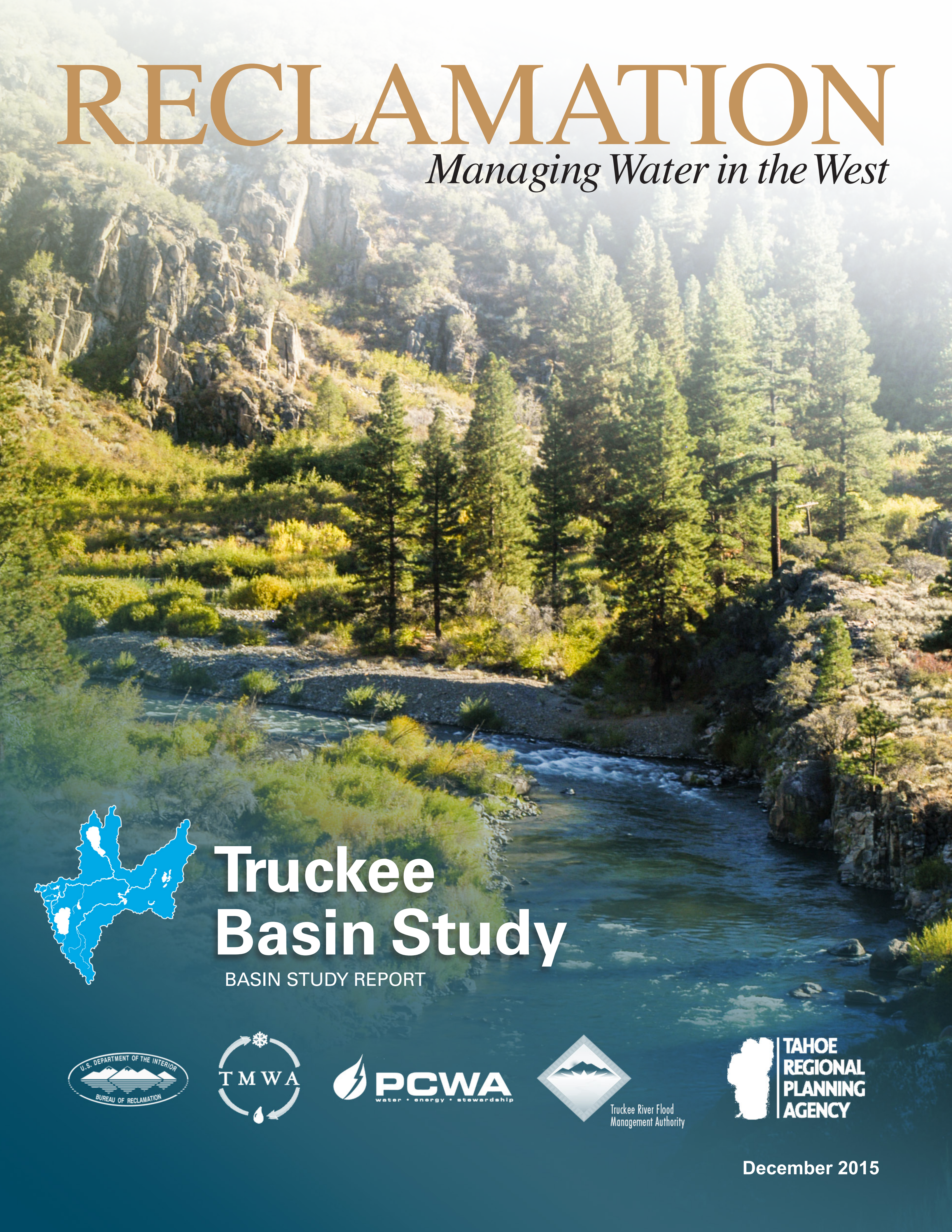

RECLAMATION

Managing Water in the West

Truckee Basin Study

BASIN STUDY REPORT

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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Abbreviations and Acronyms

°F	degrees Fahrenheit
Basin	Truckee River Basin
California DWR	California Department of Water Resources
cfs	cubic feet per second
CMIP3	World Climate Research Program's Coupled Model Intercomparison Project phase 3
COOP	Cooperative Observer Program
CRLE	Complementary Relationship Lake Evaporation
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ESA	Federal Endangered Species Act of 1966
GCM	general circulation model
GHG	greenhouse gas
GIS	geographic information system
GMP	Martis Valley Groundwater Management Plan
HDe	Hybrid Delta ensemble
HRU	hydrologic response units
IPCC	Intergovernmental Panel on Climate Change
LBAO	Lahontan Basin Area Office
LCC	Landscape Conservation Cooperatives
M&I	municipal and industrial
MODIS	moderate-resolution Imaging Spectroradiometer
NCDC	National Climatic Data Center
Nevada DCNR	Nevada Department of Conservation and Natural Resources
NSCSD	Northstar Community Services District
NWR	National Wildlife Refuge
OCAP	Operating Criteria and Procedures
PAO	Public Affairs Office
PCWA	Placer County Water Agency
PRISM	Parameter-elevation Regression on Independent Slopes Model
PRMS	Precipitation-Runoff Modeling System
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
Report	Basin Study and this Basin Study Report
SCA	snow-covered area
SNOTEL	measured snow telemetry
SRES	Special Report on Emissions Scenarios
SWE	snow-water equivalent
TAG	Technical Advisory Group

TDPUD	Truckee Donner Public Utility District
TMWA	Truckee Meadows Water Authority
TRFMA	Truckee River Flood Management Authority
TRFP	Truckee River Flood Project
TROA	Truckee River Operating Agreement
TRPA	Tahoe Regional Planning Agency
TSC	Tahoe Science Consortium
USACE	U.S. Army Corps of Engineers
USFS	U.S. Department of Agriculture Forest Service
USFWS	U.S. Department of the Interior, Fish and Wildlife Service
USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity
WEAP	Water Evaluation and Planning System
WQSA	Water Quality Settlement Agreement
WWCRA	West-wide Climate Risk Assessment

Chapter 1 Introduction

The Truckee River Basin (Basin) provides a compelling demonstration for how changes in demands and/or a region's climate could influence both natural and human water uses. Packed into this relatively small Basin is 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, the diversity of water uses within its borders has made the Basin home to every type of water resources conflict.

Despite this natural conflict, communities in the 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 massive 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.

Thus, like many basins in the West, water management practices, 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 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 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.

While uncertainty in the weather has been fundamentally addressed through past water management planning, potential changes in the climate pose new threats. Plans for managing the uncertainty in water supplies have, until recently, relied on historical gage records for describing the range of potential variability. Global climate changes are expected to increase temperatures in the Basin and potentially alter the annual volume of precipitation, resulting in water supply conditions that differ from gage records and historical experiences. While changes in average annual precipitation are uncertain, increases in temperature appear likely (Reclamation 2011b). Temperature alone also has important effects on both supplies and demands; increases in temperature could extend the growing season for irrigated crops, amplify lake evaporation, and diminish the portion of winter precipitation that accumulates as snow. In particular, reductions in snow pack – even without changes in precipitation – will strain existing infrastructure. The combination of changes in supply and demand could affect the diverse Basin water uses in incongruent ways, shifting the balance of risks and benefits that are currently shared among water users.

Further investments in infrastructure and adjustments to the institutional arrangements that govern water management will likely be required to preserve the full range of natural and economic values for water in the Basin into the future. However, neither new infrastructure nor institutional changes have a history of quick implementation; planning, funding, and construction can take decades, as can lawsuits or even structured changes to policy, regulations, or practices governing water use for a basin as highly regulated as the Truckee. For individual water user communities, addressing climate change will require an understanding of the risks posed to the entire Basin, the tradeoffs among various strategies for addressing imbalances, and decisions about which risks to address, and how. Addressing future risks through changes in law, policy, or allocation must necessarily come from processes guided by the Basin water user communities themselves.

The U.S. Department of the Interior, Bureau of Reclamation (Reclamation), has initiated a series of studies through the 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).

This chapter provides background information on the Basin Study Program and the Truckee Basin Study, including its authorization and purpose, support for the objectives of the SECURE Water Act of 2009 (Public Law 111-11), and management and oversight. It also provides an overview of the Basin Study's organization, including the location of various content or assessments developed during the study process.

Authorization

The Basin Study Program, as part of the U.S. Department of the 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.

Through the Basin Studies, Reclamation works with States, Indian Tribes, non-governmental organizations, other Federal agencies, and local partners to identify strategies to adapt to and mitigate current or future water supply and demand imbalances, including the impacts of climate change and other stressors on water and power facilities.

The Basin Study Program also includes West-wide Climate Risk Assessments (WWCRA) and Landscape Conservation Cooperatives (LCC). WWCRA assesses impacts to water supplies and demands on a reconnaissance level and include a baseline risk and impact assessment. Analyses of climate impacts on basin hydrology were performed west-wide for major river basins, including the Truckee Basin, to establish a foundation for more in-depth analyses and the development of adaptation options through Basin Studies and other planning activities. This includes baseline assessments conducted through WWCRA to evaluate risks to water supplies (change in snowpack, changes in timing and quantity of runoff, and changes in groundwater recharge and discharge) and increase in the demand for water as a result of increasing temperatures and reservoir evaporation rates.

Led by Reclamation and the U.S. Department of the Interior, Fish and Wildlife Service (USFWS), LCCs are partnerships of Federal and State agencies, Indian Tribes, universities, non-governmental organizations, international entities, and local governments, formed to develop and share applied science tools and approaches that support resource management at the landscape scale.

Purpose, Objectives, and Partners

The Basin Study and this Basin Study Report (Report) are intended to assist water management agencies in their incorporation of future risks (e.g., water shortages) into their management, decision processes, and investment considerations. This Report identifies and describes future risks to 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 for the Truckee River, it provides a foundation for future investigations through the identification of key vulnerabilities and presents options for more detailed investigations. Decisions by local communities to move forward with the options presented in the Report will likely require further information or evaluation and cooperation.

Study Area and Setting

The study area for the Truckee Basin Study, shown in Figure 1-1, 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.

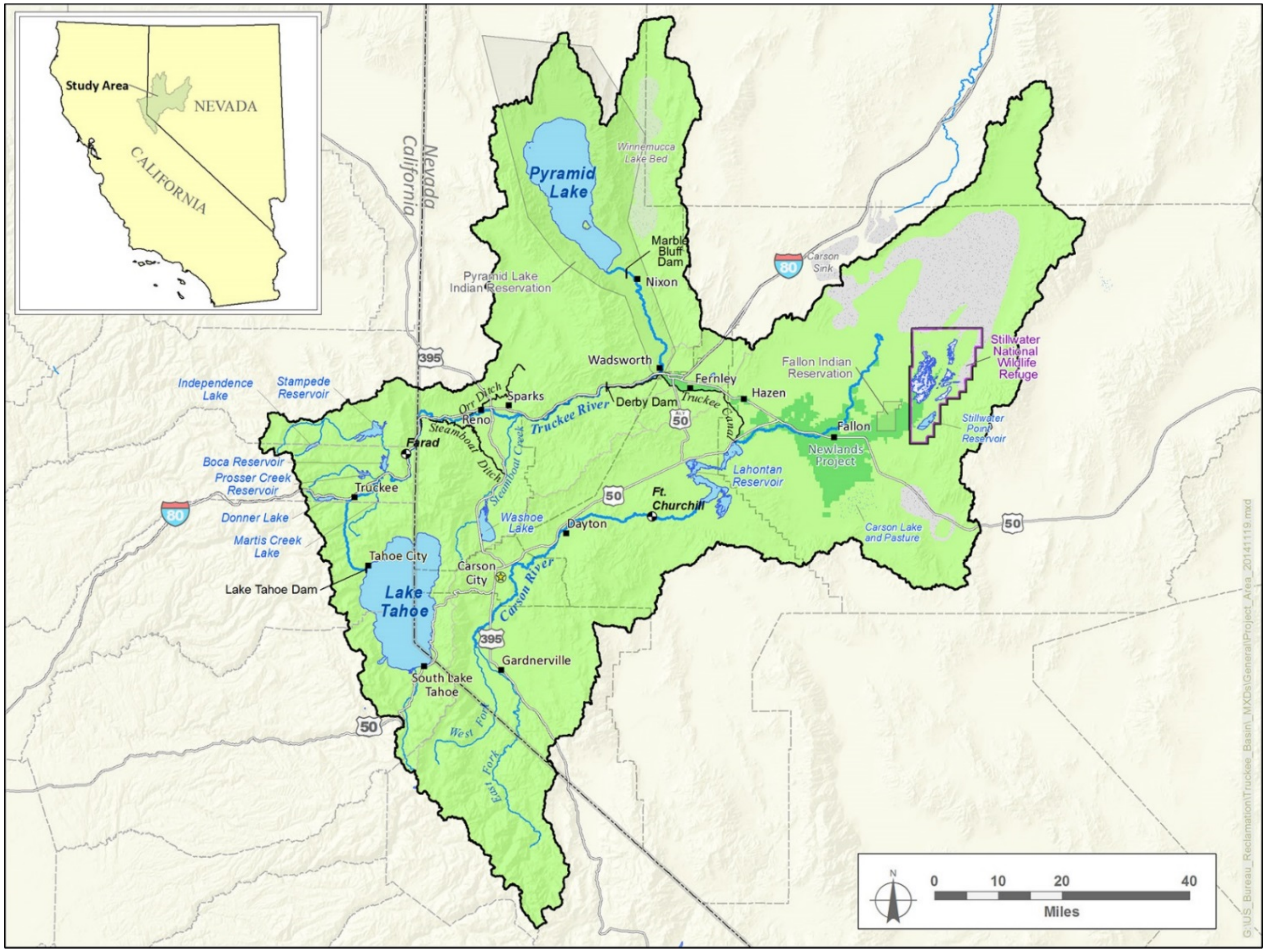

Figure 1-1. Study Area for the Truckee Basin Study

Water Resources Setting

The Truckee River supports natural ecosystems and is a vital water source for more than 400,000 people. From its origins in the high Sierra Nevada Mountains at elevations over 10,000 feet, the Basin encompasses an area of approximately 3,060 square miles in California and Nevada. While the greater portion of the Truckee River Basin's surface area and the majority of its demands for water resources lie in Nevada, most of the precipitation and virtually all of the Basin's water storage lie in California. The imbalance between the Basin's water supplies and its water demands has created conflicts surrounding the rights to, and the uses of, water resources within the Basin. The waters of the Truckee River have been fully appropriated; therefore, satisfying competing demands for human, environmental, and other uses of water will likely become increasingly difficult in the future under potential climate change.

Future Challenges and Considerations

Climate scientists have projected that median annual temperatures in the Truckee Basin could increase 5 to 6 degrees Fahrenheit by the end of the twenty-first century (approximately 2 to 10 degree Fahrenheit increase at the 5 and 95 percentile) (Reclamation 2011a). Predicted climate changes in the Basin may result in more or less precipitation overall, and could reduce snowpack or cause earlier runoff in the Truckee River's high Sierra headwaters. Predicted changes also include peak storm events which exceed many current storm events. These potential changes in water volumes have far-reaching ramifications to the individuals, businesses, agriculture, critical habitats for listed species, and tribal or cultural resources dependent on the Truckee River. Adequate planning for droughts and other hydrologic events which impart various levels of risk depends on informed assessment of the range of future conditions the Basin may experience.

Objectives and Outcomes

The Basin Study's objectives and outcomes were to:

- Develop comprehensive assessments of current water supplies and demands which are supported by the Basin Study partners.
- Employing a "best-science" approach, represent multiple scenarios for future supplies and demands which are influenced by potential future climate conditions.
- Identify risks and/or impacts of climate change to water supplies and demands.
- Where climate change impacts are identified, develop options for potential future actions or opportunities for further study in support of developing local or regional responses to address impacts.

- Achieve broad participation in the Basin Study and identify sets of climate change scenarios to consider for the Truckee Basin within the context of addressing water supply and demand risks, reliability, and other resource issues.

SECURE Water Act Water Resource Themes

The SECURE Water Act specifies eight water resources-related areas for Reclamation to address through the WaterSMART program (42 U.S.C. 10363, Sec. 9503(a)(3)):

> *A. the ability of the Secretary to deliver water to the contractors of the Secretary;*
>
> *B. hydroelectric power generation facilities;*
>
> *C. recreation at reclamation facilities;*
>
> *D. fish and wildlife habitat;*
>
> *E. applicable species listed as an endangered, threatened, or candidate species under the Endangered Species Act of 1973 (16 U.S.C. 1531 et seq);*
>
> *F. water quality issues (including salinity levels of each major reclamation river basin);*
>
> *G. flow and water dependent ecological resiliency; and*
>
> *H. flood control management;*

Each of these water resource areas are likely to be affected by changes in water supply reliability due to future changes in climate, demand, or other conditions, and each of them are of concern to the water users and communities in the Truckee Basin. However, these "themes" have varying degrees of applicability for different water users; not all are a concern for everyone in the Basin. The Basin Study addressed the SECURE Water Act themes as they relate to each type of water use, or to each water user, in the Basin.

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 1-2. Each of the partner agencies represented a valued and often unique perspective for water management in the Truckee Basin. PCWA's participation was enabled through the development of the Martis Valley Groundwater Management Plan (Martis Valley GMP) as a cost-share basis for the Basin Study, which included funding and support from Truckee Donner Public Utility District (TDPUD) and Northstar Community Services District (NSCSD). 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.

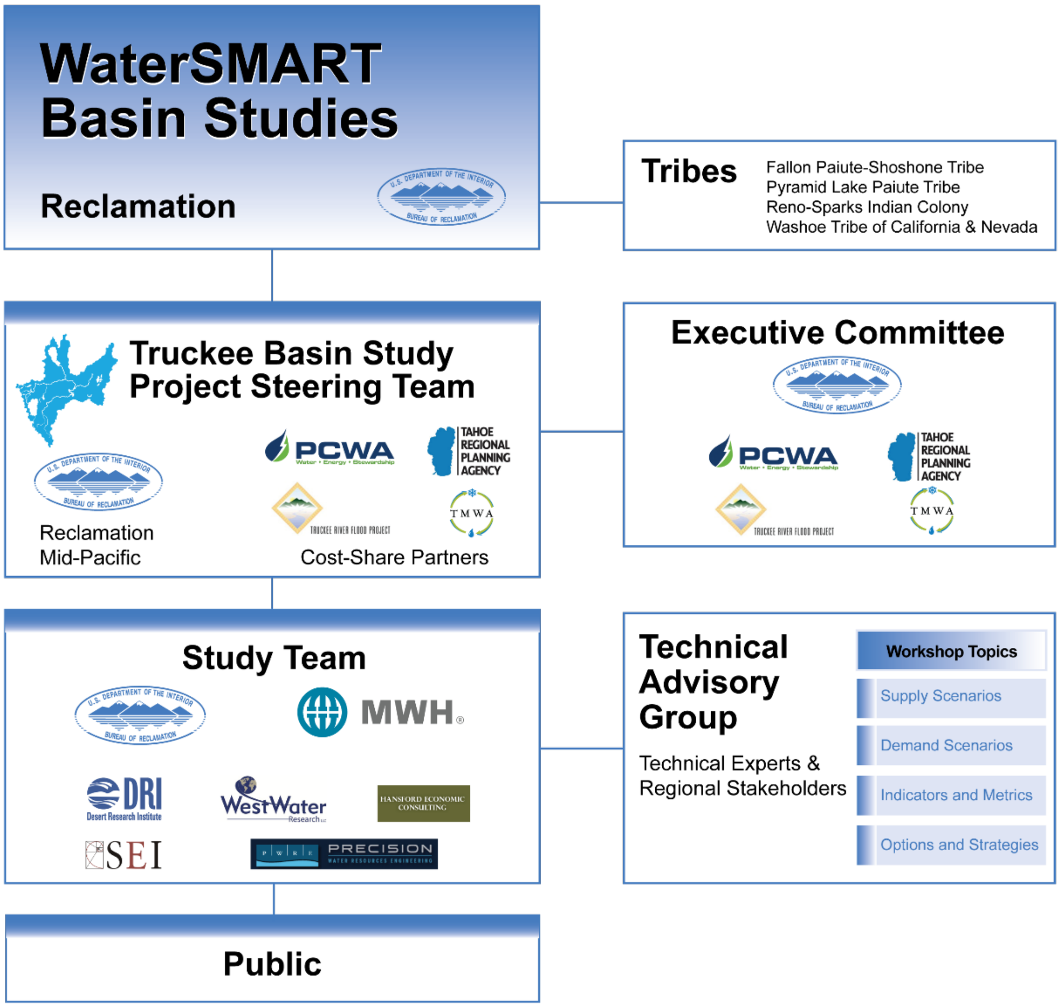

Figure 1-2. Organizational Structure for the Truckee Basin Study

Study Team

Led by Reclamation's Project Manager, Arlan Nickel, members of the study team included Reclamation staff in Sacramento at the Mid-Pacific Region Office, as well as staff of MWH, the prime planning consultant. This team conducted the day-to-day coordination, planning, and other activities to complete the Basin Study. Reclamation and MWH jointly oversaw the technical contributions of the team identified in Figure 1-2. The study team worked with staff in Reclamation's Lahontan Basin Area Office (LBAO) to coordinate the technical direction of the

Basin Study, and with Public Affairs Office (PAO) staff to plan and execute engagement and outreach activities to support the Basin Study process.

Project Steering Team

The Project Steering Team included management-level staff from Reclamation, PCWA, TRPA, TMWA, and TRFMA, and provided overall input, support, and direction to the study team. The Project Steering Team also identified key stakeholders for engagement in the Basin Study process and helped recognize issues that needed to be addressed at a policy level for the study.

Executive Committee

The Executive Committee included policy-level representatives from Reclamation and from the cost-share partner agencies. This committee determined all key and advanced issues that were not able to be resolved at either the study team or Project Steering Team levels.

Organization of this Report

This Report summarizes the range of planning, technical, and engagement activities conducted during the course of the Basin Study. A number of appendices provide additional detail regarding methods or results for the assessments included in the Basin Study, or document processes such as stakeholder outreach and engagement. Organization of this Report is as follows:

- Chapter 1 (Introduction) – Provides the authorization, purpose, and context for the Basin Study.

- Chapter 2 (Scenario Planning and Supporting Information) – Describes the Basin Study's scenario planning approach and supporting sources of information.

- Chapter 3 (Water Supply Assessment) – Presents the water supply conditions developed for use in the Basin Study, including representations of historical supply (based on gage records), present supply, and future supply (under five different climate conditions).

- Chapter 4 (Water Demand Assessment) – Presents the water demand conditions developed for use in the Basin Study, including the present demand for water (based on 2012-level demands) and future demand (under two separate economic growth conditions).

- Chapter 5 (Water Management Conditions) – Describes the infrastructure, facilities, and regulatory conditions that represent current water management practices in the Basin.

- Chapter 6 (Risk and Reliability Assessment) – Characterizes future water supply risk and reliability both Basin-wide and for different areas and water uses in the Basin.

- Chapter 7 (Responses to Risks) – Describes options suggested by water users for addressing risks to reliability, and evaluates their performance.

- Chapter 8 (Suggested Next Steps for Truckee Basin Communities) – Reviews key findings from the options evaluation and discusses opportunities for further study in support of developing local or regional responses to future conditions.

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Chapter 2 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 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 provides a framework to evaluate the influence that specific variables of future conditions have on the Basin's supply-demand balances. This approach has been broadly applied to water resource reliability assessments; however, the application of scenario planning to the Truckee Basin Study required some customization to account for the broad levels of uncertainty that exist in its scenarios. The scenario planning approach taken by the Basin Study has important implications for how study results should be interpreted.

> **Scenario planning** is an approach to strategic planning that explores the joint impact of various uncertainties. A scenario provides a narrative for how multiple uncertain conditions can converge in a singular manner and lead to various different outcomes. Scenario planning uses different combinations of uncertain conditions to capture the richness and indeterminate nature of the future.

This Basin Study is the longest-range water supply assessment conducted to date for the Truckee Basin, and the first to consider the effects of climate change on supply and demand Basin-wide. As the first effort of its kind in the region, significant effort was spent in assembling information that would be used to represent current conditions, and in estimating the likely range of future conditions. To the extent possible, existing and available information generated through the considerable planning efforts of Basin communities were used for quantifying and describing current and future conditions used to build the Basin Study's scenarios. In cases where gaps existed between the available studies and the Basin Study needs, input was obtained from stakeholders through workshops and individual meetings.

This chapter presents the scenario planning approach applied by the Basin Study and provides an overview of the information used for developing and evaluating scenarios.

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 entire geography of the Basin. When looking to plan for the future, they must consider how investments made today will influence their ability to manage both current and future challenges.

Scenario planning is a highly effective approach for development of flexible, long-term plans and making decisions where future conditions are uncertain. It first emerged as a planning method after World War II, when the U.S. military began using scenario planning to envision different approaches its opponents might use and develop alternative strategies to respond (Mietzner et al. 2007). The defense community continued to use and refine this approach for several decades, during which time the business community also began employing this planning method, notably during the oil crisis of the 1970s.

In a general sense, all scenario planning shares commonalities with the early documented uses of this approach: regardless of the specific application, development and analysis of scenarios is a way of systematically imagining, characterizing, and combining different variables, events, conditions, or pathways to reveal future problems or challenges and to design potential responses. Thus, the central purpose of scenario development shifts away from predicting the most likely future condition, and instead focuses on understanding the full range of possibilities for how the future could look. As a result, the scenario planning approach has been widely applied for addressing water resource planning needs, although specific methodologies have varied considerably (Water Utility Climate Alliance 2010, California DWR 2013b, Reclamation 2012).

The following sections describe the value of scenario planning for the Basin Study, the components of scenarios developed and the related sources of uncertainty, the analytical process applied by the Basin Study for assessing future risks and evaluating mitigation options, and the analytical tools applied for conducting the scenario analysis.

Use of Scenario Planning for Managing Uncertainty in the Basin Study

The principal challenge of long-range planning efforts like the Basin Study stem from the wide range of possible future conditions and an acknowledged inability to reliably foresee conditions in the distant future.

Traditionally, planning studies for infrastructure development, land use, and water resources have addressed an expected range of future conditions – known as the “planning horizon” – for a period of less than 50 years. Regionally, many of the current general plans in the Basin use 30-to-40 year planning horizons for estimating and addressing the needs of water, land use, and transportation infrastructure. In such cases, the near-term future is easier to imagine and reasonably foreseeable. Similarly, Federal water resources planning studies have traditionally used a singular Without-Action condition to represent foreseeable conditions in the study area (WRC 1983).

The needs of the Basin Study forced a departure from traditional planning approaches in two important ways. First, the Basin Study considered a planning horizon through the end of the twenty-first century (an 88 year projection). This extended horizon is needed to make full use of the climate change projections that are available, but also introduces considerable amounts of uncertainty. Second, the Basin Study incorporated uncertainty by evaluating multiple future conditions, each of which is considered possible (in contrast to the use of a singular anticipated future condition).

The use of multiple future scenarios has fundamental implications for how the Basin Study results should be interpreted. For contrast, the traditional approach of using a singular expected future condition results in analysis is to answer the question, “what will the long-term future bring and how can we defend against it?” The use of multiple future conditions disrupts this line of question because defending against all future scenarios could require taking multiple actions, some of them contradictory. Thus, the interpretation of future conditions described by the Basin Study required a different approach. The scenario planning approach taken by the Basin Study organizes around a reframing of the original question: “how can we choose actions today that will be consistent with our long-term interests, regardless of the future?” (Lempert 2003).

Development of Scenarios

The Basin Study and this Report characterize the drivers that influence the reliability of Basin water resources through the use of three “scenario components.” These components are illustrated in Figure 2-1.

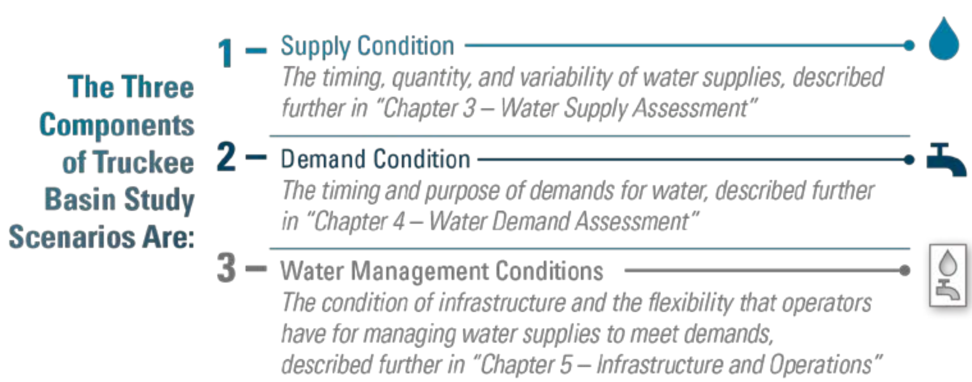

Figure 2-1. Components of Basin Study Scenarios

The range of uncertainty affecting each component results in multiple possible future “conditions” for each scenario component. Because each of the individual scenario components could have multiple future conditions, the Basin Study did not select a singular "future" – the future is ultimately represented by multiple scenarios that include all the possible combinations of conditions.

Supply Component

The "supply" scenario component includes descriptions of surface runoff and hydrologic processes, such as snow accumulation and melt, rates of surface water evaporation, and groundwater recharge.

The Basin Study relied on two sources of information for the development of supply conditions: historical stream gage data and simulated hydrologic conditions. From these sources of information, the Basin Study constructed seven supply conditions: one Historical condition (based on gage data), the Reference condition (based on simulations), and five future supply conditions (based on simulations). Figure 2-2 depicts the relationship of these seven supply conditions to one another in terms of the Basin Study's planning timeline.

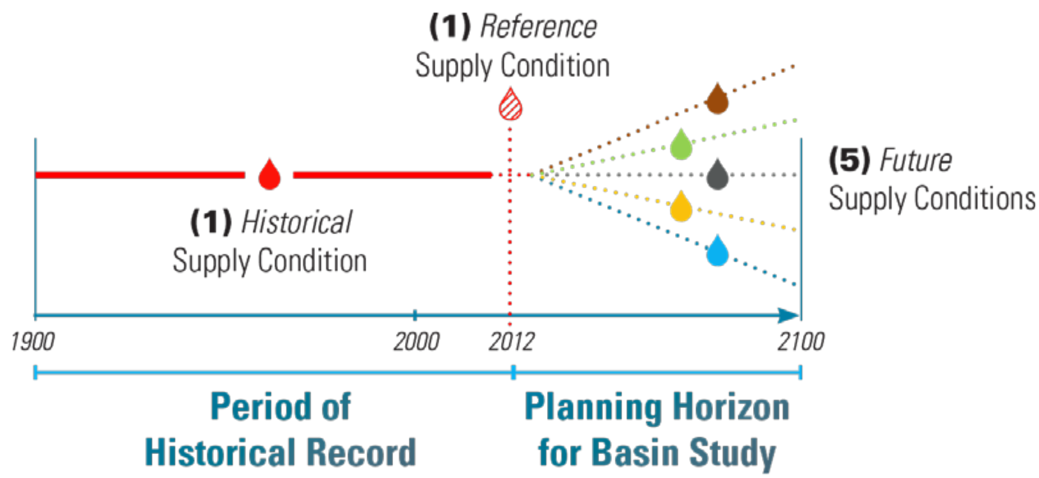

Figure 2-2. Supply Conditions Used in Basin Study Scenarios

The historical condition is based on stream gage records for the Basin dating back to 1901. This historical condition has been assembled from gage records for use 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 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" supply condition, and is simulated from historical meteorological conditions (see "Chapter 3 – Water Supply Assessment"). Future conditions are also simulated, and use projected meteorological conditions that are based on projected changes in climate.

"Chapter 3 – Water Supply Assessment," describes and compares the different supply conditions used in the Basin Study.

Demand Component

The "demand" scenario component provides descriptions of diverted and in-river water uses in the Basin. All demand conditions were developed using data or input from water users throughout the Basin. Figure 2-3 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.

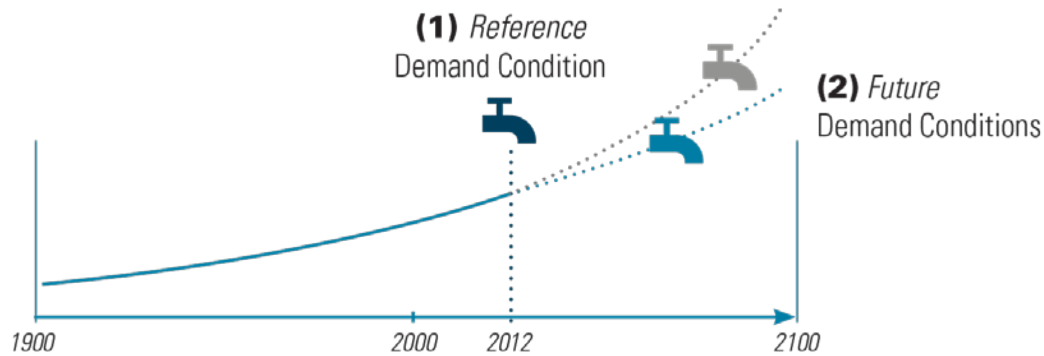

Figure 2-3. Demand Conditions Used in Basin Study Scenarios

The "Reference" demand condition is assembled from records of water use from 2012, and represents a "current" water demand condition.

Uncertainty in the future demand conditions was accommodated through the development of two future demand storylines. The two future demand storylines were estimated to bracket the predicted variability in future water use, which are considered to largely result from future economic conditions. Through the use of previous studies and reports and input from Basin water users and stakeholders, the Basin Study developed the "Robust Economy" and "Existing Trends" storylines to bracket the range of potential future water use in the Basin.

"Chapter 4 – Water Demand Assessment" describes and compares the current and future demand conditions used in the Basin Study.

Water Management Component

The "water management" scenario component provides descriptions of facilities, regulatory requirements, operational rules, and water management practices in the Basin (for example, TROA). Water management conditions were developed using existing information and water user input. The Reference water management condition is based on the current conditions throughout the Basin, and is described in "Chapter 5 – Water Management Conditions."

The Basin Study developed and evaluated several changes in water management in response to vulnerabilities that emerge from future supply and demand conditions. These are considered "options" and were identified for evaluation in the Basin Study through engagement with water users and stakeholders. Options are considered, generally, structural or non-structural actions that would address future vulnerabilities by changing sources of supply, managing demands, or adjusting institutional arrangements and regulations. The options identified and evaluated are presented in "Chapter 7 – Responses to Risk."

Figure 2-4 depicts the Reference water management condition and how it may change through implementation of one or more options to address future vulnerabilities.

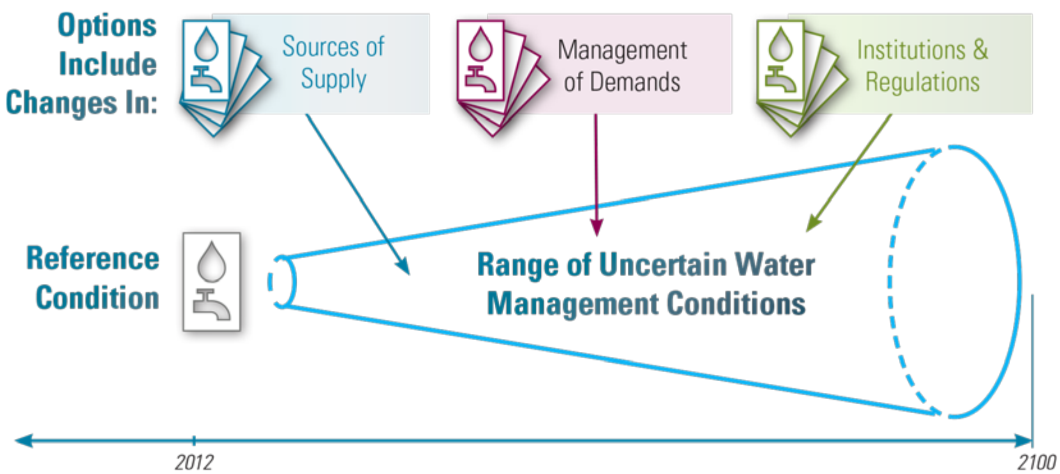

Figure 2-4. Options Shape Water Management Conditions Used in Basin Study Scenarios

Basin Study Scenarios

Scenario planning relies upon the construction and comparison of a broad range of conditions in order to understand risks, vulnerabilities, and causality, and for the evaluation of options to mitigate risks. The scenarios developed for the purpose of the Basin Study include one Reference scenario; five Without-Action scenarios, each defined by a different future supply condition; and five Option scenarios, also defined by different future supply conditions, for each option evaluated by the Basin Study.

The composition of these scenarios and their roles in the Basin Study are described in the sections that follow. The Basin Study also constructed several supplemental scenarios as needed to support analyses in several sections of this Report.

Reference Scenario

The Reference scenario is assembled from the combination of Reference conditions for all three scenario components, as shown in Figure 2-5. There is only one Reference scenario, as there is only one current condition for each of the scenario components.

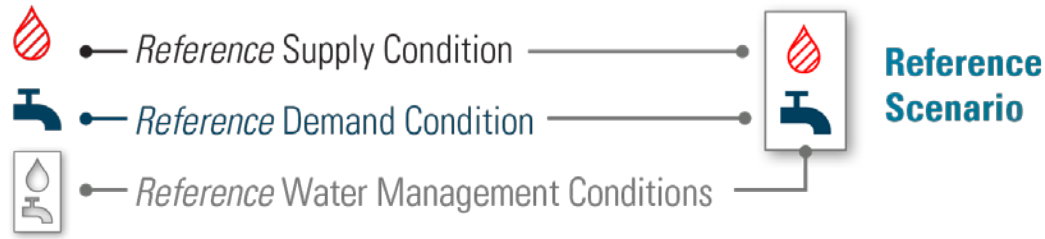

Figure 2-5. Construction of the Reference Scenario

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 Basin under the current 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 conditions. Figure 2-6 demonstrates the make-up of the ten Without-Action scenarios, resulting from each combination of five future supply conditions, with the two future demand conditions, and the single water management condition. Each of the ten Without-Action scenarios are considered to be equally likely.

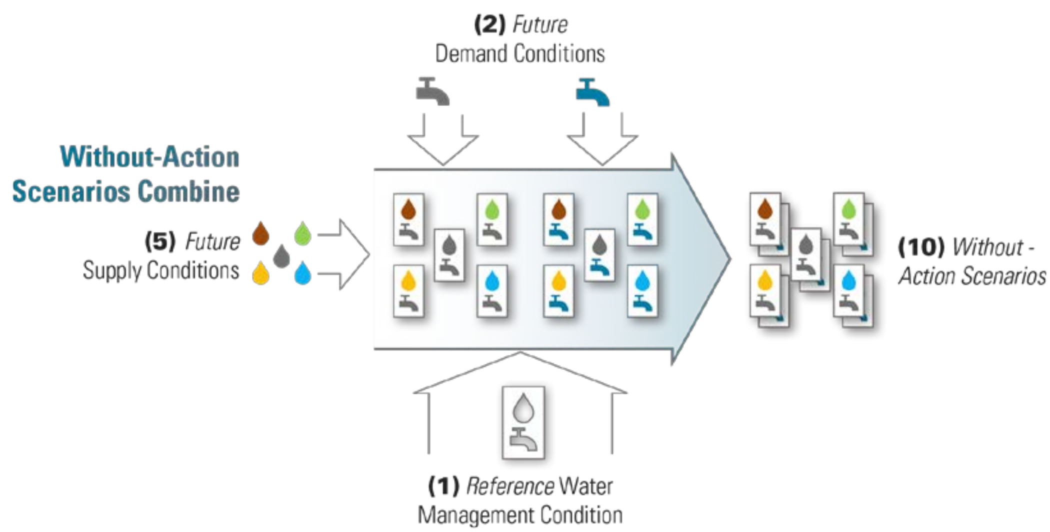

Figure 2-6. Construction of Without-Action Scenarios

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 evaluated in the Basin Study. Figure 2-7 demonstrates the make-up of the ten option scenarios that result from the evaluation of any single option.

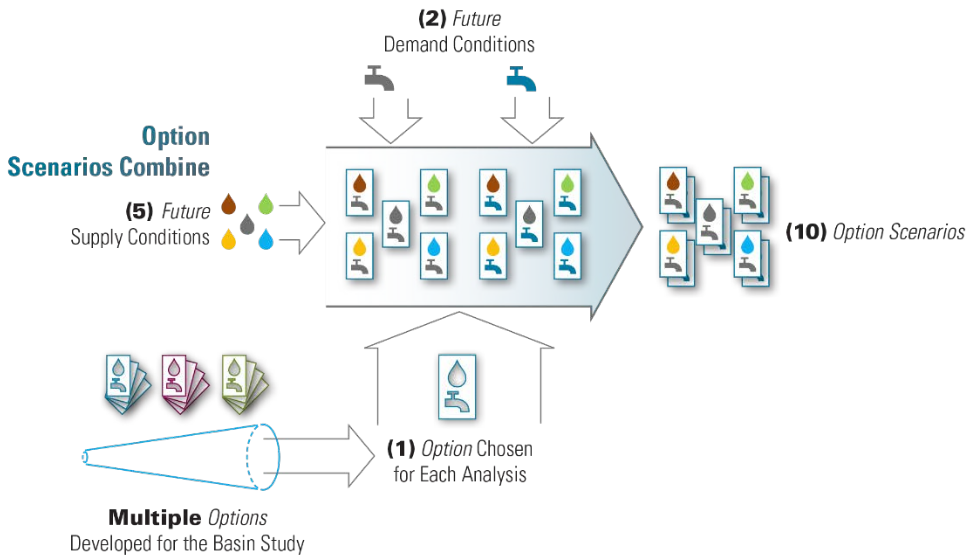

Figure 2-7. Construction of Option Scenarios

This Basin Study selected options for evaluation in response to the vulnerabilities identified in “Chapter 6 –Risk and Reliability Assessment.”

Basin Study Assessments

Comparisons of scenarios form the basis for anticipating the result of changes in future supply, demand, or water management conditions. The comparisons most relied upon in the Basin Study, and their location in the Report, are described in Figure 2-8.

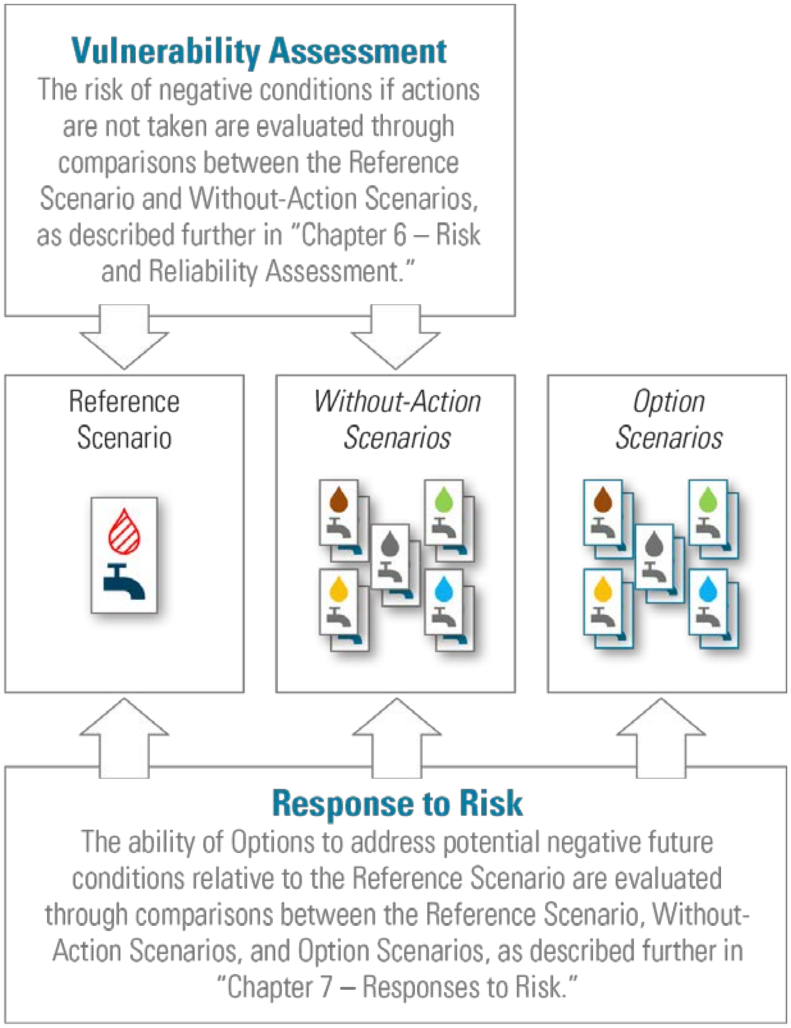

Figure 2-8. Basin Study Comparisons

Simulation of Scenarios

The Basin Study used the TROA-light Planning Model for simulation of all Basin Study scenarios, which provided the basis for understanding imbalances between supply and demand. This model includes all the major rules of TROA operations, and continues to be developed in coordination with regional stakeholders, separately from the Basin Study process.

The TROA-light Planning Model was developed through a collaborative effort of the TROA signatories, including Reclamation, TMWA, the Pyramid Lake Paiute Tribe, and the states of California and Nevada (Interior and California 2008). The TROA-light Planning Model is a daily-time step water management simulation model built in the RiverWare modeling environment. Simulations are performed for up to a 100-year period of simulation, based on hydrology data for the 1901 – 2000 period of record. The model allows simulation of Basin water management operations under TROA, including operations of all major dams and reservoirs in the Truckee and Carson basins: Lake Tahoe, Donner, Independence, Boca, Prosser, Stampede, Derby, and Lahontan. The model also includes all of the major diversions in the system for municipal and industrial as well as agriculture including the Truckee Canal, Lahontan Reservoir, and the Newlands Project. Current flow and regulatory standards in the basins are included as constraints in the model, including the Newlands Project Operating Criteria and Procedures (OCAP), the 1935 Truckee River Agreement, the 1944 Tahoe Prosser Exchange Agreement, and TROA. The model receives regular review and refinements from regional stakeholders in anticipation of its use for future planning studies, has a wider circulation than other available Basin operation models, and is generally considered the best available Basin operations model.

Sources of Information

The Basin Study relied on both existing information and input from Basin water users and stakeholders to inform the assessments used in development of the scenarios and related analyses of options.

As a heavily studied and regulated river basin, the Truckee Basin has been the subject of numerous previous investigations to determine existing levels of water use, plan for future water needs, and assess the effects of various projects on the Basin's environment and communities. These existing studies and reports provided background and context for both the Basin Study itself and also informed key study assessments. The Basin Study also leveraged concurrent activities by cost-share partners and other Basin water users, stakeholders, and organizations, including development of new or updated plans and models for land use, water supply, and climate change assessments.

To supplement existing information on water resources conditions and needs in the Truckee Basin, the Basin Study team sought the input of water users and other stakeholders throughout the study process. Engagement occurred through individual meetings with different planning- or water-focused organizations and during Technical Advisory Group (TAG) meetings.

Summary of Existing Studies and Reports

One goal of the Basin Study is to use existing studies, reports, and sources of information suggested by non-Federal cost-share partners and Basin stakeholders to develop baseline information and assumptions for water supply conditions, demand conditions, infrastructure and regulations, and reliability concerns in the Basin. This goal was particularly important in helping to capture critical information that stakeholders believe should be considered, and reemphasizing that the Basin Study formulation and approach will build from the existing local stakeholder knowledge base.

The following studies and reports were recommended by the cost-share partners as a starting point for understanding the needs and issues in the Truckee Basin:

- ***2010 Urban Water Management Plan* (PCWA) –** This plan includes an assessment of current demand and supply within PCWA's service areas through build out and a water shortage contingency and drought response plan (PCWA 2011).

- ***2010-2030 Water Resources Plan* (TMWA) –** This document reviews, updates, develops, or modifies several existing TMWA supply and demand strategies based on events occurring in the mid-to-late 2000s, including the economic recession's effects on growth, regional water resource planning changes, utility consolidation, the signing of TROA, and updated water metering data (TMWA 2009). Climate change, drought uncertainties, and source water contamination were identified as the largest threats to water supply quantity and quality.

- ***2011 Urban Water Management Plan* (TDPUD) –** This plan includes an assessment of current demand and supply within TDPUD's service areas through build out and a water shortage contingency and drought response plan (TDPUD 2011).

- ***2013 Martis Valley GMP* (PCWA, TDPUD, NSCSD) –** The Martis Valley GMP is a planning tool used by the partner agencies in efforts to ensure long-term quality and availability of shared groundwater resources in the Martis Valley groundwater basin. The GMP includes overall goals, basin management objectives, and actions for implementation to help manage groundwater resources sustainably (Martis Valley GMP Partners 2013).

- ***The Effects of Climate Change on Lake Tahoe in the 21st Century* (Tahoe Environmental Science Center (UC Davis and USDA Forest Service Pacific Southwest Research Station)) –** This study was performed to better understand the potential effects of climate change on future air temperature, amount and type of precipitation, stream discharge, sediment and nutrient loading, best management practice performance, and water quality (Tahoe Environmental Science Center 2010). All scenarios showed an upward trend in air temperature throughout the century. The most rapid increase of air temperatures was seen in the Geophysical Fluid Dynamics Laboratory model A2 scenario, which increased by about 5 degrees Celsius by the end of the century. This warming trend would have a major effect on lake temperature.

- ***Lahontan Cutthroat Trout Recovery Plan* (USFWS) –** This plan was developed by USFWS to guide actions and strategies to achieve recovery of the Lahontan cutthroat trout and delisting as "threatened." It describes the species' historic range in the Lahontan Basin (including in the

Truckee, and Carson, and Walker river basins), habitat and spawning requirements, and current impediments to recovery (USFWS 1995). The plan also established the first set of flow regimes for the Truckee River to support Lahontan cutthroat trout.

- ***Living River Plan*** **(Truckee River Flood Project) –** This plan developed by the Truckee River Flood Project (TRFP) proposed several flood management measures that include a minimal number levees and flood walls along the river, a river parkway with graded benches and terraces to slow flood waters, realigning the North Truckee Drain, and acquiring open space and a detention pond (TRFP 2011). The Living River Plan would achieve flood damage protection from a 100-year flood event on the Truckee River for Truckee Meadows.

- ***Newlands Project Planning Study Special Report*** **(Reclamation) –** The Newlands Project Planning Study developed and evaluated a set of alternatives to safely satisfy project water rights following a 2008 breach of the project's Truckee Canal (Reclamation 2013). Alternatives developed included different methods of ensuring safety, including canal rehabilitation, and meeting future demand of project water rights holders for agricultural, municipal, and environmental uses. The study included assessments of current and future water demand for the project.

- ***Short-term Action Plan for Lahontan Cutthroat Trout in the Truckee River Basin*** **(Truckee River Basin Recovery Implementation Team) –** A collaborative, multiagency team of state, Federal, Tribal, and other organizations developed this plan to update and continue guiding the Lahontan cutthroat trout recovery effort and activities initiated in the Lahontan Cutthroat Trout Recovery Plan (USFWS 1995). It revised the previously established Truckee River flow regimes to more closely mimic the conditions of a natural river system preferred by both the Lahontan cutthroat trout and cui-ui (TRIT 2003).

- ***Sun Valley Pilot Hydrology Study*** **(TRFP) –** This study was conducted to compare and contrast results from three different geographic information system (GIS)-based hydrologic modeling software programs to determine the best option for use by TRFP (TRFP 2010). The models were used to simulate the hydrologic response to the 2005 New Year's Eve storm at the Sun Valley Detention Facility, located within the Sun Valley watershed between Reno and Sparks, Nevada.

- ***Tahoe Science Update Report*** **(Tahoe Science Consortium (Tahoe Regional Planning Agency and the USDA Forest Service Pacific Southwest Research Center)) –** The Tahoe Science Consortium (TSC) was established to assist in the collaboration between resource management agencies and research organizations. The Tahoe Science Update Report, updated each year, provides an overview of completed, current, and new research projects in the Lake Tahoe Basin (Tahoe Science Consortium 2010, 2011).

- ***TROA Environmental Impact Statement/Environmental Impact Report* (U.S. Department of the Interior and California Department of Water Resources) –** The TROA EIS/EIR evaluated a proposed action to implement Public Law 101-618, section 205(a), which directs the Secretary of the Interior to negotiate an agreement with California and Nevada to increase the operational flexibility and efficiency of certain reservoirs in the Lake Tahoe and Truckee River basins (Interior and California 2008).

Existing reports relied on for background information, data, or other information used in the Basin Study appear in Table 2-1, along with their authoring organization and the Basin Study assessments or analysis they supported.

Table 2-1. Reports, Documents, and Data used in the Basin Study

Report	Organization	Basin Study Activities Supported
2010-2030 Water Resources Plan (2009)	Truckee Meadows Water Authority	Water Demand Assessment, Risk and Reliability Assessment, Options Analyses
Lahontan Cutthroat Trout Recovery Plan (1995)	U.S. Department of the Interior, Fish and Wildlife Service	Study Background and Understanding
Martis Valley GMP (1998)	Placer County Water Agency	Water Demand Assessment
Martis Valley GMP (2013)	Martis Valley GMP Partners (PCWA/TDPUD/NSCSD)	Water Demand Assessment
MTBE Litigation Studies (1990s)	South Tahoe Public Utility District	Study Background and Understanding
Newlands Project Planning Study Special Report (2013)	Reclamation	Study Background and Understanding, Water Demand Assessment
Regional Plan Fact Sheets (2013)	Tahoe Regional Planning Agency	Study Background and Understanding
Short-term Action Plan for Lahontan Cutthroat Trout in the Truckee River Basin (2003)	Truckee River Recovery Implementation Team	Study Background and Understanding, Risk and Reliability Assessment, Options Analyses
State of the Lake Reports (2011 and 2012)	University of California, Davis	Study Background and Understanding
Sun Valley Pilot Hydrology Study (2010)	Truckee River Flood Management Authority	Study Background and Understanding, Water Supply Assessment
Tahoe Science Update Report (2010 and 2011)	Tahoe Science Consortium	Study Background and Understanding
The Effects of Climate Change on Lake Tahoe in the 21st Century	Tahoe Environmental Center	Study Background and Understanding, Water Supply Assessment
The Living River Plan (2011)	Truckee River Flood Project	Study Background and Understanding

Table 2-1. Reports, Documents, and Data used in the Basin Study (contd.)

Report	Organization	Basin Study Activities Supported
Truckee River Operating Agreement Environmental Impact Statement/Environmental Impact Report (2008)	U.S. Department of the Interior and State of California	Study Background and Understanding, Water Demand Assessment, Water Supply Assessment, Risk and Reliability Assessment, Options Analyses
Urban Water Management Plan (2010)	Placer County Water Agency	Water Demand Assessment
Urban Water Management Plan (2011)	Truckee Donner Public Utility District	Water Demand Assessment
Washoe County Consensus Forecast 2012-2032 (2012)	Tahoe Regional Planning Agency	Water Demand Assessment
Water Supply Supplemental Storage Analysis (2013)	City of Fernley	Water Demand Assessment

Key:
GMP = groundwater management plan
MTBE = methyl tertiary-butyl ether
NSCSD = Northstar Community Services District
PCWA = Placer County Water Agency
TDPUD = Truckee Donner Public Utility District

Concurrent Activities Leveraged for the Basin Study

At any given time, dozens of investigations with relevance for the Truckee Basin are likely occurring related to water resources, climate, and regional growth. In addition to the sources in Table 2-1, the Basin Study leveraged several such related projects that were underway during the study process:

- Update to the City of Fernley's Water Master Plan
- Update to TMWA's Water Master Plan
- Ongoing Precipitation-Runoff Modeling System (PRMS) and GSFLOW model development by Desert Research Institute, in collaboration with PCWA and U.S. Geological Survey (USGS)
- WWCRA evapotranspiration and evaporation modeling
- Research into the effects of climate change on the Pyramid Lake Paiute Tribe ("Climate Change Vulnerability of Native Americans in the Southwest" project)
- Unpublished California Department of Water Resources (California DWR) water tracking for TROA

Use of information being developed for these efforts ensured that the Basin Study relied on the most current understanding of climate science and Basin conditions.

Engagement and Outreach

The Basin Study's approach to outreach and engagement was based on: (1) the need for specific types of input at various points during the study process, and (2) the high level of stakeholder interest and involvement in water-related matters in the Truckee Basin.

Stakeholder Engagement

The Basin Study used input from Basin water users, stakeholders, and technical experts to:

- Frame the plausible range of future demands in the Truckee Basin.
- Describe water resources-related conditions of concern and evaluate related future conditions.
- Identify and evaluate options that could mitigate future risks or shortages.

Engagement with stakeholders occurred primarily through two mechanisms: meetings and workshops held with the TAG, and individual meetings with planning and water agencies throughout the Basin on an as-needed basis. The agencies, organizations, tribes, and other interested parties engaged during the Basin Study appear in Table 2-2.

> This report refers to parties with an interest in the Truckee Basin's water resources as both **stakeholders** and **water users.** These terms are sometimes used interchangeably, with "stakeholders" often serving as a catch-all term for the full range of Basin interests. However, where possible, the report specifies whether the parties referenced are water users, agencies, or other types of stakeholders.

Table 2-2. Stakeholders Engaged in the Basin Study

Bureau of Reclamation, Mid-Pacific Region Office	Stetson Engineers
Bureau of Reclamation, Lahontan Basin Area Office	Storey County
California Department of Water Resources	Tahoe Regional Planning Agency
California Department of Water Resources, North Central Regional Office	The Nature Conservancy
Carson Water Subconservancy District	Truckee Donner Public Utility District
Churchill County	Truckee Meadows Regional Planning Agency
Churchill County Planning Department	Truckee Meadows Water Authority
City of Fernley	Truckee River Flood Management Authority
Desert Research Institute	Truckee River Watershed Council
Lyon County	Truckee-Carson Irrigation District
Nevada Department of Environmental Protection	U.S. Department of Agriculture, Forest Service
Nevada Division of Water Resources	U.S. Department of the Interior, Fish and Wildlife Service
Nevada State Engineer's Office	U.S. Geological Survey

Table 2-2. Stakeholders Engaged in the Basin Study (contd.)

National Oceanic and Atmospheric Administration, National Weather Service	University of Nevada, Reno
North Star Community Service District	University of Nevada, Reno, Cooperative Extension
Placer County Water Agency	Sierra Nevada Conservancy
Placer County	Washoe County
Pyramid Lake Fisheries	Western Regional Water Commission
Pyramid Lake Paiute Tribe	Wolf Rifkin Shaprio Schulman & Rabkin, LLP
Sierra Nevada Conservancy	

TAG Meetings The TAG served as the primary method of engagement with the region's very active stakeholder community, many of whom have extensive professional experience with water-related matters in the Truckee Basin. The TAG was comprised of representatives from agencies, organizations, and tribes throughout the Basin who self-identified or were recommended by the Project Steering Team. Membership in the TAG was intended to be flexible and informal. At various points during the study process, TAG meetings were convened to focus on helping developing the approach for – or reviewing the products of – a given task or step in the Basin Study. The structure of the group allowed members to be involved only in those meetings most relevant or central to their interests. Each TAG meeting was announced publicly with a news release from Reclamation.

The following TAG meetings were held in support of the Basin Study process:

- Supply Assessment Meeting – June 24, 1013
- Demand Assessment Meeting – August 26, 2013
- Indicators Workshop – June 14, 2014
- Options and Findings Meeting – November 3, 2014

Participants in the TAG meetings represented the organizations in Table 2-2. Material presented at TAG meetings, input received from meeting participants, and all records of meeting participation appear in "Appendix A – Engagement Record."

Planning and Water Agencies A series of meetings with local or regional planning or water agencies were conducted during the Basin Study to develop an understanding of potential future growth in the Basin, which was used to conduct the demand assessment described in detail in "Chapter 4 – Water Demand Assessment." All of the agencies who participated in these meetings are included in Table 2-2. Material presented during meetings with these agencies is included in "Appendix A – Engagement Record."

Tribal Outreach and Engagement

Engagement with Tribes in the study area occurred in an official government-to-government capacity, and also in a less-formal manner.

At the launch of the Basin Study, Reclamation reached out to the following Federally Recognized Tribes with formal letters offering a briefing on the Basin Study and requesting their participation in the study process:

- Fallon Paiute-Shoshone Tribe
- Pyramid Lake Paiute Tribe
- Reno-Sparks Indian Colony
- Washoe Tribe of Nevada & California

Pyramid Lake Paiute Tribal members and staff also participated in the Basin Study as members of the TAG. Letters of invitation to Tribes and records of the Pyramid Lake Paiute Tribe's participation are presented in "Appendix A – Engagement Record."

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Chapter 3 Water Supply Assessment

A central purpose of the Basin Study was to detect future imbalances in supply and demand and identify actions to respond to them. The following assessment of the Basin's existing and future water supplies provides important context for how the balance between supply and demand may change in the future.

> The Basin Study considered **supply** to be the timing and volume of surface water runoff and groundwater replenishment.

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 current water management. Thus, the availability of water to meet demand in the Truckee Basin is largely related to annual weather conditions and overall climate.

Just as the regional ecosystems have adapted to the prevailing climate, so have human settlements. Extensive infrastructure has been built to align the availability of water supply to the timing of demands, and to temper the effect of annual variability in water supply on agricultural, municipal, and industrial water users. While the ecosystems and infrastructure of the Truckee Basin are well suited to the historical variability in water supply, climate changes may create new challenges for either or both.

Assessments of future supply, however, are highly uncertain due to large unknowns. Areas of uncertainty include many of the factors that are driving climate changes (e.g., global trends in population, international GHG emissions policies, greenhouse gas (GHG) reduction technologies, global and local economies, and net GHG emissions) as well as limitations in our ability to simulate future conditions with high precision (e.g., imprecision in models used to simulate physical processes that react to GHG emissions). The Basin Study used a scenario planning approach described in "Chapter 2 – Scenario Planning and Supporting Information" that preserves this uncertainty and allows for the full range of potential future supply conditions to be considered relative to a Reference scenario.

The Basin Study constructed scenarios from three components, one each for: supply, demand, and water management conditions. The supply condition describes the hydrologic availability of water resources as determined through the water supply assessment summarized in this chapter. The Basin Study's water supply assessment included development of the seven distinct supply conditions shown in Figure 3-1:

- A Historical supply condition represented by the historical hydrology captured in gage records.
- A Reference supply condition represented by a simulated hydrology without climate change.
- Five future supply conditions represented by a simulated hydrology with a range of future climates.

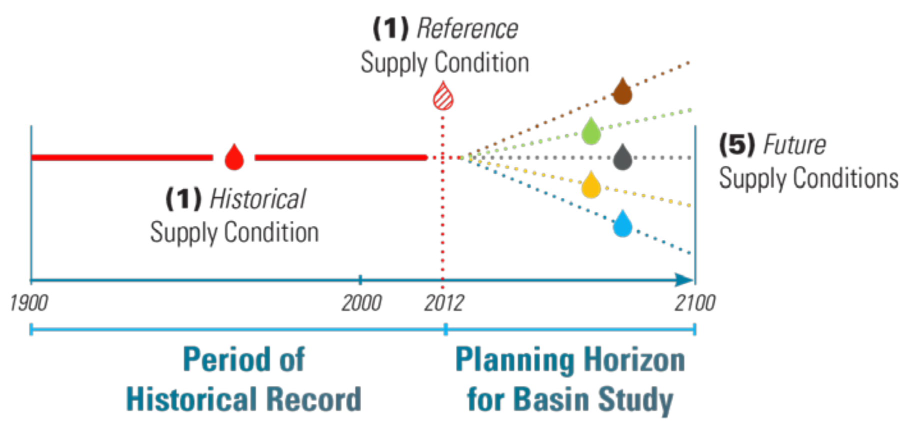


Figure 3-1. Supply Conditions Developed for the Basin Study

The supply conditions shown in Figure 3-1 are used variously throughout the Basin Study to construct scenarios, reveal vulnerabilities related to the Basin's water resources, and test options for preserving the Baseline level of water supply reliability for different water users.

The following chapter describes the Basin's historical hydrology and projected future water supply conditions, and provides comparisons between them. The discussion of the Basin's historical supply includes observations of the Basin's historical climate and hydrology. The discussion of future hydrology summarizes the technical approach applied for bracketing the range of potential future hydrologic conditions in the Basin, related to the broad range of projected global climate conditions.

Importantly, the Basin Study relied on the simulated Reference supply condition hydrology, as opposed to the historical records of hydrology, as the basis for comparisons to future supply conditions. The basis for using the Reference supply condition hydrology largely stems from it having been developed in the same manner as the climate change conditions, thereby providing a purer understanding of which future outcomes result from changes in climate (as opposed to discrepancies between model outputs and the historical record). A comparison between the historical and Reference supply condition hydrology is provided to demonstrate differences between the two.

Summary of Historical Supply

Historical records present a helpful benchmark for describing supply conditions, primarily because they are familiar to the Basin's water using communities. As a result, the Basin Study summarizes and presents historical supply conditions alongside several of the comparisons in this chapter. However, as previously noted, the Basin Study does not use historical supply conditions as a baseline and, instead, uses a Reference supply condition simulated using the same climate data as the future supply conditions.

This section summarizes historical information on climatic processes that drive Basin hydrology and presents historical surface water availability for each of the subbasins in the TROA-light Planning Model.

> **Climate** is the composite or prevailing weather conditions (such as temperature or precipitation) of a region, throughout the year, averaged over a series of years (NWS 2013).

Historical Climate

Initial climate and weather observations in the Truckee Basin were most likely made by indigenous populations during pre-settlement times. These cultures, so dependent on the land, water, and biological resources, likely took note of the region's climate and planned accordingly. Temperature, precipitation, and runoff patterns were also important to early settlers in the 1800's and contributed to the success or failure of agriculture, logging, mining, and railroad endeavors. Precipitation data monitoring began in Donner Pass in 1870 with basic measurements taken every eight hours by Central Pacific Railroad employees (McLaughlin n.d.). Several decades later in 1905 Dr. James E. Church established the first Sierra weather observatory on Mt. Rose (Donner Summit Historical Society 2009).

> **Normals** are 30-year averages of meteorological conditions, such as air temperature, precipitation, etc., and represent the fundamental attributes of local climate. Normal and climatology are often used interchangeably.

Since these early climate observation efforts, several Federal and State programs have been established in the Western U.S. to monitor weather and climate, including automated airport stations, Remote Automated Weather Stations, and the National Weather Service Cooperative Observer Program (COOP). COOP was initiated in 1890, and several COOP observations in the Truckee Basin begin in the early 1900s. In 1950, the National Oceanic and Atmospheric Administration’s National Climatic Data Center (NCDC) was established as the country’s official weather and climate records archive. The NCDC is the official source of U.S. Normals, which are calculated each decade in accordance with World Meteorological Organization recommendations.

The various weather and climate data sets gathered in the last century, along with climate modeling, have increased understanding about interannual climate patterns and what specifically drives temperature and precipitation in the Truckee Basin. This information provides context to the Basin’s ecosystems and human infrastructure and operations, and is the foundation of the current water supply assessment described in this chapter. The full set of historical temperature and precipitation observations developed for the Basin Study appears in “Appendix B – Historical Climate and Hydrology.”

Local Climate Drivers

The Truckee Basin is located in the Great Basin, a hydrographic region that includes most of Nevada, half of Utah, and portions of California, Idaho, Oregon, and Wyoming (Figure 3-2). The Great Basin includes more than 180,000 square miles of contiguous, endorheic (also called “terminal”) basins, having no river or ocean outlet. Snow accumulation and melt cycles have dominated the hydrologic processes for the Truckee Basin’s streams and rivers.

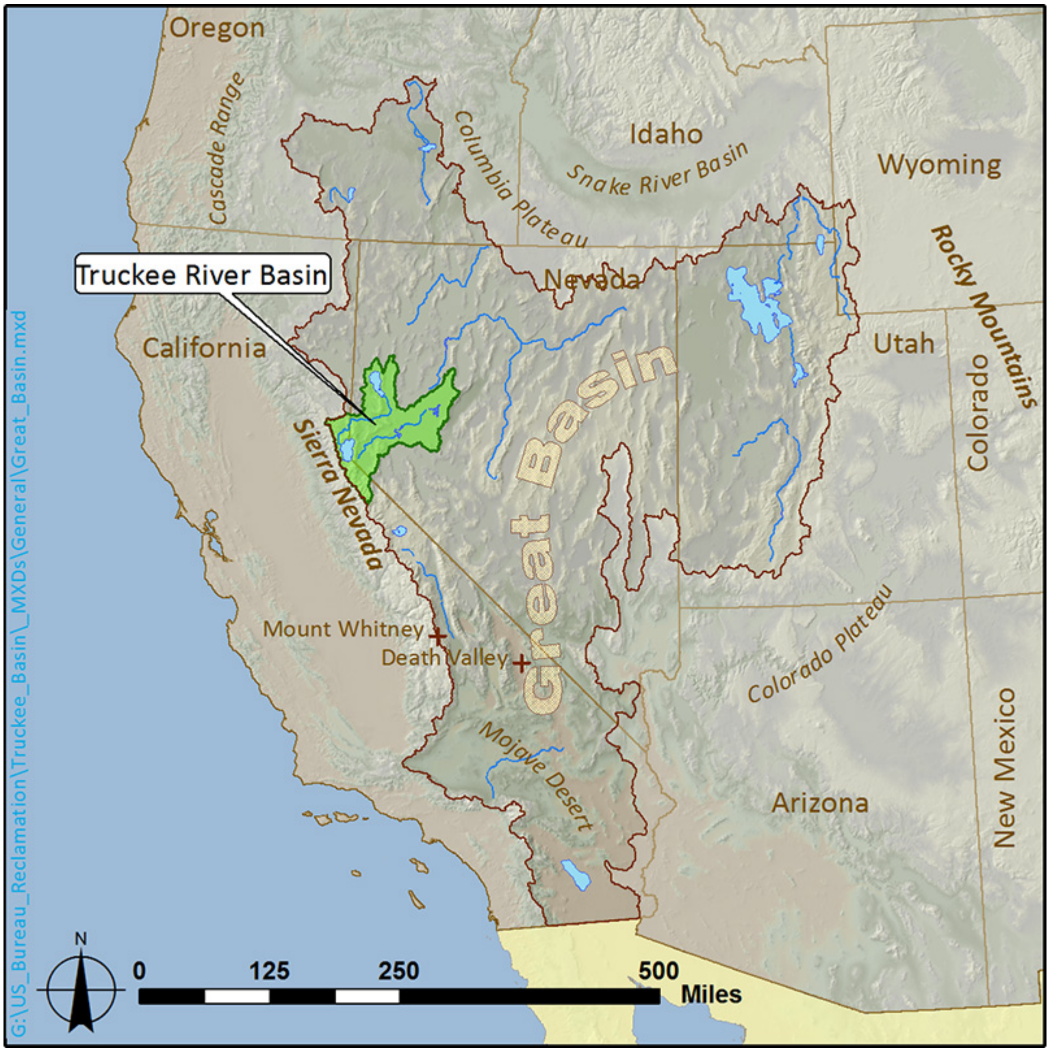


Figure 3-2. Boundaries of Great Basin and Truckee Basin

The Basin's climate is typical of areas within the Great Basin. Temperatures vary widely in the region, with normal winter lows in the Sierra Nevada below freezing and summer highs above 100 degrees Fahrenheit (°F) in the lower areas. For example, the temperatures recorded at Tahoe City range from -16°F to 94°F, and the temperatures recorded in the Fernley/Wadsworth area range from -31°F to 111°F (NOAA 2013). Precipitation declines toward the east; typical annual precipitation at Tahoe City is about 32 inches, whereas the Fernley/Wadsworth area receives less than 6 inches (NOAA 2013). Summer precipitation occurs as rain from localized solar heating and evaporation, rising air, and associated thunderstorms.

The Sierra Nevada range greatly influences the climate of the Truckee Basin and creates large contrasts in precipitation. The mountains create orographic effects as Pacific Ocean air masses from prevailing winds travel over the Sierra Nevada range. Warm, moist air traveling east from the ocean ascends the mountain's western slopes and cools, condensing air moisture into clouds and precipitation, which falls almost exclusively as snow at higher elevations between November and April. Moving down the eastern slope of the Sierra, the air warms via compression and results in less precipitation, creating a semiarid to arid climate in the lower regions of the Basin (Interior and California 2008). The Sierra Nevada can also influence temperatures in the Basin by blocking continental arctic air masses, preventing long periods of cold weather.

Temperature

The 1981 to 2010 normal temperature in the Truckee Basin ranges between 58.4 and 79.6°F (Figure 3-3). The average maximum and minimum average annual temperatures range between approximately 50°F and 100°F (Figure 3-4 and Figure 3-5). Seasonal maximum and minimum temperatures are lower and higher, respectively, as seen in weather station records. 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.

The higher elevation regions around Lake Tahoe have mild summers and cold winters. Summer daily temperatures at Tahoe City typically range between 40 and 80°F (Figure 3-6). Winter daily temperatures typically range between 20 and 40°F. Annual and monthly average temperatures range between 20 and 70°F (Figure 3-7). Average August temperature is about 60°F; average January temperature is about 29°F. The highest temperature recorded at Tahoe City was 94°F (August 1933); the lowest recorded temperature was -16°F (December 1972).

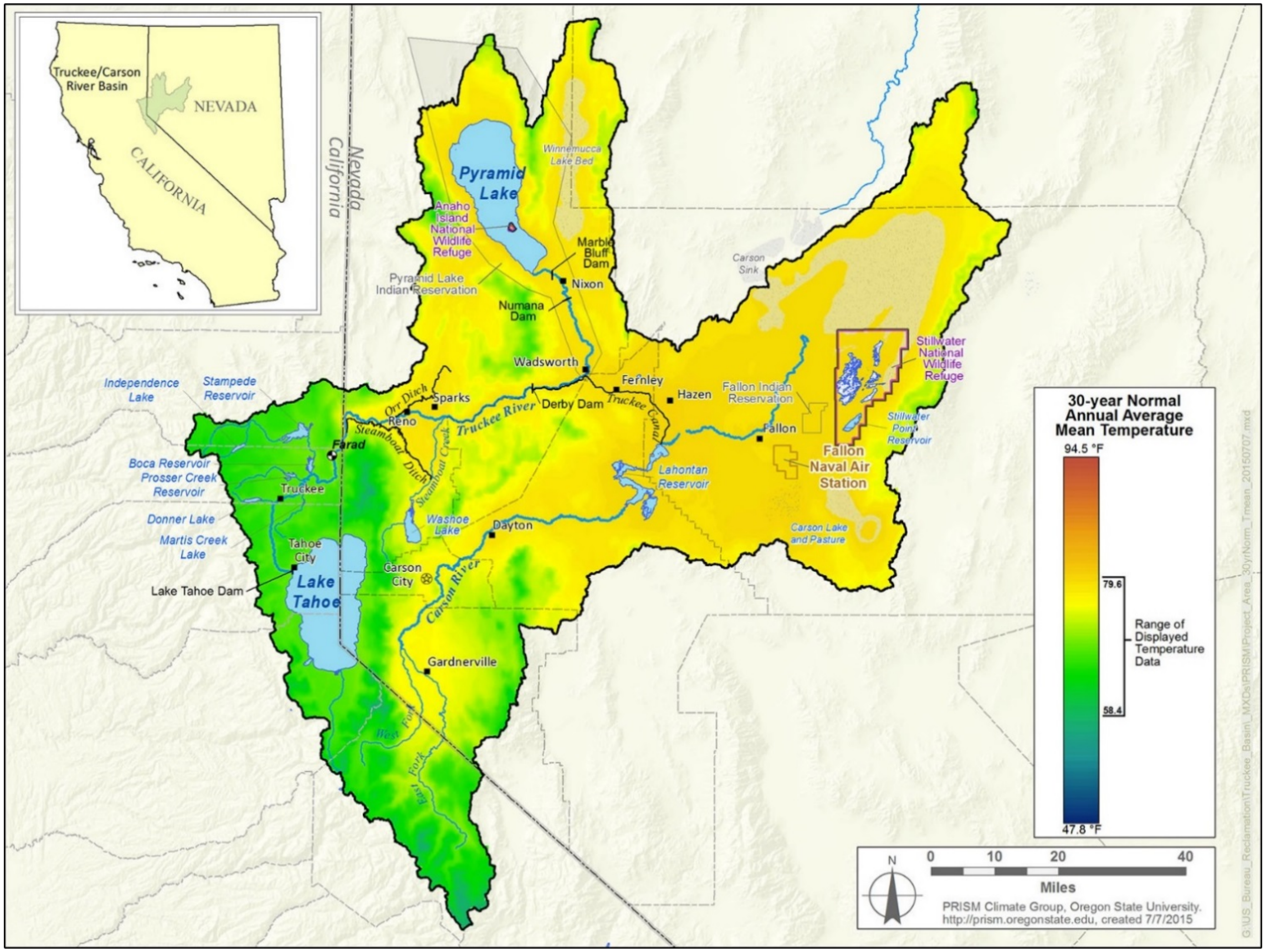


Figure 3-3. Average Annual Temperatures in Truckee Basin (1981-2010)

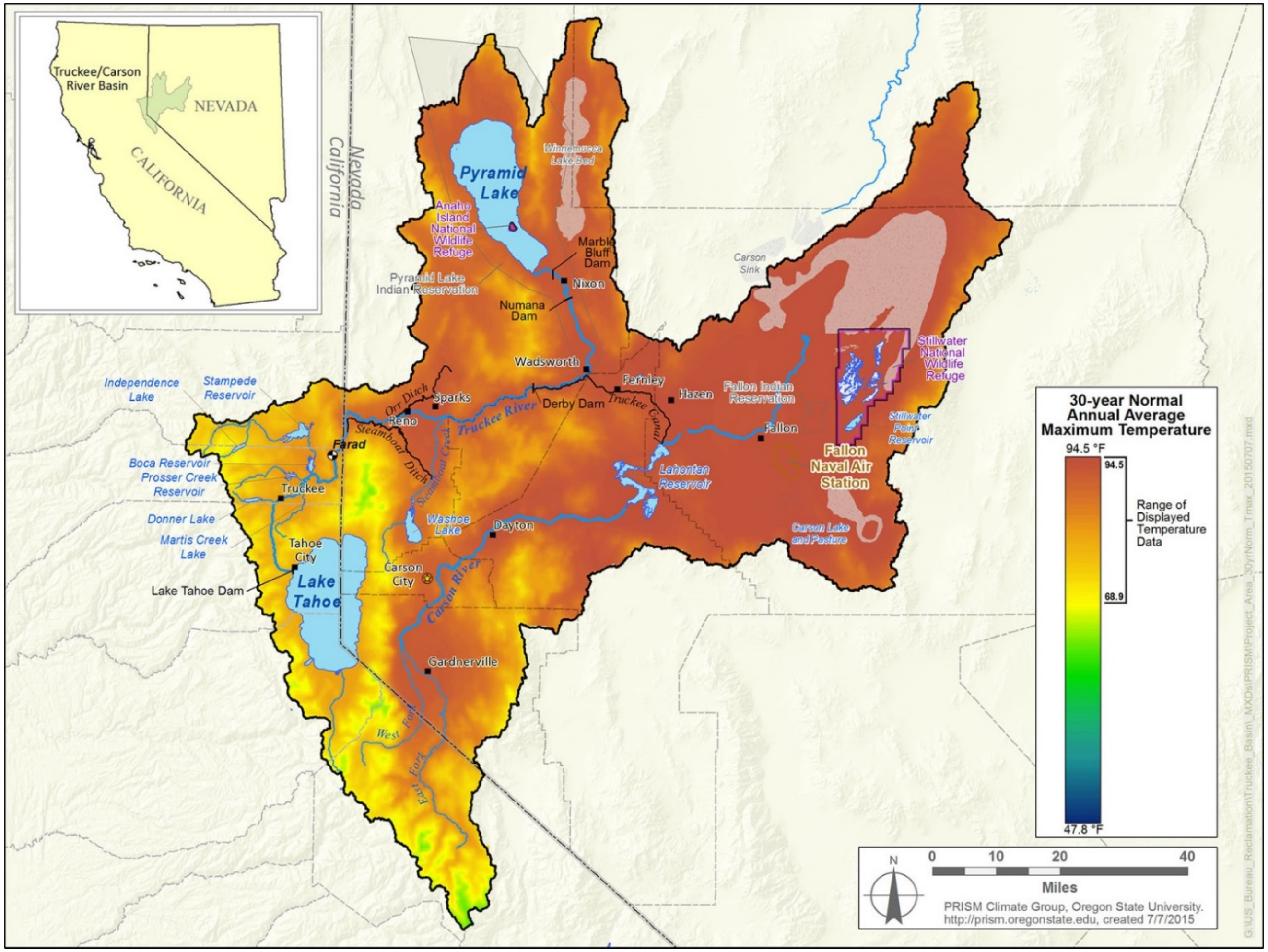


Figure 3-4. Average Annual Maximum Temperatures in Truckee River Basin (1981-2010)

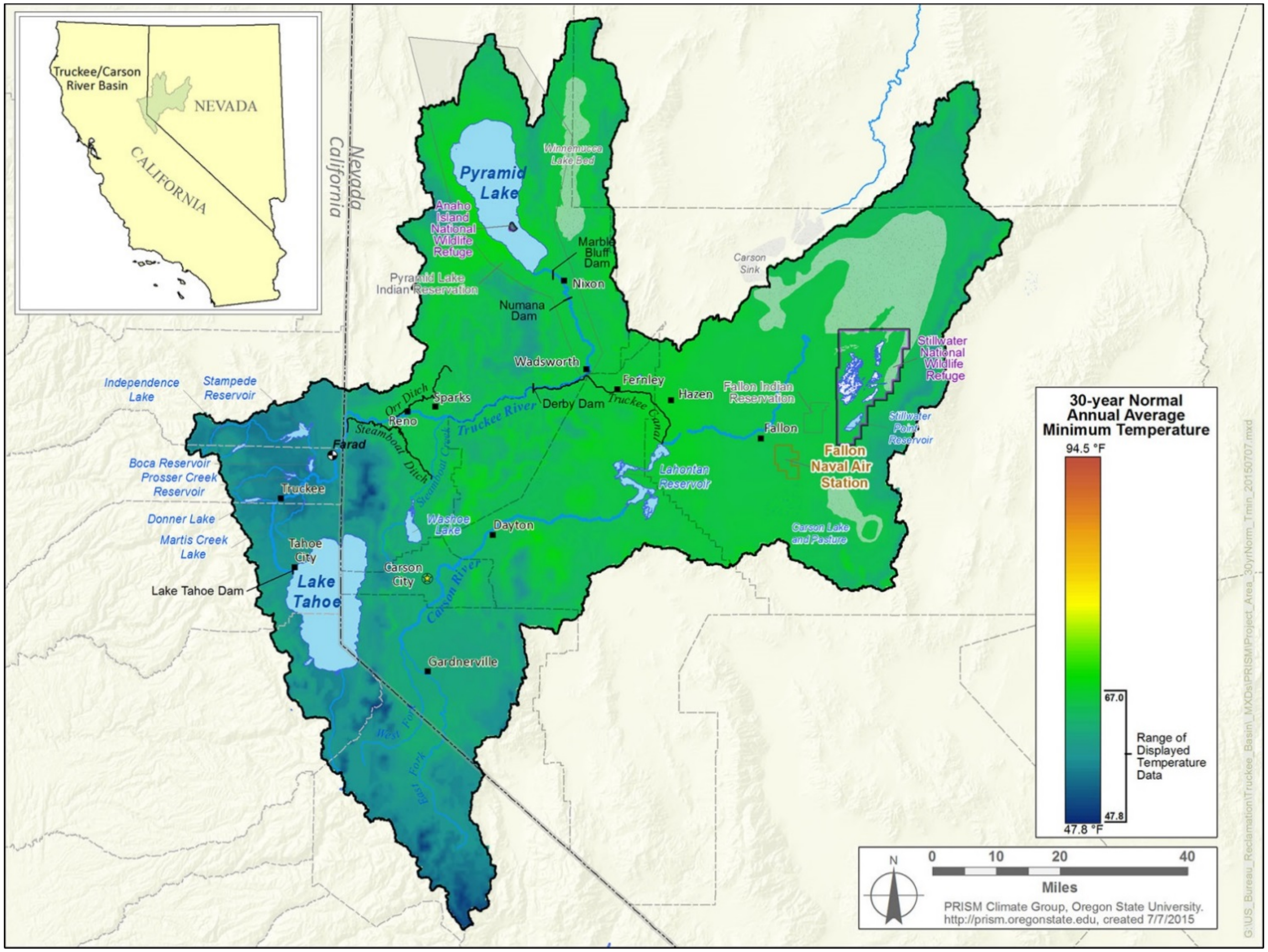


Figure 3-5. Average Annual Minimum Temperatures in Truckee Basin (1981-2010)

The average annual temperature at the Tahoe City station has risen by about 2°F in the last century (1910 to 2008), which has driven increases in average minimum (i.e., nighttime) temperatures (Forest Service 2012). The rise in nighttime temperatures at Tahoe City is higher than in other California locations and may be linked to Lake Tahoe’s thermal mass (surface water temperatures have increased 1°F in only the last 25 years) (Forest Service 2012).

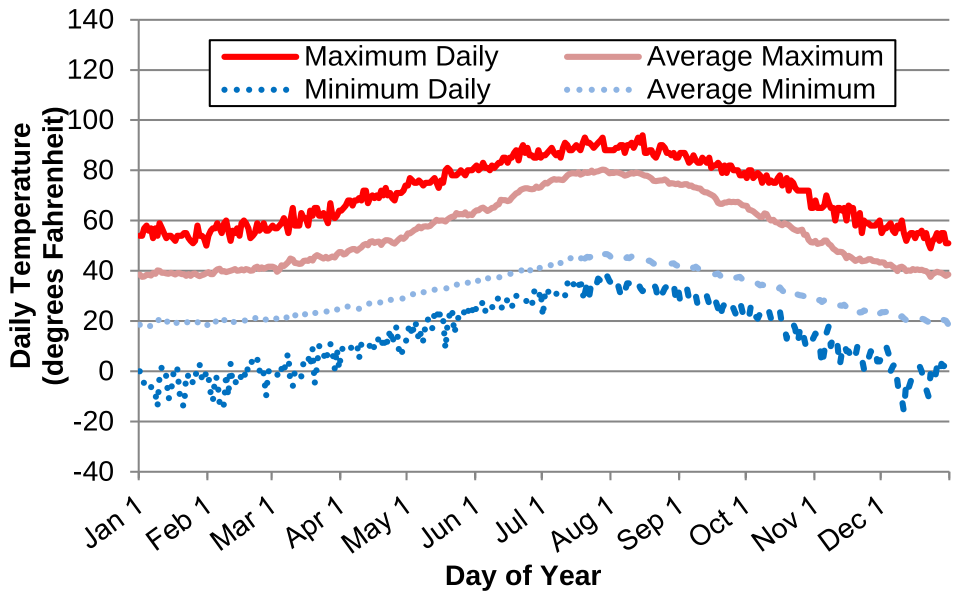


Figure 3-6. Maximum/Minimum Daily Temperatures at Tahoe City, California (1932–2012)

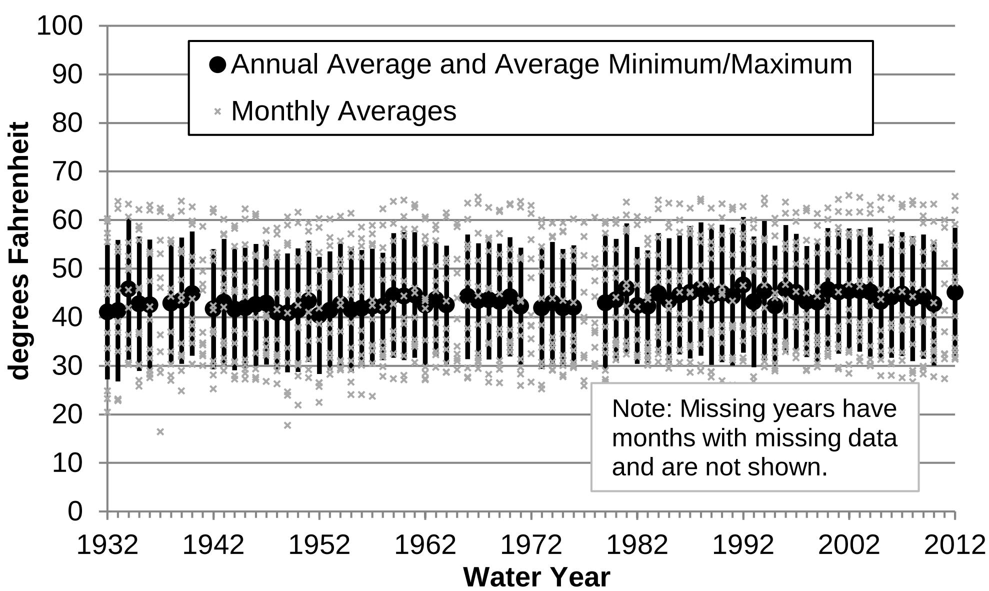


Figure 3-7. Annual and Monthly Average Temperatures at Tahoe City, California (1932–2012)

The basin climate in Nevada is semiarid to arid, and summers have clear, warm days and cool nights. Summer daily temperatures at the Reno-Tahoe International Airport typically range between 40 and 90°F (Figure 3-8). Winters are not severe, with daily temperatures typically ranging between 20 and 50°F. Annual and monthly average temperatures range between 20 and 80°F (Figure 3-9). Average August temperature is about 70 °F; average January temperature is about 33 °F. The Highest temperature recorded at Reno was 108 °F (July 2002); lowest temperature on record was -16 °F (January 1942).

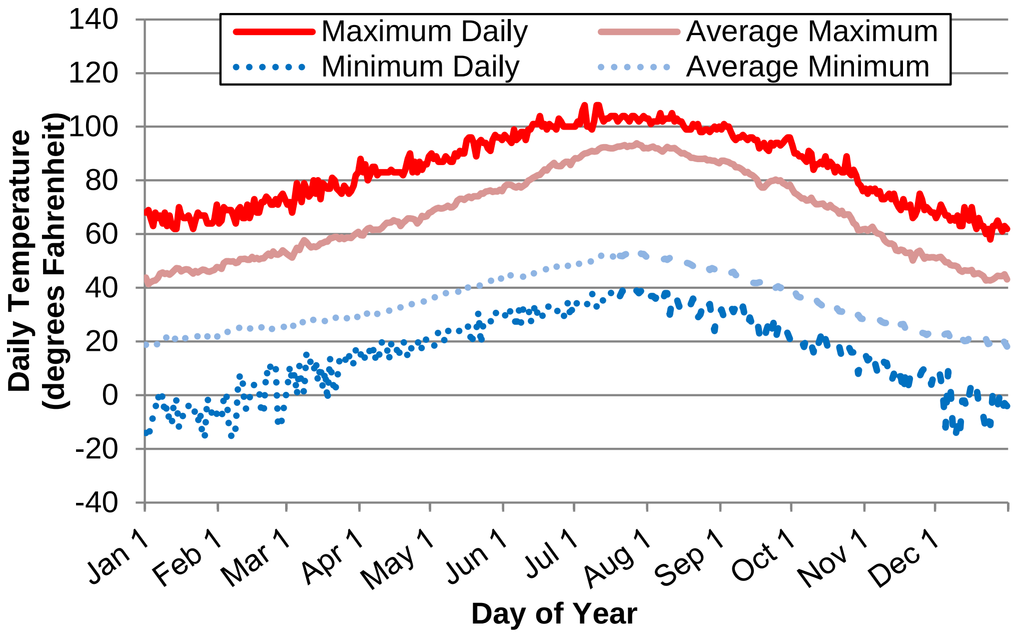


Figure 3-8. Maximum/Minimum Daily Temperatures at Reno-Tahoe International Airport (1938–2012)

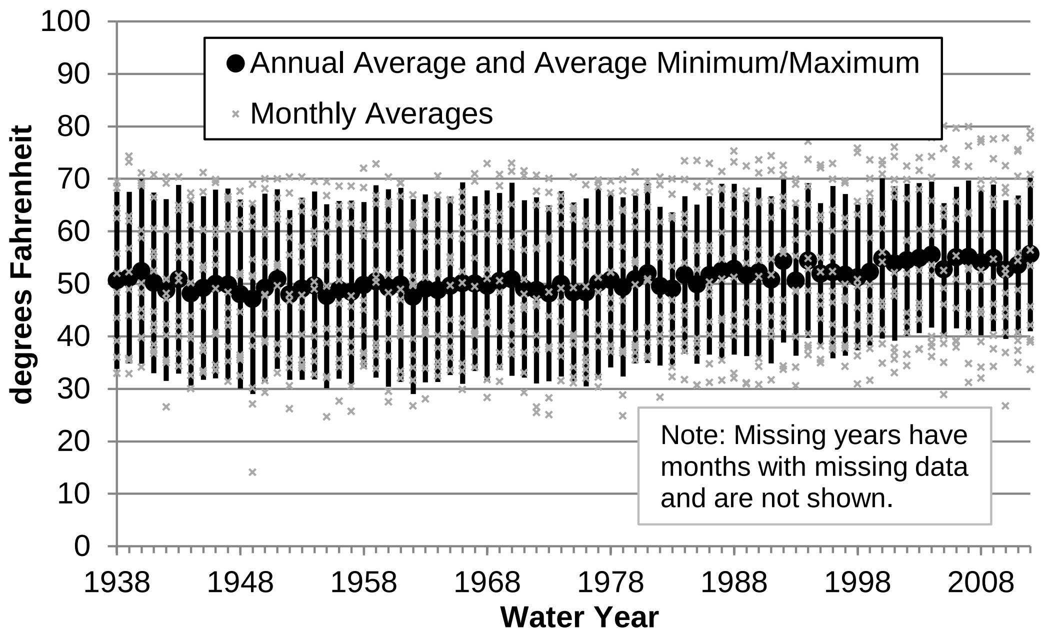


Figure 3-9. Annual and Monthly Average Temperatures at Reno-Tahoe International Airport (1938–2012)

The warmest region in the Truckee Basin is the Truckee River's terminus, Pyramid Lake. Summer daily temperatures at Sutcliffe, Nevada, near Pyramid Lake typically range between 50 and 90°F (Figure 3-10). Daily winter temperatures typically range between 30 and 50°F. Annual and monthly average temperatures range between 30 and 80°F (Figure 3-11). Average August temperature is about 75 °F; average January temperature is about 37 °F. The highest temperature recorded was 105 °F (July 1967); the lowest temperature on record was -8°F (December 1990).

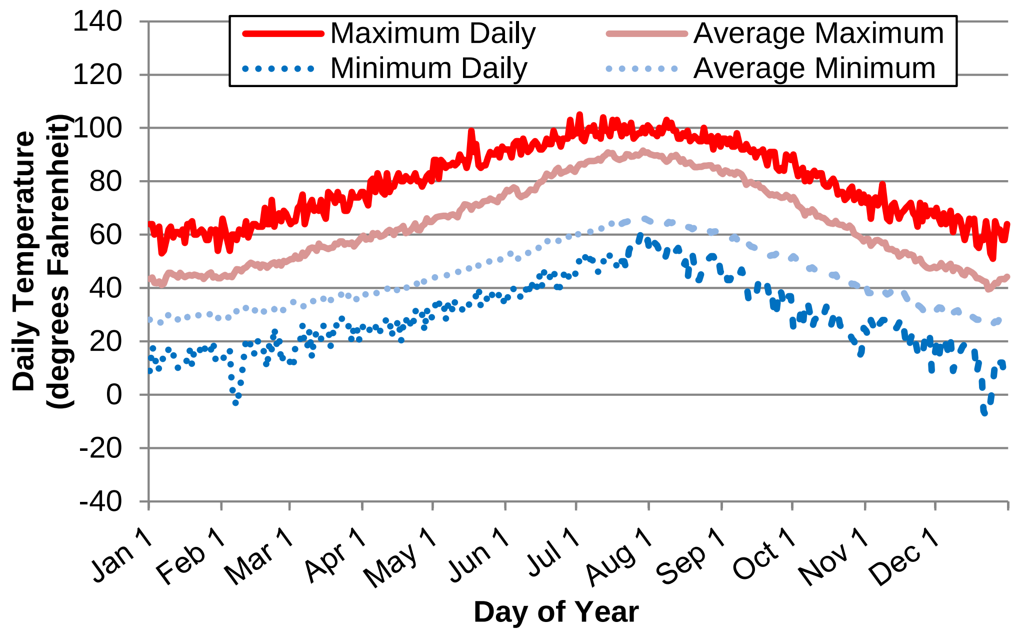


Figure 3-10. Maximum/Minimum Daily Temperatures at Sutcliffe, Nevada (1969–2012)

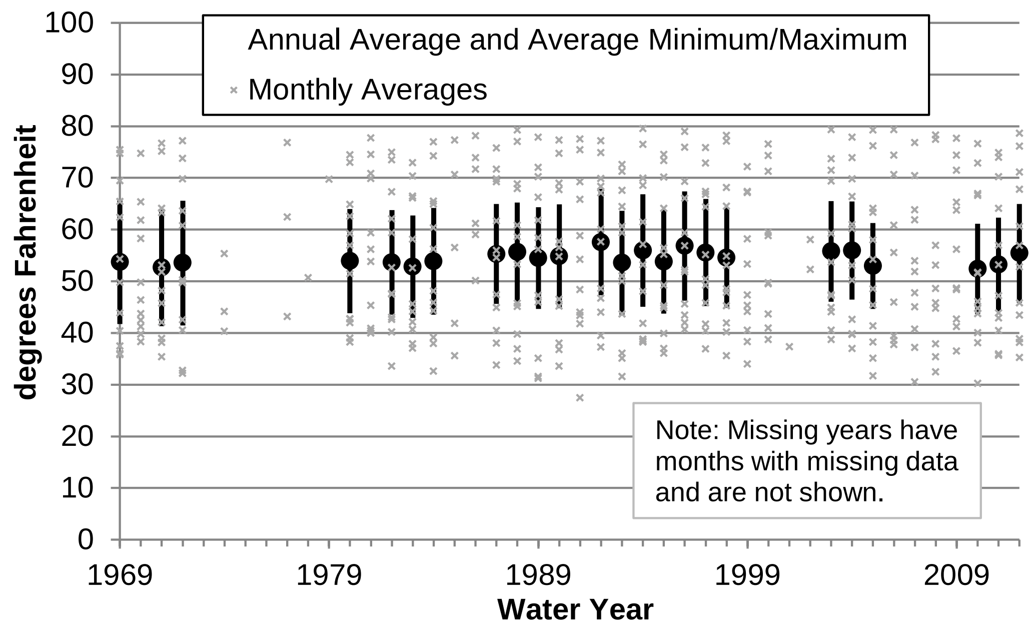


Figure 3-11. Annual and Monthly Average Temperatures at Sutcliffe, Nevada (1969–2012

Precipitation

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. The lower regions around the Carson River are especially dry, receiving on average less than 5 inches of precipitation each year. Climate normals (1981 to 2010) for average precipitation are shown in Figure 3-12.

In the Sierra Nevada, precipitation falls almost exclusively as snow from November to April (Figure 3-13). Summer thunderstorms are common but produce little rain. The percentage of annual precipitation falling as snow (versus rain), however, has dropped over the last century in several locations. Currently, about 34 percent of precipitation at Tahoe City falls as snow, compared with 54 percent at the beginning of the last century (Forest Service 2012). The lowest annual precipitation recorded at Tahoe City was 9.34 inches (1976); the highest annual precipitation was 66.41 inches (1996). Average annual precipitation is about 32 inches (Figure 3-14). Average annual and year-to-year precipitation variability has risen at this station over the last century (Forest Service 2012).

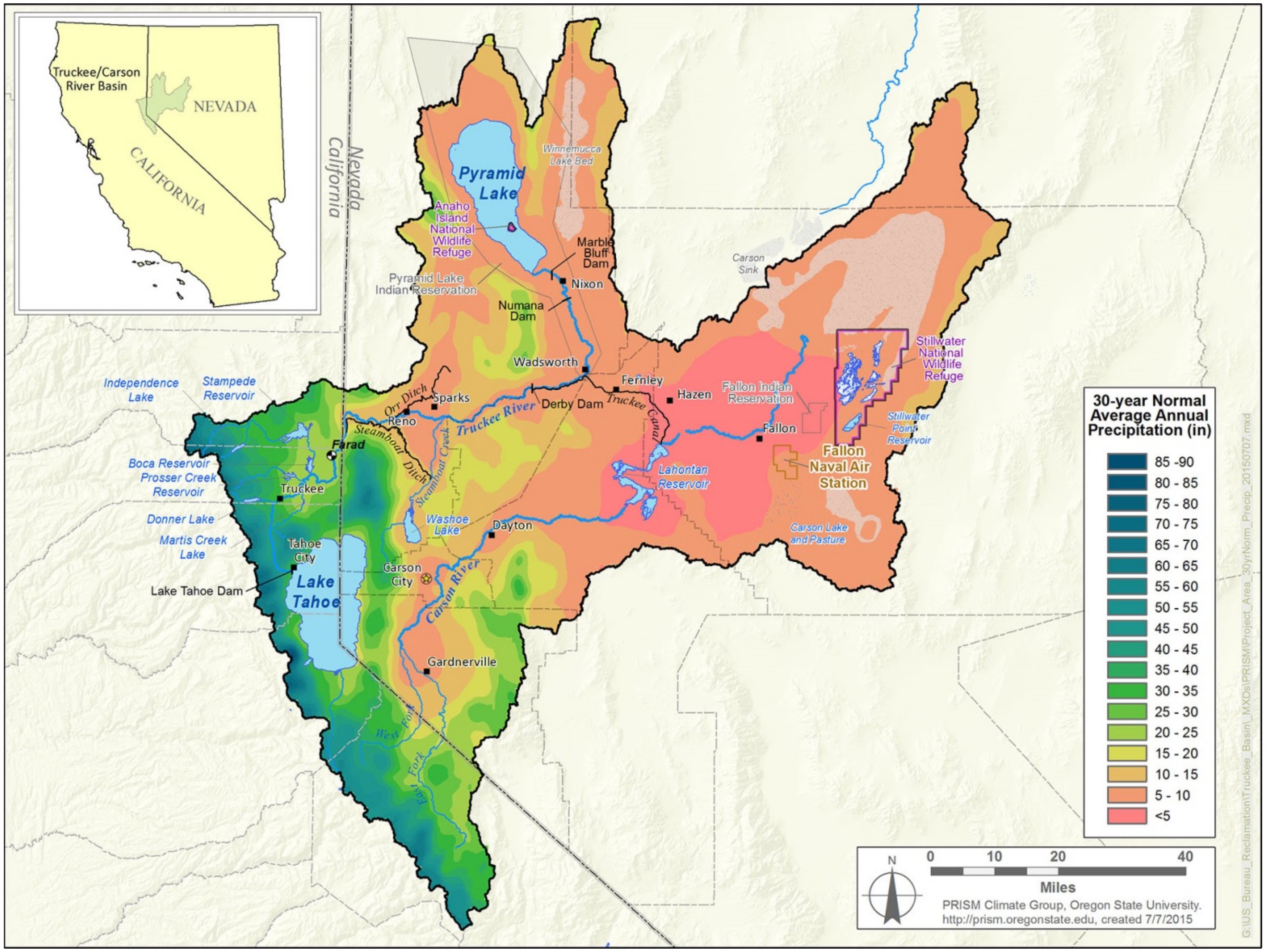
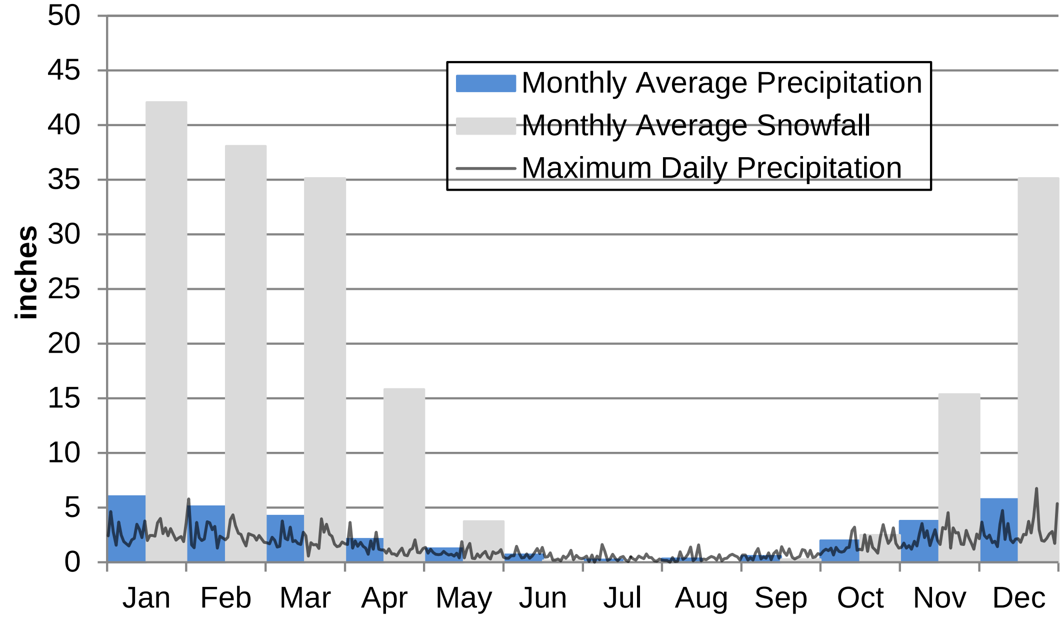
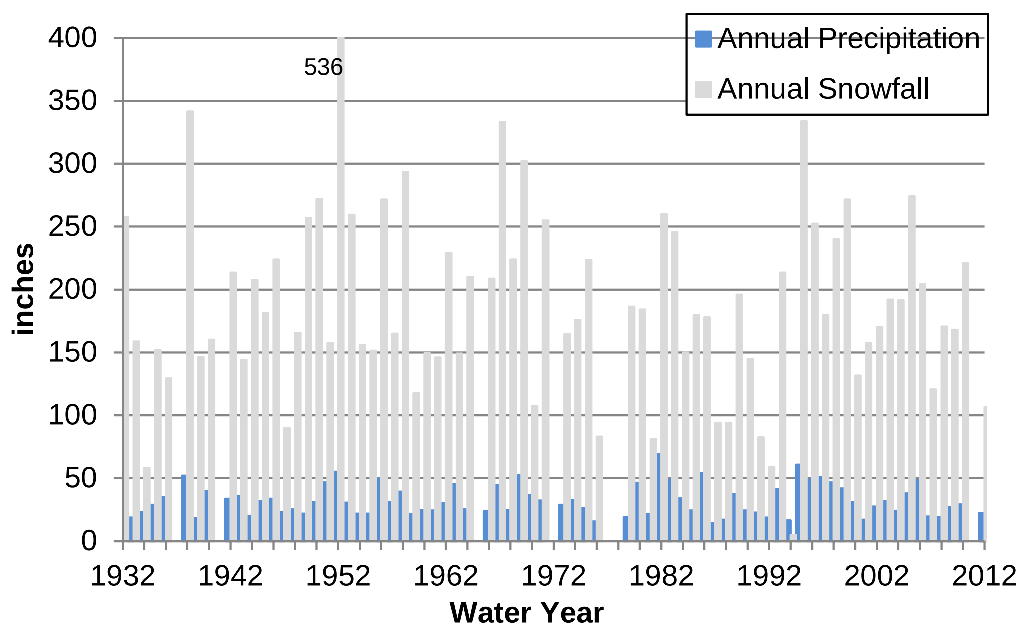


Figure 3-12. Average Annual Precipitation in Truckee Basin (1981-2010)



Note: Scale differs from that in Figures 3-15, 3-17.

Figure 3-13. Monthly Average Precipitation at Tahoe City, California (1932–2012)



Note: Absent years have months with missing data and are not shown. Scale differs from that in Figures 3-16, 3-18.

Figure 3-14. Annual Precipitation at Tahoe City, California (1932–2012)

The Truckee Basin in Nevada is more arid than the California portion of the Basin due to rain shadow effects from the Sierra Nevada (Figure 3-15). The lowest annual precipitation recorded at the Reno-Tahoe International Airport was 1.55 inches (1947); the highest annual precipitation was 13.23 inches (1983). Average annual precipitation is about 7.5 inches (Figure 3-16).

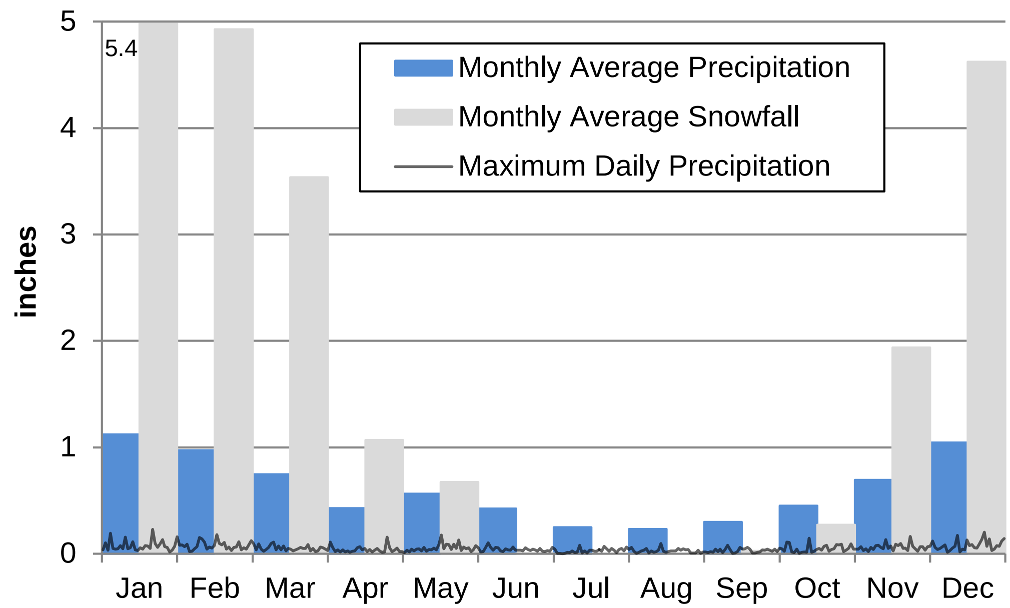
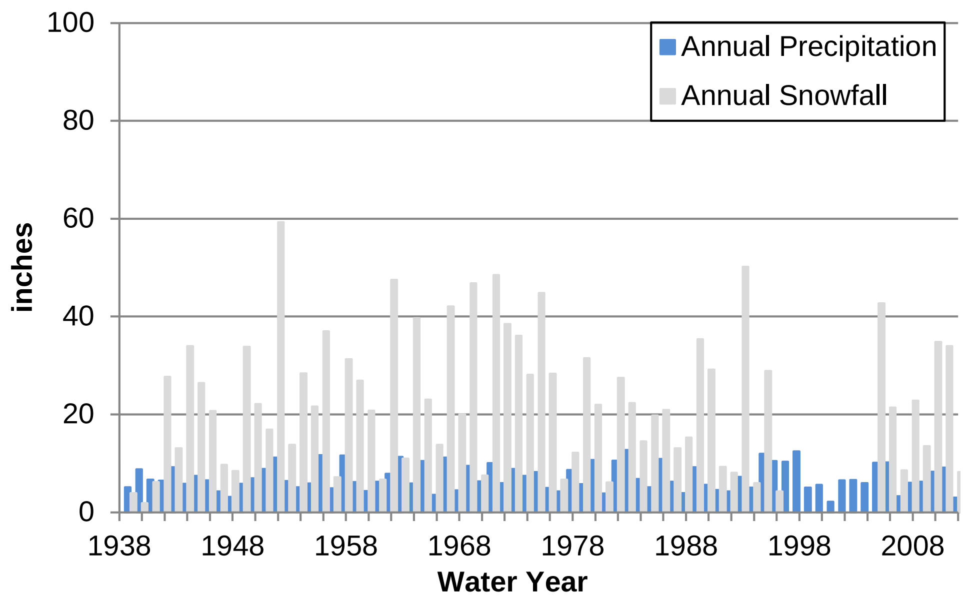


Figure 3-15. Monthly Average Precipitation at Reno-Tahoe International Airport (1938–2012)



Note: Absent years have months with missing data and are not shown.

Figure 3-16. Annual Precipitation at Reno-Tahoe International Airport (1938–2012)

Pyramid Lake, like most of the Great Basin region, is arid (Figure 3-17). The lowest annual precipitation recorded at Pyramid Lake (Sutcliffe) was 3.96 inches (2007); the highest annual precipitation was 15.37 inches (1996). Average annual precipitation is about 7.3 inches (Figure 3-18).

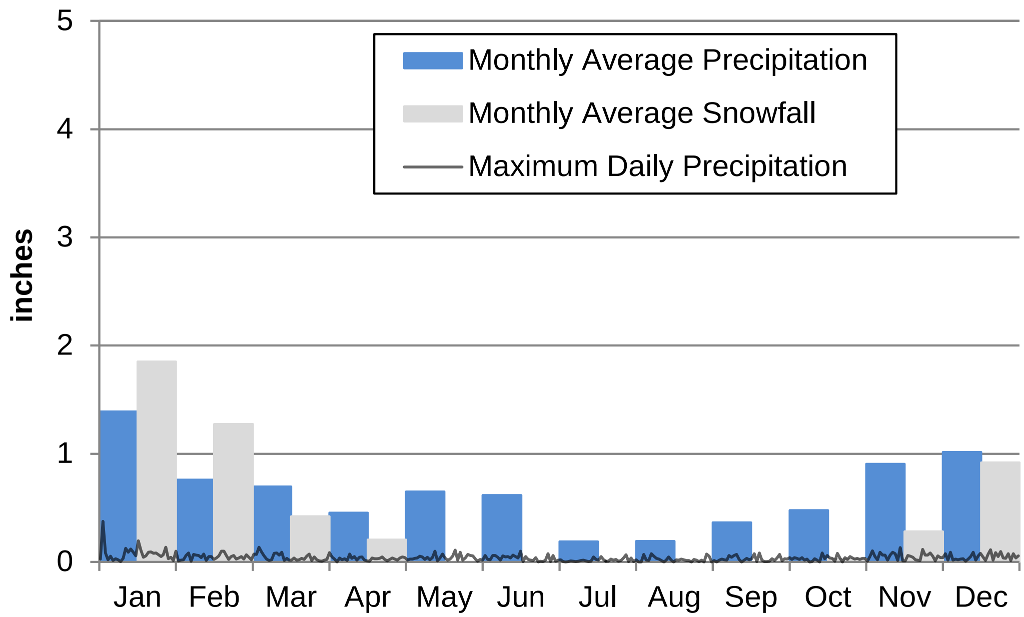
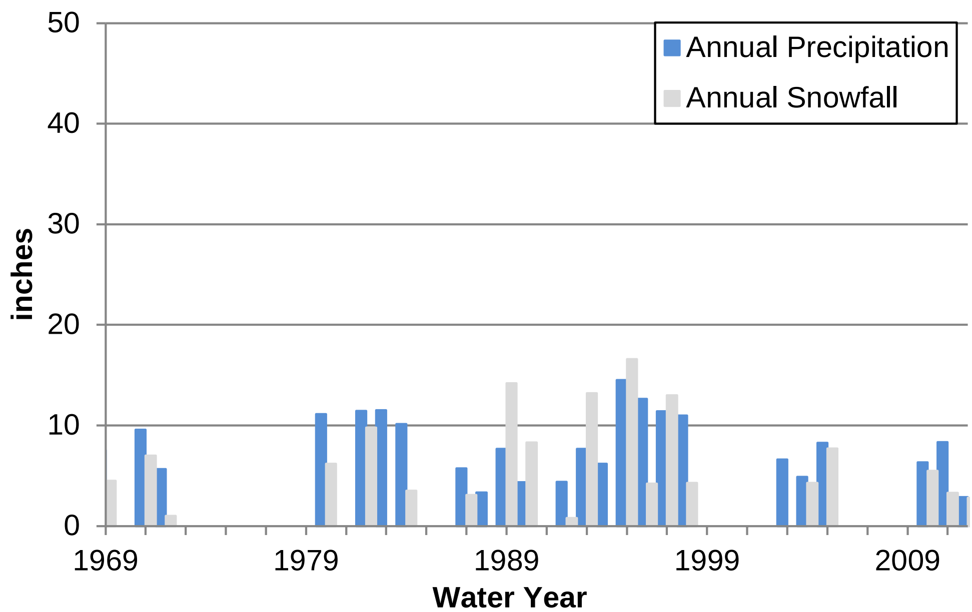


Figure 3-17. Monthly Average Precipitation at Sutcliffe, Nevada (1969–2012)



Note: Absent years have months with missing data and are not shown.

Figure 3-18. Annual Precipitation at Sutcliffe, Nevada (1969–2012)

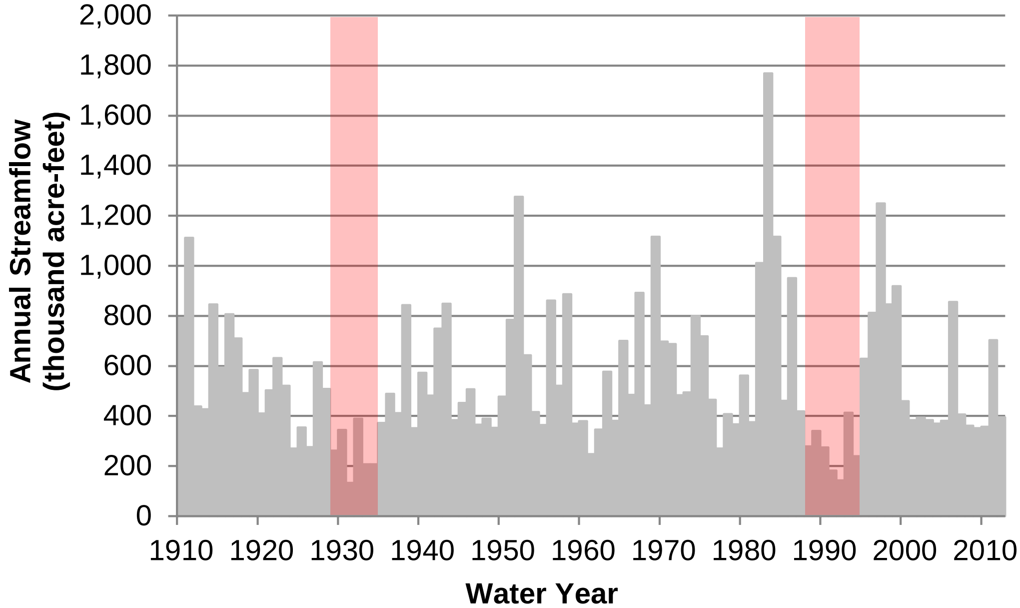
Extreme Events

The Truckee Basin has historically been characterized by periods of drought and flooding events. There is high variability in flow throughout the historical record (Figure 3-19). Several definitions of drought exist in the Truckee Basin and have been developed for specific large-scale studies (e.g., TROA EIS) or for specific water users. These definitions have been incorporated into the Basin Study when applicable, but in general terms a drought cycle’s length and magnitude is solely a function of climatic conditions over a period of years. Consecutive years of low precipitation in the Lake Tahoe Basin and Truckee River upstream from Farad produce dry conditions and meteorological drought cycles for the entire Truckee Basin. In years of lower-than-average snowpack, the risk increases as to whether or not there is a continuing drought cycle with less than average river flows (TMWA 2009). The two most severe droughts on record in the Truckee Basin (shown in Figure 3-19) occurred:

- From 1928 through 1935, causing the average annual flow at the Farad gage to drop to 303,240 acre-feet from its long-term average 547,250 acre-feet (water years 1910-2012); and,

- From 1987 through 1994 (drought of record) where the average annual flow at Farad was 286,350 acre-feet.

The lowest recorded flow at Farad was 37 cubic feet per second (cfs) in September 1933. The most recently completed drought cycle occurred from 2000 to 2005. As of 2014, much of the Western U.S., including the Truckee Basin, has been in a severe multiyear drought; however, the ultimate length of this drought period is as yet unknown, and thus it was not considered in the Basin Study analysis.



Note: Red shading indicates the two most severe recorded drought periods in the Truckee Basin.

Figure 3-19. Annual Gaged Streamflow in Truckee River at Farad (Water Years 1910–2012)

Winter floods have occurred many times since Reno and Sparks were founded with storms occurring any time between November and April. The primary cause of winter flooding is warm winter rainstorms that fall on the Sierra Nevada snowpack. The famous New Year's flood of 1997 (Figure 3-20) was a classic winter flood on the Truckee River causing more than $450 million (unadjusted) in reported damage (USACE 2013). This flood was caused by several warm storm systems known as the "Pineapple Express" that originate from warm Pacific waters near Hawaii. Summer floods may also occur as flash floods when cloudbursts cause rainfall rates as high as 10 inches per hour for short durations.

Figure 3-20. Truckee River Flood in Reno, Nevada in 1997

Five significant floods were recorded in the Truckee Meadows area in the nineteenth century and at least nine occurred in the twentieth century (USACE 2013). Major floods occurred in 1907, 1909, 1928, 1937, 1950, 1955, 1963, 1986, and 1997. Flood control measures implemented in about 1960 reduced the magnitude and frequency of flood events. The official USGS records for the 1997 flood give a peak flow of 18,200 cfs and 18,400 cfs at the Reno and Vista gages, respectively. The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center modeled peak values at 23,000 cfs and 20,700 cfs, respectively (USACE 2013).

Historical Gage Records

The historical understanding of hydrology for the Truckee Basin is based on gage records available for the last 30-to-100 years. Planning studies in the Truckee Basin typically use 100 years of historical data (from water years 1901 to 2000) to calculate or simulate water supply and operations. These hydrologic records come from observed streamflow gage records, historical reservoir elevations, historical evaporation records, and historical precipitation data. However, inflow is closely linked to snowpack, and this relationship is especially important when assessing the effects of changes in temperature and other climatic conditions on hydrology. As the historical record of snowpack in the Basin extends only to 1980, the most complete and useful hydrologic record thus only encompasses about a thirty-year period.

Source: Courtesy of U.S. National Weather Service

Figure 3-21. Truckee River at Farad Gage Site

A paleohydrology dataset is currently being developed for the Truckee Basin under a separate effort, and will provide a view of hydrologic conditions in the Basin prior to recorded human history. This effort is likely to reveal whether the record of hydrologic conditions in the Basin during the past century are fairly typical for the region, or if they represent a departure from average conditions. Evidence of pre-recorded history suggest the Basin has in the past experienced prolonged, severe droughts. Just south of Lake Tahoe at Fallen Leaf Lake, tree stumps lie submerged more than 30 meters from the present shoreline; research suggests that the last megadrought which allowed these trees to grow in the lakebed may have lasted about 200 years (Kleppe et al. 2011). In conjunction with model projections of future climate, a paleohydrology dataset would likely improve the collective understanding of the range of future conditions possible in the Basin.

Unregulated inflow, also called “sidewater,” are inflows not regulated or controlled by dams or other structures and their associated operations.

Historically, Lake Tahoe is the source of approximately 30 percent of the Truckee River’s flow at the Farad, California, gage station (Interior and California 2008); the remaining flow derives from sidewater and controlled tributaries to the river. Average annual net inflow to Lake Tahoe is 180,400 acre-feet. From Lake Tahoe, the Truckee River flows generally north and east through California for about 40 miles and enters Nevada near Farad. The main tributaries are

Donner, Martis, and Prosser creeks and the Little Truckee River, all of which are regulated by dams. The unregulated drainage area produces 30 percent of the average annual runoff at Farad. Historic annual discharge of the Truckee River at Farad ranges from a low of 133,500 acre-feet in 1931 to a high of 1,769,000 acre-feet in 1983. Average annual discharge at Farad is 561,800 acre-feet (Interior and California 2008). The Truckee River flows another 80 miles from Farad to Pyramid Lake. The main Nevada tributary is Steamboat Creek. A portion of Truckee River flow is diverted at Derby Dam into the Truckee Canal. Stream gage records for the Truckee River upstream from Derby Dam near Vista, Nevada, show an average annual flow of about 603,800 acre-feet during the period from 1900 to 2010 (Interior and California 2008).

Historic annual discharge of the Carson River to Lahontan Reservoir (measured at Fort Churchill) ranges from a high of 804,600 acre-feet in 1983 to a low of 26,260 acre-feet in 1977. Average annual discharge to Lahontan Reservoir was 276,000 acre-feet per year for the period of 1911 to 2000 (Interior and California 2008).

Table 3-1 presents the historical minimum, average, and maximum annual discharge at key locations in the Truckee Basin (Figure 3-22). Additional details on specific streamflow gages can be found in the TROA EIS/EIR (Interior and California 2008).

Table 3-1 presents the historical minimum, average, and maximum annual discharge at key locations in the Truckee Basin (Figure 3-22). Additional details on specific streamflow gages can be found in the TROA EIS/EIR (Interior and California 2008).

Table 3-1. Historical Truckee River Annual Discharge

Location	Period of Record	Minimum (acre-feet)	Average (acre-feet)	Maximum (acre-feet)
Truckee River at Tahoe City, California	1909–2000	109	170,500	832,700
Donner Creek at Donner Lake, California	1929–2000	5,580	26,330	60,300
Martis Creek near Truckee, California	1959–2000	4,990	19,700	53,930
Prosser Creek downstream from Prosser Dam, California	1943–2000	17,690	64,000	154,900
Little Truckee River downstream from Boca Dam, California	1939–2000	40,250	135,000	340,200
Truckee River at Farad, California	1909–2000	133,500	561,800	1,769,000
Truckee River at Reno, Nevada	1907–2000	76,700	509,400	1,701,000
Steamboat Creek at Steamboat, Nevada	1962–2000	1,390	15,550	83,000
Truckee River at Vista, Nevada	1900–2000	114,600	603,800	2,017,000
Truckee River downstream from Derby Diversion Dam	1918–2000	4,450	304,000	1,760,000
Truckee River near Nixon, Nevada	1958–2000	17,500	425,100	1,889,000

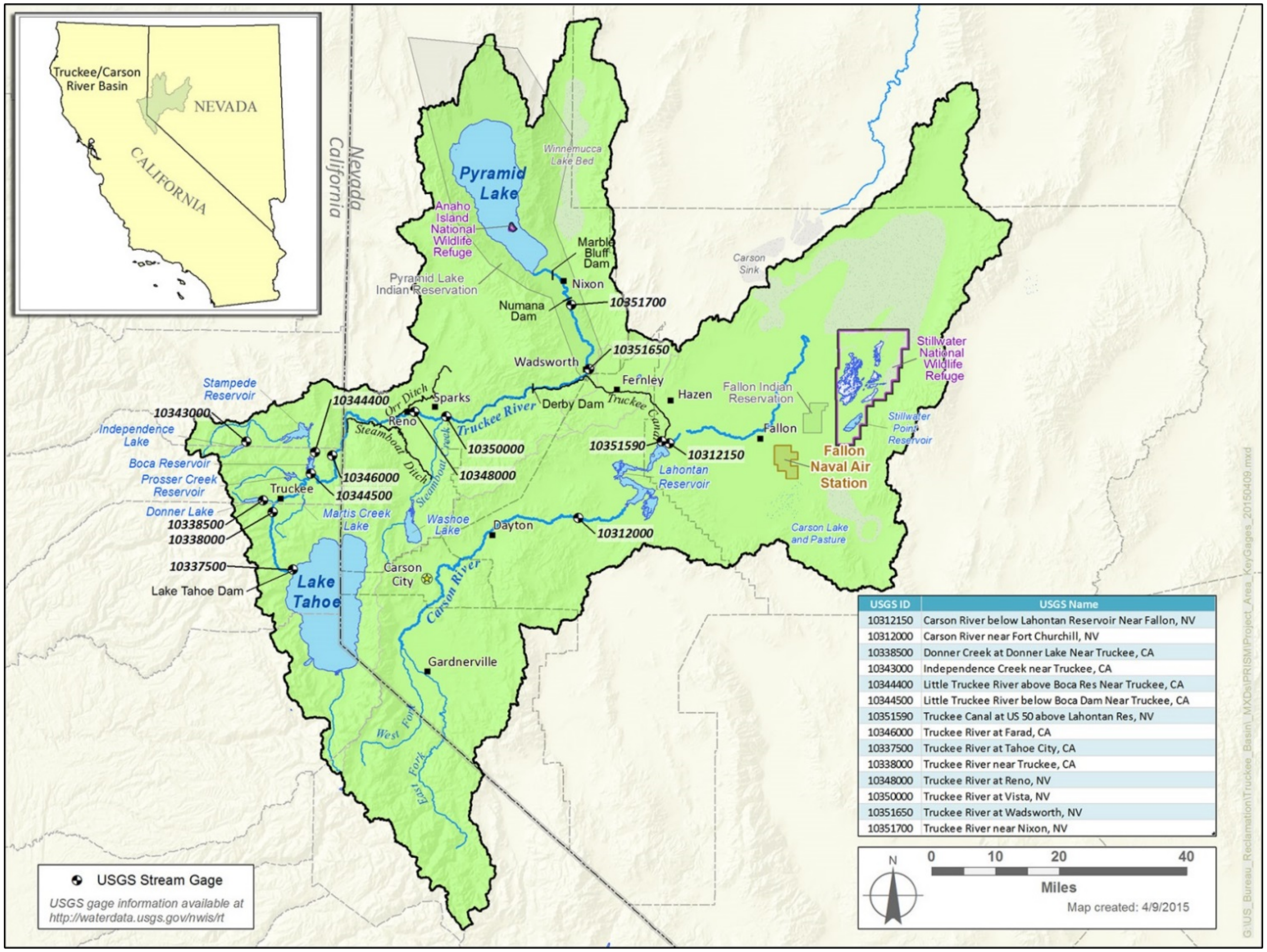


Figure 3-22. Truckee Basin Key Streamflow Gage Locations

TCDAT Hydrology Dataset

A monthly hydrology dataset called TCDAT has been the universally applied representation of historical monthly volumes at key locations in the Truckee Basin, and has been used to support several planning and decision-making processes, including the TROA EIS/EIR (Interior and California 2008).

Reclamation developed the initial data set in the 1970s for use in early planning tools. In the early 1980s, the model used 80 years of monthly runoff data (water years 1901 to 1980) at key river system points to simulate hydrologic conditions. This hydrology data set was composed mainly of historical records, but where no historical records existed, runoff data were estimated using correlations to known flows, precipitation-runoff relations, and professional judgment (Interior and California 2008). Documentation for this hydrology data set includes informal notes, memoranda by various parties, portions of summaries and analysis of specific simulations, and the collective memory of agency staff involved in model development (Interior and California 2008).

> **Accretions and depletions** are the unregulated and often ungaged inflows and losses in a stream segment. Accretions could include agriculture return flows, groundwater inflow, and urban stormwater runoff. Depletions could include groundwater seepage, evaporation, and ungaged diversions.

In 1988, the monthly hydrology was modified to segregate input data for Martis Creek Lake, Donner Lake, Independence Lake, and Hunter Creek. This data set was used in negotiating the 1989 Preliminary Settlement Agreement. In 1994, the hydrologic data set was updated to include water years 1981 to 1992 and was used in the Negotiations Settlement model.

In 1998, in support of TROA negotiations and the Draft EIS/EIR, water years 1993 to 1997 were added to the monthly hydrologic data set. This data set was also used in the Truckee River Water Quality Settlement Agreement analyses. Water years 1998-2000 were added in 2001 to assist additional TROA negotiations and evaluations in the revised Draft EIS/EIR and Final EIS/EIR.

A consortium of parties including Reclamation, the Pyramid Lake Paiute Tribe, TMWA, and the states of California and Nevada invested in the development of a daily 100-year historical hydrology data set to improve resolution of water supply modeling studies. The data set consists of 100 years of daily flows at all major input nodes for the TROA-light Planning Model, from October 1, 1900, to September 30, 2000.

The revised daily hydrology for the TROA-light Planning Model was derived from TCDAT by disaggregating monthly into daily flows (Stetson 2010). The planning model hydrology also uses an accretions/depletions data set derived from historical data for local inflows below Farad (Stetson 2012). Major input nodes for the planning model above the Truckee River at Farad gage include seven reservoir inflows representing the majority of Truckee Basin supply, along with unregulated inflow. Downstream from Farad, the planning model includes accretion/depletion node locations. Because the TROA-light Planning Model simulates Newlands Project operations, an input node is included for Lahontan Reservoir inflows at the Carson River near Fort Churchill gage. Inflow and accretion/depletion node locations are shown in Figure 3-23.

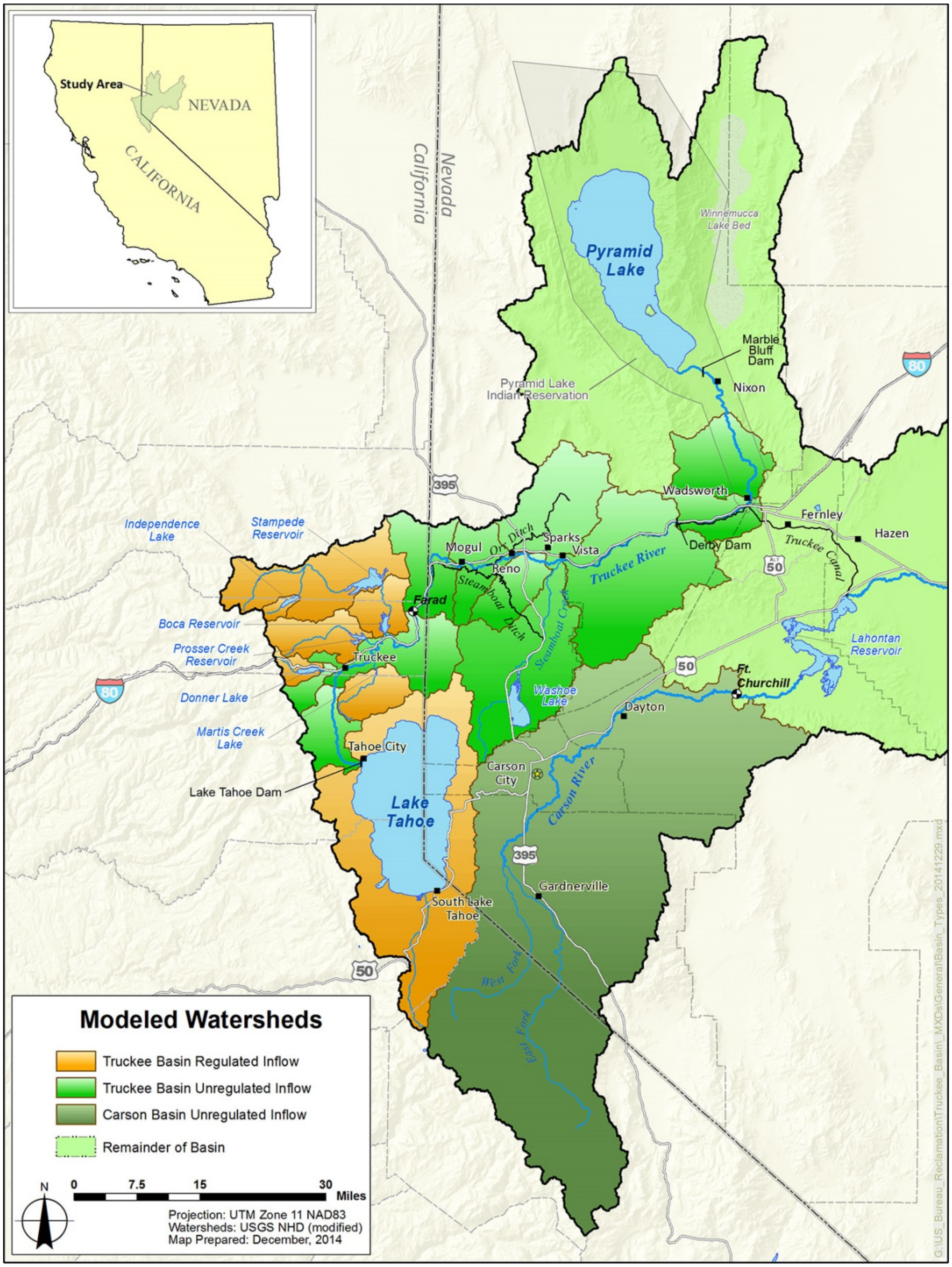


Figure 3-23. TROA-light Planning Model Reservoir and Unregulated Inflow Locations

Table 3-2 presents the annual inflow by watershed in the Truckee Basin as provided by the TCDAT data, consistent with the nodes used in the TROA-light Planning Model.

Table 3-2. Annual Inflow by Truckee Basin Watershed (1901–2000)

Sub-basin	Average Annual Inflow (thousand acre-feet)	Maximum Annual Inflow (thousand acre-feet)	Minimum Annual Inflow (thousand acre-feet)
Lake Tahoe[1]	**179.0**	**813.0 (1983)**	**-203.2 (1924)**
Truckee River Reservoirs	**246.8**	**639.9**	**51.3**
Donner Lake	29.0	61.1 (1982)	7.2 (1977)
Martis Creek Reservoir	18.9	54 (1983)	4.9 (1924)
Prosser Creek Reservoir	64.5	141.8 (1982)	15.5 (1924)
Independence Lake	18.6	34.9 (1907)	5.0 (1924)
Stampede Reservoir	110.6	289.7 (1983)	18.6 (1977)
Boca Reservoir	5.2	58.4 (1997)	0.1 (1992)
Unregulated Inflows Above Farad	**166.4**	**413.6**	**32.9**
Truckee River Below Lake Tahoe Inflow	73.9	190.6 (1952)	14.1 (1924)
Donner Creek Below Donner Lake Inflow	28.5	76.2 (1952)	5.2 (1924)
Remaining Sidewater	64.0	146.8 (1953)	13.6 (1924)
Inflow Downstream from Farad	**19.2**	**97.0**	**-0.1**
Farad To Mogul	14.1	70.4 (1997)	0.9 (1924)
Mogul To Reno	3.1	21.7 (1997)	-1.4 (1924)
Reno To Sparks	0.8	1.8 (1983)	0.1 (1992)
Sparks To Vista	0.0	0 (1901)	0 (1901)
Vista To Derby	1.2	3.1 (1997)	0.3 (1994)
Lahontan Reservoir	**297.2**	**804.6 (1993)**	**26.3 (1977)**

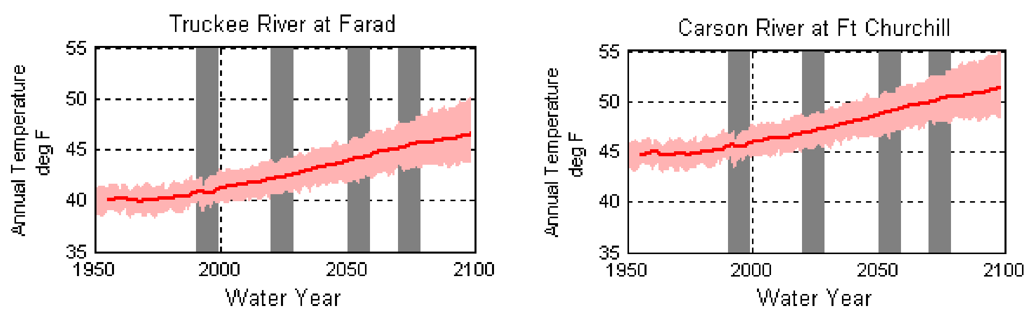
Note:
[1] Lake Tahoe inflow is net inflow (change in lake storage minus outflow).

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 Basin. The assessment conducted for the Basin Study included the development of five climate ensembles specifically for the Basin, and then applying each ensemble to hydrology models that simulate the effect of climatic conditions on hydrologic processes in the Truckee Basin (i.e., snow accumulation and melt, surface runoff, and lake evaporation). A sixth climate condition, the Reference condition, was developed concurrent with the five ensembles to represent current conditions without climate change and to be used as a baseline for comparison with future conditions.

Completing this assessment required addressing two challenges: one related to climate change projections in general, and another related to the relatively small geographic extent of the Truckee Basin. With regard to the first challenge, the number of possible future conditions is vast and it is highly uncertain which (if any) of the projections is the most likely to occur. Second, the tools that were available for simulating the effect of climate change on hydrology were configured at a spatial scale that made it difficult to determine the specific effects of climate changes for each reservoir within the Basin.

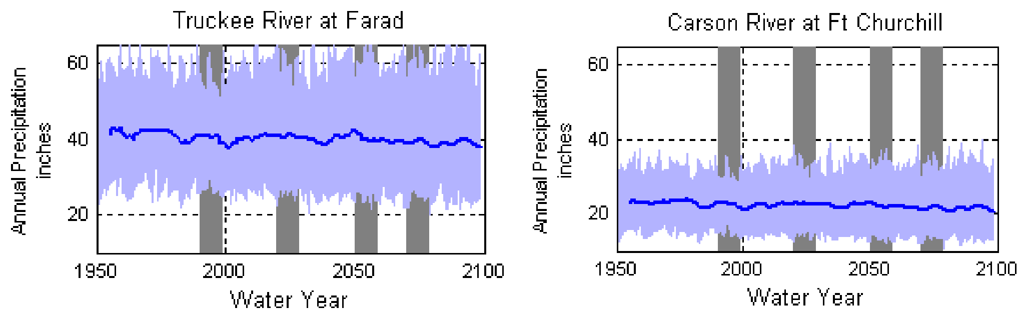
The primary source of uncertainty for assessing future water supply in the Truckee Basin is the large range of potential future climatic conditions that could transpire during this century. Projections for the Truckee Basin's climate include a range of potential changes in both the volume of annual precipitation and the seasonal temperature conditions (Reclamation 2011a). 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 3-24) (Reclamation 2011a, 2011b). A similar range of temperature changes is projected for the Carson River Basin above Fort Churchill, Nevada.



Source: Reclamation 2011a

Figure 3-24. Range of Mean Average Annual Temperatures Projected for the Truckee and Carson Basins Through 2100

The same climate projections suggest that annual precipitation in the Truckee and Carson basins may decrease slightly by the end of the twenty-first century (Figure 3-25). Increases or decreases in average annual precipitation would directly influence the availability of water supplies by changing the amount of water running off into the Basin's lakes, rivers, and streams, as well as the amount of water recharging groundwater resources.



Source: Reclamation 2011a

Figure 3-25. Range of Mean Average Annual Precipitation Projected for the Truckee and Carson Basins Through 2100

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. The Basin Study also used a planning approach that aggregates all combinations of potential future climates in the Basin into five "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.

The second challenge for assessing future water supply for the Truckee Basin is related to the models, data, and other tools typically used for simulating changes in hydrology due to climate change. Extensive assessments have been conducted to understand how hydrology throughout the Western U.S. may be altered by climate change, including for the Truckee Basin (Reclamation 2011b). In 2011, Reclamation selected and applied the Variable Infiltration Capacity (VIC) hydrology model for an initial series of basin investigations and found that for many Western basins, such as the Colorado River Basin, the VIC models performed adequately at simulating monthly and annual hydrology. However, Reclamation recommended that further studies or planning in basins with a small geographic size relative to the WWCRA modeled grid cells (such as the Truckee Basin) should carefully consider the use of WWCRA data sets (Reclamation 2011b). Assessing climate change impacts on small water users and evaluating local options that operate at small spatial scales to address climate change may require a finer grid cell size.

To address climate change in the small geographic extent of the Truckee Basin, this Basin Study used a hydrology model that operates at a smaller spatial scale than the WWCRA analyses. The model selected for the Basin Study was found to provide an adequate simulation of monthly and annual runoff that is commensurate with the VIC model's performance in other larger basins.

The following sections of this chapter present additional detail on the methodologies applied for the Basin Study to assess future water supply, including selecting the Reference supply condition, the approach to bracketing future climatic conditions, the approach to development of future hydrology and lake evaporation, and a comparison of historical, current, and projected future hydrologic conditions.

Selection of the Reference Supply Condition

The Basin Study selected a hydrology simulated from historical meteorology instead of using the historical gage records as the Reference supply condition. This selection was guided by differences between the gage records and the simulated hydrology that stem from several factors. The selected hydrology model was calibrated to match the historical hydrology, however models are simplifications of real-world systems and never match them completely. Sources of discrepancy between records of historical hydrology and simulated hydrology include the following:

- Conditions that influence hydrology in the Basin (e.g., land use and vegetation cover) have been changing over the past century, which are evident in the historical gage records. The simulated hydrology for the Basin holds these factors constant.

- The description of meteorology used as an input to the hydrology model is based on data recorded at meteorological stations and extrapolated across the Basin; errors may exist either in the measurements at the station or in the extrapolation methodologies.

- The historical hydrology contains unknown and unquantified errors in gage measurement, and in methods used to resolve data gaps and to approximate the contributions of ungaged tributaries to the Truckee River's flow.

As a result, any comparisons made in the Basin Study between the historical and future supply conditions would have thus included a mixture of differences resulting from climate change and from the formulation of the historical and simulated hydrology data. Thus, the use of historical gage data in the Reference scenario would have made it difficult to isolate the differences in future conditions resulting solely from climate changes.

In order to understand which changes in the Basin's supply result from climate change alone, the Reference supply condition was selected to be the simulated current hydrology based on historical climate. The same biases and errors exist in both the Reference supply condition and future supply conditions and the only difference between them reflects changes in the climate.

The Reference supply condition climate projection was prepared by repeating historical precipitation and maximum and minimum temperature data (Livneh et al. 2013) from the period of October 1, 1915, through September 30, 2003. This 1/16-degree spatial resolution historical data set was used because of its longer period data availability. A wet bias was identified in the historical Livneh et al. precipitation data prior to the 1949 period, and was removed based on monthly scaling factors computed using Parameter-elevation Regression on Independent Slopes Model (PRISM) and Livneh data. The 1/16-degree historical data was averaged to 1/8-degree spatial resolution to match the spatial resolution of the disaggregated climate change ensembles (see the “Future Climate Projections Selection” section below.)

Although the Reference condition is intended to represent a “current” climate (absent future climatic changes) and is based on historical meteorological conditions, this Report often presents results from the Reference supply condition alongside future conditions (i.e., supply conditions for 2012 through 2100) for ease of comparison.

Bracketing Future Climate with Ensembles

Projecting the ways in which the climate may change in the future involves attempting to capture a large range of highly variable potential future conditions. There exists a wide array of types and sources for greenhouse gas emissions that may drive climate changes into the future. Globally, human sources of emissions include automobiles, industrial activity, coal or gas power plants, and a number of other sources. Non-human sources of emissions also exist. The emission of greenhouse gasses throughout the globe is fundamentally uncertain, being a product of global and local economies, population, regulatory requirements, and available technologies, all of which may change in the future in a variety of ways. The IPCC has developed several emissions scenarios to bracket the uncertainty surrounding the future global patterns of greenhouse gas emissions for use in climate models (IPCC 2000). WWCRA uses three of these IPCC emissions scenarios.

Multiple general circulation models (often referred to as GCMs or global climate models) exist for simulating future climate conditions, each with its own emphasis, strengths, and weaknesses (Reclamation 2011b). Due to these differences, GCMs often specify multiple climate system conditions throughout the coming century. Combined, the three greenhouse gas emission scenarios simulated through the assemblage of 16 models and varying initial condition assumptions within some models resulted in 112 projections for global climatic conditions. The complex blend of strengths and weaknesses among the models contributes to the uncertainty in interpreting climate projections (Hawkins and Sutton 2009).

Translating global scale climate changes to regional climate and weather, such as winter storm track positions approaching the West Coast, also introduces uncertainties in climate change projections. Multiple techniques, typically called "downscaling," can apply global projections at a regional scale, but each technique has its own assumptions and weaknesses and does not fully account for regional climate links to global patterns.

The combined variations of different emissions scenarios, climate models, and downscaling techniques are too numerous to describe meaningfully for the Basin Study. A Hybrid Delta ensemble (HDe) approach was used to develop a simplified, meaningful set of climate change projections that also preserves uncertainty about temperature and precipitation in the future. The ensemble approach simplifies the process of using climate projections in climate change studies by bundling projections from a variety of different climate models into five distinct climate change ensembles. The ensembles represent the outer-bound ranges of temperature and precipitation changes, and also include a central tendency of all the projections (Figure 3-26).

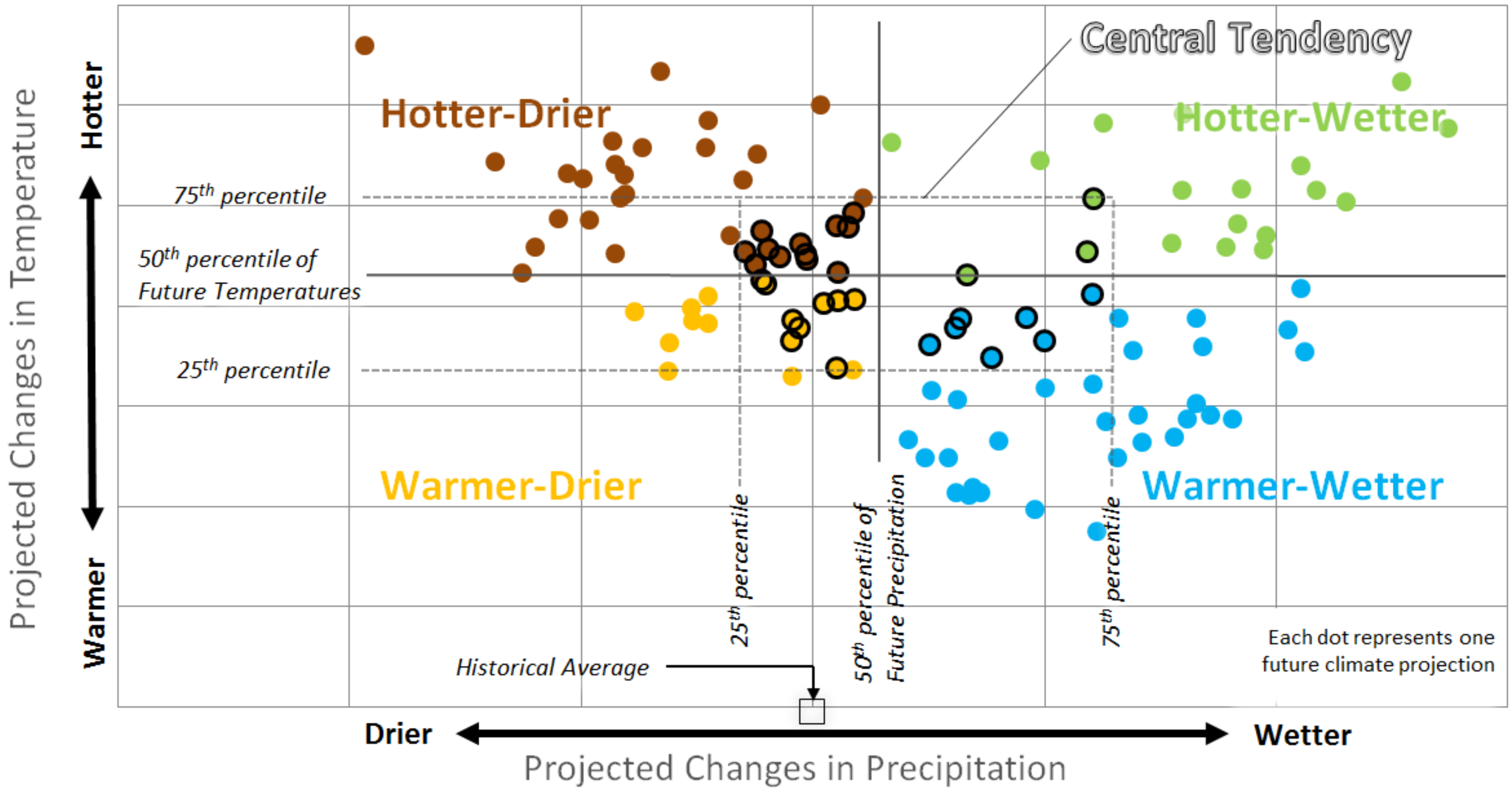


Figure 3-26. Climate Projections Grouped into Ensembles and used in the Truckee Basin Study

Development of the Basin Study's climate ensembles required three discrete steps, described in the sections that follow and the appendices to this Report:

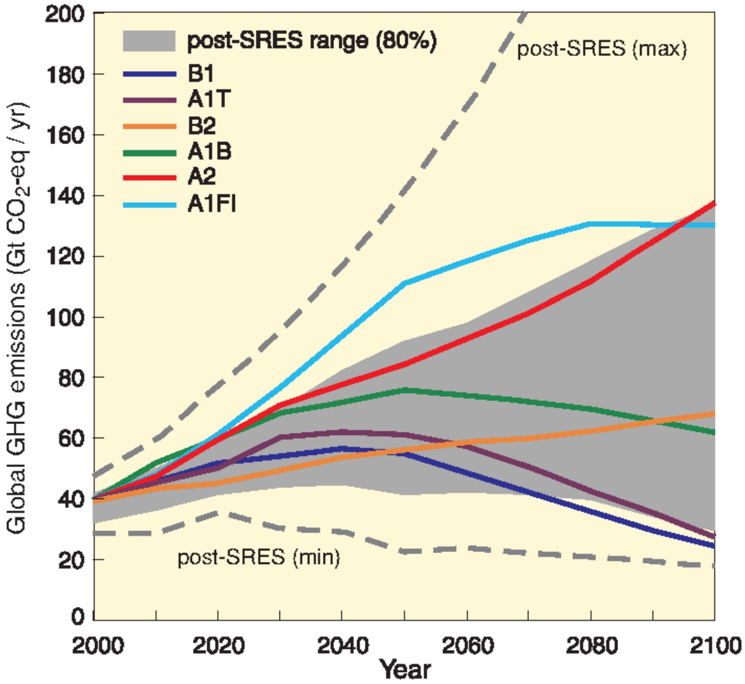
1. Selecting a set of GCM climate projections
2. Grouping GCM climate projections into five ensembles
3. Additional translating, or "downscaling," of GCM outputs for use in the selected hydrology models

Future Climate Projections Selection

In 2000, the IPCC developed various greenhouse gas emission scenarios that have since been used in most future climate modeling to support numerous climate change mitigation and adaptation studies (IPCC 2000, 2007a, Reclamation et al. 2013). The emissions scenarios, published in the Special Report on Emissions Scenarios (SRES), include a wide range of greenhouse gas emissions caused by different levels of future demographic, economic, and technological growth. The IPCC developed Figure 3-27 to illustrate the range of emissions anticipated for each SRES scenario.

Through the WWCRA process, Reclamation selected climate change projections for use in the Basin Studies overseen by the Mid-Pacific Region office using the three IPCC SRES emissions scenarios (Reclamation 2011a):

- SRES A2 (higher emissions path): Technological change and economic growth are more fragmented and slower. Population growth is slower, but increases continually.
- SRES A1B (middle emissions path): Technological change and economic growth occur rapidly. Technological change in the energy system is balanced across all fossil and non-fossil energy sources, where balanced is defined as not relying too heavily on one particular energy source.
- SRES B1 (lower emissions path): Rapid change in economic structures toward service and information, with emphasis on clean, sustainable technology. Reduced material intensity and improved social equity.



Source: IPCC 2007b
Key:
GHG = greenhouse gas
GT = gigaton
SRES = Special Report on Emission Scenarios;

Figure 3-27. Greenhouse Gas Emission Scenarios used in Climate Modeling

CMIP3 versus CMIP5: When the Truckee Basin Study was initiated, the CMIP3 dataset was selected for use because the dataset's next iteration, CMIP5, was still being evaluated by the IPCC. Although there are differences between CMIP3 and CMIP5, they both exhibit similar ranges of uncertainty in precipitation and temperature that pose the same types of challenges for management of the Truckee Basin. Thus, while improvements in the scientific expectations for the future climate of the Basin may change over time, the challenges (and potential solutions) that exist and are identified in the Basin Study using CMIP3 will persist.

The SRES scenarios describe the quantity and timing of global emissions of greenhouse gases; this information is used as inputs to GCMs that assess the influence of increasing emissions on the global climate. Various governments and other organizations have developed GCMs, and researchers continue to study and refine GCMs to improve the way these models address and simulate different uncertainties and processes, such as atmospheric circulation, clouds, aerosols, biogeochemical fate of emissions, ocean circulation, deep ocean heat uptake, ice sheet dynamics, sea level, land cover effects from water cycle, and vegetative and other biological changes (Reclamation 2011b). The Basin Study uses 112 climate projections from a dataset that combines projections from sixteen different GCMs, and was developed as part of the World Climate Research Program's Coupled Model Intercomparison Project phase 3 (CMIP3) (Meehl et al. 2007).

On its own, a projection of future global climate informs very little regarding conditions in a specific basin. One challenge with these climate projections is that the spatial and temporal resolution of climate model output is often too coarse for regional and local water resources studies, because the model grid cells are very large and capture a high range of climate variability (Figure 3-28) (Fowler et al. 2007; Maurer et al. 2007). To address this, Reclamation bias corrected and downscaled the 112 CMIP3 climate projections to 1/8-degree (12-kilometer) resolution using a relatively simple spatial disaggregation technique (Wood et al. 2002). Reclamation has this technique in Basin Studies because of its suitability for application to a large collection of climate projections for the Western U.S. for the twenty-first century.

> Many types of models, including climate models, use a grid to separate sections of the spatial or geographic area where different characteristics (such as temperature or precipitation) will be simulated. **Spatial resolution** (expressed in degrees of latitude and longitude, kilometers, or miles) is the size of the model's grid cells. **Temporal resolution** is how often the model calculates information about those characteristics. The finer a model's resolution, the more detailed and accurate are its results.

The IPCC's *Fourth Assessment Report* (IPCC 2007b) describes the CMIP3 data set in greater detail, and Reclamation's *West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections* (Reclamation 2011b) provides additional information on both the CMIP3 data set and the downscaling techniques used by the Basin Study.

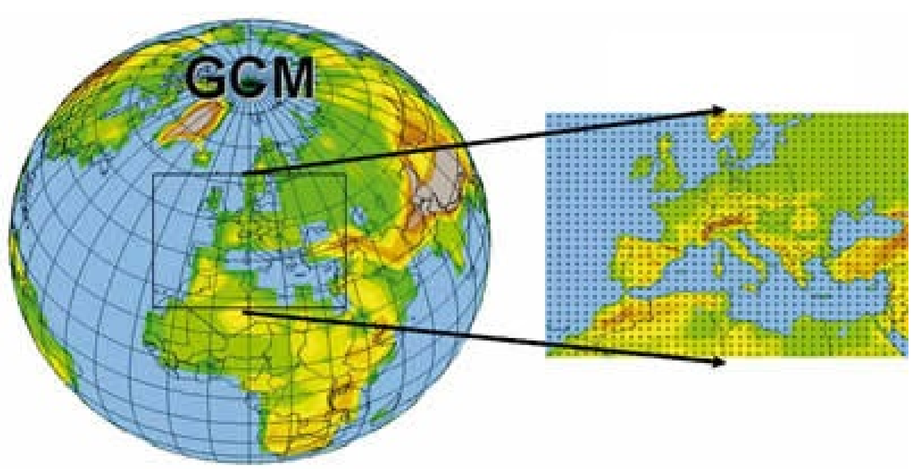


Figure 3-28. Downscaling GCMs for Regional or Local Application

Ensemble Development Process

To simplify the use of all 112 climate projections, yet still capture a meaningful range of future climate uncertainty, an HDe approach was used to develop five statistically relevant climate ensembles (Figure 3-26). Each ensemble is built for the period from 2012 through 2099 using a transient approach in which climate conditions gradually change as the simulation moves through time.

The first step to develop an ensemble is to categorize the 112 climate projections based on whether they are above or below the median change in temperature and precipitation. The central tendency ensemble consists of projections within the 25^{th} and 75^{th} percentiles (Figure 3-26). A nearest-neighbor statistical method was used to build the four other ensembles using select projections around the 10th and 90th percentile changes in temperature and precipitation. If all projections in each quadrant are used to produce a full ensemble, it results in a smaller range of climate variability because some of the central tending projections may be included. The nearest neighbor statistical approach represents seasonal trends of larger ensembles, but retains the variability range of smaller ensembles (California DWR 2013a, Reclamation 2014a).

Once the projections have been categorized into an ensemble, adjustment factors (also known as change factors or “deltas”) are calculated and applied to historical time series (the Basin Study used the Reference supply condition) using a quantile mapping approach to produce a single climate change time series for each ensemble (Reclamation 2014a). Percent changes for precipitation and incremental changes for temperature were used as adjustment factors in this Basin Study. This mapping approach maintains the historical sequencing of droughts and flood in the climate change time series while perturbing precipitation and temperature magnitudes according to each ensemble.

The five resulting future climate ensembles (Figure 3-25), relative to the median projection include: Warmer-Drier, Hotter-Drier, Hotter-Wetter, Warmer-Wetter, and a Central Tendency.

Additional details on HDe methodology can be found in the Bay-Delta Conservation Plan EIR/EIS Modeling Technical Appendix (Reclamation et al. 2013b) and the Central Valley Project Integrated Resource Plan (Reclamation 2014).

Additional Downscaling to Local Weather Stations

Similar to the CMIP3 data described above, the HDe climate projections also have a resolution (1/8 degree), which is too coarse for use in the Basin Study’s hydrology model. A second downscaling process was performed to map both the ensemble and Reference supply condition time series to applicable climate station data in the Basin. This process, detailed in “Appendix C – Future Supply Technical Reports,” brought the ensemble and Reference supply condition climate time series to a finer resolution for further hydrology analyses in the Basin Study.

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.

Several Reclamation studies, such as the Colorado River Basin Study, have been able to directly apply the outputs of WWCRA's studies or use the VIC models in order to evaluate changes in hydrology. The approach for the Truckee Basin Study also 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 noted large biases and poor correlations between historical and simulated hydrologies for some portions of the Truckee Basin watershed. This was not a reflection of problems with the VIC model, however; the model and WWCRA data sets have been used successfully through the Western U.S. for climate change studies, and are highly suitable for the basins for which they were developed. Rather, it is likely that incompatibilities in the spatial scale of the hydrology models and the manner in which the climate change ensembles were developed made them less applicable for the Truckee and Carson basins. As a result, the Basin Study developed a set of PRMS models that are highly-suited to representing the effects of climate change on snow accumulation and melt, and thus hydrology, in the Truckee Basin and its small sub-watersheds.

The PRMS model has several advantages for the Truckee Basin, specifically. It uses computational grid cells that are 300 meters square, which is granular enough to be appropriate for use in very small basins. This resolution was found to adequately capture the distribution of topography and climate in the upstream portions of the Truckee River watershed without requiring unreasonable computational requirements. For comparison, the VIC model's cells are 12 kilometers square (covering roughly 55 square miles) – while this accounts for only 0.02 percent of the Colorado River Basin, for example, it would cover nearly 2 percent of the Truckee Basin. Because of the Basin's size and topography, many of VIC model's cells contain areas that are both very high and very low in elevation, and the average condition that is ultimately simulated likely misrepresents snowfall accumulation and melt processes. Snow accumulation and melt are central drivers of hydrology in the Truckee and Carson rivers. The PRMS model's very fine spatial resolution to simulate inflow to reservoirs in each of the Basin's sub-watersheds, while still capturing the variability in climate that lead to differences in snow accumulation and melt between reservoirs (Figure 3-30). Additionally, conditions within each PRMS model cell are calculated for each timestep as an average condition for the entire area being represented.

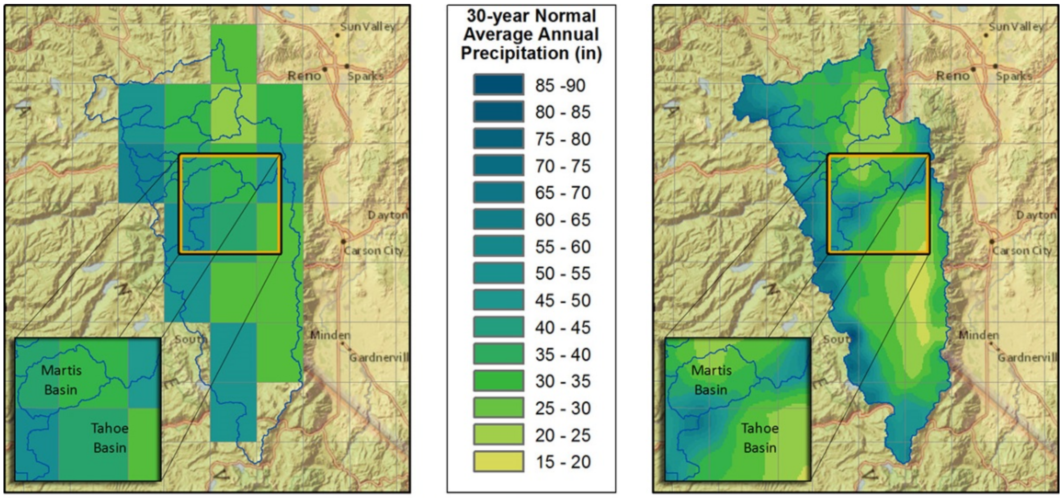


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Figure 3-29. Comparison of Spatial Scale of VIC and PRMS for the Truckee Basin Above Farad, Using Average Precipitation to Demonstrate Resolution in Modeled Subbasins

PRMS is a physical process-based modeling system developed to evaluate the response of various combinations of climate and land use on streamflow and general watershed hydrology (USGS 2013). The Basin Study's PRMS models included a simplified representation of groundwater and simulate hydrology in the Basin above Farad, California, which represents 90 percent of contributing surface runoff in the Truckee Basin. Additionally, a portion of the models were developed for local application by Basin Study cost-share partner PCWA, who is applying them along with a coupled groundwater model to conduct climate change evaluations of groundwater in the Martis Valley.

For lower portions of the Truckee Basin and for inflows to Lahontan Reservoir, numerical hydrology models such as PRMS were not available. For these places, regression equations were used to correlate flows on the Truckee River system to flows anticipated in these subbasins. In the Carson Basin, annual inflows to Lahontan Reservoir govern diversions from the Truckee River, and regression equations capture the general availability of water supplies sufficiently for understanding how the Truckee Canal might operate under different hydrologic conditions. Improvements in the representation of hydrology for both of these areas could benefit the understanding of how climate change will alter Basin operations, but will not significantly change our understanding of challenges or opportunities that exist in the future under climate change.

The model used to simulate evaporative losses from lakes and reservoirs in the Truckee Basin used the same downscaled climate inputs as PRMS to provide parity among the hydrology results. Additional information regarding the development of the PRMS models and the full range or their outputs can be found in "Appendix C – Future Supply Technical Reports."

Numerical Hydrology Models

The PRMS modeling environment assesses the effect of watershed components (e.g., precipitation, temperature, land use) on watershed responses (i.e., streamflow, recharge). The Basin Study applied three separate PRMS models to simulate hydrology of the portion of the Truckee River watershed upstream of the Farad gage station.

Model Domain and Parameterization Figure 3-29 shows the spatial coverage of these three models, which separately consider the watersheds contributing to Lake Tahoe (red), Martis Valley (beige), and the Little Truckee River and sidewater downstream of the Town of Truckee (green).

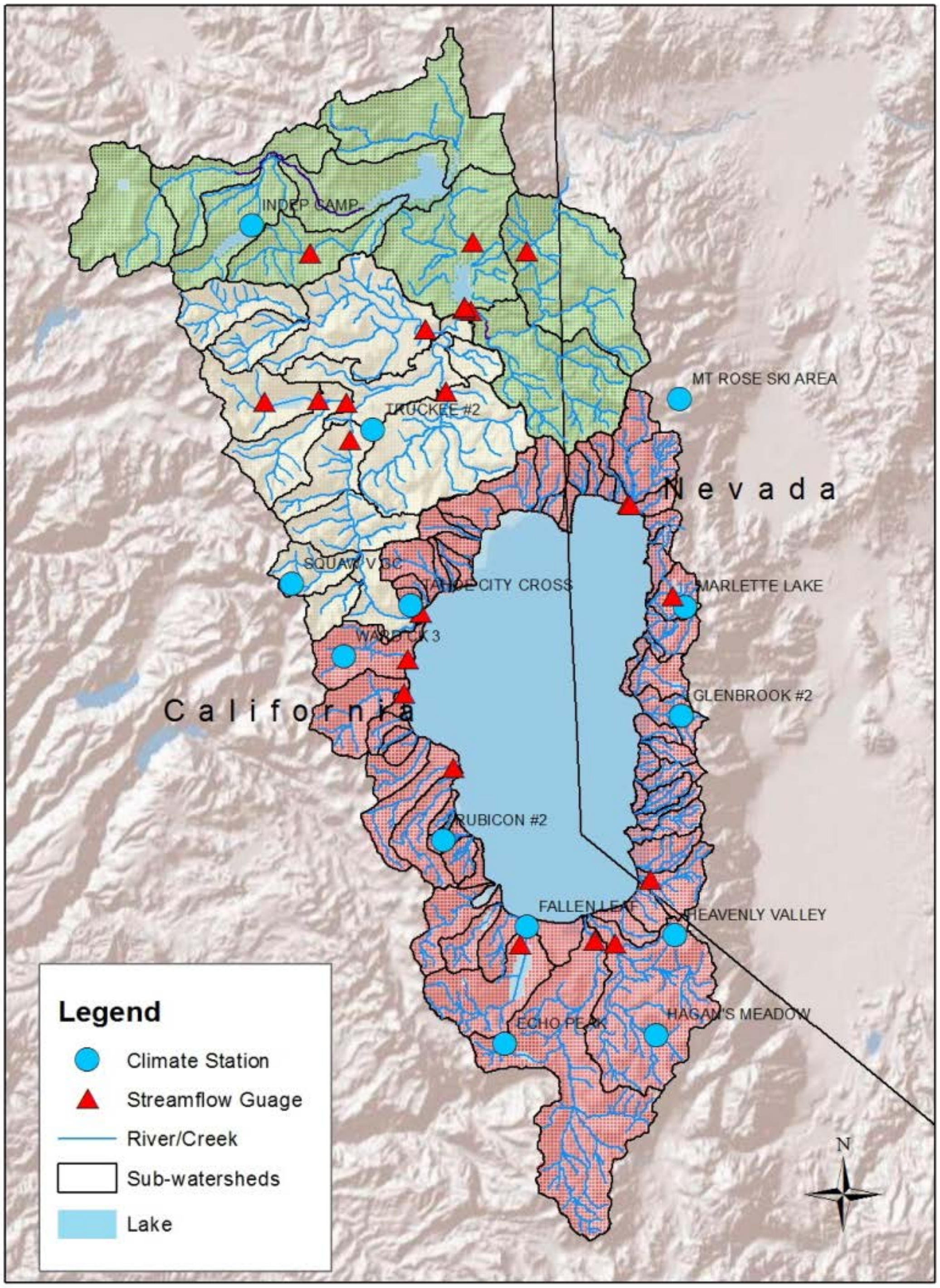

Figure 3-30. The Truckee Basin, Including the Tahoe Watershed, Martis Watershed, and Little Truckee Watershed

All three models were developed in a consistent manner using practices established by the USGS (Markstrom et al. 2008). Model development included the application of spatial data and analysis (i.e., GIS information) to delineate and define a network of hydrologic response units (HRU) based on characteristics such as drainage boundaries; elevation, slope, and aspect; plant type and cover; land use; distribution of precipitation, temperature, and solar radiation; soil morphology and geology; and flow direction. Gridded data sets of elevation, geology, vegetation, soils, and land use were then used to discretize and parameterize PRMS model cells of 300 meter-by-300 meter spatial resolution over each model domain.

For all three PRMS models, climatic data is spatially distributed across the domain based on relationships developed between mean monthly precipitation patterns from the PRISM (Daly et al. 1994), and daily temperature and precipitation recorded at multiple climate monitoring stations throughout the Basin. The use of local climate monitoring stations as the basis for mapping climate across the Basin required that future climate projections be downscaled specifically to each weather station. The climate stations used in the Basin Study are identified in Figure 3-29 and Table 3-3.

Table 3-3. Climate Stations Used for Precipitation Runoff Modeling System Calibration and Future Climate Downscaling

Climate Station	Description	Latitude	Longitude	Elevation
Independence Camp	CA SNOTEL SITE	39.452800	-120.292683	7,003 feet
Squaw V GC	CA SNOTEL SITE	39.189983	-120.264750	8,029 feet
Truckee #2	CA SNOTEL SITE	39.300867	-120.184067	6,509 feet
Echo Peak	CA SNOTEL SITE	38.849033	-120.078500	7,670 feet
Fallen Leaf	CA SNOTEL SITE	38.934050	-120.054567	6,236 feet
Glenbrook	NV COOP	39.075	-119.941	6,350 feet
Hagan's Meadow	CA SNOTEL SITE	38.851850	-119.937417	7,776 feet
Heavenly valley	CA SNOTEL SITE	38.924333	-119.916467	8,582 feet
Marlette lake	NV SNOTEL SITE	39.163950	-119.896717	7,880 feet
Mt. Rose Ski Area	NV SNOTEL SITE	39.315733	-119.894733	8,801 feet
Rubicon #2	CA SNOTEL SITE	38.999200	-120.130317	7,689 feet
Tahoe City Cross	CA SNOTEL SITE	39.171617	-120.153617	6,797 feet
Ward Creek #3	CA SNOTEL SITE	39.135617	-120.217633	6,655 feet
Boca	CA COOP	39.3886	-120.094	5,575 feet

Calibration Process A robust, multi-step approach was used to both calibrate each PRMS watershed model and evaluate model performance relative to observed historic streamflows, Moderate-resolution Imaging Spectroradiometer (MODIS) snow-covered area (SCA), and measured snow telemetry (SNOTEL) snow-water equivalent (SWE). The PRMS calibration period was 1980-2010. Each model was calibrated to streamflows at internal sub-watersheds and at the outlet of the watershed. PRMS-simulated SCA and SWE were compared to

MODIS SCA and observations from SNOTEL sites. The use of gaged streamflows, SCA, and SWE to evaluate model performance is possible due to the fine spatial resolution of the model grids.

Several stream gages were identified to confirm the performance of the surface runoff in PRMS: 10 gaging stations in the Tahoe model, six in Martis, and four in the Little Truckee. Each of these gages is identified in Figure 3-29 and Table 3-4. Some of the gages in the Truckee River watershed are located at reservoirs and the data they collect represents a regulated, rather than natural, streamflow. Extensive analysis is thus required to determine natural flows at these locations. For these gages, the Basin Study relied upon TCDAT information, as it represents a back-calculated naturalized flow.

Table 3-4. Stream Gages Used for Precipitation Runoff Modeling System Calibration

Station Name	USGS ID	Record Type
Sagehen Creek	10343500	Gaged
Independence Creek	10343000	Natural
Little Truckee at Stampede	10344400	Natural
Boca	10344500	Natural
Truckee River	10338000	Natural
Squaw Creek	NA	Gaged
Donner Creek	10338500	Natural
Cold Creek	10338700	Natural
Martis Creek	NA	Natural
Prosser Creek	10340500	Natural
Trout Creek	10336780	Gaged
Incline Creek	10336700	Gaged
Third Creek	10336698	Gaged
Upper Truckee River	10336610	Gaged
General Creek	10336645	Gaged
Blackwood Creek	10336660	Gaged
Ward Creek	10336676	Gaged

Key:
NA = not applicable
USGS ID = U.S. Geological Survey identification number

The importance of accurately portraying snow across the subbasins of this relatively small watershed, combined with the high spatial resolution of the Basin Study's selected numerical hydrology modeling tool, make it important to use similarly detailed information about snow accumulation and cover. The relatively limited period of availability for this data constrains the calibration period to approximately the last three decades, and limits the use of bias-corrected spatial downscaling techniques to that period.

Output The Basin Study makes use of three specific outputs from the PRMS model: natural streamflows, snow accumulation, and groundwater recharge.

Natural streamflow is the principle PRMS output used in the Basin Study. Streamflow for each of the HRUs was assembled to match the watershed representation used by the TROA-light Planning Model. The Basin Study assesses the SWE and SCA primarily because of the importance that snow accumulation and retention plays in the operations of Truckee Basin reservoirs. Producing spatially distributed snow accumulation plots was computationally prohibitive for the Basin Study, and so SWE and SCA terms were evaluated for the Tahoe, Martis Valley, and Little Truckee models as a single average condition (total volume for SWE and percent coverage for SCA).

A number of water users within the Truckee Basin rely on groundwater as their primary water source. To understand the manner in which future climate changes may affect groundwater availability for these users, the Basin Study evaluates groundwater recharge. As defined in PRMS, "recharge" accounts for the water infiltrating beneath the root or soil zone after considering surface runoff and evapotranspiration.

Additional information regarding the development of the PRMS models and the full range or their outputs can be found in "Appendix C – Future Supply Technical Reports."

Regression Hydrology Models

The Basin Study relies on regression relationships embedded in the TROA-light Planning Model to describe stream and aquifer interactions at 11 locations on the Truckee River between the Farad gage and Pyramid Lake, and for inflows to Lahontan Reservoir at the Fort Churchill gage station on the Carson River. These models extrapolate from hydrologic conditions on the Truckee River (above the Farad gage station) to describe hydrologic conditions at the locations specified. Ongoing research by USGS and Carson River Basin stakeholders is anticipated to continue to define physical conditions and processes to further refine future streamflow projections at these locations.

Reclamation developed hydrologic regression models for the lower portions of the Truckee River for general application in the TROA-light Planning Model. Development of models was motivated by difficulties in describing hydrologic conditions below the Farad gage. The hydrologic contribution of the watershed downstream of the Farad gage has been historically small (approximately 10 percent) in comparison to upstream portions. The relatively small magnitude of hydrologic inputs combined with the effect of extensive human use of the land and river has made it difficult to uncouple the record of natural runoff and groundwater contributions from human uses, such as agricultural practices. The regression models produce both accretions and depletions, which are applied in the TROA-light Planning Model to flows on the Truckee River at the following gage locations: Mogul, Reno, Sparks, Steamboat Creek at Rhodes Road, Truckee Meadows Water Reclamation Facility, Vista, Derby, Wadsworth, Nixon, and at Pyramid Lake.

Reclamation developed a hydrologic regression model for the Carson River at Ft. Churchill specifically for the Basin Study. The PRMS model of the Carson River being developed by the USGS and the Water Evaluation and Planning System (WEAP) modeling environment were considered for application in the Basin Study, but were found to be inappropriate due to the duration of time that would be required to develop and/or apply them.

For the Basin Study, each regression equation uses hydrology information developed with PRMS for the Truckee River upstream of the Farad gage to produce hydrologic inflows on the Truckee and Carson Rivers. The specific processes for developing each regression model are provided in "Appendix C – Future Supply Technical Reports."

Lake Evaporation Models

Reservoir evaporation is often referred to as a "loss" or is considered a demand associated with a reservoir's primary use, but for the purposes of this study reservoir and lake evaporation is considered alongside runoff or reservoir inflows in assessing the Basin's hydrology and water supply. The reservoirs and lakes evaluated in the study are listed in Table 3-5, and shown in Figure 3-23.

Table 3-5. Reservoirs and Lakes used in Lake Evaporation Assessment

Water Body Name	Elevation (feet)	Designed Maximum Storage Capacity (acre-feet)
California		
Lake Tahoe	6,227	744,600
Donner Lake	5,981	9,500
Martis Creek Lake	5,827	20,000
Prosser Creek Reservoir	5,745	29,800
Independence Lake	6,949	17,500
Stampede Reservoir	5,951	226,500
Boca Reservoir	5,643	41,100
Nevada		
Pyramid Lake	3,901	NA
Lahontan Reservoir	4,147	289,700

Historical evaporation rates (inches per year) for these water bodies were estimated using a simplified approach appropriate for operational purposes, and is based on combined energy and aerodynamic equations with a simple heat storage accounting procedure. The approach, termed the Complementary Relationship Lake Evaporation (CRLE) model (Morton 1986), requires monthly estimates of solar radiation, air temperature, dewpoint temperature, and estimates water 'skin' temperature, albedo, emissivity, and heat storage impacts. The CRLE approach overcomes operational challenges associated with more complex methods, and allows for robust regional and long range application with limited weather data. The CRLE model has been fairly well-tested and extensively applied in operations and modeling of open water evaporation (Huntington and McEvoy 2011). The CRLE model was also chosen for estimating WWCRA baseline and projected open water evaporation for several reservoirs in the Western U.S.

The CRLE model was used in this study to estimate future average lake evaporation rates by developing daily future solar radiation, dewpoint, and average daily temperature estimates for the six future climate ensembles. Open water evaporation and net evaporation (considers precipitation over the water body) is estimated to increase at all water bodies, with net evaporation increasing more gradually relative to historical conditions due to temperature changes. Additional information and results of CRLE modeling are in “Appendix C – Future Supply Technical Reports.”

Comparison of Historical, Current, and Future Supply

This section presents outcomes from the future hydrology modeling and compares it to the Historical supply condition and the Reference supply condition. Hydrology inputs to water operations or planning models play a significant role in analyzing water supply. Historical hydrology data effectively set expectations for, and public perception of, average water supply. Comparing potential future hydrology to a historical perception of supply gives Basin water users context in assessing the effects of climate change and how to mitigate for its impacts.

The water supply availability and timing results presented in this section illustrate potential future changes in the range, frequency, magnitude, and seasonality of water supply inflows. All of these inflow characteristics define the setting in which the Truckee Basin’s infrastructure must be operated to balance supplies and demands.

A summary of all historical and future hydrology inflows are in Table 3-6, represented as unregulated or full natural flow. Major watershed inflows above the Truckee River at Farad gage include Lake Tahoe, six other reservoirs, and three unregulated watersheds. These inflows represent 90 percent of the Basin’s water supply. Accretion/depletion inflow locations downstream from Farad and Lahontan Reservoir inflows at the Carson River near the Fort Churchill gage provide the remainder of the Basin’s water supply.

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Table 3-6. Annual Inflow by Truckee Basin Watershed

	Historical[1]			**Reference[2]**			**Warmer-Drier[2]**			**Hotter-Drier[2]**			**Hotter-Wetter[2]**			**Warmer-Wetter[2]**			**Central Tendency[2]**		
	Avg. (TAF)	**Max. (TAF)**	**Min. (TAF)**	**Avg. (TAF)**	**Max. (TAF)**	**Min. (TAF)**	**Avg. (TAF)**	**Max. (TAF)**	**Min. (TAF)**	**Avg. (TAF)**	**Max. (TAF)**	**Min. (TAF)**	**Avg. (TAF)**	**Max. (TAF)**	**Min. (TAF)**	**Avg. (TAF)**	**Max. (TAF)**	**Min. (TAF)**	**Avg. (TAF)**	**Max. (TAF)**	**Min. (TAF)**
Lake Tahoe[3]	161.7	813.0	-203.2	307.2	663.3	39.9	269.2	677.1	23.2	255.1	665.0	17.6	359.1	823.5	32.9	363.6	877.7	40.9	312.6	703.5	26.9
Truckee River Reservoirs																					
Donner Lake	28.0	61.1	7.2	30.1	70.2	9.9	27.4	71.7	7.0	26.1	66.8	5.9	34.5	90.3	9.5	34.7	85.2	11.2	30.8	80.4	8.1
Martis Creek Reservoir	18.0	54.0	4.9	18.7	43.9	4.8	16.1	43.3	3.4	14.5	39.4	2.3	21.8	55.2	4.7	22.2	56.8	5.6	18.7	47.3	4.1
Prosser Creek Reservoir	62.4	141.8	15.5	60.7	139.3	17.1	52.2	138.9	11.7	47.6	124.4	8.3	68.7	176.7	15.8	70.7	169.0	18.3	60.0	153.6	13.3
Independence Lake	17.8	34.1	5.0	17.0	41.5	3.3	15.2	44.1	2.1	14.9	42.0	1.7	19.9	55.4	4.0	20.0	51.2	4.1	17.5	47.4	2.6
Stampede Reservoir	106.6	289.7	18.6	111.7	342.4	12.2	97.8	368.5	8.1	93.3	336.7	6.4	141.1	473.3	14.9	140.7	428.9	16.1	117.7	395.9	10.2
Boca Reservoir	5.6	58.4	0.1	8.9	34.2	0.7	7.7	36.8	0.5	7.1	31.1	0.5	12.0	47.9	0.7	11.9	43.2	0.8	9.6	39.2	0.6
Unregulated Inflows Above Farad																					
Truckee River Below Lake Tahoe Inflow	70.1	190.6	14.1	74.5	179.6	16.3	68.2	185.2	10.0	65.9	174.5	7.6	88.9	240.4	17.1	88.4	222.8	20.1	78.1	209.1	13.1
Donner Creek Below Donner Lake Inflow	27.0	76.2	5.2	28.0	66.4	8.7	25.5	67.7	5.8	24.3	63.1	4.7	32.3	85.7	8.3	32.5	80.8	9.8	28.7	76.0	6.9
Remaining Sidewater	61.4	146.8	13.6	68.7	183.5	14.0	60.9	194.1	9.6	58.0	179.2	7.5	84.7	251.5	14.9	84.4	230.4	17.2	71.8	211.9	11.7
Inflow Downstream from Farad[4]																					
Farad To Mogul	14.3	70.4	0.9	15.7	51.1	1.7	12.1	41.8	0.9	8.2	29.7	0.7	17.4	52.3	1.0	19.8	76.4	1.4	14.0	46.4	0.9
Mogul To Reno	3.2	21.7	-1.4	3.9	14.9	-0.7	2.7	12.6	-7.3	1.3	8.7	-7.2	4.3	15.6	-6.8	5.2	22.7	-1.7	3.3	13.7	-6.8
Reno To Sparks	0.8	1.8	0.1	0.8	1.6	0.4	0.7	1.4	0.3	0.6	1.3	0.3	0.8	1.6	0.3	0.9	2.0	0.4	0.7	1.4	0.3
Sparks To Vista	0.0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vista To Derby	1.2	3.1	0.3	1.2	2.8	0.6	1.0	2.3	0.3	0.9	1.8	0.3	1.2	2.7	0.3	1.3	4.0	0.5	1.1	2.4	0.3
Lahontan Reservoir	277.1	804.6	26.3	258.2	678.7	49.1	202.8	514.6	32.6	169.4	427.6	23.5	257.4	638.8	43.5	283.5	683.3	53.8	226.0	556.9	38.0

Notes:
Reservoir inflows are not cumulative. Inflow is from contributing watershed between reservoir and upstream reservoir(s).
Inflows downstream from Farad include stream net accretions and depletions. Negative values indicate the river is losing more water than gaining via ungaged diversions or infiltration.
Inflow to Pyramid Lake is a reflection of upstream operations – as such, it is impossible to present inflow to Pyramid Lake as strictly a hydrologic phenomenon. For this reason, Pyramid Lake is not included in this table; discussions of inflow to Pyramid Lake are presented in subsequent chapters.
[1] Water Years 1913-2000
[2] Water Years 2012-2099
[3] Historical values for inflow to Lake Tahoe include evaporation and other losses, causing negative values in some years.
[4] Negative streamflow values result from depletions exceeding accretions.

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Water Supply Availability

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, the distribution and magnitude of precipitation resulted in Lake Tahoe's outlet being the source of about 30 percent of the Truckee River's flow. Forty percent of flow is regulated by other Federal and non-Federal reservoirs located in California and the remaining 30 percent is unregulated. The existing infrastructure and water policies were built to manage this historical distribution and range of water supply. The following subsections describe how potential future changes in precipitation would affect hydrology inflows and groundwater recharge at select locations.

Lake Tahoe Inflows

Average annual net inflow to Lake Tahoe has been approximately 162,000 acre-feet, historically. Historical Lake Tahoe inflow data is considered a net inflow because it is calculated from ungaged streamflow estimates and measurements of lake releases, evaporation, and lake elevations. This net inflow calculation complicates direct comparisons to monthly inflows in the Reference supply condition.

Projected changes in future climate under the Central Tendency would increase average annual inflow to Lake Tahoe by approximately 2 percent compared to the Reference supply condition. Other future climates would decrease or increase inflow by approximately 18 percent. Changes in inflow are driven by the extent to which precipitation changes, although hotter conditions will reduce Lake Tahoe storage through a higher rate of evaporation. Changes in extreme annual runoff values would also mirror precipitation changes, with drier climates producing lower minimum annual inflows and wetter climates producing higher maximum annual inflows.

Truckee River at Farad Gage Inflows

Truckee River inflows at the Farad gage are characterized in the Basin Study independent of Lake Tahoe inflow due to differing model assumptions and operations. Inflows at Farad described in this section do not include releases from Lake Tahoe, only inflows originating between Lake Tahoe and the Farad gage. The main tributaries providing 60 percent of historical inflow at Farad are Donner, Martis, and Prosser creeks and the Little Truckee River. The remaining inflow was produced from unregulated drainage areas.

Inflows at the Farad gage typically peak in May for both the Historical and Reference supply conditions, and the Reference supply condition would have slightly more inflow on average than historical conditions (Table 3-7 and Figure 3-31). The Central Tendency would be wetter (3 percent on average) than the Reference supply condition, especially in the Little Truckee River watershed (see Stampede and Boca reservoirs in Table 3-6). Projected future changes in climate would produce between 85 to 120 percent of inflow compared to the Reference supply condition.

Similar to Lake Tahoe inflows, wetter futures, regardless of temperature, would produce more inflow. None of the future climates would likely change the spatial distribution of precipitation in the watershed, and the methods for modeling distribution of precipitation preserves many of these local relationships. Thus, for all the simulated ensembles the historical 60 percent of inflow continues to originate from regulated tributaries.

Table 3-7. Monthly Average Inflow at Farad Gage (excluding Lake Tahoe Releases) for Historical and Reference Supply Conditions

Monthly Average Inflow (acre-feet)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Historical Supply Condition	688	775	1,250	2,425	3,338	2,121	638	227	269	281	431	594
Reference Supply Condition	844	931	1,488	2,617	3,295	1,991	620	251	202	308	503	699

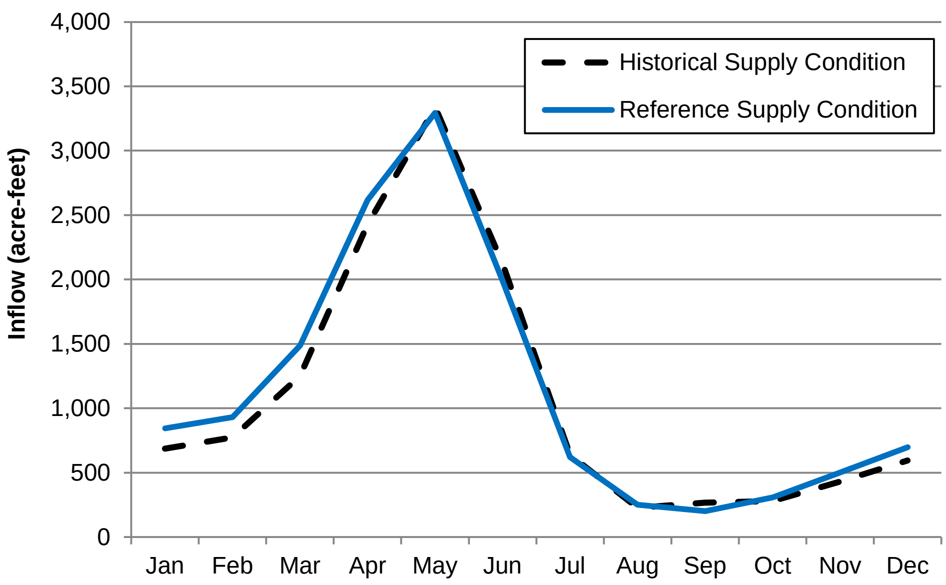

Figure 3-31. Comparison of Monthly Average Inflow at Farad Gage (excluding Lake Tahoe Releases) for Historical and Reference Supply Conditions

Carson River Inflow to Lahontan Reservoir

Historic annual discharge of the Carson River to Lahontan Reservoir (measured at Fort Churchill) ranged from a high of 804,600 acre-feet in 1983 to a low of 26,260 acre-feet in 1977. Average annual discharge to Lahontan Reservoir was 277,000 acre-feet per year for the period of 1913 to 2000. The Reference supply condition would have 7 percent less inflow on average than historical conditions but would have a similar temporal distribution (Table 3-8 and Figure 3-32).

Future climate change under the Central Tendency ensemble would decrease average annual inflow to Lahontan Reservoir by 12.5 percent compared to the Reference supply condition. Other climate conditions would decrease or increase Carson River inflow to Lahontan Reservoir by 34 or 10 percent, respectively, compared to the Reference supply condition. Wetter climates would produce more inflow.

Table 3-8. Monthly Average Inflow to Lahontan Reservoir for Historical and Reference Supply Conditions

Monthly Average Inflow (acre-feet)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Historical Supply Condition	684	789	832	1,140	2,199	1,887	485	65	33	123	346	537
Reference Supply Condition	303	961	669	755	2,182	1,997	519	311	195	265	131	225

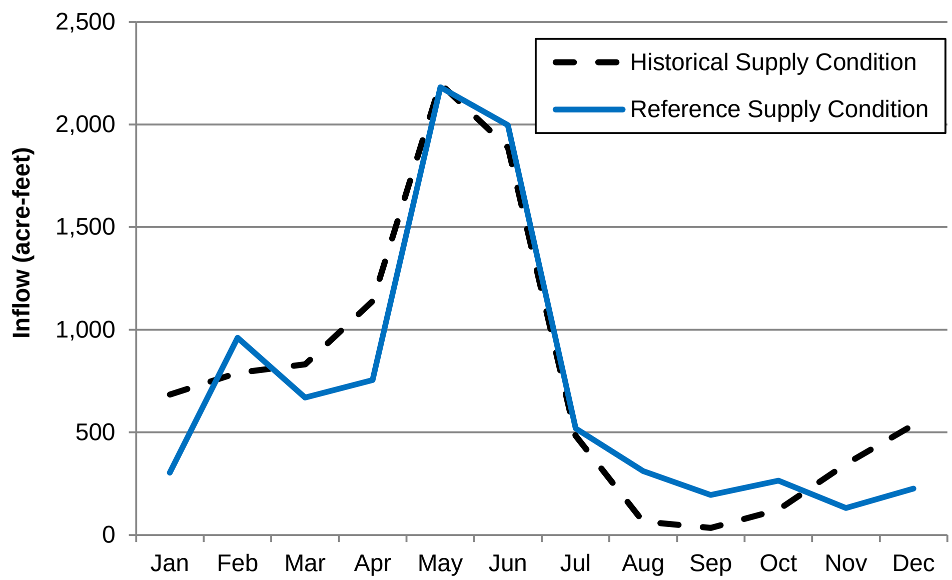

Figure 3-32. Comparison of Monthly Average Inflow at Farad Gage (excluding Lake Tahoe Releases) for Historical and Reference Supply Conditions

Groundwater Recharge

Average annual groundwater recharge would change with changes in precipitation, however a direct comparison between Historical and Reference supply conditions cannot be made because a record of historical recharge data does not exist for the Truckee Basin. Simulated rates of recharge under the Central Tendency, which are based on simplified representations of groundwater processes in PRMS, would result in about 5 percent less recharge than the Reference supply condition. Decreases in the Martis Valley under drier climates (up to 23 percent) and increases under wetter climates (up to 9 percent) would occur compared to the Reference supply condition. Hotter climates would also affect groundwater recharge, although to a lesser extent than precipitation changes. The Hotter-Drier climate would decrease Martis Valley groundwater recharge an additional 10 percent beyond the Warmer-Drier climate due to decreases in the extent of snowpack and a faster snowmelt season. Recharge results for the Martis Valley are displayed in Figure 3-33.

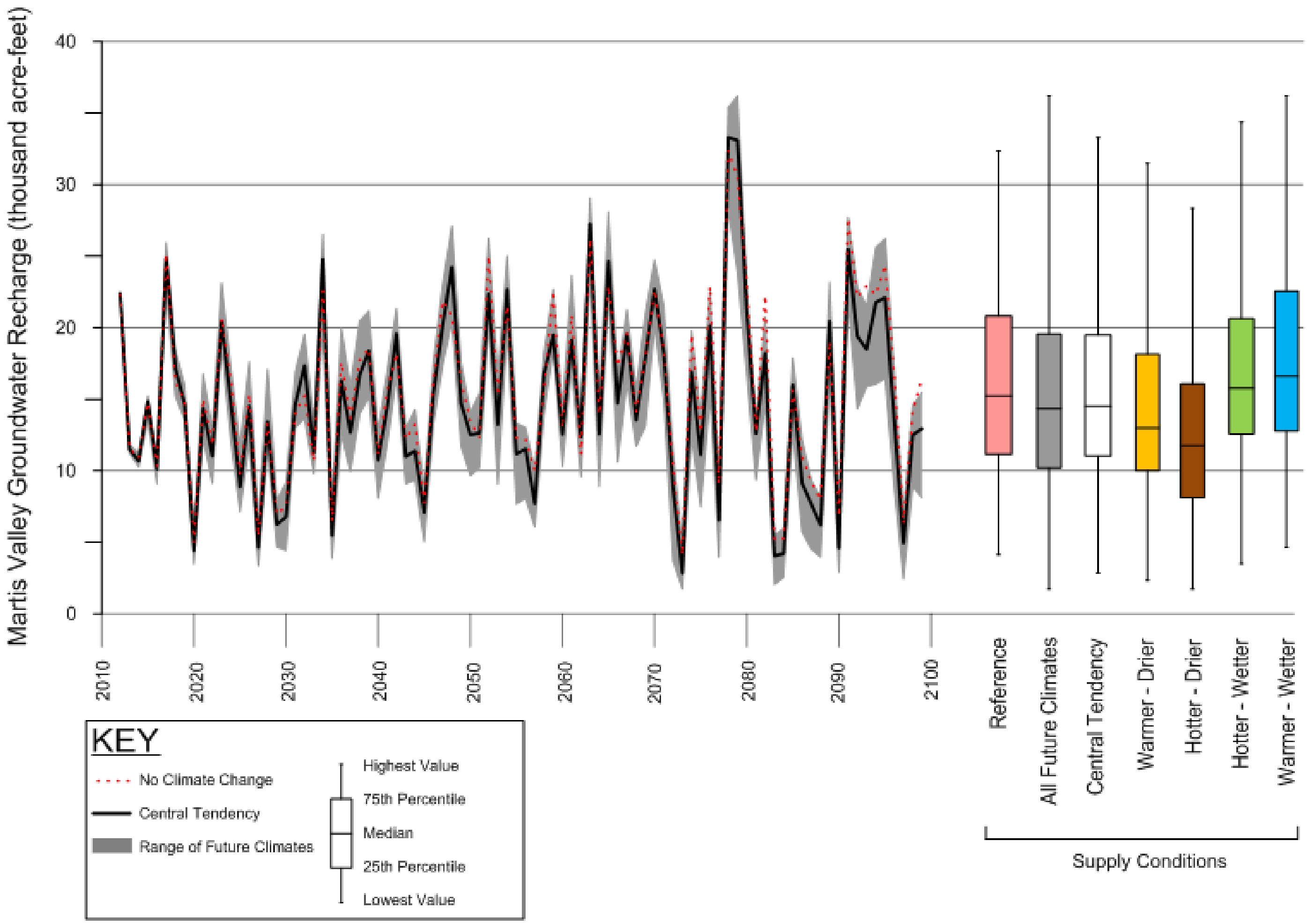

Figure 3-33. Comparison of Annual Recharge for the Martis Valley

Water Supply Seasonal Timing

Changes in temperature would also have complex and 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 conditions, the 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.

Sierra Snowpack

Snowpack in the Sierra Nevada range is expected to steadily diminish in comparison to historical and Reference supply condition simulations over the coming century as the climate of the Truckee Basin warms. Figure 3-34 provides a time series comparison of historical and future snow water equivalents for the Truckee Basin upstream of the Farad gage, along with a statistical summary of historical conditions, the Reference supply condition, all future climate change ensembles, and each ensemble separately.

For this plot, historical snow water equivalents are simulated using historical climate data to run the PRMS model. A much greater variability (i.e., a greater span between the 25^{th} and 75^{th} percentile) is apparent in the historical period in comparison to the Reference supply condition, even though the historical has a much shorter period. The compressed variability of the Reference supply condition likely stems from the differences between the two climate time series (see "Selection of the Reference Supply Condition" section), which creates a small but noticeable statistical mismatch with the historical conditions. As previously noted, while comparisons between historical and future climate change ensembles is possible, some of the differences may result from the process used to generate the data, and not necessarily from anticipated changes in the climate. However, the process used to generate the Reference supply condition is identical to that applied to develop the future climate ensembles, which allows for direct comparison between and among them.

Snow covered area is primarily affected by temperature, which is why the median snow water equivalent of the Central Tendency is less than the Warmer-Drier climate ensemble. Even under wetter conditions, hotter conditions would decrease the amount of precipitation that falls as snow, and would increase the speed of snowpack melt. For this reason, among the future climate change ensembles, the Warmer-Wetter climate ensemble shows the least loss of snow pack and the Hotter-Drier shows the most. Notably, the median snowpack for all ensembles is less than the lower percentile of snowpack for the Reference supply condition, and the upper percentile for all ensembles is less than the median for the Reference supply condition.

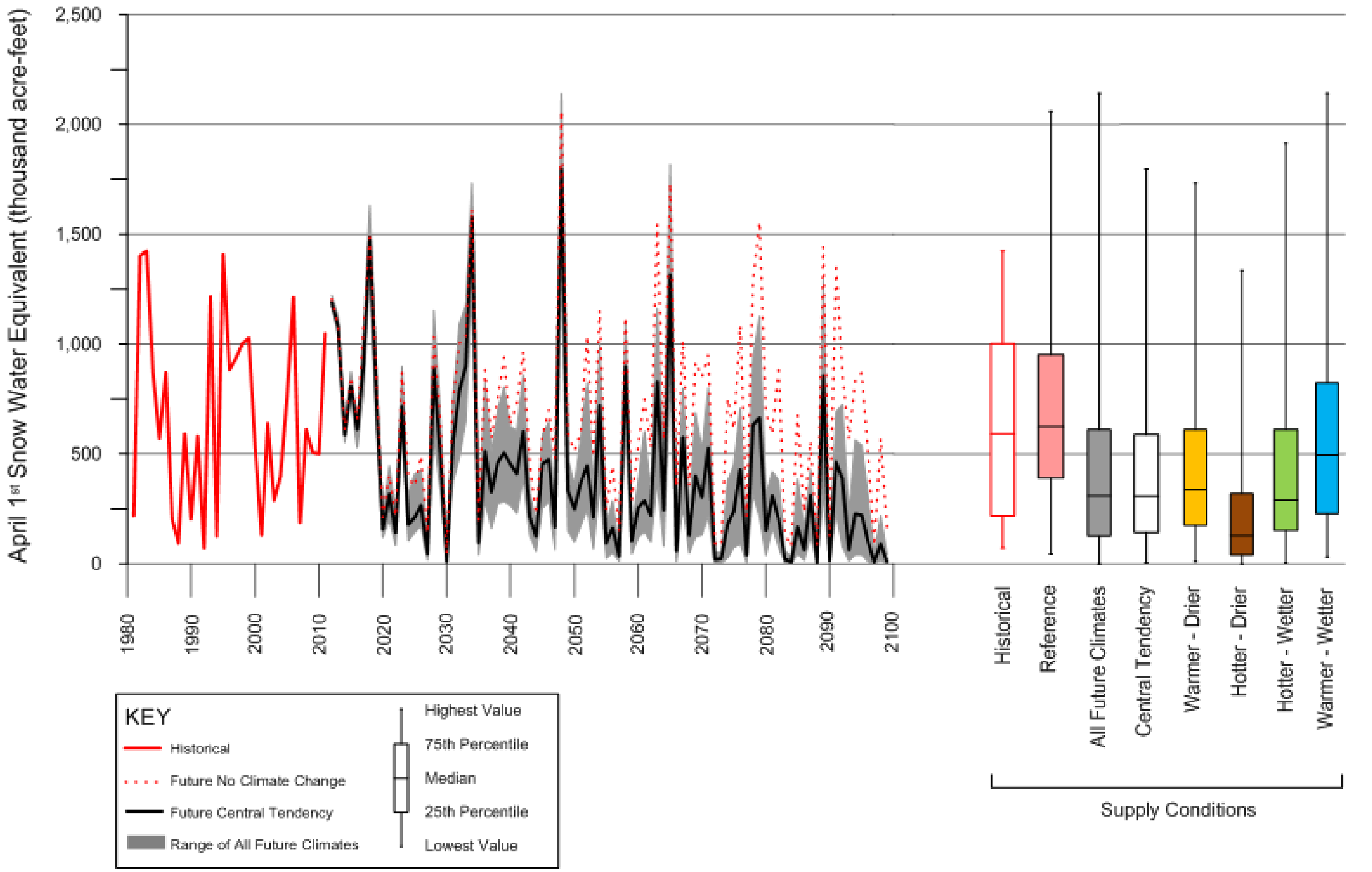

Figure 3-34. Comparison of Simulated Historic and Future April 1st Snow Water Equivalent for the Truckee Basin Upstream of Farad Gage Station

Lake Tahoe Inflows

Peak snowmelt runoff in the Lake Tahoe Basin has historically occurred in May and June, which is slightly later than other areas in the Truckee Basin because its higher elevations retain snow later into the spring and summer. The future climate ensembles would maintain this general pattern during the early twenty-first century (Figure 3-35). However, 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 (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.

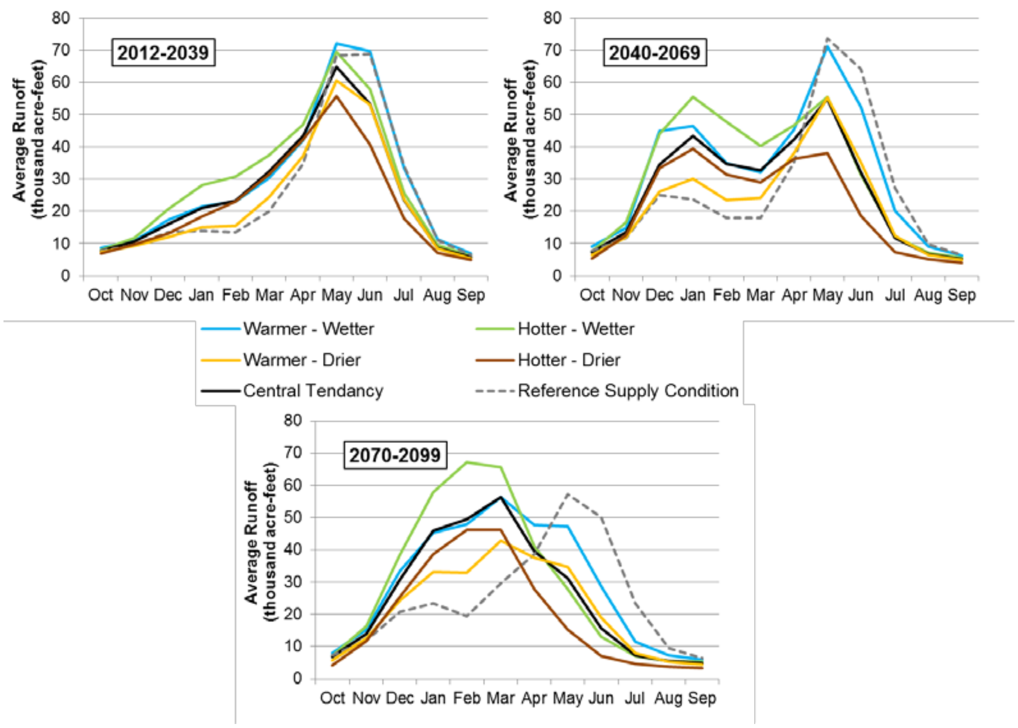

Figure 3-35. Monthly Average Runoff in Lake Tahoe Basin for Water Years 2012 – 2039, 2040 – 2069, and 2070 – 2099

Truckee River at Farad Gage Inflows

Peak snowmelt runoff in the Truckee River below Lake Tahoe has historically occurred in April and May. As seen previously in Figure 3-31, this pattern is also seen in the Reference supply condition. The future climate change ensembles would maintain this general pattern during the early twenty-first century (Figure 3-36). However, as snowpack and snowmelt patterns change with increasing temperatures through the end of the century, the peak runoff period shifts toward the months with higher precipitation, peaking consistently in March. The timing and trends observed in the average hydrology for Lake Tahoe are also evident at the Farad gage.

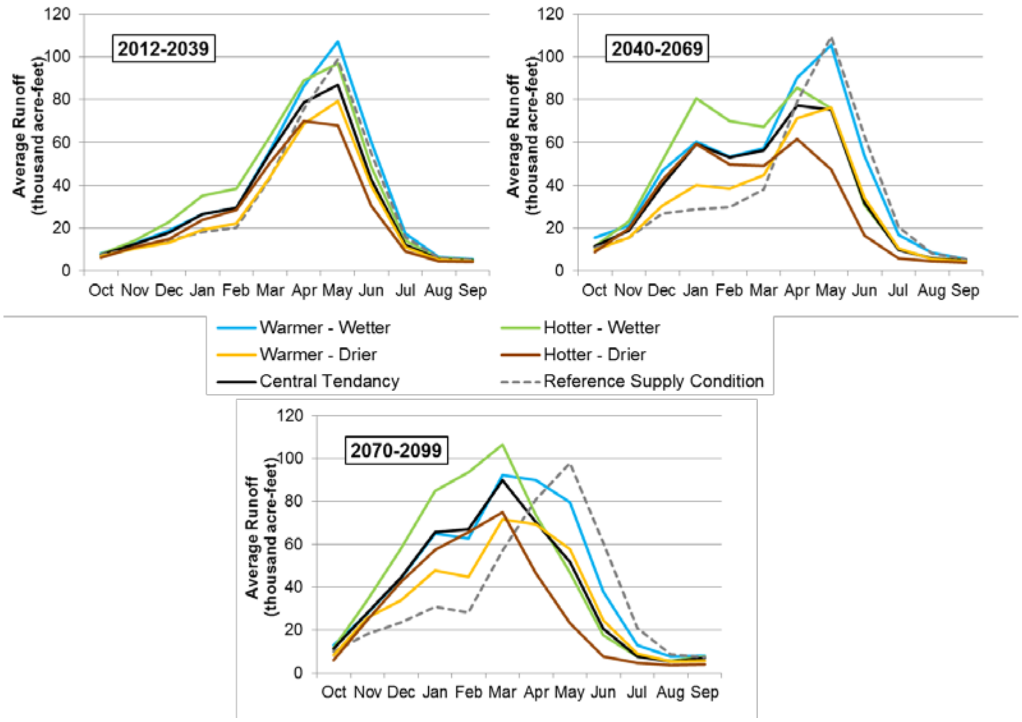

Figure 3-36. Monthly Average Runoff at Truckee River at Farad Gage for Water Years 2012 – 2039, 2040 – 2069, and 2070 – 2099

Carson River Inflow to Lahontan Reservoir

Peak snowmelt runoff in the Carson River at Fort Churchill has historically occurred in May and June. As seen previously in Figure 3-32, this pattern is also seen in the Reference supply condition. The future climate ensembles would maintain this general pattern during the early twenty-first century (Figure 3-37). However, as snowpack and snowmelt patterns change with increasing temperatures through the end of the century, the peak runoff period shifts toward the months with higher precipitation, peaking consistently in February for most climate ensembles.

The double-peak appearance of the Carson River hydrology towards the end of the century stems from the use of a regression-model approach. The Carson River regression models are based upon historical correlations (1950 through 2000) between flows in the Truckee and Carson rivers, and do not take into account physical processes such as snow accumulation and melt that are sensitive to future changes in temperature and precipitation. In this case, the regression equations for the Carson River appear to maintain high peak conditions in May in some future climate ensembles because low flows in the Truckee River watersheds in May have nevertheless resulted in a spring pulse flow on the Carson River. Thus a peak appears to occur on the Carson in May, even though the physical conditions needed to produce a spring pulse are unlikely to exist in the Carson Basin toward the end of the century. The regression models for each month are also built around different watersheds in the Truckee River Basin (see "Appendix C – Future Supply Technical Reports"), and may also be limited when applying future climate change runoff patterns to historical correlations.

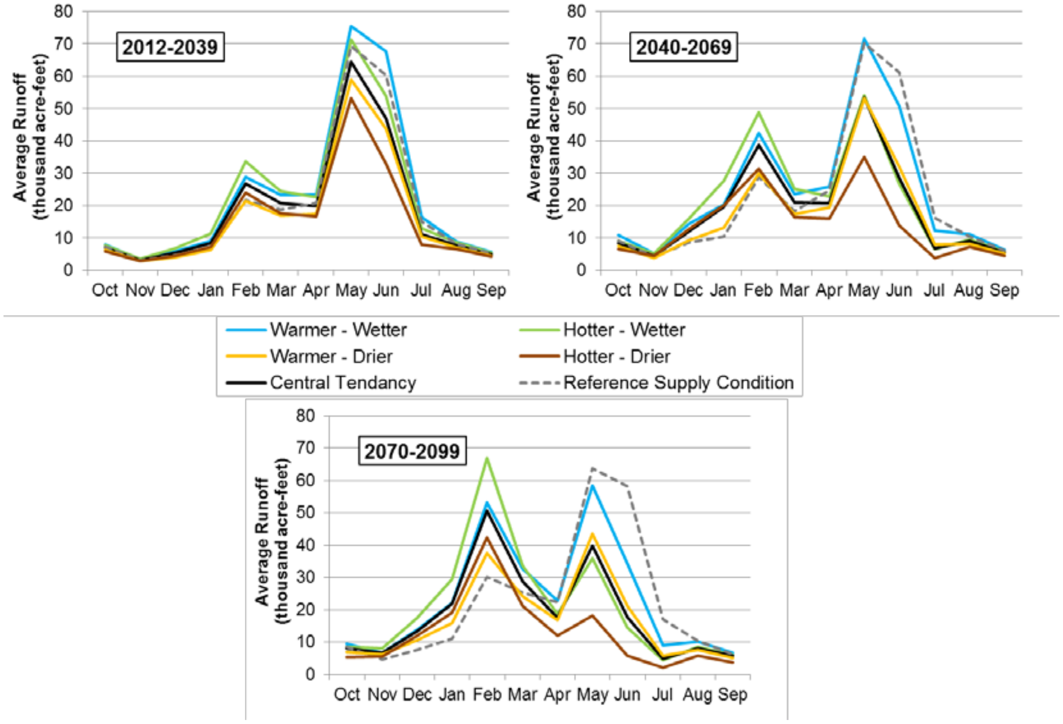

Figure 3-37. Monthly Average Runoff at Carson River at Fort Churchill Gage for Water Years 2012 – 2039, 2040 – 2069, and 2070 – 2099

Lake Evaporation

The Truckee Basin is especially sensitive to climate change because of Lake Tahoe's unique water balance. Lake Tahoe's annual evaporation as a percentage of its useable volume is far and away the highest of all reservoirs due to the fact that most of its storage is unavailable to release.

Figure 3-38 provides a timeseries comparison of future evaporation at Lake Tahoe, along with a statistical summary of the Reference supply condition, all future ensembles, and each ensemble separately. Annual evaporation is shown in inches rather than acre-feet because the total volume of evaporation depends on the lake's elevation and actual surface area. For example, Lake Tahoe has a surface area of approximately 120,000 acres. Given this area, the median annual evaporation of 46 inches under the Reference supply condition would result in a loss of 460,000 acre-feet per year, on average. In comparison, the greatest annual evaporation among the future climate change ensembles is 54 inches; at peak elevation, this would result in a loss of 540,000 acre-feet per year (17 percent higher). The operation of Lake Tahoe influences its surface area, and thereby the losses experienced at the lake. Those effects are explored in greater detail in "Chapter 6 – Risk and Reliability Assessment" and "Chapter 7 – Responses to Risks."

As shown in Figure 3-38, in general, evaporation rates increase over the coming century as the climate of the Truckee Basin warms. Among the future climate ensembles, the Warmer-Wetter shows the least increase in evaporation and the Hotter-Drier shows the most. Notably, the median for all ensembles is greater than the highest percentile of the Reference supply condition, and the lowest percentile for all ensembles is greater than the median.

The trends shown for Lake Tahoe are similar to those seen across the Truckee Basin.

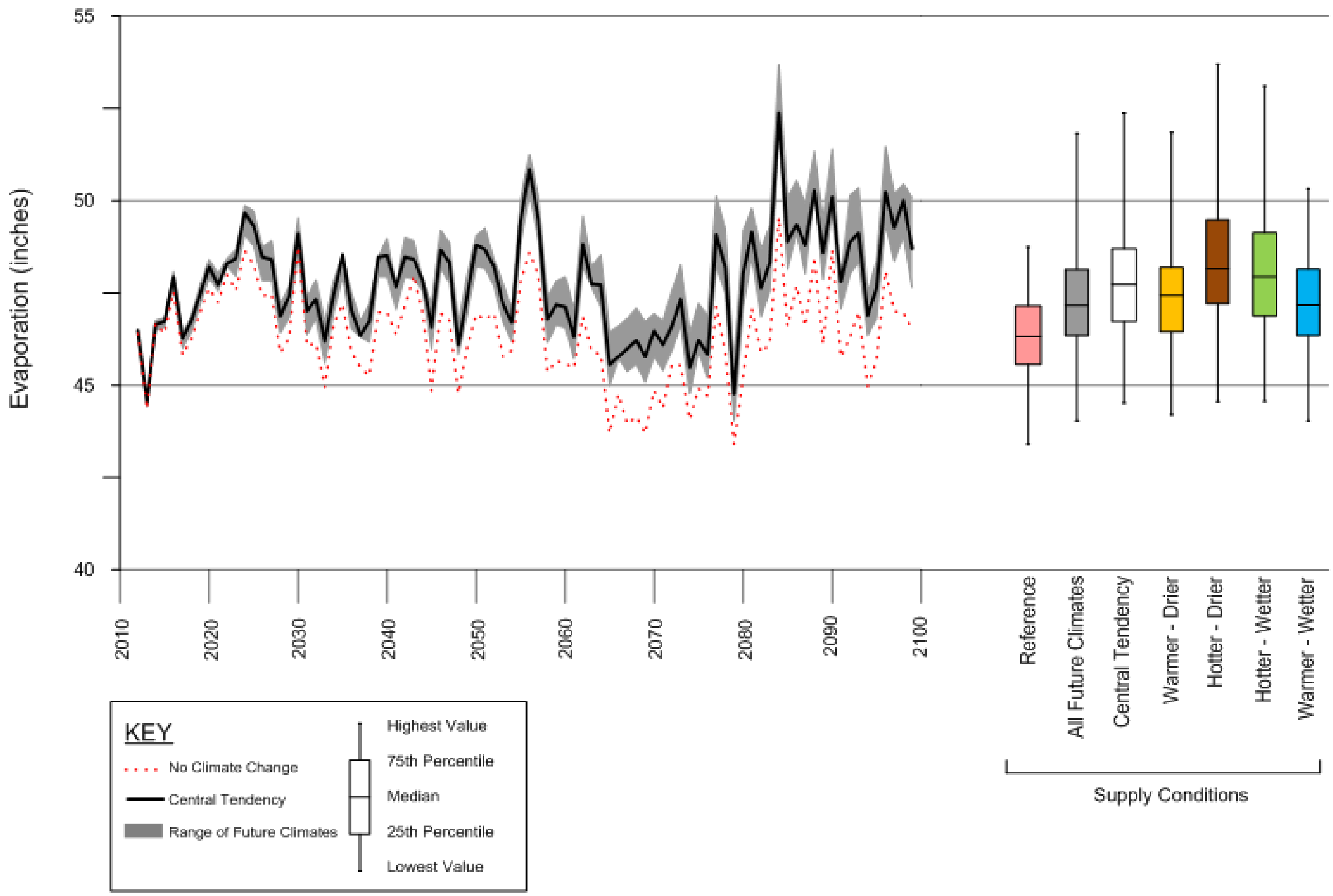

Figure 3-38. Comparison of Future Annual Evaporation Rates from Lake Tahoe

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Chapter 4 Water Demand Assessment

Identifying the range of potential future risks to the Truckee Basin's water supply and water users requires both an understanding of the future supply that may be available and the extent of future needs for water in the Basin.

The Truckee Basin's water rights are highly regulated and its water uses have been carefully planned for by local communities, tribes, the states of California and Nevada, and the Federal government. Nonetheless, certain challenges exist for assessing current and future water demands in the Basin. Some of these challenges are unique to the Truckee Basin, while others are universal and unrelated to the region's specific conditions, characteristics, or history.

First, a multitude of entities maintain information about water use and service in the Truckee Basin, including dozens of utilities around Lake Tahoe and in the California portion of the Basin. Individually quantifying and assessing each entity's water rights and demands would require thorough study beyond the scope or purpose of the Basin Study. Additionally, the linkages between water use and population growth are complex and related to a number of different factors, and calculations of changes in per capita water use are also not standardized across all municipalities, making cross-comparisons potentially misleading. Thus, instead of trying to predict how demographic changes will affect future water demand, the Basin Study's demand assessment relied on a general understanding of different types of water users' behaviors and goals to estimate how and when water rights and allocations will be exercised in the future. This understanding is based both on review of previous studies and reports and stakeholder input. The Basin Study assumed that, as the Basin's water rights are fully adjudicated, all adjudicated water rights will be exercised at some point in the future.

Another challenge is the ongoing debate and disagreement regarding which Truckee Basin water rights may be called upon and used. Mile-for-mile, the Truckee River is considered one of the "most litigated" and fought-over streams in the U.S. Conflicts over control of its use began around the turn of the twentieth century, and long-standing disagreements between farmers, cities, tribes, and others regarding which rights and uses are valid and legitimate continue today. This makes establishment of widely accepted estimates of current and future demand very difficult. A notable exception to this condition is TROA, which identified agreed-upon demand estimates for many Basin water users. To address this challenge, the Basin Study relied heavily on information developed for TROA for the demand assessment in this chapter. Additionally, the Basin Study team sought stakeholder input and review of the demand assessment to ensure the estimates were acceptable to Basin communities and consistent with their own plans for the future.

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 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 Basin.

> **Storyline:** A narrative description of future conditions that would have an effect on water use in the Truckee Basin. These qualitative descriptions are used to develop quantitative

The storyline-development method for assessing water demands supports the Basin Study's scenario planning approach described in "Chapter 2 – Scenario Planning and Supporting Information." 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 Basin in the future.

The Basin Study constructs scenarios from three components: a supply condition (see "Chapter 3 – Water Supply Assessment"), a demand condition, and a water management condition. The demand condition describes the consumptive uses of water in the Basin as determined through the water demand assessment summarized in this chapter. The Basin Study's water demand assessment included development of three distinct demand conditions shown in Figure 4-1:

- A Reference condition represented by records of demand from the year the Basin Study began.
- Two future demand conditions representing the outer bounds of future growth and estimated using the storylines described in this chapter.

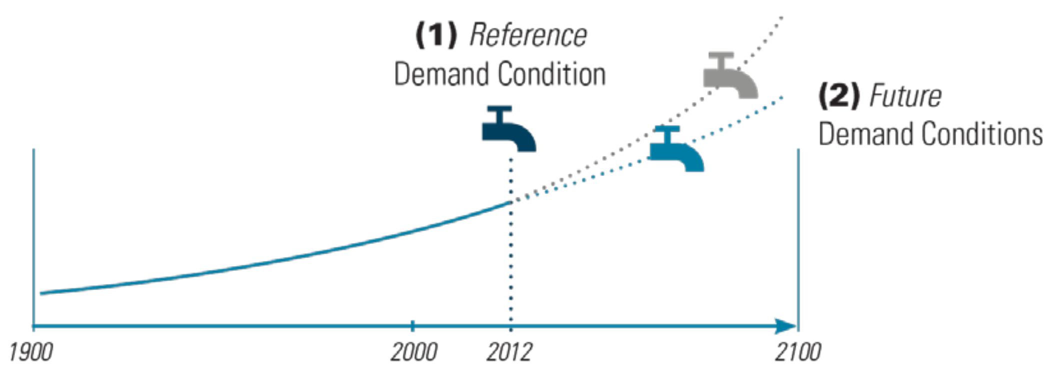


Figure 4-1. Demand Conditions Developed for the Basin Study

The Basin Study did not develop a historical demand condition for two reasons: (1) it is unlikely that demand will decrease in the future, making a comparison with historical demand not instructive for study purposes; and (2) in the past, diversions from the Truckee River were not always consistent with the established, adjudicated water rights, which could result in an artificially high assessment of historical demand levels.

The future demand conditions are used variously throughout this Report to construct scenarios, reveal vulnerabilities related to the Basin's water resources, and test options for preserving the Reference condition-level of water supply reliability for different water users.

This chapter presents the process to develop storylines that represent both current conditions and the range of plausible future conditions in the Basin. Narrative descriptions of each storyline and a quantitative assessment of water demand for different water users under all three demand storylines are also presented.

Truckee Basin Water User Communities

The Basin Study relied on the use of five distinct "water user communities" to capture variation in water use and water resources concerns throughout the Basin. This also allows for presentation of analyses and results in a simplified format that reflects geographic and other distinctions that may be familiar to water users and other readers of this Report.

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. Thus, even where the Basin Study 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 for each community are very general and defined by preexisting land-use, ownership, or hydrologic boundaries. This format is also intended as a shorthand approach to allow readers to quickly identify the portions of the Report most relevant to their interests.

The assessment summarized in this chapter presents the Reference and future demand estimates for each of the following water user communities:

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

Development of Demand Storylines

The Basin Study used the California Water Plan as a model for developing demand storylines based on stakeholder input (California DWR 2013). This process included several steps:

1. **Initial identification of potential drivers of future demand.** A “driver” is a condition or characteristic that affects demand for water in a given area. The Basin Study identified several categories of drivers:

    - Economic and Financial
    - Institutional and Political, including the recovery of listed species
    - Natural Systems
    - Technological
    - Social Values and Pursuits

2. **Meetings with agencies to discuss potential drivers of future demand.** Once initial drivers were identified, meetings were held with multiple agencies with water or planning-related statutory responsibilities in the Truckee Basin to discuss drivers and obtain sources of information for developing assessments of the existing demands.

3. **Development of draft future demand storyline.** Using the input obtained during meetings with agencies, the Basin Study developed two draft storylines to bracket the potential high and low extents of future demand. Agency feedback indicated that the economy was expected to be the primary driver of future water demand, and thus the two future demand storylines are focused on describing different economic conditions that could occur in the Basin.

4. **Review of draft future demand storylines by agencies**. Once the demand storylines had been developed in draft form, they were distributed to the agencies along with a feedback form for providing input (see “Appendix A – Engagement Record”). Following this review, the demand storylines were revised.

5. **Quantification of demand storylines**. Using the sources of demand information provided by the agencies and identified in the review of previous studies and reports (see “Chapter 2 – Scenario Planning and Supporting Information”) a quantitative depiction of current and future demand was developed for Basin water user communities.

6. **Review of quantified demand storylines by agencies**. The quantified demand storylines were circulated for review by the agencies and revised using feedback received.

Through this process, two storylines were developed to represent potential future water demand in the Basin, and one demand storyline was developed to represent current water demand in the Basin:

- **Reference**: This storyline represents current demand as of 2012, when the Basin Study began. It represents a snapshot in time and thus includes no future growth.
- **Existing Trends**: This future demand storyline is based on the type of growth experienced in the late 2000s (post-recession). It represents a lower bound for water use and diversions.
- **Robust Economy**: This future demand storyline is based on the type of growth experienced in the late 1990s and early 2000s (pre-recession). It represents an upper bound for water use and diversions in the Truckee Basin.

Reference Demand

The Reference demand storyline represents existing consumptive demand in the Truckee Basin. This storyline reflects demand water conditions that were current in 2012, the year the study began, and serves as a basis of comparison with future demand storylines. In this storyline, demands are held constant throughout the study period (2012 – 2100). For comparing results from the two future demand storylines, the Reference demand storyline assumes that TROA has been implemented and is being administered by the signatory parties. Under the Reference demand, water demand in the Truckee Basin is represented by a full range of uses: municipal and industrial, agricultural, hydropower, recreation, and ecosystem and environmental purposes. Although they are also described qualitatively in this chapter, ecosystem demands are held constant across all demand storylines.

Recent Records of Water Use

Records of water use present important context for the volatility in demand over time and the perceptions for near- and long-term changes in water use. The following sections present sources of information that describe water use and were used to develop the Reference demand condition.

Lake Tahoe, California and Nevada

Potable water in the Lake Tahoe Region is pumped, treated, and delivered by nearly 60 public and private water purveyors and numerous private sources. Implementation of TROA would make interstate allocation enter into effect for the Tahoe Region, with a cap of 34,000 acre-feet per year, and reporting requirement for each state.

Annually, the California Department of Water Resources collects and summarizes water delivery records for the California-based water agencies surrounding Lake Tahoe. Records are kept in preparation for compliance requirements under TROA. To date, these reports have not been published because of delays in the implementation of TROA. Specific trends and water use records were provided by the California Department of Water Resources for use in the Basin Study (California DWR 2014).

Annually, the Nevada Department of Conservation and Natural Resources (Nevada DCNR) collects and publishes pumpage (also called water use) inventory for watersheds across Nevada. The inventories are intended to improve management of water resources and demonstrate compliance with applicable laws. Inventories are based on reported information, field verifications, and approximations of domestic well uses.

Records of total Nevada water use for the Lake Tahoe watershed are published online.[1] Nevada reported that patterns of demand over time reflect upgrades to water delivery systems, variations in weather, and changes in land use (Nevada DCNR 2014). The water use reports published note that weather influences demand for water in that longer winters reduce the total volume of water applied to maintain residential lawns. The predominant changes in land use reported were residential infill, where existing residences are refurbished to larger homes and likely demand additional water.

Truckee River, California

As with the Lake Tahoe watershed, the California Department of Water Resources collects and summarizes water delivery records for the California water agencies along the Truckee River, downstream from Lake Tahoe to the Nevada border. Records are kept in preparation for compliance requirements under TROA. To date, these reports have not been published because of delays in the implementation of TROA. Specific trends and water use records were provided by the California Department of Water Resources for use in the Basin Study (California DWR 2014).

Truckee Meadows, Nevada

The TMWA maintains comprehensive records of water diversions and deliveries for its retail service area in Washoe County, Nevada. These records were provided by TMWA for use in the Basin Study.

Truckee River Ditches, Nevada

The Federal Water Master's office in Reno, Nevada, maintains records of water diversions and deliveries for agricultural water rights holders along the Truckee

[1] http://water.nv.gov/data/pumpage/?basin=090

River for administration of the *Orr Ditch* Decree. These records were provided for use in the Basin Study.

City of Fernley and Newlands Project, Nevada

Reclamation maintains records of water diversions and deliveries to the Newlands Project for the administration of the project's 1997 OCAP. These records were provided for use in the Basin Study.

Pyramid Lake Indian Reservation, Nevada

The Federal Water Master's office in Reno, Nevada, maintains records of water diversions and deliveries for agricultural water rights holders to the Pyramid Lake Paiute Tribe for administration of the *Orr Ditch* Decree. These records were provided for use in the Basin Study.

Reference Demand by Water User Community

The Reference demand for each of the Basin's water user communities is described in the sections that follow, along with brief descriptions of water user community locations.

Lake Tahoe Basin

The "Lake Tahoe Basin" water user community is located between the Carson Range on the east and the Sierra Nevada on the west, and is divided by the California-Nevada state line (Figure 4-2). Roughly one-third of the basin area is in Nevada and two-thirds in California, for a total land area of about 202,000 acres (TRPA 2012). Lake Tahoe, the basin's prominent feature, is about 12 miles wide and 22 miles long, with a surface area of 192 square miles and 75 miles of shoreline (TRPA 2012). Maximum elevation of the lake's surface is 6,229 feet above sea level. Steeply sloping mountains (up to nearly 11,000 feet above sea level) surround the lake, with a few flat or moderately sloping areas surround the lake, offering limited accessibility for development. The drainage area upstream from Lake Tahoe Dam is 506 square miles.

Figure 4-2. Location of the Lake Tahoe Basin Water User Community

Current demands at Lake Tahoe include M&I water uses for various public utilities and public and commercial recreational facilities. The Basin Study evaluates water demand for the Lake Tahoe Basin as a single depletion of water to account for surface and groundwater depletions made by water users in California and Nevada.

About 60,000 people live in the Lake Tahoe Basin, with more than 50 percent of employment in the service and recreational industry. Adjacent recreational lands and facilities are primarily owned and managed by U.S. Department of Agriculture Forest Service (USFS), the states of California and Nevada, local entities, such as North Tahoe Public Utility Department and Tahoe City Public Utility Department, and South Lake Tahoe. Intermingled with the government-operated areas are privately owned and operated campgrounds, marinas, golf courses, hotels, restaurants, casinos, and numerous resorts and other commercial businesses. Lake Tahoe Basin demands are met by various local utilities, including Incline Village General Improvement District, North Tahoe Public Utility District, Tahoe City Public Utility District, and South Tahoe Public Utility District, as shown in Table 4-1.

Table 4-1. Municipal Water Districts and Systems in the Lake Tahoe Basin

North Tahoe	
Fulton Water Company	North Tahoe Public Utility District
Links System	Dollar Cove System
Cedar Flat System	Carnelian System
Agate Bay Water Company	Tahoe Marina/Estates
Miscellaneous Domestic Water Systems	Tahoe Vista, Kings Beach, Brockway System
Tahoe City-West Shore	
Tahoe City Public Utility District	Talmont Estates
Dollar Point	Ward Creek
Tahoe City	Ward Well
Rubicon Properties	Tahoe Pines
Alpine Peaks	Tahoe Swiss Village
McKinney Shores	Madden Creek
Rubicon Palisades/Tahoe Hills	Quail Lake
Fulton Water Company-Panorama	McKinney Water District
Lake Forest	Tahoma Meadows
Tahoe Sierra Estates	Tahoe Cedars
Timberland	Water's Edge Condominiums
Skyland	Meeks Bay Vista
Glenridge	Tamarack
Lakeview Water Company	Miscellaneous and private water systems
Lake Park Terrace	State Parks
Tahoe Park	U.S. Forest Service
Tahoe Park Heights	
South Tahoe	
South Tahoe Public Utility District Service Area	Tahoe Paradise Water and Gas Company Service Area (now owned by South Tahoe Public Utility District)
Lakeside Service Area	North Fallen Leaf Lake Area
Tahoe Keys Service Area	South Fallen Leaf Lake Area
Lukins Service Area	Echo Lake Area
Angora Service Area (now owned by South Tahoe Public Utility District)	Miscellaneous private users

Table 4-1. Municipal Water Districts and Systems in the Lake Tahoe Basin (contd.)

Douglas County	
Kingsbury Water Company Edgewood Water Company Round Hill General Improvement District Elk Point County Club U.S. Forest Service, Nevada Beach Camp Galilee Presbyterian Conference Point Zephyr Cove Water Company Zephyr Cove Lodge	Skyland Water Company Eickmeyer Water Company Snug Harbor Water Company Zephyr Cove Schools Zephyr Cove Fire Stations Cave Rock Water Company Logan Creek Water Company Glenbrook Company South Tahoe Properties Utility Company
Washoe County	
Nevada State Park, Sand Harbor Incline Village General Improvement District	Crystal Bay Water Company Incline Beach Association

Source: TRPA 2012

Lake Tahoe is a destination spot for domestic and international visitors and offers year-round recreational opportunities. Visitation (and water use) is greatest during the summer recreational season (June, July, and August); however, several ski resorts and casinos in the area attract a large number of visitors through the winter season. Ski resort snowmaking typically uses several hundred acre-feet of water each winter (Interior and California 2008).

The Reference demand assumes annual demand for the California portion of Lake Tahoe is 14,616 acre-feet (California DWR 2014). Annual demand for the Nevada portion of Lake Tahoe is 7,495 acre-feet (Nevada DWR 2014).

Truckee River Basin in California

The "Truckee River Basin in California" water user community includes the portion of the Basin between Lake Tahoe Dam and Farad, California (Figure 4-3).

Figure 4-3. Location of the Truckee River Basin in California Water User Community

The Basin Study characterized water demand for the California portion of the Truckee Basin as the total M&I and agricultural water uses along the Truckee River, Little Truckee River, and in Martis Valley. In relation to the Truckee River, the demand storylines encompass the anticipated surface water diversions and return flows in the Truckee River Basin between Lake Tahoe and the Farad gage.

The Truckee Donner Public Utility District serves most M&I demand along the Truckee River in California, including the Town of Truckee downtown area, the Armstrong and Biltz tracts, Glenshire, Tahoe Donner, Meadow Park, Gateway, Sierra Meadows, Ponderosa

Palisades, Ponderosa Ranchos, Gray's Crossing, Olympic Heights, Old Greenwood, Prosser Heights, Prosser Lakeview, Donner Lake, and Hirschdale. The district currently serves about 12,600 water customers, including several golf courses.

Most water demand in the Martis Valley area occurs in the Lahontan subdivision, an exclusive golf and residential facility south of Truckee, as well as a few existing and planned customers in the Martis Camp subdivision. With fewer than 1,000 accounts, demands are primarily for golf courses and residential lots; several accounts are second homes or bare lots awaiting new home construction (PCWA 2011). Placer County Water Agency contracts with the Northstar Community Services District to deliver water to the Martis Valley area.

Under the Reference demand condition, annual demand for the Truckee River Basin in California is 10,937 acre-feet (California DWR 2014) and is served predominantly from groundwater sources.

Truckee Meadows

The "Truckee Meadows" water user community includes the Nevada side of the Basin west of Derby Dam (Figure 4-4). The Basin Study characterized water demand for Truckee Meadows as both M&I and agricultural water uses.

This includes the total M&I water demand for the cities of Reno and Sparks, as well as in the surrounding developed areas of Washoe County, in addition to agricultural water use on lands served by ditches that historically divert from the Truckee River using *Orr Ditch* Decree water rights. In relation to the Truckee River, the following description encompasses both the anticipated M&I surface water diversions and return flows between the Farad and Vista stream gages, and the anticipated agricultural surface water diversions and return flows between Farad and Nixon, Nevada.

Figure 4-4. Location of the Truckee Meadows Water User Community

Reno is located in the southern part of Washoe County and is the largest city in northern Nevada. Sparks borders Reno and together the two cities, known as the Reno-Sparks metropolitan area or Truckee Meadows, cover about 142 square miles (TMRPA 2013). The Truckee Meadows region covers most developed land in the southern 25 percent of Washoe County (except developed area in the Lake Tahoe Basin).

Truckee Meadows is a high desert valley bounded on the west by the Carson Range, on the east by the Virginia Range, and on the north and south by low hills (Interior and California 2008). The Truckee River flows through downtown Reno, merging with several small tributaries such as Steamboat Creek, which originates at Washoe Lake and drains the southern and eastern parts of Truckee Meadows.

TMWA is the largest M&I water retailer/wholesaler in Truckee Meadows and the Truckee River Basin. Hydrographic basins served by TMWA include the central Truckee Meadows, Sun Valley, Spanish Springs (both within its retail and wholesale service areas), west Lemmon Valley, and the Truckee Canyon (Verdi/Mogul).

TWMA also operates several hydroelectric power plants along the river as it descends into Truckee Meadows. Three active run-of-the-river hydroelectric power plants are located along the Truckee River between the Little Truckee River and Reno: Fleish, Verdi, and Washoe. To generate power, water is diverted to flumes (i.e., wooden or earthen canals) that convey the water to the riverside plants, where the water is passed through penstocks and rotating turbines or through bypass spillways; the water is then returned to the river.

The Truckee Meadows economy is based on commercial and industrial development that includes offices, warehouses, and shipping and distribution centers; low water use industry, such as education and research, entertainment and tourism; mining; and geothermal energy production-related activities. TMWA's service area includes about 84 percent of Washoe County's population residing in the Reno-Sparks metropolitan area (TMWA 2009). TMWA's 2010 retail and wholesale area population was 371,000, with 90,761 active retail water services (TWMA 2009).

Major agricultural diversions from the river at Truckee Meadows include Steamboat Canal, Lake Canal, and the Last Chance, Orr, and Pioneer ditches. On the east side of Truckee Meadows at Vista, the river enters the Truckee River canyon. About 18 miles past Truckee Meadows, the river reaches Derby Dam. Irrigation diversions to the Newlands Project are discussed in a separate section in this chapter. Twenty miles downstream from the Derby Diversion Dam, the Truckee River enters the Pyramid Lake Indian Reservation and turns north at Wadsworth. The river flows for another 17 miles to Numana Dam, which diverts irrigation water to the Pyramid Lake Indian Reservation.

Land adjacent to the Truckee River has been used for agriculture since the 1800s, mostly for pasture or alfalfa fields to support the beef industry. Agricultural acreage along the river and associated farm-generated income has decreased the last few decades. This decreasing trend is reflective of competition for Truckee River water rights for M&I demands, water quality-related demands, and other instream flow uses (e.g., fisheries, wildlife).

The Reference demand for the Truckee Meadows water user community is 123,083 acre-feet. This includes 83,140 acre-feet of Truckee Meadows M&I demand (Interior and California 2008). It also uses the currently applied extent of *Orr Ditch* Decree agricultural water rights (39,943 acre-feet) reported by the Federal Water Master as the basis of current water demand for agriculture along the Truckee River (Table 4-2) (Federal Water Master 2014).

Table 4-2. Reference Demand Estimates for Truckee Meadows Agriculture

Truckee Meadows Diversions	Annual Demand (acre-feet)	Diversions Downstream From Truckee Meadows	Annual Demand (acre-feet)
Steamboat Ditch	11,500	Murphy Ditch	255
Highland Ditch	1,650	McCarran Ditch	412
Last Chance Ditch	3,849	Washburn Ditch	190
Lake Ditch	2,500	Gregory Ditch	285
Orr Ditch	8,350	Herman Ditch	2,540
Cochran Ditch	190	Proctor Ditch	1,590
Eastman Ditch	70	Olinghouse No. 1 Ditch	222
Pioneer Ditch	880	Fellnagle Ditch	475
		Olinghouse No. 3 Ditch	510
		Indian Ditch	4,475
Total	**28,989**	**Total**	**10,954**

Source: Federal Water Master 2014

Pyramid Lake

The "Pyramid Lake" water user community encompasses the existing Pyramid Lake Indian Reservation, which surrounds Pyramid Lake and the lower Truckee River reaches (Figure 4-5). Pyramid Lake is located 35 miles northeast of Reno, Nevada. The Pyramid Lake Indian Reservation surrounds the lake and the lower Truckee River, and includes the communities of Sutcliffe, Nixon, and Wadsworth. The reservation is 476,728 acres in area, of which Pyramid Lake occupies some 109,000 acres.

Figure 4-5. Location of the Pyramid Lake Water User Community, as Defined by the Pyramid Lake Indian Reservation

The Basin Study characterized water demand for Pyramid Lake as the total agricultural and M&I water uses for water rights held under the *Orr Ditch* Decree at the Pyramid Lake Indian Reservation. Water rights held by the tribe include Claims 1 and 2, as well as 2,135.1 acre-feet of *Orr Ditch* headgate rights obtained from the Herman, Pierson, Proctor, and Fellnagle ditches. In relation to the Truckee River, the following description encompasses the anticipated surface water diversions and return flows around Nixon, Nevada, upstream from Pyramid Lake.

The Pyramid Lake Indian Reservation is the largest tribal reservation in Nevada, both in area and in population; there are approximately 1,388 tribal residents (PLPT 2010). The tribe uses about 366,600 acres to graze livestock and 1,093 acres to irrigate hay, pasture, and forage (UNR 2002). Several tribal members belong to the Pyramid Lake Cattleman's Cooperative Association, which uses the reservation desert open range to manage individual cattle herds (PLPT 2013).

The Pyramid Lake Paiute Tribe holds water rights with the highest priority date (December 8, 1859), referred to as Claims 1 and 2 of the *Orr Ditch* Decree. Under Claim 1, the tribe has the right to divert irrigation water in an amount not to exceed 4.71 acre-feet per acre for 3,130 acres of bottom land (14,742 acre-feet per year). Claim 2 gives the right to divert 5.59 acre-feet per acre for 2,745 acres of bench land (15,345 acre-feet per year).

The Reference demand for the Pyramid Lake water user community includes a diversion of 4,228 acre-feet for Claim 1 and no diversions of Claim 2, with the balance of both devoted to in-stream uses.

Newlands Project

The "Newlands Project" water user community includes lands with Newlands Project water rights in the west-central Nevada counties of Churchill, Lyon, Storey, and Washoe (Figure 4-6).

The Basin Study characterized water demand for the Newlands Project as the total agricultural, M&I, and environmental water uses served by the Carson River under the *Alpine* Decree and Claim 3 rights under the *Orr Ditch* Decree, in addition to groundwater used by the City of Fernley.

In relation to the Truckee River, the following description encompasses the surface water diversions at Derby Dam for conveyance to the Truckee Division water rights holders along the Truckee Canal or as supplemental to Carson River supply to the Carson Division rights holders at Lahontan Reservoir.

In addition to irrigation, the Newlands Project serves water rights for wetlands at the Stillwater National Wildlife Refuge (NWR), Carson Lake and Pasture, and the Fallon Paiute-Shoshone Indian Reservation. Drainage from Newlands Project canals also serves as a source of water for wetlands, and in years with wet hydrological conditions, excess flows spilled or released from Lahontan Dam reach Stillwater NWR and Carson Lake and Pasture.

Figure 4-6. Location of the Newlands Project Water User Community

The Newlands Project is also authorized for M&I use under Public Law 101-618, although the project has not yet delivered water for this purpose. Currently, water rights held by municipalities are typically leased back to agriculture to support incidental groundwater recharge. Churchill County's M&I use currently depends on groundwater supplies that are recharged by irrigation water use (Churchill County 2007).

Fernley is located within and adjacent to the boundaries of the Newlands Project's Truckee Division. Fernley's population was 19,093 in 2012, making up about 35 percent of Lyon County's population (U.S. Census Bureau 2012). The city contains developed subdivisions, commercial entities, and small farms and ranches. Fernley currently supplies all potable water needs with groundwater pumped from several municipal wells. Groundwater is treated at the Fernley Water Treatment Plant and then delivered to residential and commercial customers. The city has extensive groundwater rights (10,360 acre-feet) to supply current demand, and has also secured surface water rights for potential future use in conjunction with groundwater rights.

The Reference demand of the Newlands Project water user community is 198,967 acre-feet. This is based on the application of 56,997 acres of water rights for the Newlands Project, as reported in Table 4-3. In volumetric terms, the demand is 191,151 acre-feet from Lahontan Reservoir, plus conveyance losses; and 4,084 acre-feet for the Truckee Division agricultural users along the Truckee Canal, plus conveyance losses. It also includes 3,732 acre-feet of demand for the City of Fernley per 2012 water demand records maintained by Reclamation; however, Fernley has reported 4,040 acre-feet of demand, which is the treated water volume produced in 2012 at the water treatment plant (Fernley 2014a).

Table 4-3. Reference Demand for Newlands Project Water Rights Holders

		Acres	Demand (acre-feet)
Carson Division Rights			
Agricultural	Commercial and Noncommercial Farms	42,018	149,832
	Fallon Paiute-Shoshone Irrigated Lands	2,504	8,765
M&I	City of Fallon and Churchill County	766	2,799
Environmental	USFWS Water Rights	7,259	21,645
	Carson Lake and Pasture	2,244	6,710
	Fallon Paiute-Shoshone Tribal Wetlands	468	1,400
Carson Division Subtotal		55,260	191,151
Truckee Division Rights			
Agricultural	Commercial and Noncommercial Farms	907	4,084
M&I[1]	City of Fernley & Lyon County	829[2]	3,732[2]
Truckee Division Subtotal		1,737	7,816
Current Newlands Project Demand		**56,997[3]**	**198,967**

Notes:
[1] Does not include Fernley's full 2012 demand met through groundwater (up to 4,040 acre-feet).
[2] Fernley's rights may be used for irrigation of agricultural lands, but would likely be subject to the review and approval of the Nevada State Engineer; current use by the city has been on an annual and temporary basis.
[3] Reflects the 2012 Newlands Project irrigated acreage.

Future Water Demand

Two storylines were developed to bracket the high and low ends of potential future water use in the Truckee Basin. These storylines emerged from discussions with Basin planning and water agencies, as described earlier in the chapter, with economic conditions as the primary driver affecting water use in the Basin.

- **Existing Trends Storyline –** 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 during the recent economic recession of the mid-late 2000s. Generally, development and water use are depressed and this storyline represents a lower bound for future water use within the Basin.

- **Robust Growth Storyline –** 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 are accelerated and this storyline represents an upper bound for future water use within the Basin.

Table 4-4 compares the different factors identified to drive water demand in the Basin under both storylines.

Table 4-4. 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

Although the storylines presented in Table 4-4 were formulated in coordination with, and reviewed by, planning agencies and regional stakeholders, they are not projections for future growth. Rather, they represent outer bounds for the regional changes that could be anticipated in the coming century and associated changes in water demand. As of 2015, the regional economic downturn has subsided, and recent investments in the industrial sector in Reno and Fallon are expected to stimulate residential and agricultural growth, both of which will affect water use in the future.

The differences in drivers of demand under the two storylines highlighted in Table 4-4 are consistent with and observable in the Basin Study's quantified estimates of demand described later in this section. Figure 4-7 shows a comparison of the changes in consumptive demand through the end of the twenty-first century for both demand storylines and different water user communities.

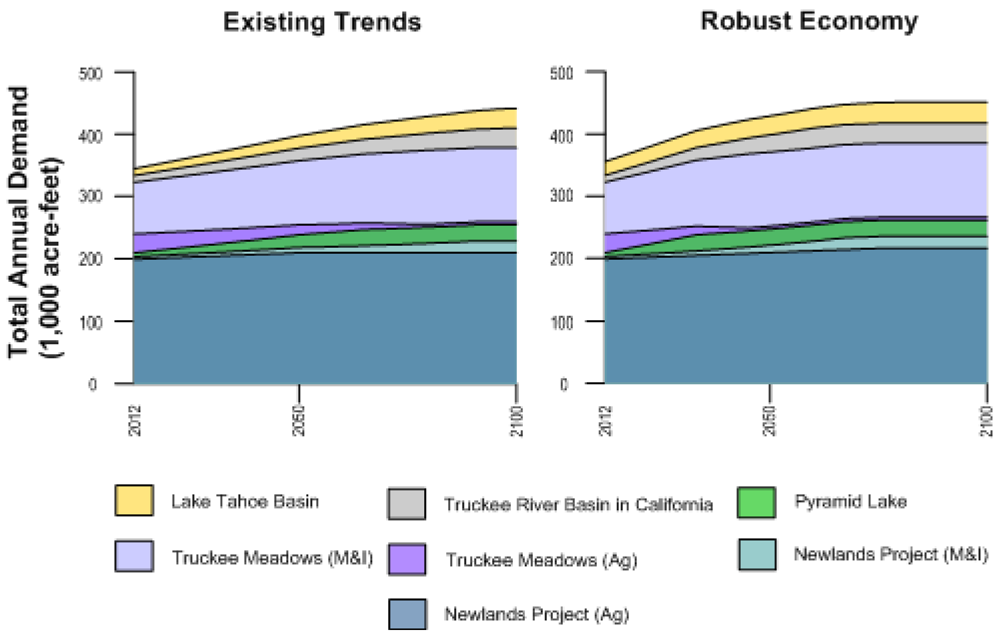
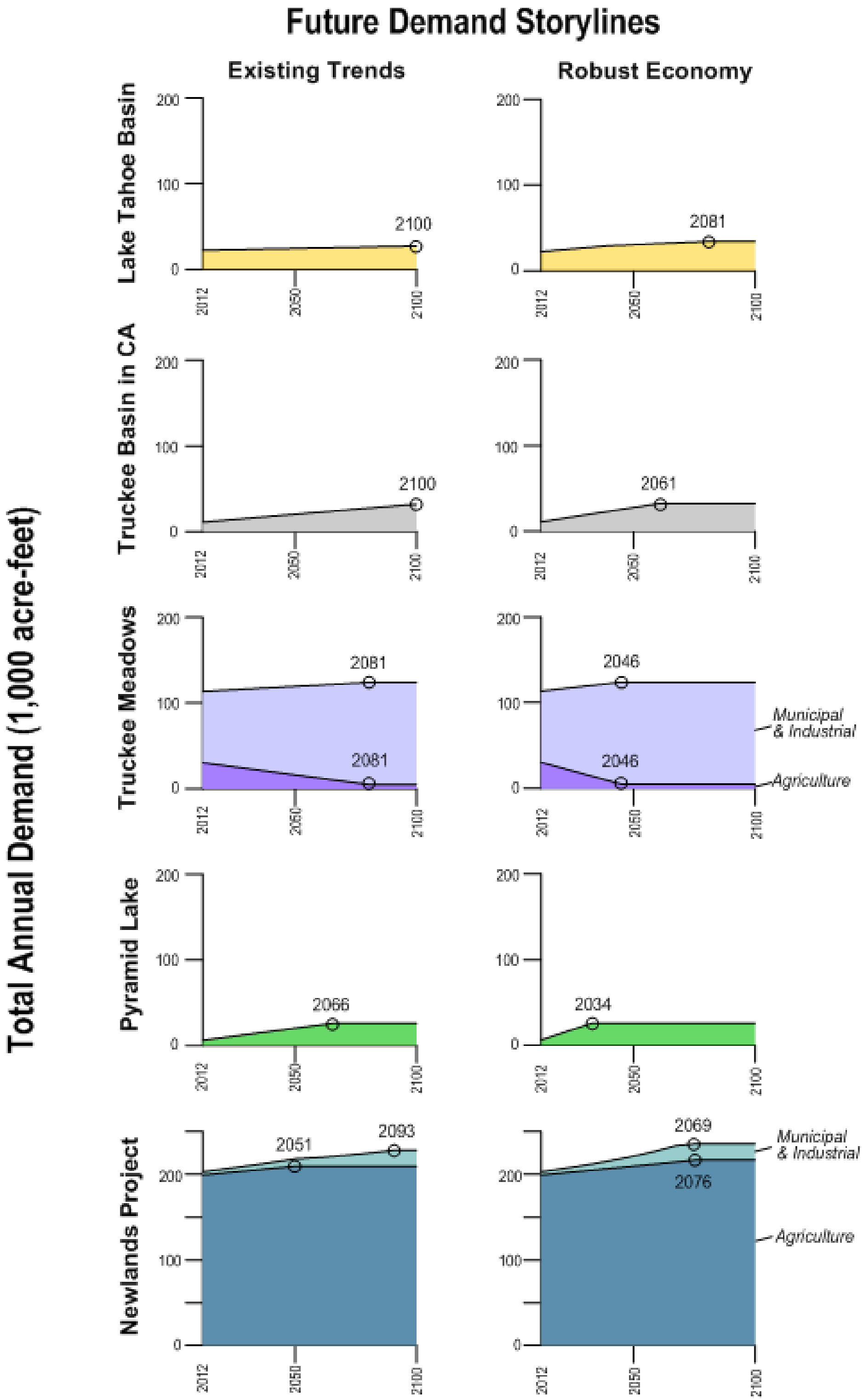


Figure 4-7. Total Truckee Basin Water Demand Under Future Storylines

Overall, the water user communities reach their full use of water rights sooner under the Robust Economy storyline than the Existing Trends storyline, but by century's end, total annual water demand in the 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 rights are currently being exercised or are planned to be exercised fully by water users. Figure 4-8 also shows a comparison of each water user community's future demand, but includes the approximate year in which demand is projected to stop changing.

The changes in agricultural water use are also consistent with Table 4-4, wherein agricultural land and water rights in the Truckee Meadows 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 needs 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).



Graphs present two different pathways for future changes in demand for the identified water user communities of the Truckee Basin. Demand in each community is projected to stop changing at a specific point in time due to assumed resource constraints (such as full exercise of water rights), as indicated by circles and years on the graph.

Figure 4-8. Comparison of Consumptive Demand Under Future Storylines

Future Demand by Water User Community

When the future demand storylines were presented to the agencies, each provided a unique response influenced by their current water uses and particular visions for how economic conditions, land uses, and other factors will change in the future. The following section provides numerical interpretations of demand for each water user that are associated with each future demand storyline.

Lake Tahoe Basin

For future demand under the Existing Trends storyline, the Lake Tahoe Basin economy would remain primarily dependent on recreation and tourism, with activities focused on the lake in summer and on skiing in the winter. There would be slight increases in the footprint for ski resorts, and increases in winter temperatures would increase demand for manufactured snow. Urban development would consist primarily of rehabilitation or reconstruction. Although the California portion of Lake Tahoe has a future annual water supply allocation of 23,000 acre-feet, local and regional development limits would likely prevent California from making full use of its water supply allocation under Public Law 101-618. The 2012 Lake Tahoe Regional Plan projects a population growth of about 0.5 percent per year through 2035 based on these limits. Recent trends in water demand growth in the California portion of Lake Tahoe, however, have been about 0.1 percent per year (California DWR 2014). This value is used for California water demand growth in the Existing Trends storyline. The Nevada portion of the Lake Tahoe Basin is currently close to using its full allocation (11,000 acre-feet) and is assumed to reach its full allocation for water use by 2100 under a less robust economy. This water demand storyline is considered a lower bound of Lake Tahoe Basin water demand growth and with the Robust Economy storyline would capture the 2012 Lake Tahoe Regional Plan projections within the Basin Study's demand storyline range.

For future demand under the Robust Economy storyline, the local economy would remain primarily dependent on recreation and tourism. Urban development would also consist primarily of rehabilitation or reconstruction, but would occur at a faster pace because of higher economic trends driving tourism and vacation home purchases. It is anticipated that more robust growth in the California portion of Lake Tahoe would push water use toward the full allocation of 23,000 acre-feet by 2080 (Table 4-5). The Nevada portion of the Lake Tahoe Basin would also be using their full allocation (11,000 acre-feet), although sooner than California, which is consistent with Nevada's more aggressive projections (Nevada DWR 2014).

Table 4-5. Lake Tahoe Basin Demand Estimates

	Reference Storyline	**Existing Trends Storyline**	**Robust Economy Storyline**
Demand (acre-feet)	22,111	27,000	34,000
California[1]	14,616	16,000	23,000
Nevada[2]	7,495	11,000	11,000
Year in Which Full Demand is Reached	NA	Not met for California; 2100 for Nevada	2080 for California; 2040 for Nevada

Key:
NA = not applicable
Notes:
[1] California Reference demand and Existing Trends storyline demand growth provided by California DWR (2014). Robust Economy storyline demand is Truckee River allocation for California under Public Law 101-618. Robust Economy storyline demand growth provided by California DWR (2014).
[2] Nevada Reference demand provided by Nevada DWR (2014). Robust Economy storyline demand is Truckee River allocation for Nevada under Public Law 101-618. Future growth rates provided by Nevada DWR (2014).

Truckee River Basin in California

For the Existing Trends storyline, the economy of the California portion of the Truckee River Basin would remain primarily dependent on recreation and tourism, similar to the Lake Tahoe Basin. However, there are fewer development capacity limits, and it is anticipated that the California portion of the Truckee River Basin would use their entire water supply allocation in the future. Current rates of annual population growth (about 1.25 percent), which have been inhibited by the recent economic recession, would continue under this storyline (California DWR 2014, TDPUD 2011). Because of the assumed slow economic growth, future water demand would not approach full use of existing water supply allocations until century's end, and is considered a lower bound of water demand growth for the California portion of the Truckee River Basin. Areas in Martis Valley would most likely reach local development capacity limits much earlier.

For the Robust Economy storyline, the economy would also be recreation and tourism based. The local and regional economy would return to more expansive growth trends and would reach full allocation by 2060 (Table 4-6). The Robust Economy storyline growth is consistent with the region's M&I demand trajectory in the TROA EIS/EIR (about 21,000 acre-feet by 2033) and captures major M&I demands projected in previous local planning studies (about 23,000 by 2040) (PCWA 2011, TDPUD 2011).

Table 4-6. Truckee River in California Demand Estimates

	Reference Storyline	Existing Trends Storyline	Robust Economy Storyline
Demand (acre-feet)[1]	10,937	32,000	32,000
Year in Which Full Demand is Reached	NA	2100	2060

Key:
NA = not applicable
Notes:
[1] California 2012 demand provided by California DWR (2014). Future demand for both future storylines is Truckee River allocation for California under Public Law 101-618. Existing Trends storyline growth rate provided by California DWR (2014). Robust Economy storyline growth rate approximated from the TROA EIS (Interior and California 2008, PCWA 2011, and TDPUD 2011).

Truckee Meadows

For the Existing Trends storyline, the future Truckee Meadows economy would continue to be based on activities similar to the Reference demand storyline. Individual household water consumption is not expected to increase because of a continued trend toward natural landscaping and smaller lawns due to on-going social trends and in response to rising water prices over time. Infill development and advancement in residential appliances would also reduce per capita urban water use.

Truckee Meadows growth and development would likely occur first by shifting to infill redevelopment to provide for higher population density within the previously built environment, followed by developing adjacent lands where development is more difficult or at higher risk to flood, fires, or landslides. The expansion of urban populations would absorb adjacent lands. Irrigated cropland would decrease in areas where urban development has increased. Urban development in the Truckee Meadows would absorb many of the existing commercial agricultural lands and their water rights, though small acreages of noncommercial agricultural lands would remain. As a result, water rights appurtenant to Truckee Meadows agricultural lands would be transferred to M&I uses for Reno and Sparks.

Technology would continue to decrease energy use in water treatment and distribution, and water treatment technology would allow more cost-effective use of groundwater. It is assumed that cities would continue to pursue and implement higher efficiency technologies, such as reclaimed water/purple pipe systems. By 2080, however, wastewater treatment costs to maintain water quality standards in the Truckee River below Vista would become prohibitive for new development in the Reno-Sparks area (TMWA 2012). Given that most or all of the agricultural water rights in the Truckee Meadows would be transferred to M&I use, any changes to agricultural practices and crops on land still in production would have a relatively small effect on demand.

Under this storyline, full demand would be restricted to TMWA's 119,000 acre-feet of water rights, and would occur at 2080 (Table 4-7). The year 2080 is a few decades prior to TMWA estimates for when full use of water rights would occur, but according to TMWA this would be a reasonable outer-bound timeframe (TMWA 2014b). Future agriculture demand along the Truckee River would be 4,460 acre-feet at the point of full water rights usage in Reno and Sparks, representing an 88 percent decrease from current demands (Table 4-8). Agriculture-to-urban water transfers are assumed to track Truckee Meadows urban encroachment on agricultural lands.

For the Robust Economy storyline, commercial and industrial enterprises, water use trends, and technology development would be similar to the Existing Trends storyline, but economic development and population would grow more rapidly. The healthy economic conditions attributed to this storyline, however, would still be limited by water quality requirements for the Truckee River and the expense of treating wastewater effluent for a larger population. The TROA limit of 119,000 acre-feet from sources within the Truckee Basin would be reached sooner (by 2045) at a rate consistent with earlier local planning studies (97,000 acre-feet by 2030, TMWA 2009). For Truckee Meadows agriculture, conditions under the Robust Economy storyline differ only in the rate of full water rights usage and resulting agriculture-to-urban water transfers.

Table 4-7. Truckee Meadows M&I Demand Estimates

	Reference Storyline	Existing Trends Storyline	Robust Economy Storyline
Demand (acre-feet)[1]	83,140	119,000	119,000
Year in Which Full Demand is Reached	NA	2080	2045

Key:
NA = not applicable
Notes:
[1] Demands provided by TMWA (2009). Growth rates provided by TMWA (2014b).

Table 4-8. Truckee Meadows Agriculture Demand Estimates

	Reference Storyline	Existing Trends Storyline	Robust Economy Storyline
Demand (acre-feet)[1]	39,943	4,860	4,860
Year in Which Full Demand is Reached[2]	NA	2080	2045

Key:
NA = not applicable
Notes:
[1] Current demand from Federal Water Master (2014). Future demand from TROA EIS/EIR (Interior and California 2008).
[2] Agriculture water rights along the Truckee River are assumed to be transferred to Truckee Meadows M&I demands, and follow this demand's growth rates.

Pyramid Lake

For the Existing Trends storyline, an increase in Pyramid Lake water demands is assumed that is equal to the extent of demand anticipated in the TROA EIS/EIR (Table 4-9) (Interior and California 2008). Water use would be split evenly between agricultural and municipal uses. Growth in water demand is presumed to lag growth in the Truckee Meadows.

For the Robust Economy storyline, future water use would be similar to the Existing Trends storyline, but increased economic activity within the region would increase demand for regional agricultural products. This increased agricultural demand would encourage the tribe to use agricultural water rights sooner. Plans have identified additional needs for surface water to maintain elevations at Pyramid Lake and support ecosystem habitat and spawning. However, since these rights have yet to be acquired, they are not included in demand for the Pyramid Lake water user community.

Table 4-9. Pyramid Lake Demand Estimates

	Reference Storyline	Existing Trends Storyline	Robust Economy Storyline
Demand (acre-feet)[1]	4,228	33,690	33,690
Year in Which Full Demand is Reached	NA	2090	2033

Key:
NA = not applicable
Notes:
[1] 2012 demand from the Federal Water Master. Future demands from the TROA EIS/EIR (Interior and California 2008). Existing Trends storyline growth rate assumed similar to City of Fernley. Robust Economy storyline growth rate from TROA EIS/EIR (Interior and California 2008).

Newlands Project

For ease of presentation, the description of future demand for the Newlands Project water user community separates use of Newlands Project surface water rights from the city of Fernley's use of groundwater. Future demand for the Newlands Project water rights holders is described first.

Both future storylines anticipate that the Newlands Project will continue to serve a primarily agricultural community with limited residential and industrial growth for sustaining the agricultural economy. Churchill County especially "respects its agricultural traditions, [recognizes] the growing economic impact of agriculture, and wants to retain its rural, agricultural, character and quality of life" (Churchill County 2007). Limited changes would occur in either storyline to agricultural practices and crops.

Both storylines would continue to anticipate water rights transfers within the Newlands Project, including:

- Agricultural rights acquisitions by the USFWS for use at Stillwater NWR.

- Agricultural water rights acquisitions for the retirement goal stipulated in Nevada Assembly Bill 380, to be achieved through the Water Rights Compensation Program.
- Transfers of water rights from the Truckee Division for environmental use by the Pyramid Lake Paiute Tribe under the Water Quality Settlement Agreement (WQSA).
- Dedications of water rights from the Truckee Division for M&I use by the City of Fernley.

Some of these actions would result in the permanent removal of Newlands Project water rights from service (Reclamation 2013). The Existing Trends storyline, however, would transfer fewer water rights because fewer rights would be offered for sale and transfer (Table 4-10). Fewer water rights are typically available for transfers in a depressed economy because of reduced "pressure" from land development removing rights from agricultural use (Grimes 2014). In combination, these changes reduce the potential use of current water rights by about 3 percent under the Existing Trends storyline.

The two future storylines also differ in their treatment of currently "inactive" water rights. For context, of the 73,675 acres of water rights that have been at one point included in the Newlands Project, 16,715 have been retired, forfeited or abandoned, or are inactive or unused to date. The Basin Study anticipates that a total of 10,079 acres will have been removed from service by 2050 (Reclamation 2013). The mechanisms for recognizing water rights as retired, forfeited or abandoned requires individual review of each water right by an appropriate entity, such as the Nevada State Engineer through oversight of water rights in Nevada or the U.S. Federal Court through oversight of the *Orr Ditch* and *Alpine* decrees.

"Inactive" water rights refers to the approximately 6,636 acres of water rights that for the past three decades have paid assessments and fees to TCID for maintaining their rights, but have not called upon water and are not anticipated to be removed from service through the transfers and retirement programs identified above (Reclamation 2013). It is unknown what proportion of these rights is persistently versus intermittently inactive; however, the acreage of inactive rights accounts for about 10 percent of the water rights within the Newlands Project that have not been permanently removed from service.

For the Existing Trends storyline, currently inactive water rights for USFWS, Fallon Paiute-Shoshone irrigated lands, and Carson Lake and Pasture lands would be "activated." It is also assumed that Carson Division M&I acres remain active, similar to the Reference demand storyline. Any acquisition of Carson Division agricultural lands by Churchill County to maintain agricultural application and groundwater recharge (Churchill County 2007) would come from currently active Carson Division irrigation rights. Transfers to the USFWS would also come from currently active Carson Division irrigation rights (Table 4-10).

For the Robust Economy storyline, increased economic activity within the region would increase demand for regional agricultural products, particularly dairy and related feed products. This increased agricultural demand would increase competition for Newlands Project water rights and would encourage water rights holders with currently unused rights to seek to transfer and apply them, consistent with Federal and State laws. A more robust economy would also encourage some development, which would transfer agricultural rights to municipal use. Developers would sell excess water rights to buyers, such as the Stillwater NWR, who would meet their acquisition goal under this storyline (Table 4-10).

It is assumed for this future storyline that all currently inactive water rights would be “activated” and the demand for water in the Newlands Project would increase about 9 percent, in comparison with the Reference demand storyline (Table 4-10). Some of the “activated” commercial and noncommercial Carson Division irrigation rights, along with additional Carson Division irrigation rights, would be transferred to the USFWS. Currently, per a Federal court ruling, any water rights transferred for use at wetlands must be exercised at the established duty for wetlands, which is 2.99 acre-feet per acre, regardless of the original duty associated with exercise of the rights for agricultural purposes. Any acquisition of Carson Division agricultural lands by Churchill County to maintain agricultural application and groundwater recharge (Churchill County 2007) would come from remaining active Carson Division rights.

Table 4-10. Newlands Project Demand Estimates

		Reference Storyline		Existing Trends Storyline			Robust Economy Storyline		
		Total Acres	**Total Demand (acre-feet)**	**Change from Reference Demand Acres**	**Total Acres**	**Total Demand (acre-feet)**	**Change from Reference Demand Acres**	**Total Acres**	**Total Demand (acre-feet)**
Carson Division Rights									
Ag	Commercial and Noncommercial Farms	42,018	149,832	-6,032 (to USFWS)	35,986	128,582	-12,064 (to USFWS) +1,384 (full use of current water rights)	31,338	114,737
	Fallon Paiute-Shoshone Irrigated Lands	2,504	8,765	+521 (full use of current water rights)	3,025	10,588	+521 (full use of current water rights)	3,025	10,588
M&I	City of Fallon and Churchill County[1]	766	2,799	0	766	2,799	0	766	2,799
Env	USFWS Water Rights	7,259	21,645	+6,032 (from Carson Division Agriculture) +1,680 (full use of current water rights)	14,971	43,808	+12,064 (from Carson Division Agriculture) +1,680 (full use of current water rights)	21,003	61,844
	Carson Lake and Pasture	2,244	6,710	+159 (full use of current water rights)	2,403	7,185	+159 (full use of current water rights)	2,403	7,185
	Fallon Paiute-Shoshone Tribal Wetlands	468	1,400	0	468	1,399	0	468	1,399
Carson Division Subtotal		55,260	191,151	+2,359	57,619	194,361	+3,743	59,003	198,551

Table 4-10. Newlands Project Demand Estimates (contd.)

		Reference Storyline		Existing Trends Storyline			Robust Economy Storyline		
		Total Acres	**Total Demand (acre-feet)**	**Change from Reference Demand Acres**	**Total Acres**	**Total Demand (acre-feet)**	**Change from Reference Demand Acres**	**Total Acres**	**Total Demand (acre-feet)**
Truckee Division Rights									
Ag	Commercial and Noncommercial Farms	907	4,084	+523 (activation of current water rights) -1,230 (to City of Fernley) -200 (to WQSA)	0	0	+1,394 (full use of current water rights) -1,230 (to City of Fernley) -600 (to WQSA)	471	2,120
M&I	City of Fernley & Lyon County[2]	829[3]	3,732[3]	+1,274 (full use of current water rights) +1,230 (from Truckee Division Agriculture)	3,333	14,999	+1,463 (full use of current water rights) +1,230 (from Truckee Division Agriculture)	3,522	15,660
Truckee Division Subtotal		1,737	7,816	+1,596	3,333	14,999	+2,256	3,993	17,780
Current Newlands Project Demand		56,997	198,967	+3,955	60,952	209,360	+5,999	62,996	216,331

Note:

[1] Churchill County may purchase additional Newlands Project irrigated lands to maintain agricultural application and groundwater recharge (Churchill County 2007). Because these purchases are unknown at this time, these acres are assumed to be in Carson Division commercial and noncommercial farms acreage.

[2] Demand for Truckee Division M&I rights are described through storylines for the City of Fernley. Future water right acquisitions provided by City of Fernley (Fernley 2014b).

[3] Fernley's rights may be used for irrigation of agricultural lands, but would be subject to the review and approval of the Nevada State Engineer and are currently restricted to use on a temporary basis.

For the Existing Trends storyline, Fernley's economy would continue to be based on commercial and industrial development that includes offices, warehouses, shipping and distribution centers, and low-water-use industries. Fernley's growth and development would occur in existing planned areas and then would extend into undeveloped adjacent areas. Growth in Fernley is presumed to lag growth in Truckee Meadows, as growth is assumed to first shift to infill redevelopment and new development in Truckee Meadows, followed by increasing development in commuter-accessible communities (like Fernley) along the Interstate 80 corridor. Fernley expansion would absorb remaining adjacent agricultural lands in the Newlands Project's Truckee Division. Technology would continue to decrease energy use in water treatment and distribution, and water treatment technology would allow more cost-effective use of groundwater.

Population growth would drive water demands, but growth would be slow in the early century. Growth rates would be less than 2 percent for the first 20 years, consistent with Nevada State Demographer projections (Fernley 2104b). Individual household water consumption is not expected to increase substantially in the early century (210–220 acre-feet per 1,000 people) because of a continued trend toward conservation (increased water meter fees and billing rates have decreased demand) (Fernley 2014b). Water use in the later part of the century, however, would increase as slow economic activity and associated population growth (2 percent) would increase service connections to and usage from Fernley's water system. Additional users paying for systems costs would lower individual billing rates and also promote moderate increases in water use (up to 240 acre-feet per 1,000 people) (Fernley 2014b).

Under this storyline, full water rights demand would be 18,930 acre-feet, and would occur in 2091 (Table 4-11), consistent with the growth and water use rates discussed previously. This full water rights demand occurs when Fernley's population reaches about 80,000 people. Service of the full water rights demand would require the delivery of surface and groundwater supplies. Surface rights are assumed to include existing rights and anticipated future dedications from converted lands within the Fernley Division of the Newlands Project.

For the Robust Economy storyline, commercial and industrial enterprises, water use trends, and technology development would be similar to the Existing Trends storyline, but economic development and population would grow more rapidly (Table 4-11). Population growth in the latter half of the century would reach 3 percent and would increase service connections to and usage from Fernley's water system at a faster rate (Fernley 2014b). Higher increases in water use would be expected under this storyline (up to 255 acre-feet per 1,000 people) and full water rights demand would occur sooner (Fernley 2014b). The healthy economic conditions attributed to this storyline, however, would still lag Truckee Meadows growth and development.

Table 4-11. City of Fernley Demand Estimates

	Reference Storyline	Existing Trends Storyline	Robust Economy Storyline
Demand (acre-feet)[1]	3,732[2]	18,930	18,930
Year in Which Full Demand is Reached	NA	2091	2067

Key:
NA = not applicable
Notes:
[1] 2012 demand provided by Reclamation. Existing Trends and Robust Economy storyline demands are from Fernley 2013. Demand growth rates provided by Fernley (2014b).
[2] Fernley's rights may be used for irrigation of agricultural lands, but would be subject to the review and approval of the Nevada State Engineer and are currently restricted to use on a temporary basis.

Effects of Climate Change on Future Demand

Human demands are not the only water needs likely to change in the future. The added complexity of a changing climate also increases needs of ecosystems and crops. The needs of different Basin ecosystems and how species may react to climate-driven changes in supply are not well known. Changes in climate are also likely to increase overall crop demand. Although the Basin Study notes these changes in demand, they are not quantified as part of the demand assessment because the demand assessment is constrained by the exercise of existing rights, rather than all demands that are possible. Nonetheless, changes in ecosystem and crop demands factor into the Basin Study's reliability and vulnerability assessments (see "Chapter 6 – Risks and Reliability").

Changes in Agricultural Demand

Irrigation of Newlands Project croplands is a large consumptive demand in the Carson and Truckee basins. 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 these needs. 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.

Current and future crop irrigation water demands (crop water demand minus effective precipitation) estimates were developed for the Basin Study following methods established through WWCRA (Reclamation 2015). These methods are state-of-the-art for the computation of crop evapotranspiration and net irrigated water requirements, and consider data intensive, physically-based models of the soil column, crop growth, and water demand. The baseline demand estimates developed for this study are based on the most recent available crop data and on climate conditions during the period 1950 through 1999 (see "Appendix C – Future Supply Technical Reports"). Figure 4-9 shows how irrigation demands under Reference demand acreage conditions would increase under future climate change conditions. Hotter future climate conditions would have higher irrigation demand than warmer future conditions, and drier future climate conditions would have higher demand than wetter future conditions. Average changes in 30-year irrigation demands (centered around 2020, 2050, and 2080) were calculated and applied (as evident in the "steps" in Figure 4-9), similar to WWCRA.

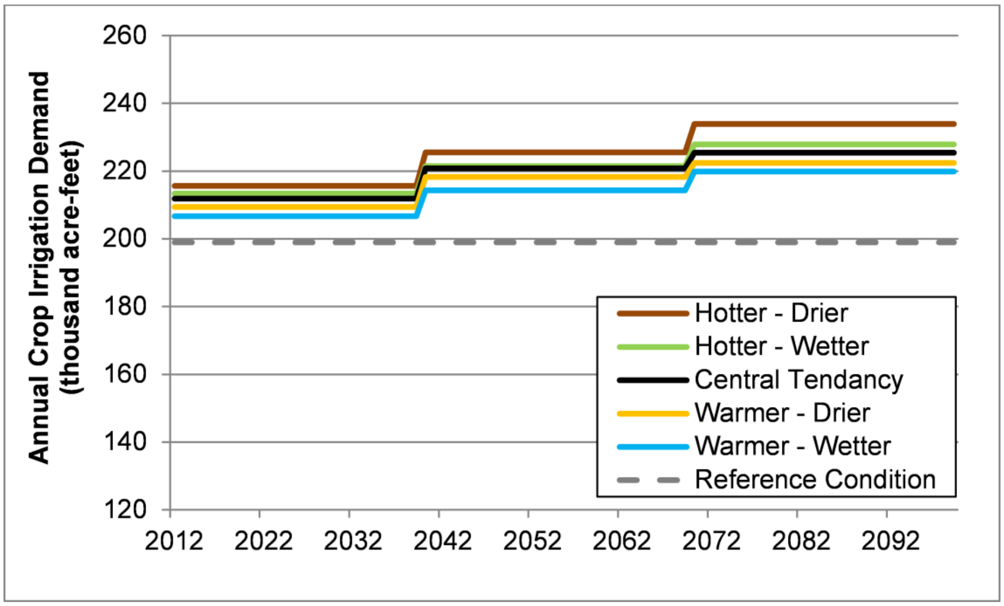


Figure 4-9. Newlands Project Crop Irrigation Demand Under Changing Climate

Changes in Ecosystem Needs

The Basin Study held ecosystem demands constant across all demand conditions, and accounted for current ecosystem demands by including them as regulatory and other requirements for water operations in the TROA-light Planning Model. Fish flow regimes in the lower Truckee River and operations at Stampede Reservoir to support species at Pyramid Lake are both examples of how ecosystem demands are accounted for as part of the Basin Study's tools, assessments, and analyses. However, these operations may also need to change to ensure they continue to support ecosystems functions as conditions change in the future.

Environmental conditions vary widely from year to year in the Truckee Basin and have done so for thousands of years. Pyramid Lake fishes and their ecosystems have evolved to respond to years when temperature, streamflow, and water quality conditions are well suited for spawning and propagation. These long-lived species can wait out the less desirable years with poor environmental conditions.

Seasonality shift refers to a tendency for peak flows in the Western U.S. to occur earlier in time. This phenomenon results from increases in temperature that reduce the accumulation of precipitation as snow over the coming century.

Changes in ambient temperatures and seasonality shifts in streamflow could alter the timing of breeding patterns of 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 needs 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.

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Chapter 5
Water Management Conditions

The Basin Study sought to characterize future risks to water resources throughout the Truckee Basin and test methods for maintaining a balance between supplies and demands into the future. As presented in "Chapter 2 – Scenario Planning and Supporting Information," the Basin Study achieved this through scenario analysis where a given condition is compared against scenarios of differing constructions to reveal vulnerabilities, causality, and to test options for preserving the level of water supply reliability under the Reference scenario among Basin water users.

The Basin Study constructed scenarios from three components: a supply condition, a demand condition, and a water management condition. In general terms, the supply condition describes the hydrologic availability of water resources (see "Chapter 3 – Water Supply Assessment") and the demand condition describes the consumptive uses of water in the Basin (see "Chapter 4 – Water Demand Assessment"). The water management condition describes the features of the Basin that govern capture and delivery of supplies for meeting demands, most notably infrastructure specifications and regulatory policies and requirements. The Basin Study included development of both a Reference water management condition and other potential future water management conditions through the implementation of options, as shown in Figure 5-1. The Reference conditions are described in this chapter, while the potential future water management conditions are represented by the options described in "Chapter 7 – Responses to Risk."

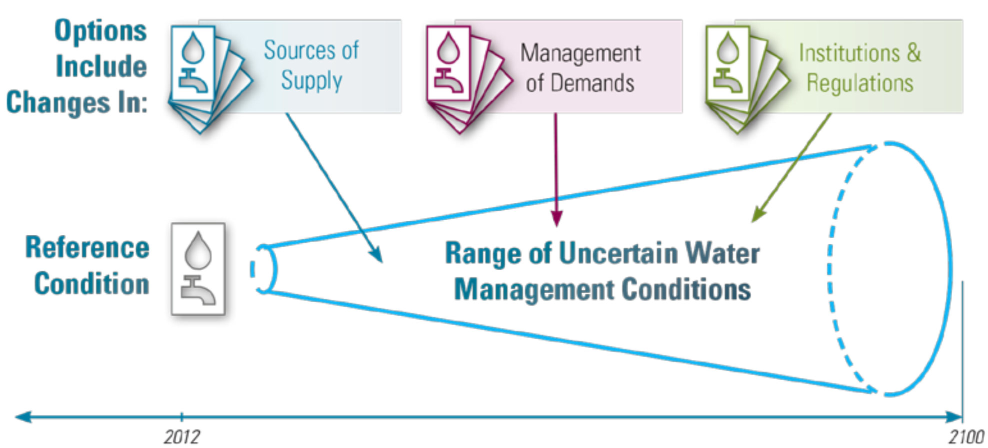


Figure 5-1. Relationship Between the Reference and Future Water Management Conditions Developed for the Basin Study

This chapter describes the present condition assembled for the infrastructure and operations in the Truckee Basin. As such, this chapter inventories the infrastructure, operations, regulations, and other institutional arrangements that represent the management of Truckee Basin water resources in the Basin Study's Reference scenario.

Changes to policies and infrastructure are to be expected in the future, such as the implementation of TROA or changes in municipal diversion and treatment capacities that accommodate growth in demand. To the extent that these changes align with the purpose of the Basin Study, they have been incorporated into the current condition. However, changes that respond to risks or vulnerabilities have not been included in the current condition, and are left for development and exploration as part of the Basin Study's adaptation strategies and options in "Chapter 7 – Responses to Risk."

Current Infrastructure and Facilities

Wide-scale water diversions from Lake Tahoe and the Truckee River began in the mid-nineteenth century to supply activities and settlements associated with gold and silver mining operations of the Comstock Era in Nevada. Management of the Truckee River's flow was key to moving timber and finished lumber products around the Basin to be used for construction and fuel. A private timber crib dam was constructed in 1870 at the outlet of Lake Tahoe to regulate flows in the Truckee River so that logs could be floated to sawmills in Truckee, California. Originally, releases from the dam were primarily used for milling purposes and to generate hydroelectric power.

Source: Erman 1991

Figure 5-2. Log Drive on Little Truckee River

Long before Federal involvement in the Basin's water management, settlers in the study area created irrigation ditches. In 1861, construction began on the Pioneer and Cochran ditches in Truckee Meadows, which supplied water to hay meadows (Nevada DWR 1997). As early as 1863, hay ranches were established in Truckee Meadows and Lahontan Valley (Raven 1990). Early settlers selected prime spots along drainages and diverted water for irrigating crops and pastures, with increasing reliance on irrigation. By 1879, increased water use throughout the region, combined with continued expansion of beef production, stimulated plans for water storage (Townley 1977).

Since these early efforts to manage the Basin's water resources to support human uses, a variety of different facilities have been constructed to support not just human uses, but environmental needs as well. This section describes the major infrastructure used to meet the needs of Basin water user communities and included in the Basin Study's Reference scenario.

Reservoirs and Lakes

The Truckee River reservoir system includes 7 facilities with surface water storage capabilities: Lake Tahoe, Donner Lake, Martis Creek Lake, Independence Lake, Prosser Creek Reservoir, Stampede Reservoir, and Boca Reservoir. While not within the boundaries of the Truckee River hydrologic area, Lahontan Reservoir is a major facility of the Newlands Project and thus also important for the Truckee Basin. Each of these facilities is described below.

Lake Tahoe

Lake Tahoe is located in the Sierra Nevada between California and Nevada, and contributes approximately one-third of the surface flow to the Truckee River, which begins at the lake's outlet. Only the top 6 feet of the lake's capacity (amounting to 744,600 acre-feet) may be used for water storage (USGS 2001). Lake Tahoe Dam is operated by Reclamation and part of the Newlands Project.

Figure 5-3. Lake Tahoe Dam at the Mouth of the Truckee River

Lake Tahoe has a key role in meeting Floriston rates, the Truckee River's instream flow requirements (described under "Current Operations, Institutions, and Regulations"). Water may first be released from Lake Tahoe to meet Floriston rates if the lake's elevation is greater than 6,225.5 feet above mean sea level (msl); if the lake's elevation is lower, water is first released from Boca Reservoir to meet Floriston rates (State Water Board 2002). The Federal Water Master may vary this to maintain relatively constant flow in the river downstream from Lake Tahoe. These releases from Tahoe can only be made if a similar amount of water is available for exchange or storage in Prosser Creek Reservoir (called "Tahoe Prosser Exchange" water). This water is later used for Floriston rates.

Donner Lake

Donner Lake is located on Donner Creek, a tributary to the Truckee River. Its storage capacity is 9,500 acre-feet. TMWA and TCID jointly hold rights to a majority of the lake's supply; TDPUD also holds rights to 1,000 acre-feet at the lake which were acquired during the purchase of the Del Oro water system in the 1980s (Reclamation 2013, PCWA 2015). As these supplies are privately owned, releases are not used to meet Floriston rates. The dam is operated to prevent the water surface elevation from exceeding 5,935.8 feet above mean sea level (State Water Board 2002). Except for minimum instream flows, water can only be released during June, July, and August if the lake elevation is greater than 5,932.0 feet. By November 15, the lake elevation must be lowered to 5,926.9 feet to meet dam safety requirements. During normal operations, all inflow is released between November 15 and April 15.

Martis Creek Lake

Martis Creek Lake is located on Martis Creek, a tributary to the Truckee River. The dam is owned and operated by the USACE for flood control purposes. Total capacity is 20,000 acre-feet, although the lake is maintained significantly below this due to dam safety concerns. During flood events, Martis Creek Reservoir only temporarily accumulates water according to U.S. Army Corps of Engineers flood control requirements.

Independence Lake

Independence Lake is located on Independence Creek, a tributary of the Little Truckee River. The lake's storage capacity is 17,500 acre-feet (USGS 2001). TMWA owns water rights at Independence Lake and each year can store the first 3,000 acre-feet of inflow in the lake before Floriston rates are met; TMWA can store more water in the lake only if Boca Reservoir is full and Floriston rates are being met (State Water Board 2002). However, as these supplies are privately owned, releases are not used to meet Floriston rates.

Prosser Creek Reservoir

Prosser Creek Reservoir is located on Prosser Creek, a tributary of the Truckee River. The dam and reservoir are part of Reclamation's Washoe Project and provide water supply and flood control benefits. From April 10 to August 10 of each year, the reservoir can store up to 29,800 acre-feet of water provided that Floriston rates are being met, OCAP diversion allowance, and Boca, Independence, and Stampede storage targets are satisfied (USGS 2001, State Water Board 2002). By November 1 of each year, the reservoir must be drawn down to provide 20,000 acre-feet of flood control storage space.

Stampede Reservoir

Stampede Reservoir is located below the mouth of Davies Creek on the Little Truckee River. The dam and reservoir are part of Reclamation's Washoe Project. The reservoir's capacity is 226,500 acre-feet. The dam and reservoir provide flood control, water supply, and fisheries benefits. Since 1983, Stampede Reservoir has also been dedicated to storing water for the benefit of fisheries along the Truckee River and at Pyramid Lake (Reclamation 2011h). By November 1 of each year, Stampede Reservoir must be drawn down to provide 22,000 acre-feet of flood control storage space (State Water Board 2002). Other than this requirement, water can be stored in Stampede Reservoir if Floriston rates are met, Boca and Independence reservoirs are full, and OCAP diversion allowance and Floriston rates are met. While Stampede Reservoir is operated primarily to support fisheries, since 1994, TMWA has had the opportunity to store water in Stampede Reservoir through an interim storage contract with Reclamation for up to 14,000 acre-feet (Reclamation 2013).

Boca Reservoir

Boca Reservoir is located at the mouth of the Little Truckee River. The dam and reservoir are part of Reclamation's Truckee Storage Project, and are operated for flood control and to meet Floriston rates and downstream demand. The reservoir's capacity is 41,100 acre-feet. By November 1 of each year, Boca Reservoir must be drawn down to provide 8,000 acre-feet of flood control storage space (State Water Board 2002). If Floriston rates are being met, the reservoir can store up to 25,000 acre-feet; if Floriston rates and downstream demand are both being met, the reservoir can store up to 40,000 acre-feet. Releases are made from Boca Reservoir or Lake Tahoe to maintain the Floriston rates.

Figure 5-4. Boca Dam and Reservoir on the Little Truckee River

Lahontan Reservoir

Lahontan Reservoir is located on the Carson River and stores the river's natural flow along with Truckee River water diverted via the Truckee Canal. The reservoir has a storage capacity of 289,700 acre-feet, and up to 317,000 acre-feet when flashboards are installed on the spillway crest (Reclamation 2013, USGS 2001). Lahontan Reservoir operations are subject to OCAP as described under "Current Operations, Institutions, and Regulations."

Figure 5-5. Lahontan Dam and Reservoir

Truckee Canal

The Truckee Canal is a major water conveyance feature of the Newlands Project. Derby Dam, located on the Truckee River about 20 miles downstream from Reno, diverts a portion of the river's flow for irrigation of the project's Truckee Division lands and for conveyance 32 miles to Lahontan Reservoir to provide a supplementary water supply for the project's Carson Division (Reclamation 2013).

As designed, the canal has an initial capacity that corresponds to an unchecked flow of 1,500 cubic feet per second (cfs) and an ending capacity of 900 cfs. However, canal capacity restrictions have been in place since 2008, following a breach of the Truckee Canal that inundated nearly 600 properties in the city of Fernley. Operations of the Truckee Canal are subject to these restrictions and also to OCAP, described below under "Current Operations, Institutions, and Regulations."

Municipal Diversion and Delivery

A range of infrastructure exists to support municipal demand in the Truckee Basin's water user communities. This includes dams, canals, ditches, pipes, groundwater wells and pumps, and water treatment facilities for both surface water and groundwater. As this chapter serves as a description of the operations and infrastructure used in the scenarios and related analyses, it is important to note how municipal diversions are represented in the TROA-light Planning Model. The assumptions used for municipal diversions and deliveries in the planning model are described below.

The Lake Tahoe Basin currently relies on both surface water from the lake and groundwater to meet M&I needs, and operates infrastructure to support these uses. The Basin Study assumes that in the future, increased demand in this water user community will result from depletions in storage from Lake Tahoe, without specifically attributing whether the depletions came from groundwater, surface water, or lake storages.

The Truckee River Basin in California currently relies on groundwater for their M&I supplies, and future development in water supply will likely favor groundwater supplies, first. As uncertainties exist regarding how additional groundwater development will affect surface-groundwater interactions along the Truckee River, the Basin Study represents their future demand as a surface diversion from the Truckee River. Through the use of this conservative assumption, future extractions from groundwater are represented as reductions in flow on the Truckee River.

TMWA relies on a combination of surface water and groundwater for their M&I supplies. As with the Lake Tahoe Basin and the Truckee River Basin in California, the Basin Study assumes TMWA will meet increased demand through surface water diversions from the Truckee River (TMWA 2009).

The City of Fernley currently relies on groundwater to meet its full M&I demand. The Basin Study assumes the city will exercise its Newlands Project surface water rights, as needed, to meet increases in demand that exceed current groundwater supplies. Delivery of surface supplies are simulated in the planning model as diversions from the Truckee River at Derby Dam.

Hydroelectic Generation

Hydroelectric power is generated at a number of facilities throughout the Truckee Basin, including both Federal and locally owned and operated facilities.

Stampede Powerplant is operated by Reclamation and produces an average of about 12 million kilowatt-hours annually (Reclamation 2011e).

TMWA owns four hydroelectric powerplants along the Truckee River, three of which are in operation: Fleish, Verdi, and Washoe. All three were originally built in the early 1900s to supply electricity for mining and nearby settlements. Combined, they produce an average of 6.7 megawatts of power, and 50 million kilowatt hours annually (TMWA 2013).

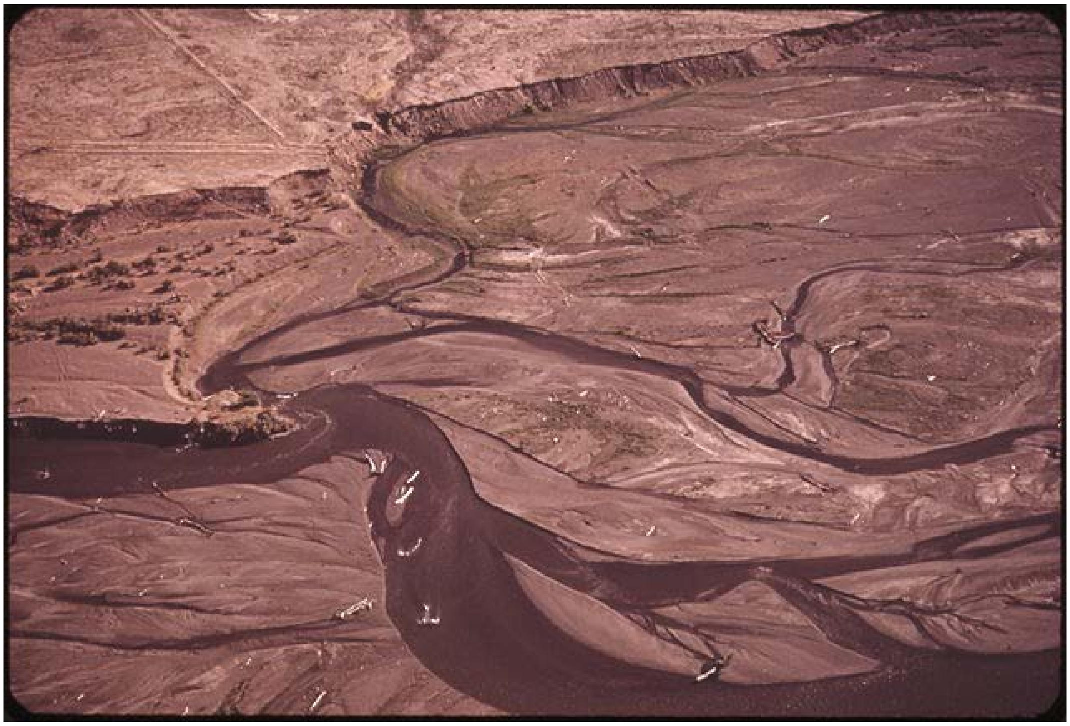
In the Carson Basin, power is generated by TCID at Old Lahontan powerplant, “New” Lahontan powerplant, and the V Canal (26-foot Drop) powerplant. In recent years, the three plants have produced a combined total of an average of 180 million kilowatt hours annually (Reclamation 2013).

Marble Bluff Dam and Fishway

Marble Bluff Dam and Fishway are located on the lower Truckee River near the delta where the river meets Pyramid Lake. The facility’s purpose is to prevent erosion of the channel and to divert water into a fishway to allow spawning cui-ui and Lahontan cutthroat trout passage around the delta. The facility is part of Reclamation’s Washoe Project, and the fishway is maintained by USFWS.

Figure 5-6. Marble Bluff Dam on the Lower Truckee River

For much of the early twentieth century through the 1960s, in-basin and out-basin diversions significantly reduced flow in the lower Truckee River, causing Pyramid Lake’s water elevation to decline by 86 feet between 1911 and 1967 (Nevada Division of Water Resources 1997). The lower lake level resulted in a lower base level at the mouth of the Truckee River, which caused the river to downcut its channel and flood plain into deltaic deposits. The delta at the mouth of the Truckee River is a major factor for passage by cui-ui and Lahontan cutthroat trout. Over time, the significant reductions in river flows and lake levels, numerous diversion structures in the Truckee River, and the sawdust, sewage and increased sediment load in the river, and populations of both cui-ui and Lahontan cutthroat trout at the lake became imperiled. Under the Federal Endangered Species Act (ESA), the Lahontan cutthroat trout has been classified as “threatened” since 1975, and the cui-ui has been classified as “endangered” since 1967.



Source: National Archives and Record Administration

Figure 5-7. Aerial View of the Truckee River's Delta at Pyramid Lake in 1970

Current Operations, Institutions, and Regulations

The management of water in the Truckee Basin is dictated by an array of agreements, rules, regulations, procedures, and documents that reflect both the need to meet many types of demands for water and the historical conflicts that characterize competition for the Basin's limited water resources. The first conflicts over the Truckee River's waters arose in the mid-nineteenth century, as various entities attempted to obtain rights to control flow out of Lake Tahoe to support in-river uses and to supply communities as far away as San Francisco (Nevada DWR 1997). Once Federal involvement in the Basin began in 1903 with the establishment of the Newlands Project, Basin water users began decades of legal entanglements that resulted in full adjudications of Truckee River water rights and a series of agreements on how the river should be managed. Concurrent to this, the development of water conveyance and control infrastructure required new sets of operating rules and governance. This section describes the institutional arrangements and operations used to manage the Basin's water supplies and which are included in the Basin Study's Reference scenario.

Truckee River General Electric Decree *(1915)*

The *Truckee River General Electric* Decree resulted from a condemnation action by the Federal government against the Truckee River General Electric Company over control and use of Lake Tahoe Dam, which was owned by the electric company but affected Reclamation's ability to serve water rights downstream.

The decree granted Reclamation an easement to operate Lake Tahoe Dam and to use the surrounding property owned by the power company and other downstream users. However, Reclamation was required to operate the dam to provide specified year-round flow rates, called "Floriston rates," in the Truckee River for the benefit of the power company (Interior and California 2008).

Truckee River Agreement (1935)

The Truckee River Agreement was negotiated among Reclamation, Sierra Pacific Power Company (the precursor of TMWA as the municipal water supplier for Reno-Sparks), TCID, the Washoe County Conservation District, the United States, and other parties representing Nevada and Lake Tahoe interests to resolve conflicts over Truckee River water rights and Lake Tahoe water elevations. The parties agreed to operate Lake Tahoe and Boca Reservoir to meet Floriston rates set by the *Truckee River General Electric* Decree, which were modified to supply water for irrigation, municipal use, and hydropower generation (Interior and California 2008).

Floriston rates are so named because they were measured at a gage near the state line in Floriston, California (now measured at the gage at Farad, California). When these rates are met, downstream water demand in the Basin is expected to be satisfied. If the Floriston rates are not being met by natural flow, water must be released from Lake Tahoe and/or Boca Reservoir to maintain the required rate of flow.

Table 5-1 includes the required flow in the river per Floriston rates at various times during the year, and Table 5-2 includes the "reduced" Floriston rates that go into effect during lower Lake Tahoe elevations.

Table 5-1. Floriston Rates

October – February	**March – September**
400 cubic feet per second	500 cubic feet per second

Table 5-2. Reduced Floriston Rates

Lake Tahoe Elevation	**October**	**November – March**	**March**	**April – September**
< 6,225.25 feet	400 cfs	300 cfs	300 cfs	500 cfs
6,225.25 – 6,226.0 feet	400 cfs	350 cfs	350 cfs	500 cfs
> 6,226.00 feet	400 cfs	400 cfs	500 cfs	500 cfs

Key:
cfs = cubic feet per second

Orr Ditch Decree (1944) and *Alpine* Decree (1980)

The *Orr Ditch* and *Alpine* decrees establish the adjudicated water rights on the Truckee and Carson rivers, respectively.

The *Orr Ditch* Decree quantified individual Truckee River water rights in Nevada. It established amount, places, types of use, and priorities of the various rights, including those of the Pyramid Lake Paiute Tribe (Claims 1 and 2) and the Newlands Project (Claim 3). The U.S. District Court Federal Water Master in Reno, Nevada, enforces the terms of the decree. The decree also incorporates previous requirements, such as the Truckee River Agreement. In September 2014, a Federal court modified the *Orr Ditch* Decree to incorporate TROA, and ruled that any excess or unappropriated Truckee River water must flow to Pyramid Lake.

The *Alpine* Decree documented Carson River water rights in California and Nevada, and is the primary means by which the river and its reservoirs are operated, also overseen by the Federal Water Master. For the Newlands Project, the *Alpine* Decree defined the annual net consumptive use of surface water for irrigation at 2.99 acre-feet, a water duty of 4.5 acre-feet per acre for bench lands, and a 3.5 acre-feet per acre duty for bottom lands.

Interstate Agreements

In 1955, the California-Nevada Interstate Compact Commission was formed with representatives from California, Nevada, and the United States, to develop an interstate allocation of the waters that cross the boundaries between both states, including the Truckee, Carson, and Walker rivers. The resulting agreement, the California-Nevada Interstate Compact, was adopted by both state legislatures in draft form but never ratified by Congress (State Water Board 2002).[1] Nonetheless, the states tend to honor the compact's provision for the amount of flow from each river that either state can rightfully claim to be used within its boundaries.

Based on the terms of the original compact, Nevada was allocated approximately 90 percent of the Truckee River Basin's waters. Water supplies were also reserved for growth in the Lake Tahoe and Truckee areas of California. Total annual diversions from the Lake Tahoe Basin were not to exceed 34,000 acre-feet, of which 23,000 acre-feet were allocated to California and 11,000 acre-feet were allocated to Nevada (Nevada DWR 1997).

Section 204 of PL 101-618 officially establishes interstate allocation of the waters of the Truckee River and Lake Tahoe that will go into effect when TROA is implemented:

- **Lake Tahoe Basin –** Consistent with the Interstate Compact provisions, Nevada and California could annually divert up to 11,000 acre-feet and

[1] California-Nevada Interstate Compact, California Water Code Sec. 5976 and Nev. Rev. Stat. Sec. 538.600.

23,000 acre-feet, respectively, from combined surface water and groundwater sources in the Lake Tahoe basin for use in the basin (Interior and California 2008). Each year, after 600 and 350 acre-feet of water have been used for snowmaking in California and Nevada, respectively, 16 percent of any other water diverted and used for snowmaking counts against each state's allocation.

- **Truckee River Basin in California –** California could divert no more than 32,000 acre-feet of water from the Truckee River basin (a maximum of 10,000 acre-feet could be surface water diversions), and use no more than 17,600 acre-feet consumptively, per year (Interior and California 2008). As with the Lake Tahoe Basin, there are also specific rules regarding how much water may be used for snowmaking, the manner in which water can be stored above ground or underground, and how and where groundwater wells may be installed.

TROA

TROA is a negotiated agreement for operation of Federal reservoirs on the Truckee River upstream from Reno. Mandatory signatories to TROA include the United States, Pyramid Lake Paiute Tribe, TMWA (as the successor to Sierra Pacific Power Company), and the states of California and Nevada (Interior and California 2008). The agreement is intended to assure coordination of the operation reservoirs for the purposes of storage, release, and exchange of water. TROA provides storage space which will increase municipal drought supplies, benefit instream flows for threatened and endangered fish species of Pyramid Lake and water quality purposes, and enhance reservoir levels for recreational use.

TROA will carry out the terms and conditions of the Preliminary Settlement Agreement between Sierra Pacific Power Company and the Pyramid Lake Paiute Tribe as ratified by the United States, which will allow changes in the exercise of municipal water rights (generally, during times of water surplus) to benefit threatened and endangered Pyramid Lake fishes and allow storage of water in Federal reservoirs for the cities of Reno and Sparks during drought. In short, it provides flexibility to TROA parties and others for how reservoirs are operated to meet the needs of various – and sometimes conflicting – uses of the Truckee River's water.

Section 205(a) of Public Law101-618 directed the Secretary for the Interior to negotiate the agreement, but also required that TROA ensure that water is stored in and released from Truckee River reservoirs to satisfy the exercise of *Orr Ditch* Decree water rights.

Flood Control Operations

Flood control operations at Truckee River reservoirs are based on various regulations and procedures established by different agencies. Martis Creek Lake and Prosser Creek, Stampede, and Boca reservoirs are operated based on flood control criteria issued by the USACE. Operations at these reservoirs restrict reservoir releases when Truckee River flows through Reno are above 6,000 cfs. Lake Tahoe is not operated for flood control, and is operated to avoid exceeding lake elevations above 6,229.1 feet. Donner and Independence lakes are also not operated for flood control, but have storage limits and operating restrictions to comply with California licensing requirements and dam safety criteria (USGS 2001).

In general, flood control operations vary by season. In the fall, typically by November 1, reservoir levels are lowered to ensure sufficient flood storage space is available to capture higher inflows during winter and spring. In the winter, typically from November through the end of March, the reservoirs maintain their flood storage space. In the spring, from April to June, reservoirs fill to their maximum storage capacity with runoff from snowmelt. In the summer, from July through September, reservoirs are operated to release water to meet downstream demand.

In total, about 1.1 million acre-feet of storage space is available in Truckee River reservoirs for managing water supplies; of this, 65,000 acre-feet of space is needed, seasonally, for flood management purposes (State Water Board 2002).

Newlands Project Operations

Newlands Project operations are governed by the Newlands Project OCAP and the Truckee Canal capacity safety restrictions.

OCAP (1997)

OCAP is a set of regulations that dictate how the Newlands Project is operated to protect the service of project water rights; regulate diversions from the Truckee River to only the amount needed to serve project water rights; and maximize the project's use of Carson River supplies. OCAP sets allowable diversions from the Truckee River based on annual estimates of irrigated acreage and dictates other components of how TCID must operate and maintain the project.

OCAP incorporates numerous considerations and criteria that address conditions that have been developing throughout the Truckee Basin since the 1960s. In February 1967, Pyramid Lake reached its lowest elevation in recent history (3,783.9 feet mean sea level). Shortly thereafter, the Pyramid Lake cui-ui fish species was identified as in danger of extinction under the Federal Endangered Species Act of 1966 (ESA). In response to these factors, the Secretary issued regulations for the Newlands Project known as OCAP. The principal purpose of OCAP was to regulate diversions at Derby Diversion Dam to maximize use of Carson River water and minimize use of Truckee River water for the Newlands Project. As a result of litigation (*Pyramid Lake Paiute Tribe of Indians v. Morton*, 1973), a Federal court ruled that OCAP then in effect was insufficiently protective of Pyramid Lake. The Secretary issued new OCAP in February 1973 to comply with the court's order. The 1973 OCAP imposed stricter limits on diversions from the Truckee River to the Newlands Project than had the previous OCAP. From

1984 to 1987, interim OCAPs were issued while a longer-term OCAP was prepared and ultimately issued in 1988. OCAP was adjusted most recently in 1997.

From January through June, OCAP sets monthly storage targets for Lahontan Reservoir that are based on runoff forecasts for the Carson River and other projections. Combined with anticipated project demand, these storage targets dictate the volume of Truckee River water that can be diverted at Derby Dam and stored at Lahontan Reservoir to supplement the Newlands Project's Carson River supply.

Truckee Canal Safety Restrictions

A court order issued following the 2008 breach has limited the Truckee Canal's flow to 350 cfs. Reclamation also imposed stage restrictions at four sections of the canal corresponding to the 350 cfs flow rate. Reclamation has reviewed the risks of continuing to operate the Truckee Canal and has concluded that substantial improvements will be needed to allow the canal to safely convey as much water as it has historically. While the diversion rates at Derby Dam and conveyance in the canal have fluctuated since the canal's completion in 1905, diversion rates in recent years before the 2008 breach have averaged around 600-900 cfs. The facility's advanced age – around 110 years old – and structural issues make future breaches likely (Reclamation 2011c). Urbanization has increased the potential for a breach to cause damage, injuries, or deaths. Reclamation has weighed the high likelihood and increased consequences of a breach, and found the resulting risk to be unacceptable for a Federal facility (Reclamation 2008a, b). The combination of failures with high likelihoods and with high consequences has led Reclamation to require extensive rehabilitation actions, especially for the urbanized portions of the Truckee Canal (Reclamation 2011b). Until the canal is rehabilitated to reduce the identified safety risks that exist, conveyance restrictions on the portion of the Truckee Canal near Fernley will likely remain in place (Reclamation 2013).

Pyramid Lake Fish Flow Regimes

A collaborative working group led by USFWS developed a set of fish flow regimes for the Truckee River and Pyramid Lake as part of a recovery plan for the Lahontan cutthroat trout (USFWS 1995). These flow regimes were used successfully from 1995 through 2000, resulting in substantial improvements to riparian habitat conditions in the lower Truckee River downstream from Derby Dam. In 2002, USFWS began working with the Pyramid Lake Paiute Tribe to develop a new set of flow regimes (TRIT 2003). The six flow regimes (Figure 5-8) developed through this effort were intended to release less water in the spring and more water in late summer and fall than previous cui-ui spawning flow criteria, resulting in measured releases of water in the Truckee River over the entire year. The strategy was designed to more closely mimic a natural river system while protecting habitat for both cui-ui and Lahontan cutthroat trout (Interior and California 2008).

The flow regimes are based on six hydrologic year types, along with the availability of Stampede Project Water (and Fish Credit Water under TROA) in storage on March 1. The hydrologic year types are determined each year based on forecasted conditions at Stampede Reservoir between March and July. Each flow regime has a set of monthly inflow targets for Pyramid Lake. An appropriate regime is selected each month, from March through July, as the Stampede Reservoir inflow forecast is updated. A single flow regime is selected for operations from August through the following February.

These inflow targets are modified in years with substantial spring runoff. When both May and June inflow to Pyramid Lake exceeds 1,000 cfs, the August and September inflow targets are set to 300 cfs. When lower Truckee River flow is below the inflow target, Fish Water is released from Prosser Creek and/or Stampede Reservoirs to supplement the flow.

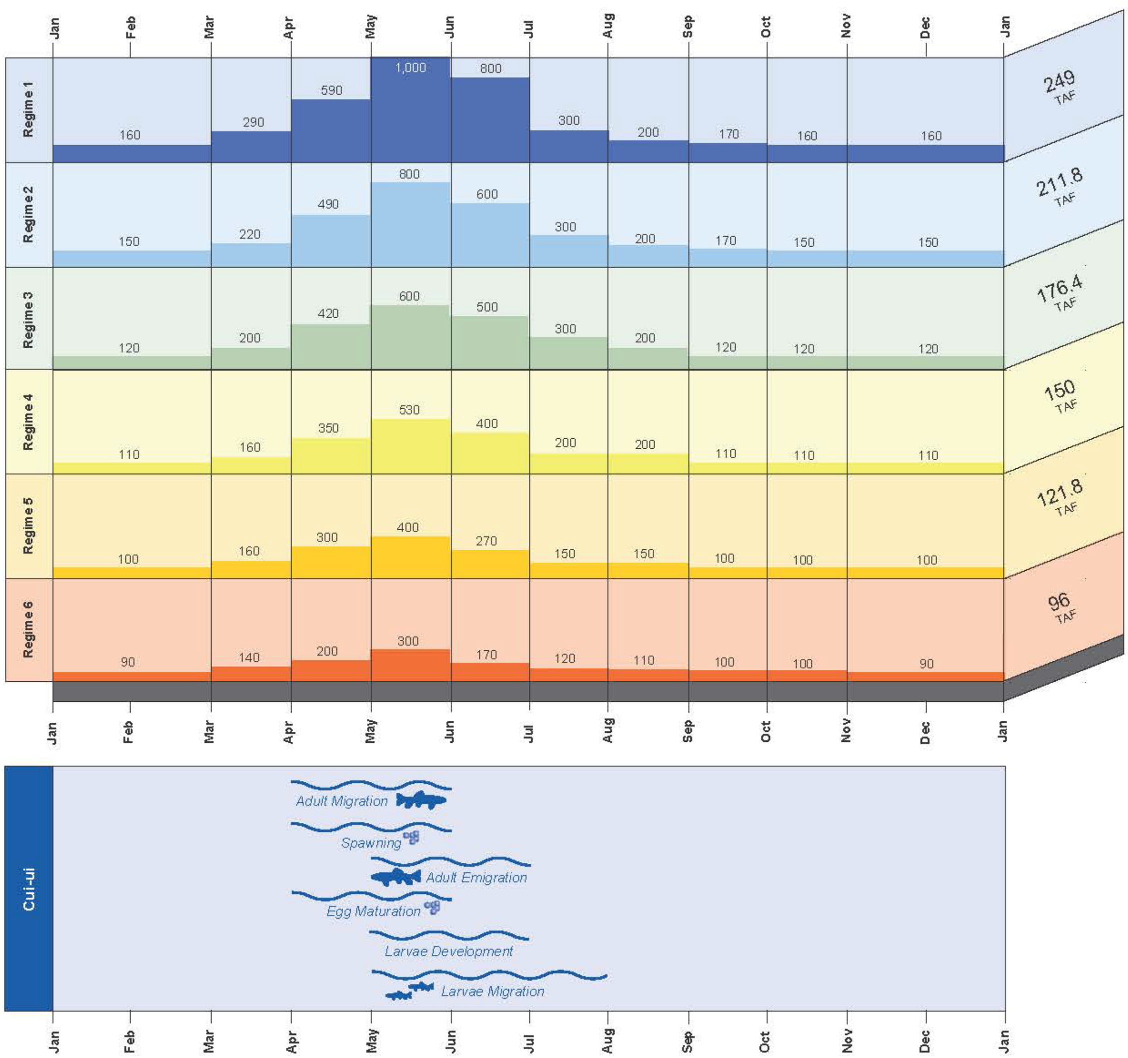


Figure 5-8. Flow Regimes and Historical Timing of Cui-ui Life Stages

Chapter 6 Risk and Reliability Assessment

One of the Basin Study's key products is the identification of challenges facing water user communities in the Truckee Basin. The following 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 relied on scenario analysis and engagement with water users and other stakeholders to address these questions. As described in "Chapter 2 – Scenario Planning and Supporting Information," scenario analysis involves systematic testing and comparing of different potential future conditions, where each scenario assembled represents one possible future condition. The Basin Study scenarios are assembled through combination of (a) one supply condition, (b) one demand condition, and (c) one set of water management conditions. This chapter provides assessments of Basin-wide vulnerabilities and of future reliability for each Truckee Basin water user community based on comparisons between the Reference scenario or conditions and multiple Without-Action scenarios. Basin-wide vulnerabilities consider the ability to manage infrastructure and meet key objectives in the Basin under the full range of future supply and demand conditions. The water user reliability assessment documents how changes in future conditions affect each 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.

This chapter is organized in two sections: the first assesses potential vulnerabilities that could be experienced under future conditions from a broad, Basin-wide perspective, and the second characterizes and assesses risk and reliability for specific water user communities in the Truckee Basin.

Future Risk and Reliability

The concepts of risk and reliability are interrelated. "Risk" refers to a combination of the likelihood and the consequence of a negative outcome. For instance, flood risk is described in terms of a certain storm return frequency (e.g., 500-year flood) and the corresponding effect on human lives and property. “Reliability” refers to the probability and frequency of failure: the reliability of a water delivery system would be expressed in terms of the frequency and magnitude of shortages to its customers. Commonly, risk is used to describe undesirable events caused by factors outside of human control (floods, seismic events, fires, etc.) and reliability often characterizes failures in systems that have been designed by humans (reservoir systems, treatment plants, levees, etc.). Nevertheless, both risk and reliability are used to characterize the anticipated frequency and magnitude of undesirable conditions.

The Basin Study describes the risk and reliability of future water use on the Truckee River through two assessments:

1. Identification of key vulnerabilities to the range of potential future supply and demand conditions.

2. Descriptions of how well the current infrastructure and operations can meet the needs of each water user community under the range of potential future conditions.

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. The Reference scenario relies upon simulated hydrologic information, as described in “Chapter 3 – Water Supply Assessment,” that differs from historical gage records. While the Reference provides the most appropriate point of comparison with all future scenarios or conditions, the region’s water users have an important familiarity with historical water supplies. Where possible and relevant, the following analysis also presents historical records and results from the Historical supply condition. The purpose of including historical information is not to provide a “second baseline,” but rather to allow the reader to understand where differences exist between historical information and the conditions that exist uniformly across the Reference scenario and future Without-Action scenarios.

> Vulnerability is a risk of negative conditions that could be experienced by Truckee Basin water users if action is not taken. Vulnerabilities are identified through comparisons between the Reference scenario and Without-Action scenarios.

The following section presents the vulnerabilities that have Basin-wide implications, followed by separate assessments of reliability for each water user community. The reliability assessments for water user communities provide the basis for understanding how future conditions in the Truckee Basin influence the water resources upon which the Basin’s human and natural ecosystems rely.

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 modestly sensitive 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. In part, the low variability that results from different demand conditions reflects the care and planning that has gone into setting limitations on growth and water use within the Truckee Basin. When appropriate, discussions in this section are limited to comparisons between the Reference scenario and one scenario for each of the five future supply conditions (Central Tendency, Hotter-Drier, Hotter-Wetter, Warmer-Drier, and Warmer-Wetter). For brevity in discussion and clarity in presentation, these comparisons show Without-Action scenarios that include only one future demand condition – typically, Robust Economy – as opposed to including all ten scenarios in the presentation and discussion. Although the difference in water use between the two future demand conditions is small relative to uncertainties in future supply, use of the Robust Economy demand condition for the scenario comparisons captures the greatest extent of vulnerabilities due to future conditions.

Vulnerabilities due to uncertainties in water supply availability are related to potential changes in annual precipitation and increases in temperature. Changes in precipitation have a direct influence on water supplies. Increases in temperature, however, are more complex. First, increased temperatures will reduce the accumulation of snow, which has been relied upon as a source of water in the spring and summer. Second, temperature increases promote evaporation, which has implications for water supplies at Lake Tahoe and surface elevations at Pyramid Lake. The influences of these factors on water management in the Truckee Basin are best observed in the operation of reservoirs and the ability to meet operating objectives along the Truckee River. The ability to manage inflows, refill, and maintain carry-over storages are most sensitive to changes in the supply conditions, particularly changes in supply and seasonality shifts. The ability to manage the Truckee River for Floriston rates, Newlands Project diversions and fishery restoration objectives at Pyramid Lake are affected similarly.

Climate also influences agricultural water use. Higher year-round temperatures are anticipated to prolong the growing season, which in turn increases the volume of water needed to maintain irrigation needs of every farm. A lengthened growing season will render it difficult for current water rights to maintain the current acreage of crops in the Basin in their current well-watered condition. As a result, crops may adapt through reductions in yield, or potentially fail. The Basin Study did not address the complex outcomes of crops experienced as a result of given water supply conditions, and instead focuses on the ability to maintain the acreages of crops identified in the demand storylines in a well-watered condition.

Similar to agriculture, increases in outdoor use are possible by urban and industrial users. However, the Basin Study assumes that urban demands will be kept within the bounds of water rights through the political and economic management of urban water supplies. Thus, future demands for urban water users are expected to stay within the ranges described by the future demand storylines, and not exhibit climate induced growth.

Finally, climate also influences ecosystems, and it is uncertain how aquatic ecosystems may adapt to future changes in the natural runoff. For instance, the timing of reproduction life cycles for cui-ui and Lahontan cutthroat trout may happen earlier in the year, as peak flows and low temperatures shift toward the winter. Changes in the ability to maintain water quality standards may also influence ecosystem needs. Additionally, the timing of needs may change for migratory birds that use Lahontan Valley Wetlands and other lakes and meadows in the Basin as resting points on the Pacific flyway. While the Basin Study recognized the potential for changes in the timing or volume of water needed to meet the restoration and maintenance goals for these ecosystems, the drivers for change are difficult to address with the information available to the Basin Study. For the purpose of the Basin Study, the ability to meet ecosystem needs was addressed in the assessment of water use reliability through an evaluation of how well current flow targets are maintained.

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 6-1 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 6-1 arises between future climate conditions; the changes in elevation resulting from various future demand conditions is relatively smaller.

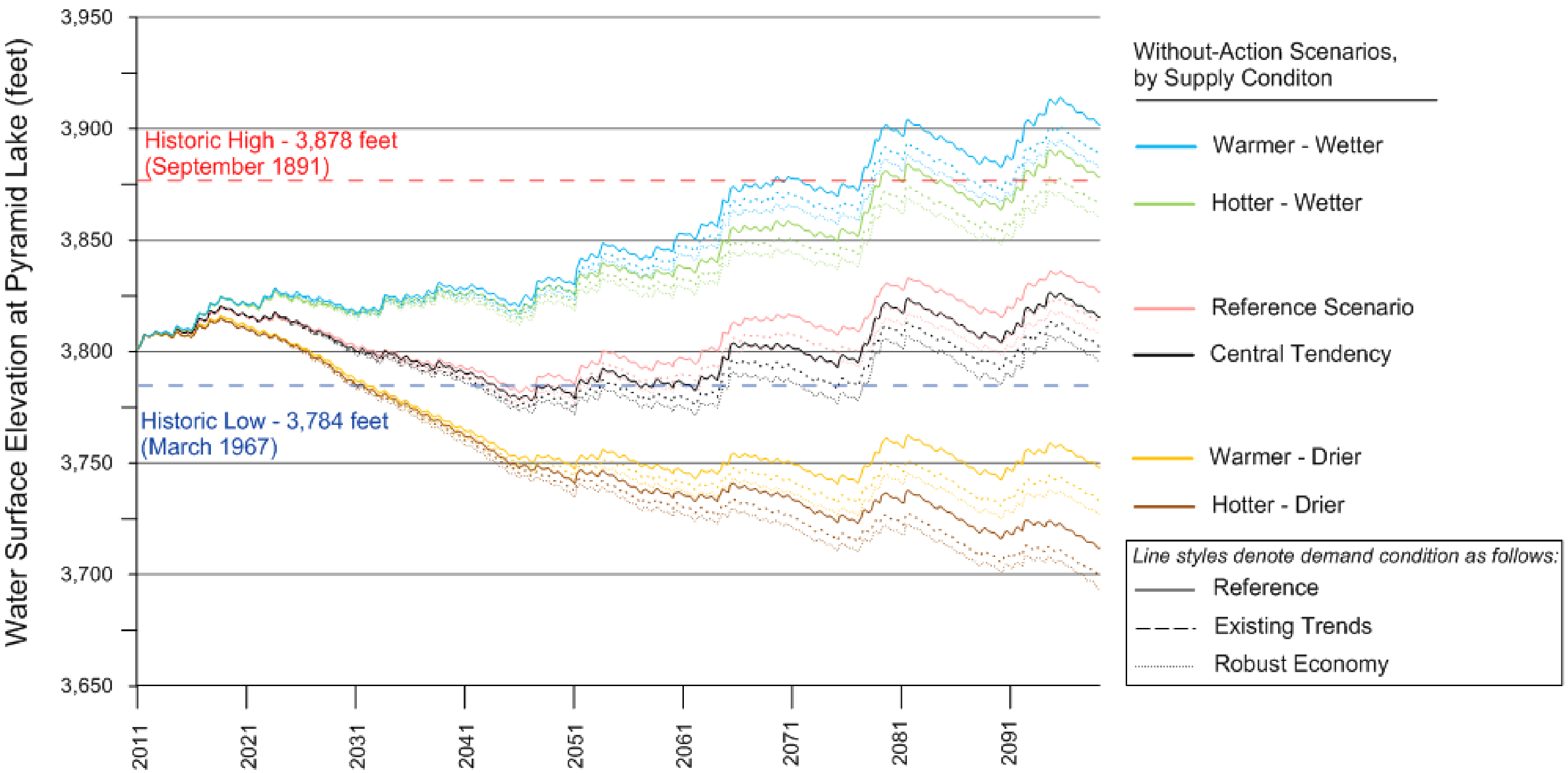


Figure 6-1. Projected Future Water Surface Elevations at Pyramid Lake Under Different Scenarios

Figure 6-1 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 the regions 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 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 Basin water supplies, water users and local communities may see a benefit in focusing their future planning and investment efforts on options that provide resiliency or 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 prevented from increasing 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.

Vulnerabilities to Changes in Precipitation A direct relationship exists between precipitation rates and the availability of surface and groundwater supplies in the Truckee Basin. Table 6-1 and Figure 6-2 present the relative availability of surface and groundwater sources among historical and projected future conditions. Generally, the Reference and Central Tendency supply conditions have similar rates of precipitation, which is reflected in the average volumes of groundwater recharge and runoff for both the Truckee and Carson rivers, as well as the groundwater recharge in the Martis Valley.

Table 6-1. Comparison of Simulated, Average Annual Supplies

	Mean Annual Natural Runoff for the Truckee River at Farad (TAF)	**Average Annual Carson River inflow to Lahontan Reservoir (TAF)**	**Average Annual Recharge in Martis Valley (TAF)**
Supply Condition	**(difference in comparison to Reference condition)**		
Reference	418	258	15.6
Central Tendency	433 (+3%)	226 (-12%)	14.8 (-5%)
Warmer-Drier	371 (-11%)	203 (-21%)	13.6 (-13%)
Hotter-Drier	352 (-16%)	169 (-34%)	12.1(-23%)
Hotter-Wetter	504 (+20%)	257 (-0.3%)	16.1 (+3%)
Warmer-Wetter	506 (+21%)	284 (+10%)	17.0 (+9%)

Key:
TAF = thousand acre-feet

Average natural flow at the Farad gage was 396,664 acre-feet per year for the period of 1911 to 2000 (Interior and California 2008). Future conditions on the Truckee River produce between 84 to 121 percent of the Reference condition. The Central Tendency would be 3 percent wetter on average than the Reference.

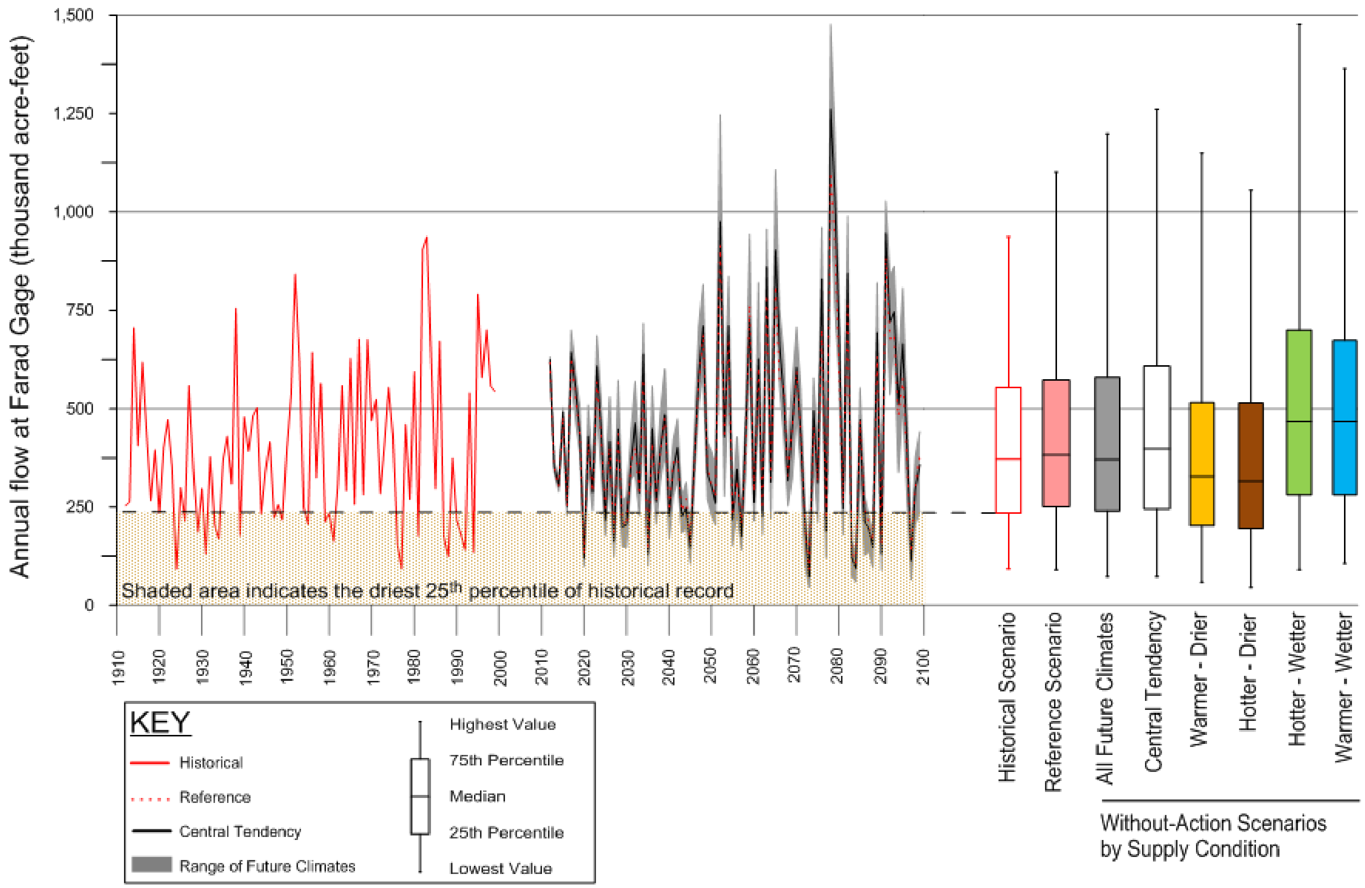


Figure 6-2. Comparison of Natural Flows at the Farad Gage, Excluding Lake Tahoe

Average annual discharge on the Carson River to Lahontan Reservoir was 276,000 acre-feet per year for the period of 1911 to 2000 (Interior and California 2008). The Basin Study uses a regression relationship to relate flows on the Truckee River to inflows at the Fort Churchill gage on the Carson River, upstream from Lahontan Reservoir (see "Appendix C – Future Supply Technical Reports" for more details). Using this approach, future conditions on the Carson River produce between 66 to 110 percent of the Reference scenario. The Central Tendency would be 12 percent drier on average than the Reference scenario.

Average annual groundwater recharge would change with changes in precipitation. Simulated rates of recharge, which are based on simplified representations of groundwater processes in PRMS, show decreases in the Martis Valley under a drier climate (up to 23 percent) and would increase under a wetter climate (up to 9 percent), in comparison to the Reference scenario. The Central Tendency would have about 5 percent less recharge than the Reference. Scenarios with hotter conditions would also affect groundwater recharge, although to a lesser degree than precipitation changes. The Hotter-Drier scenario would decrease Martis Valley groundwater recharge an additional 10 percent beyond the Warmer-Drier due to decreases in snowpack extent and a faster snowmelt season.

The reader should be aware that a separate and more robust application of the PRMS model was being developed for describing groundwater conditions in the Martis Valley, in parallel with the Basin Study. This second study used the PRMS surface water model applied in the Basin Study, but also includes a coupled groundwater model that allows for improved representation of surface and groundwater interactions. Differences in the resolution and formulation of the models may result in differences in the reported groundwater recharge in the two studies. In the event of disagreement, the reader is encouraged to favor use of the more detailed study (Rajagopal, et al., 2015). Despite differences in the reported absolute values for recharge between the two studies, the trends identified in this Basin Study are considered valid and appropriate for describing the sensitivities of groundwater recharge to changes in climate.

Extreme Events Drought and prolonged periods with low flows occur in all scenarios, but are exacerbated in drier scenarios. 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, Reclamation assessed the potential changes in flood frequency that could occur in the Truckee Basin under future climatic and hydrologic conditions. This flood 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 event considered to be the flood-of-record for the Basin. In fact, future conditions may increase the likelihood of a flood of any magnitude – the Basin may experience more floods like the 1997 event, but would experience more floods considered "less extreme," also. 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. Analyses that assume future flood frequency will follow the same distribution as historical floods in the Truckee Basin are likely to underestimate the potential for flooding in the future. The flood analysis conducted in parallel to the Basin Study is included in this report as "Appendix E – Truckee River Flood Frequency and Magnitude Analysis."

Vulnerabilities to Increases in Temperature Generally, temperatures in the Truckee Basin are anticipated to increase over the coming century, causing complex effects on hydrologic processes. Most notably, rising temperatures will increase evaporative losses at Lake Tahoe and reduce the proportion of winter precipitation that accumulates as snow.

Increases in Surface Water Evaporation Evaporation rates increase over the coming century as the climate of the Truckee Basin warms (Table 6-2) (see "Chapter 3 – Water Supply Assessment" for additional details).

Table 6-2. Changes in Lake Tahoe Evaporation

Supply Condition	Lake Tahoe Evaporation (difference in comparison to Reference condition)	
	Water Years 2012-2099	**Water Years 2070-2099**
Central Tendency	+3%	+4%
Warmer-Drier	+2%	+3%
Hotter-Drier	+4%	+5%
Hotter-Wetter,	+4%	+5%
Warmer-Wetter	+2%	+3%

Evaporation rates are expressed in units of depth, but the volume of water evaporated from a lake is also a function of lake surface area. For example, Lake Tahoe and Donner Lake could have similar evaporation rates, but the vast surface area of Lake Tahoe would result in considerably more water lost to the atmosphere.

The managed storage in Lake Tahoe has a unique and unfavorable geometry for a reservoir. While the lake has an average depth of 1,000 feet, only the six feet above the natural rim controlled by Tahoe Dam can be used for water supply; the considerable volume beneath the natural rim remains unavailable for delivery. In addition, the surface area of the lake is 191 square miles. Thus, the reservoir portion of Lake Tahoe has the depth of a hotel swimming pool and a surface area similar to the largest managed reservoirs in the United States (Lake Mead behind Hoover Dam covers 247 square miles, and Franklin D. Roosevelt Lake at Grand Coulee Dam covers 124 square miles). Lake Tahoe is further challenged in operating as a reservoir because its outlet only allows for the delivery of a maximum of 1.5 feet of its stored supplies in any given year, leaving any single year gains in storage susceptible to loss before they can be delivered. In combination with the estimated evaporation of 3.4 feet per year, Lake Tahoe experiences a high evaporation-to-storage volume ratio among reservoirs.

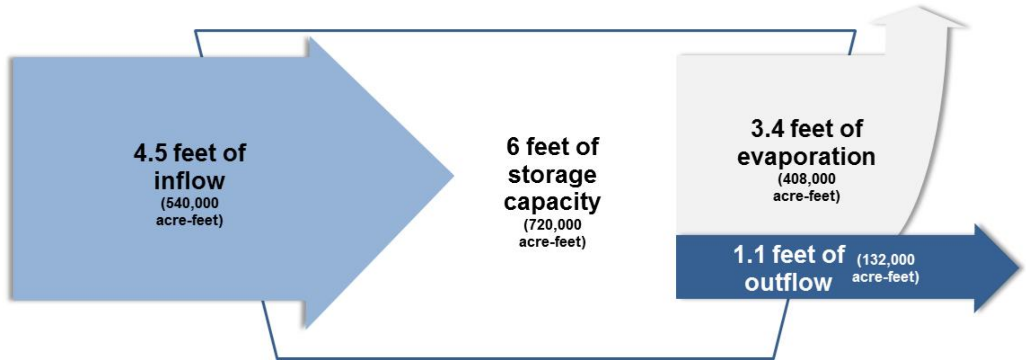


Figure 6-3. Average Relationship Between Inflow, Evaporative Losses, and Outflow at Lake Tahoe for the Reference Scenario

Under the Reference supply condition, approximately 65 percent of Lake Tahoe's potential storage capacity evaporates each year (Figure 6-3). This means about 75 percent of the average annual inflow into Lake Tahoe evaporates before it can be delivered.

Because of this geometry, water supplies in Lake Tahoe will be sensitive to small increases in average annual temperatures. A 5-percent increase in evaporation at Lake Tahoe would reduce the annual average outflow by about 20 percent. Historically, outflow from Lake Tahoe to the Truckee River represents approximately one-third of the annual Truckee River flows at Farad. Compounded changes in precipitation and evaporation due to increases in temperature may move Lake Tahoe's elevation outside of the normal range (Figure 6-4).

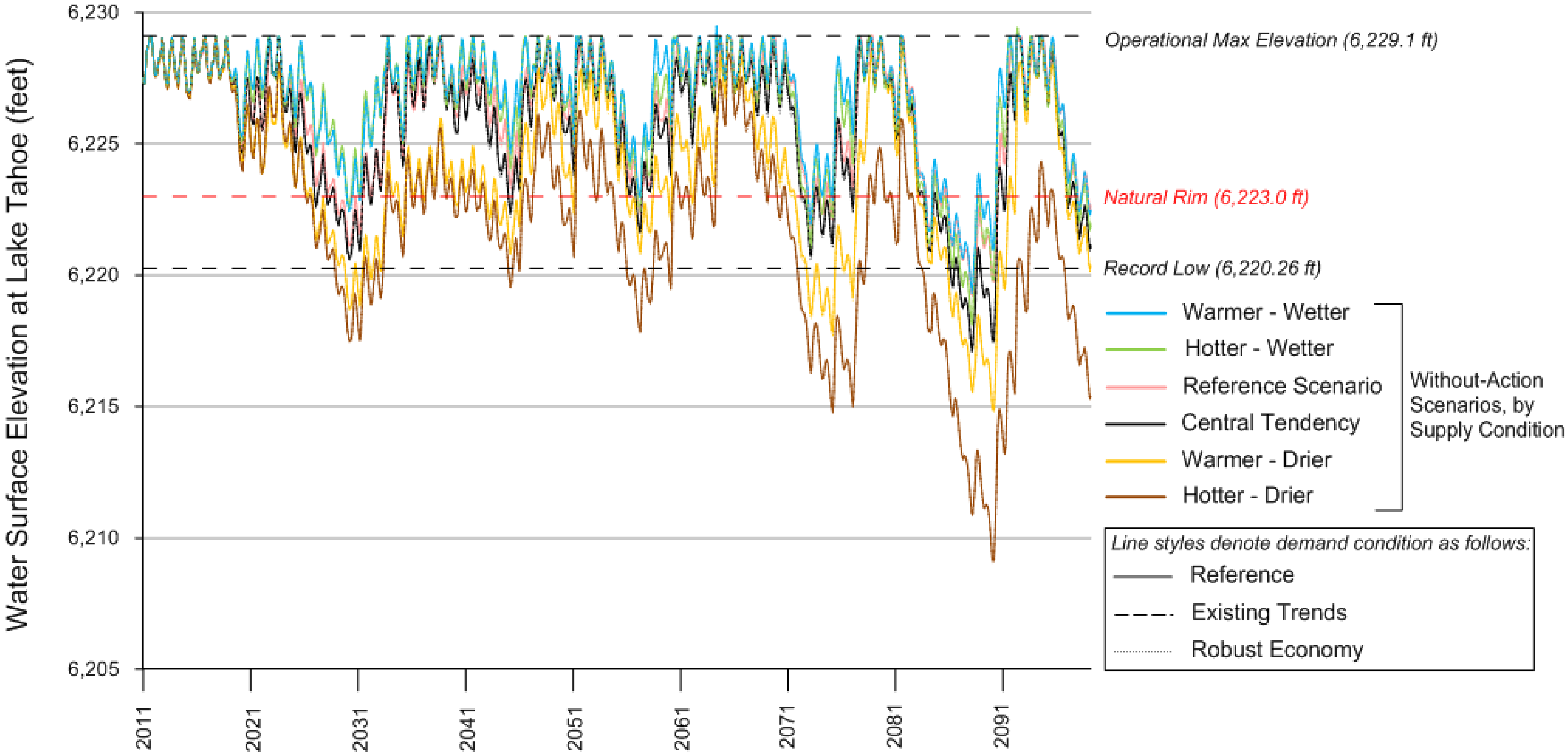


Figure 6-4. Projected Future Water Surface Elevations at Lake Tahoe

Reduced Snow Accumulation and Earlier Peak Runoff The peak snow accumulation in the Truckee Basin has historically occurred in April, with a gradual melt-off that lasts through August. In the future, seasonality shifts move the peak surface runoff to February and March by the end of the century (see “Chapter 3 – Water Supply Assessment”).

Table 6-3. Changes in April 1 Snow Water Equivalent

	Water Years 2012-2099		Water Years 2070-2099	
	Lake Tahoe Basin	Between Lake Tahoe and Farad Gage	Lake Tahoe Basin	Between Lake Tahoe and Farad Gage
Supply Condition	(TAF, percent difference)		(TAF, percent difference)	
Reference	268, N/A	425, N/A	221, N/A	407, N/A
Central Tendency	153, -43%	256, -40%	65, -71%	160, -61%
Warmer-Drier	166, -38%	266, -37%	91, -59%	197, -52%
Hotter-Drier	98, -63%	154, -64%	20, -91%	56, -86%
Hotter-Wetter	154, -42%	264, -38%	54, -76%	143, -65%
Warmer-Wetter	215, -20%	365, -14%	124, -44%	277, -32%

Key:
TAF = thousand acre-feet

From a water supply perspective, reductions in snow accumulation are similar to reductions in reservoir storage volumes. Historically, the bulk of annual precipitation falls in the Truckee Basin between the months of October and April. Changes in climate are not anticipated to alter this timing; rising temperatures are expected to reduce the volume that accumulates in snowpack. The effects of this can be seen by comparing total surface runoff during the wet season (October through May) with the volume of water held in snow on April 1 (termed “snow water equivalent”), as depicted in Figure 6-5 and Figure 6-6. On average, winter inflows increase (or stay the same) for all scenarios. Increases in winter inflow could create flood management challenges, which were not addressed directly in the Basin Study. For water supplies, the reduction in April 1 snowpack creates challenges for meeting demands later in the year.

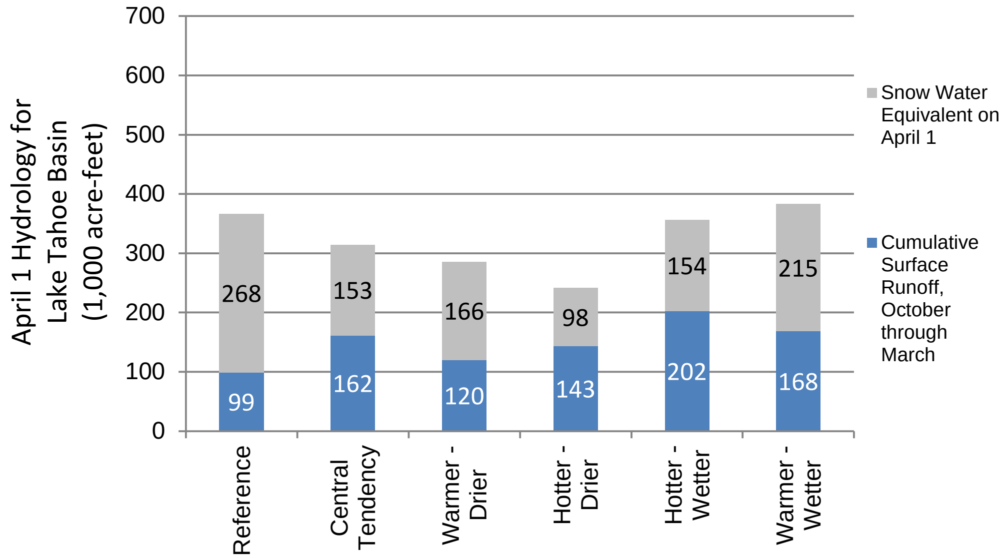


Figure 6-5. Comparison of Runoff and Snow Accumulation for the Lake Tahoe Basin (2012 – 2099), by Supply Condition

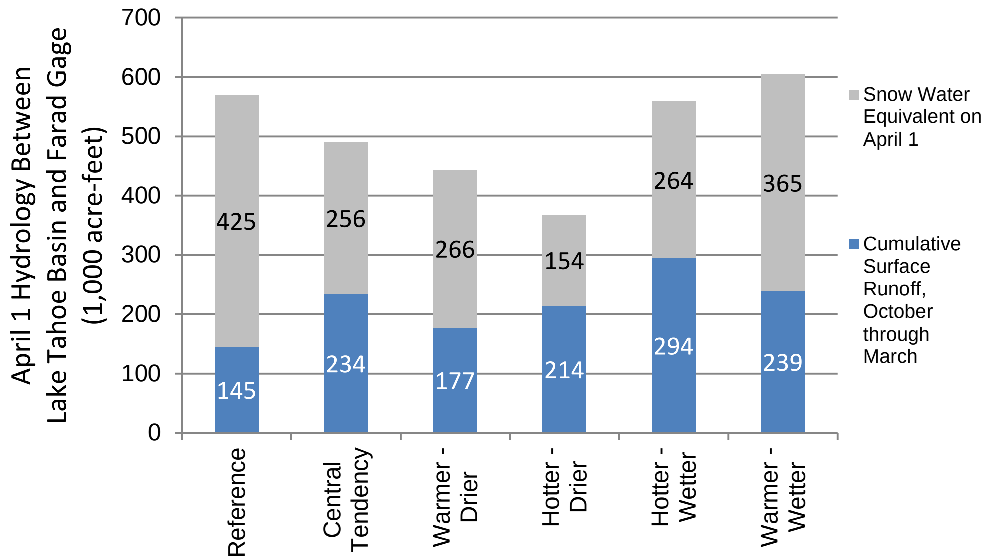


Figure 6-6. Comparison of Runoff and Snow Accumulation between Lake Tahoe and Farad (2012 – 2099), by Supply Condition

Under the Reference supply condition, snow in the Truckee River tributaries retains 427,000 acre-feet on April 1 – 693,000 acre-feet if snow in the Lake Tahoe watershed is included. This volume has historically melted through August, playing an important role in meeting summer water supply needs on the Truckee River. By comparison, the managed storage in Truckee River tributaries has a capacity of approximately 344,000 acre-feet (not including Lake Tahoe's 745,000 acre-feet), which is 80 percent of the historical average snowpack on April 1.

The loss of storage in snow will impact the Basin-wide management of water in two distinct ways. First, reductions of natural flow during the spring will require an increase of releases from reservoir storage. Second, the duration of time that reservoirs are relied upon for meeting deliveries and stream flow objectives will expand as the runoff begins to move into the months with precipitation. Since most of the reservoirs and operations for them have been designed or negotiated around the historical climate, these changes stress the balance between supply and demand.

Water Management Challenges under Future Climatic Conditions

Projected changes in precipitation and increases in temperatures have compounding effects on the management of water supplies. These effects manifest in the reduced ability of reservoirs to capture and control inflows for meeting key instream flow objectives.

Changes in the Control of Inflows at Reservoirs Truckee Basin reservoirs face challenges under all future conditions. In general, the challenges vary widely by climate condition, but little by demand. Future conditions challenge the control that reservoirs exert over inflows, the ability to refill reservoirs during wet hydrologic conditions, and depart from the Reference scenario on key water management operations.

The Influence of Future Supply and Demand Conditions Reservoirs capture stream flows when abundant, and deliver them when needed. The dams in the Truckee Basin are operated to refill each year, beginning in April. Depending on the reservoir, storage is applied to meeting demands in the same year of its capture and/or as carry-over storage.

Figure 6-7 depicts average and total monthly storages (water years 2012 to 2099) for Truckee River reservoirs; storages in Lake Tahoe and Lahontan Reservoir are not included. The top plot depicts the influence of future demand conditions on storage; the bottom, future supply conditions. Notably, future demands reduce the carry-over storages in comparison to the Reference scenario by 15,000 acre-feet in all months, roughly. Differences in between the two future conditions are imperceptible. Under all three scenarios, average storage begins to rise in March, hitting a maximum storage in May and June, with a drawdown that brings the reservoir below flood management curves by the end of September.

The bottom plot in Figure 6-7 shows variability in storages with supply conditions, and reveals this as a higher vulnerability in comparison with demands (top plot). With the exception of Warmer-Wetter, all Without-Action scenarios enter the year with a lower average carry-over. Several processes occur earlier for Without-Action scenarios in comparison to the Reference scenario, all due to seasonality shifts: reservoir refill, peak storages, and reservoir drawdown.

For future supply conditions, greater proportions of winter precipitation occur as rain, which starts reservoir refill earlier. Because spring and summer flows are correspondingly lower, the point at which demand exceeds reservoir inflow begins earlier. This prevents accumulation of storage through May and June (the peak storage months in the Reference) and reduces the end of year carry-over storage because reservoir drawdown occurs for a month or two longer than the Reference scenario.

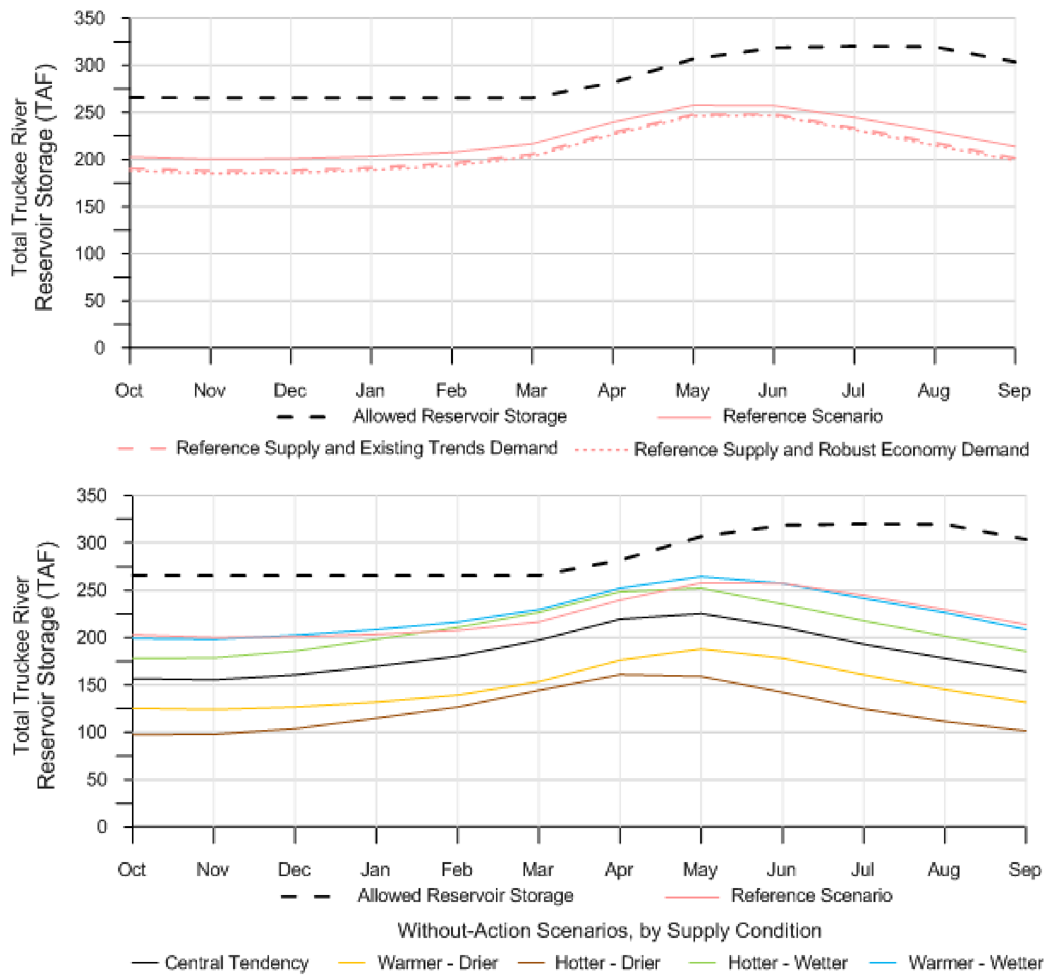


Figure 6-7. Effect of Future Supply and Demand on Monthly Reservoir Storage in Truckee River Reservoirs

Control of Inflows at Reservoirs Understanding the balance of inflow and outflow at each reservoir, as well as the disposition of outflows (i.e., regulated/controlled, unregulated/spilled, evaporated, carried over) allows for understanding how efficiently the storage capacity of each reservoir captures excess inflows for future regulated releases. Increases in precipitation and temperature, and seasonality shifts create visible changes in the operations of reservoirs.

Figure 6-8 provides pie charts that allow for the comparison of inflows to the lakes, reservoirs and unregulated watersheds in the Truckee River Basin and the average ability to control those flows by supply condition. “Unregulated releases” describes both spills and uncontrolled tributaries along the Truckee River.

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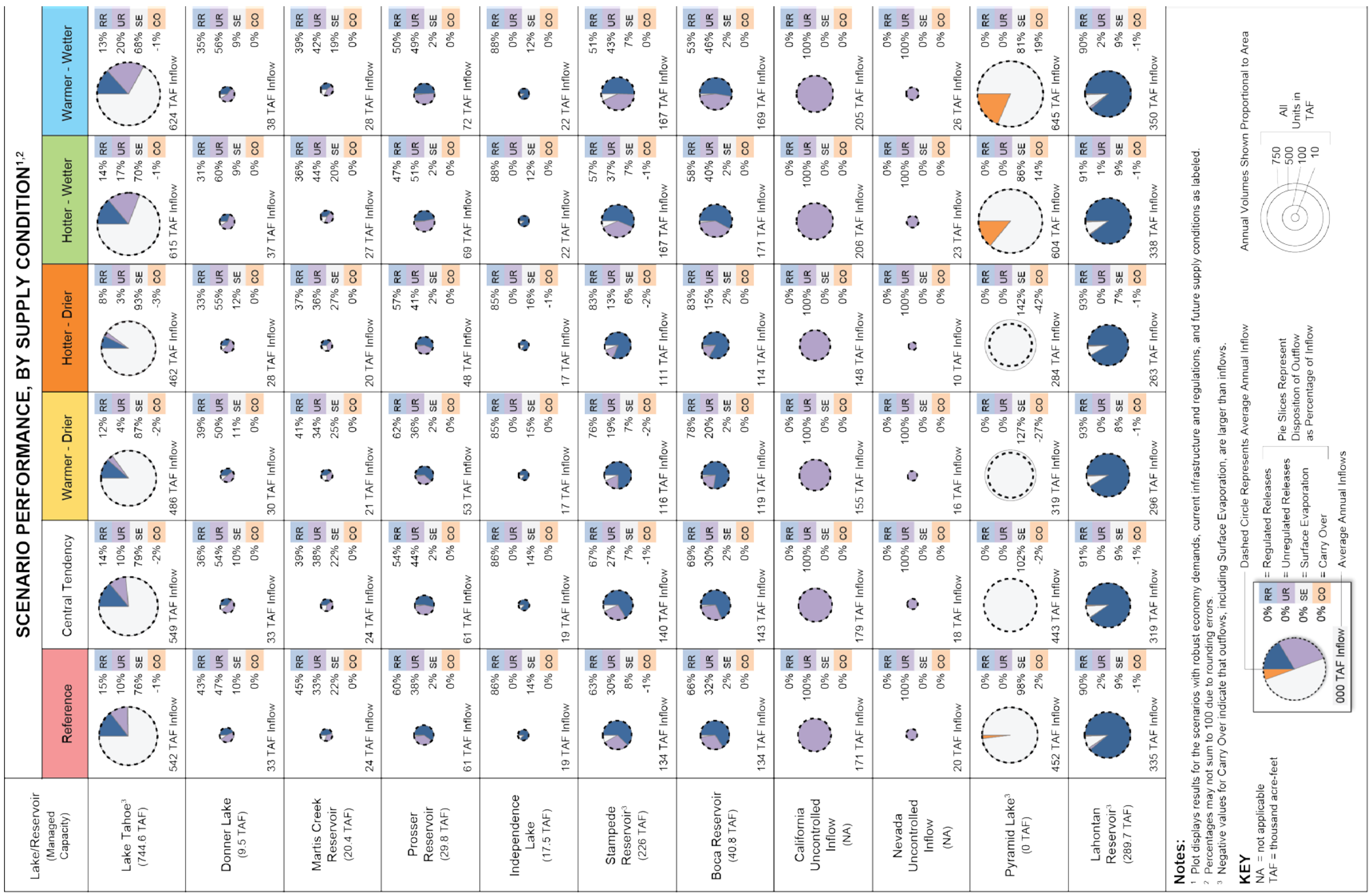

Figure 6-8. Comparison of Future Inflow and Outflow at Key Locations

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Figure 6-8 demonstrates the following key points:

- Changes in reservoir operations tend to result in a similar outcomes among precipitation conditions. Scenarios with drier conditions allow for more efficient reservoir operations (i.e., higher percentage of inflow is released for water supply). Generally, this occurs because reservoir elevations are lower under drier conditions, reservoir inflow is lower, and fewer spills occur. Scenarios with wetter conditions have higher spills because of higher inflows, and because the reservoir rules do not allow for full refill. This indicates a potential increase in flood management risk, also.

- Under the Central Tendency, reservoirs generally function in a manner consistent with the Reference scenario, from a long-term average perspective. However, as demonstrated earlier (Figure 6-7), the Central Tendency maintains consistently lower storage in comparison to the Reference scenario, which compromises water deliveries in some years.

- Potential increases in temperature and evaporation affect both the yield at Lake Tahoe and elevations at Pyramid Lake; however, changes in precipitation volume have an even larger effect on the range of future conditions at either lake. For example, at Lake Tahoe, the differences in yield (blue and purple shading) relative to surface evaporation (grey shading) are most pronounced when comparing the wetter and drier scenarios. At Pyramid Lake, the lake gains in elevation when year-to-year carryover (orange shading) is positive, which occurs only in the Reference scenario and wetter scenarios. When Pyramid Lake loses elevation, such as occurs most prominently in drier scenarios, carryover is negative, and the inflow (dashed black line) is less than the amount of water lost through evaporation (grey shading).

- Operations at Lahontan Reservoir appear consistently proportional between evaporation (grey shading) and yield (blue and purple shading), but smaller inflows seen in drier scenarios may create more reliance on diversions from the Truckee River to meet the reservoir's storage targets.

Changes in the Truckee River reservoirs are hard to discern individually in Figure 6-8 because of small relative size of inflow and operation of some reservoirs. Figure 6-9 provides similar pie charts for the Truckee River reservoirs as a singular unit (excluding Lake Tahoe, Pyramid Lake, uncontrolled inflow basins, or Lahontan Reservoir). This figure highlights the following observations about Truckee River reservoir operations:

- Similar to observations for Figure 6-8, the Central Tendency seems to allow for a similar management of inflows as in the Reference scenario.

- Compared to the Reference scenario, wetter scenarios generally exhibit an increase of 50,000 acre-feet in annual inflow, and an increase of 40,000 to

47,000 acre-feet in annual spills (purple). This indicates that many of the potential gains in precipitation under wetter scenarios occur during periods when either flood management curves prevent their capture, or when reservoirs are already full and additional storage would be needed to make use of the additional supplies.

- Compared to the Reference scenario, scenarios with drier conditions generally exhibit a decrease of 40,000 acre-feet in annual inflow, and a decrease of 30,000 acre-feet in annual spills (unregulated releases). This demonstrates that drier conditions have larger vacancies in storage that are able to absorb a greater proportion of high inflow events, when they occur. Notably, spills still occur.

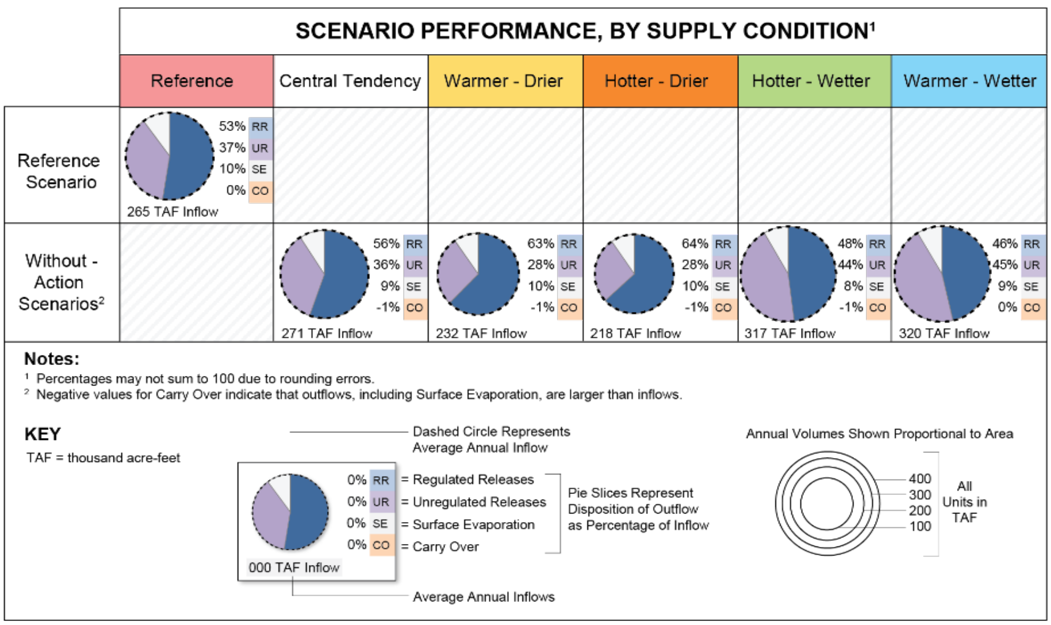


Figure 6-9. Comparison of Future Inflow and Outflow for Truckee River Reservoirs

Challenges in Refilling Reservoirs Seasonality shifts reduce the potential for refilling reservoirs. 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. As the peak runoff moves earlier in time, the ability to meet full pool storages after April is reduced. Figure 6-10 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. 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.

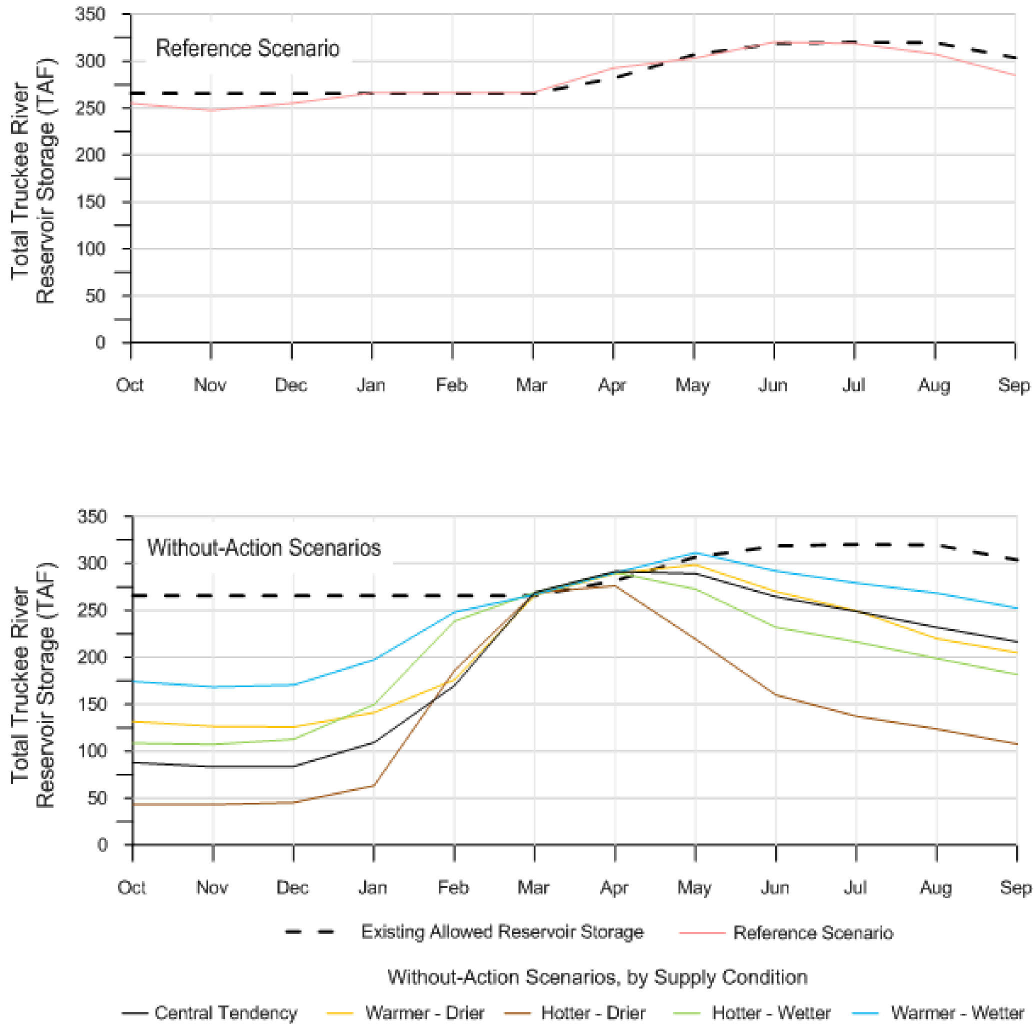
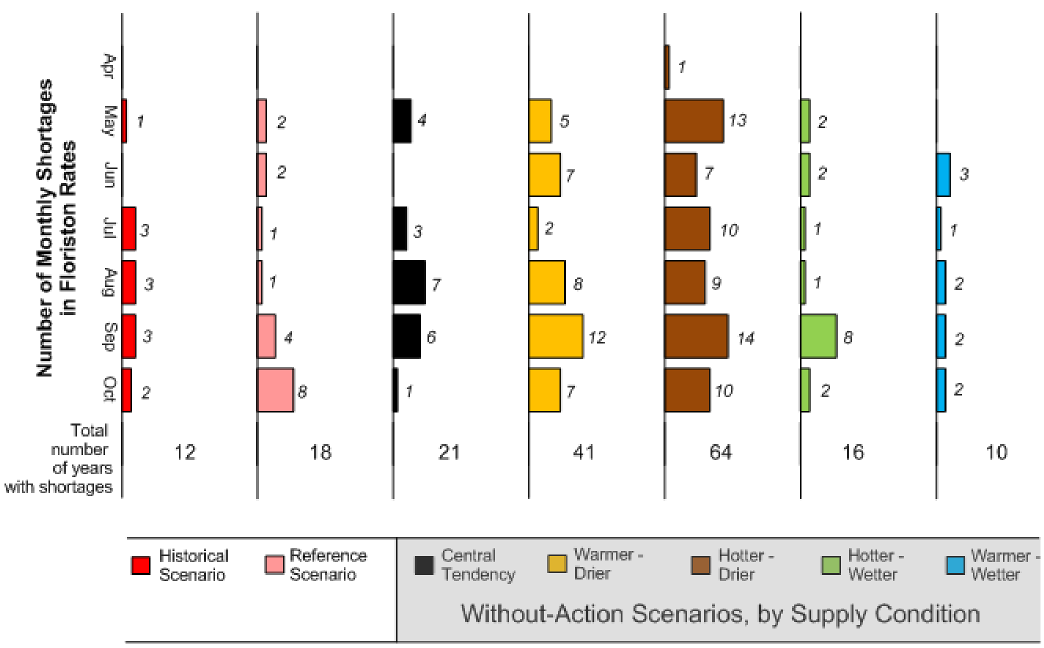


Figure 6-10. Comparison of Truckee River Reservoirs to Refill for Year 2082

Challenges in Meeting Key Operating Objectives Future conditions affect water management operations that affect all water users in the Truckee Basin. Challenges are most notable in water management operations for meeting Floriston rates, diversions for the Newlands Project, and the Pyramid Lake flow regimes.

Reliability of Floriston Rates Floriston rates effectively create a minimum flow target for the Truckee River at the California-Nevada border to meet water right diversions further downstream. The maintenance of the Floriston rate plays a central role in water supplies operations in the Basin. For instance, in Lake Tahoe and Boca Reservoir, water may only be stored when rates are being met, and both TMWA and the Newlands Project rely on the maintenance of Floriston rates for meeting their water supply objectives. Operationally, Floriston rates are maintained until they cannot be, and releases to meet them end abruptly when storage in Lake Tahoe and Boca Reservoir are exhausted. When this occurs, flows in the entire Truckee River recede and use of the Truckee River to meet demands becomes difficult. For example, if Floriston rates are forecast to drop anytime between April and October, TMWA responds with specific drought management actions. Responses by TMWA can include the use of supplemental or emergency supplies, or taking temporary demand management actions that resolve imbalances.

The ability to maintain Floriston rates varies significantly by future supply conditions, and is less sensitive to changes in demands. Because of its importance in meeting downstream water supplies, both the initial month in which rates lapse and the frequency of lapses across all months of the year are important. Figure 6 11 compares the months when Floriston rates are first dropped for seven scenarios, for 2012 through 2099 (a period of 88 years) based on 2012 demand. Figure 6-12 compares the frequency that all months in the 88 year period miss rates for the same scenarios. Comparisons are most appropriately made between the Reference scenario and the Without-Action scenarios. A scenario that considers Historical conditions was also provided to demonstrate differences between historical gage records and the Reference supply conditions.



Note:
Scenarios displayed include the Robust Demand storyline (described in Chapter 4) and the Reference (current) water management conditions (described in Chapter 5).

Figure 6-11. Timing of Lapses in Floriston Rates by Supply Condition

Note:
Scenarios displayed include Robust Demand storyline (described in Chapter 4) and the Reference (current) water management condition (described in Chapter 5).

Figure 6-12. Frequency of Lapses in Floriston Rates by Supply Condition

Changes in the reliability of Floriston rates have several implications for Truckee River water users:

- More frequent, earlier, or longer lapses in meeting Floriston rates may mean that water users such as TMWA will need to secure additional supplies or adjust drought plans or policies intended to help meet demand under prolonged shortages.
- Lapses in Floriston rates in the winter would also affect most M&I demands. Drought reserves may be needed during low demand months in winter, which may affect drought contingency plans. For instance, TMWA uses groundwater during summer months and recharges during the winter. If Floriston rates are not maintained through the year, they may now be needed during the winter. As a result, the ability to recharge the aquifer may be compromised.
- TCID is entitled to any remaining Floriston rate water that reaches Derby Dam and does not belong to Claim 1 and 2 under the Orr Ditch Decree, and relies upon these supplies to refill Lahontan Reservoir by June. Increased lapses in Floriston rates during the winter could place TCID behind schedule in obtaining its target supplies to serve project water rights.

- It will be difficult for other water users who rely on Floriston rates to meet future demand without securing alternative supplies or implementation of drought response policies.

Newlands Project Water Supplies The Newlands Project relies upon diversions from the Truckee River to augment water supplies from the Carson River when needed. In some years, diversions are made only for a small portion of the Newlands Project that relies solely on Truckee River diversions (the Truckee Division of the project), and the bulk of the project has its demands met entirely by the Carson River (the Carson Division of the project). Reclamation estimates that the diversion of Truckee River water would meet 25 percent of the Newlands Project demands (and up to a maximum of 75 percent in any one year) under the current regulatory environment (Reclamation 2013).

The proportion of flow diverted from the Truckee River for the Newlands Project and the relative reliance of the Newlands Project on the Truckee River are sensitive to changes in the hydrology of both Truckee and Carson river basins. Table 6-4 demonstrates the relationship between average flows for the range of potential future climates, and the implications on diversions at Derby Dam and reliance on the Truckee River by the Newlands Project.

Table 6-4. Comparison of Truckee Basin Supplies

Supply Condition	Mean Annual Natural Runoff for the Truckee River at Farad (TAF)	Average Annual Carson River Inflow to Lahontan Reservoir (TAF)	Proportion of Flow at Derby Dam Diverted for Newlands Project[1]	Proportion of Newlands Project Deliveries Provided by the Truckee River[2]
Historical[3]	562[4]	275[5]	28%[6]	31%[7]
Reference	418	258	19%	27%
Central Tendency	433	226	22%	33%
Warmer-Drier	371	203	29%	35%
Hotter - Drier	352	169	31%	39%
Hotter-Wetter	504	257	16%	28%
Warmer-Wetter	506	284	13%	23%

Notes:
[1] Calculated using scenarios with Robust Economy demand storyline.
[2] Results are insensitive to changes in demand.
[3] Historical diversions for the Newlands Project have been found to be inconsistent with Federal law and are inappropriate for comparison to future conditions. The Reference supply condition should be used as the baseline for comparison in this table.
[4] USGS gage records for 1909-2000.
[5] USGS gage records for 1911-2000.
[6] USGS gage records for 1958-2000.
[7] USGS gage records for 1967-2000.

Key:
TAF = thousand acre-feet

Future conditions show a general tendency for the Newlands Project to rely more heavily upon diversions from the Truckee River to meet the existing water rights. This tendency stems in part from seasonality shifts on the Carson River, shifts in when Floriston rates are met, and the lack of Carson Basin storage above Lahontan Reservoir; Lahontan Reservoir cannot manage earlier runoff through the summer. This increased reliance is most notable on the Truckee River during the drier supply conditions, where it translates into a greater proportion of the Truckee River flows.

Pyramid Lake Flow Regimes For the purpose of the Basin Study, actions to maintain aquatic species at Pyramid Lake are simulated through a rigid application of fish flow regimes. In a given year, one of six flow regimes is selected for implementation in April. Each of the six flow regimes has a different flow requirement, with higher flows specified for years with greater abundance of water supplies. Each year's flow regime is determined from (a) the volume of water in Stampede Reservoir and (b) the forecasted inflow between April and July. Higher volumes of storage and inflow implies a higher flow is to be maintained at Nixon. Flow regimes are intended to establish a healthy riparian corridor, which includes meeting the needs of aquatic species.

The flow regimes are affected by seasonality shifts in two important ways: (1) by breaking the historical correlation between the abundance of flow in a year and volume of flow that occurs between April and July; and (2) by creating greater demand for releases from Stampede Reservoir in the spring and summer, when inflows were historically high. Similar to other water uses, shortfalls are more frequently experienced in the late summer and fall because of the earlier (and therefore longer) reliance upon storage to meet instream flow requirements. Both of these effects are observable in Figure 6-13, particularly in scenarios with drier conditions.

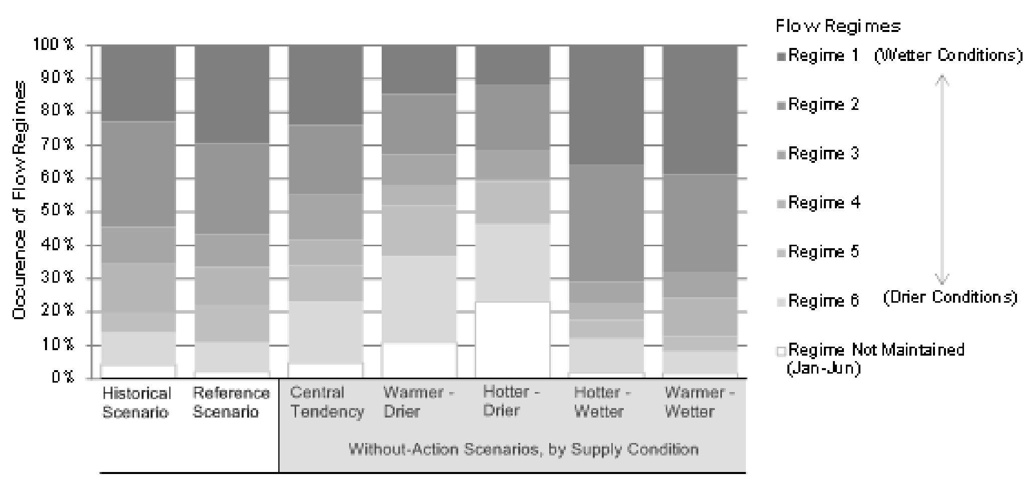


Figure 6-13. Percent of Years Each Flow Regime Would Occur Through 2099

Figure 6-13 displays the relative frequency of the different flow conditions for the Reference scenario and Without-Action scenarios. Notably, wetter scenarios appear similar to the Reference scenario; however, these scenarios generally have higher flows than the Reference supply condition. If flow regimes were selected based upon total annual inflows, the distribution of flow regimes would favor wetter (i.e., lower number) flow regimes. However, flow regimes are selected based upon forecasted inflows between April and July. The combination of seasonality shifts and wetter conditions gives the appearance that supply conditions have remained consistent with the Reference scenario, when in fact they have become wetter. This also applies to drier scenarios, which are skewed more heavily towards the drier year types (i.e., higher number regimes) than would be the case if the total annual availability of flows were considered.

Most notably in drier scenarios, flow regimes are maintained less frequently throughout the year. While most of the failures to maintain flow regimes occur when following drier year types (i.e., higher number regimes), they do occur for wetter year types (i.e., lower number regimes) in drier scenarios. Years where flow regimes are not met result from the depletion of storages in Stampede Reservoir. In general, seasonality shifts place an earlier and higher burden on storage in Stampede Reservoir for meeting the flow regimes. This increased reliance reduces the reliability of storages in Stampede Reservoir, resulting in a lower frequency of years when flow targets can be sustained throughout the year. The seasonality shift itself may or may not adversely affect Pyramid Lake elevations; however, under drier conditions greater annual inflows may be required to maintain elevations due to increased lake evaporation.

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 Basin. Two significant vulnerabilities exist to the Truckee Basin as a result of these potential changes: one to agriculture and another to managed ecosystems.

Other changes in water use will likely occur, such as increases in winter snow manufacturing and municipal landscaping demands, which are not addressed because of their relatively low consumptive use (e.g., snow manufacture) or their potential to be managed in a way that preserves the viability of the water user community (e.g., municipal demand).

Vulnerabilities to Irrigated Agriculture The Newlands Project represents the largest consumptive use of Truckee River water, second only to the volume of evaporation at Tahoe and Pyramid lakes. The project includes nearly 60,000 acres of irrigated farmland, predominantly planted in alfalfa.

Conveyance and on-farm application losses are assumed to not be affected by climate, although in practice they may be. Crop water requirements, however, are anticipated to increase as higher temperatures increase evapotranspiration rates and extend the growing season for alfalfa into the spring (see Table 6-5). 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 Reference, with the Hotter-Wetter and Hotter-Drier conditions exhibiting the most extreme changes. The methods used to develop estimates of future crop water demand are described in "Appendix C – Future Supply Technical Reports."

Table 6-5. Changes in Newlands Project Crop Water Demand Due to Temperature Increase

Supply Condition	Difference in Crop Water Demand (annual inches of demand); Change Relative to Reference Scenario	
	Water Years 2012-2099	**Water Years 2070-2099**
Reference	37.1; NA	
Central Tendency	40.9; +10%	42.1; +13%
Warmer-Drier	40.2; +8%	41.5; +12%
Hotter-Drier	42.6; +15%	45.5; +20%
Hotter-Wetter	41.7; +12%	43.2; +16%
Warmer-Wetter	41.4; +12%	42.7; +15%

Key:
NA = not applicable
Note: Changes in evapotranspiration are consistent across all demand conditions.

For all Without-Action scenarios, water deliveries are made based on water rights demands that are similar to Reference scenario crop water demands. As a result, future increases in demand will result in shortages to the crops; the demand will exceed the water rights available per acre.

Vulnerabilities to Managed Ecosystems Ecosystem restoration efforts exist in nearly every corner of the Truckee and Carson basins motivated by the desire for maintaining natural habitat and a recognition for ecosystem services provided for residents of the Basin. These include Lake Tahoe sediment reduction efforts; headwaters meadow and forest management restoration efforts; Truckee River riparian corridor restoration aimed at flood management, improved water quality, and riparian and ecosystem benefits; restoration efforts for species at Pyramid Lake; and Lahontan Valley wetlands maintenance in the Carson Valley. While all of these efforts have the ability to influence water quality and ecosystem health, the Basin Study focused on the effects of flows to Pyramid Lake and Lahontan Valley wetlands. This is due to the significant role they play in shaping the timing and volume of water released on the Truckee and Carson rivers.

Changes in Lifecycles of Aquatic Species Changes in ambient temperatures and seasonality shifts may stimulate shifts in the breeding patterns of aquatic species.

In particular, shifts in the needs of Lahontan cutthroat trout and cui-ui could influence water management decisions.

Earlier in this chapter, the ability to meet current fish flow requirements was shown to decline with the onset of seasonality shifts. These current requirements, which include peak flows in May, could lose their relevancy for future aquatic ecosystem needs. For instance, if fisheries respond to earlier peak runoff conditions that occur in February, March or April, any attempt to sustain the peak flow in May could be insufficient, unused by the fisheries, and more costly to reservoir storages than was the case under the Reference scenario.

A modeled assessment of linkages between climate, hydrology, and life-cycles for aquatic ecosystems has not been developed for the Truckee Basin, specifically. Development of such an assessment would support a comprehensive understanding of the specific vulnerability of these species to changes in climate, and the vulnerability of other water management operations to changes in fishery restoration needs.

Changes in Vegetation and Waterfowl Needs at Wetlands Lahontan Valley wetlands are the largest single water user in the Newlands Project, and as such play an important role in the operation of the Truckee Canal and Lahontan Reservoir. Presently, releases for water are made with the intention of restoring wetland habitat and, as such, have been shaped to mimic natural hydrologic patterns.

The Lahontan Valley wetlands sustain native vegetation, and play an important role as a refuge for migratory birds. Similar to effects of climate change on agricultural crops, changes in seasonal temperatures may shift the timing of water needs for native vegetation. These shifts may also result in earlier plant growth and greater water needs for each acre of managed wetland. Migratory birds may also be affected by global climate changes across the entire migratory flyway, and their arrival at the Lahontan Valley wetlands may also shift in time.

Risk and Reliability for Water Users

Reliability is a measure of how well water demands are met for a given set of conditions.

Tolerances and expectations for risk and reliability vary among the water users in the Truckee Basin. Future conditions projected in the Basin Study are expected to diverge from historical patterns, and changes are unlikely to affect all water users uniformly. Even for similar types of water use, future conditions may vary by geography. For example, an unprecedented multi-year water shortage may not change the long-term viability of cui-ui in Pyramid Lake, but could have devastating effects on municipalities and fisheries in upstream reservoirs. To address these differences in risk and reliability among water users and across the geography of the Basin, separate assessments of future reliabilities are provided for the five water user communities identified and considered throughout this study.

Delineating future conditions as either favorable or unfavorable creates a further challenge for risk and reliability assessments, as no definitive guidance exists on the point at which conditions become problematic for water users. Where possible, the Basin Study relied upon previous studies and water supply plans for information about tolerance to risk and desired reliability for different water users. While these reports thus provided useful information regarding needs and priorities of water users, they are limited in their ability to provide clear distinctions between which water supply conditions are acceptable or unacceptable, much less catastrophic, to water users. The Basin Study addressed this through targeted engagement with water users and other Basin stakeholders to identify risks to reliability that can be assessed using existing, available tools and information.

A series of group and individual meetings with water users and other stakeholders informed the Basin Study's understanding of desired conditions for different types of water uses. However, even Basin water users had difficulty identifying exact breaking points, or "thresholds," for when conditions become unfavorable for them. One reason is that the Basin Study presented unfamiliar conditions in which the future looks strikingly different from the historical hydrology and experiences of users in the Basin. Additionally, conditions that are unfavorable or catastrophic may not be triggered by singular, discrete events, but are instead multifaceted and may be experienced as a result of cumulative conditions around the Basin. The risks to reliability facing water users are therefore nearly endless, making it difficult to speculate about the myriad individual ways in which the system may become unreliable. Nonetheless, water user input received indicated which conditions in the Basin were most important to them.

Indicators are parameters selected to represent water system conditions and can be used to understand their relationships to ecosystems, social systems, and economic systems (California DWR 2013). They provide information about how a condition changes over time.

Metrics are uninterpreted measurements of conditions, such as rates of streamflow, temperatures, or volumes of groundwater recharge.

Both existing information and input from water users identified metrics of concern for various water user communities throughout the Basin. These metrics were the basis of indicators developed for the Basin Study. These indicators compared measured conditions to the full range of potential future conditions simulated by the Basin Study. Indicators describe whether conditions are improved or degraded by projected future changes, which is important for determining whether desired levels of reliability are met in the future for different water users. As water supply reliability is not solely dependent on any single indicator, the condition described by any given indicator does not necessarily reveal overall reliability of the system; but, collectively, the set of indicators for each water user community provides information about reliability in the future.

The following section describes the indicator development process and lists each indicator developed for the Basin Study's water user communities. It also provides sets of multiple indicators, or "dashboards," that, collectively, provide an overview of each community's water supply reliability under different future conditions.

Indicator Identification and Development Process

To understand how the performance of the Truckee River system changes relative to a range of potential future conditions, several indicators were developed that display which important characteristics of the Basin's water supply system are affected. An indicator provides an interpretation of how a measured condition, or metric, affects water users. Indicators were developed in coordination with water users during the development of technical information about the potential range of future conditions.

The use of indicators to identify risks to reliability due to changing future conditions is inspired by an approach constructed for the California Water Plan. The California Water Plan developed indicators that would help monitor progress toward water resources sustainability by meeting a series of objectives established for the plan (California DWR 2013).

One analogy for the use of indicators and metrics is an automobile's dashboard instrument panel: various indicator lights alert the driver to conditions that may represent safety risks or potential problems with the car (Figure 6-14).

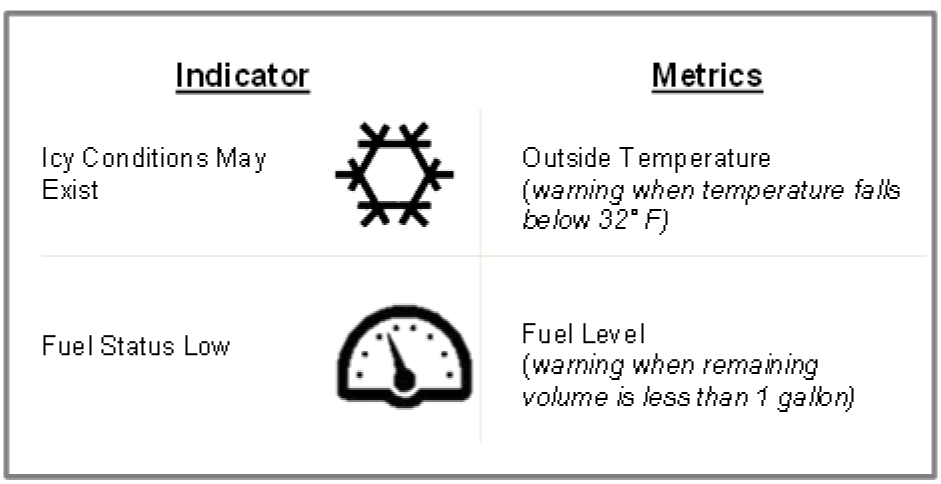


Figure 6-14. Automobile Instrument Panel Indicators and Metrics

When the car's sensors register that the outside temperature (the metric) has fallen below 32° Fahrenheit, an instrumental panel light (the indicator) turns on to alert the driver to undesirable conditions (potential ice on the road).

The indicators developed for this Basin Study are based, broadly, on the water resource themes in the SECURE Water Act:

- Water delivery and allocation
- Hydropower
- Recreation
- Fish and wildlife habitat
- Endangered, threatened, or candidate species
- Water quality
- Flow and water-dependent ecological resiliency
- Flood control management

Guided by the SECURE Water Act themes, the Basin Study's indicator development process used existing information to identify metrics of concern for different water users, a combination of modeling data about the future from different sources, and input provided by water users and other stakeholders.

The outputs from existing models and tools developed for the Basin Study were used to identify metrics for the indicators. The Basin Study's water supply and demand assessments included review of various historical datasets and other technical information. The team also modeled numerous systems related to climate, streamflow, and operations, all of which offered numerous potential measurements for metric and indicator development. Data about future climatic conditions in the Basin, including precipitation, temperature, and evaporation, were developed for the future climate ensembles described in "Chapter 3 – Water Supply Assessment." Data about future runoff quantities and patterns, and a simplified representation of groundwater recharge, were developed using the hydrology models also described in Chapter 3 – Water Supply Assessment." Planning model simulations of the infrastructure and operations described in "Chapter 5 – Water Management Conditions," were used to calculate the ability of different water users to meet demand and to determine how effectively current infrastructure operates in the future. Examples of the relationships between SECURE Water Act water resource themes, identified metrics, water user communities, and sources of information for metrics and indicators is shown in Table 6-6.

Table 6-6. Relationships Between SECURE Water Act Themes and Basin Study Risk and Reliability Assessment

SECURE Water Act Theme	Concerns Associated with the Theme	Metrics Related to Concern	Water User Communities	Source of Metrics for Use in Indicators
Water Delivery and Allocation	Water Supply Availability	Average Annual Shortages (M&I and Agriculture)	Truckee River Basin in California	TROA-light Planning Model
	Availability of Groundwater Resources		Truckee Meadows	
			Pyramid Lake	
			Newlands Project	
		Average Annual Groundwater Recharge	Lake Tahoe Basin	PRMS Hydrology Model
			Truckee River Basin in California	
Hydropower	Power Generation	Average Annual Powerhouse Diversions	Truckee Meadows	TROA-light Planning Model
		Average Annual Energy Generation	Newlands Project	
Recreation	Winter Sports	Average Snow-covered Land Area	Lake Tahoe Basin	PRMS Hydrology Model
	Reservoir-based Recreation	Monthly Streamflow	Truckee River Basin in California	TROA-light Planning Model
		Monthly Reservoir Storage Levels		
		Shallow Water Fish Spawning Habitat		
		April-October Reservoir Elevations		
	River-based Recreation	Monthly Streamflow	Truckee River Basin in California	
		April-October Streamflow	Truckee Meadows	
Fish and Wildlife Habitat	Wetland Maintenance	Annual Wetlands Deliveries	Newlands Project	
		Annual Reservoir Spills to Wetlands		
		Duration of Shortages to Wetlands		
	See "Recreation" and "Endangered, Threatened, or Candidate Species" for other related metrics.			
Endangered, Threatened, or Candidate Species	Fish Passage & Spawning Conditions	Monthly Lake Elevation	Pyramid Lake	TROA-light Planning Model
		Monthly Lake Inflow		
		January-June Lake Inflow		
Water Quality	Regulatory Requirements	August-October Streamflow Downstream from TMWRF	Truckee Meadows	

Table 6-6. Relationships Between SECURE Water Act Themes and Basin Study Risk and Reliability Assessment (contd.)

SECURE Water Act Theme	Concerns Associated with the Theme	Metrics Related to Concern	Water User Communities	Source of Metrics for Use in Indicators
Flow and Water-dependent Ecological Resiliency	*See "Recreation," "Fish and Wildlife Habitat," and "Endangered, Threatened, or Candidate Species" for related metrics.*			
Flood Control Management	*See "Appendix E – Truckee River Flood Frequency and Magnitude Analysis."*			

Key:
TMWRF = Truckee Meadows Water Reclamation Facility
TROA = Truckee River Operating Agreement

Similar to the California Water Plan's indicator development approach, the Basin Study's process relies on a blend of model data, described above, and public input. However, the Basin Study's process was less extensive than the California Water Plan's, due both to the relatively shorter period of study and to the fact that this study is the first conducted that focuses on overarching future reliability concerns for the entire Truckee Basin.

Development of the draft indicators began with a review of previous studies and reports related to the Truckee Basin, described in "Chapter 2 – Scenario Planning and Supporting Information." This included Federal and state environmental documents, local general plans, and local or regional plans focused on water supply, ecosystem recovery, and other objectives. These reports provided a far-reaching and comprehensive perspective on Basin water users' priorities, concerns, and needs, but had limited application for the Basin Study's indicator development process because their planning approach, content, and purpose differ substantially from the Basin Study's. For example, in general, both the general plans and EISs reviewed consider a single set of future conditions; the Basin Study uses a scenario planning approach that considers a range of future conditions related to climate, population, and other factors.

Additionally, most existing water-related plans are intended to demonstrate whether different resources are affected when conditions change, or to document steps to be taken to address unfavorable conditions when they already exist, instead of delineating favorable or unfavorable conditions for a particular water user – information critical for the identification of indicators.

Finally, as previously noted, the Basin Study's planning horizon of nearly 90 years is far longer than the horizon of less than 50 years planners typically use; thus, any information about future conditions developed for these studies may only apply to about half of the future period considered in the Basin Study. Nonetheless, each of these documents provided essential guidance on the conditions of concern in the Basin for different water users, and the metrics that should be considered in development of the indicators.

Although the draft indicators and metrics developed for the Basin Study were informed by existing information that focuses on water resource needs in the Truckee Basin, their usefulness also relies heavily upon input from water users and other stakeholders. Basin Study partner agencies and other water users were engaged throughout the indicator development process to obtain more information about their specific preferences and concerns, and to validate the Basin Study's understanding of the Basin's needs.

Once initial indicators were developed by the Basin Study team, Reclamation convened a workshop for the Basin Study TAG to share results from the supply and demand assessments, receive feedback on indicators and metrics, and obtain input on potential options and strategies for consideration in the Basin Study. Initial, draft indicators were presented, categorized by water user community. Workshop participants provided feedback on both the type of indicators chosen and the information used to develop them. Participants also recommended a number of new indicators and metrics for different water user communities using blank "indicator suggestion" forms. More than 30 people participated in this workshop, and represented a broad range of Basin water users and stakeholders, including municipalities, local water agencies, Tribes, irrigators, universities, conservation groups, and resource agencies. Meeting material, notes, and comments from the TAG workshop are included in "Appendix A – Engagement Record." After the TAG workshop, the draft and newly identified indicators were refined during several follow-up discussions with water users.

Basin Study Indicators

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 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 Basin, but also simplifies the discussion by taking advantage of commonalities among water users.

The sections that follow include specific indicators developed for each water user community using previous studies and reports, feedback obtained during the TAG workshop, and other water user input. They are intended to capture conditions directly related to water supply reliability for each water user community.

Indicators for the Basin Study take two forms, as a dial or as a light, each with its own set of benefits for use in the risk and reliability assessment. Indicators in the form of a light are similar to an "on/off" switch: they are useful in describing conditions that have a known threshold or tipping point between acceptable/good and unacceptable/bad. Indicators in the form of dials are helpful for displaying relative positions among a set of conditions evaluated; they are especially useful for providing relative comparisons when a precise threshold for success and failure is unknown but certain conditions are generally understood to be better or worse. The Basin Study developed a set of icons for both types of indicators similar to the icons used in Consumer Reports' product ratings (Figure 6-15).

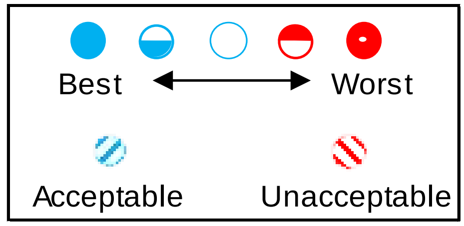


Figure 6-15. Symbols Used in Indicators and Dashboards to Signify Performance among Scenarios

For each indicator developed and described in the sections that follow, the best score shown is based on the highest score in the Basin Study's reliability assessment modeling results. For example, the frequency of shortfalls experienced by a particular water user can be counted for each scenario, and scenarios with the lowest or fewest shortfalls will receive the highest ratings among corresponding indicators, whereas scenarios with the highest or most-frequent shortfalls will receive the lowest rating.

Indicators represent the range of conditions that occur under different scenarios developed and evaluated in the Basin Study and do not reflect, objectively, whether these are the best or worst possible conditions for the water resources needs and concerns of Basin communities. For example, a scenario with 10 shortages is generally worse than a scenario with 5 shortages, from the perspective of water users. However, this is a subjective measurement, meaning that both 10 years and 5 years may be acceptable or unacceptable depending on other conditions (such as the magnitude of shortage or a water user's ability to cope).

Water user community indicators below are ordered by diversion locations along the Truckee River, starting upstream at Lake Tahoe and ending at Pyramid Lake. The scales and values from best to worst reflect the relative preference for various conditions expressed by the water users. Each scale from best-to-worst or acceptable-unacceptable includes values for each "break point" between ratings.

Lake Tahoe Basin The Lake Tahoe Basin is located between the Carson Range on the east and the Sierra Nevada on the west, and is divided by the California-Nevada state line. Current demands at Lake Tahoe include M&I water uses for various public utilities serving customers around the lake and for public and commercial recreational facilities, including fishing, boating, and skiing and other snow-dependent winter recreation.

Indicators for the Lake Tahoe Basin water user community focus on groundwater and snow-covered area.

INDICATOR	KEY FOR SCENARIO RANKINGS
LTB-1: Groundwater Recharge Groundwater pumping provides a significant portion of water supply to communities in the Lake Tahoe Basin. The South Tahoe Public Utility District, for example, is the largest water provider in the Basin with 13 active groundwater supply wells (STPUD 2011). This indicator signals potential challenges for M&I users that pump groundwater within the Lake Tahoe Basin. Groundwater supplies are replenished when precipitation or surface water percolates below the ground surface. Higher annual ground water recharge indicates fewer challenges for M&I groundwater users.	**Metric:** Lake Tahoe Basin Groundwater Recharge **Best:** Highest score based on scenarios with the highest average annual groundwater recharge. **Worst:** Lowest score based on scenarios with the lowest average annual groundwater recharge. Best ← → Worst > 65 ≤ 65 ≤ 61 ≤ 57 ≤ 53 *TAF / year*
LTB-2: Average Snow Covered Land Area In the Sierra Nevada, precipitation falls almost exclusively as snow from November to April (accounting for 85 percent of annual precipitation). This historical climate condition drives a large winter recreation industry, which generates employment and income in the retail trade and service sectors of the economy. This indicator signals potential challenges for the Lake Tahoe Basin winter recreation industry. Larger areas covered in snow each winter indicates that the dozens of ski resorts and other snow-related businesses would be successful in attracting visitors. Larger snow-covered areas also indicate less need for snow making.	**Metric:** Lake Tahoe Basin Snow-Covered Area **Best:** Highest score based on scenarios with the highest percentage of average snow covered land area November through April. **Worst:** Lowest score based on scenarios with the lowest percentage of average snow covered land area November through April. Best ← → Worst > 71% ≤ 71% ≤ 65% ≤ 60% ≤ 55%

Truckee River Basin in California This water user community represents the California portion of the Truckee Basin, including the M&I, agricultural, and recreation water uses along the Truckee River and Little Truckee River, and in Martis Valley.

Indicators for the Truckee River Basin in California water user community include the frequency and magnitude of water supply shortages for M&I users, groundwater recharge in the Martis Valley, conditions for sportfishing, and conditions for reservoir and in-river recreation.

INDICATOR	KEY FOR SCENARIO RANKINGS
TBC-1: Frequency of M&I Water Supply Shortages High water supply reliability and competitive municipal water rates are components of a healthy economic condition in the communities on the California side of the Truckee Basin. During times of drought, Stage 2 water conservation measures are first implemented to reduce demand by more than 10 percent (TDPUD 2011). These drought contingency restrictions on businesses and homeowners could affect the local economy. This indicator considers annual M&I water supply deliveries less than 90 percent of demand as a shortage. A low occurrence, or frequency, of annual shortages indicates a more reliable water supply that can better support the local economy.	**Metric:** Truckee River Basin – California M&I Annual Water Shortages **Best:** Highest score based on scenarios with the lowest percentage of years where less than 90 percent of water demand is met. **Worst:** Lowest score based on scenarios with the highest percentage of years where less than 90 percent of water demand is met. Best ← → Worst ≤ 10% ≤ 20% ≤ 30% ≤ 40% > 40%
TBC-2: Maximum M&I Water Supply Shortage Natural disasters and other events, like extremely low precipitation years, can interrupt M&I water supplies, especially when the source is surface water. Mandatory water conservation measures are sometimes implemented to manage demand, including watering restrictions, heavy fines, and drought rates. This indicator considers the maximum annual M&I water supply shortage (as a percent of annual demand). A small maximum annual shortage indicates a more robust water supply and less need for mandatory water conservation measures under drought emergencies.	**Metric:** Truckee River Basin – California M&I Annual Water Shortages **Best:** Highest score based on scenarios with the lowest maximum annual M&I water supply shortage. **Worst:** Lowest score based on scenarios with the highest maximum annual M&I water supply shortage. Best ← → Worst ≤ 6% ≤ 11% ≤ 16% ≤ 22% > 22%
TBC-3: Martis Valley Groundwater Recharge Most water demand in the Martis Valley area occurs in the Lahontan subdivision, a golf and residential facility south of Truckee, as well as a few existing and planned customers in the Martis Camp subdivision (PCWA 2011). Groundwater currently meets most water demand in the area and is expected to be the primary source for any increased future demand. The Truckee-Donner Public Utility District also currently supplies drinking water via groundwater from the Martis Valley groundwater basin (TDPUD 2011). This indicator considers average annual Martis Valley groundwater recharge, which occurs when precipitation or surface water percolates below the ground surface to replenish groundwater supplies. Higher annual ground water recharge indicates fewer challenges for M&I users that pump groundwater within Martis Valley.	**Metric:** Martis Valley Annual Groundwater Recharge **Best:** Highest score based on scenarios with the highest average annual groundwater recharge. **Worst:** Lowest score based on scenarios with the lowest average annual groundwater recharge. Best ← → Worst > 16 ≤ 16 ≤ 15 ≤ 14 ≤ 13 *TAF / year*

INDICATOR	KEY FOR SCENARIO RANKINGS
TBC-4: Preferred River Flows for Fish Rainbow and brown trout are the most common non-native fish in the Truckee River and are popular game species. The California Department of Fish and Wildlife has recommended preferred flows in several Truckee River and tributary reaches for rainbow and brown trout spawning, incubation, and rearing life stages (Interior and California 2008). This indicator considers minimum preferred flows that were determined by the limits of flow that can sustain fish populations. (Interior and California 2008). The higher percentage of months that meet minimum preferred flows indicates healthier ecosystem and recreational conditions.	**Metric:** Monthly Streamflow at Various Locations in the Truckee River Basin **Best:** Highest score based on scenarios with the lowest percentage of months that do not meet minimum preferred flows for fish. **Worst:** Lowest score based on scenarios with the highest percentage of months that do not meet minimum preferred flows for fish. Best ← → Worst ≤ 37% ≤ 42% ≤ 47% ≤ 53% > 53%
TBC-5: Reservoir Fish Survival Sufficient storage in lakes and reservoirs are important for fish survival because low water levels can increase temperatures and decrease dissolved oxygen, leading to fish stress and kills. Minimum storage levels have been recommended by the California Department of Fish and Wildlife for Independence Lake and Prosser Creek, Stampede, and Boca reservoirs to maintain fisheries, water quality, and aquatic productivity (Interior and California 2008). This indicator considers monthly minimum reservoir storage levels needed for fish survival in select Truckee River reservoirs. A lower percentage of months below fish survival targets indicates healthier ecosystem and recreational conditions.	**Metric:** Monthly Storage Levels in Independence Lake and Prosser Creek, Stampede, and Boca Reservoirs **Best:** Highest score based on scenarios with the lowest percentage of months below fish survival levels. **Worst:** Lowest score based on scenarios with the highest percentage of months below fish survival levels. Best ← → Worst ≤ 12% ≤ 17% ≤ 22% ≤ 27% > 27%
TBC-6: Shallow Water Fish Spawning Habitat Donner and Independence lakes contain the best shallow water fish spawning habitat in the Truckee River Basin in California compared to other reservoirs because of less water surface elevation fluctuations and more gradual slopes. Shallow water fish spawning habitat is important to native and non-native species that spawn in the lake. This indicator considers the surface area of June shallow water fish spawning habitat (less than 1 meter deep) in Donner and Independence lakes. A lower percentage of years below 85 percent of baseline conditions (Interior and California 2008) indicates healthier ecosystem and recreational conditions.	**Metric:** June Shallow Water Fish Spawning Habitat in Donner and Independence Lakes **Best:** Highest score based on scenarios with the lowest percentage of years below 85 percent of baseline habitat area. **Worst:** Lowest score based on scenarios with the highest percentage of years below 85 percent of baseline habitat area. Best ← → Worst ≤ 19% ≤ 26% ≤ 34% ≤ 42% > 42%

INDICATOR	KEY FOR SCENARIO RANKINGS
TBC-7: River Recreation Use – Rafting/Kayaking The Truckee River in California is well known for its scenic and recreational value. Popular activities include fishing and river running. Recreationists desired specific flows that can vary widely depending on activity (Interior and California 2008). This indicator considers recreationist participation in rafting and kayaking based on desired flows (Interior and California 2008). Higher river recreational use indicates a stronger summer recreational season.	**Metric:** Monthly Streamflow at Various Locations in the Truckee River Basin **Best:** Highest score based on scenarios with the highest percentage of recreationists that would continue to use the river between April and October. **Worst:** Lowest score based on scenarios with the lowest percentage of recreationists that would continue to use the river between April and October. Best ⟷ Worst ● > 28% · ◒ ≤ 28% · ○ ≤ 25% · ◓ ≤ 22% · ⊙ ≤ 20%
TBC-8: River Recreation Use – Fishing The Truckee River in California is well known for its scenic and recreational value. Popular activities include fishing and river running. Recreationists desired specific flows that can vary widely depending on activity (Interior and California 2008). This indicator considers recreationist participation in fly fishing and spin/lure/bait fishing based on desired flows (Interior and California 2008). Higher river recreational use indicates a stronger summer recreational season.	**Metric:** Monthly Streamflow at Various Locations in the Truckee River Basin **Best:** Highest score based on scenarios with the highest percentage of recreationists that would continue use the river between April and October. **Worst:** Lowest score based on scenarios with the lowest percentage of recreationists that would continue use the river between April and October. Best ⟷ Worst ● > 68% · ◒ ≤ 68% · ○ ≤ 67% · ◓ ≤ 66% · ⊙ ≤ 64%
TBC-9: Reservoir Recreation Access Recreational facilities and opportunities associated with lakes and reservoirs in the Truckee River Basin are accessible, affordable, and diverse. These facilities experience high use, including repeat visitation, and contribute substantially to the region's summer economy (Interior and California 2008). A significant percent of summer visitor depend on lake boat access, which can vary depending on lake or reservoir operations and hydrologic conditions. This indicator measures boat ramp usability and lake or reservoir access using water surface elevations (Interior and California 2008). A small percentage of months with impeded access indicates a stronger summer recreational season.	**Metric:** Lake and Reservoir April-October Water Surface Elevations at Various Truckee River Reservoirs **Best:** Highest score based on scenarios with the lowest percentage of months between April and October with impeded lake or reservoir access. **Worst:** Lowest score based on scenarios with the highest percentage of months between April and October with impeded lake or reservoir access. Best ⟷ Worst ● ≤ 43% · ◒ ≤ 49% · ○ ≤ 56% · ◓ ≤ 62% · ⊙ > 62%

Truckee Meadows The Truckee Meadows water user community represents M&I and agriculture in Nevada side of the Truckee Basin west of Wadsworth, and includes both the TMWA and its customers, as well as agricultural users who receive water from ditches off of the Truckee River. Truckee Meadows M&I includes the cities of Reno and Sparks, as well as the surrounding developed areas of Washoe County. Truckee Meadows agriculture includes lands served by ditches that historically divert from the Truckee River using Orr Ditch Decree water rights. Major agricultural diversions from the river at Truckee Meadows include Steamboat Canal and Lake, and the Last Chance, Orr, and Pioneer ditches.

Indicators for the Truckee Meadows water user community include the frequency and magnitude of water supply shortages for both municipal users and agricultural users, frequency of shortages in meeting Floriston rates, average hydropower generation, ability to meet water quality requirements in the lower Truckee River, and opportunities for in-river recreation.

INDICATOR	KEY FOR SCENARIO RANKINGS
TM-1: Frequency of M&I Water Supply Shortages High water supply reliability and competitive municipal water rates are components of a healthy economic condition in the Truckee Meadows area. Projected changes in supplies and demands can affect water facility and capital improvement plans, which can affect rates and fees, and ultimately affect the local economy (TMWA 2009). TMWA, the largest M&I water retailer/wholesaler in the Truckee Basin, has a primary planning focus of ensuring a consistent supply of water for its customers and the economy they support (TMWA 2009). This indicator considers annual M&I water supply deliveries less than 90 percent of demand as a shortage. Deliveries between 90 and 100 percent of demand are assumed to be adequately managed under existing voluntary and system demand management measures, and would not cause undue stress on the economy. A low occurrence, or frequency, of annual shortages indicates a more reliable water supply that can support the local economy.	**Metric:** Truckee Meadows M&I Annual Water Shortages **Best:** Highest score based on scenarios with the lowest percentage of years where less than 90 percent of water demand is met. **Worst:** Lowest score based on scenarios with the highest percentage of years where less than 90 percent of water demand is met. Best ← → Worst ≤ 3% ≤ 5% ≤ 8% ≤ 10% > 10%
TM-2: Maximum M&I Water Supply Shortage Natural disasters and other events, like extreme low precipitation years, can interrupt M&I water supplies (TMWA 2009). Mandatory water conservation measures may be implemented to manage demand, including watering restrictions, heavy fines, and drought rates. TMWA's goal, however, is to minimize customer disruption during acute water supply shortages (TMWA 2009). This indicator considers the maximum annual M&I water supply shortage (as a percent of annual demand). A small maximum annual shortage indicates a more robust water supply and less need for mandatory water conservation measures.	**Metric:** Truckee Meadows M&I Annual Water Shortages **Best:** Highest score based on scenarios with the lowest maximum annual M&I water supply shortage. **Worst:** Lowest score based on scenarios with the highest maximum annual M&I water supply shortage. Best ← → Worst ≤ 9% ≤ 18% ≤ 27% ≤ 36% > 36%
TM-3: Frequency of Floriston Rate Shortages TMWA's water supply is primarily dependent on resources available from the Truckee River, mostly mainstem Truckee River water rights (i.e., Floriston rate water) (TMWA 2009). TMWA uses Floriston rates to explain to customers the impact of a drought on available water supplies (TMWA 2009). In drought situations, "Supplies are Adequate" if Floriston rates are available through Labor Day; if Floriston rates are not available through Labor Day then "Supplies are Impacted" (TMWA 2009). This indicator considers annual Floriston rate shortages. An annual shortage is defined as not meeting Floriston rates (within 50 cfs) through August. A low occurrence, or frequency, of annual Floriston rate shortages indicates a more reliable water supply and fewer drought restrictions.	**Metric:** Monthly Floriston Rate Flows **Best:** Highest score based on scenarios with the lowest percentage of years that do not meet Floriston rates (within 50 cfs) through August. **Worst:** Lowest score based on scenarios with the highest percentage of years that do not meet Floriston rates (within 50 cfs) through August. Best ← → Worst ≤ 33% ≤ 45% ≤ 57% ≤ 69% > 69%

INDICATOR	KEY FOR SCENARIO RANKINGS
TM-4: Average TMWA Hydropower Flows TWMA operates three active run-of-the-river hydroelectric power plants along the Truckee River between the Little Truckee River and Reno. To generate power, water is diverted to flumes (i.e., wooden or earthen canals) that convey the water to the riverside plants; after generating energy the water is returned to the river. Collectively, TMWA's hydroelectric plants produce an average of 6.7 megawatts of power, enough to power approximately 3,500 households (TMWA 2012). This indicator considers Truckee River diversions used to generate hydropower. Higher diversions indicate more annual energy generation and associated revenue.	**Metric:** TMWA Powerhouse Annual Diversions **Best:** Highest score based on scenarios with the higher average annual hydropower diversions. **Worst:** Lowest score based on scenarios with the lower average annual hydropower diversions. Best ← → Worst > 914 · ≤ 914 · ≤ 854 · ≤ 794 · ≤ 733 *TAF / year*
TM-5: Ability to Achieve Water Quality Standards Streamflow is one of the most important water quality indicators in the Truckee River Basin (Interior and California 2008). Low flows can cause temperature increases and stagnant water, and can cause dilution issues for point and non-point sources, including Truckee Meadows Water Reclamation Facility (TMWRF). TMWRF is currently able to comply with Total Maximum Daily Load requirements, but future demand growth may require very costly advanced treatment technologies (Truckee River Third Parties 2014). Lower low-flow conditions could exacerbate this situation. This indicator considers August and October low-flows (95 percentile) downstream from TMWRF (Interior and California 2008). These months are considered the low-flow irrigation and non-irrigation months, respectively. Higher low flows indicate a higher ability to achieve water quality standards.	**Metric:** Truckee River August and October Streamflow Downstream From TMWRF **Best:** Highest score based on scenarios with higher low-flow conditions (95 percentile) in August and October. **Worst:** Lowest score based on scenarios with lower low-flow conditions (95 percentile) in August and October. Best ← → Worst > 310 · ≤ 310 · ≤ 259 · ≤ 208 · ≤ 157 *cfs*
TM-6: River Recreation Use – Rafting/Kayaking The Truckee River in Truckee Meadows area is suitable for river recreation activities. Popular activities include fishing and river running. Recreationists desired specific flows that can vary widely depending on activity (Interior and California 2008). This indicator considers recreationist participation in rafting and kayaking based on desired flows (Interior and California 2008). Higher river recreational use indicates a stronger summer recreational season.	**Metric:** April-October Streamflow at Various Locations in the Truckee Meadows Area **Best:** Highest score based on scenarios with the highest percentage of recreationists that would continue to use the river between April and October. **Worst:** Lowest score based on scenarios with the lowest percentage of recreationists that would continue to use the river between April and October. Best ← → Worst > 18% · ≤ 18% · ≤ 16% · ≤ 15% · ≤ 14%

INDICATOR	KEY FOR SCENARIO RANKINGS
TM-7: River Recreation Use – Fishing The Truckee River in Truckee Meadows area is suitable for river recreation activities. Popular activities include fishing and river running. Recreationists desired specific flows that can vary widely depending on activity (Interior and California 2008). This indicator considers recreationist participation in fly fishing and spin/lure/bait fishing based on desired flows (Interior and California 2008). Higher river recreational use indicates a stronger summer recreational season.	**Metric:** April-October Streamflow at Various Locations in the Truckee Meadows Area **Best:** Highest score based on scenarios with the highest percentage of recreationists that would continue to use the river between April and October. **Worst:** Lowest score based on scenarios with the lowest percentage of recreationists that would continue to use the river between April and October. Best ←→ Worst > 67% ≤ 67% ≤ 65% ≤ 63% ≤ 62%
TM-8: Frequency of Crop Water Demand Shortages in Ditches along the Truckee River Agricultural lands along the Truckee River lands served by ditches that historically divert from the Truckee River using Orr Ditch Decree water rights. Potential changes in future temperatures and precipitation could increase the consumptive water demand of crops beyond what can be provided by current water rights, which could adversely affect economic conditions in this agrarian region This indicator considers the ability of water rights supply to meet crop demand. Newlands Project agricultural users have historically used an average of about 95 percent of their total water rights under non-drought conditions (Reclamation 2013). This indicator uses 95 percent delivery of total water rights as a threshold for indicating whether crop demands have been met in a given year (at or above 95 percent), or not (below 95 percent). A low occurrence, or frequency, of annual crop shortages indicates a more reliable water supply that can support local agriculture.	**Metric:** Truckee River Agriculture Crop Shortages **Best:** Highest score based on scenarios with the highest frequency of years meeting crop demand. **Worst:** Lowest score based on scenarios with the lowest frequency of years meeting crop demand. Best ←→ Worst ≤ 24% ≤ 36% ≤ 47% ≤ 59% > 59%
TM-9: Maximum Crop Water Demand Shortage in Ditches along the Truckee River Extreme low precipitation years can interrupt agriculture water supplies, which could force temporary fallowing of agriculture lands. This indicator considers the maximum annual crop water demand shortage. A small maximum annual shortage indicates a more robust water supply.	**Metric:** Truckee River Agriculture Crop Shortages **Best:** Highest score based on scenarios with the lowest maximum annual crop water demand shortage. **Worst:** Lowest score based on scenarios with the highest maximum annual crop water demand shortage. Best ←→ Worst ≤ 72% ≤ 72% ≤ 72% ≤ 72% > 72%

Pyramid Lake The Pyramid Lake water user community is encompassed by the Pyramid Lake Indian Reservation, located 35 miles northeast of Reno, Nevada. The Pyramid Lake Indian Reservation surrounds Pyramid Lake and lower Truckee River reaches. Water uses in this community include agriculture, M&I, and fisheries needs. Agriculture and M&I uses are satisfied by Orr Ditch Decree water right claims 1 and 2 from the Truckee River and Truckee River agricultural ditches. Pyramid Lake fisheries water uses are to maintain streamflow and habitat for the Lahontan cutthroat trout and cui-ui, as guided by fish flow regimes developed by USFWS (TRIT 2003).

Indicators for the Pyramid Lake water user community include frequency and magnitude of water supply shortages for agriculture and M&I, fish passage conditions and opportunities in the lower Truckee River and delta, availability of spawning and incubation flows, frequency of certain spawning conditions, and establishment and maintenance of riparian habitat.

INDICATOR	KEY FOR SCENARIO RANKINGS
PL-1: Frequency of Water Supply Shortages High water supply reliability and competitive municipal water rates are components of a healthy economic condition for the Pyramid Lake Paiute Tribe. Similar to other municipalities, drought contingency restrictions on businesses and homeowners could affect the local economy. This indicator considers annual M&I and agriculture water supply deliveries less than 90 percent of demand as a shortage (similar to other Basin municipalities). A low occurrence or frequency of annual shortages indicates a more reliable water supply that can better support the local economy.	**Metric:** PLPT M&I and Agriculture Annual Water Shortages **Best:** Highest score based on scenarios with the lowest percentage of years where less than 90 percent of water demand is met. **Worst:** Lowest score based on scenarios with the highest percentage of years where less than 90 percent of water demand is met. Best ← → Worst ≤ 6% ≤ 12% ≤ 18% ≤ 24% > 24%
PL-2: Maximum Water Supply Shortage Natural disasters and other events, like extreme low precipitation years, can interrupt M&I and agriculture water supplies. Mandatory water conservation measures may be implemented to manage demand, including watering and irrigation restrictions, heavy fines, and drought rates. This indicator considers the maximum annual M&I and agriculture water supply shortage (as a percent of annual demand). A small maximum annual shortage indicates a more robust water supply and less need for mandatory water conservation measures under drought emergencies.	**Metric:** PLPT M&I and Agriculture Water Shortages **Best:** Highest score based upon scenarios with the lowest maximum annual water supply shortage. **Worst:** Lowest score based upon scenarios with the highest maximum annual water supply shortage. Best ← → Worst ≤ 14% ≤ 21% ≤ 28% ≤ 36% > 36%
PL-3: Delta Passage and Channel Stability Persistently low Pyramid Lake elevations could prevent the cui-ui and Lahontan cutthroat trout from passing through the delta, Marble Bluff Dam, and the connecting river channel for spawning. Beyond creating passage barriers, low elevations can also cause channel head cutting conditions and threaten the stability of Marble Bluff Dam. Scenarios that have average elevations below 3,784 (the record low elevation at Pyramid Lake) at the end of the century would prevent passage and may threaten the structural integrity of Marble Bluff Dam (USFWS 2014). An end-of-century lake elevation that is persistently below 3,784 (average elevation between 2080 and 2100) indicates that passage for spawning would be prevented and create channel conditions where Marble Bluff Dam would likely become unstable.	**Metric:** Pyramid Lake Monthly Surface Elevation **Good:** Good conditions exist if the average Pyramid Lake elevation is above 3,784 feet (from 2080 – 2100). **Poor:** Poor conditions exist if the average Pyramid Lake elevation is below 3,784 feet (from 2080 – 2100). Good ← → Poor ≥ 3,784 ≤ 3,784 *Feet*

INDICATOR	KEY FOR SCENARIO RANKINGS
PL-4: Availability of Good Adult Passage Adult passage begins between January and June, depending on the hydrologic and meteorological conditions. Good adult passage occurs when flows are maintained at or above 420 cfs into Pyramid Lake for two consecutive months (as described in flow targets for Flow Regime 3 (TRIT 2003)). Passage is challenged when the peak two months fall below 420 cfs. The abundance of years with 420 cfs of inflow to Pyramid Lake for two consecutive months between January and June indicates the availability of good adult passage.	**Metric:** Pyramid Lake Monthly Inflow **Best:** Highest score based on scenarios with the highest percent of years that meet or exceed 420 cfs for two consecutive flow months between January and June. **Worst:** Lowest score based on scenarios with the lowest percent of years that meet or exceed 420 cfs for two consecutive flow months between January and June. Best ⟷ Worst > 76% ≤ 76% ≤ 70% ≤ 63% ≤ 57%
PL-5: Maintenance of Spawning and Incubation Flows The spawning migration begins between January and June, depending on the timing of adult passage, and continues for 4 to 8 weeks. Fertilized eggs hatch in 1 to 2 weeks. After eggs hatch, the yolk-sac larvae spend 5 to 10 days in the gravel before emerging. This indicator considers the frequency of conditions that meet Flow Regime 3 targets for the peak flow month and the month prior to indicate maintenance of good spawning and egg maturation conditions (TRIT 2003).	**Metric:** Pyramid Lake Monthly Inflow **Best:** Highest score based on scenarios with the highest percent of years that meet or exceed Flow Regime 3 targets for the peak flow month and the month prior. **Worst:** Lowest score based on scenarios with the lowest percent of years that meet or exceed Flow Regime 3 targets for the peak flow month and the month prior. Best ⟷ Worst > 66% ≤ 66% ≤ 58% ≤ 48% ≤ 39%
PL-6: Persistence of Poor Spawning Conditions Both cui-ui and Lahontan cutthroat trout are long lived species and don't necessarily need to spawn every year to perpetuate the species. Flow Regime 4 was designed with the intention of meeting minimal fisheries requirements, and is considered to provide basic life stage needs for cui-ui and Lahontan cutthroat trout. The number of consecutive years that fall below flows specified in Flow Regime 4 (between January and June) indicates the persistence of challenging spawning conditions for cui-ui and Lahontan cutthroat trout (TRIT 2003).	**Metric:** Pyramid Lake Inflow **Best:** Highest score based on scenarios with the shortest duration of years with flows below January through June targets specified in Flow Regime 4. **Worst:** Lowest score based on scenarios with the longest duration of years with flows below January through June targets specified in Flow Regime 4. Best ⟷ Worst ≤ 2 ≤ 4 ≤ 6 ≤ 8 > 8 *Consecutive Years*

INDICATOR	KEY FOR SCENARIO RANKINGS
PL-7: Establishment of Riparian Habitat Wetter hydrologic years in the Lower Truckee River promote the establishment of riparian vegetation, which in turn stabilizes the river channel, reduces sediment production, and decreases river temperatures (Interior and California 2008). The frequency of years with flows at, or above Flow Regime 1 targets between January and June indicate the frequency of riparian habitat establishment (TRIT 2003).	**Metric:** Annual Flow Regime **Best:** Highest score based on scenarios with the highest percentage of years with flows at or above those specified in Flow Regime 1 between January and June. **Worst:** Lowest score based on scenarios with the lowest percentage of years with flow at or above those specified in Flow Regime 1 between January and June. Best ⟷ Worst > 36% ≤ 36% ≤ 29% ≤ 22% ≤ 16%
PL-8: Maintenance of Riparian Habitat Riparian aquifers can fall below the reach of riparian vegetation during low flow conditions, leading to stress or mortality for riparian vegetation. Flow Regime 6 was designed with the intention of preserving flow riparian habitat (TRIT 2003). The frequency of years that completely meet Flow Regime 6 (between January and June) indicates the health of vegetation in the riparian corridor.	**Metric:** Pyramid Lake Inflow **Best:** Highest score based on scenarios with the highest percentage of years with flows at or above those specified in Flow Regime 6 between January and June. **Worst:** Lowest score based on scenarios with the lowest percentage of years with flows at or above those specified in Flow Regime 6 between January and June. Best ⟷ Worst > 88% ≤ 88% ≤ 78% ≤ 67% ≤ 56%

Newlands Project The Newlands Project encompasses nearly 60,000 acres of land in the west-central Nevada counties of Churchill, Lyon, Storey, and Washoe. Newlands Project water uses include agriculture and environmental, although some water rights are also owned by municipalities. Newlands Project water comes from the Carson River and also from the Truckee River under Claim 3 of the Orr Ditch Decree. As the city of Fernley holds Newlands Project water rights and its municipal water use is related to project operations, Fernley is also included as part of the water user community.

Indicators for the Newlands Project water user community include frequency and magnitude of crop water shortages and municipal shortages, availability of supply to wetlands, and hydropower generation.

INDICATOR	KEY FOR SCENARIO RANKINGS
NP-1: Frequency of Newlands Project Crop Water Demand Shortages Currently, the Newlands Project delivers water to about 46,000 acres of actively irrigated agricultural land in the Lahontan Valley and to lands near Fernley, Nevada. The annual volume of Project water demand is set by the "duty" of individual Project rights, the acreage of rights among each duty, and cultural practices for taking different proportions of the total water right duty (agricultural users have historically used an average of about 95 percent of their total water rights) (Reclamation 2013). Potential changes in future temperatures and precipitation could increase the consumptive water demand of crops beyond what can be provided by current water rights, which could adversely affect economic conditions in this agrarian region. This indicator considers the ability of water rights supply to meet 95 percent of crop demand. A low occurrence or frequency of annual crop shortages indicates a more reliable water supply that can support local agriculture.	**Metric:** Newlands Project Annual Crop Shortagese **Best:** Highest score based on scenarios with the lowest percentage of years that do not meet at least 95 percent of crop demand. **Worst:** Lowest score based on scenarios with the highest percentage of years that do not meet at least 95 percent of crop demand. Best ← → Worst ≤ 23% ≤ 37% ≤ 52% ≤ 67% > 67%
NP-2: Maximum Crop Water Demand Shortage for Newlands Project Extreme low precipitation years can interrupt agriculture water supplies, which could force temporary fallowing of agriculture lands. This indicator considers the maximum annual crop water demand shortage (as a percent of annual demand). A small maximum annual shortage indicates a more robust water supply.	**Metric:** Newlands Project Crop Shortages **Best:** Highest score based on scenarios with the lowest maximum annual crop water demand shortage. **Worst:** Lowest score based on scenarios with the highest maximum annual crop water demand shortage. Best ← → Worst ≤ 54% ≤ 62% ≤ 71% ≤ 79% > 79%
NP-3: Average Lahontan Basin Wetlands Water Right Deliveries In addition to irrigation, the Newlands Project serves water rights for wetlands at the Stillwater National Wildlife Refuge (NWR), Carson Lake and Pasture, and Fallon Paiute-Shoshone Indian Reservation wetlands. USFWS manages the wetlands to approximate the area's natural biological diversity to benefit breeding and migrating waterfowl, shorebirds, and other water birds and wintering waterfowl (USFWS 2002). Current annual wetlands water right demands are about 30,000 acre-feet. This indicator considers average annual Newlands Project wetland water right deliveries. Meeting more of the water right demand on average indicates a more reliable water supply for habitat and wildlife.	**Metric:** Newlands Project Annual Water Right Wetlands Deliveries **Best:** Highest score based on scenarios with the highest average annual water right delivery as percent of water right demand. **Worst:** Lowest score based on scenarios with the lowest average annual water right delivery as percent of water right demand. Best ← → Worst > 95% ≤ 95% ≤ 91% ≤ 88% ≤ 84%

INDICATOR	KEY FOR SCENARIO RANKINGS
NP-4: Average Lahontan Reservoir Spills Drainage from Newlands Project canals also serves as a source of water for wetlands, and in years with wet hydrological conditions, excess flows spilled or released from Lahontan Dam reach Stillwater NWR and Carson Lake and Pasture. Lahontan Reservoir spills are not considered a Project delivery, but do benefit the wetlands. This indicator considers average annual Lahontan Reservoir spills that benefit the Stillwater NWR and other wetlands. Larger average annual spills indicate a healthier wetland environment under variable hydrologic conditions.	**Metric:** Lahontan Reservoir Annual Spills **Best:** Highest score based on scenarios with the highest average annual Lahontan Reservoir spills (as a percent of annual demand). **Worst:** Lowest score based on scenarios with the lowest average annual Lahontan Reservoir spills (as a percent of annual demand). Best ← → Worst > 20% ≤ 20% ≤ 15% ≤ 10% ≤ 5%
NP-5: Total Lahontan Valley Wetlands Water Supply This indicator considers total Lahontan Valley wetlands water supply delivers, including regulated Newlands Project water right deliveries and Lahontan Reservoir spills considered in other indicators. More complete water supply delivers as a percentage of water right demand puts less pressure on managing agencies to secure additional supplies.	**Metric:** Newlands Project Annual Wetlands Deliveries; Lahontan Reservoir Annual Spills **Best:** Highest score based on scenarios with the highest average annual water supply (Newlands Project supplies and Lahontan Reservoir spills) as percent of annual demand. **Worst:** Lowest score based on scenarios with the lowest average annual water supply (Newlands Project supplies and Lahontan Reservoir spills) as percent of annual demand. Best ← → Worst > 115% ≤ 115% ≤ 106% ≤ 98% ≤ 90%
NP-6: Duration of Lahontan Valley Wetlands Water Supply Shortages This indicator considers the longest duration of consecutive years that Lahontan Valley wetlands water supply delivers, including regulated Newlands Project water right deliveries and Lahontan Reservoir spills, are below 90 percent of water right demand. Wetland ecosystem processes can better weather shorter dry spells without more direct, emergency type actions from managing agencies.	**Metric:** Newlands Project Annual Wetlands Shortages **Best:** Highest score based on scenarios with shorter dry spells (consecutive years below 90 percent of water right demand). **Worst:** Lowest score based on scenarios with longer dry spells (consecutive years below 90 percent of water right demand). Best ← → Worst ≤ 3 ≤ 4 ≤ 5 ≤ 6 > 6 *Consecutive Years*

INDICATOR	KEY FOR SCENARIO RANKINGS
NP-7: Average Newlands Project Hydropower Generation While hydropower generation is not a consumptive use of Newlands Project water, it is an important component of operations and supports the Project financially, contributing around one-third of Truckee-Carson Irrigation District's (TCID) operating revenue (Reclamation 2005). Hydropower facilities include the Old Lahontan Powerplant (1,920 kW) and New Lahontan Powerhouse (4,000 kW) at Lahontan Dam, and the 26-Foot Drop Powerplant on the V canal (800 kw). This indicator considers Newlands Project powerhouse average annual energy generation (megawatt-hours). Higher energy generation indicates less risk to TCID's operating revenue.	**Metric:** Newlands Project Powerhouses Annual Energy Generation **Best:** Highest score based on scenarios with higher average annual energy generation. **Worst:** Lowest score based on scenarios with lower average annual energy generation. Best ⟷ Worst ≤ 24 ≤ 24 ≤ 23 ≤ 21 > 19 *GWh / Year*
NP-8: Frequency of Fernley Water Supply Shortages High water supply reliability and competitive municipal water rates are components of a healthy economic condition in the City of Fernley. During times of drought, Stage 2 water conservation measures are first implemented to reduce demand by more than 10 percent (Fernley 2008). These drought contingency restrictions on businesses and homeowners could affect the local economy. This indicator considers annual M&I water supply deliveries less than 90 percent of demand as a shortage. A low occurrence or frequency of annual shortages indicates a more reliable water supply that can better support the local economy.	**Metric:** City of Fernley M&I Annual Water Shortages **Best:** Highest score based on scenarios with the lowest percentage of years where less than 90 percent of water demand is met. **Worst:** Lowest score based on scenarios with the highest percentage of years where less than 90 percent of water demand is met. Best ⟷ Worst ≤ 1% ≤ 3% ≤ 4% ≤ 6% > 6%
NP-9: Maximum Fernley M&I Water Supply Shortage Natural disasters and other events, like extreme low precipitation years, can interrupt M&I water supplies, especially Fernley's surface water rights. Mandatory water conservation measures may be implemented to manage demand, including watering restrictions, heavy fines, and drought rates. This indicator considers the maximum annual M&I water supply shortage (as a percent of annual demand). A small maximum annual shortage indicates a more robust water supply and less need for mandatory water conservation measures under drought emergencies.	**Metric:** City of Fernley M&I Water Shortages **Best:** Highest score based on scenarios with the lowest maximum annual M&I water supply shortage. **Worst:** Lowest score based on scenarios with the highest maximum annual M&I water supply shortage. Best ⟷ Worst ≤ 3% ≤ 7% ≤ 10% ≤ 13% > 13%

Assessments of Reliability for Water User Communities

The indicators developed with input and guidance from water users were used as the basis for assessing reliability for each water user community. Broadly, the SECURE Water Act water resources themes represent the range of reliability concerns for Basin communities, and provide important context for understanding the connections between water resources and water uses. Table 6-7 summarizes the effects of climate change on future reliability in the Basin for each of the SECURE Water Act themes.

Table 6-7. 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 peak runoff and base flows. 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

Each Basin water user has a blend of distinctly different concerns regarding the resources described above. The following sections characterize future reliability for the Basin water user communities based on the water user-defined indicators defined earlier in this chapter under "Basin Study Indicators" and presented in a single dashboard of indicators for each community. Each dashboard is a table that displays performance for each water user community's indicators (rows) under different scenarios (columns), both as a symbol (dial or light) and as a value for the metric on which the indicator was based (as described in the indicator definitions above). For example, for an indicator such as "Frequency of M&I Water Supply Shortages," the dashboard would show one of the symbols in Figure 6-15 to indicate the relative frequency of shortages for a given scenario, but also show the underlying value for the indicator's performance under that scenario – in this case, the percentage of years analyzed in which a certain amount of shortage is experienced.

In the multiple indicator dashboard tables that follow, the first set of columns (under the "Reference" header for "Demand Condition") represent the values for indicator performance under scenarios that combine the Historical supply condition or Reference supply condition with the Reference demand condition (2012 demand levels). This allows for the comparison of scenario performance between the Reference and Historical conditions.

The second set of columns (under the "All Future Demand Conditions" header for "Demand Condition") combines each of the simulated future supply conditions, by climate, with a demand condition that represents a combination of both future demand storylines. This combined future demand condition is being introduced here to allow for consideration of the effects of future climate on scenario performance in isolation of any changes in demand.

The third set of columns (under the "All Future Climate Conditions" header for "Supply Condition") combines each of the demand conditions with a supply condition that represents a combination of all future climates. This allows for consideration of the effects of future demand on scenario performance in isolation of any changes in climate (and thus supply).

The reliability dashboards in the following sections report on relative conditions for different scenarios developed for the Basin Study, but do not represent an interpretation of how favorable a condition is for a specific water user, nor how the conditions would affect their needs and priorities. The Basin's water users best understand their needs and concerns, and only they can determine the extent to which conditions shown will present a problem for the water-related resources important for their communities.

Lake Tahoe Basin

LTB-1: Groundwater Recharge Groundwater recharge in the Lake Tahoe Basin is predominately influenced by quantity and intensity of precipitation. More rain or snow under wetter conditions would lead to more groundwater recharge compared to drier conditions (Table 6-8). Groundwater recharge would not be affected by future demand changes and is solely a function of future climate.

Under drier conditions, groundwater availability could decrease due to less groundwater recharge.

Temperature also affects groundwater recharge, although to a lesser extent than does precipitation. Groundwater recharge would be lower in hotter conditions than warmer conditions because more evapotranspiration in the watershed would decrease water available for recharge. Likewise, hotter temperatures would also cause faster spring snowmelt periods, causing more water to runoff into Lake Tahoe rather than infiltrate in the ground, as compared to merely warmer conditions.

LTB-2: Snow Covered Land Area Temperature is the dominating factor driving the amount of land covered in snow each year (Table 6-8), because temperature influences whether precipitation falls as snow or rain. Hotter temperatures would also decrease the snowpack's extent in the spring by accelerating the spring melt. Even a Warmer-Drier scenario would have more land area covered in snow than wetter but hotter scenarios, such as Central Tendency or Hotter-Wetter, because more of the additional precipitation under the latter conditions would fall as rain.

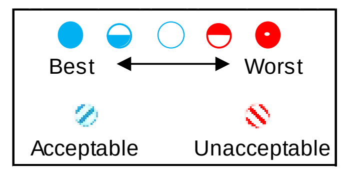
Similar to groundwater recharge, snow covered land area is solely a function of climate and would not change with increased water demand. Snow covered land area would decrease for all future climate change conditions because they are all warmer or hotter than the Reference condition, further underscoring temperature's impact on snow covered land area. Snow-dependent winter recreation in the Lake Tahoe Basin could be affected under all future climate change conditions due to the reduction in snow-covered area.

Table 6-8. Lake Tahoe Basin Indicator Values

Demand Condition	**Reference**		**All Future Demand Conditions**							**Ref.**	**Existing Trends**	**Robust Economy**
Supply Condition	**Historical**	**Reference**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter-Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
LTB-1: Lake Tahoe Basin Groundwater Recharge (AF/year)	NA	○	○	○	○	⊙	⊙	●	●	○	○	○
LTB-2: Lake Tahoe Basin Average Snow Covered Land Area (%)	NA	●	●	◓	◓	○	⊙	◓	◒	◓	◓	◓
LTB-1: Lake Tahoe Basin Groundwater Recharge (AF/year)	NA	60,376	60,376	59,921	60,476	53,195	49,341	67,471	69,120	59,921	59,921	59,921
LTB-2: Lake Tahoe Basin Average Snow Covered Land Area (%)	NA	76.2	76.2	58.9	59.0	63.7	49.3	56.2	66.4	58.9	58.9	58.9

Note: Values and ranges vary by indicator, and are presented in the "Basin Study Indicators" section of this chapter and in "Appendix D – Indicator Dashboards for Water User Communities."

Key:
AF = acre-foot
conds. = conditions
Ref. = reference



Truckee River Basin in California

TBC-1, TBC-2: M&I Shortages Of the total annual Truckee River allocation for California under TROA (32,000 acre-feet), water use is expected to increase 8,700 acre-feet, with a limitation of 10,000 acre-feet in surface water diversions. Groundwater currently meets most M&I water demand in the Truckee River Basin in California and is expected to be the primary source to meet future increases in demand into the future. Further, PCWA has evaluated historical groundwater infiltration rates and found them to be 32,000 acre-feet/year on average, which would prevent the need for surface water diversions.

This Basin Study was motivated to consider operations that relied on surface water diversions from the Truckee River for this water user community, due to the desire to test the effects of this reliance on both the Truckee River Basin in California and downstream water users and poor resolution in surface and groundwater interaction in the TROA-light Planning Model. Poor representation of the surface-groundwater interactions are important, because, increases in groundwater use by the Truckee River Basin in California water user community may lead to reductions in surface flows in the Truckee River. The physical relationship between ground and surface water supplies has not been developed specifically for the Truckee Basin; therefore, the only way to approximate effects on downstream communities was to divert all demands above the Reference levels from the Truckee River (see “Chapter 4 – Water Demand Assessment”).

As a result, readers that believe that future diversions from the Truckee River will not be made and that this water user community will continue to rely solely on groundwater extractions can, correspondingly, ignore the results of these indicators and rely on TBC-3 to understand the potential vulnerabilities to future groundwater infiltration rates.

The Basin Study finds that storage operations could reduce or eliminate surface water shortages reported in this study. The Truckee River Basin in California would experience surface water shortages under all future climate and demand conditions (Table 6-9). Shortages would be more frequent under hotter and drier conditions, as well as under the more aggressive Robust Economy demand. Because M&I users in the Truckee River Basin in California do not have designated storage reserves, this demand is susceptible to decreases in streamflow caused by reduced runoff and increased reservoir evaporation. This is especially evident in the maximum shortage indicator (TBC-2), where an extremely dry year in any future climate condition could eliminate surface water availability for this water user community. Also due to the lack of designated storage reserves, changes in runoff timing would affect shortages if peak flows occur well in advance of higher summer demands.

TBC-3: Groundwater Recharge Groundwater recharge in the Truckee River Basin in California, specifically the Martis Valley Groundwater Basin, is predominately influenced by the quantity of precipitation. More rain or snow in wetter conditions would lead to more groundwater recharge compared to drier climates (Table 6-9). Groundwater recharge would not be affected by future demand changes and is solely a function of future climate. Under drier conditions, groundwater availability could decrease due to less groundwater recharge.

Temperature also affects groundwater recharge, although to a lesser extent than does precipitation. Groundwater recharge would be lower in hotter conditions than warmer conditions because more evapotranspiration in the watershed would decrease water available for recharge. Likewise, hotter temperatures would also cause faster spring snowmelt periods, causing more water to runoff as surface water rather than infiltrate in the ground, as compared to merely warmer conditions.

TBC-4: Preferred Fish Flows Maintaining preferred river flows in the Truckee River Basin in California is strongly dependent on precipitation levels (Table 6-9). More rain or snow in wetter conditions would lead to more surface water runoff, storage, and spills when compared to drier conditions. Temperature, however, would also affect preferred fish flows, although to a lesser extent than precipitation (i.e., smaller differences between warmer conditions and hotter conditions than between wetter conditions and drier conditions). Hotter temperatures would cause more lake evaporation, especially in Lake Tahoe, which would cause less water to be available for water supply releases or spills to the Truckee River. Hotter temperatures would also change runoff timing, which would shift peak flows away from current preferred flow target patterns. Increased evaporation and runoff timing would be substantial enough to cause even a wetter future (e.g., the Hotter-Wetter condition) to not substantially exceed preferred fish flows achieved under the Reference condition.

Future demand conditions would have little effect on preferred fish flows compared to potential changes due to climate (Table 6-9). Climate and associated regulated and unregulated runoff are the main drivers of fish riverine habitat quality and availability in the Truckee River Basin’s upper watershed.

TBC-5, TBC-6: Reservoir Fish Survival and Shallow Water Fish Spawning Habitat Targets Similar to preferred fish flows in the river, reservoir inflows are the predominant factor in meeting reservoir fish survival and in-lake shallow water fish spawning habitat targets. Wetter conditions would miss targets less often than drier conditions (Table 6-9). Increased lake evaporation associated with hotter conditions would also hinder meeting reservoir fish survival targets even under wetter conditions. Increased future demand would decrease overall reservoir storage, which would also affect the ability to meet targets.

TBC-7, TBC-8, TBC-9: River and Reservoir Recreation Rafting and kayaking opportunities on the Truckee River in California are often dependent on prolonged, high flows, which would increase under wetter conditions compared to the Reference supply condition (Table 6-9). More rain or snow in wetter conditions would lead to more surface water runoff, storage, and spills when compared to drier conditions. Fishing opportunities, however, are more dependent on lower flows, and would benefit under drier conditions. It is possible that hotter temperatures would change runoff timing, which could shift peak recreation use periods of the year from historical patterns. Changes in hydrology have a relatively large effect on the ability to meet and maintain recreation flows, and thus river recreation appears insensitive to changes in demand (Table 6-9). Climate and associated regulated and unregulated runoff are the main drivers of conditions needed for river recreation in the Truckee River Basin in California.

The indicators used to assess reservoir recreation largely relate to lake access, which is dependent on the lake’s surface water elevation. Similar to reservoir fish targets, reservoir recreation access would be impeded more under drier conditions, followed by hotter conditions, due to the associated increase in lake evaporation. Increased future demand would also decrease overall reservoir storage.

Because of the manner in which this indicator is constructed, with an emphasis on lower flows that allow for on-river fishing access between April and October, the Historical and Reference supply conditions both perform worse than the climate change conditions. This is largely because of seasonality shifts in the hydrology, which result in lower flows during the identified recreation period.

Table 6-9. Truckee River Basin in California Indicator Values

Demand Condition	**Reference**		**All Future Demand Conditions**							**Ref.**	**Existing Trends**	**Robust Economy**
Supply Condition	**Historical**	**Ref.**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter -Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
TBC-1: Frequency of M&I Water Supply Shortages (% of years)	●	●	●	○	◒	○	⦿	◒	●	●	◒	○
TBC-2: Maximum Annual M&I Water Supply Shortage (% of demand)	●	●	⦿	⦿	⦿	⦿	⦿	⦿	⦿	●	⦿	⦿
TBC-3: Martis Valley Groundwater Recharge (AF/year)	NA	◒	◒	○	○	◓	⦿	●	●	○	○	○
TBC-4: Preferred River Flows for Fish (% of months outside preferred flows)	◓	●	●	○	◒	◓	⦿	●	●	○	○	○
TBC-5: Reservoir Fish Survival (% of months below targets)	●	●	●	○	◒	◓	⦿	◒	●	◒	○	○
TBC-6: Shallow Water Fish Spawning Habitat (% of years below June targets)	●	●	●	○	○	○	⦿	○	●	○	○	○
TBC-7: River Recreation Use - Rafting/ Kayaking (% participation)	●	◒	◒	○	○	⦿	⦿	◒	●	○	○	○
TBC-8: River Recreation Use - Fishing (% participation)	⦿	⦿	⦿	○	○	◒	●	◓	⦿	○	○	○
TBC-9: Impeded Reservoir Recreation Access (% of months)	●	●	●	○	◒	○	⦿	◒	●	●	◒	○

Note: Values and ranges vary by indicator, and are presented in the "Basin Study Indicators" section of this chapter and in "Appendix D – Indicator Dashboards for Water User Communities."

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Best ← → Worst
Acceptable Unacceptable

Table 6-9. Truckee River Basin in California Indicator Values (contd.)

Demand Condition	**Reference**		**All Future Demand Conditions**							**Ref.**	**Existing Trends**	**Robust Economy**
Supply Condition	**Historical**	**Ref.**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter -Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
TBC-1: Frequency of M&I Water Supply Shortages (% of years)	0.0	0.0	9.1	22.2	15.3	27.3	50.0	11.4	6.8	0.0	19.5	24.8
TBC-2: Maximum Annual M&I Water Supply Shortage (% of demand)	0.0	0.0	27.2	27.4	27.3	27.3	27.4	27.2	27.2	0.0	27.4	27.2
TBC-3: Martis Valley Groundwater Recharge (AF/year)	n/a	15,614	15,614	14,720	14,834	13,564	12,075	16,101	17,025	14,720	14,720	14,720
TBC-4: Preferred River Flows for Fish (% of months outside preferred flows)	37.4	34.1	35.0	42.7	40.7	48.5	58.0	34.8	31.5	42.5	42.5	42.9
TBC-5: Reservoir Fish Survival (% of months below targets)	10.3	7.0	10.4	17.9	14.8	21.8	31.5	12.3	9.0	13.5	17.3	18.5
TBC-6: Shallow Water Fish Spawning Habitat (% of years below June targets)	6.3	10.8	10.8	28.9	27.0	26.4	49.7	27.8	13.6	28.2	28.8	29.1
TBC-7: River Recreation Use – Rafting /Kayaking (% participation)	29.4	27.3	26.9	22.8	22.2	18.7	16.8	26.1	30.2	22.9	22.8	22.8
TBC-8: River Recreation Use - Fishing (% participation)	62.2	63.2	63.6	66.4	66.7	67.4	69.5	65.5	63.1	66.3	66.5	66.4
TBC-9: Impeded Reservoir Recreation Access (% of months)	36.0	36.5	39.3	51.3	49.2	57.2	68.2	44.4	37.8	48.7	50.9	51.8

Key:
AF = acre-foot
M&I = municipal and industrial
conds.= conditions
Ref. = Reference

Truckee Meadows

TM-1, TM-2: M&I Shortages M&I shortages in the Truckee Meadows would occur in less than 5 percent of years for all future climates except for the Hotter-Drier condition, in which shortages would occur in 12.5 percent of years (Table 6 10). TMWA, the largest M&I water retailer/wholesaler in the Truckee Meadows, manages its facilities and stored surface water reserves to meet demands beyond the summer months during dry years when river supplies are less available (TMWA 2009). This management of contingency supplies offsets all but the largest decreases in future water supply. The Hotter-Drier condition would decrease inflows because of less precipitation, and decrease storage due to greater evaporation, especially in Lake Tahoe. These impacts would compound in drought periods (when the maximum annual shortage would be about 45 percent of demand) and would affect TMWA's water supply.

TM-3: Frequency of Floriston Rate Shortages Precipitation and associated regulated and unregulated runoff are the main factors in achieving Floriston rates (Table 6-10). Wetter conditions would reduce the frequency of Floriston rate shortages through August, while drier conditions would increase the frequency. The Hotter-Drier condition would double the frequency of Floriston rate shortages compared to the Reference condition due to the compounded effects of less runoff and a change in peak runoff timing. As previously discussed, this frequency of Floriston rate shortages would affect TMWA's water supply.

TM-4: TMWA Hydropower Flows A drier future climate would be the largest threat to maintaining current hydropower generation flows at the three active run-of-the-river hydroelectric power plants along the Truckee River between the Little Truckee River and Reno (Table 6-10). Drier conditions would reduce the water supply available for releases through the powerhouses because river flows would be lower. Decreases in water supply for energy generation could affect TMWA's operating revenue. Low-flow conditions would also worsen under future demand conditions, although to a lesser extent than under drier conditions.

TM-5: Ability to Achieve Water Quality Standards A drier future climate would have the largest effect on achieving water quality standards due to increased low-flow conditions (Table 6-10). Low flows can cause temperature increases and stagnant water, and could cause dilution issues for point and non-point sources, including Truckee Meadows Water Reclamation Facility.

TM-6, TM-7: River Recreation Rafting and kayaking participation on the Truckee River in Truckee Meadows are often dependent on prolonged, high flows, and would increase under future wetter climates compared to the Reference condition (Table 6-10). Increased rain or snow under wetter conditions would lead to more surface water runoff, storage, and spills when compared to drier conditions. Fishing participation, however, is more dependent on lower flows, and would benefit under drier conditions and hotter conditions. River recreation opportunities are not sensitive to future demand changes (Table 6-10). Climate and associated regulated and unregulated runoff are the main drivers of conditions needed for river recreation in the Truckee River Basin.

TM-8, TM-9: Agriculture Shortages The frequency of years in which Truckee Meadows-area agricultural water users experience a shortage would increase under drier conditions (Table 6-10). In all future climates, including the Reference condition, the maximum annual shortage Truckee Meadows agricultural users would experience is 71.8 percent, due to the extreme dry years which occur in all future conditions.

Table 6-10. Truckee Meadows Indicator Values

Demand Condition	Reference		All Future Demand Conditions							Ref.	Existing Trends	Robust Economy
Supply Condition	**Historical**	**Ref.**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter -Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
TM-1: Frequency of M&I Water Supply Shortages (% of years)	●	●	●	◒	●	◒	◉	●	●	●	◒	◒
TM-2: Maximum Annual M&I Water Supply Shortage (% of demand)	●	●	●	◉	○	◓	◉	●	●	○	◉	◉
TM-3: Frequency of Floriston Rate Shortages (% of years)	●	●	●	○	◒	◓	◉	●	●	◒	○	○
TM-4: Average Annual TMWA Hydropower Flows (AF)	●	●	●	◒	◒	○	◉	●	●	◒	◒	◒
TM-5: Ability to Achieve Water Quality Standards (dry year flow in cfs)	◒	●	●	○	◒	◓	◉	●	●	◒	○	○
TM-6: River Recreation Use - Rafting/Kayaking (% participation)	●	◒	◒	○	◓	◉	◉	◒	●	○	○	○
TM-7: River Recreation Use - Fishing (% participation)	◉	◉	◉	○	○	◒	●	◓	◉	○	○	○
TM-8: Frequency of Agricultural Water Supply Shortages (% of years)	●	●	●	◒	◒	○	◉	●	●	◒	◒	◒
TM-9: Maximum Annual Agricultural Water Supply Shortage (% of demand)	●	●	○	◉	◉	◉	◉	○	●	●	◓	◉

Note: Values and ranges vary by indicator, and are presented in the “Basin Study Indicators” section of this chapter and in “Appendix D – Indicator Dashboards for Water User Communities.”

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Best ←→ Worst
Acceptable Unacceptable

Table 6-10. Truckee Meadows Indicator Values (contd.)

Demand Condition	**Reference**		**All Future Demand Conditions**							**Ref.**	**Existing Trends**	**Robust Economy**
Supply Condition	**Historical**	**Ref.**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter -Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
TM-1: Frequency of M&I Water Supply Shortages (% of years)	0.0	0.0	0.0	3.4	1.1	3.4	12.5	0.0	0.0	0.5	3.2	3.6
TM-2: Maximum Annual M&I Water Supply Shortage (% of demand)	0.0	0.0	0.0	45.3	21.4	30.9	45.3	5.3	0.1	26.4	45.3	45.3
TM-3: Frequency of Floriston Rate Shortages (% of years)	22.7	27.3	27.8	45.0	38.1	60.8	80.7	25.0	20.5	43.4	44.8	45.2
TM-4: Average Annual TMWA Hydropower Flows (AF)	936,582	924,569	921,010	861,403	903,225	793,753	672,577	962,454	975,006	863,242	862,641	860,165
TM-5: Ability to Achieve Water Quality Standards (dry year flow in cfs)	306	334	318	251	260	175	106	354	361	272	258	244
TM-6: River Recreation Use - Rafting/Kayaking (% participation)	18.3	17.4	16.8	15.4	15.0	13.4	12.8	16.9	18.7	15.5	15.4	15.3
TM-7: River Recreation Use - Fishing (% participation)	61.6	60.9	61.4	64.5	64.9	66.7	68.6	62.3	59.9	63.8	64.4	64.6
TM-8: Frequency of Agricultural Water Supply Shortages (% of years)	13.6	18.2	18.8	34.0	25.0	44.9	69.9	17.0	13.1	33.4	33.6	34.3
TM-9: Maximum Annual Agricultural Water Supply Shortage (% of demand)	59.8	71.8	71.8	71.8	71.8	71.8	71.8	71.8	71.8	71.8	71.8	71.8

Key:
AF = acre-foot
cfs = cubic feet per second
M&I = municipal and industrial
TMWA = Truckee Meadows Water Authority
conds.= conditions
Ref. = Reference

Pyramid Lake

PL-1, PL-2: M&I and Agricultural Shortages M&I and agriculture water shortages would occur in less than 5 percent of years under all future climate conditions and demand conditions (Table 6-11). Maximum annual shortages would be worse under drier conditions (up to about 20 percent of demand) and could affect the PLPT's water supply.

PL-3: Delta Passage and Channel Stability Pyramid Lake elevations in drier conditions would be consistently lower than the lake's historical low surface elevation (3,784 feet) toward the end of the twenty-first century (Table 6-11). As described previously in this chapter (Figure 6-1), any decrease in streamflow caused by less precipitation would be reflected at Pyramid Lake, as it is the Truckee River's terminus. All future demand conditions that consider the full range of future climate change would exhibit similar effects. Chronic low lake elevations could limit delta passage for cui-ui and Lahontan cutthroat trout and increase head cutting conditions that could threaten Marble Bluff Dam stability.

PL-4: Availability of Good Pyramid Lake Fishes Adult Passage Wetter conditions would benefit adult passage of Pyramid Lake fishes compared to the Reference condition (Table 6-11) due to additional precipitation and the associated streamflow into Pyramid Lake. Although the timing of peak runoff in wetter conditions could shift to earlier in the year (see "Chapter 3 – Water Supply Assessment"), Pyramid Lake fishes may adapt the timing of their spawning run, similar to historical runs under early high flow conditions (USFWS 2014). Drier conditions would be detrimental to opportunities for adult fish passage due to lower flow in the Truckee River. Higher consumptive demands in the Truckee River Basin, as seen in the Robust Economy demand storyline, may also reduce the frequency of flows needed for adult passage; however, changes in hydrology related to climate change have a much more prominent effect on the availability of these flows.

PL-5: Maintenance of Spawning and Incubation Flows Similar to adult passage, spawning and incubation of Pyramid Lake fishes would benefit from wetter conditions. Wetter conditions would meet or exceed Flow Regime 3 targets more often than under the Reference condition. Drier conditions would decrease achievement of spawning and incubation flows by about 50 percent compared to the Reference condition (Table 6-11). Higher consumptive demands in the Truckee River Basin, as seen in the Robust Economy demand storyline, may also reduce spawning and incubation flows; however, changes in hydrology related to climate change have a much more prominent effect on the availability of these flows.

PL-6: Persistence of Poor Spawning Conditions Poor spawning conditions are measured by the persistence, in number of consecutive years, of having flows below Flow Regime 4 targets. The shortest period with poor spawning conditions for Pyramid Lake fishes would be 6 consecutive years (Table 6-11), and the six-year duration occurs under both Reference and wetter conditions. A period of low-flow conditions occurs in all future climate conditions, corresponding to the regional drought of record was mapped into projected future conditions. Although the drought exists across all future conditions, the severity of the drought varies with the future climate projections. For instance, the drier conditions exacerbate the low-flow period, resulting in poor spawning conditions that persist for a quarter-century.

PL-7, PL-8: Establishment and Maintenance of Riparian Habitat in Lower Truckee River The Warmer-Wetter condition would increase the number of years in which Flow Regime 1 or Flow Regime 6 targets are met or exceeded compared to the Reference condition (Table 6-11) (see "Chapter 5 – Water Management Conditions" for additional details on flow regimes). This would be beneficial to riparian vegetation establishment and maintenance. The number of months in which Flow Regime 1 targets are met would increase under the Hotter-Wetter condition (Figure 6-13); however, increased lake evaporation losses and changes in peak runoff periods would decrease the number of years when the Flow Regime 1 targets are met for the entire January through June period compared to the Reference condition. Drier conditions would reduce the flows needed for a healthy riparian habitat corridor. Higher consumptive demands in the Truckee River Basin would also affect riparian habitat establishment and maintenance flows, although not to the extent of changes in hydrology.

Table 6-11. Pyramid Lake Indicator Values

Demand Condition	**Reference**		**All Future Demand Conditions**							**Ref.**	**Existing Trends**	**Robust Economy**
Supply Condition	**Historical**	**Ref.**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter -Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
PL-1: Frequency of PLPT Water Supply Shortages (% of years)	NA	NA	●	●	●	●	●	●	●	NA	●	●
PL-2: Maximum Annual PLPT Water Supply Shortage (% of demand)	NA	NA	◒	◒	◒	◒	◒	●	●	NA	◒	●
PL-3: Delta passage and channel stability (average end-of-century lake elevation)	▨	▨	▨	▧	▨	▧	▧	▨	▨	▧	▧	▧
PL-4: Availability of good Pyramid Lake fishes adult passage (% of years)	●	◒	◒	○	○	◉	◉	●	●	○	○	○
PL-5: Maintenance of spawning and incubation flows (% of years)	●	◒	◒	○	○	◉	◉	●	●	○	○	○
PL-6: Persistence of poor spawning conditions (consecutive years)	◓	○	○	◉	◓	◉	◉	○	○	◉	◉	◉
PL-7: Establishment of riparian habitat in Lower Truckee River (% of years)	●	●	●	○	◓	◓	◉	○	●	○	○	○
PL-8: Maintenance of riparian habitat in Lower Truckee River (% of years)	◒	●	●	○	○	◓	◉	●	●	◒	○	○

Note: Values and ranges vary by indicator, and are presented in the “Basin Study Indicators” section of this chapter and in “Appendix D – Indicator Dashboards for Water User Communities.”

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Best ← → Worst
▨ Acceptable ▧ Unacceptable

Table 6-11. Pyramid Lake Indicator Values (contd.)

Demand Condition	Reference		All Future Demand Conditions							Ref.	Existing Trends	Robust Economy
Supply Condition	**Historical**	**Ref.**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter -Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
PL-1: Frequency of PLPT Water Supply Shortages (% of years)	NA	NA	1.7	1.6	1.1	3.4	3.4	0.0	0.0	NA	3.2	0.0
PL-2: Maximum Annual PLPT Water Supply Shortage (% of demand)	NA	NA	16.8	19.4	17.1	18.1	19.4	7.2	7.7	NA	19.4	8.5
PL-3: Delta passage and channel stability (average end-of-century lake elevation)	3,826.0	3,827.8	3,809.9	3,703.8	3,798.1	3,732.3	3,703.8	3,861.7	3,883.2	3,719.8	3,708.4	3,703.8
PL-4: Availability of good Pyramid Lake fishes adult passage (% of years)	72.7	71.6	68.2	63.0	63.6	50.6	45.5	76.1	79.0	65.2	63.4	62.5
PL-5: Maintenance of spawning and incubation flows (% of years)	68.2	60.2	59.1	47.3	45.5	34.1	25.6	61.9	69.3	51.4	48.0	46.6
PL-6: Persistence of poor spawning conditions (consecutive years)	8	6	6	24	8	24	23	6	6	24	24	24
PL-7: Establishment of riparian habitat in Lower Truckee River (% of years)	36.4	33.0	29.5	17.5	14.8	13.6	4.5	19.9	34.7	19.1	17.7	17.3
PL-8: Maintenance of riparian habitat in Lower Truckee River (% of years)	77.3	87.5	79.0	64.3	65.3	50.0	39.2	81.3	85.8	70.7	65.0	63.6

Key:
PLPT = Pyramid Lake Paiute Tribe
conds. = conditions
Ref. = Reference

Newlands Project

NP-1, NP-2: Crop Demand Shortages Crop water demand shortages in the Newlands Project would be most sensitive to future changes in both precipitation and temperature, rather than changes in acres under cultivation (Table 6-12). Shortages would occur more frequently under drier conditions than wetter climate conditions due to decreased water supplies in both the Truckee and Carson river basins. Shortages would also occur more frequently under hotter conditions than warmer climate conditions because hotter temperatures increase crop evapotranspiration.

Under the Hotter-Drier condition, which experiences the largest decreases in water supply and largest increases in crop water demand, some level of shortage would occur in about 80 percent of years. Maximum annual crop water demand shortages (between 70 and 90 percent of annual demand) for most future climate conditions would be caused by the compounding effects of hotter temperatures and deeper drought conditions in the latter part of the twenty-first century.

The frequency of crop water demand annual shortages in the Newlands Project would increase under all future climate change conditions compared to the Reference conditions, even for wet years. Although changes in precipitation, and the associated water supply, is the more dominant factor in crop water demand shortages, the general increase in shortages under all future climate change conditions occurs because increased evapotranspiration would increase crop water demand beyond available water supplies in several years. At times the crop water demand would even be beyond the total water right volume available to the Newlands Project (Table 6-12). Therefore, even under ideal water supply conditions, the Newlands Project’s water rights would not be able to meet the increased crop demand due to evapotranspiration.

NP-3, NP-4, NP-5, NP-6: Lahontan Valley Wetlands Water Supplies The primary water supplies for Lahontan Valley wetlands are Newlands Project water rights and spills from Lahontan Reservoir. Both supplies would change under future climates (Table 6-12). Newlands Project water right supplies would decrease under drier conditions due to less precipitation and associated runoff in the Truckee and Carson river basins. Less inflow into Lahontan Reservoir in drier climate conditions would also decrease the volume of reservoir spills that supply the wetlands. Drier conditions would also increase the longest duration of consecutive annual shortages to the Lahontan Valley wetlands. Hotter temperatures, even under wetter climates, would increase lake evaporation throughout the Basin, which would also decrease available supplies. Under hotter climates, increased lake evaporation in Lahontan Reservoir would also reduce spills because additional space would be available in Lahontan Reservoir during large runoff events.

NP-7: Average Newlands Project Hydropower Generation A drier future climate would have the largest effect on maintaining current hydropower generation levels at the Lahontan powerhouses and the 26-Foot Drop Powerplant (Table 6-

12). Drier climates would decrease the water supply available for controlled releases through the powerhouses. Decreases in water supply for energy generation could affect TCID's operating revenue.

NP-8, NP-9: Fernley M&I Shortages M&I shortages in the City of Fernley would occur in less than 5 percent of years for all future climates except for the Hotter-Drier condition, in which shortages would occur in about 7 percent of years (Table 6-12). The Hotter-Drier condition would decrease water supplies because of less precipitation, and would decrease storage due to increased lake evaporation, especially in Lake Tahoe. These impacts would compound in drought periods (the maximum annual shortage would be about 16 percent of demand) and could affect Fernley's water supply.

Table 6-12. Newlands Project Indicator Values

Demand Condition	Reference		All Future Demand Conditions							Ref.	Existing Trends	Robust Economy
Supply Condition	**Historical**	**Ref.**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter-Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
NP-1: Frequency of Crop Water Demand Shortages (% of years)	●	●	●	○	○	○	⊙	○	●	○	○	○
NP-2: Maximum Annual Crop Water Demand Shortage (% of demand)	◒	●	●	⊙	⊙	⊙	⊙	◓	◒	⊙	⊙	⊙
NP-3: Average Lahontan Basin Wetlands Water Right Deliveries (% of annual demand)	●	●	●	◒	◒	○	⊙	●	●	◒	◒	◒
NP-4: Average Lahontan Reservoir Spills (% of annual demand)	●	●	○	⊙	⊙	⊙	⊙	⊙	○	◓	⊙	⊙
NP-5: Total Lahontan Basin Wetlands Water Supply (% of annual demand)	●	●	◒	◓	◓	◓	⊙	○	◒	○	◓	◓
NP-6: Duration of Lahontan Valley Wetlands Water Supply Shortages (consecutive years)	●	●	●	⊙	◓	◓	⊙	●	●	⊙	⊙	⊙
NP-7: Average Newlands Project Hydropower Generation (GWh/year)	●	●	●	○	◒	◓	⊙	●	●	○	○	◒
NP-8: Frequency of Fernley Water Supply Shortages (% of years)	●	●	●	◒	◒	○	⊙	●	●	●	●	○
NP-9: Maximum Annual Fernley M&I Water Supply Shortage (% of demand)	●	●	◒	⊙	⊙	⊙	⊙	◓	◒	●	⊙	⊙

Note: Values and ranges vary by indicator, and are presented in the "Basin Study Indicators" section of this chapter and in "Appendix D – Indicator Dashboards for Water User Communities."

● ◒ ○ ◓ ⊙
Best ←→ Worst
Acceptable   Unacceptable

Table 6-12. Newlands Project Indicator Values (contd.)

Demand Condition	**Reference**		**All Future Demand Conditions**							**Ref.**	**Existing Trends**	**Robust Economy**
Supply Condition	**Historical**	**Ref.**	**Reference**	**All Future Climate Conds.**	**Central Tendency**	**Warmer -Drier**	**Hotter -Drier**	**Hotter-Wetter**	**Warmer -Wetter**	**All Future Climate Conditions**		
NP-1: Frequency of Crop Water Demand Shortages (% of years)	11.4	8.0	9.1	44.5	41.5	48.3	81.3	37.5	14.2	43.9	45.5	43.6
NP-2: Maximum Annual Crop Water Demand Shortage (% of demand)	54.5	45.5	52.0	87.5	81.5	84.1	87.5	72.3	55.9	85.7	87.0	87.5
NP-3: Average Lahontan Basin Wetlands Water Right Deliveries (% of annual demand)	95.6	97.9	97.1	91.6	93.7	89.8	80.8	96.0	97.5	92.8	91.8	91.4
NP-4: Average Lahontan Reservoir Spills (% of annual demand)	28.8	25.2	11.2	4.6	3.5	1.2	0.5	5.2	12.6	8.1	4.9	4.3
NP-5: Total Lahontan Basin Wetlands Water Supply (% of annual demand)	124.4	123.1	108.2	96.2	97.2	91.0	81.3	101.2	110.1	100.9	96.6	95.7
NP-6: Duration of Lahontan Valley Wetlands Water Supply Shortages (consecutive years)	3	3	3	7	6	6	7	3	3	7	7	7
NP-7: Average Newlands Project Hydropower Generation (GWh/year)	24.4	24.2	24.5	22.4	23.2	20.6	17.4	24.9	25.8	22.1	22.3	22.5
NP-8: Frequency of Fernley Water Supply Shortages (% of years)	0.0	0.0	0.0	2.5	1.7	2.8	6.8	1.1	0.0	0.0	1.1	3.9
NP-9: Maximum Annual Fernley M&I Water Supply Shortage (% of demand)	0.4	0.1	5.1	16.4	14.2	14.4	16.4	12.9	6.2	1.5	15.1	16.4

Key:
Conds.= conditions
GWh = gigawatt hour
M&I = municipal and industrial
Ref. = REference

Chapter 7
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 Basin, as described in previous chapters of this Report. This chapter identifies a set of actions that seem reasonable to consider in an attempt to address future supply-demand imbalances. Generally, the Basin Study avoided assessments of actions that seek to transfer benefits between water user communities in a manner that deviates from the current supply-demand balance in the Basin.

Unquestionably, Basin stakeholders and water users have the best understanding of local needs and tolerances to risk. Further, they are the most equipped to identify which actions seem most reasonable for pursuit in response to future risks. The Basin Study team obtained input from stakeholders to identify individual actions, or "options," for responding to climate change. All of the options presented in this chapter were suggested for consideration by one or more stakeholders or agencies involved in Truckee Basin water management. Among the 140 options collected, many were similar either in function or intent, reflecting common perspectives among stakeholders about needs and opportunities to improve water management in the Basin.

The following chapter organizes the options thematically under one of three strategic approaches, or "adaptation strategies": Institutional Change, Supply Augmentation, and Demand Management. Existing information on the effectiveness of each option is presented where appropriate. A subset of the options have been identified for additional evaluation as part of the Basin Study, and technical assessments of their performance is presented as part of the evaluation of the three adaptation strategies.

Identification of Options and Strategies

The options presented in this Report were identified or suggested for investigation by Basin water users and other stakeholders, including municipalities, irrigators, Tribes, resource agencies, local and regional planning agencies, and environmental or conservation groups. Suggested options were grouped and prioritized for evaluation based on the completeness of the option, and on the expected contribution of the option towards restoring Reference scenario-level balances between Basin supplies and demands.

Input from Water Users and Other Basin Stakeholders

Engagement with the TAG serves as the primary vehicle for obtaining technical input on the Basin Study from the broad array of Basin stakeholders. The options identified for evaluation in the Basin Study were generated by stakeholders during a TAG workshop in July 2014, and through subsequent follow-up discussions with stakeholders who could not attend the workshop.

The July TAG workshop was hosted at TRPA offices in South Lake Tahoe and attended by 36 individuals representing 20 entities in the Truckee Basin. To provide background and context for the discussion of adaptation options, the workshop included a presentation on the technical approaches used to characterize future conditions and the findings regarding Basin-wide risks and vulnerabilities, which are described in Chapters 2 through 6. This review provided workshop participants with important background and context for options discussion by highlighting the type of conditions that might need to be addressed.

TAG workshop participants were organized into breakout groups to discuss future vulnerabilities, and to identify actions that were high priorities for their communities and also more broadly in the Basin. Participants identified approximately 140 suggestions for options to consider in the Basin Study; all options appear in their original form or wording in "Appendix A – Engagement Record."

Following the workshop, individual discussions were held with TAG members who were either unable to attend the workshop, or who desired to provide additional information regarding their recommended options. The options described and considered in the Basin Study originated from suggestions by representatives from the organizations and entities shown in Table 7-1.

Table 7-1. Agencies 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 host of options generated by the TAG included both specific actions that would address the needs of different types of water users, and also more general actions that address the vulnerabilities of the entire Basin. Some options recommended were structural in nature, but others were non-structural and focused on broad, Basin-wide institutional changes that might provide the flexibility needed to adapt to a range of future climates. Likely reflecting an understanding of the sizeable risks to the entire Basin and need for future collaboration, stakeholders avoided recommending controversial "third rail" actions, such as dredging the rim of Lake Tahoe, installation of a pipeline from Lake Tahoe to supply Reno, or construction of new dams on the Truckee River's tributaries or on the Carson River.

Organization of Options into Strategies

The options collected from water users represent a wide range of actions that could be implemented in the Basin. For presentation and evaluation purposes, the Basin Study team developed a shorter, consolidated list of options that preserves the ideas and goals of the full list of options generated. Multiple similar options were grouped together and, if appropriate, consolidated into single options. 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. The grouping is the category of activity or water use the option focuses on implementing or changing.

Interestingly, the options identified in response to the information provided were almost evenly split among suggestions for supply augmentation, demand management, and institutional changes. Institutional changes include legal and/or non-structural suggestions, such as Basin-wide planning activities, changes in reservoir operating policies, and modifications to water rights and regulations (Figure 7-1). Table 7-2 presents the consolidated set of options, organized by adaptation strategy and grouping.

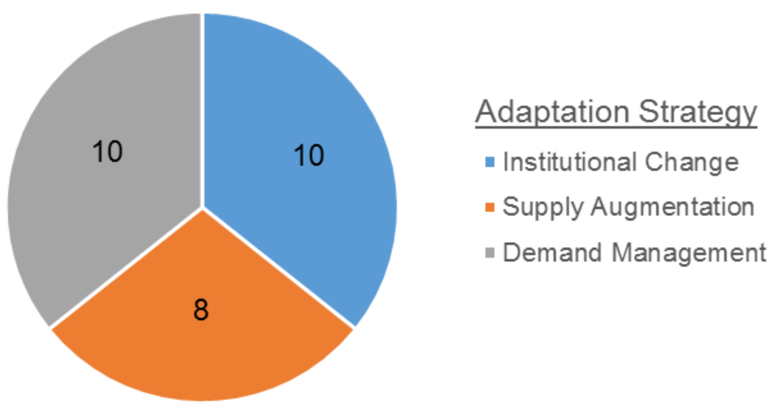


Figure 7-1. Quantities of Options Identified for Consideration, by Adaptation Strategy

Table 7-2. 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

Evaluation of Options and Strategies

All of the options suggested by Basin stakeholders for evaluation in the Basin Study have been retained by and are presented in this Report (and in their original wording in “Appendix A – Engagement Record”) 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 Basin Study should not be considered “recommendations,” and many of the options that did not received 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.

The following section describes the process applied in evaluating the options suggested, followed by sections which present the evaluation of the options organized under each of the three adaptation strategies.

Process for Evaluating Options

The Basin Study's process for evaluating options included an initial, high-level assessment for all options recommended by Basin water users, followed by a more detailed analysis for a select number of options using Basin Study tools, such as the TROA-light Planning Model.

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 require further research to reduce uncertainty regarding the ability of the action to resolve imbalances, not all of which could be accommodated by the Basin Study process. As a result, the options presented are evaluated at a range of different levels of detail.

The prioritization of options for further evaluation is based on the completeness of the option and the availability of information needed to asses it, and the degree to which the option seeks to resolve Basin-wide imbalances. The considerations applied in selecting options for further evaluation are provided below.

Completeness of Options

The options suggested for evaluation in the Basin Study range in detail from actions that have been described and evaluated in detail in previous studies, to actions that have not yet been formally studied or considered in the Basin. In cases where previous studies and reports could not provide an understanding of potential future performance toward resolving future imbalances in supply and demand, options were considered for further evaluation.

In order to be evaluated, options must have a measurable or specified effect on 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. In this way, the option is considered "complete." The options selected for further evaluation in the Basin Study all share a clear purpose and specific mechanisms that change future conditions in measurable ways. For example, a suggestion to reconfigure TROA credit storage allocations in certain reservoirs could not be considered without extensive engagement among the TROA signatories, the outcomes of which could not be anticipated.

Applicability to Basin-Wide Vulnerabilities

The options selected for further evaluation are those anticipated either to address water supply vulnerabilities for the entire 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 Basin Study's Reference scenario (which represents current water management operations and regulations, and does not include future changes in demand or climate). For example, if municipal water supplies become much less reliable than supplies to meet agricultural or ecosystem demands in the future when compared to reliabilities under the Reference scenario, options may exist that help restore the supply-demand balance for all users consistent with the Reference scenario. In general, options were not selected for detailed evaluation if they were anticipated to pick clear "winners" or "losers" by shifting benefits from one water user at the expense of another.

Depending on what the future actually holds, the Basin and its water user communities may ultimately wish to craft a balance among users that differs from the Reference scenario. In that case, information and analysis in the Basin Study will be useful for discussions about how to approach a new balance among water users throughout the Basin.

Use of Basin Study Tools

The use of an equivalent process to evaluate the different effects of options allows for more thorough comparisons. Where possible, options were tested using the TROA-light Planning Model; however, the ability to test options in the model was not considered in the prioritization of options for evaluations. To evaluate options while avoiding speculation about complex political questions, some options were evaluated by extrapolating from the results of other scenarios. For instance, extrapolation from other model results was used to evaluate the effects of adding water storage in the Truckee Basin.

Institutional Changes Strategy

Institutional conditions in the Truckee Basin – such as regulatory requirements, municipal water management practices, infrastructure operating rules and guidelines, and legal settlements – have emerged over the past century from careful and incremental public debate, litigation, and action at every level of government. Like most other basins across the Western U.S., the expected outcomes of institutional policies reflect diligent consideration of future conditions using modern engineering techniques. However, these techniques have largely relied upon the historical hydrology as the baseline for future supply availability.

Future supply conditions projected for the Basin Study vary largely from historical conditions. Without action, all water users will experience unprecedented imbalances in supply and demand under the driest future conditions. In reaction to these conditions, Basin water users have expressed that the effects of climate change may require consideration of untraditional or radical changes to the region's water rights and policies. The options presented in this section include broad, large-scale, mostly nonstructural actions that seek to either improve the health and reliability of water user communities throughout the Basin, or to preserve the balance of water supplies and demands that would exist under the Reference scenario.

Implementation considerations for each of the Institutional Change options will likely vary based on the degree to which the option deviates from the Basin's existing water management practices and structures, including those described in "Chapter 5 – Water Management Conditions." Each will also require the involvement of a variety of different Basin interests. However, in general, it is likely that the costs for implementation of many of the Institutional Change options would be lower than for some of the more structural options included in the Supply Augmentation and Demand Management strategies that could require construction.

Some of the Institutional Change options represent, or would require, fundamental changes in the region's water laws and practices, such as modifying prior appropriation laws. A thorough evaluation of these options would require assumptions about operations that would be highly speculative and would require extensive input and discussion from Basin water users that could not be facilitated by the Basin Study process. Where possible, the Basin Study addresses these options by making simplified assumptions, and focusing on broad effects without speculating on how implementation would affect each water user community.

Table 7-3 includes descriptions of the Institutional Change options, organized by grouping. Some of the options have previously been evaluated in other studies and reports, with a range of findings about performance and effectiveness. For each Institutional Change option, Table 7-3 provides a brief summary, references any existing evaluation in other studies, and notes whether the option was evaluated further in the Basin Study. Additional assessments of options selected for further evaluation are provided in the sections that follow Table 7-3.

Table 7-3. Institutional Change Options Considered for the Basin Study

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Basin-wide Planning	Define regional priorities and goals for water use	Each water user in the Basin independently plans for its water needs and how to address them in the future. However, under some future climate conditions, water supply reliability may decrease for all users but in an asymmetric manner. In such circumstances, a basin-wide plan that describes how supplies would be prioritized for use would help communities in the Basin cope with scarcity. The plan would likely require involvement of both the states of California and Nevada, along with municipalities, tribes, resource agencies, and other organizations.	Evaluation using the Basin Study's tools would require assumptions that are too speculative. Therefore, this option was not evaluated further for the Basin Study.
	Create open water markets	Water rights in California and Nevada are granted/confirmed and overseen by state officials. In some cases, water rights are restricted in where they can be exercised and used. Creation of an open water market would provide water users flexibility in managing their supplies. Creation of an open-market system would likely require changes to state law, and potentially to water rights.	Evaluation using the Basin Study's tools would require assumptions that are too speculative. Therefore, this option was not evaluated further for the Basin Study.
	Eliminate prior appropriation	In many Western states, California and Nevada included, some or all water rights are granted based partially on the principle of “prior appropriation”: senior water users are granted priority for water use during times of shortage. In some cases, appropriative water rights can be lost through non-use, which discourages water use efficiency during shortages. Eliminating the principle of prior appropriation would remove the incentive some users have to exercise their rights fully no matter the conditions of scarcity.	Evaluation using the Basin Study's tools would require assumptions that are too speculative. Therefore, this option was not evaluated further for the Basin Study.

Table 7-3. Institutional Change Options Considered for the Basin Study (contd.)

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Surface Water Reservoir Management	Allow TCID carryover storage in Truckee River reservoirs	TROA provides flexibility for Basin water user communities to use Truckee River reservoirs to manage available supplies to meet human and ecosystem needs. TCID is not a TROA signatory, but multi-year storage in Truckee River reservoirs would improve water supply reliability for the Newlands Project. This option would require the agreement of TROA signatories, and possibly, a modification to TROA.	Evaluation using the Basin Study's tools would require assumptions on operations that are too speculative. Therefore, this option was not evaluated further for the Basin Study, although it was previously considered in the Newlands Project Planning Study and found to provide potential benefits (Reclamation 2013).
	Change balance of credit storage available to users at Truckee River reservoirs	TROA provides flexibility for Basin water user communities to use Truckee River reservoirs to manage available supplies to meet human and ecosystem needs. This option would require the agreement of TROA signatories, and possibly, a modification to TROA.	Evaluation using the Basin Study's tools would require assumptions on operations that are too speculative. Therefore, this option was not evaluated further for the Basin Study, although it was previously considered in the Newlands Project Planning Study and found to provide potential benefits (Reclamation 2013).
	Remove storage limits at Truckee River reservoirs	Storage limits at Truckee River reservoirs are based on flood management needs and other requirements. Seasonality shifts in runoff could result in Truckee River reservoirs becoming less effective at capturing and storing, and delivering water supplies when runoff is highest. Removing or relaxing storage limits at Truckee River reservoirs would allow reservoirs to be operated to capture runoff when it is most available and release it as needed. However, this option may also affect flood management and could potentially result in less water flowing to Pyramid Lake.	Evaluated as option "Adapt Reservoir Flood Management Operations."

Table 7-3. Institutional Change Options Considered for the Basin Study (contd.)

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Surface Water Reservoir Management (contd.)	Modify flood control curves to adapt to climate	A certain amount of space is required to be available in Truckee River reservoirs during the fall and winter to accommodate potential increases in inflow during large weather events. Flood management requirements combined with earlier runoff due to seasonality shifts could result in reservoirs not capturing water supplies that ordinarily would have been captured later in the year when less flood space was needed. Aligning reservoir flood management requirements with the runoff changes anticipated under a warmer climate would ensure reservoirs are operated to capture runoff when it is most available and release it as needed. However, this option may also affect flood management and could potentially result in less water flowing to Pyramid Lake.	Evaluated as option "Adapt Reservoir Flood Management Operations.”
	Modify OCAP criteria at Lahontan Dam to improve success of refill	Under the Newlands Project OCAP, when certain specific storage targets are met at Lahontan Reservoir, diversions from the Truckee River must cease. Future seasonality shifts may reduce the ability of Lahontan Reservoir to meet end-of-month storage targets because flows on the Truckee River that once appeared in May and June occur earlier in time. Changing OCAP storage targets to occur earlier in the year would improve the success of refill at Lahontan Reservoir. However, this could potentially result in less water flowing to Pyramid Lake.	Evaluated as option "Adapt OCAP Storage Targets.”

Table 7-3. Institutional Change Options Considered for the Basin Study (contd.)

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Surface Water Rights Management	Allow management of water between Pyramid Lake fisheries and Lahontan Valley wetlands	Water supplies from the Truckee River support managed ecosystem and habitat needs at two major locations in the basin: at Pyramid Lake and at the Lahontan Valley wetlands. Additionally, national wildlife refuges at both locations contain important habitat for either endemic or migratory species. USFWS is responsible for ensuring both areas receive the water supplies necessary to support habitat and ecosystem functions. If a structure were in place to allow USFWS to manage water supplies cooperatively between the two locations, the water needs of ecosystems and species in either could be met flexibly. However, the Lahontan Valley wetlands were historically supported by the Carson River; the connection between Lahontan Valley wetlands and the Truckee River exists only through Newlands Project rights acquired to support the wetlands.	The Basin Study focuses on options with broad benefits and effects, and this option relies on one water user community to address Basin-wide supply-demand imbalances. Also, evaluation using the Basin Study's tools would require assumptions on operations that are too speculative. Therefore, this option was not evaluated further for the Basin Study.
	Consolidate agricultural water rights	In the Newlands Project, which represents the majority of agricultural water use in the study area, water rights are granted at a certain number of acre-feet per acre. Future changes in temperature will result in a longer growing season, requiring more water overall during the irrigation season. Project water rights could be consolidated by reducing the total acreage of the Newlands Project, but keeping the total volume of water rights that could be delivered. This would allow remaining acreage in the project to receive a higher volume of water rights that would be required under a warmer climate. This option would likely require modification of the adjudicated decrees governing water rights in the Truckee and Carson basins.	Evaluated as option "Consolidate Agricultural Rights.”

Key:
OCAP = Operating Criteria and Procedures
TCID = Truckee-Carson Irrigation District
TROA = Truckee River Operating Agreement
USFWS = U.S. Fish and Wildlife Service

Adapt Reservoir Flood Management Operations

Seasonality shifts could decrease the efficiency of Truckee River reservoirs in capturing, storing, and delivering water supplies. Even if the quantity and pattern of annual precipitation does not change in the future, warmer temperatures could reduce the accumulation of snow and shift the peak runoff to an earlier period when reservoir storages are constrained by flood management rules that specify how much and when storage must be available to capture inflow from anticipated winter floods. This condition would force reservoirs to forego the capture of supplies that could ultimately help refill reservoirs. This lost water supply would result in less stored water being available through the high demand summer months and less carryover for drought periods. Relaxing or shifting the timing of flood management rules would mitigate vulnerabilities related to seasonality shifts in runoff cause by climate change. However, it also could potentially result in less flows to Pyramid Lake because of reductions in spills from the reservoirs.

Typically, flood management objectives for each reservoir are established in a set of operating guidelines produced by the USACE, often called flood management “rule curves.” Basin water users and stakeholders suggested that the Basin Study develop new flood rule curves that more closely align with future climate conditions. However, the Basin Study used a different approach to assess the benefits of modifying flood management operations.

The Basin Study’s model and hydrology were formulated for use in evaluating water supply benefits primarily, and a different set of tools would be necessary to design a new set of flood management operating guidelines. Additionally, as with many aspects of Truckee Basin water management, flood rule curves were developed based on a historical understanding of the region’s hydrology. Future hydrology, and therefore supplies, are based on transient climates where shifts occur gradually over time. Thus, each year the hydrology and progress of seasonality shifts is different. Model simulations of flood operations assume the flood rule curves are applied rigidly, but this is not always the case in actual flood operations. In practice, the operator of a reservoir might note snowpack and other hydrologic conditions affecting potential runoff and apply his or her professional judgment to assess whether the risk of large snowmelt floods has passed, and whether the reservoir could be safely refilled. As a result, actual flood management operations may eventually adapt to gradual changes in climate, and also would not be captured by the Basin Study’s model.

For these reasons, the Basin Study evaluated this option by considering an upper bound of potential gains in water supply that would result from fully removing all flood management requirements from Truckee River reservoirs. This approach was appropriate given the way in which type of information being used in the model simulations, and the inherent uncertainties associated with climate change and actual reservoir operations as noted above. In this manner, the maximum benefit of shifts in flood operations to water supplies could be assessed. Additional information on the technical formulation of this option in the TROA-light Planning Model is provided in "Appendix F – Technical Assumptions for Option Evaluation."

Effects on Basin-Wide Operations Adapting reservoir operations allows Truckee Basin reservoirs to be more flexible in capturing and delivering runoff. However, as shown in Figure 7-2, these adaptations would only increase the volume of inflow that is controlled (as opposed to uncontrolled or spilled) by 1 to 2 percent in comparison to the Without-Action scenarios. Wetter scenarios would continue to spill a higher proportion of inflow compared to drier scenarios. The 50,000 acre-foot annual increase in inflow in wetter scenarios would be mostly lost to spills, and this loss would not decrease substantially by adapting reservoir operation rules. The higher percentage of spills in wetter scenarios, therefore, would not be predominantly caused by periods when flood management curves prevent their capture. Additional storage would be needed to make use of these uncontrolled supplies.

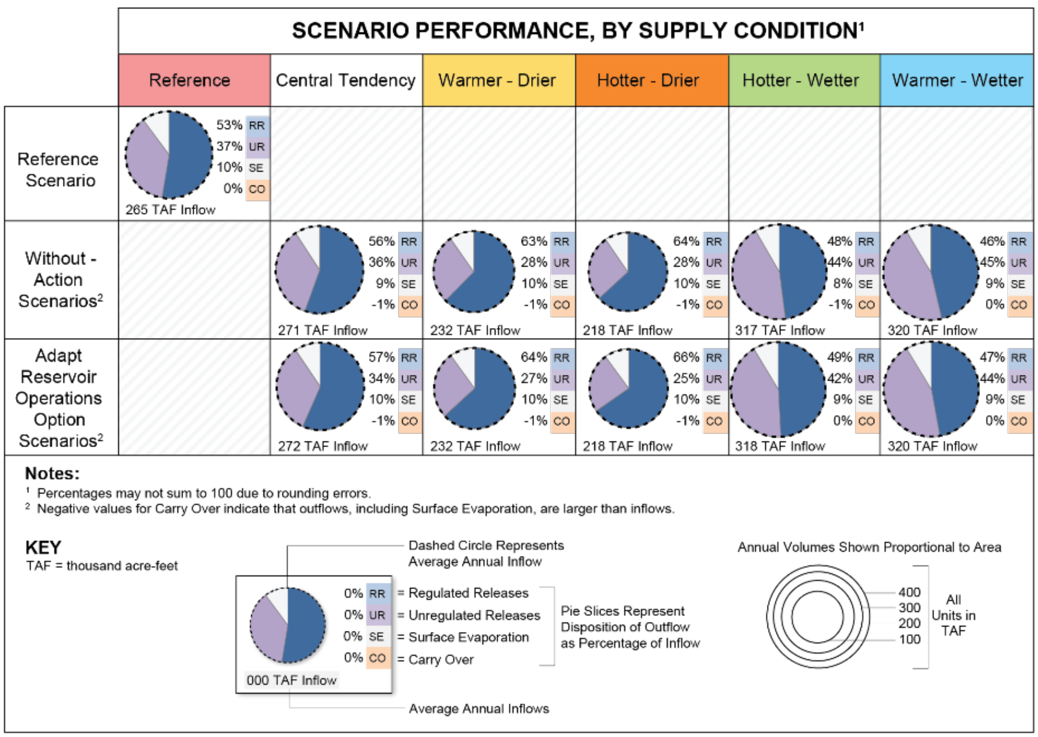


Figure 7-2. General Operations in Truckee River Basin Reservoirs Downstream from Lake Tahoe under Adapt Reservoir Flood Management Operations Option

Seasonality shifts reduce the potential for refilling reservoirs. As the peak runoff moves earlier in time, the ability to meet full pool storages after April is reduced. The top and middle plots in Figure 7-3 show how shifting peak inflows would not be captured fully because of flood management constraints in the late winter and early spring. The bottom plot in Figure 7-3 shows the volume of water supply that could be captured (represented by the area above the operations curve and below the scenarios curves) if this option were implemented. This increase in capture would then allow reservoir storage to last longer into the summer season, providing up to an additional 50,000 acre-feet in drier scenarios.

However, this increase in capture would not substantially decrease the proportion of spills, especially in wetter conditions. As seen in the bottom plot in Figure 7-3, inflow capture would still be restricted by total reservoir capacity (note the maximum extent of storage, around 325,000 acre-feet, in March and April). Most additional inflow in wetter scenarios would be lost due to this maximum capacity constraint.

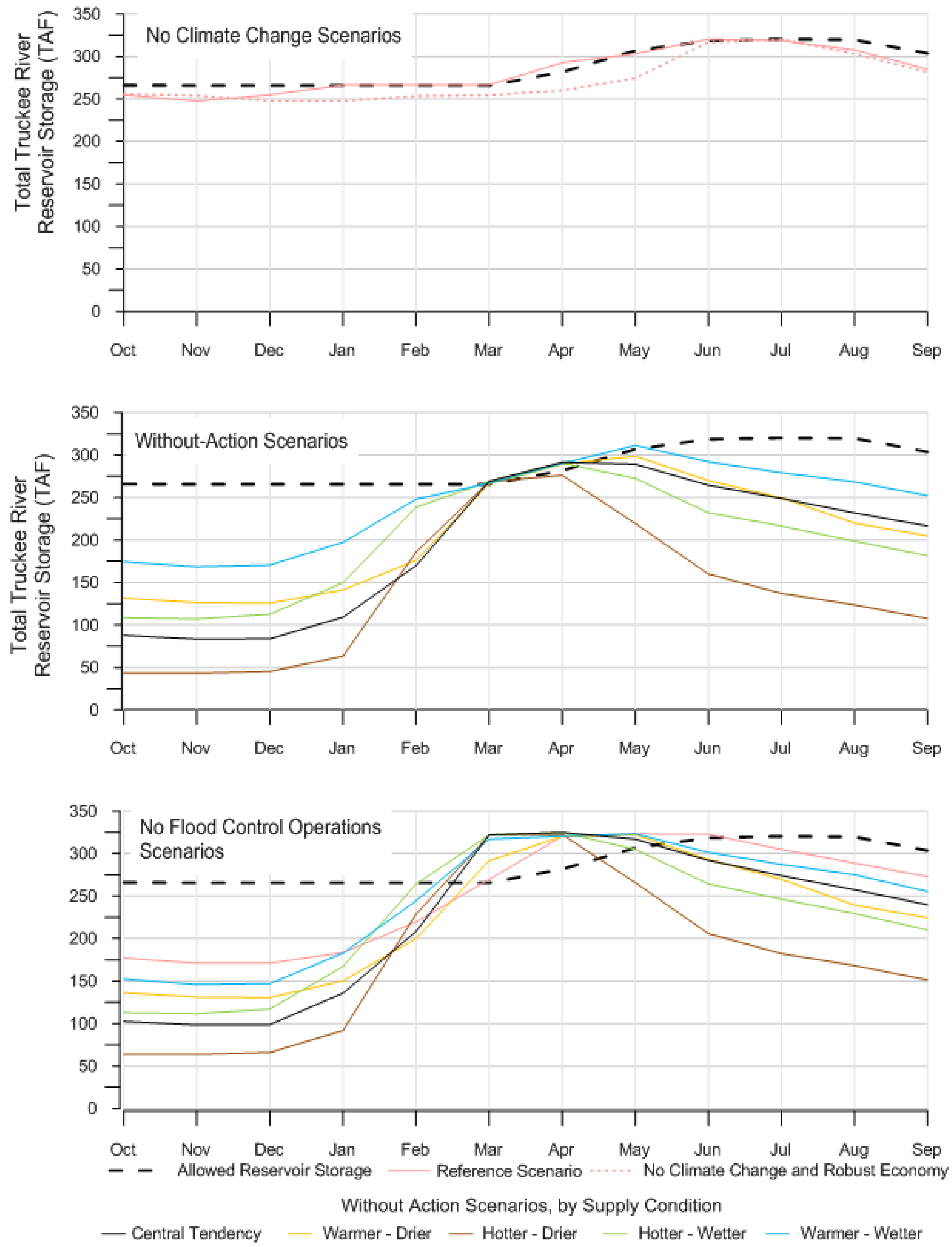
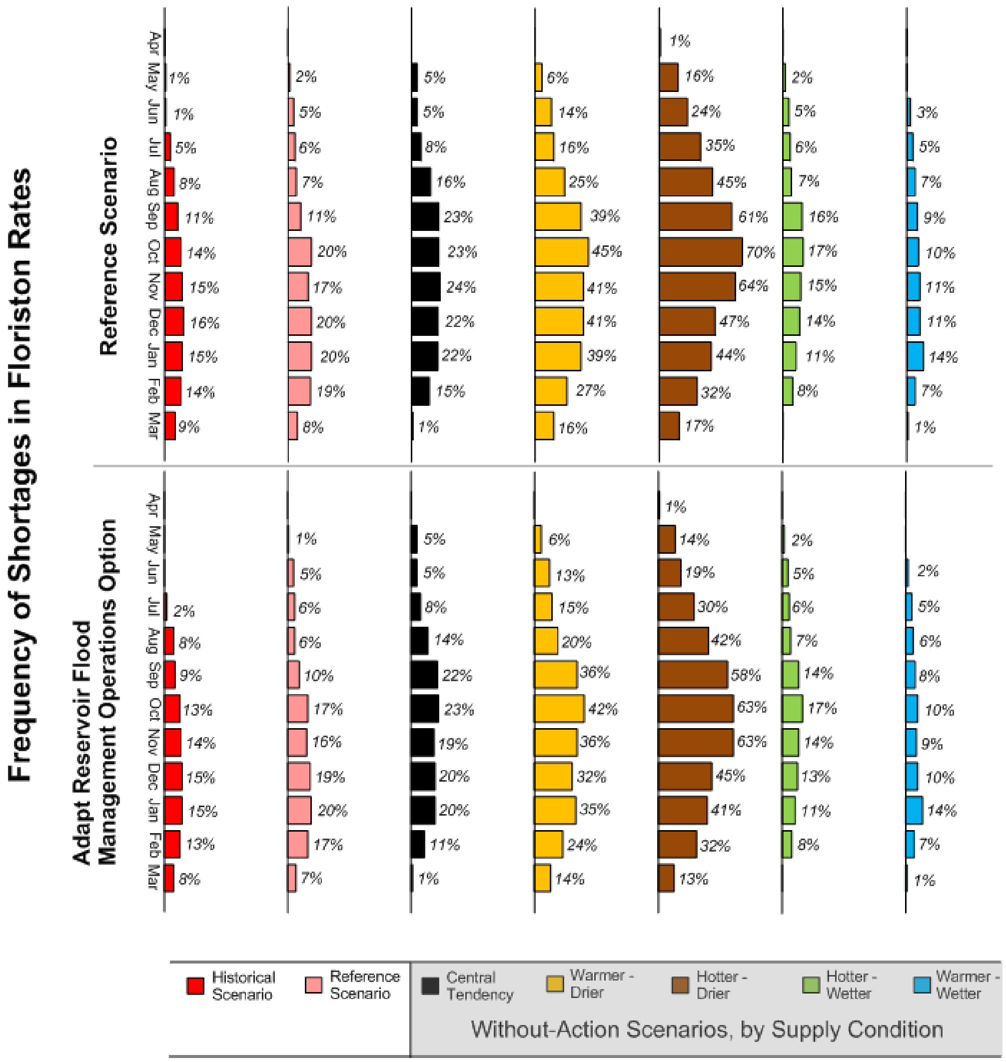


Figure 7-3. Flood Rule Curve Constraints Under Adapt Reservoir Flood Management Operations Option

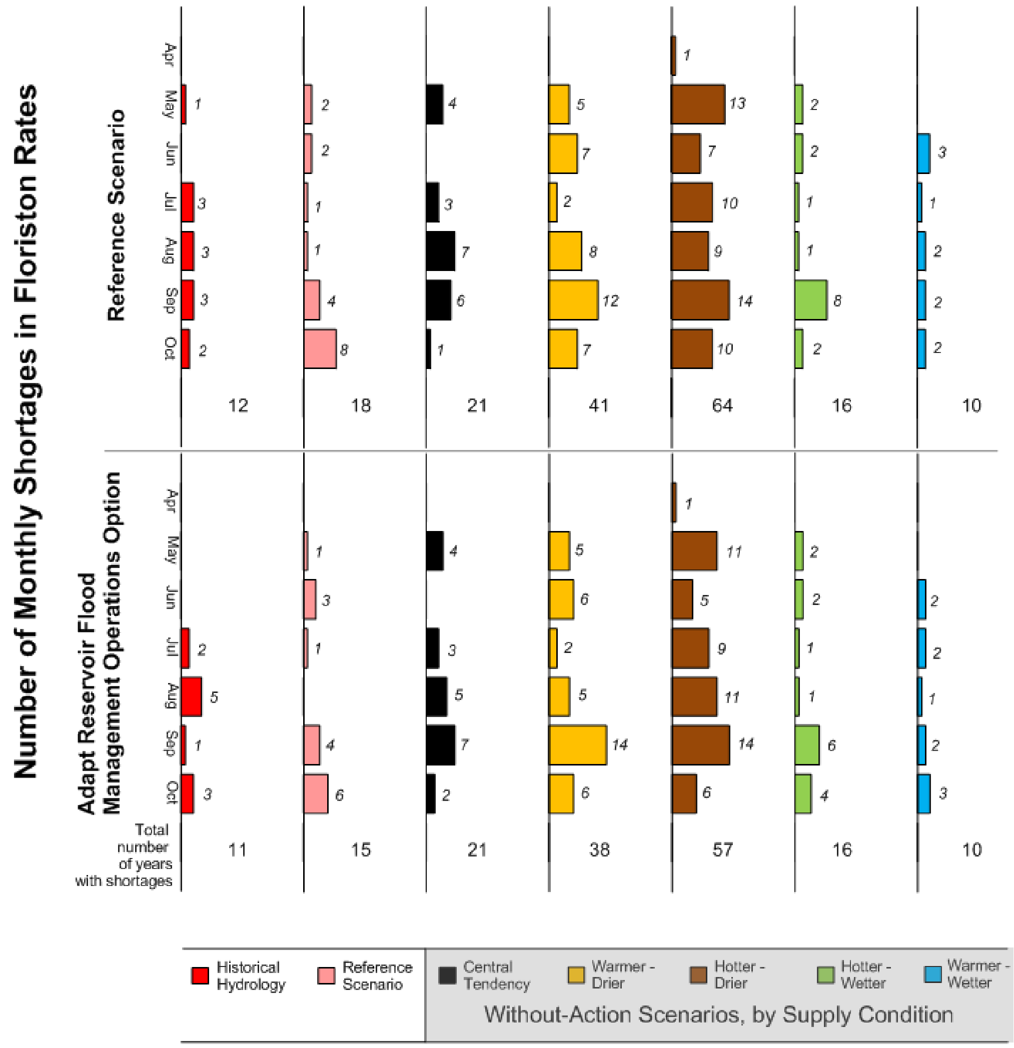
Under this option, the frequency of monthly Floriston rate shortages would decrease in February through June compared to Without-Action scenarios (Figure 7-4). Under future climates, the peak runoff would shift to the February-April period and would not be fully captured due to requirements for flood management space in the reservoirs. By relaxing flood management space requirements, the reservoirs would have more flexibility in capturing earlier and quicker runoff periods, which would help maintain Floriston rates during the spring and early summer season. This is especially evident in Figure 7-5, where the first Floriston rate shortage would generally occur later under the Reference scenario compared to the Without-Action scenarios. As with other options that would capture water at Truckee River reservoirs, this option could potentially result in less flows to Pyramid Lake if it prevents spills.

Floriston rate shortages in drier scenarios, however, would continue to occur sooner and more frequently than under the Reference scenario without adapting flood management operations, and would stress municipal supply and drought reserves.



Note:
Scenarios displayed include Robust Economy demand storyline (described in Chapter 4).

Figure 7-4. Monthly Frequencies of Floriston Rate Shortages Under Adapt Reservoir Flood Management Operations Option



Note:
Scenarios displayed include Robust Economy demand storyline (described in Chapter 4).

Figure 7-5. Occurrence of First Floriston Rate Shortage in April Through October Under Adapt Reservoir Flood Management Operations Option

Mitigation of Shortages Reservoir fish habitat would improve with more flexible reservoir operations. Flexible reservoir operations would result in fewer spills and would keep more water in reservoir for longer periods of time. The frequency of meeting fish survival and shallow water spawning habitat targets would improve between 3 and 26 percent across all scenarios.

More flexible reservoir operations would decrease the frequency of annual Truckee Meadows M&I water supply shortages in the Hotter-Drier scenario by up to 9 percent. Maximum annual Truckee Meadows M&I water supply shortages would slightly decrease for most climate conditions. The frequency of annual Newlands Project agriculture water supply shortages in drier scenarios would decrease up to 3 percent.

Years with adequate adult passage flows for Pyramid Lake fishes would decrease between 8 and 13 percent for drier scenarios, but years with adequate spawning flows would increase by 7 to 15 percent. These effects are good examples of complex dependencies between operations on opposite ends of the Basin. For instance, in a small number of years, water from a quick melt would be spilled in Without-Action scenarios due to flood management constraints. If captured, this spill water would provide adult passage flows for at least two consecutive months between January and June, but not necessarily provide peak spawning flows. Relaxing reservoir operations would manage the spilled water, thereby decreasing adult passage flows that were dependent on the spills.

Spawning flows would increase in wetter years that, under Without-Action scenarios, were meeting adult passage flow regardless of flood management operations, but would miss the peak months of April and May for spawning because of the timing and magnitude of the melt and resulting spills. Relaxing reservoir operations would better capture and manage these peak flows for the benefit of meeting Pyramid Lake fish flow regimes peak flows. The longest duration of years with poor spawning flows occurs in the drier scenarios. Under these scenarios, conditions would not improve under relaxed reservoir operations because flow targets would still exceed available flow in those drier years. Although cui-ui are long-lived, longer durations of poor spawning conditions in drier scenarios would adversely affect Pyramid Lake fish populations.

Implementation Considerations This option would likely need consideration, study, and coordination with all parties involved in Basin-wide water operations. This option may affect flood risk and flood management operations in the Basin, and this possibility would need to be assessed in greater detail by the USACE, TRFMA, and other flood management entities to ensure that the option’s water supply benefits do not come at the cost of reduced flood protection for Basin communities. Reclamation’s assessment of potential changes in future flood frequency in the Truckee Basin is included in “Appendix E – Truckee River Flood Frequency and Magnitude Analysis.”

Additionally, to the extent uncontrolled supplies (spills) are captured through additional storage, flows to Pyramid Lake could decrease. Capture of the spills through additional storage would require new appropriations of Truckee River water rights. As the Truckee River is fully appropriated and most of the spilled water flows to Pyramid Lake, this option would require full participation of the Pyramid Lake Paiute Tribe.

Adapt OCAP Storage Targets

The Newlands Project OCAP was designed to prevent the project from diverting more water from the Truckee River than is needed for meeting project water rights. An important restriction on Truckee River diversions stems from end-of-month storage targets at Lahontan Reservoir for the months of April, May, and June. If volumes in Lahontan Reservoir exceed the storage target for the current month, then further diversions from the Truckee River are not allowed. The storage targets vary with conditions on the Carson River, but generally begin in April at lower elevations and relax through June.

OCAP storage targets were carefully designed through detailed technical evaluation and studies, but with the historical climate and hydrologic processes in mind. As such, future seasonality shifts may reduce the ability of Lahontan Reservoir to meeting end-of-month storage targets because flows on the Truckee River that once appeared in May and June occur earlier in time. Under these conditions, the storage targets could prevent the Newlands Project from fully using its water rights and reduce the reliability of the project.

The following assessment evaluates the effect of allowing the June end-of-month target to be met as early as April. Further information on the technical formulation in the TROA-light Planning Model are provided in "Appendix F – Technical Assumptions for Option Evaluation."

Effects on Basin-Wide Operations Relaxing OCAP storage targets could, in some years, result in higher diversions from the Truckee River for the Newlands Project; however, this option is not anticipated to substantially affect Basin-wide operations for the different water user communities. For example, decreases in Pyramid Lake surface water elevations are estimated to be less than 1 foot for all Option scenarios compared to Without-Action scenarios (Figure 7-6). Excess diversions from the Truckee River are not projected to be significant because OCAP storage targets would not overly constrain spring storage in Lahontan Reservoir at the detriment of meeting final June targets, even with earlier or faster runoff periods in both the Carson and Truckee rivers. However, these results from computer modeling are based on averages and do not track individual years.

Under future climate change, OCAP storage targets would only constrain storage in Lahontan Reservoir in Without-Action scenarios. Because OCAP storage targets are not the predominant factor in constraining June Lahontan Reservoir storage, relaxing these targets would not substantially increase overall Truckee River diversions away from Pyramid Lake.

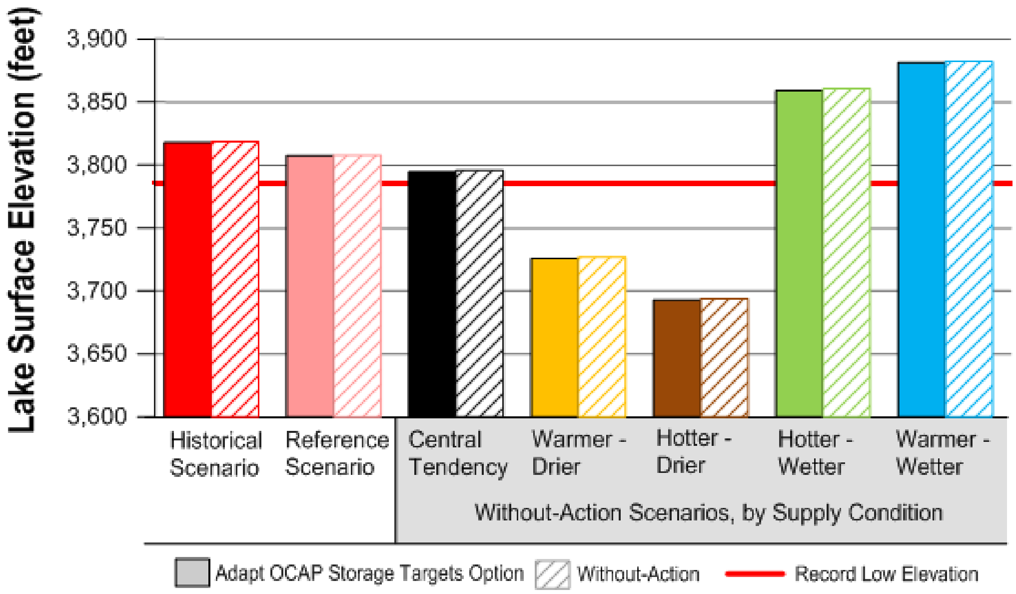


Figure 7-6. Average End-of-Century Pyramid Lake Elevations Under Adapt OCAP Storage Targets Option

Mitigation of Shortages Adapting Newlands Project OCAP reservoir storage target requirements would not substantially increase Newlands Project agriculture and wetland deliveries. As discussed, OCAP storage targets would not be the predominant factor in constraining June Lahontan Reservoir storage volumes.

Although changes in storage targets are revealed to limit some opportunities to meet Newlands Project water rights, there are an equal number of instances when this option allows for Lahontan Reservoir to receive more water than is legally permissible. However, the conditions where storage targets are exceeded are all towards the beginning of the century (when seasonality shifts are minimal) and the conditions where the relaxation of targets allows for appropriate refill are towards the end. This indicates that, as seasonality shifts progress, that this type of modification may be more acceptable or more appropriate.

Implementation Considerations Any future changes to OCAP would likely need to be studied and considered in great detail by Reclamation, the Pyramid Lake Paiute Tribe, TCID, and other parties to ensure the outcomes would not conflict with the protections OCAP provides to ecosystems and habitat in the lower Truckee River and at Pyramid Lake. While this need for additional study likely applies to any changes to OCAP, it is especially important for this specific change, given that the Basin Study's evaluation of this option shows that there is a potential for over-diversions from the Truckee River during the early part of this century.

Consolidate Agricultural Rights

Increases in temperature are expected to result in a prolonged growing season for irrigated agriculture in the Truckee and Carson basins. Increases in temperature would also increase crop evapotranspiration demands. These changes would increase annual per acre demand by alfalfa; alfalfa is the predominant crop grown in the Newlands Project, which represents the large majority of irrigated agriculture in the study area (Table 7-4).

Table 7-4. Projected Annual Per-acre Net Irrigation Water Requirements for the Newlands Project's Carson Division

Supply Condition	Estimated Average Annual Net Irrigation Water Requirement for the Newlands Project (inches/year)		
	2012 – 2039	**2040 – 2069**	**2070 – 2099**
Reference	37.1	37.1	37.1
Central Tendency	39.8	41.7	42.7
Warmer-Drier	39.3	41.2	42.1
Hotter-Drier	40.7	42.8	44.5
Hotter-Wetter	40.1	41.8	43.2
Warmer-Wetter	38.6	40.3	41.5

Newlands Project water rights restrict the per-acre application of water. Current water rights in the Newlands Project allow for 3.5 to 4.5 acre-feet of applied water per acre for irrigated agriculture, depending on the location and condition of the lands, and these rights are served at the head gates of water righted lands – meaning that conveyance losses to the land are not factored into the water right. Generally, approximately fifteen percent of applied water on well-managed lands with shallow water tables is lost to groundwater, and the remainder is retained in the root-zone and consumptively used by crops (Reclamation 2013). In the future, attempts to sustain the current extent of irrigated agriculture with the current blend of crop types, cultural practices and per-acre water rights, will result in shortfalls to crops. Under these conditions, however, per-acre crop demands could be met in full (for a smaller total acreage) if water rights volumes from a larger area of water righted lands were allowed to be applied to a smaller acreage of land. Augmentation of Newlands Project water right volumes were not considered under this option.

The changes in acreages shown in Table 7-5 were applied to acreages in Robust Economy demand conditions for the purpose of evaluating this option; Existing Trends demand conditions had similar changes in acreages. Further information on the technical formulation in the TROA-light Planning Model is provided in "Appendix F – Technical Assumptions for Option Evaluation."

Table 7-5. Reductions in Newlands Project Irrigated Acreages Applied for the Consolidate Agriculture Rights Option

Supply Condition	Decrease in Newlands Project Irrigated Land		
	2012 – 2039	**2040 – 2069**	**2070 – 2099**
Central Tendency	5.0%	7.1%	7.8%
Warmer-Drier	4.1%	6.4%	7.0%
Hotter-Drier	6.3%	8.5%	9.9%
Hotter-Wetter	5.5%	7.3%	8.4%
Warmer-Wetter	3.1%	5.2%	6.3%

Effects on Basin-Wide Operations Consolidating Newlands Project agriculture water rights would not substantially change the use of Carson and Truckee river water supplies (Table 7-6) to meet project demands, although it could possibly improve project efficiency. The percentage of water diverted at Derby Dam versus allowed to flow to Pyramid Lake would also not be affected (Table 7-7). Under this option, annual irrigated acreage and season lengths would change, but the volume of water used in the Newlands Project would remain limited to the extent of existing project water rights.

Table 7-6. Newlands Project Use of Carson and Truckee River Inflows

	Historical	**Reference**	**Central Tendency**	**Warmer -Drier**	**Hotter-Drier**	**Hotter-Wetter**	**Warmer-Wetter**
Consolidate Agriculture Rights Option Scenarios							
Supplies from Carson River	75.9%	73.1%	67.3%	65.2%	61.3%	72.2%	76.7%
Supplies from Truckee River	24.1%	26.9%	32.7%	34.8%	38.7%	27.8%	23.3%
Without-Action Scenarios							
Supplies from Carson River	76.0%	73.1%	67.3%	65.1%	61.3%	72.1%	76.5%
Supplies from Truckee River	24.0%	26.9%	32.7%	34.9%	38.7%	27.9%	23.5%

Table 7-7. Division of Truckee River Flows at Derby Dam

	Historical	Reference	Central Tendency	Warmer -Drier	Hotter-Drier	Hotter-Wetter	Warmer-Wetter
Consolidate Agriculture Rights Option Scenarios							
Flow diverted to Truckee Canal	17.7%	19.3%	22.2%	28.6%	31.2%	15.7%	13.0%
Flow to Pyramid Lake	82.3%	80.7%	77.8%	71.4%	68.8%	84.3%	87.0%
Without-Action Scenarios							
Flow diverted to Truckee Canal	17.6%	19.3%	22.2%	28.6%	31.1%	15.8%	13.1%
Flow to Pyramid Lake	82.4%	80.7%	77.8%	71.4%	68.9%	84.2%	86.9%

Mitigation of Shortages By consolidating agricultural water rights, the frequency of Newlands Project shortages would decrease between 1 and 28 percent across all future climate change scenarios. Frequency of shortages under the Warmer-Wetter scenarios would decrease 28 percent because shortages would be infrequent in both the Reference scenario and Option scenarios (decrease from 14 percent to 10 percent of years with shortages). The decrease in shortages for other future scenarios would be less than 10 percent. Shortages would continue to occur because during drier years, which can be exacerbated by climate change, supplies would still be limited.

Implementation Considerations This option would operate best under flexible terms that would allow TCID to manage and optimize the acreage and applied water year by year. It could also be accomplished through purchase of water right acres that would be retired, with their water-righted duties to be applied to other lands in the project. Implementation of this option may entail modifications to Truckee River and Carson River water rights and thus would require close coordination with parties to the *Orr Ditch* and *Alpine* decrees as well as the Nevada State engineer and TCID. Conditions would need to be established or reaffirmed that would restrict the Newlands Project to existing water right volumes and allocations.

Supply Augmentation Strategy

Uncertainty in the future climate results in a number of scenarios where reductions in supply are the dominant stressor on Truckee Basin water user communities. Future potential decreases in precipitation and increases in lake evaporation at Lake Tahoe would decrease the quantity of water supply available for all Truckee Basin water user communities. For these scenarios, supply augmentation arises as an obvious strategic response.

Options considered under the Supply Augmentation Strategy are intended to increase the overall water supply to the Basin or improve water supply reliability. All of the Supply Augmentation options are, in some form, structural in nature;

some are focused on improving the Basin’s supply by increasing storage opportunities, others attempt to generate a new supply of water for the Basin, and still others aim to improve management of other natural systems, with a side effect of improving the Basin’s water supply. However, as the Truckee River is fully appropriated and most of the spilled water flows to Pyramid Lake, implementation of options that increase storage of Truckee River water would require full participation of the Pyramid Lake Paiute Tribe.

Implementation considerations for each of the Supply Augmentation options will likely vary tremendously, reflecting the diverse set of actions suggested by stakeholders for this strategy. As many of these options require construction, associated costs may, in general, be higher than for some of the Institutional Change options, and include both capital and operations and maintenance costs. Such options will also likely require coordination and cooperation of multiple agencies to plan, finance, and implement. Some options, such as those providing new storage, may also require additional study and negotiations to determine how it would fit with the Basin’s existing water rights.

The simulation approach in this Basin Study does not allow for assessing how groundwater would be affected by forest management practices, but groundwater recharge could be improved in some areas. Removing vegetation would decrease interception and subsequent evaporation of precipitation. Less evapotranspiration would also occur from the root zone. Both conditions would improve groundwater infiltration.

Table 7-8 includes descriptions of the Supply Augmentation options, organized by grouping. Some of the options have previously been evaluated in other studies and reports, with a range of findings about performance and effectiveness. For each Supply Augmentation option, Table 7-8 provides a brief summary, references any existing evaluation other studies, and notes whether the option was evaluated further in the Basin Study. Additional assessments of options selected for further evaluation are provided in the sections that follow Table 7-8.

Table 7-8. Supply Augmentation Options Considered for the Basin Study

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Alternative Sources	Interbasin Transfer of Groundwater	Prehistoric Lake Lahontan once covered a wide swath of the Great Basin, and deposited groundwater in a number of sub-basins in Nevada and California. Although the lake no longer exists, the groundwater remains and could be pumped out and imported for use as a source of additional supply in the basin. This would likely require acquisition of groundwater rights. Previous studies have investigated opportunities at Dixie Valley, Honey Lake Valley, Red Rock Valley, Granite Springs Valley, Dry Valley, San Emidio, and Hualapai Flat (Reclamation 2013, TMWA 2009). However, the same changes in precipitation that affect the Truckee Basin may also influence the yield of neighboring groundwater basins, and thus the future yield from these basins is uncertain.	Evaluation using the Basin Study's tools would require assumptions on effectiveness that are too speculative. Therefore, this option was not evaluated further for the Basin Study, although it was previously considered for the Newlands Project, Churchill County, and TMWA (Reclamation 2013, Churchill County 2005, TMWA 2009).
Conveyance Facility Improvements	Augment Truckee Canal capacity	In a warmer climate, seasonality shifts would decrease the duration of time available for diverting Truckee River supplies that are available to the Newlands Project. The Truckee Canal has been capacity-limited since 2008 due to safety concerns. Rehabilitating the Truckee Canal to permit higher flows could mitigate vulnerabilities related to climate change by allowing adequate diversion of water supply when it was available. Rehabilitation would include actions such as installation of a cutoff wall along the urbanized portion of the canal. This option was previously evaluated for its ability to provide water supply reliability (Reclamation 2013).	Evaluated as option "Truckee Canal Rehabilitation.”
Groundwater Storage	Enhanced groundwater recharge	Existing surface storage mechanisms in the Truckee Basin will likely become less effective in the future due to changes in climatic conditions. Increasing the physical ability to store winter precipitation could mitigate vulnerabilities related to the seasonality shifts caused by climate change. Groundwater storage and recovery programs allow for water that cannot be captured in surface reservoirs to be stored underground for later extraction and use. Such a program would likely need to be considered in context of existing surface water and groundwater rights.	Evaluated as option "Additional Truckee River Basin Storage.”

Table 7-8. Supply Augmentation Options Considered for the Basin Study (contd.)

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Modifications to the Hydrologic Cycle	Forestry-based watershed management	Fire suppression and logging practices in the Sierra Nevada have resulted in large areas of forest that are overly dense with small trees and brush. These dense forests alter streamflow patterns: forest cover intercepts snow, thereby reducing snow storage on the ground and the resulting runoff; and dense forests intercept, evaporate, and transpire more water. Restoring a forest’s ability to store snow and reducing evapotranspiration by thinning the vegetation may release more water as runoff and increase groundwater infiltration and storage. Recent studies have indicated that the use of specific forest management techniques in the Lake Tahoe Basin and Tahoe National Forest could potentially result in as much as an additional 21,000 acre-feet per year of runoff in the study area; however, yield could be substantially lower during drought periods. Improvements in groundwater infiltration are also likely, but not specifically addressed.	Evaluated as option "Forest Management.”
	Weather modification	Precipitation is one of the chief drivers of water supply availability. Weather modifications such as cloud seeding are aimed at enhancing snowfall in mountainous regions to increase snowpack and resulting runoff, augmenting supply for the basin. Cloud seeding works by releasing chemical particles such as silver iodide into the atmosphere, which helps ice crystals form. A cloud seeding program has been in operation in the Truckee and Tahoe basins since the 1980s, and has produced an estimated 64,000 acre feet of additional supply on average per year (DRI 2010b). It is unknown whether additional gains are possible.	Evaluation using the Basin Study's tools would require assumptions on effectiveness that are too speculative. Therefore, this option was not evaluated further for the Basin Study.
	Wetland, meadow, and stream corridor restoration	Through decades and centuries of human use, the natural landscapes in the Truckee Basin have become heavily altered. For example, stream corridors have been incised or straightened, wetlands drained, and meadows developed or used for grazing. Restoration activities are intended to return some of these landscapes to a state in which more natural ecosystem functions exist. It is anticipated that this option would improve water quality, but the water supply benefits are unknown.	Evaluation using the Basin Study's tools would require assumptions on effectiveness that are too speculative. Therefore, this option was not evaluated further for the Basin Study.

Table 7-8. Supply Augmentation Options Considered for the Basin Study (contd.)

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Surface Storage	Additional Carson River storage	Seasonality Shifts on the Carson River lead to higher spills from Lahontan Reservoir, and increase the Newlands Project's reliance on the Truckee River, which can stress water supplies for different needs in the Truckee Basin. Additional storage on the Carson River could effectively increase supplies in the Truckee Basin by reducing spills at Lahontan Reservoir. Based on Carson River water rights and management, Lahontan Reservoir would be the most effective location for expanding storage, likely accomplished through a dam raise.	Evaluated as option "Raise Lahontan Dam."
	Increase Truckee River reservoir storage	Future reductions in reservoir efficiency stem from changes in climatic conditions, such as reduced water supplies, seasonality shifts, and combinations of both. Existing storage capacity cannot replace the lost ability of the historical climate to freeze winter precipitation as snow and thaw it during periods of the year when demands are higher. Increasing the physical ability to store winter precipitation could mitigate vulnerabilities related to the seasonality shifts caused by climate change. Storage could be increased by raising an existing dam or constructing a new dam and reservoir. New storage in the Truckee Basin would need to be considered in context of existing water rights and the intended beneficiary and uses. However, this could potentially result in less water flowing to Pyramid Lake.	Evaluated as option "Additional Truckee River Basin Storage."

Truckee Canal Rehabilitation

Future climate changes that result in decreased precipitation would reduce the quantity of water supply available for the Newlands Project from both Carson and Truckee rivers. Seasonality shifts would also decrease the duration of time available for diverting Truckee River supplies that are available to the Newlands Project. Restoring the capacity of the Truckee Canal consistent with its most recent conveyance capacities before the 2008 breach and resulting safety restrictions could mitigate vulnerabilities related to climate change by allowing adequate diversion of water supply when it was available.

This option considers implementation of the 600 cfs alternative developed as part of the Newlands Project Planning Study (Reclamation 2013). This option includes the installation of high-density polyethylene cutoff walls along the Fernley portion of the Truckee Canal, in addition to other actions that resolve safety issues for the urbanized portion of the canal and would allow the canal capacity to be restored to 600 cfs. Unlike other options that consider installation of a geomembrane and concrete liner, this option is not anticipated to alter seepage losses from the Truckee Canal. Further information on the technical formulation in the TROA-light Planning Model is provided in “Appendix F – Technical Assumptions for Option Evaluation.”

Effects on Basin-Wide Operations The Newlands Project currently receives, on a long-term average basis, about 75 percent of its water supplies from the Carson River and 25 percent from Truckee River diversion at Derby Dam. Both supplies are stored and managed at Lahontan Reservoir. Under drier Without-Action scenarios, Carson River inflows to Lahontan Dam would decrease, increasing the Newlands Project’s reliance on Truckee River supplies (Table 7-9). This would decrease the percentage of Truckee River streamflow that passed through Derby Dam to Pyramid Lake (Table 7-9).

Compared to the Without-Action scenarios, rehabilitating the Truckee Canal would allow the Newlands Project to more fully use their Truckee River apportionment when flow is available (Table 7-12). Increasing the canal capacity to 600 cfs would decrease the time when canal capacity would constrain meeting Lahontan Reservoir June storage targets. Increased Truckee Canal diversions would decrease the percentage of river flow to Pyramid Lake (Table 7-10). Decreased Pyramid Lake inflows would lower end-of-century lake elevations for all scenarios, although only drier scenario elevations would continue to be below historic levels (Figure 7-7).

Table 7-9. Newlands Project Use of Carson and Truckee River Inflows under Truckee Canal Rehabilitation Option and Without-Action Scenarios

	Historical	Reference	Central Tendency	Warmer-Drier	Hotter-Drier	Hotter-Wetter	Warmer-Wetter
Truckee Canal Rehabilitation Option Scenarios							
Supplies from Carson River	74.5%	71.1%	64.5%	61.8%	56.9%	69.3%	74.5%
Supplies from Truckee River	25.5%	28.9%	35.5%	38.2%	43.1%	30.7%	25.5%
Without-Action Scenarios							
Supplies from Carson River	76.0%	73.1%	67.3%	65.1%	61.3%	72.1%	76.5%
Supplies from Truckee River	24.0%	26.9%	32.7%	34.9%	38.7%	27.9%	23.5%

Table 7-10. Division of Truckee River Flows at Derby Dam under Truckee Canal Rehabilitation Option and Without-Action Scenarios

	Historical	Reference	Central Tendency	Warmer-Drier	Hotter-Drier	Hotter-Wetter	Warmer-Wetter
Truckee Canal Rehabilitation Option Scenarios							
Flow diverted to Truckee Canal	19.0%	21.1%	25.0%	32.9%	37.2%	17.9%	14.5%
Flow to Pyramid Lake	81.0%	78.9%	75.0%	67.1%	62.8%	82.1%	85.5%
Without-Action Scenarios							
Flow diverted to Truckee Canal	17.6%	19.3%	22.2%	28.6%	31.1%	15.8%	13.1%
Flow to Pyramid Lake	82.4%	80.7%	77.8%	71.4%	68.9%	84.2%	86.9%

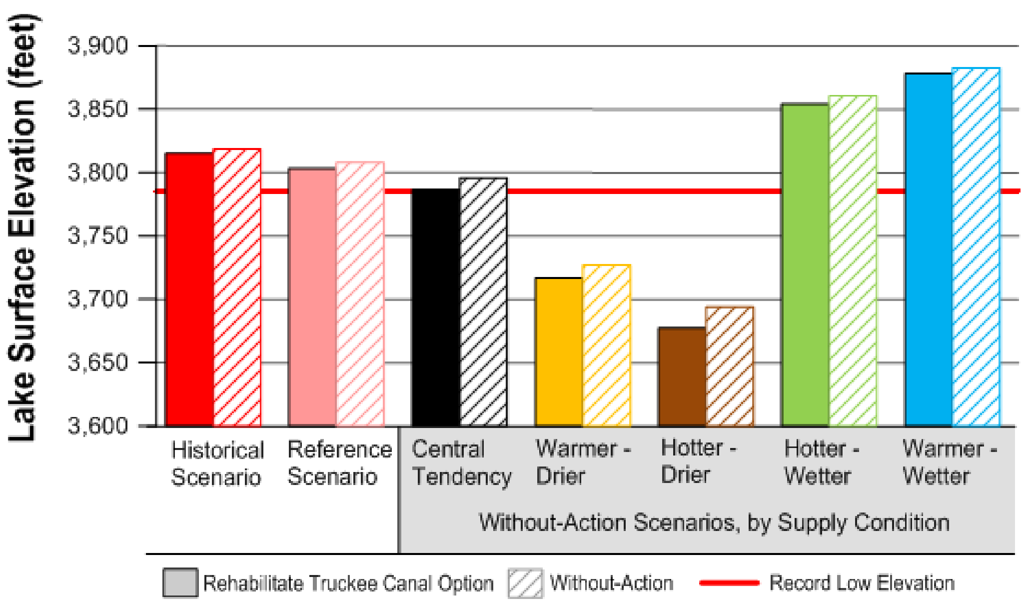


Figure 7-7. End-of-Century Average Pyramid Lake Elevations Under the Rehabilitate Truckee Canal Option

Mitigation of Shortages Compared to the Without-Action scenarios, restoring the Truckee Canal's capacity would reduce the frequency of annual Newlands Project crop demand shortages between 4 and 12 percent. Crop demand shortages, however, would remain well above shortages seen under the Reference scenario. Increasing temperatures would continue to increase crop evapotranspiration demand beyond available supplies, especially in drier scenarios. Maximum annual crop demand shortages would decrease up to 12 percent in wetter scenarios, but would remain unchanged in drier scenarios. Supplies in both the Carson and Truckee river basins would be minimal in drought years in drier scenarios, and would not be augmented by a restored canal capacity.

Spills from Lahontan Reservoir would increase and would benefit Lahontan Valley wetlands (up to a 6 percent increase in total supply). The longest duration of Lahontan Valley wetlands water supply shortages would also decrease between 1 and 3 years. Additional supplies from an expanded Truckee Canal capacity would also increase hydropower generation at Newlands Project facilities between 4 and 14 percent.

A restored Truckee Canal capacity may not necessarily affect groundwater recharge and supplies for the City of Fernley, depending on the specific design selected (Reclamation 2013).

Implementation Considerations Implementation is currently underway for a similar action to repair the portion of the Truckee Canal determined to be unsafe following the 2008 canal breach. Reclamation is undertaking a NEPA process to document potential environmental effects, such as impacts to fisheries impacts at Pyramid Lake or groundwater for Fernley. This process could include coordination with TCID to determine project details and design, and also with other parties such as the Pyramid Lake Paiute Tribe and the City of Fernley to discuss potential impacts in the study area.

Additional Truckee River Basin Storage

Shortfalls in the Without-Action scenarios are exacerbated by the inability of reservoirs to operate as they have historically due to changes in climatic conditions, such as reduced water supplies, seasonality shifts, and combinations of both. These challenges cannot be resolved entirely with current infrastructure. As demonstrated in results for the Adapt Reservoir Flood Management Operations option, even the complete removal of operational requirements that interfere with reservoir refill would still result in substantial volumes of spill: existing storage capacity cannot replace the lost ability of the historical climate to freeze winter precipitation as snow and thaw it during periods of the year when demands are higher. Increasing the physical ability to store winter precipitation could mitigate vulnerabilities related to the seasonality shifts caused by climate change.

New storage could take a variety of forms, including groundwater infiltration, aquifer storage and recovery, and new or modified surface reservoirs. Storage could also be imagined to occur in conjunction with out-of-basin transfers, where surplus supplies delivered for temporary storage outside of the Truckee Basin. Perhaps more importantly, the development of new storage in the Truckee Basin would need to be evaluated in context of water rights and the intended beneficiary. Such considerations would require extensive coordination and careful evaluation to determine the feasibility of implementing a project.

For the purpose of the Basin Study, the ability of new storage to resolve changes in imbalances was evaluated without specific attribution of the location or type of storage, and without attribution to a specific beneficiary. This option evaluates the ability of new storage to reduce collective Basin shortages to Reference scenario-levels by capturing and storing spills from existing Truckee River reservoirs.

For the Basin Study, Basin-wide imbalances were evaluated by summing water supply shortfalls each month for all M&I, agricultural, and wetland demands downstream from Lake Tahoe. A similar monthly time series of spills was taken from Donner, Prosser Creek, Martis Creek, and Boca reservoirs (Independence and Stampede reservoir spills are recaptured by Boca Reservoir and were not included to avoid double counting). Both imbalances and spills were taken from Adapt Reservoir Flood Management Operations option scenarios. Use of the results from the Adapt Reservoir Flood Management Operations scenarios as the starting point for this option provides gains in reservoir refill from that option.

Spills from the Truckee River reservoirs were made available to store in the new facility, and the size of the facility tested varied between 0 and 800,000 acre-feet to allow for inspection of different storage options. To account for the potential losses of any reservoir option, the storage and evaporation characteristics of Prosser Creek Reservoir were applied to new storage.

Effects on Basin-Wide Operations   Previous analysis of Without-Action scenarios and other options have revealed that existing reservoirs are not optimized to manage a future hydrology affected by climate change. Existing reservoir capacity is not appropriately sized for wetter conditions, where less than 50 percent of the inflow is controlled and most of the gains in inflow (in comparison to the Reference) are reflected as increases in spills, nor is it appropriately sized for drier conditions where, even though spills decrease because of less inflow, it is even more vital to capture and deliver that limited supply. By increasing reservoir storage capacity in the Truckee River Basin by 90,000 acre-feet, more of the inflow would be controlled (over 50 percent), representing up to a 16,000 acre-foot increase in controlled releases above the Without-Action scenarios (Figure 7-8). Regulated reservoir releases in drier conditions would increase up to 24,000 acre-feet.

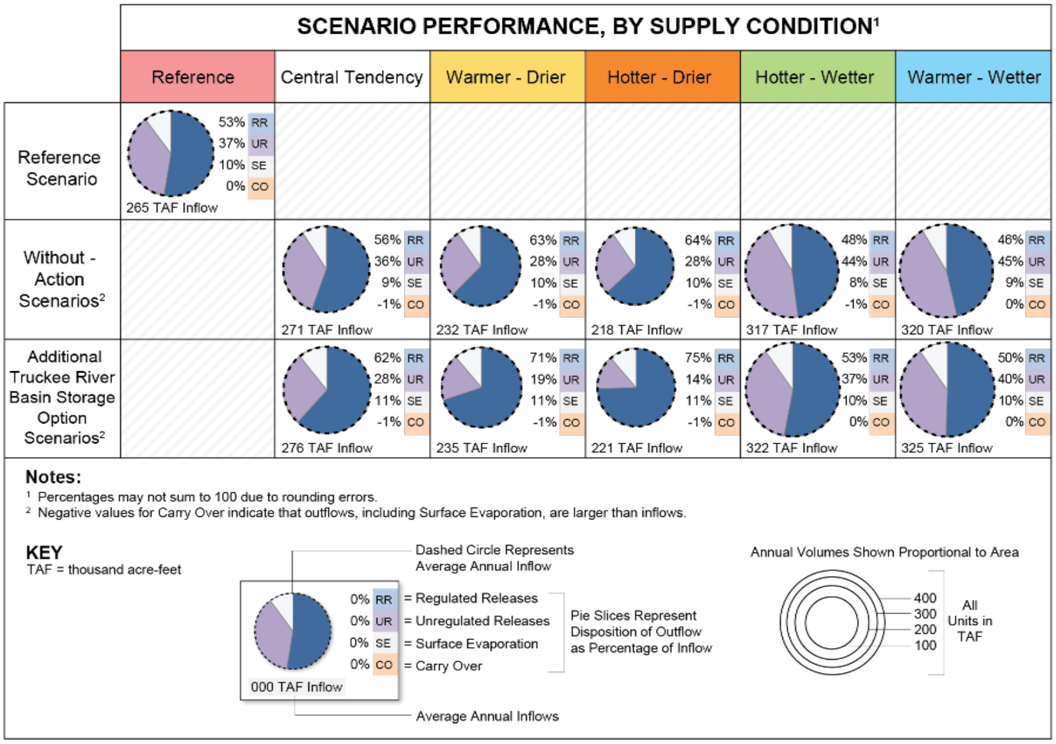


Figure 7-8. General Operations in Truckee River Basin Reservoirs Downstream from Lake Tahoe Under Additional Truckee River Basin Storage Option

Mitigation of Shortages When flood management constraints are removed from Truckee Basin reservoirs the average annual M&I, agriculture, and wetland water supply shortages for all water user communities would be about 10,000 acre-feet under the Reference scenario. An additional 90,000 acre-feet of storage capacity (just more than double Boca Reservoir's capacity) would be needed under the Central Tendency scenario to reach a shortage level similar to the Reference scenario (Figure 7-9). About 800,000 acre-feet of new storage (equal to building about four more Stampede Reservoirs) would be needed to decrease average annual shortages to below 10,000 for most future climates. The smallest average annual shortage achievable for the Hotter-Drier scenario, however, would only be about 13,000 acre-feet. No matter the additional storage size, this future condition would not have sufficient supply to meet demands at a similar level to the Reference scenario.

Adding storage capacity would decrease most shortages in the Basin, but would impact water supply reliability for Pyramid Lake. Because the Basin is a closed system, Pyramid Lake and its fishery benefit from any unused flow or spills. Any reductions in spills via new storage would decrease Pyramid Lake inflow. Pyramid Lake fishes could benefit, however, if a portion of the new storage was dedicated for fish water. Additional fish water in storage could mitigate fish flow regime vulnerabilities, especially under drier future conditions.

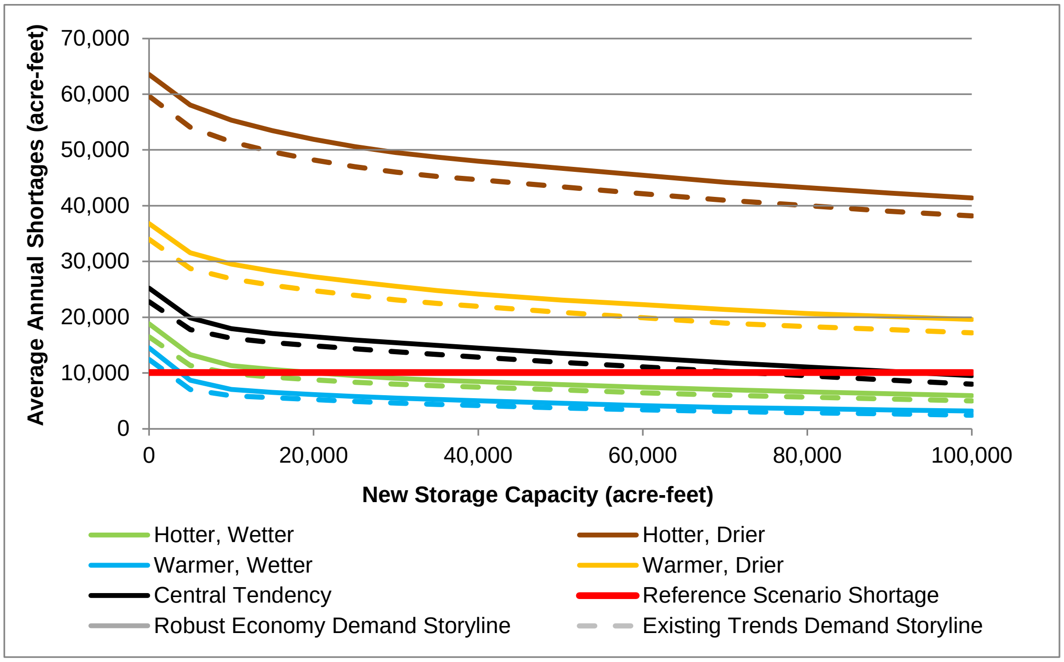


Figure 7-9. Total Basin Water Supply Shortages Under Additional Truckee River Basin Storage Option

Implementation Considerations To the extent uncontrolled supplies (spills) are captured through additional storage, flows to Pyramid Lake could decrease. Capture of the spills through additional storage would require new appropriations of Truckee River water rights. As the Truckee River is fully appropriated and most of the spilled water flows to Pyramid Lake, implementation of this option would require full participation of the Pyramid Lake Paiute Tribe.

Additionally, implementation of this option would require consideration, study, and coordination with other parties involved in Basin-wide water operations to determine its effect on flood management. This possibility would need to be assessed in greater detail by the USACE, TRFMA, and other flood management entities to determine how new storage might be integrated into Basin flood management operations and to ensure that water supply benefits do not come at the cost of reduced flood protection for Basin communities. Reclamation's assessment of potential changes in future flood frequency in the Truckee Basin is included in "Appendix E – Truckee River Flood Frequency and Magnitude Analysis."

Forest Management

Forest thinning and management practices have been proposed for the Truckee Basin for a variety of potential benefits, including as a method for augmenting water supplies. A forest management option was broadly supported by many TAG workshop participants (see "Appendix A – Engagement Record"), some of whom are currently conducting studies as to the benefits of certain forest management practices for increasing runoff throughout the Basin, and groundwater infiltration in the Martis Valley.

Historical fire suppression and logging activities in the Sierra Nevada have resulted in large areas of forest that are overly dense with small trees and brush. These dense forests alter stream flow patterns in comparison to the pristine forest conditions: the dense forest cover intercepts a greater portion of snow, reducing snow storage on the ground and the resulting runoff; and the dense forests intercept, evaporate, and transpire higher portions of surface and groundwater. Management of the forest through selective thinning activities that reduce forest coverage and underbrush could increase snow accumulation in open lands, reduce evapotranspiration from trees and underbrush, and thereby result in higher total annual runoff for the watershed. Forest management also provides additional benefits of fire prevention and pest management.

The ability of forest thinning to improve supplies hinges on the extent and location of forest identified for treatment relative to Basin reservoirs, and the timing and volume of yields that result from treatment. Several uncertainties exist in the likely extent of forest that could be treated and in the resulting potential for increasing surface water supplies; the Basin Study takes an “upper bound” approach in its assumptions for both. In pursuing the upper bound of possible benefits, this Basin Study presumes that refinements will be pursued further if the upper bound estimates show promise, and acknowledges that the benefits derived from this option may be less than assessed herein. Although this option would likely increase both surface water and groundwater supplies, the research available for evaluating this option was limited to surface supplies. As a result, groundwater is not specifically addressed in this analysis.

This option was developed in coordination with The Nature Conservancy in parallel with ongoing pilot studies to quantify the broad range of benefits that could be derived from forest management activities in the Lake Tahoe Basin (see “Appendix F – Technical Assumptions for Options Evaluation”). The extent of forest considered for treatment was limited only to accessible National Forest lands in California. The location of accessible land was determined through spatial analysis. All forest land cover was considered appropriate for treatment. Forest cover was considered accessible and safe for treatment, so long as it existed within 1,000 feet of existing dirt or paved roads and had hill slopes of less than 40 degrees. Roadless and Wilderness areas were excluded from consideration. Table 7-11 and Figure 7-10 present the resulting lands considered available for management, by sub-basin.

Table 7-11. Estimated Forest Land Available for Treatment

Sub-watershed Name	Acres of Treatable Forest
Stampede Basin	44,760
Tahoe Basin	40,154
Boca Basin	19,427
Below Tahoe	14,746
Prosser Basin	12,498
Remaining Sidewater	4,030
Martis Basin	1,269
Donner Basin	955
Below Donner	732
Independence Basin	88
TOTAL	**138,659**

The extent of forest treatment identified in Table 7-11 is nearly three times the area planned for thinning treatment in the next five years across the two national forests: Lake Tahoe Basin Management Unit (32,206 acres) and Tahoe National Forest (15,641 acres). Again, this extent of land is an upper bound for the treatment area and would need to be refined with input from the U.S. Forest Service (PSW Research Station and USFS management). North et al. (2012) estimated the annual need across the Sierra Nevada, based on Fire Return Interval, is about 490,000 acres per year of all management (thinning and burning). Areas of high conservation value, such as riparian areas (Van de Water and North 2010, 2011) and California spotted owl protected activity centers (North et al. 2010) have high potential for high severity fire due to fuel loads contributed to by multiple canopy layers and surface fuels (Collins et al. 2010). These areas have been avoided from a management perspective, and are being damaged by high severity fires (North et al. 2012), and should therefore be included in management plans with a more selective and careful approach.

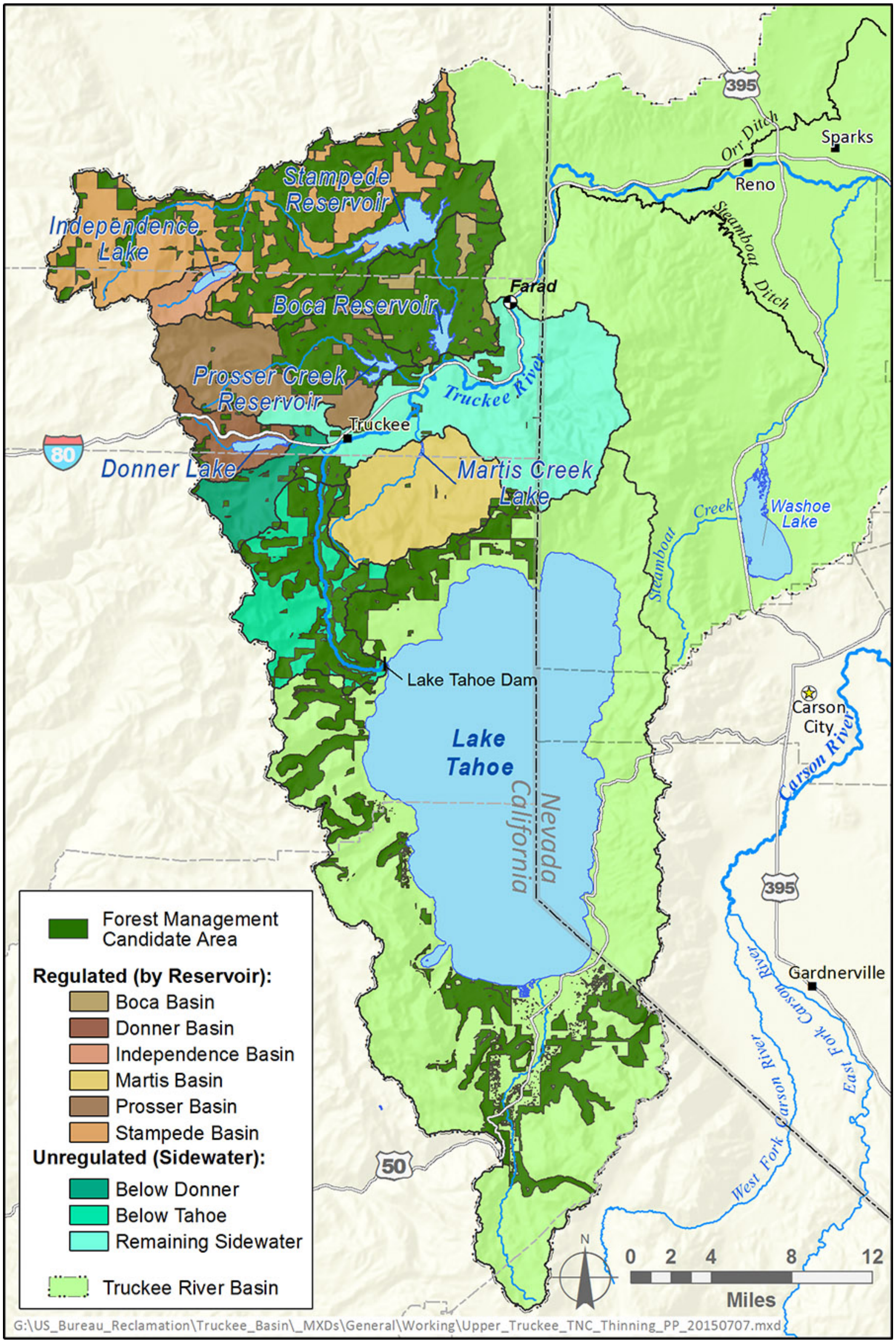


Figure 7-10. Spatial Distribution of Forest Considered Available for Treatment under the Forest Management Option

As several unknowns exist about the potential for forest management to generate additional water supply, the range of potential yield increases could vary greatly. The approach taken for the Basin Study assumed that one third of the forest area would be thinned to reduce the risk of mega-fires and meet the recent instances of ecological forest thinning. The resulting estimates of annual water yield would be 0.15 acre-feet per acre, or approximately 21,000 acre-feet total (Table 7-12). For context, the extent of forest thinning being planned for the next five years in the Truckee River Basin will treat one-third the estimate for the hypothetical increased treatment area, and may be expected to yield one-third of the average annual benefits anticipated by this option.

The methods used to estimate yield are based upon the relationships documented by Bales, et al. (2011). Further information on the technical approach is provided in "Appendix F – Technical Assumptions for Options Evaluation."

Table 7-12. Estimated Increase in Yield from Forest Management Option by Sub-Watershed

Sub-watershed Name	Average Annual Increase in Yield (acre-feet)
Stampede Basin	6,714
Tahoe Basin	6,023
Boca Basin	2,914
Below Tahoe	2,212
Prosser Basin	1,875
Remaining Sidewater	604
Martis Basin	190
Donner Basin	143
Below Donner	110
Independence Basin	13
TOTAL	**20,799**

Variability between years could not be addressed through existing literature, and the estimated average annual yield was applied to all years. Total annual increase in yield was distributed throughout the year as inflows to appropriate locations, proportional to average monthly unimpaired inflows for the Truckee Basin (Table 7-13). Daily inflows were equal within like months.

Table 7-13. Monthly Distribution of Yield from Forest Management Option

Month	Proportion of Annual Inflow
January	5%
February	5%
March	10%
April	19%
May	26%
June	16%
July	5%
August	2%
September	2%
October	2%
November	3%
December	4%
TOTAL	**100%**

The Forest Management option would not likely address vulnerabilities associated with seasonality shifts in inflow or other temperature-related vulnerabilities. Peak runoff periods with increased inflows resulting from focused forest management practices would shift in timing compared to the Reference scenario, similar to the Without-Action scenarios. Furthermore, the potential for longer growing seasons or increased evapotranspiration from forests (similar to increases in the irrigated agricultural growing season) are not considered in this option or accounted for in the Basin Study.

Effects on Basin-Wide Operations As noted in “Chapter 6 – Risk and Reliability Assessment,” all projected future climates would challenge the ability of Truckee Basin reservoirs to operate as efficiently or yield similar water supply as under the Reference scenario. These challenges would persist under the Forest Management option because this option does not specifically address reservoir operations.

Compared to the Without-Action scenarios, under this option, reservoir inflow could only increase about five percent and would not substantially resolve or exacerbate reservoir vulnerabilities brought on by climate change (Figure 7-11). Drier scenarios would continue to include larger vacancies in reservoir storage able to absorb a greater proportion of high inflow events when they occur. In drier scenarios, spills would not increase and the 21,000 acre-foot annual increase in inflows under this option would be available for water supply deliveries. Wetter conditions would continue to include higher spills because inflows exceed reservoir capacity (as defined by flood management rules). About half of the additional 21,000 acre-feet in annual inflow would spill.

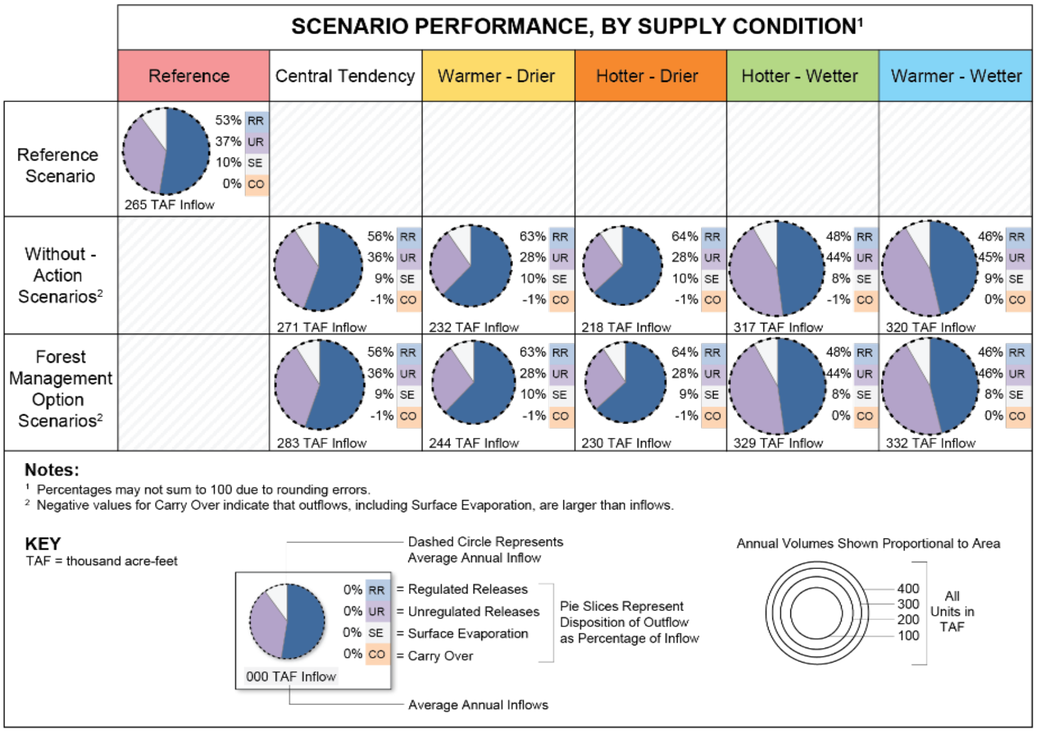


Figure 7-11. General Operations in Truckee River Basin Reservoirs Downstream from Lake Tahoe under Forest Management Option

Introducing more inflow into the Truckee River through forest management would increase Pyramid Lake elevations because all unused inflow and return flows accumulate into the terminal lake. Average end-of-century Pyramid Lake surface water elevations would increase by up to eight feet for all Option scenarios compared to Without-Action scenarios (Figure 7-12). Lake elevations in drier scenarios, however, would continue to be below historical records and would hinder fish passage and channel stability through the delta.

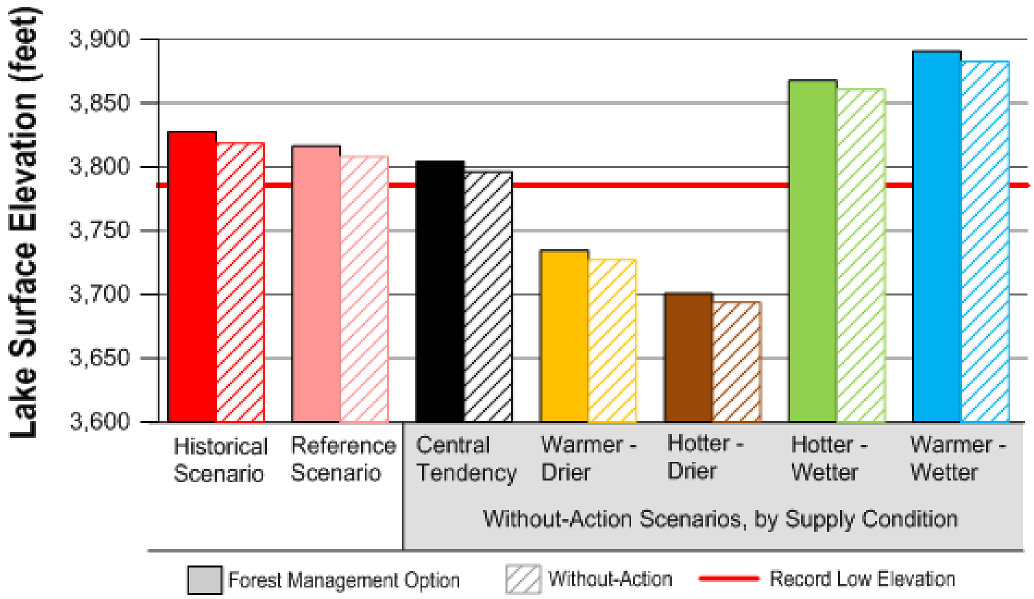


Figure 7-12. End-of-Century Average Pyramid Lake Elevations under Forest Management Option

Mitigation of Shortages The ability of forest management to mitigate shortages rests on its potential to increase runoff during times when Basin supplies and demands would otherwise remain imbalanced. These conditions, obviously, occur most during years with low precipitation.

For lack of guidance on how to distribute average annual improvements in runoff among year types, this Basin Study portrayed the outcome of this option as an average annual increase in each year, regardless of precipitation conditions. Although precise information on the performance of this type of activity across the range of precipitation conditions was not available for the Basin Study, it is anticipated that the benefit of these activities would diminish during years with low precipitation. As a result, the performance of this option toward mitigating shortages would be overstated if quantified. While the model results are available for inspection and further discussion and refinement, the analysis provided below has been limited to qualitative statements to reduce the potential for misuse.

In general, augmentation of Basin inflows through managing forests would decrease the frequency of annual Truckee Meadows M&I water supply shortages in drier scenarios. Higher inflows would increase annual water supply and the frequency of meeting Floriston rates on which Truckee Meadows M&I demand depends. The maximum annual Truckee Meadows M&I water supply shortage would decrease across all Option scenarios.

Increased inflows would also increase low flow conditions downstream from TMWRF, which would improve the ability to meet water quality standards compared to Without-Action scenarios. Drier scenarios would continue to have substantially lower low flow conditions than under the Reference scenario.

Adult passage and spawning flows for Pyramid Lake fish would improve slightly compared to Without-Action scenarios. The longest duration of years with poor spawning flows in drier scenarios, however, would not improve with additional flow under forest management practices because flow targets would still exceed available flow in those years. Although cui-ui are long lived, longer durations of poor spawning conditions in drier scenarios would adversely affect Pyramid Lake fish populations.

Increased inflow from forest management practices would improve Newlands Project water supply reliability in drier scenarios by decreasing the frequency of annual shortages. The number of years with shortages in wetter scenarios would not decrease because shortages under these wetter conditions occur in exceptional drought periods and would not be addressed by forest management practices.

Implementation Considerations This option would require vegetation maintenance across large areas of forested land, both initially and periodically thereafter, to maintain the water supply benefit. Such activities would likely need to be planned and managed in coordination with the range of public and private landowners in the Basin, including the USFS, as well as with agencies that have regulatory or land-use authority, including TRPA. This option also requires further study to ensure that the water supply benefits are substantial enough to warrant large-scale changes in forest management practices.

Raise Lahontan Dam

Seasonality shifts create several inefficiencies for the Newlands Project. Seasonality Shifts on the Carson River lead to higher spills from Lahontan Reservoir, and increase reliance on the Truckee River, which can stress water supplies in the Truckee Basin. The Raise Lahontan Dam option would effectively increase supplies in the Truckee Basin by reducing spills at Lahontan Reservoir, which thereby reduces the Newlands Project diversions from the Truckee River.

This option considered a 200,000 acre-foot expansion of Lahontan Reservoir. A larger Lahontan Reservoir would have a larger surface area that could promote additional losses to evaporation. Bathymetric relationships between storage and surface area were derived from digital elevation models and applied to the additional reservoir storage above the existing dam crest elevation.

Effects on Basin-Wide Operations The Newlands Project currently receives about 75 percent of its water supplies from the Carson River and 25 percent from Truckee River diversion at Derby Dam. Both supplies are stored and managed at Lahontan Reservoir. Under drier Without-Action scenarios, Carson River inflows to Lahontan Dam would decrease, increasing the Newlands Project’s reliance on Truckee River supplies (Table 7-14). This would also decrease the percentage of

Truckee River streamflow that passes through Derby Dam to Pyramid Lake (Table 7-15).

Increasing storage capacity would allow Lahontan Reservoir to reduce spills and deliver a greater portion of Carson River inflows to crop demand. Raising Lahontan Dam would be an especially effective action for managing supplies in a wetter climate, which would include higher Carson River inflows that would frequently spill under Without-Action scenarios. Increased storage capacity would not fully mitigate drier future climate scenarios, however, due to reductions in Carson River supply; and the Newlands Project would continue to rely more heavily on Truckee River supplies under drier scenarios, even with additional Carson River storage.

Although additional storage capacity in Lahontan Reservoir would increase the effectiveness of using Carson River water supplies, it would not increase diversions from the Truckee River, even with continued crop demand shortages. OCAP establishes end-of month storage targets in Lahontan Reservoir, and limits the volume of water that can be delivered from the Truckee River to the volumes necessary for meeting these storage targets. Increased capacity would reduce Carson River spills, thereby meeting OCAP targets more often with Carson River inflow and reducing Truckee River diversions to the Newlands Project. Pyramid Lake water surface elevations, especially in wetter scenarios, would benefit slightly from these reduced diversions (Figure 7-13).

Table 7-14. Newlands Project Use of Carson and Truckee River Inflows under Raise Lahontan Dam Option and Without-Action Scenarios

	Historical	**Reference**	**Central Tendency**	**Warmer -Drier**	**Hotter -Drier**	**Hotter-Wetter**	**Warmer-Wetter**
Raise Lahontan Dam Option Scenarios							
Supplies from Carson River	78.7%	75.2%	69.1%	66.0%	61.8%	75.1%	80.0%
Supplies from Truckee River	21.3%	24.8%	30.9%	34.0%	38.2%	24.9%	20.0%
Without-Action Scenarios							
Supplies from Carson River	76.0%	73.1%	67.3%	65.1%	61.3%	72.1%	76.5%
Supplies from Truckee River	24.0%	26.9%	32.7%	34.9%	38.7%	27.9%	23.5%

Table 7-15. Division of Truckee River Flows at Derby Dam under Raise Lahontan Dam Option and Without-Action Scenarios

	Historical	**Reference**	**Central Tendency**	**Warmer -Drier**	**Hotter-Drier**	**Hotter-Wetter**	**Warmer -Wetter**
Raise Lahontan Dam Option Scenarios							
Flow diverted to Truckee Canal	15.2%	17.5%	20.5%	27.5%	30.5%	13.6%	10.8%
Flow to Pyramid Lake	84.8%	82.5%	79.5%	72.5%	69.5%	86.4%	89.2%
Without-Action Scenarios							
Flow diverted to Truckee Canal	17.6%	19.3%	22.2%	28.6%	31.1%	15.8%	13.1%
Flow to Pyramid Lake	82.4%	80.7%	77.8%	71.4%	68.9%	84.2%	86.9%

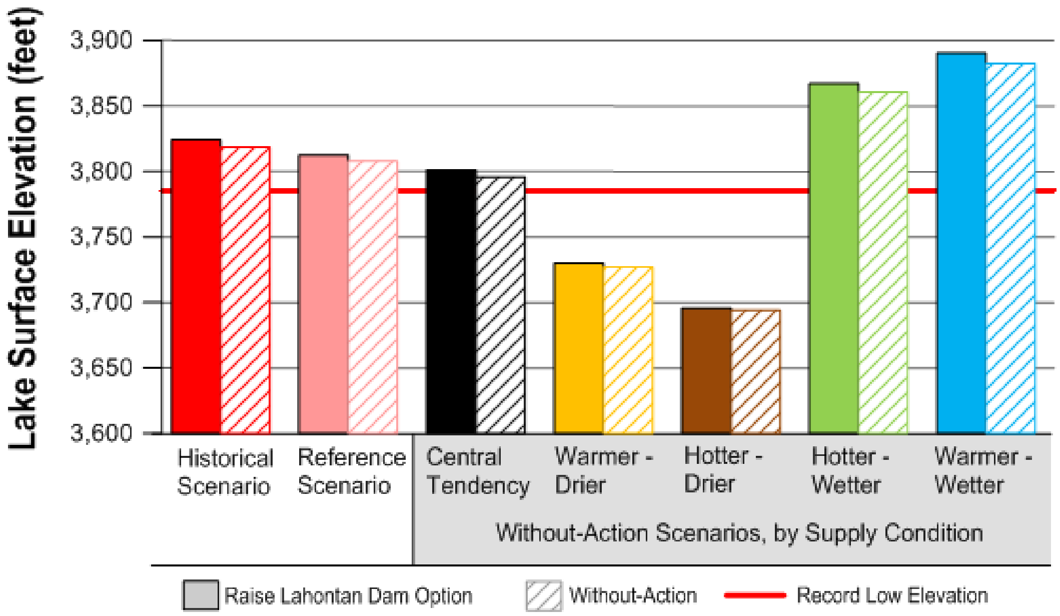


Figure 7-13. End-of-Century Average Pyramid Lake Elevations under the Raise Lahontan Dam Option

Mitigation of Shortages As described, additional storage capacity in Lahontan Reservoir would produce a number of changes to water supply deliveries in the Truckee and Carson river basins, but would not increase water supply reliability for Newlands Project crop demands overall. Because OCAP targets would be met more with Carson River water instead of Truckee River water there would be no net gain in water supply reliability for crops. Thus, additional storage space would not benefit Newlands Project agriculture demands unless OCAP storage targets – or the process for setting them – were modified.

Reducing Carson River spills at Lahontan Reservoir would increase efficiency in using this supply for crop demands, but would decrease the water supply reliability for Lahontan Valley wetlands that otherwise benefits from Lahontan Reservoir spills. Compared to the Without-Action scenarios, in wetter Option scenarios, where spills are more common, raising Lahontan Dam would reduce the Lahontan Valley wetlands' total water supply by up to 9 percent. Total Lahontan Valley wetland water supplies in these wetter scenarios, however, would still meet more than 95 percent of demand.

Because OCAP restricts additional Truckee River diversions if Lahontan Reservoir storage targets are being met with Carson River inflow, then water previously diverted to the Newlands Project at Derby Dam would flow to Pyramid Lake, benefiting fish adult passage and spawning flows. Compared to the Without-Action scenarios, wetter Option scenarios would see up to a 5 percent increase in these types of flows. Drier scenarios would not receive substantially more fish flow because lower Carson River inflows would fill increased Lahontan storage less often. In other words, OCAP targets would not be met more often by

Carson River water and Truckee River diversions remain about the same under drier Without-Action scenarios.

Implementation Considerations This option would shift a major source of supply for the Newlands Project from the Truckee River to the Carson River under certain conditions. Each river supports important habitat and ecosystems at its terminus; by reducing spills from Lahontan Reservoir, it also reduces supply to wetlands to the benefit of Pyramid Lake. Thus, study would likely be needed to determine effects on fisheries and water-dependent ecosystems at Pyramid Lake and Lahontan Valley wetlands. Entities involved in implementation would likely include TCID and USFWS.

Demand Management Strategy

A multitude of options exists for each water user in the Basin to undergo demand management. Some options attempt to address reliability by reducing or changing the timing of water demand for one or more types of use. Other options include structural actions, such as infrastructure improvements that would increase efficiency, and also nonstructural actions that require altering human behavior and practices.

The form of demand management that is possible in the Basin varies by the composition and needs of each water user community. Every community must determine the actions it can take to address demand under the driest scenarios if supply augmentation options are not possible; and, each community alone knows the degree to which it can achieve its goals under diminished supplies. The Basin Study focuses on options that resolve imbalances, without concentrating the imbalances on any one community.

Among all the options identified for the Basin Study, Demand Management options appear to represent the broadest array of actions, and would thus have the widest range of potential implementation considerations, including costs and cost-sharing, institutional coordination, and participation among Basin water users.

Table 7-16 includes descriptions of the Demand Management options, organized by grouping. Some of the options have previously been evaluated in other studies and reports, with a range of findings about performance and effectiveness. For each Demand Management option, Table 7-16 provides a brief summary, references any existing evaluation other studies, and notes whether the option was evaluated further in the Basin Study. Additional assessments of options chosen for further evaluation are provided in the sections that follow Table 7-16.

Table 7-16. Demand Management Options Considered for the Basin Study

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Agricultural Use	Convert to low water-use crops	Switching from alfalfa, the predominant crop in the study area, to a less water-intensive crop may produce high value crops and reduce overall water demand. Previous studies have found that farmers are unlikely to convert crops, even when offered financial assistance, because the region's agricultural economy is geared toward alfalfa production and alfalfa offers more certain returns annually than the alternatives (Reclamation 2013).	The Basin Study focuses on options with broad benefits and effects, and this option relies mainly on one water user community to address Basin-wide supply-demand imbalances. Therefore, this option was not evaluated further for the Basin Study, although it was previously considered in the Newlands Project Planning Study and found to have lower benefits than anticipated (Reclamation 2013).
	Reduce conveyance losses	Many agricultural canals and ditches in the study area are unlined and open to the air, which results in evaporation and seepage losses. Options to reduce conveyance losses include lining canals or replacing open ditches with pipes. Previous studies found these options to increase the Newlands Project's efficiency (Reclamation 1994, 2013).	The Basin Study focuses on options whose effectiveness may change in the future, and the effectiveness of this option is not anticipated to be sensitive to changes in climate and demand. Therefore, this option was not evaluated further for the Basin Study, although it was previously considered in the Newlands Project Planning Study and found to perform well for increasing reliability (Reclamation 2013).
	Transfer agricultural water rights to municipal and industrial uses	Communities in the study area (including Reno-Sparks and Fernley) purchase agricultural water rights to serve municipal needs. Transferring agricultural water rights to municipal and industrial uses may lower overall demand very slightly; in the Newlands Project, agricultural water rights acquired for such uses must be taken at a lower duty than if used for irrigation. However, the overall effect is not anticipated to have a significant effect on demand.	The Basin Study focuses on options with broad benefits and effects, and this option relies mainly on one water user community to address Basin-wide supply-demand imbalances. Therefore, this option was not evaluated further for the Basin Study. However, the Basin Study's scenarios include future demand storylines that account for anticipated transfers of water rights to municipal and industrial uses.

Table 7-16. Demand Management Options Considered for the Basin Study (contd.)

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Agricultural Use (contd.)	Water rights retirement	The Pyramid Lake Paiute Tribe and other entities have purchased Truckee River water rights and used them to augment instream flows. By purchasing and retiring agricultural water rights in the Truckee Basin, overall consumptive demand would decrease and additional water would flow to Pyramid Lake.	The Basin Study focuses on options with broad benefits and effects, and this option relies mainly on one water user community to address Basin-wide supply-demand imbalances. Therefore, this option was not evaluated further for the Basin Study, although it was previously considered in the Newlands Project Planning Study (Reclamation 2013).
	Water use efficiency improvements	Flood irrigation is usually the water application method of choice for alfalfa, the predominant crop grown in the study area. On-farm water use efficiency improvements include laser-levelling fields and transitioning from flood to drip or sprinkler irrigation to improve water application. By reducing the amount of water used to irrigate, consumptive demand may go down. Previous studies found that the majority of suitable fields in the study area are already laser-levelled, and that if appropriate for crop types, sprinkler technology would save up to one-half an acre-foot of water per acre of land (Reclamation 2013). Demand could decrease as a result of such actions, but this would not affect the overall volume of agricultural water rights that could be exercised in the Basin.	The Basin Study focuses on options with broad benefits and effects, and this option relies mainly on one water user community to address Basin-wide supply-demand imbalances. Therefore, this option was not evaluated further for the Basin Study, although it was previously considered in the Newlands Project Planning Study (Reclamation 2013).
Environmental Flows	Revise flow targets to correspond with peak flows under climate change	A set of fish flow regimes are used to help manage the fisheries at Pyramid Lake. Fishery managers select a flow regime to maintain into Pyramid Lake based on observed fishery activity and on projected hydrologic conditions (wetter or drier) for any given year. The flow regimes are patterned after historic natural hydrologic patterns of flow and timing in the lower Truckee River, which will likely differ under future climate change. By adapting fish flow regimes targets to be set on a more flexible schedule, a more appropriate fish flow regime can be implemented for a given year's hydrology.	Evaluated as option "Adapt Fish Flow Regimes."

Table 7-16. Demand Management Options Considered for the Basin Study (contd.)

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Municipal & Industrial Use	Increase outreach and education on conservation	Public awareness campaigns and education are important tools for helping communities understand how to use water efficiently in their homes and yards. Increased municipal water use efficiency would reduce overall demand in the basin. The link between public education and specific gains in demand reduction are unknown.	The Basin Study focuses on options with broad benefits and effects, and this option relies mainly on one water user community to address Basin-wide supply-demand imbalances. Also, evaluation using the Basin Study's tools would require assumptions on performance that are too speculative. Therefore, this option was not evaluated further for the Basin Study.
Municipal & Industrial Use (contd.)	Mandate efficiency improvements	Municipal and industrial water needs are some of the largest, and most inelastic, water demands in the basin. State or local governments could pass laws requiring that municipal water suppliers reduce their overall demand by a certain amount, or could ban the use of high-flow toilets and other appliances considered to be less water-efficient. Or, municipal water suppliers could implement such requirements for their customers, with fines for noncompliance. Increased municipal efficiency may reduce overall demand in the Basin and help municipal users cope with shortages. TMWA anticipates limited potential improvements in water supply availability to be gained from additional future efficiency improvements (TMWA 2013)	The Basin Study focuses on options with broad benefits and effects, and this option relies mainly on one water user community to address Basin-wide supply-demand imbalances. Therefore, this option was not evaluated further for the Basin Study.
	Outdoor use efficiency improvements	Municipal and industrial water needs are some of the largest, and most inelastic, water demands in the basin. Municipal water suppliers could offer incentives for customers to reduce their outdoor water use by, for instance, installing more efficient irrigation equipment, or by removing lawns and xeriscaping. Increased municipal efficiency may reduce overall demand in the Basin and help municipal users cope with shortages. TMWA anticipates limited potential improvements in water supply availability to be gained from additional future efficiency improvements (TMWA 2013)	The Basin Study focuses on options with broad benefits and effects, and this option relies mainly on one water user community to address Basin-wide supply-demand imbalances. Therefore, this option was not evaluated further for the Basin Study.

Table 7-16. Demand Management Options Considered for the Basin Study (contd.)

Grouping	Option	Anticipated Outcomes and Benefits	Consideration in the Basin Study
Water Quality	Water quality improvements for the lower Truckee River	Water quality in the lower Truckee River is related to a number of factors, such as flow, temperature, and discharge from TMWRF treatment plants. A TMDL has already been set for the lower Truckee River, and TMWA and others are actively working to meet water quality requirements and objectives. It is unknown how improvements in water quality would help manage Basin demands, and additional assessments would be required to determine whether current objectives meet the needs of aquatic ecosystems.	The Basin Study focuses on options with broad benefits and effects, and this option relies mainly on one water user community to address Basin-wide supply-demand imbalances. Also, evaluation using the Basin Study's tools would require assumptions on performance that are too speculative. Therefore, this option was not evaluated further for the Basin Study.

Key:
TMDL = total maximum daily load
TMWA = Truckee Meadows Water Authority
TMWRF = Truckee Meadows Water Reclamation Facility

Adapt Fish Flow Regimes

Similar to flood management operations, differences exist between the manner in which flow regimes for fisheries at Pyramid Lake are implemented in real-time and the manner in which they are simulated in the TROA-light Planning Model. In real-time, flows are managed dynamically, in consideration of storages in Stampede Reservoir, and largely in response to observed fishery activity at Pyramid Lake. In simulation, flow targets are selected and applied based upon forecasted inflows for April through July, and storage conditions in Stampede Reservoir.

The manner in which the fish flow regimes are applied in the TROA-light Planning Model reveals a number of challenges in carrying the current operating guidelines into the future as written, as described in "Chapter 6 – Risk and Reliability Assessment." The fish flow regimes are patterned after historical natural hydrologic patterns (i.e. stream flow patterns absent reservoirs). Because of this basis in historical climate, with peak flows being tied to May, any seasonality shifts in future hydrology upset the selection of flow regime levels and the ability to maintain them through the year. Specifically, target selections that are based on March through July runoff forecasts will be incorrect. Further, the earlier end of peak runoff relies heavily on storage in Stampede Reservoir to maintain historical flow patterns through the summer.

The divergence of flow regimes from the timing of future hydrology may also indicate a divergence from the timing of ecosystems needs. Changes in climate could promote shifts in the timing of fishery life cycles for species at Pyramid Lake. As peak flows occur earlier, temperature and turbidity signals may occur sooner and encourage earlier migration and spawning for cui-ui and Lahontan cutthroat trout. If this occurs, attempts to preserve peak flows in May with a slow recession through summer may be out of sync with ecosystem needs and be placing an unnecessary burden on storage in Stampede Reservoir.

As evaluated, this option adjusts flow targets in two ways. First, the selection of the flow regime is adjusted to account for a migration in the month of peak flows. The five-month window of inflows centered on May was moved to earlier in the year, corresponding to the actual peak hydrology of each year. Second, the flow regimes were also shifted such that the peak month could occur as early as February.

This option presumes that biological needs are tied to the peak flow, alone. While this option improves the maintenance of flow targets, the effectiveness in meeting the needs of fisheries in the future cannot be guaranteed. Further study into the relationship between future conditions, temperatures and water quality in the river, and other fisheries needs would improve the understanding of whether this option will be useful for aquatic habitat.

As with flood operations at Truckee River reservoirs, actual operations may adapt to these changes in climate in due course, through constant responses to observations in fish behavior and ecosystem needs. Nevertheless, the simulation of changes in the use of water supplies for ecosystem purposes demonstrates important potential changes that will be helpful to anticipate for water management in the Basin.

Effects on Basin-Wide Operations By adapting fish flow regime targets to be set on a more flexible schedule, a more appropriate fish flow regime can be implemented for a given year's hydrology. For example, wetter conditions would have higher peak inflows in earlier months, and flexible targets would be set to match those flows. This can be seen in Figure 7-14, where wetter scenarios would meet more of the "wetter" (i.e. lower number) flow regimes than the Reference scenario.

Adapting fish flow regime targets would also lessen the reliance on storage at Stampede Reservoir to meet late spring and early summer targets. Without climate change, under the Reference scenario, these targets would typically be met with the natural runoff period. With climate change and an earlier snowmelt, rigid peak flow targets in the late spring would require drawing water in storage to meet those targets, thereby reducing fish water storage and overall reliability of that supply. Matching targets to flows would save fish water storage to meet targets during times of year when it is needed, and would increase the frequency of meeting targets as compared to Without-Action scenarios (Figure 7-14).

This option would only address seasonality shifts and their effects on meeting fish flow regime targets. There would be no increases or decreases in total water supply available to meet these targets – just a change in timing of the supply's use by the fisheries. Under this option, the total volume of water reaching Pyramid Lake would not substantially change compared to the Without-Action scenarios, nor would Pyramid Lake end-of-century elevations change significantly (Figure 7-15).

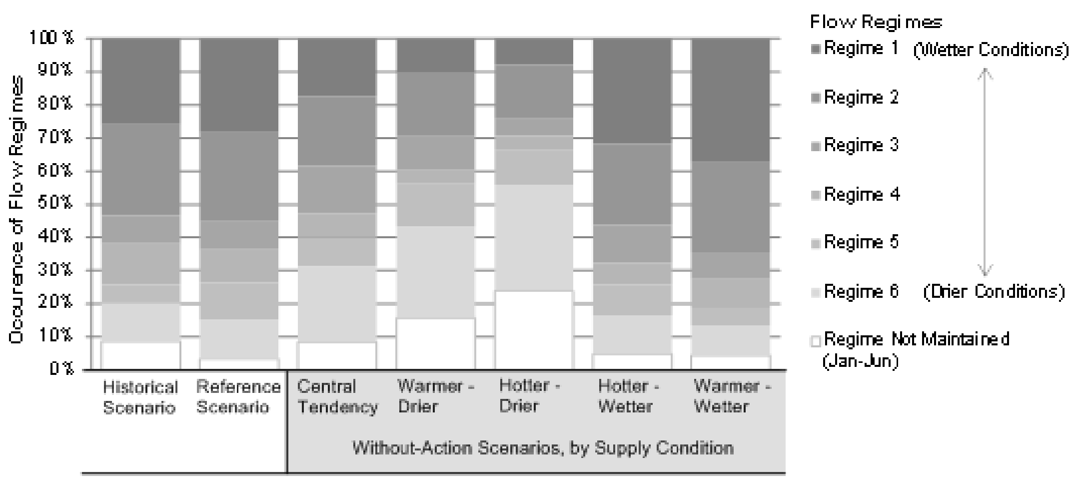


Figure 7-14. Achievement of Pyramid Lake Fishes Flow Regime Targets Under Adapt Fish Flow Regimes Option

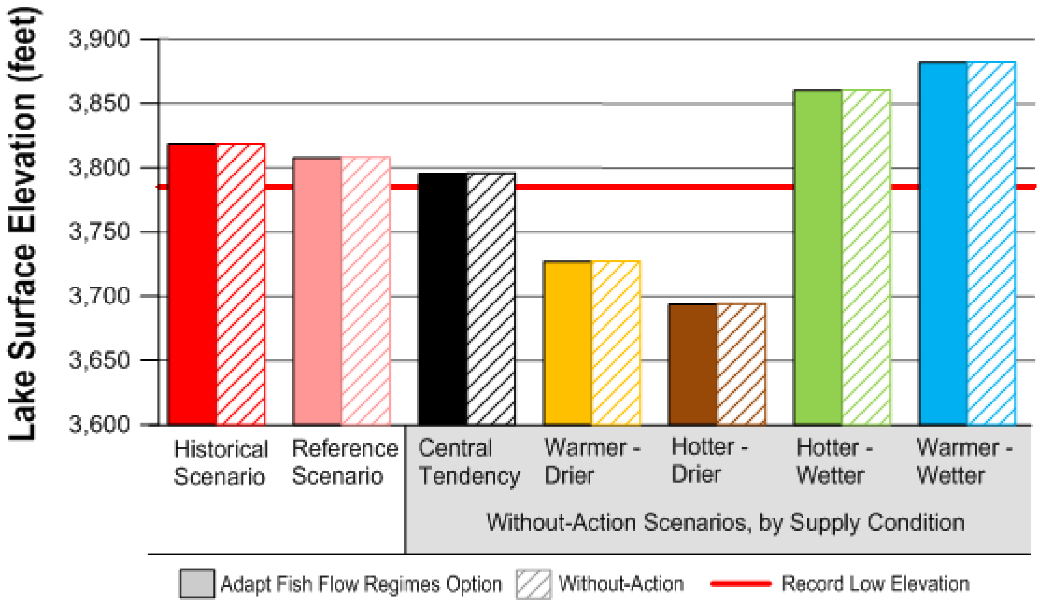


Figure 7-15. End-of-Century Average Pyramid Lake Elevations Under Adapt Fish Flow Regimes Option

Mitigation of Shortages Pyramid Lake adult passage and spawning flows would improve for all climates compared to Without-Action scenarios. Adult passage flows would increase between 1 and 10 percent, whereas spawning flows would increase between 10 and 71 percent (with the highest improvement for Hotter-Drier scenario). Spawning flows improve substantially because these flows are dependent on meeting flows for the peak month and the month prior. By aligning the flow regime targets with the climate change-shifted hydrology, peak flow regime targets would more easily be met with the river's hydrology and fish water storage could be used more judiciously.

The longest duration of years with poor spawning flows in drier scenarios, however, would not improve with adapted fish flow regime targets: available flow still would not achieve flow targets in exacerbated drought conditions. Although cui-ui are long lived, longer durations of poor spawning conditions in drier scenarios would adversely affect Pyramid Lake fish populations.

Implementation Considerations Implementation of this option would likely involve the range of agencies who previously developed the six-flow regime for the Truckee River (TRIT 2003). This group includes USFWS, California Department of Fish and Wildlife, Pyramid Lake Paiute Tribe, Reclamation, the Bureau of Indian Affairs, fisheries interests, USGS, and potentially others.

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 Basin water supply-demand imbalances.

This 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 Truckee Basin Study.

This chapter summarizes some of the key findings from the Basin Study's options evaluations and recommends activities that would improve or apply the information developed for the Basin Study. Suggestions for possible next steps stemming from the results of this Basin Study have been organized under the following themes:

1. Actions and activities that would promote or improve the incorporation of future risks identified by the Basin Study into existing planning processes for individual communities, and for the Basin as a whole.

2. Pursuit of risk mitigation or adaptation options that correspond with the intentions developed through the three identified Basin Study adaptation strategies (supply augmentation, demand management, and institutional changes).

3. Improvements or updates to scenario components with the intention of refining the understanding of key vulnerabilities or otherwise reducing the uncertainties identified for future supplies or demands.

Key Findings from the Options Evaluations

The Basin Study identified a number of different options recommended by water users and other stakeholders for addressing future vulnerabilities and risks to reliability. Some of these options were evaluated in greater detail by the Basin Study, as described in “Chapter 7 – Responses to Risks.” 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 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 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 Basin interests to resolve one or more potential issues related to flood management, fisheries, water rights, and other water resources concerns. Multiple options, such as Forest Management and Additional Truckee River Basin Storage, would also require substantial additional study to resolve uncertainties about performance and project specifics.

Table 8-1 presents key findings from the detailed options evaluations and analyses included in “Chapter 7 – Responses to Risks.”

Table 8-1. 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 8-1. 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 8-1. 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

Incorporation of Future Risks into Existing Water User Plans

This Report provides the first comprehensive assessment on how climate change could influence water supply reliability in the Truckee Basin. Because of its relatively small geographic scale, the Truckee Basin allows for consideration of a high level of detail regarding how changes in future conditions may affect individual water users. Consequently, directly relevant information about the potential risks of climate change and the effectiveness of various strategies for responding to the risks has become available to Basin water users for the first time. A central challenge at the completion of this Basin Study is for water users, local communities, and other agencies to determine how they can best use this new information.

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.

Regional Planning Forum

This Basin Study is a first step toward developing a common Basin-wide understanding of future risks. Due to the small and interconnected nature of the Truckee Basin, plans and responses to climate change may have implications which would benefit from a common Basin-wide understanding of such risks, transparency in the vision held 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 helpful in achieving these by providing:

- Common processes for the interpretation of future risks
- A transparent forum for developing a common understanding of:
  - Current and future risks
  - Options for responding to risks
  - Tradeoffs among communities for each option
  - Refinement of action plans that meet regional needs
- A mechanism for sharing costs of future investigations

Considerable investments have been made to develop a regional understanding about the implications of water use in the 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

Comparisons among Basin Study scenarios provide the basis for understanding how future conditions may affect water supply reliability for different users and Basin-wide. Modeling results alone, however, require interpretation to understand whether future conditions are definitively good or bad, especially for a given community. The Basin Study relied on a combination of previous studies and reports and stakeholder input to identify which model results are most important to assess for each water user community. The conditions that were identified as important have been included in Basin Study analyses as indicators (“Chapter 6 – Risk and Reliability Assessment”).

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. Using the earlier example, it may be possible that even the lowest-rated scenarios (the scenario with the most frequent shortages) 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 needs. Political and administrative considerations also provide important context for interpreting future conditions. For example, the financial conditions of a community may relate to the community’s ability to absorb changes in the costs of water supplies, and to the willingness of a community to accept changes in the quality or level of service.

Some indicators for select communities may ultimately require additional information or models to assess, which relates to another suggestion to consider development of modeling tools and information.

Pursuit of Actions to Address Future Imbalances

The Basin Study assessed several options for addressing the range of future supply-demand imbalances in the Truckee Basin. While many of the options evaluated are too broad for direct implementation, they provide important context for the effectiveness of three adaptation strategies that exist for addressing future imbalances in the Basin: Supply Augmentation, Demand Management, and

Institutional Changes. The precise value of the options described requires further evaluation and discussion among the Basin water users in order to determine relative effectiveness and feasibility for each.

No singular action was found to sustain the balance between supplies and demands provided under the historical climate or Reference scenario; however, each of the options evaluated addresses at least a portion of the affects from future changes in climate. Ultimately, addressing future changes will require a combination of options from among the three adaptation strategies identified. The precise composition and intentions of these efforts, however, will require additional study, planning, and close coordination among Basin stakeholders.

Development of Modeling Tools and Information

The Basin Study relied upon projected future conditions that were assembled before, and absent the context of, the key vulnerabilities that emerged from the Basin Study's risk and reliability assessment. As the first of its kind in the 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 investments in modeling and analysis. In this manner, the relationship between uncertainty and key vulnerabilities can be used to provide guidance on the priorities for developing a more detailed and complete understanding of future challenges the Basin may face.

Additional analysis could also provide valuable information on the ability of water user communities to endure various future conditions. This is particularly true for aspects of a water user community that cannot be directly related, or easily extrapolated, from the results from the TROA-light Planning Model used by the study to evaluate scenarios.

The following assessments and model development tasks were identified through comments from the TAG, interviews with stakeholders, or through the process of conducting analysis of vulnerabilities and adaptation options. Where relevant, linkages to vulnerabilities and uncertainties have been described.

Improvements to the Understanding of Basin-Wide Vulnerabilities

- **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. The ability to predict changes in the needs for these water users and sustain critical habitat has important implications for the entire Basin.

- **Incorporation of paleohydrology and updated climate projections** – At the time the Basin Study was conducted, reconstructions of hydrology for prerecorded history (paleohydrology) were not available, and updates to the climate change data set were being released. Assessment of Basin Study options with paleohydrology data would allow for a better understanding of how historical variability might have affected the Basin, and perhaps set different expectations for baseline performance and the drought of record. Inspection of the updated climate projections (CMIP5) would provide an updated understanding for whether uncertainties in the future climate have been converging or changing.

Improvements to the Understanding of Water User Vulnerabilities

- **Inclusion of the Carson River Basin –** Development of supply, demand, and infrastructure and operational conditions in the Carson Basin upstream of Lahontan Reservoir would benefit water users in this neighboring basin, including the Newlands Project. The refined understanding for the supplies available to the Newlands Project may also refine the understanding for how diversions from the Truckee River may change in the future.

- **Coupled groundwater/surface water model development –** Several communities in the Basin rely on groundwater as a primary source of water supply. These communities include those in the Lake Tahoe Basin, the California portion of the Truckee Basin, and several areas in the upper Carson Basin and in Lahontan Valley. The Truckee Meadows area also includes groundwater in its blend of water supplies. Necessarily, each of these communities would benefit from an improved understanding of how climate change may alter natural processes for groundwater recharge and storage. This would also be useful for developing a comprehensive understanding of how climate and water use affects many aquatic, riparian and terrestrial ecological systems.

- **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 –** At the time the Basin Study was conducted, the TROA-light Planning Model was being issued for use for the first time. Several aspects of the model require further discussion and refinement before they may be implemented in the model, including the California Guidelines for recreation, and the use of credit storage for water quality on the lower Truckee River. Refinements to these would improve the understanding of how TROA implementation will proceed, and therefore improve upon the Basin Study's analysis.

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