents the largest consumptive use of Truckee River water in the basin, second only to the volume of evaporation at Tahoe and Pyramid lakes. Slight shifts in the growing season length and alfalfa cutting cycles relative to the Reference condition are anticipated by the 2020s. By the end of the century, significant shifts in growing season length, crop development, and cutting cycles are noticeable relative to the farmers' historical experiences. Under future climatic conditions, crop water demands are projected to increase between 8 and 15 percent, with increases as high as 20 percent by the end of the century. Conveyance and on-farm application losses may also be affected by climate.

Risk and Reliability for Water Users

The Truckee Basin has a diverse set of water users and interests, including municipal, agricultural, and environmental. Each water user has different goals and visions for how economic conditions, land uses, and other factors could change in the future and affect – or be affected by – water supply reliability. Additionally, the manner in which each type of water use occurs varies based on geography, diversion facilities and other infrastructure, and whether the source is surface water or groundwater. As with other assessments completed for the Truckee Basin Study, the risk and reliability assessment relies on the use of water user communities to describe concerns and conditions in a way that captures the variation throughout the Truckee Basin, but also simplifies the discussion by taking advantage of commonalities among water users.

The Basin Study team worked with water users to develop 37 specific indicators that could be used to identify how certain water resources-related concerns would fare in the future under a range of different supply and demand conditions. Each indicator describes a relative set of favorable and unfavorable conditions related to a specific resource or issue identified. The Basin Study team used these indicators to determine which scenarios performed well for the resources in question, and to help demonstrate how different resources were sensitive to changes in supply or demand, both independently and together. Figure ES-18 shows an indicator developed for the Lake Tahoe Basin water user community related to groundwater recharge.

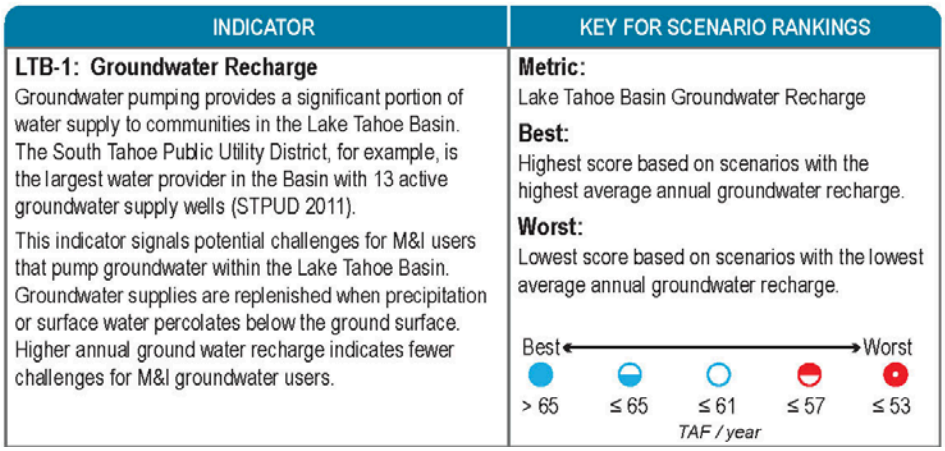


Figure ES-18. Groundwater Recharge Indicator Developed for the Lake Tahoe Basin

Specific indicators were developed for each water user community using previous studies and reports, feedback obtained during technical workshops, and other input, and are included in Chapter 6 of the Report. They are intended to capture conditions directly related to water supply reliability for each water user community (Lake Tahoe Basin, Truckee Basin in California, Truckee Meadows, Pyramid Lake, and Newlands Project). Sets of indicators were developed into "dashboards" for each water user community that showed how different future Without-Action scenarios ranked in the analysis for their particular water-related resources and issues of concern.

Summary of Potential Impacts in the Truckee Basin

The SECURE Water Act water resources themes mirror the range of reliability concerns for Truckee Basin communities, and provide important context for understanding the connections between water resources and water uses. Table ES-2 summarizes the effects of climate change on future reliability in the Truckee Basin for resources of concern to water users, organized under each of the SECURE Water Act themes.

Table ES-2. SECURE Water Act Themes in the Truckee Basin

Theme	Potential Impacts in the Truckee Basin
Water Delivery and Allocation	Anticipated increases in evaporation have a pronounced impact on water supplies from Lake Tahoe due to its large surface area, which puts one-third of typical Truckee River flows at risk. Future warming temperatures also shift the timing of runoff, complicating the operation of reservoirs.
Hydropower	TMWA generates hydropower at several locations along the Truckee River, however this generation is not regionally significant and risks to its future availability correspond with the potential for reduced flow in the river. For the Newlands Project, which diverts Truckee River water, hydropower generation revenue provides 40 percent of the operating budget of TCID, and reductions in future supplies at Lahontan Reservoir may present a financial risk to TCID and indirectly to Reclamation.
Recreation	Recreation resources could experience negative effects stemming from the shifts in the peak runoff, which could affect lake levels during peak recreation periods, flows for sport fisheries, and flows in-river for rafting and kayaking. Snow-dependent winter sports like skiing may also be impacted due to reduced snowpack and shorter season caused by warming conditions. See also the effects for "Fish and Wildlife Habitat."
Fish and Wildlife Habitat	Habitat requirements for sport fisheries may be challenged by difficulties in operating reservoirs for meeting primary benefits of the reservoirs (water deliveries, riverine fisheries) in a reliable manner. Also, riparian communities could be impacted by changes in timing and volume of runoff. See also the effects for "Endangered, Threatened or Candidate Species."
Endangered, Threatened or Candidate Species	Effects on cui-ui and Lahontan cutthroat trout are difficult to assess with certainty. The volumes of water available for fishery flows could be diminished, and sustaining them from February through August will be more difficult because of projected changes in the timing of runoff, especially under warmer/hotter or drier conditions. A significant uncertainty also exists in how these species might adapt to changes in the natural flows. Scenarios with higher evaporative losses prevent migratory passage between Pyramid Lake and the Truckee River, which would prevent passage for both cui-ui and Lahontan cutthroat trout to current Truckee River breeding areas. Also, Lahontan cutthroat trout in Independence Lake could be affected during spawning if spring lake levels and flows into upper Independence Creek are not adequate.
Water Quality	Meeting water quality standards in the lower Truckee River may be more difficult for TMWA, as natural flows in the late summer are reduced. Clarity in Lake Tahoe was not addressed because lake clarity is t related to sedimentation and turbidity resulting from human activity and natural sources. The Basin Study did not include a predictive model that describes how climate change may change those influencing factors.
Flow and Water-dependent Ecological Resiliency	Water supplies for the Stillwater National Wildlife Refuge may be at risk, particularly for scenarios where spills from Lahontan Reservoir on the Carson River are lower. See also "Endangered, Threatened or Candidate Species."
Flood Control Management	Flood magnitude and frequency relationships may change; peak flows may be higher in magnitude, and high-flow events may occur more frequently. Contributing factors include reduced snow accumulation and more precipitation occurring as rain.

Key:
TCID = Truckee-Carson Irrigation District
TMWA = Truckee Meadows Water Authority

Responses to Risks

Water supply conditions for the coming century will affect Truckee Basin water user communities in uncertain and diverse ways. The Basin Study measured the risks and vulnerabilities of individual water user communities relative to a set of baseline conditions for the Truckee Basin, and identified a set of actions that seem reasonable to consider in an attempt to address future supply-demand imbalances.

Unquestionably, Truckee Basin stakeholders and water users have the best understanding of local needs and tolerances to risk. As a result, they are the best suited to identify which actions seem most reasonable for pursuit in response to future risks. The Basin Study team obtained input from study partners and stakeholders to identify individual actions, or options, for responding to climate change. As earlier described in the "Water Management Conditions" section and shown in Figure ES-15, these options would change the Reference water management condition by taking a given action to address future risks. The options presented in the Report were identified or suggested for investigation by Truckee Basin water users and other stakeholders, including municipalities, irrigators, Tribes, resource agencies, local and regional planning agencies, and environmental or conservation groups (Table ES-3).

Table ES-3. Organizations that Participated in the Identification of Options

City of Fernley	Truckee Meadows Water Authority
The Nature Conservancy	Truckee River Flood Management Authority
Placer County Water Agency	Truckee River Watershed Council
Pyramid Lake Paiute Tribe	Truckee-Carson Irrigation District
Tahoe Regional Planning Agency	U.S. Fish and Wildlife Service
Bureau of Reclamation, Lahontan Basin Area Office	U.S. Forest Service

The options proposed represent a wide range of actions that could be implemented in the Truckee Basin. Among the 140 options initially collected, many were similar either in function or intent, reflecting common perspectives about needs and opportunities to improve water management in the Truckee Basin. For presentation and evaluation purposes, the Basin Study team developed a shorter, consolidated list of options (Table ES-4) that preserves the ideas and goals of the full list of options generated. Concurrently, options were organized into both an "adaptation strategy" and a "grouping." Adaptation strategies are the types of approaches an option uses to address risks: Institutional Changes, Demand Management, or Supply Augmentation.

Table ES-4. Options Identified by Water Users

Adaptation Strategy	Grouping	Option
Institutional Changes	Basin-wide Planning	Define regional priorities and goals for water use
		Eliminate prior appropriation
	Surface Water Reservoir Management	Allow TCID carryover storage in Truckee River reservoirs
		Change balance of credit storage available to users at Truckee River reservoirs
		Remove storage limits at Truckee River reservoirs
		Modify flood control curves to adapt to climate
		Modify OCAP criteria at Lahontan Dam to improve success of refill
	Surface Water Rights Management	Allow management of water between Pyramid Lake fisheries and Lahontan Valley wetlands
		Create open water markets
		Consolidate agricultural water rights
Supply Augmentation	Alternative Sources	Interbasin transfer of groundwater
	Conveyance Facility Improvements	Augment Truckee Canal capacity
	Groundwater Storage	Enhanced groundwater recharge
	Modifications to the Hydrologic Cycle	Forestry-based watershed management
		Weather modification
		Wetland, meadow, and stream corridor restoration
	Surface Storage	Additional Carson River storage
		Increase Truckee River reservoir storage
Demand Management	Agricultural Use	Convert to low water-use crops
		Reduce conveyance losses
		Transfer agricultural water rights to municipal and industrial uses
		Water rights retirement
		Water use efficiency improvements
	Environmental Flows	Revise flow targets to correspond with peak flows under climate change
	Municipal & Industrial Use	Increase outreach and education on conservation
		Mandate efficiency improvements
		Outdoor use efficiency improvements
	Water Quality	Water quality improvements for the lower Truckee River

Key:
OCAP = Operating Criteria and Procedures
TCID = Truckee-Carson Irrigation District

Process for Evaluating Options

The Basin Study's process for evaluating options included an initial, high-level assessment for all options recommended by Truckee Basin water users, followed by a more detailed analysis for a smaller subset of options using the model tools developed for the Basin Study.

All of the options suggested by Truckee Basin stakeholders for evaluation in the Basin Study are presented in Chapter 7 and Appendix A of the Report because they represent the perspectives, concerns, and priorities of individuals and communities in the Truckee Basin. The options selected for further technical evaluation in the Truckee Basin Study should not be considered

"recommendations," and many of the options that did not receive detailed evaluation in this study still offer concrete and tangible opportunities to address water management challenges that may arise in Truckee Basin in the future.

Where possible, the Basin Study's evaluations relied upon information from previous studies. In some cases, the development and evaluation of options was conducted with input from water users. However, many options suggested carry inherent political complexities that require broad discussion to resolve, or may require further research to reduce uncertainty regarding the ability of the action to resolve imbalances. Due to the different scale and amount of existing information available about each option, the selected options were evaluated at varying levels of detail.

Options were selected through the use of a qualitative selection process that considered several factors, including the following criteria:

- **Completeness:** To be evaluated, options must have a measurable or specified effect on Truckee Basin supplies, demands, or operations. Stated differently, the information needed to evaluate the option must already exist, and analysis would not require significant speculation about changes in operations, supply, or other features and characteristics of future conditions.

- **Applicability to Basin-Wide Vulnerabilities:** The options selected for further evaluation are those anticipated either to address water supply vulnerabilities for the entire Truckee Basin, or to help restore a balance between supplies and demands, and among users and uses, that is similar to what exists basin-wide under the Reference scenario.

- **Use of Basin Study Tools:** Preference was given to options that could be tested using existing technical tools and models and in similar ways, which allowed for a more instructive cross-comparison of option performance. For instance, options were tested using the TROA-light Planning Model whenever appropriate.

The options evaluated in detail through the Basin Study process, along with key findings on performance and implementation considerations, are shown in Table ES-5.

Table ES-5. Summary of Option Performance and Evaluations

	Ability of Options to Mitigate for Undesirable Future Conditions		
	Basin-wide Vulnerabilities	**Water User Shortages**	**Future Consideration or Development**
Adapt Flood Management Operations	Mitigates for some seasonality shifts by capturing precipitation that would have been held in snowpack in the historical climate. Availability of storage space is much smaller than snowpack, and thus cannot completely mitigate for climate changes.	Small shifts in the timing of managed flows occur related to capture of additional water. Option does not fully restore the historical operating regime or the supply-demand balance under the Reference scenario. Reduces shortages for M&I and agriculture by 3-9 percent. Increases years with adequate spawning flows at Pyramid Lake by up to 15 percent. Reduces adult passage flows by up to 13 percent in drier scenarios. Shifts benefits among lifecycle stages for Pyramid Lake fisheries, challenging passage but improving spawning conditions.	Could affect flood management in the Truckee Basin and would require balancing water supply benefits with flood risks. Implementation may involve the USACE, Reclamation and TRFMA for developing acceptable flood management strategies, and the Pyramid Lake Paiute Tribe for fisheries and water rights-related concerns.
Adapt OCAP Storage Targets	Mitigates for seasonality shifts by adjusting Newlands Project OCAP operations and end-of-month storage targets at Lahontan Dam. Does not mitigate for basin-wide changes.	Helps Lahontan Reservoir refill at the end of the century when climate changes have the most pronounced effect on hydrology, but violates central tenets of OCAP by over-diverting Truckee River water in the earlier portions of the century when climate has subtle changes in hydrology.	Detailed study and careful evaluation in close coordination with the Pyramid Lake Paiute Tribe and TCID may be needed to ensure the intended balance in Truckee River water supplies is not disrupted.
Consolidate Agricultural Rights	Responds to increased crop water demands by reducing acreages of cultivation. Allows for an earlier beginning of the irrigation season, but does not otherwise mitigate basin-wide changes.	Reduces frequency of shortages in the Newlands Project by up to 28 percent without significantly affecting any other water users in the Truckee Basin.	May involve major changes to water rights and would likely be closely coordinated with parties to the *Orr Ditch* and *Alpine* decrees, TCID, and the Nevada State Engineer.

Table ES-5. Summary of Option Performance and Evaluations (contd.)

	Ability of Options to Mitigate for Undesirable Future Conditions		
	Basin-wide Vulnerabilities	**Water User Shortages**	**Future Consideration or Development**
Truckee Canal Rehabilitation	Addresses seasonality shifts and reductions in precipitation by restoring Truckee Canal diversion and conveyance capacity.	Reduces the frequency of annual crop demand shortages for the Newlands Project by 4-12 percent. Increases spills to Lahontan Valley wetlands by 6 percent and reduces long-term shortages to wetlands by up to 3 years. Increases TCID hydropower generation by 4-14 percent.	Implementation is currently underway for a similar action. Reclamation is undertaking a NEPA process to document potential environmental effects, such as impacts to fisheries impacts at Pyramid Lake or groundwater for Fernley. Coordination would likely be needed among the Pyramid Lake Paiute Tribe, TCID, and the City of Fernley.
Additional Truckee River Basin Storage	Mitigates for some seasonality shifts and reductions in precipitation and snowpack by capturing and storing additional supply that would otherwise be spilled.	This option, tested in a conceptual manner, shows some ability for a new storage facility to reduce future shortfalls for all water users in the Truckee Basin. To fully mitigate for potential losses associated with climate change through increased storage, the current available storage in the Truckee Basin would need to be more than doubled.	Detailed study by a project proponent would be needed to determine specific details of future storage, including potential locations and storage capacities. Implementation would likely involve coordination among Reclamation, the Pyramid Lake Paiute Tribe for fisheries and water rights-related concerns, and possibly the USACE and TRFMA for consideration of flood management operations.
Forest Management	Reduces evapotranspiration from forest cover. Could be an important contribution to water supplies originating in the upper Truckee Basin, but performance is uncertain.	Water supplies could be improved for all water users, but there may be limitations of this option during dry years and when supplies are most needed.	More rigorous study would be needed to understand the full potential of this option to improve water supplies, particularly in dry conditions. Implementation would likely involve coordination with USFS, other public or private landowners, and TRPA. Option includes vegetation maintenance across large areas of forested land, and likely periodic clearing of vegetation to maintain the water supply benefit.

Table ES-5. Summary of Option Performance and Evaluations (contd.)

	Ability of Options to Mitigate for Undesirable Future Conditions		
	Basin-wide Vulnerabilities	**Water User Shortages**	**Future Consideration or Development**
Raise Lahontan Dam	Increases storage of Carson River supplies for the Newlands Project, effectively increasing availability of supplies basin-wide.	Reduces diversions from the Truckee River in wetter conditions only. Does not change reliability for the Newlands Project. Increases flow to Pyramid Lake by up to 5 percent, but reduces supply to Lahontan Valley wetlands by up to 9 percent.	Detailed study would likely be needed to determine effects on fisheries and water-dependent ecosystems at Pyramid Lake and Lahontan Valley wetlands. Implementation would likely involve TCID and USFWS.
Adapt Fish Flow Regimes	Mitigates for seasonality shifts by changing the timing of flow regimes in the Truckee River. Does not otherwise mitigate basin-wide changes.	Increases adult passage flows by 1-10 percent and spawning flows by 10-71 percent. Does not change duration of years with poor spawning flows.	Implementation would likely involve coordination among the range of agencies who previously developed the six-flow regime for the Truckee River (TRIT 2003).

Key:
M&I = municipal and industrial
NEPA = National Environmental Policy Act
OCAP = Operating Criteria and Procedures
TCID = Truckee Carson Irrigation District
TRFMA = Truckee River Flood Management Authority
USACE = U.S. Army Corps of Engineers
USFS = U.S. Forest Service
USFWS = U.S. Department of the Interior, Fish and Wildlife Service

A significant benefit of the Truckee Basin Study stems from the development and assembly of a toolkit that is appropriate for understanding the risks of future climate changes, and capable of testing options to respond to those risks. This toolkit includes the TROA-light Planning Model, the upper basin PRMS hydrology models, and the water user indicators. The availability of these tools will continue to benefit local water users beyond the publication of the Basin Study.

The toolkit was applied to evaluate options identified in Table ES-5 above. Each of the options was found to provide some measure of relief from future water shortages or other challenges related to a changing climate. For example, the Consolidate Agricultural Rights option reduces Newlands Project agricultural water shortages under certain climate conditions by up to 28 percent, and also could be implemented concurrent with other options because it otherwise does not affect water management in the rest of the Truckee Basin. As another example, the Adapt Fish Flow Regime option increases adult passage flows in the lower Truckee River by 1 to 10 percent and spawning flows by 10 to 71 percent under certain climate conditions, but likewise does not resolve shortages for other users in the basin. Other options were found to have the side effect of transferring water supply benefits from one type of use or user to another. No single option will fully preserve the balance of water supplies, demands, and uses Truckee Basin communities have relied upon in recent history and which is represented by the Basin Study's Reference scenario.

All of the options considered would require coordination with other Truckee Basin interests to resolve one or more potential issues related to flood management, fisheries, water rights, and other water resources concerns. Multiple options would also require substantial additional study to resolve uncertainties about performance and project specifics. Resolution of these details is likely to be complex. The closed geography of the basin makes even small changes in water management highly perceptible, and the strictly regulated nature of the Truckee River and its water rights may present challenges to implementing new projects or large changes. As a result, even projects that clearly mitigate for risks from climate change will still require broad support among water users throughout the Truckee Basin. This is particularly true for options that appear to benefit only one water user community.

A major recommendation from Truckee Basin stakeholders in responding to climate change was to use collaborative planning processes that engage the basin's various communities and water users. Considerations and recommendations for the continued development of Basin Study options or future planning efforts are described in the discussion of next steps in Chapter 8.

Suggested Next Steps for Truckee Basin Communities

Truckee River water users and stakeholders have long understood that growing demands, coupled with the potential for reduced supplies due to climate change, may put water users and resources relying on the river at risk of prolonged water shortages in the future. The Basin Study built on earlier work and is the next significant step in developing a comprehensive knowledge base and suite of tools and options that could address the risks posed by Truckee Basin water supply-demand imbalances.

The Report indicates that targeted investments in water conservation, reuse, and augmentation projects can improve the reliability and sustainability of the Truckee River system to help meet current and future water demands. However, nearly all of the options evaluated through the Basin Study would need to be studied and considered at various levels and by a range of parties before they could be implemented. These additional efforts would likely be performed by a broad number of agencies and parties that are committed to furthering both the analysis and planning for specific areas or issues identified by the Basin Study. Addressing future imbalances in the Truckee Basin will require diligent planning and collaboration that applies a wide variety of ideas at local, state, and basin-wide levels. Central to this collaboration are partnerships and the recognition that pursuing further study must cultivate and build upon the broad, inclusive stakeholder process that was initiated by the Basin Study.

Incorporation of Future Risks into Existing Water User Plans

While Reclamation's Basin Study Program provides standardized scientific information on how climate change affects water resources across the Western U.S., the processes for incorporating climate change into political and decision making forums varies widely by region and community. Recently, Federal and State legislative requirements and executive policies have emerged that require climate change to be incorporated into water resource plans. However, best practices and standardized technical and policy guidance for doing so do not yet exist. Thus, it is often up to local communities and regional planning consortiums to construct frameworks for interpreting and including climate change in their planning processes. Effectively incorporating future risks identified by the Basin Study into existing water resources planning processes could be supported by locally or regionally driven efforts to expand upon the information generated through the Basin Study:

- **Regional Planning Forum –** Plans and responses to climate change may have implications which would benefit from a common basin-wide understanding of risks, transparency in a vision and objectives shared by individual communities for the future, and/or a collective commitment to take action. A regional planning process with participants representing a broad coalition of interests could be highly valuable in achieving these by providing a common processes for the interpretation of future risks, options for responding to risks, tradeoffs among communities for future

actions, and a mechanism for cost-sharing on future studies. Considerable investments have been made to develop a regional understanding about the implications of water use in the Truckee Basin, particularly surrounding and through TROA negotiations and implementation. The efforts to support TROA implementation could serve as a useful model for a regional planning process.

- **Improvement of Indicators by Water Users** – An effort by water users and Truckee Basin communities to refine the indicators developed during the Basin Study could improve the degree to which the Basin Study's assessments can be used for future planning. The indicators developed for this Basin Study report on the quality of future conditions in a relative manner. For example, the frequency of water supply shortages experienced by a particular water user can be counted for each scenario, and scenarios with lower or fewer shortages will receive higher ratings among corresponding indicators. However, the Basin Study indicators do not provide objective value judgments; it may be possible that even the "worst" scenario can be accommodated by a given water user. Identifying whether conditions are either good or bad can depend on multiple considerations. From a technical standpoint, the effect of future conditions depends on the water requirements of each community, the capabilities of their existing infrastructure, and the characteristics of various available water supplies for managing their demands. Political and administrative considerations also provide important context for interpreting future conditions.

Development of Modeling Tools and Information

The Basin Study relied upon projected future conditions that were assembled before the development of the key vulnerabilities that emerged from the Basin Study's risk and reliability assessment. As the first of its kind in the Truckee Basin, this Basin Study presents an opportunity to inspect sources of uncertainty in supplies and demands and determine whether uncertainty in the analysis could be reduced or corrected with additional modeling and analysis.

The following assessments and model development tasks were identified through input from technical stakeholders, or by the Basin Study team through the process of conducting analysis of vulnerabilities and adaptation options.

- **Refinement of ecosystem demands and vulnerabilities –** An understanding of the relationship between changes in the climate, changes in the demands of aquatic, wetland, and riparian ecosystems and migratory waterfowl and shorebirds that result from changes in the climate, and the ability to accommodate these demands with existing supplies would benefit from further analysis and model development.

- **Incorporation of paleohydrology and updated climate projections** – More recent estimates of past and potential future hydrology have become

available since the Basin Study technical work was completed. These include updated climate projections and also "paleohydrology" data sets, or estimates of historical water supply availability based on information drawn from prehistoric physical records, such as tree rings. Comparing the new estimates with the information included in the Basin Study may provide additional information about potential future conditions and what changes the Truckee Basin could experience in the future.

- **Inclusion of the Carson River Basin –** With the interbasin connection provided by the Truckee Canal, development of supply, demand, and infrastructure and operational conditions in the Carson Basin upstream from Lahontan Reservoir would benefit water users in this neighboring basin, including the Newlands Project.

- **Coupled groundwater/surface water model development** – The communities in the Truckee Basin who rely on groundwater as a primary source of water supply would benefit from an improved understanding of how climate change may alter natural processes for groundwater recharge and storage.

- **Economics model for the Truckee Basin –** For communities that rely heavily upon recreational uses of water, such as snow-dependent or lake recreation, the application of a regional socioeconomics model may provide further clarification about the implications of climate change on the goals of each community.

- **TROA implementation refinements –** As currently configured, the TROA-light Planning Model used in the Basin Study simplifies or is limited in its ability to represent certain elements of TROA, for example the California guidelines for recreation and the use of credit storage to support water quality on the lower Truckee River. In many cases, this is because such elements require further discussion and refinement before they can be implemented in real-world operations. The continued development of these aspects of TROA will likewise require expression in the model environment so that the model continues to be an accurate and useful tool for Truckee Basin planning efforts.

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