

Evaluating Watershed Ecosystem Services & Market Mechanisms in Douglas County, NV



UNIVERSITY OF CALIFORNIA, SANTA BARBARA

ADVISOR

Scott Jasechko



AUTHORS

McKenzie Bradford

Paige FitzGibbon

Eric Holmes

Marina Lindsay

Austin Melcher

CLIENT

The Nature Conservancy 

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Douglas County, Nevada: An Investigative Look at Climate
Change and Adaptive Watershed Management Economics**

A Group Project submitted in partial satisfaction of the requirements for the
degree of Master of Environmental Science and Management for the Bren
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by

MCKENZIE BRADFORD
PAIGE FITZGIBBON
ERIC HOLMES
MARINA LINDSAY
AUSTIN MELCHER

Committee in charge:
SCOTT JASECHKO

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As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

McKenzie Bradford

Paige FitzGibbon

Eric Holmes

Marina Lindsay

Austin Melcher

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

ADVISOR: Scott Jasechko

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ABBREVIATIONS & KEY TERMS

Acronym	Definition
AET	Actual Evapotranspiration
AF	Acre Feet (of water)
AMSL	Feet Above Mean Sea Level
BLM	Bureau of Land Management
CanESM2	Second Generation Canadian Earth System Model

CEQA	California Environmental Quality Act
CFS	Cubic Feet Per Second
CMIP5	Climate Model Inter-Comparison Project Version 5
CNRM-CM5	National Centre For Meteorological Research 5
CWA	Clean Water Act
CWES	Center for Watersheds and Environmental Sustainability
DEM	Digital Elevation Model
DRI	Desert Research Institute
EIS	Environmental Impact Statement
ET	Evapotranspiration
EVI	Enhanced Vegetation Index
FEMA	Federal Emergency Management Agency
GCM	Global Circulation Model
GHG	Greenhouse Gases
HadGEM2-ES	Hadley Center's Hadley Global Environment Model 2 - Earth System
HCP	Habitat Conservation Plan
HUC	Hydrologic Unit Codes
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
LULC	Land-Use/Land-Cover
MESM	Masters of Environmental Science and Management
Mgal	Million Gallons
MLR	Multiple Linear Regression
MODIS	Moderate Resolution Imaging Spectroradiometer
MRLC	Multi-Resolution Land Characteristics Consortium
NCDC	National Climate Data Center
NHD	National Hydrology Dataset
NLCD	National Land Cover Database
NPDES	National Pollution Discharge Elimination System
PES	Payments for Ecosystem Services
PET	Potential Evapotranspiration
PWS	Payments for Watershed Services
RCP	Representative Concentration Pathway
RIOS	Resource Investment Optimization System
SWE	Snow Water Equivalency
TDR	Transfer of Development Rights
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Loads
TNC	The Nature Conservancy
UNR	University Nevada Reno

ABSTRACT

Located at the base of the Eastern Sierra Nevada the watersheds of Douglas County, Nevada are fed primarily by snowmelt flowing down the mountains in the form of countless streams, creeks, and rivers. Water managers of the Carson and Walker River Basins seek to address variations in the type (precipitation or snowmelt) and timing of water delivered to these as a result of changing climate which may detrimentally affect the downstream communities and local wildlife who rely on these supplies. Watershed stakeholders including ranchers, farmers, recreationists, and wildlife conservation groups such as The Nature Conservancy (TNC), the client of this research study, hold an invested interest in identifying priority areas for conservation projects and selecting market mechanisms to promote these efforts. To accomplish these management goals, the Walker Rangers research group worked to quantify the existing scientific baseline of water-based ecosystem services, model variations to these services in respect to climate change, as well as identify priority areas for conservation work in order to recommend future management actions. Based on computer modeling of baseflow, nitrogen export, and phosphorus export, major findings of this report indicate that over the next 30 years overall baseflow is expected to decrease, resulting in less water available overall with mixed results on water quality conditions. Modeled priority areas for conservation management activities were identified along the river headwaters and around intensive agriculture areas located within the floodplains. This research is intended to encourage and support existing conservation efforts by providing a central set of recommendations to a diverse group of managers throughout Douglas County, Nevada and surrounding watersheds.

EXECUTIVE SUMMARY

Water resource management is a complex and interdisciplinary field requiring advanced local scientific knowledge as well as a developed understanding of politics and local market forces. Typical methods that are often considered for watershed management include establishing conservation easements, restoring meadowlands and forests, as well as utilizing market mechanisms. Due to the unique characteristics of each watershed in terms of stakeholder investment interests, administration resources, as well as geologic and hydrologic conditions each of these methods must be tailored to the watershed of interest for best results.

In the past few decades, water resource managers across the globe and especially in the western United States, in areas prone to water shortages due to periodic drought conditions, have looked to diversify their conservation and planning efforts to address uncertainty and variable changes in their water supply options. In particular, The Nature Conservancy (TNC), the client of this research report is involved in work utilizing innovative management strategies such as water funds, water banking, and other forms of water transfers to facilitate these conservation efforts – as they address their mission to protect the natural lands and waters around the globe.

In the past few decades, conservation easements have become an effective tool for TNC and their partners to facilitate conservation and floodplain restoration in Douglas County. Local planners and water managers throughout the county and surrounding watersheds seek to protect and restore floodplain areas from excessive land development. Due to an increasing population in Douglas County between the 1990s and early 2000s, the presence of subdivisions has become more common in the floodplains, removing natural lands and impeding the natural function of the river and its surrounding floodplain. TNC and their partners are interested in determining if a water fund in Douglas County is a feasible option to further their efforts to conserve, protect, and restore these lands and waters in light of impending climate change and transitions in land use.

Douglas County, Nevada lies at the base of the Eastern Sierra mountain range and spans the range of two watershed basins: the Carson River Basin and the Walker River Basin. Both rivers basins are fed primarily by snowmelt from the Sierra snowpack as rivers and floodplains experience increased flows after the spring melt. Water Resource Managers across the county and into the surrounding watersheds are increasingly concerned with the effects of climate change on these seasonal patterns of flow, the type and timing of water that enters the watershed (precipitation, snowmelt, or flooding), land use transitions as floodplain areas are converted to subdivisions, as well as increasing water demands as availability of water resources vary.

TNC proposed this research project to evaluate existing watershed ecosystem services (establishing a scientific baseline for future comparisons) and identify market mechanisms that may be feasibly applied given the existing stakeholders and investment interests in the

area. In order to evaluate and monitor conservation efforts in the future, the watershed analysis portion of this research will serve as a baseline for comparison for future changes. This research is meant to serve as the initial groundwork for ongoing feasibility assessments and continued monitoring of ecosystem service functionality in Douglas County.

To accomplish the goals of this research project the Bren school research team 1) prepared two watershed analysis reports evaluating existing water quality and quantity conditions of the Walker and Carson River basins, 2) modeled variation in Water Yield and Nutrient Delivery (nitrogen and phosphorus) using the Natural Capital Project's InVEST software, 3) analyzed case studies of existing market mechanisms, and 4) prepared a series of recommendations to support existing conservation work in the area.

The following research defines the existing scientific baseline conditions (for water quantity, quality, and ecosystem services) within the Carson and Walker river basins, models how water-based ecosystem services may change with variations to climatic conditions and land use activities, and finally, identifies how sensitive these variations are. In addition, research on existing market mechanisms were used to identify applicable market-based management strategies to help mitigate these changes in the future.

In particular, concerns exist for water quality conditions, with all major stretches of both the upper Walker and Carson rivers being listed as 303d impaired waters under the Clean Water Act (CWA). Water quality concerns are further intensified due to extensive ranching and agriculture activities that have caused high concentrations of nutrients (nitrogen and phosphorus) and fecal coliform bacteria.

Modeled results from InVEST indicate that under all considered climate change scenarios, baseflow in both the Walker and Carson river basins is predicted to decrease over the next 30 years. Based on modeled nutrient deliveries, water quality conditions and effects across the basin are mixed; however, the most sensitive regions to climate change effects exist in the upper headwaters of the river systems as well as around existing agricultural activities.

Recommendations include prioritizing conservation easement placement in areas that contribute most to river baseflow and nutrient loadings, applying best management practices (BMPs) to existing conservation easement properties in order to help improve water quality conditions, as well as outlining prescriptive next steps for feasibility studies.

In order to optimize watershed benefits and returns on investment for conservation projects, local researchers and water resource managers are encouraged to 1) consider the impacts of climate change and land use conversion when selecting priority areas for management projects, 2) account for stakeholder investment capacity in future opportunities, and 3) perform feasibility assessments for specific project implementations.

BACKGROUND

The following report is a Group Master's Thesis Project submitted as part of the satisfactory requirements for the Bren School of Environmental Science & Management Master of Environmental Science and Management (MESM) degree. Clients submit proposals to address a specific environmental problem, involving scientific evaluation and application of management recommendations.

The Nature Conservancy (TNC) proposed this research project to evaluate changes to water-based ecosystem services including water supply and water quality in respect to a changing climate and land use conditions – specifically the increasing population and development of the floodplain in Douglas County, Nevada. Water managers throughout the Eastern Sierra face numerous challenges in the coming years, requiring innovative solutions and collective efforts from stakeholders across the watershed.

THE NATURE CONSERVANCY (TNC) WORK AND MISSION

Across the globe, TNC strives to protect natural land and waters by means of scientific analysis and management actions. These efforts are further motivated by preserving sensitive habitat, engaging in land stewardship activities, advanced scientific investigation, and effective management strategies. In Nevada, the driest state in the nation as of 2019, TNC's efforts are targeted at protecting water resources and maintaining river functionality across the floodplains by partnering with local landowners and government agencies, among others. With populations, such as that of Douglas County, experiencing significant growth rates over the past forty years, land use development and water supply security for drinking water and irrigation have emerged as pressing concerns.

In the past, water scarcity issues were often addressed by traditional means such as installing new dams for reservoir storage rather than looking to alternative measures and adaptive management activities. Unfortunately, dams come with numerous environmental and human hazards as indicated by recent events such as the Oroville dam spillways in California failing and plans to remove dams from the Klamath River basin bordering California and Oregon. Failing infrastructure, blocking fish passageways, and impeding river functionality are only a few of the issues that come with using dams and these outdated, traditional management strategies. To avoid these consequences, TNC and its partners seek to investigate innovative strategies that simultaneously safeguard water storage, improve human safety, and protect sensitive habitat areas –through alternative, adaptive management solutions.

River Fork Ranch

One such habitat area of note in Nevada is TNC's project known as River Fork Ranch, an 800-acre property in the Carson Valley Floodplain boarding the confluence of the eastern

and western forks of the Carson River. River Fork Ranch is part of a conservation easement, agreement made in part to protect the Carson Valley floodplain from ongoing developmental pressures in Douglas County. Due to its proximity to the river and The Nature Conservancy's overarching goals to preserve land habitat and river functionality in Douglas County, numerous studies have been conducted in the area for species population counts, river quality, and changes to river function over time. To inform future management decisions TNC seeks to evaluate watershed functionality in relation to changing climate conditions as well as assess if a water fund mechanism would be feasible in the region.

TNC has an established history of utilizing market mechanisms to promote conservation efforts and engage stakeholders in effective landscape management. Specifically, throughout Latin America numerous water fund projects have been initiated with relative success –addressing management problems between upstream and downstream water users. Interest has moved to Douglas County due to the local TNC's office concern with changing climatic conditions, that are altering the timing of precipitation events, water availability, and affecting existing ecosystem services across the Sierra Nevada. Without intervention, a reduction in these benefits may negatively affect the valuable agricultural and ranching operations, projected urban growth, as well as health and safety of residents and wildlife.

Due to the looming effects of climate change as well as drastic population growth in the Douglas County region, TNC has turned their efforts to investigating how these impacts might be mitigated through management activities. Various plans have been enacted to inhibit development in the threatened floodplains, including transfer of development rights programs (TDR) and conservation easements. The following contents of this report are meant to be used in conjunction with these efforts, offering additional recommendations for prioritized areas, applicable market solutions, and general strategies to combat climate change effects throughout local watersheds.

DOUGLAS COUNTY

Douglas County (**Figure 1**) is located in western Nevada at the base of the Eastern Sierra Nevada mountain range. This location places the county in what is known as a rain shadow, where little precipitation falls as a result of the mountains sheltering the land below from rain-carrying winds. Due to this aspect of the region, water supply for Douglas County is primarily driven by the Sierra Nevada snowpack, resulting in large seasonal variations in water supply (Cobourn, 2001; Scalzitti et al., 2016). As climate changes, these seasonal variations are expected to shift, resulting in more drastic flooding events as well as longer dry periods.

Originally founded in 1861, Douglas County is one of the original counties of the Nevada territory (Genecology Inc., 2017). Agricultural land use is heavily encouraged in this

region, with the Douglas County Master Plan explicitly stating that “Douglas County shall plan for the continuation of agriculture as a distinct and significant land use in the county.” At the time of the 2012 USDA census, Douglas County’s agricultural sector produced \$301.9 million and employed 715, totaling 8% of the county’s production output and 2.4% of county employment (Nevada Department of Agriculture, 2015). Douglas County contains 255 farms, covering 101,000 acres or roughly 22% of the county’s land area. The largest agricultural land use is cattle and calf production, accounting for over \$10 million in farm business income in 2016 (Headwaters Economics, 2018).

Over the past few decades the population of Douglas County has increased drastically, growing by 70% since 1990 (US Census Bureau, 2019). This increasing water demand and changing runoff timing is anticipated to stress both agricultural and municipal water users. In 1996, the issue of population growth management was recognized as a priority by adding the Growth Management Chapter (20.500) into Douglas County Code (Douglas County, 2011). Since this addition, numerous programs have been implemented to manage growth and protect traditional rural lifestyles. Programs include set urban service areas (discouraging development outside existing areas –including water, sewer, parks, and schools), development rights transfer programs, open space acquisition programs (first Open Space Plan adopted in 2000), and pursuing grant funding to preserve open space lands (Douglas County, 2011). Considering predicted growth and changing population dynamics, evaluating water supply and security are essential to preserving daily life activities in Douglas County.

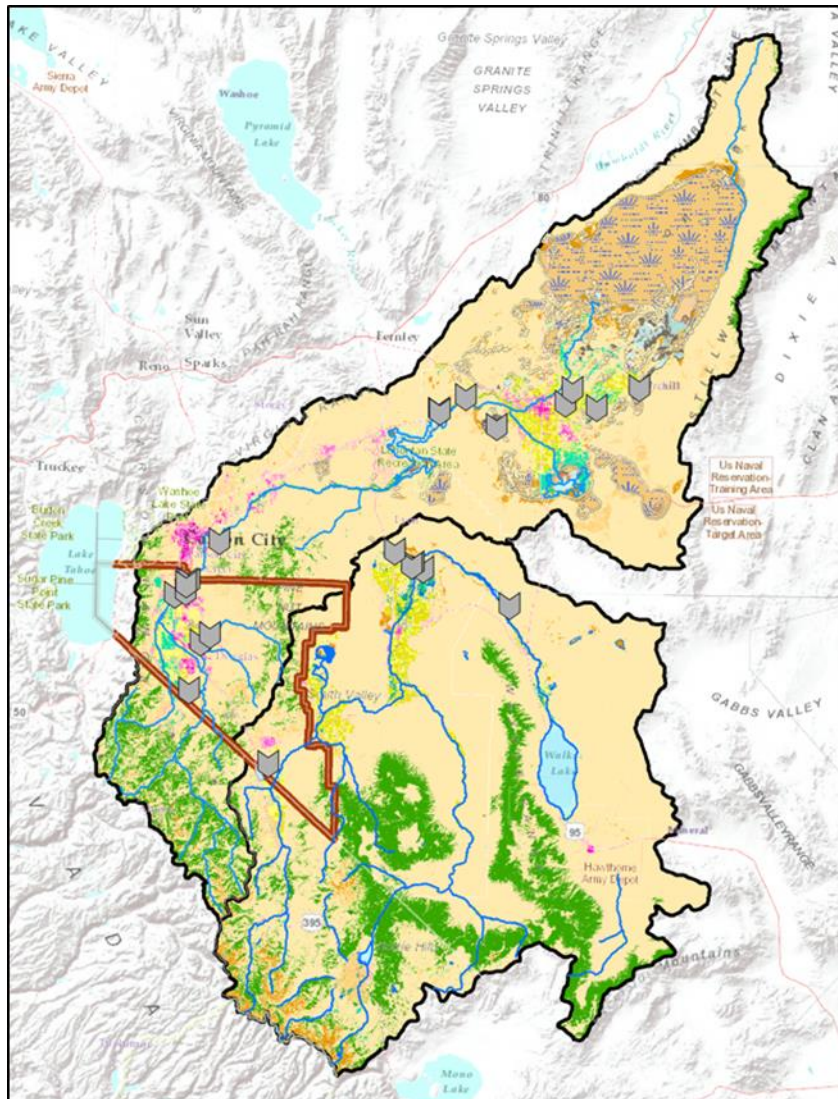


Figure 1. Douglas County (outlined in red), Nevada and the surrounding Carson and Walker Basins.

WATERSHEDS AND BASINS

In order to fully capture the effects of upstream users and impacts on downstream users for water supply in Douglas County, this research was conducted on a basin-wide scale, incorporating the two major basins that intersect Douglas county. The county crosses both the Walker and Carson river basins, originating at their headwaters in the Eastern Sierra, and overlapping across the states of Nevada and California. In addition to the background information provided in the body of this report, two preliminary watershed analysis reports were prepared for the Walker River Basin (Appendix A) and the Carson River Basin (Appendix B).

WALKER BASIN

The Walker basin, an area of approximately 2.6 million acres, runs along the eastern edge of the Sierra Nevada mountain range and the western edge of the Great Basin (**Figure 2**). The area includes riparian, riverine, and lacustrine environments that provide ecosystem services for wildlife, agriculture, recreation, as well as both urban and rural housing. Water supply in the basin is fed primarily by water from the Sierra Nevada mountain range; the East and West Forks of the Walker River flow from south to north through the Bridgeport, Antelope, and Smith Valleys that converge in Mason Valley to form the major branch of the Walker River. This portion of the Walker River flows through the Mason Valley Wildlife Management Area and the Walker River Paiute Reservation before reaching Walker Lake.

Basin elevation extends to nearly 3,800 feet within the watershed's boundaries, bordered by larger formations in the nearby Sierra Nevada mountain range. The Walker Basin contains numerous eco-regions including the Jeffery Pine forests in the high Sierra, and the playa, cottonwood stands, and xeric shrublands along the lower river (U.S Fish & Wildlife, 2015). Areas of high gradient in the upper regions provide cold-water fish habitat and prime cutthroat spawning conditions (U.S Fish & Wildlife, 2015). As the rivers descend into lower ranges, agricultural valleys comprise most of the landscape. Climate in this region varies drastically, with high elevations exhibiting humid, cold, high-precipitation conditions while low elevations experience arid, hot conditions around Walker Lake. Higher elevations in this region vary in temperature from 24 °F to 62 °F and receive an annual average of 9 inches of precipitation and 43 inches of snowfall. Lower elevations in this region vary in temperature from 41°F to 71°F and receive an annual average of less than 5 inches of precipitation and 2.8 inches of snowfall (Western Regional Climate Center, 2006).

The Walker Basin contains four major reservoirs; Walker Lake (currently at 44% capacity with 1,230,000 acre-feet), Weber Reservoir (currently at 62% capacity with 7,054 acre-feet), Topaz Lake (currently at 34% capacity with 20, 850 acre-feet), and Bridgeport Reservoir (currently at 30% capacity with 13,450 acre-feet) (USGS, Walker Basin Hydro mapper, 2018). Walker Lake, one of five remaining freshwater terminal lakes on the globe, exists as the terminus of the Walker River –a remnant of former Lake Lahontan (Audubon, n.d.). Walker Lake serves as an “Important Bird Area” due to the presence of endangered species, such as the sage grouse, and its role in supporting over 10,000 unique species of birds (California Department of Fish and Wildlife, 2018). Currently six dams – diverted for agricultural use - impede the flow of Walker Lake and have contributed to nearly 160 ft in lake level decline (USGS, 2015). This decreased inflow to Walker Lake has resulted in an overall decrease in biodiversity in the region and has further endangered species at risk. Furthermore, total dissolved solids (TDS) concentrations have increased in magnitude from 2,500 mg/L to 25,000 mg/L (USGS, 2015). All major sections of the Walker River are

listed as 303(d) impaired by the Clean Water Act (CWA) due in part to the presence of pollutants from waste discharge from grazing operations, mercury found in the biota and sediment from previous mining operations, and various other sources of pollution. The importance of water quality controls in the Walker basin is emphasized by the unique aspect of Walker Lake being a desert terminal lake with a declining surface area. In other words, the pollutants already found in the lake may become more concentrated even without the addition of any new pollutants.

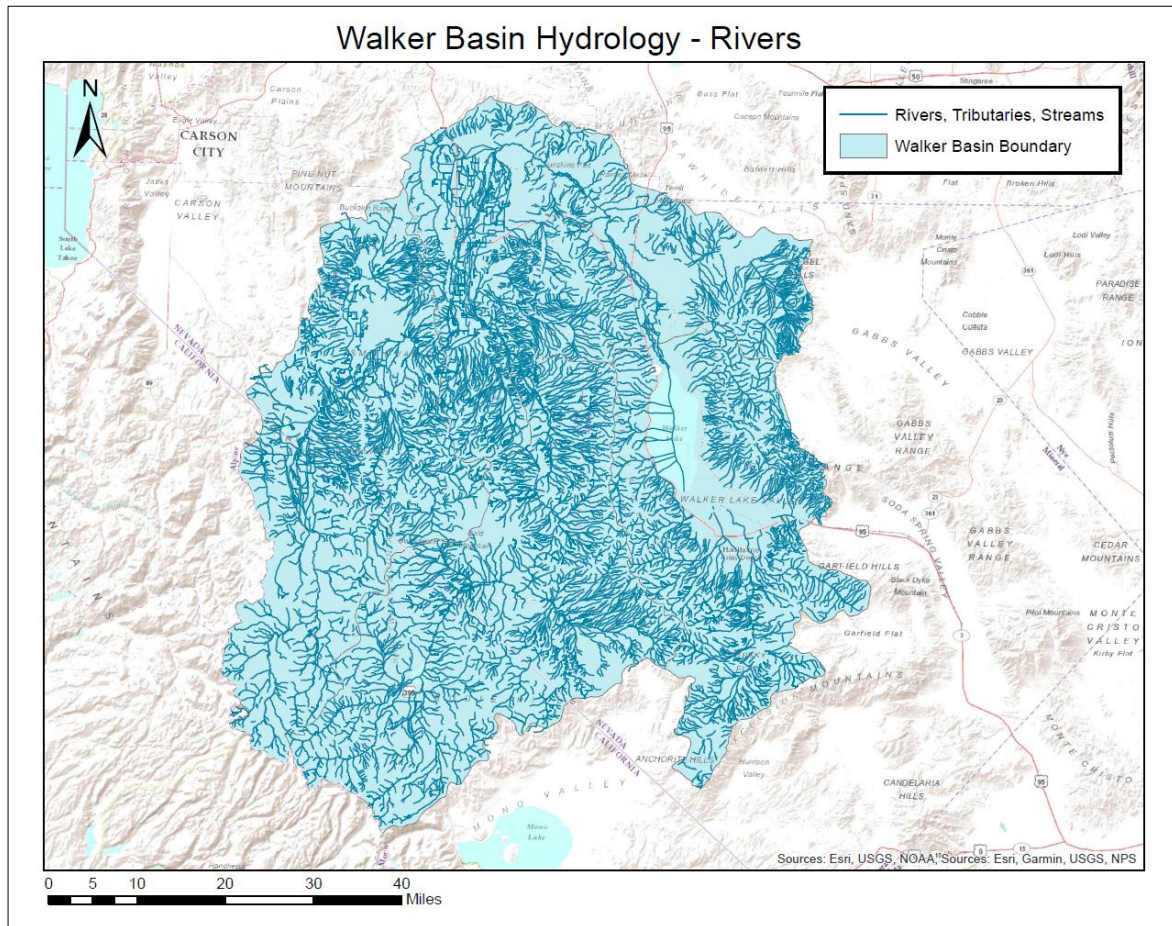


Figure 2. Walker Basin and hydrologic features. Data Source: BASINS.

The Walker River Basin is comprised of more than 763,000 acres of Bureau of Land Management (BLM) lands for various projects and purposes (USBR, n.d.). On these BLM lands, projects include wild horse herd management, recreation, leases on mineral and energy interests, grazing allotments, and numerous mining claims (USBR, n.d.). It is important to note, however, that most of these mining claims are currently inactive, although abandoned copper mines are still present in the area. The majority of the basin is

comprised of rangeland and cropland in the lowlands, with forests scattered across the mountains of the upper basin. Predominant crops grown across the Walker Basin include alfalfa, onion, corn, and turf as well as feedlots and dairy productions (USBR, n.d.). Wetlands (forested and non-forested) and protected wildlife management areas provide habitat for numerous species of flora and fauna, including several critically endangered species.

The Walker Basin is contained within the boundaries of Alpine County, Mono County, Douglas County, Lyon County, and Mineral County (making up a combined estimated population of 119,170). Based on U.S. Census Bureau data these county populations have been increasing drastically over the past few decades aside from the populations of Alpine and Mineral counties which have actually declined. Between 1990 and 2010 the population of Lyon County more than doubled, while Mono and Douglas Counties grew by roughly 43% and 70%. If the population continues to grow at the current rates, with an average increase of 10% in the most recent years, population in the Walker Basin will continue to increase. However, the population growth appears to be somewhat leveling off as average growth across counties has decreased from 50% on average to 10% in the past two decades. Considering that the watershed is not perfectly aligned within the context of these county boundaries, data from the U.S Census as “designated places” was also analyzed to population counts within the basin on a smaller scale. Based on the 12 major cities within the watershed, current populations are around 12,438 individuals.

Major industries in the Walker Basin include agriculture, forestry, fishing and hunting (Mono County), mining, quarrying, oil and gas extraction (Lyon County), and public administration and health care (Alpine, Douglas, Mineral Counties) in regard to economic activities (Data USA, 2018). Average ages across the basin span from roughly 39 to 50 (Data USA, 2018), while median household incomes across the county range on average from \$37,750 to \$62,375 (Data USA, 2018). Beneficial uses for Walker River and Walker Lake include irrigation, livestock, recreation, industrial use, municipal or domestic use, and supporting wildlife and aquatic life, especially threatened or endangered species (Sharpe et al., 2007). The land surrounding Walker River is predominantly used for agricultural crops, including alfalfa, broccoli, clover, corn, garlic, grain, grass, lettuce, oats, onions, pasture, spinach, turf, and wine grapes (Sullivan et al., 2011). The predominant crop in the Walker Basin is alfalfa, ~ 90% of all crops in Nevada are comprised of alfalfa (Robison, 2015). Within the Walker Basin, alfalfa uses, on average, 2.8 acre-feet of water per acre (Schultz, 2008). The most recent estimates reveal that there are approximately 110,850 acres of irrigated land in the Walker Basin (Sharpe et al., 2007). This suggests that alfalfa crop irrigation uses approximately 310,380 acre-feet of water per year.

Recent plans for land use alterations via land acquisition projects, involve expanding existing agriculture and rangeland parcels in the area. Changes to residential and commercial land use within the Walker Basin appear minor to other land uses at this time.

Landownership is primarily held by BLM, U.S Department of Defense, Tribal parties, the State of Nevada, and U.S. Forest Service with private lands making up the rest of the dominant area (USBR, n.d.). Proposed future land management options for Lyon County and Douglas County both indicate substantial areas of rangeland and vacant land that will remain relatively undeveloped.

CARSON BASIN

The Carson Basin, an area of approximately 2.5 million acres, is located north of the Walker Basin at the base of the eastern Sierra Nevada mountain range (**Figure 3**). The Carson River has two forks, the East Fork, fed by snowmelt near Sonora Pass, and the West Fork, fed by snowmelt near Carson Pass that flow from south to north to form the main stem of the river before flowing into the Carson Sink (Cobourn, 2001). The river's significant tributaries include Clear Creek as well as Indian and Bryant Creek, which cross the California-Nevada state border.

The Carson River watershed is formed by multiple mountain ranges, including the Sierra Nevada, Carson Range, and Virginia Range that vary in elevation from approximately 6,000 to 11,000 feet above mean sea level (amsl) (USGS, 2006). The Carson River is fed by snowmelt and rain in the high elevation headwaters of the upper watershed and outlets into the lower lying Carson Sink (approximately 4,000 feet amsl in elevation) located in the desert region of the watershed. The headwaters are characterized by the steep mountains of the eastern Sierra Nevada, which gradually level out into the flatter, partially filled alluvial valley areas of the Carson Desert.

The upper Carson River watershed experiences long, cold winters and short, moderately warm summers due to its high elevation. Temperatures typically range from a maximum near 75 °F in July to a minimum of approximately 20 °F in February, with an annual mean temperature over the past 30 years of about 44 °F. Most of the precipitation for the watershed falls in this higher elevation region as snow during the winter when precipitation can reach up to 5 inches per month and rain during the summer with a low of approximately half an inch per month (Prism Climate Group, 2018). The annual average precipitation in the upper watershed ranges from 10 to 20 inches for elevations below 9,000 feet, while elevations above 9,000 feet can receive more than 40 inches of precipitation annually (CWSD, 2006). The middle and lower areas of Carson River watershed experience higher temperature summers due to their lower elevation. Temperatures typically range from a maximum near 94 °F in July to a minimum of approximately 21 °F in December and January, with an annual mean temperature over the past 30 years of about 53 °F. The middle and lower portions of the Carson River watershed are semi-arid and arid year-round due to the rain shadow effect of the Sierra Nevada (CWSD, 2006). Precipitation falls mostly as rain with winter months experiencing approximately half an inch of rain while

summer months may receive as little as 0.1 inches of rainfall. On average the lower and middle portions of the watershed receive approximately 5 inches of precipitation annually (Prism Climate Group, 2018).

Surface water storage exists in multiple parts of the watershed with the largest being the Lahontan Reservoir, located in the lower third of the Carson River watershed. The Lahontan Reservoir primarily used for irrigation and can receive supplemental water from the Truckee River through a diversion tie-in. The historical average flow diverted from the Truckee River to the Lahontan Reservoir is approximately 117,300 acre-feet-per-year (from 1967 to 2010), although less water is diverted during wet years and more during dry years. There is also approximately 11,000 acre-feet-per-year of surface water storage in the upper watershed, which includes the Mud Lake reservoir (CWSD, 2013).

The Carson River watershed has five primary groundwater basins: Carson Valley, Eagle Valley, Dayton Valley, Churchill Valley, and Carson Desert Valley. The perennial yield of these groundwater basins (usable water equal to the amount of recharge) typically decreases downstream due to lower precipitation levels downstream caused by the rain shadow effect of the Sierra Nevada. The Stillwater National Wildlife Refuge, located at the terminus of the Carson River in the lower watershed near the Carson Sink, is an integral migratory bird area, supporting over 280 species during bird migration. Currently 25 dams exist along the Carson River, and as a result of these frequent diversions, water flow in the Carson River has been greatly reduced, threatening wildlife habitats in the Carson Sink.

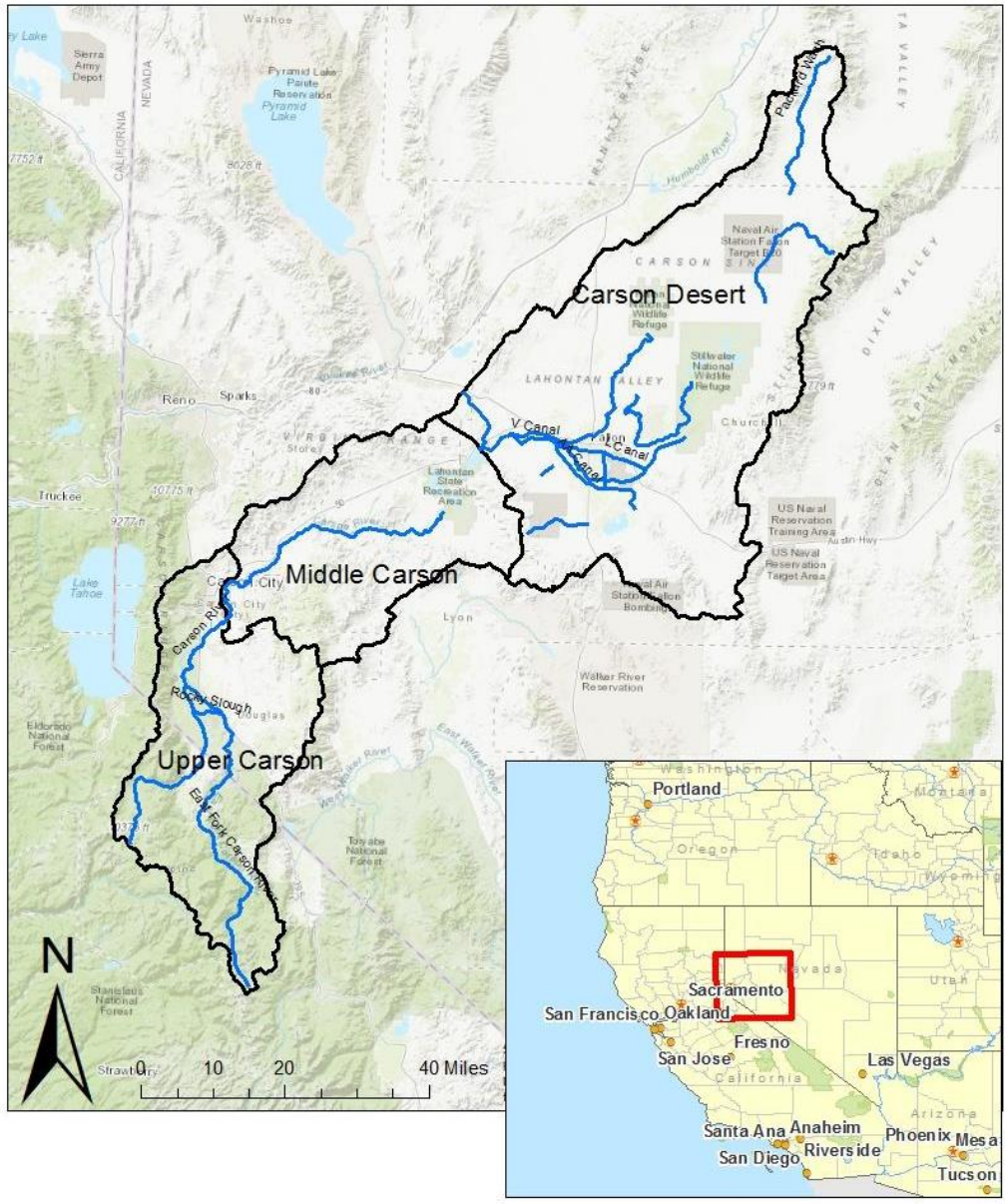
The Carson River also contains two superfund sites; the Leviathan Mine and Carson River Mercury Site. Both sites were contaminated as a result of mining-related activity and have historically led to problematic acid-mine drainage throughout the river, causing Indian Creek and the East Fork to be 303(d)-listed by the Clean Water Act (CWA) for pH violations (Morway et al., 2017). Fish tissue samples in both forks and all tributaries of the river experience high levels of trace metals due to historic mining activities (Bonzongo et al., 2006). All of the main stems of the Carson River are listed as 303(d) impaired for failure to meet total suspended solids, turbidity, temperature, and total phosphorus. The watershed has exhibited an overall degradation in quality over the past twenty years. Dissolved oxygen has decreased, while temperature, mercury, lead, and nitrogen have exhibited a positive trend.

Land ownership in the Carson Watershed is dominated by federal lands (primarily U.S. BLM and U.S. Forest Service Lands) that comprise approximately 73% of the area. The other largest landowners are private landowners, making up approximately 23% of the watershed and tribal lands accounting for approximately 3.5% of the land in the watershed (Headwaters Economics, 2018). The largest land covers in the watershed include shrubland (approximately 41%), other land that comprised of barren land and wetlands (approximately 30%), and grassland (approximately 20%). Smaller land uses include

forested land (approximately 6%), cropland (less than 1%), and urban land uses (less than 1%).

The population of the Carson River watershed as of 2010 contains around 100,000 people located within cities and an additional 32,000 rural residents, according to the U.S. Census Bureau. The largest city within the watershed is the state capital, Carson City. The most populous county is Lyon County, since Carson City is an independent city located within its own administrative zone. The median household income of the watershed's residents is around \$58,700. Population growth is anticipated to rise in the watershed, particularly in Carson City where the annual growth rate averaged 2.6% through 2010. Much of the new residential development is occurring in the wildland-urban interface and threatens to reduce the amount of land used by agriculture and that supports important habitat for wildlife. For example, Churchill County has experienced an approximately 230% decrease in agricultural lands from 1982 to 1997 as a result of expanded residential development (CWSD, 2006). The urban population of the Carson Valley is anticipated to double from 2000 to 2025 and urban population growth is anticipated to exceed the total water supply of the Carson River by 2035 (University of Nevada, 2001). The biggest consumptive water use in the Carson Valley is agriculture (up to 80% of consumptive water use), centered on the Newlands Irrigation Project near Fallon, Nevada.

The Carson River watershed provides valuable agricultural land, development, and recreation uses. These users have historically been at odds, with ranchers opposing new subdivisions and recreational users opposing unsustainable development and activities. Recently, ranchers have been embracing conservation easements to alleviate the pressure of development. However, important stakeholders in the Carson River watershed still have many conflicting views on how to best manage land and water rights. Suburbanization has already impacted the upper Carson watershed and predicted growth reports for the cities of Minden and Gardnerville indicate that the trend will likely continue.



**Figure 3. Carson River Watershed and defined segments (upper, middle, lower).
Data Source: BASINS.**

EXISTING MANAGEMENT PROJECTS AND CONCERNS

River Restoration

From 1996 to 2007 approximately 70 river restoration projects were completed on the Carson River. These projects include flood protection and levee repair or replacement, habitat enhancement through planting and sediment removal, as well as stream

rehabilitation and bank stabilization. As of 2008 an additional 11 river restoration projects were also underway in the Carson River corridor (CWSD, 2006).

Floodplain Conservation

Floodplain conservation through implementation of conservation easements and land acquisition have occurred throughout the Carson River corridor. Seven large-scale conservation easements and land acquisitions have taken place as of 2008 along the Carson River with an additional 19 negotiations currently underway (CWSD, 2006).

In addition to conservation easements and land acquisitions, multiple planning and community efforts exist in the Carson River corridor to promote floodplain conservation. These include a River Corridor Working Group that was established to investigate multiple floodplain conservation options, a Regional Floodplain Management Plan that establishes a framework for identifying and implementing floodplain conservation projects within the Carson River corridor, and multiple TDR programs that provide financial compensation to landowners to preserve lands in ranching and conservation (CWSD, 2006).

Outreach & Education

The Carson River Conservancy has been involved with outreach and education programs intended to promote an understanding and awareness of watershed resources and issues in the Carson River watershed. One program has included community participation in workdays on the river to help understand and improve water quality through hands-on experience. Other groups in the Carson River watershed have also produced interactive watershed maps that are available online, watershed tours, reports, newsletters, and symposiums focusing on the water quality and quantity issues within the Carson River watershed (CWSD, 2006).

Carson River Watershed Adaptive Stewardship Plan (2006)

The Carson River Watershed Adaptive Stewardship Plan was created as an integrated water management planning tool and as a regulatory compliance document for the Clean Water Act Section 319. The plan is intended to accomplish the following objectives:

- Provide an Overview of The Watershed and Its Challenges
- Identify Potential Sources of Nonpoint Source Pollution
- Discuss Short- And Long-Term Strategies and Actions to Address These Potential Sources
- Provide A Tracking Mechanism for Projects and Programs
- Identify Future Project and Program Opportunities
- Address the Nine Criteria Elements of The Clean Water Act Section 319 Program

The document provides extensive background on the watershed's geological, wildlife, plant, hydrological, cultural, land use, and rights/ownership. The sources of nonpoint source pollution in the watershed are identified and management actions are recommended for improving the water quality in the watershed. These management actions are also accompanied by specific monitoring and funding requirements (CWSD, 2006).

Carson River Watershed Literacy Action Plan (2015)

The Carson River Watershed Literacy Action Plan is a supplement to the Carson River Watershed Stewardship Plan that addresses the education and messaging around the Carson River watershed management activities. The plan identified three main stakeholder groups: the adult public (residents and businesses), youth, and public decision makers. The plan identifies the main hurdles to educating and understanding the value of the watershed for different topical areas and audiences as well as specific actions for enhancing awareness of the watershed (CWSD, 2015).

Carson River Watershed Regional Flood Management Plan (Updated 2013)

The Carson River Watershed Regional Flood Management Plan was created in 2008 and updated with a supplement in 2013. The floodplain areas and risks are detailed in the plan by segment of the Carson River in compliance with Federal Emergency Management Agency (FEMA) standards. Strategies for reducing and monitoring flood risk are also identified for implementation within the Carson River watershed, including outreach and education objectives. Additionally, annual reports are issued by CWSD detailing progress towards floodplain objectives listed in the plan and the status of project and program implementation (CWSD, 2008; CWSD, 2013; CWSD, 2017).

Middle Carson River Habitat Conservation Plan

The Middle Carson River Habitat Conservation Plan (HCP) was created to accommodate the diver interests of the Carson River, including ranching, urban development, wildlife habitat, and recreational uses. The plan provides descriptions of various habitat communities, challenges faced by human uses and wildlife habitat in the plan area, and projects for restoring and improving habitat. Plan does not include landscape-level actions but instead focuses on avian species habitat. This habitat is used as an indicator of overall habitat condition within the plan area and restoration of these habitats are assumed to benefit the diverse range of species within the plan area (JBR Environmental Consultants Inc., 2012).

West Walker River Watershed Management Plan (2007)

The West Walker River Watershed Management Plan is intended to identify California and Mono County's ability to improve watershed management for the West Walker River. The plan describes the existing issues facing the watershed in regard to water quantity and water

quality, as well as their effects on vegetation and other ecological functions within the watershed. Potential actions to improve the health of the watershed, including a list of best management practices and monitoring objectives are listed in the plan. The best management practices most applicable to Mono County include the following:

1. Erosion and Nutrient Control
2. Erosion Control
3. Grazing and Pasture Management
4. Road Construction and Maintenance
5. Landscaping
6. Construction, Development, And Commercial Improvements

Alongside these best management practices, a list of eight over-arching principles were included within the recommendation:

1. Prevention of Erosion Is Better and Cheaper Than Trying to Control Erosion
2. Treat the Cause – Not the Symptom – Of Erosion
3. Disconnect the Road (Or Other Disturbance) From the Stream Channel
4. Protect the Riparian Zone
5. Keep Existing Vegetation Wherever Possible
6. Direct Runoff Away from Bare Soil or Disturbed Areas
7. Keep Runoff Velocities Low
8. Each Solution Should Not Create More Problems Than It Is Solving

Additionally, the watershed management plan recommends comprehensive monitoring programs and data acquisition methodologies in order to identify emerging issues and evaluate the effectiveness of implemented BMPs (Mono Water, 2007).

Walker Lake Basin Project (2007)

In 2007, the Desert Research Institute (DRI) and the University of Nevada, Reno began the Walker Lake Basin Project, a research program that aims to restore Walker Lake and Walker River. The program contains 10 projects on the following subjects:

1. Development of A Water Rights GIS Database of The Walker Basin
2. Development of A Decision Support Tool in Support of Water Right Acquisitions in The Walker River Basin
3. A Socio-Economic, Political, And Environmental Analysis of Land and Water Rights Acquisitions in The Walker River Ecosystem
4. Analysis of Alternative Agriculture and Vegetation Management
5. Research on Plant, Soil, And Water Interactions
6. Assessing the Importance of Water Acquisitions to Health of The In-Stream Environment, Aquatic Ecology, And TDS Loading to Walker Lake

7. Make Recommendations to Maximize Water Conveyance and Minimize Degradation of Water Quality in Walker Lake Due to Erosion, Sediment Transport, And Salt Delivery
8. Water Conservation Practices for Agricultural Producers
9. Formulation and Implementation of Economic Development Strategies to Mitigate Economic and Fiscal Dislocations
10. Conduct A Study on Wild Horse and Burro Marketing

The Center for Watersheds and Environmental Sustainability (CWES) has also conducted an Environmental Impact Statement (EIS) study for potential water rights purchases in Walker Lake (DRI, 2007).

Walker Basin Restoration Program (2009)

The Walker Basin Restoration Program was established in 2009 by Congress. The purpose of the program Walker Lake restoration, as well as protection of agriculture and habitat within the Walker Basin. The program includes the following efforts:

1. Water Rights Acquisition Program
2. Water Leasing Demonstration Program
3. Research, Evaluation, Modeling, And Decision Support from The Desert Research Institute (DRI) And the University of Nevada, Reno (UNR)
4. Conservation and Stewardship Program with A Focus on Watershed Improvement, Water Conservation, Land Stewardship, And Alternative Agriculture.

Currently, the program has obtained over 98 cubic feet per second of natural flow decree water rights, 13,380-acre feet of groundwater rights, 11,760-acre feet of storage water rights, and over 15,700 acres of land from previous landowners willing to sell (NFWF, 2009). The program has also initiated revegetation projects on approximately 1,100 acres of land and donated around 1,600 acres of land to the Mason Valley Wildlife Management Area. Furthermore, the program has donated approximately \$21.8 million in funds to conservation and stewardship, improved water management, voluntary water forbearance agreements, and research within the Walker River Basin (NFWF, 2009).

Walker Basin Water Lease/Transfer Project (2014)

Mono County has been exploring the feasibility of a water lease and transfer program within the California region of the Walker Basin. The program would facilitate the sale or leasing of water rights in order to provide funds for the restoration of Walker Lake. The legislation that formed the Walker Lake Restoration Program does not allow for the sale or leasing of water rights for Walker Lake restoration without Mono County's approval of the program. In 2012, the National Fish and Wildlife Foundation (NFWF) and Mono County signed a Memorandum of Understanding that launched research on the feasibility of a water transaction program within the California region of the Walker River Basin. This report was

completed in 2014 and identified various information gaps. The next steps for this project include:

1. Exploration of Water Transfer Program Parameters
2. Prepare A Document Compliant with The California Environmental Quality Act (CEQA) To Assess Impacts
3. Amend the Mono County General Plan with New Policies to Allow for Transfers

It is anticipated that the implementation of such a program in the California region of the Walker River Basin would encourage the implementation of similar programs in the Nevada region of the Walker River Basin (Mono County, 2014).

CLIMATE CHANGE CONSIDERATIONS (WATER SUPPLY)

As a result of being primarily snowmelt-fed basins, the Carson and Walker Basins are particularly vulnerable to climate change effects on the amount of snow and the timing of the snowmelt (Scalzitti, Strong, & Kochanski, 2016). The seasonal aggregation of snow in and around the Carson and Walker basins acts as a natural reservoir storing water until the mid-months of the year. As early as March snow will begin to melt and runoff as a steady and predictable source of freshwater that plays a critical role in the health and utility of the Carson and Walker watersheds. The reason that emphasis is placed on snowpack is that the Carson and Walker watersheds reside in a rain shadow that reduces precipitation in the eastern Sierra during the mid and later quarters of the year (Sterle et al., 2017).

Understanding the past, present, and future of the Carson and Walker basin water supply is predicated on a thorough grasp of Sierra Nevada snowpack (Godsey et al., 2013).

As the population growth in Douglas County continues, municipal water demands are also anticipated to increase. Considering predicted growth and changing population dynamics, evaluating water supply reliability is essential to preserving daily life activities in Douglas County. Furthermore, the effects of climate change are anticipated to result in larger amounts of early season runoff and less runoff during the summer and later season months of the water year (CWSD, 2013). This is due to rising temperatures causing the headwater areas of the watershed to receive less snowfall and more rainfall. This increasing water demand and changing runoff timing is anticipated to stress both agricultural and municipal water users. These changing flow patterns may also further exacerbate contaminated runoff into surface water bodies from the historical mines in the region, including the Leviathan Mine Superfund Site (an old open pit sulfur mine) and the Carson River Mercury Superfund Site (CWSD, 2006).

Quantification of previous snowpack in the Sierra Nevada is limited by the date at which instrumentation such as snow pillows in the Sierra Nevada was installed. These snow pillow sites were installed in the early 1980's, and since that time they have offered a brief

glimpse into the past of Sierra snowfall by assembling information on snow water equivalent (SWE) and temperature. While there are dozens of snow pillows scattered through the mountains collecting this data there is a limited series of nine snow measurement sites that captures information for the basins under review. The strip of mountains feeding runoff to the Carson and Walker basins bolsters modest snowpack and ambient temperatures that settle just below freezing when compared to the rest of the Sierra Nevada. These facts offer a pessimistic outlook for winter snow retention as climate conditions gradually become warmer.

An emerging trend for Sierra Nevada winters is persistent multi-year droughts. Compared against 30 years of records it appears that these events are increasing in frequency and severity (Tague et al., 2010). The worst-case scenario is not less snowfall and more wet precipitation events as temperatures increase, but a mere reduction in total precipitation. For example, 2011-2015 represents the worst drought on record with Sierra snowpack being reduced by 25% (Reich et al., 2018).

There is increasing evidence that there should be a cause for alarm as models and research come together to best describe the future of Sierra Nevada winters. The few mountains that feed water to the Carson and Walker basins reach from 4,700 feet up to 10,866 feet in elevation as they sit in a maritime mountain range. These specific characteristics represent a danger zone as maritime snowpack is expected to decrease by 60-70% and elevations between 5,740 to 9,020 feet being affected most severely (Leung et al., 2004; Hauptfeld et al., 2014).

As climate changes, there will be greater uncertainty in available water supplies, meaning that the future fate of these basins could see streams running dry more frequently, decreased biodiversity, increased contaminant loading, and increased severity of seasonal flooding events. Without proper planning and management action, these changes could have a severe impact in the region for both humans and wildlife.

LANDUSE CONSIDERATIONS (WATER QUALITY)

Water quality is a fundamental concern given its role in the status of health and safety for the surrounding watershed in which it flows. Within the scope of water management there are three key water attributes of concern for managers: water quantity, timing of water delivery, and water quality. In evaluating water quality, it is important to determine the causes and types of pollution within a watershed as a valuable first step, to highlight what management options will be most effective at improving the health of the overall watershed. In the case of Douglas County, numerous pollutant sources are present in the area, complicating the water quality composition of the rivers and nearby streams and creeks.

Pollution Sources

Point sources of pollution are defined in the federal Clean Water Act (CWA) as “discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.” Typical examples of point sources include wastewater treatment plant effluent and industrial discharges from pipes into surface water bodies, but agricultural stormwater discharges and return flows are explicitly not considered point sources in the federal CWA (US EPA, 2018a). These discharges are often concentrated streams that can contain industrial chemicals, bacteria, organic matter, and high temperatures that can harm the health of surface water bodies and groundwater. As a result, point sources are regulated under the federal CWA through the National Discharge Pollution Elimination System (NPDES) permit program.

In contrast, nonpoint sources of pollution do not come from a specific conveyance, but occur through more diffuse and dispersed means. Typical examples of nonpoint sources are stormwater runoff from land, precipitation that can transfer pollutants from the atmosphere to land and surface water bodies, and atmospheric deposition of airborne pollutants. Depending on the types of land use and activities occurring, these sources can deposit fertilizers, pesticides, oils and greases, bacteria, and metals from large areas. Nonpoint source pollution is the leading cause of water quality issues in the United States, in part because of the large source areas from which these pollutants accumulate (US EPA, 2018b).

Within the Walker and Carson basins, the water quality parameters of primary concern are chlorophyll a, dissolved oxygen (DO), fecal coliform, Kjeldahl nitrogen, phosphorus, water temperature, total dissolved solids (TDS), total suspended solids (TSS), and turbidity. Major stretches of both rivers are classified as 303d listed waters for water quality impairments (**Figure 4**). While Walker Lake is not specified as a listed 303(d) impaired water, it receives its water from a listed 303(d) impaired stream and is a significant water source within the basin.

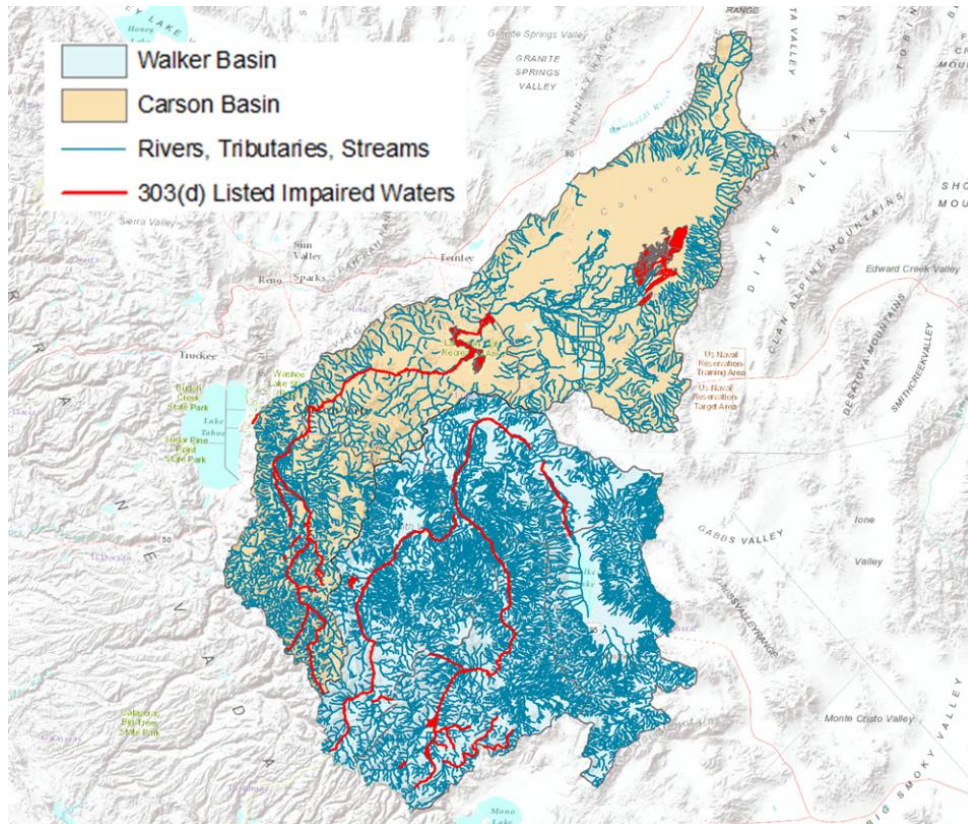


Figure 4. 303d Listed Waters for the Carson and Walker Rivers.

WATER QUALITY FACTORS FOR THE CARSON AND WALKER RIVERS

Kjedhal Nitrogen

Kjedhal nitrogen is the sum of ammonia, organic nitrogen, reduced nitrogen, nitrate, and nitrite. Together these act as essential nutrients for plants and animals. However, abundance of nitrogen in the water can promote low levels of dissolved oxygen and harm organisms and plant life. Common sources include wastewater treatment plants, lawns, cropland, and human and animal waste (US EPA, 2013).

While the headwaters of the Carson river are relatively pristine the valley floor through which these waters flow is heavily developed. These land use changes such as urban development, agriculture, and ranching dramatically alter the water's overall quality leading to issues of concern. Particularly, excessive algal growth is being observed in the East fork of the Carson River (Alvarez et al, 2018). While this growth is being observed in the surface waters of the Carson river it is the groundwater flow from developed lands that is carrying the large nitrogen load into the surface waters. Through sampling an area of concern returned average concentrations of 2.75mg/l of nitrogen (**Figure 5**). Such loading has resulted in portions of the Carson river being periodically classified as mesotrophic-eutrophic.

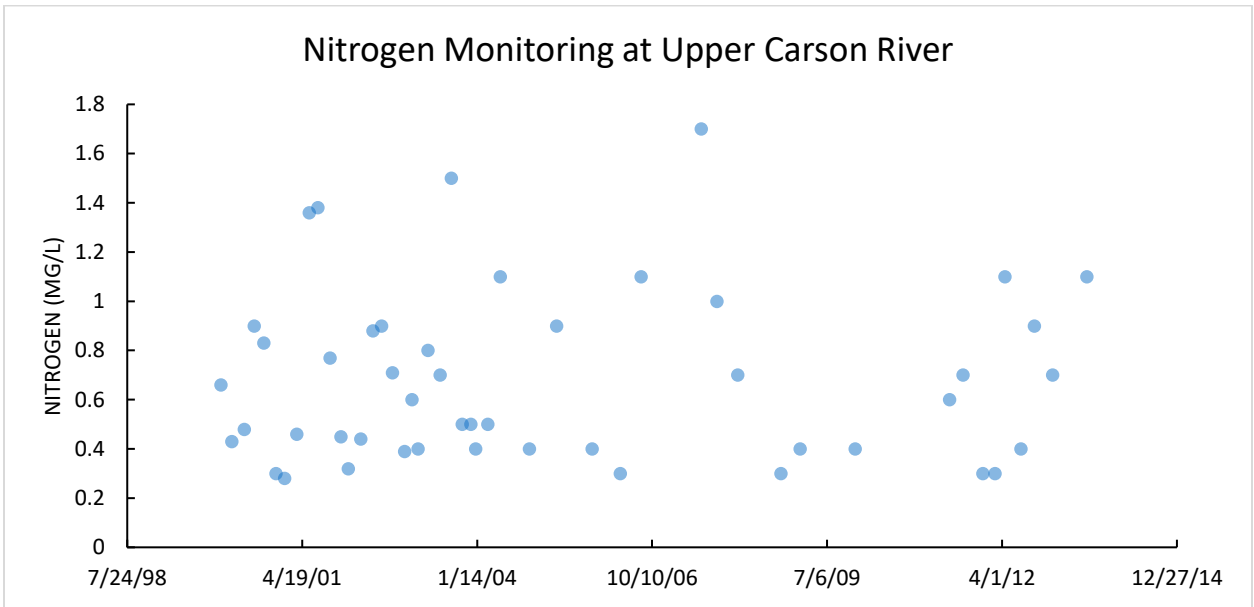


Figure 5. Nitrogen concentrations (mg/L) in the Upper Carson. Source: STORET Water Quality Data.

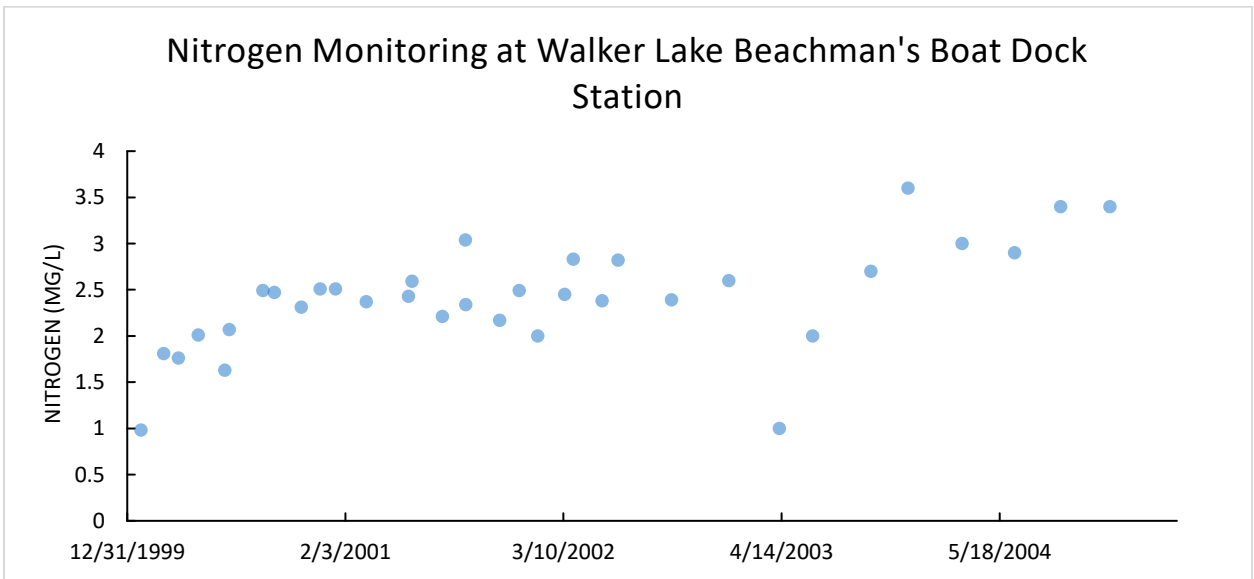


Figure 6. Nitrogen concentrations (mg/L) in Walker Lake. Source: STORET Water Quality Data.

The Walker basin, much like the Carson basin, has been dramatically altered by humans and these alterations have fundamentally shifted the quality of the Walker River's waters. Due to these alterations the East Walker River was classified as eutrophic because of the high algae production observed in its waters. Between 1999 and 2004, STORET water quality data recorded concentrations between 0.5 mg/l to 4 mg/l across the stretch of the Walker River near Beachman's boat dock (Figure 6). The large cattle grazing operations nestled along the meandering waters of the river are thought to be a large contributing factor to the nitrogen levels found in the river's waters. In 2007 ranches within the valley began cooperating with the Lahontan Regional Water Quality Control Board and U.C. Davis to alleviate the water quality issues associated with runoff from their lands (Mono Water, 2012).

Phosphorus

Phosphorus is a common component of fertilizers, manure, and organic wastes in sewage and industrial effluent. While it is an essential nutrient for plant growth it can speed up eutrophication and deterioration of a waterbody (USGS, 2018). In recent years, recorded data for phosphorous monitoring on the Carson River presents average concentrations between 0.02 and 0.06 mg/l with what appears to be a cyclic trend presented between every 2-3 years (Figure 7).

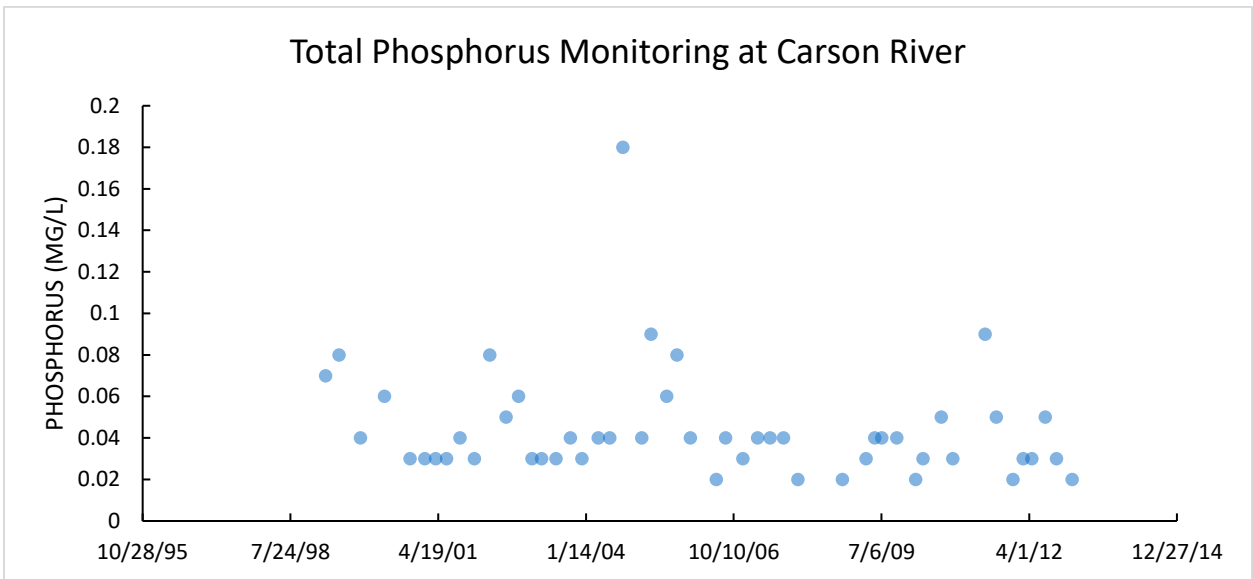


Figure 7. Phosphorus (mg/L) Measurements at Carson River. Source: STORET Water Quality Data.

A Total Maximum Daily Load (TMDL) has been established for the West Fork of the Carson River. A total of 15 sampling locations were used in 2005 to test for total phosphorus and the majority of such stations returned values in excess of the acceptable limit of phosphorus concentrations. This abundance of phosphorus has acted in conjunction with existing nitrogen and other water quality issues to exacerbate the growth of algae in the waters of the river as well as the reduction of dissolved oxygen within the water column (NDEP, 2005).

it deteriorates water quality by deflecting light from penetrating the water column and promotes the degradation of aquatic environments (USGS, 2016a). The degradation of riparian habitat on pasture and crop land promotes the release of sediment leading to turbidity issues.

Dissolved Oxygen- Although water molecules have an atom of oxygen attached to them more oxygen needs to be available in a body of water for living aquatic organisms. This incorporation of dissolved oxygen from the atmosphere tends to involve moving water and stagnant water tends to have less dissolved oxygen. Bacteria consumes oxygen as organic matter in water decays, and this poses a quality concern as excess organics and dissolved oxygen can lead to eutrophication (USGS, 2017).

Fecal Coliform- Fecal coliform is a category of bacteria that is found in the feces of warm-blooded animals. The presence of this bacteria in a waterbody is not likely to induce illness, but rather it can be used as a proxy indicating that disease causing pathogens could be in the water system (DOH, 2016).

Temperature- Temperature influences the rate at which biological activity and growth occurs in water as well as the kinds of life that can occupy a water body. If a waterbody hosts species that are accustomed to a specific temperature range and then the temperature changes, then this can negatively impact the wellbeing of species. (USGS, 2016b)

BIODIVERSITY CONSIDERATIONS

The Carson and Walker watersheds hold important significance for fishermen and fish species alike. In the Walker basin, certain fish species including the tui chub, Tahoe sucker, and Lahontan cutthroat trout serve as ecological indicators for changes in salinity and water levels (National Fish and Wildlife Foundation, 2015). Species presence in the watershed may signal ecological health and a functional system, while absence serves as a warning signal that water quantity and quality have degraded to uninhabitable conditions. At times, conditions may become so severe that species are threatened with local or permanent extinction. The Lahontan cutthroat trout (*O. clarkii henshawi*, LCT), in particular, was once thought to be extinct and is now listed as a federally threatened species (Peacock et al., 2017). Native to the hydrographic regions of northern Nevada, northeastern California, and southeastern Oregon the Lahontan cutthroat trout is a cold-water fish that was severely impacted in the 1940s by invasive species, water diversions, overfishing, and changing rainfall patterns (Peacock et al., 2017). In the late 1970s, a small population of the Lahontan cutthroat trout was discovered in Utah's Pilot Peak Mountains. By comparing the fish DNA to museum pieces this population was confirmed to be genetically distinct to those of the Truckee River watershed (Peacock et al., 2017). Since the 1940s numerous plans have been initiated to return these ecologically and culturally significant fish species to their natural ranges. In 1995 the U.S Fish and Wildlife Service published a Lahontan cutthroat trout recovery plan in which the habitat requirements are listed as cool waters and spawning habitat in protected pools; however, the trout remains a threatened species (U.S. Fish and

Wildlife Service, 1995). The Walker River in Nevada is stocked annually with the Lahontan cutthroat trout, as hatcheries release the fish into native rivers and flows (National Fish and Wildlife Foundation, 2015). This species is carefully monitored for continued improvements and progress. Consistent management decisions promoting beneficial water quality and quantity conditions in the local watersheds and adjoining areas contribute to improvements for existing fish populations, of all species.

The rain shadow produced by the eastern Sierras shapes a predominantly semi-arid vegetation system composed of salt desert and sagebrush (Baldwin et al., 2003). Many animals and migratory birds find shelter in this habitat. However, a year-round bird species, the Sage-Grouse (*Centrocercus urophasianus*), receives the most attention as its population and habitat dwindle and the USFWS considers it for listing (Sharpe, Calblk, & Thomas, 2007). As a result, the Sage-Grouse has garnered much attention and conservation funding while becoming an icon for sage brush ecosystem restoration and conservation in the area.

The majority of the Walker Watershed falls in the Great Basin; the largest desert ecosystem in North America. Its location also gives the area the unique property of being the only cold desert on the continent (Mares, 1999). The uniqueness of the area translates to a delicate balance where any stress on the ecosystem transfers stress to endemic species. Therefore, the Great Basin, and by extension The Walker Basin, hosts the second highest number of imperiled species in comparison to all other regions in the U.S. (Forbis et al., 2006). However, not all species are dependent on one habitat type. The sheer size of the basin allows for fair variability in its habitats. The surrounding mountains offer a high alpine environment sloping down into coniferous forests with pinyon-juniper woodlands that meet sagebrush scrubs before ending in a salt flat (Smith, 2000). At the geologic low point of the valley is the Walker River; a predominantly snow-fed river that produces a vein of riparian habitat that meanders its way to the terminal Walker Lake. Along this path the Salt Cedar (*Tamarix ramosissima*) has become a common invasive species which has instigated the introduction of the salt cedar leaf beetle (*Diorhabda carinulata*) as a biological control agent.

MARKET MECHANISMS AND STAKEHOLDER CONSIDERATIONS

Aside from the local projects listed previously in the existing management projects and concerns section of this report, a variety of market mechanisms were considered for the market feasibility section of this report. Market mechanisms are collectively the means by which supply and demand interactions are carried out between buyers and sellers with determined prices and quantities of a good or service that is available for sale. In the context of this report, market mechanisms refer to any and all payment or trade schemes used for water resource management and incentivizing interactions between upstream and downstream water users. Innovative and creative market solutions are constantly evolving in the world of conservation and resource management in this day and age. This report was

prepared under the context of known mechanisms operating in the local region or in practice globally; however, recommendations described here should not be limited in the case that other creative configurations also come forward at a later date.

MARKET MECHANISM TYPES (GENERALLY)

Water markets come in many forms with some aimed at water supply objectives and others at water quality initiatives. There are numerous benefits to water markets generally classified as 1) stimulating savings by valuing water with appropriate pricing 2) increasing water availability 3) improving flexibility between community stakeholder decisions 4) improving water use productivity and allocation 5) returning water to nature as instream flows and 6) improving accounting and monitoring for future water availability (Richter et al, 2016). Water supply market mechanisms may include payments for ecosystem services, water funds, water rights transfers and trading, as well as water banking among others. Likewise, typical water quality market mechanisms may include payments for ecosystem services and cap-and-trade quality trading schemes.

Payments for Ecosystem Services

Payments for ecosystem services (PES) are considered voluntary transactions where defined ecosystem services (land uses and practices) are purchased (paid for) by a service buyer under a form of conditional agreement (Rebecca L. et al., 2012). A common form of this program is often seen with municipal agencies or water managers paying farmers to perform best management practices on their farms such as reducing irrigation requirements or nutrient loadings –within their capacity to do so.

Water Fund

Water funds are considered a payment for watershed services (PWS) scheme in which numerous stakeholders pay into a trust fund financial model (or savings account in some cases) that is managed by an independent financial governing party for long term payouts (Rebecca L. et al., 2012). This may sometimes be analogous to crowd sourcing sustainable funding for ongoing conservation projects within a watershed. The main objective of the more recent water fund market mechanism system is allowing downstream users the ability to finance upstream protections for regular and clean supplies of water resources (Rebecca L. et al., 2012).

Water Rights Transfer and Trades

Water rights transfers and trading are one of the more common water market mechanisms available. The actual capacity to trade water rights (typically coupled with land property rights) varies between states and is dependent on local water rights laws and allocation practices. In theory, water rights trades and transfers are the temporary or permanent exchange of a water rights point of diversion, nature of use, or point and place of use. For

the state of Nevada, as listed in Nevada Revised Statute 111.167, it is presumed that water rights transfer with the sale of land unless specifically reserved (State of Nevada Department of Conservation and Natural Resources Division of Water Resources, 2016). To transfer water rights relevant parties must complete a “Report of Conveyance” packet which constitutes a valid water right transfer of ownership once submitted and accepted by the State Engineer (State of Nevada Department of Conservation and Natural Resources Division of Water Resources, 2016).

Water Banking

Water banking deals with water storage and is used as a tool to lease water for a temporary period between water rights holders and users (Singletary, n.d.). Water is temporarily transferred or held by a managing group without any permanent changes to water rights. These “banks” can be managed by either private or public entities with administration varying between boards or directors and individual rights holders. In some areas these actions are merely seen as paper water rights accounting.

Cap-and Trade Systems

Cap and trade systems function generally on the supposed “cap” that is placed on a quantity of pollution (or whatever good is being considered) with permits or defined pollutant (good) allowances assigned to the respective parties who then are able to trade between themselves (paying one another). These market mechanisms may often be utilized when trying to address water quality issues from numerous contributors in a watershed. These types of market programs are designed to self-regulate improvements via incorporating technology improvements and innovations as polluting parties pay one another to either alter, improve, or maintain existing operations. The most common example of this mechanism in action, in another context, is that of regional and national carbon cap-and-trade programs.

EXISTING (LOCAL) MARKETS AND TRENDS

Moving and selling water rights has been an ongoing and fundamental aspect of water management in both the Carson and Walker basins. The first major water rights appropriation that set to move water rights around these basins was the Newlands Project, which diverted much of the Truckee River at Derby Dam into the Carson River at the modern-day Lahontan Reservoir for agricultural irrigation near the City of Fallon. This project was made began in 1903 and was made possible by the federal Reclamation Act passed only a year earlier. The adjudication of water rights in both the Carson and Walker basins, coupled with the system of prior appropriation led to years of decreasing streamflow(s) and declining water quality in the ecologically important terminuses of the Walker River (i.e., Walker Lake), Carson River (i.e., Stillwater National Wildlife Refuge), and Truckee River (i.e., Pyramid Lake) (AMP Insights, 2016).

Today historical judicial rulings, such as the Orr Ditch Decree in the Walker basin and the Alpine Decree in the Carson basin, have solidified downstream tribal rights to water and have emphasized increasing flows to the important desert terminal lakes in this region. These judicial rulings, the adjudication of water rights, and competing water interests (e.g., expanding population and industries, ecological flows and tribal rights, and agricultural users) have created the necessary enabling criteria (e.g., governance structure, defined rights, adequate supply and demand, and monitoring and enforcement) for water transfers to occur in both basins (AMP Insights, 2016). In the Walker basin, the Walker Basin Conservancy is federally funded and tasked with the permanent purchase and transfer of water rights from users in the basin to Walker Lake to address declining lake levels and salinity levels. To date over 80 cubic feet per second and more than 10,700-acre feet of water have been permanently transferred to Walker Lake through this program (Walker Basin Conservancy, 2019).

In the Carson basin water rights held by agricultural users in the Newlands Project, where water from the Truckee River has been diverted and used for agricultural irrigation, have transferred water rights upstream to the Truckee Meadows area for use by municipalities to supply the expanding urban population in this area. Newland Project water rights have also been transferred for environmental purposes in both the Carson and Truckee basins. In the Truckee basin these agricultural water rights have been transferred upstream to allow increased flow to Pyramid Lake through water rights held by the Pyramid Lake Tribe to protect the cui-ui (*Chasmistes cujus*) fish species that is listed as endangered under the federal Endangered Species Act. Similarly, Newland Project water rights have been transferred to Stillwater National Wildlife Refuge to promote wetland habitat that is important for migratory birds (AMP Insights, 2016).

RELEVANT STAKEHOLDERS AND LOCAL INDUSTRIES

The Carson and Walker Rivers provides valuable agricultural land, development, and recreation uses. These users have historically been at odds, with ranchers opposing new subdivisions and recreational users opposing unsustainable development and activities. Recently, ranchers have been embracing conservation easements to alleviate the pressure of development. However, important stakeholders in the Carson River watershed still have many conflicting views on how to best manage land and water rights. Suburbanization has already impacted the upper Carson watershed and predicted growth reports for the cities of Minden and Gardnerville indicate that the trend will likely continue.

The Douglas County Master Plan Land Use Element guides future land use within the county. This includes a regional plan for the Carson Valley where the Carson River watershed is located. The Carson Valley Regional Plan contains 11 community plans, with the North, South, and Central Agricultural Community Plan accounting for the largest area (approximately 30% of the Carson Valley Regional Plan area). These plans contain land use

policies to identify locations for urban growth, preservation of natural and scenic resources, and continued agricultural and resource uses. The Carson Valley is also dominated by land owned by the Washoe Tribe, which borders the higher density residential areas around the East Fork of the Carson River.

Agricultural Users (Crop Production and Cattle Ranching)

Agricultural land use is heavily encouraged in Douglas County, with the Master Plan explicitly stating that “Douglas County shall plan for the continuation of agriculture as a distinct and significant land use in the county.” At the time of the 2012 USDA census, Douglas County’s agricultural sector produced \$301.9 million and employed 715, totaling 8% of the county’s production output and 2.4% of county employment (Nevada Department of Agriculture, 2015). Douglas County contains 255 farms, covering 101,000 acres or 22% of the county’s land area. The largest agricultural land use is cattle and calf production, accounting for over \$10 million in farm business income in 2016 (Headwaters Economics, 2018). The second largest land use is for forage land, producing hay crops intended for silage and greenchop. In 2015, 15,555 acres of Douglas County agricultural land was used for haylage (USDA, 2012). Other agricultural uses include sheep and goat farming (9.4% of farmland by acreage), vegetable and melon farming (2.4% of farmland by acreage), and greenhouse and nurseries (2.4% of farmland by acreage) (Headwaters Economics, 2018).

Despite Douglas County’s investment in keeping the area agriculturally oriented, agricultural water use rates are predicted to decrease as agricultural land parcels are increasingly subdivided to accommodate a rapidly expanding suburban population. Residents of Douglas County rejected an additional sales tax designated to preserve open space, allowing for increased suburbanization (USGS, 2006). Nevada is a designated ‘Right-to-Farm’ state, meaning that farms are only subject to nuisance lawsuits under specific conditions and are allowed to create dust, noise, odor, and pollute waterways that may flow into residential areas (Douglas County Nevada, 2017). Since 1975, agricultural water users within the Carson and Walker River Basins have increasingly switched to drip irrigation, laser leveled fields, and lined ditches (Nevada Division of Water Planning, 2017).

Municipalities and Local Residents

There are no incorporated cities or towns officially placed within Douglas County. Significant unincorporated towns in Douglas County include Gardnerville, Gardnerville Ranchos, Genoa, Glenbrook, Indian Hills, Johnson Lane, Kingsbury, Minden, Stateline, Topaz Lake, and Zephyr Cove-Round Hill Village. The most populous city being Gardnerville Ranchos, a census-designated place with 11,000 residents. Municipal managers are under considerable pressure from the county-level government to preserve the rural lifestyle and resist subdivision and growth.

The population of Douglas County has grown substantially over the past four decades. As of 2015, a reported 47,710 residents live within county borders. In 1996, the issue of population growth management was recognized as a priority by adding the Growth Management Chapter (20.500) into Douglas County Code (Douglas County, 2011). Since that additional numerous programs have been implemented to manage growth and protect traditional rural lifestyles. Programs include set urban service areas (discouraging development outside existing areas –including water, sewer, parks, and schools), development rights transfer programs, open space acquisition programs and pursuing grant funding to preserve open space lands (Douglas County, 2011). The county is made up predominantly of older, more conservative individuals, with a medium age of 51 years old and the county voting Republican in all major elections since 1996 (City-Data, 2016).

Tribal Users

The Washoe Tribe headquarters are located in Garnerville and the tribe exists as a primary landowner within Douglas County. The federally designated tribe operates four reservation communities spanning much of the non-developed areas of the Carson Valley (US Forest Service 2016). The Washoe have been in legal battles with federal and state entities since the 1940's attempting to recover their ancestral water rights. In 1970, the Washoe were granted a five-million-dollar settlement and claims to a portion of their ancestral homeland. However, this land was primarily barren rather than the productive, water-rich holdings of the Pine Nut mountains. The tribe is granted seniority in terms of water rights and continues to fight for expanded access to their ancestral water (US Forest Service 2016). Like TNC and many other conservation groups in the area, the Washoe Tribes Environmental Protection Department is also concerned with modeling the effects of climate change and lead their own conservation projects throughout the surrounding watersheds including work at the Leviathan Mine Superfund Site and restoration in Meeks Meadow. The tribe also leads a variety of education outings in the area connecting local tribe member youths with the cultural heritage and naturalist knowledge of the surrounding rivers and watersheds.

Recreationists and Tourism Industry

Tourism is an important part of Douglas County. The county borders on Lake Tahoe and includes the municipalities of Stateline and Glenbrook, communities based around winter sports and lake recreation. The county is also host to Carson Valley trails; a citizen organization founded in 1994 to address the loss of public lands due to subdivision. The non-profit organization manages 54 miles of public trails in the Genoa-Minden-Gardnerville region. These trails are located near the Carson River. Hikers can enjoy river access at the River Fork Ranch trail system, a Carson Valley Trails managed system of hiking paths located on The Nature Conservancy's land (Carson Valley Trails 2018).

In addition to winter sports and hiking trails, visitors to Carson Valley enjoy the region's fishing. The Carson River and Walker River are host to bowcutt trout, brown trout, and

rainbow trout. The Lahontan Cutthroat trout is a federally threatened fish which once populated the Carson, Walker, and Truckee rivers extensively. The fish, popular with sport fishers and the state mascot, has a recovering population within Pyramid Lake and a hatchery located along the Walker River. Fishing is especially popular in Topaz Lake and on the East Fork of the Carson River. Both the Carson and Walker River have sportfishing as a designated beneficial use, with certain reaches being designated warm-water spawning. Recreational users are dependent on the Carson and Walker Rivers being in good condition to ensure viable sport fisheries (Nevada Department of Fish and Wildlife 2015).

OBJECTIVES & SIGNIFICANCE

Water availability and timing are major concerns for the growing population of residents in Douglas County. Ranchers and agriculturalists comprising the majority of the industries in the studies watershed basins stake their livelihoods on these resources. Likewise, local wildlife including listed species and their critical habitats (previously mentioned) may be detrimentally affected by alterations to the type (rain, snowmelt, etc.) and timing of water supply resources.

Climate change, developmental pressures, and general turnover in land use lead water resource managers and conservationists to anticipate future management actions in order to address these alterations. TNC is mainly concerned with understanding what scientific baseline currently exists for available water supplies in the Carson and Walker watershed areas, how these ecosystem services will be changing in relation to climate conditions and land use (as well as how sensitive they may be to these changes) as well as which market mechanisms are likely to be the most effective in mitigating these future changes.

The research conducted and presented throughout the body of this report seeks to accomplish five main objectives:

1. Evaluate Historic Water Quantity and Quality Trends
2. Establish Current Scientific Baseline (For Hydrologic Systems and Water-Based Ecosystem Services)
3. Explore Future Scenarios (Climate Change and Land Use Modeling)
4. Conduct a Market Feasibility Study
5. Recommend Optimized Management Solutions

Deliverables accompanying these objectives include a selection of Appendix documents including two watershed analysis reports, a separate market feasibility report, as well as a manual of curated best management practices and recommendations. The overall goal and objective of this research is to supply local resource managers with an optimized selection of scientifically-based environmental management solutions that they can collectively and collaboratively implement across the Eastern Sierra Nevada.

METHODS

In order to accomplish the objectives, as outlined in this report, the research group choose to 1) perform a watershed analysis of the two relevant basins 2) evaluate ecosystem services (after a series of prioritization and selection criteria was met) and 3) conduct a market feasibility study to optimize and recommend applicable alternative management solutions. The purpose of these three evaluation methodologies was to first access historic trends in water supply, water quality, and existing management actions in the region, prepare an accurate accounting of the current scientific baseline for future monitoring and comparison, as well as recommend solutions customized for the water resource managers, stakeholders, and actual biophysical location presented in the Eastern Sierra Nevada.

WATERSHED ANALYSIS

In order to account for changes to a watershed, whether from climate variation or the results of human management activities, comparing historic trends and establishing a scientific baseline for comparison is an essential first step. A watershed is essentially a drainage basin that covers a specific land area as precipitation drains through a river (or multiple river) system. Water resource managers often create a “Watershed Management Plan” to outline existing hydrologic, geographic, and existing management projects throughout their local river basins. Watershed management plans require numerous analyses, literature reviews, as well as ongoing monitoring efforts to produce an accurate scientific baseline for reference.

Throughout this study, two preliminary watershed management plans were prepared for 1) the Walker River Basin (Appendix A) and 2) the Carson River Basin (Appendix B). In addition, existing management plans, research publications, and management tracking documents were consulted to inform the creation of these documents. Due to the prominent location of these two water baselines along the California-Nevada state line and at the base of the Eastern Sierras, these locations are well-studied with ample data and materials to draw from to inform this analysis.

These watershed management plans were prepared by analyzing data from BASINS database (US EPA, 2019) and ArcGIS mapping software on location, topography (elevation in feet), land use, soil characteristics including hydrologic group distribution (A-D soil groups and their runoff potential), erodibility, permeability, as well as hydrology (river and stream network, groundwater aquifer placements, etc.) were analyzed. In addition, SNOTEL data (NRCS, 2019) was used to access historic and recent climatic conditions (temperature and precipitation patterns) over the past thirty years. For the majority of these additional calculations (done outside ArcGIS map processing) work was completed in either excel or statistical processing software RStudio and plotted for visual analysis. Land use classifications for both river basins (except tundra which is only present in Walker Basin) include water, tundra, residential development (low, medium, and high), commercial

and industrial barren land, deciduous forest, coniferous forest, mixed forest, rangeland, cropland and pasture, as well as both forested and non-forested wetlands.

Scientific literature as well as reports from Nevada Department of Wildlife (NDOW, 2019) and Natural Heritage Program (NNHP, 2019) were used to identify biological assets in these river basins. Biological assets include Endangered Species Act listed species (for threat or endangerment), critical habitat areas, as well as areas of note –including wilderness refuges and specific population ranges. Additional information on habitat suitability (in relation to water-based ecosystem services around the respective rivers studied) was gathered for each of these species to be used in other analysis on biodiversity and ecosystem services. This information came from numerous sources including guidebooks and various species atlases as part of the larger literature review conducted for this report.

In line with researching a baseline of biological assets, human demographics were also analyzed to understand current trends in population growth, income levels, relevant industries to each basin, water supply demands (and changes over time), as well as land use related to these topics. Data was gathered from the United States Census Bureau, USGS, individual county documents, as well as scientific literature.

HISTORIC TRENDS

Demographics and Per Capita Water Demands

Population dynamics were evaluated by taking population data for the counties comprising both the Walker and Carson watershed from 1950-2010. Each analysis was conducted separately and framed for either the Carson Basin or the Walker Basin, as well as for Douglas County as a whole. The percent change in population totals were calculated between the most recent decades (1990-2010) and (2000-2010) for comparison. Calculations for water demand and per capita water use were performed by taking USGS data for “water use in the United States,” and converting into gallons used per person per day, normalized by county. These calculations (compared across county per capita use) were generated from data occurring from 1985 to 2015.

Irrigation water for agriculture crops in these areas are supplied from local water sources (surface water when available and groundwater when surface supplies are limited). To account for irrigation demands, data on agriculture usage was taken from the USDA’s CropScape mapping software and database. This software also allows for automated statistics generation for a number of selected fields. The most prevalent crops in each basin were mapped and quantified based on land used for planting. Additional calculations were performed to identify crop-water demands by referencing scientific literature. For example, alfalfa average water use was compared across Nevada, Idaho, and California for water use demands in acre feet of water per planted acre of the crop. Total irrigation withdrawals

were plotted by county in million gallons (Mgal) per day. (A single Mgal/day is equivalent to roughly 700 gallons pumped and used per minute.)

In this area, land is owned primarily by the Bureau of Land Management, the U.S. Department of Defense, Tribal parties, the State of Nevada, and the U.S. Forest Service with the remainder of private lands comprising the rest of the available acreage for human development. Due to the increasing population size observed in the past few decades in certain counties, existing land-use planning documents and zoning ordinances were also referenced for these baseline reports.

In line with evaluations on human development and water use, flood hazard maps and data were also referenced and analyzed from a variety of sources including Nevada's Division of Water Resources, the Federal Emergency Management Agency (FEMA), as well as local county documents. Due to the local river floodplain in Walker and Carson, seasonal flooding is a routine occurrence that varies with changes to type and timing of water supply in the form of precipitation. Additional flood-based analyses were conducted in conjunction with the literature review and evaluation of historic, current, and predicted water supply.

Historic, Current, and Predicted Water Supply

One of the fundamental questions posed by this research initiative concerns what do we know about the historic, current, and predicted water supply availability to Douglas County, Nevada. While future predictions are incredibly complicated, requiring intense modeling (covered in a later portion of the methodology), historic and current water supply analyses were performed using data available from USGS stream gauges, snow water equivalent (SWE, measured in accumulated inches) data from SNOTEL sites, past reports on reservoir fill capacities, and additional scientific literature. Evaluations for changes to historic and current water supplies were carried-out through the following methods 1) creation of hydrographs of specific stream gauge sites 2) an analysis of 10th, 50th, and 90th percentiles for water flow 3) an analysis of timing for flow (which months see most water instream) 4) average annual flow 5) peak timing of flow and intensity of flooding events, as well as 6) a multiple linear regression model identifying relationships between precipitation, SWE, timing (annual and monthly), temperature, and instream flow discharge.

Hydrographs & Percentiles of Flow

Hydrographs were prepared by pulling all available USGS stream gauge data for average daily flow (measured flow of cubic feet per second; cfs). Any years with missing or partial data across stream gauges were removed, for consistency and accuracy in analysis. Full sets of data were arranged based on water year (Oct 1st – September 30th) on the x-axis and dates from the year of record on the y-axis, to plot average daily flow. For each row of data, our team calculated a percentile function for the 30th, 50th, and 90th percentiles across all -

axis years on record selecting the best representative sample of data for that percentile range. This process was repeated across all daily datasets in each percentile. The results were plotted on a graph and colored for visual details.

Snow water equivalent, also known as SWE, (inches) data was procured from NRCS’ SNOTEL network portal for the entire record available. From this the 30th, 50th, and 90th percentiles were calculated and plotted. This produced three water years (October 1st to September 30th) each representing a percentile daily SWE content rate for the headwaters of the Carson and Walker Rivers. This data was then graphed in Excel as a series of line graphs.

Percent of discharge by month was calculated by taking daily average flow (cfs) data from USGS’s water monitoring portal for the entire record available. From this the 50th percentile water year was produced. The daily CFS flow rate was then summed by month and divided by the total flow for the year. This produced a percent of total annual discharge by month. This was then transformed into a graph and further enhanced in Microsoft PowerPoint where each month is represented by a circle where each percent of discharge by month is represented by a 10th of an inch in the circle’s diameter.

Conceptual Model – Multiple Linear Regression (MLR)

To aid in understanding historical interactions and relationships between major water supply variables, a simple multiple linear regression model was created for both Walker and Carson river water supply data. The MLR analysis was built using RStudio statistical analysis software –including data formatting, exploration, and final plots. Data was obtained from USGS stream gauge stations, measured in discharge of cubic feet per second (cfs), SNOTEL data for precipitation (inches), average temperature (Fahrenheit), and snow water equivalent (SWE, inches). The Walker River analysis was based on three selected USGS stream gauge stations, chosen for their location along major stretches of the river and availability of data (**Table 1**). The Carson River MLR analysis was generated based on data from four USGS stream gauge stations along major stretches, chosen for the same reason and under similar conditions to Carson (**Table 2**). For both the Carson and Walker River five (different) SNOTEL sites were selected and used –based on location along contributing areas of the headwaters (**Table 3**).

Table 1. Walker River USGS Stream Gauge Stations.

Walker Stream Gauge Stations:

USGS 10293000 E WALKER RV NR BRIDGEPORT, CA
USGS 10296000 W WALKER RV BLW L WALKER RV NR COLEVILLE, CA
USGS 10301500 WALKER RV NR WABUSKA, NV

Table 2. Carson River USGS Stream Gauge Stations.

Carson Stream Gauge Stations:

USGS 10308200 E FK CARSON RV BLW MARKLEEVILLE, CK
USGS 10310000 W FK CARSON RV AT WOODFORDS, CA
USGS 10312150 CARSON RV BLW LAHONTAN RESERVOIR NR FALLON, NV
USGS 10312275 CARSON RV AT TARZYN RD NR FALLON, NV

Table 3. SNOTEL Sites (Walker & Carson).

Walker River SNOTEL Sites:	Carson River SNOTEL Sites:
846 Virginia Lakes Ridge	462 Ebbetts Pass
587 Lobdell Lake	633 Monitor Pass
574 Leavitt Lake	356 Blue Lakes
575 Leavitt Meadows	697 Poison Flat
771 Sonora Pass	778 Spratt Creek

Preliminary exploration of available data included a check for collinearity in RStudio. This check indicated a moderate correlation between precipitation and SWE ($r = 0.53$). Average temperature was removed from the model due to the inherent collinearity between month and temperature. For the sake of this study, historical patterns in timing was a more significant question to answer than at which temperature water supply was occurring. After exploring the data and completing code for the model, plots of historical streamflow were generated at each site. Walker sites include 1) East Walker River 2) West Walker River and 3) Walker River Post Confluence. Carson plotted sites include 1) East Carson River 2) West Carson River 3) Carson River Post Lohontan Reservoir and 4) Carson River Post Fallon. Additional plots were created for each of the following sites, using time series decomposition to separate major trends, seasonality, and residuals across data. The results of these additional analysis and plots were then formatted using the code `polar = TRUE`, to show results across 365 days back-to-back for visual comparison and peak identifications.

Water Quality Analysis

In addition to a literature review of existing studies, models, and local expert knowledge; water quality conditions were analyzed by compiling data from the USGS as well as EPA’s STORET water quality database (Appendix A, Appendix B). Select water quality monitoring stations were chosen based on available data, parameters considered in study (e.g. dissolved oxygen, fecal coliform, nitrogen levels, and temperature among others).

Levels of concentration were plotted and a trend line was applied to visualize water quality trends throughout time. For the Walker basin data was available from 2007 to 2015, while for Carson data was available between 1998 and 2017. Comparisons of water quality parameter states over time was also supplemented by mapping and determining which stretches of the Carson and Walker Rivers are officially listed as 303d for water impairments and exceeded concentrations.

CLIMATE DATA

Local climate data was used to analyze trends in the headwaters of the Carson and Walker basins to determine if there have been historic patterns of changing climate. The Carson and Walker basins are located east of the Sierra Nevada crest in a “rain shadow” region with low precipitation (University of Nevada, 2001). As a result, these watersheds are fed mostly from Sierra snowmelt and are vulnerable to climate change effects on the amount of snow and the timing of the snowmelt (Scalzitti, Strong, & Kochanski, 2016). A change in these factors could severely alter the amount and timing of water availability in the Carson and Walker watersheds as well as increase the chance for flooding. Thus, climate change impacts in the Sierra Nevada headwaters are of particular importance to those who live in the area (CWSD, 2015).

Specifically, climate data from the National Climate Data Center’s (NCDC) Local Climatological Database was analyzed at a location near the Indian Creek Reservoir near Alpine Village in the eastern Sierra Nevada (approximately 1,700 meters [5,578 feet] above sea level) (Thorton et. al., 2016). To evaluate the effects of climate change in this area, the data (compiled from NCDC) was aggregated by year. Averages and extremes were then calculated for daily maximum temperature, daily minimum temperature, total precipitation, and maximum SWE. Linear model trend analyses and Mann Kendall trend tests were conducted on these factors to determine if there were significant trends in the data from 1980-2018. For some factors, a t-test was performed to compare means for different subsets of the 1980-2018 time period.

CURRENT SCIENTIFIC BASELINE

Ecosystem services are constantly changing based on the water availability, water quality, and human management actions that directly affect their state. In order to carry-out future adaptive management actions and monitoring programs it is important to start with a scientific baseline. To establish a true scientific baseline requires constantly seeking out and updating existing data information, practicing effective communication strategies, and transparency in management strategies. The following information was compiled from a variety of sources to list the general state of existing ecosystem services, at this point in time, based on type including the major categories of provisioning, regulating, supporting and cultural services (**Table 4, Table 5, Table 6, Table 7**). Future studies and management

actions will require a more thorough accounting of the specific site characteristics, species, or conservation metric the managers wish to improve upon.

Table 4. Baseline Provisioning Ecosystem Services.

<i>Ecosystem Category</i>	<i>Ecosystem Service</i>	<i>Baseline - Current Status</i>	<i>Sources</i>
Provisioning Services	Food Production	<p>Agricultural Areas:</p> <ul style="list-style-type: none"> - 45% in Carson Basin - 50% in Walker Basin <p>Economic Value:</p> <ul style="list-style-type: none"> - \$301.9 million produced from Douglas County agricultural sector (USDA, 2012) - \$10 million produced from cattle and calf production alone (Headwaters Economics, 2018) 	<p>BASINS Data</p> <p>(USDA, 2012)</p> <p>(Headwaters Economics, 2018)</p>
	Water Supply	<p>Carson River Streamflow ¹:</p> <ul style="list-style-type: none"> - Gardnerville East Fork: 264, 471 AFY - Woodfords West Fork: 74,746 AFY - Carson City: 291,007 AFY - Fork Churchill: 269,374 AFY - Truckee Canal Hazen: 113,897 AFY - Below Lahontan Reservoir: 349,014 AFY <p>Walker River Streamflow ¹:</p> <ul style="list-style-type: none"> - West Walker River: 185,000 AFY - East Walker River: 132,000 AFY - Main Walker River: 238,000 AFY <p>Douglas County Water Demand:</p> <ul style="list-style-type: none"> - Domestic per capita use: ~165 gallons/person/day - Commercial self-supplied groundwater withdrawals: ~0.61 Mgal/day - Industrial self-supplied groundwater withdrawals: ~0.17 Mgal/day - Livestock self-supplied groundwater withdrawals: ~0.21 Mgal/day - Irrigation self-supplied groundwater withdrawals: ~9.79 Mgal/day 	<p>USGS (1985 - 2015)</p>

Notes: ¹ Average Annual Streamflow

Table 5. Baseline Regulating Ecosystem Services.

<i>Ecosystem Category</i>	<i>Ecosystem Service</i>	<i>Baseline - Current Status</i>	<i>Sources</i>
Regulating Services	Water Storage	<p>Main Water Supply: - Sierra Nevada snowpack</p> <p>Reservoirs: - Lahontan Reservoir: 3,819 AFY (min)¹, 305,200 AFY (max)² - Walker Lake: 915,600 AFY (min)³, 1,295,000 AFY (max)⁴ - Weber Reservoir: 1,530 AFY (min)⁵, 10,770 AFY (max)⁶ - Topaz Lake: 2,589 AFY (min)⁷, 59,450 AFY (max)⁸ - Bridgeport Reservoir: 1,608 AFY (min)⁹, 41,940 AFY (max)¹⁰</p>	USGS Water; Water-Year Summaries
	Water Quality	<p>303(d) Impaired Listings for: - Chlorophyll a - Dissolved oxygen - Fecal coliform - Kjeldahl nitrogen - Phosphorus - Water temperature - Total dissolved solids (TDS) - Total suspended solids (TSS) - Turbidity</p>	U.S. EPA
	Floodplain Management	<p>Flood Events: - Carson Basin: 35 flood events from 1852 to present (USGS, 2013) - Walker Basin: 8 severe flood events from 1907 to present (USGS, 2013)</p> <p>Wetlands Flood Control Benefit: - \$564 to \$1,679 per AFY (CWSD, 2010)</p>	
	Erosion Control	<p>Erosion Control Issues on Major Highways: - Sediment load 100,000 lbs./yr. in Douglas County (Douglas County Master Plan, 2011)</p>	

Notes: ¹ Lowest Value (WY 2014-2018), Ranged October to December

² Highest Value (WY 2014-2018), Ranged April to July

³ Lowest Value (WY 2014-2018), Ranged August to December

⁴ Highest Value (WY 2014-2018), Ranged June to October

⁵ Lowest Value (WY 2014-2018), Ranged September to October

⁶ Highest Value (WY 2014-2018), Ranged April to June

⁷ Lowest Value (WY 2014-2018), Ranged July to October

⁸ Highest Value (WY 2014-2018), Ranged March to June

⁹ Lowest Value (WY 2014-2018), Ranged August to October

¹⁰ Highest Value (WY 2014-2018), Ranged March to July

Table 6. Baseline Supporting Ecosystem Services.

<i>Ecosystem Category</i>	<i>Ecosystem Service</i>	<i>Baseline - Current Status</i>	<i>Sources</i>
<i>Supporting Services</i>	Wildlife Habitat	<p>Forests and Meadows: - At least half of the forest and meadows in the Sierra source watersheds are estimated to be degraded or severely degraded (Podolak et al., 2015)</p> <p>Riparian Buffer Zones: -Riparian restoration projects already in place by TNC - Reduce the impacts of flooding by increasing the surface roughness of the area around a river (Nevada Division of Water Planning, 1997)</p>	
	Biodiversity	<p>Species Richness:¹ - Upper Carson (16050201): 354 - 390 - Middle Carson (16050202): 354 - 390 - Lower Carson (16050203): 327 - 353 - Walker (16050301, 16050302, 16050303, 16050304): 327 - 353</p> <p>Federally Listed Species: - Lahontan cutthroat trout (<i>O. clarkii henshawi</i>) - Sage grouse (<i>centrocercus urophasianus</i>)</p>	Southwest Regional Gap Analysis Project, U.S. Fish and Wildlife Service

Notes: ¹ Based on modeled population ranges for the Nevada National Heritage, Southwest Regional Gap Analysis Project. Numbers indicate sum of species still found within that range, the highest species richness from this study was 354-390. Richness is lower along the upper and middle Carson.

Table 7. Baseline Cultural Ecosystem Services.

<i>Ecosystem Category</i>	<i>Ecosystem Service</i>	<i>Baseline - Current Status</i>	<i>Sources</i>
<i>Cultural Services</i>	Recreation	Recreational Activities: - River floating - Kayaking - Rafting - Fishing/fly fishing - Bird watching - Water fowl hunting	
	Education	Educational Programs: - School trips to the watershed (TNC) - Monarch butterfly and naturalist projects (TNC) - Science field trips and campout groups around the rivers (TNC)	
	Aesthetics	River habitat, meadows, open fields, and the Eastern Sierra.	

CONSIDERATIONS FOR FUTURE SCENARIOS

To account for the third aspect of water availability, projected future scenarios, our research team looked to existing climate and land use models. Climate change is an important issue with most research groups in the Sierra Nevada area having publications of their own climate model results. Models are amply available, from a variety of sources. Although none of these models are accurate representations of climate change possibilities which are ultimately unknown, some are more useful than others. We decided to take an ensemble approach, referencing a variety of climate models (with credible sources) to provide for a range of possible outcomes. Due to the proximity between California and Nevada in this area of study, we looked to the California’s Fourth Climate Change Assessment for prioritization methods in choosing which models were most viable for this process (Pierce et al. 2018). Overall, the models chosen for the background watershed assessment as well as the ecosystem service evaluation are meant to provide a spectrum of possibilities. These are used to identify a range of outcomes (with confidence intervals and errors) to get a general sense of what the odds are in terms of future water availability.

FUTURE SCENARIOS - CLIMATE CHANGE

To project water availability and quality into the future, our research team looked to existing models that estimate temperature and precipitation data into the future (**Figure 9**). There are currently over 30 global circulation models (GCMs) created by institutions across

the world that model changes in the earth’s climate systems as a result of increased greenhouse gas (GHG) emissions. These models differ in the type of mechanisms they model (atmospheric aerosol forcing, ocean-atmosphere interactions, etc.) and at what level of resolution these climate systems are modeled (IPCC, 2015). As a result, no single GCM is adequate to accurately account for the range of possible climate results from increased global GHG emissions.

To address the differences in modeling techniques used by the GCMs we used an ensemble of three GCMs recommended based on the prioritization methodology for selecting GCMs in California’s Fourth Climate Change Assessment (Pierce et. al., 2018). This methodology evaluated 32 GCMs using the most recent precipitation and temperature data from the Coupled Model Intercomparison Project Phase 5 (CMIP5) that was downscaled specifically to fit the western United States region. A tiered set of selection criteria, including temperature, precipitation, and variability, were weighted and used to rank 32 different GCMs. Based on these rankings the methodology identified three of the GCMs used in our future projections analysis: 1) National Centre for Meteorological Research (CNRM-CM5) representing a generally wetter/cooler climate future for this region, 2) Canadian Centre for Climate Modelling and Analysis (CanESM2) representing an average climate future, and 3) Met Office Hadley Center’s Hadley Global Environment Model 2 - Earth System (HadGEM2-ES) representing a drier/hotter climate future.

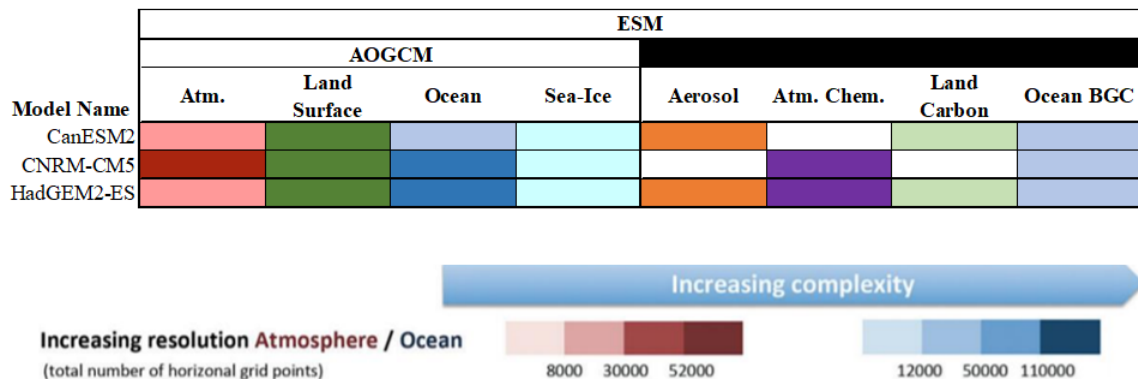


Figure 9. Characteristics of Selected Global Circulation Models. Adapted from IPCC Report (See Appendix C-1 for full list of models and additional references). Source: IPCC, 2015.

The Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) created Representative Concentration Pathways (RCPs) to represent four possible future scenarios, depending on how GHGs are emitted in the future based on land use, population, and economic factors. Two different future RCPs representing potential best case and worst-case scenarios were modeled with the three prioritized GCMs to determine the range of possible future outcomes. Scenario RCP4.5 was selected to represent a best-case future

in which GHGs are mitigated consistent with the Paris Climate Agreement, with global annual emissions levelling off by 2100 resulting in a global average temperature increase of approximately 2.4 °C by this time (Thompson et. al., 2011). On the other end of the spectrum, RCP8.5 represents the business-as-usual scenario, where GHG emissions continue to rise throughout the 21st century (Wayne, 2013).

ECOSYSTEM SERVICES EVALUATION

Ecosystem services are fundamental aspects of any watershed, and are directly affected by changes to watershed features including water, land use, and the presence of pollutants. These services can generally be thought of as services that provide additional benefits to humans other than their primary ecological purpose. These benefits may be regulating pollutants in a stream, supporting nutrient cycling, allowing for food and water to be used as consumption, as well as educational, cultural, and recreational benefits of open space. Due to the extensive number of these services, in order to be evaluated one must limit the scope and prioritize analyses.

Our ecosystem service evaluation overall involves 1) selecting which ecosystem services are to be studied in this region (which ecosystem services will be most important to the local residents and stakeholders who currently reside there?) 2) deciding how these ecosystem services should be evaluated and 3) performing the selected analyses. In some instances, the evaluations needed to be performed for the selected ecosystem services were supplemented by recent scientific publications as part of the overall literature review rather than carried out in the same way by our team. The intention of this section is to identify which ecosystem services will be most sensitive to changes in climate as well as identify major trends in these changes if applicable.

SELECTION PROCESS

Selecting Ecosystem Services for Study

With so many ecosystem services acting in tandem in one area, ecosystem services to be evaluated by this study needed to be narrowed for analysis. After an initial review and consulting scientific literature, the research team choose to focus on the following ecosystem services for additional study and evaluation:

- Water Supply and Availability (Snowpack, Forests, and Meadows)
- Flood Control
- Erosion Control (Riparian Habitat and Sediment Transport)
- Food Production
- Fish and Wildlife
- Water Quality: Nutrient Delivery and Filtration
- Recreation, Education, and Culture

To further evaluate these ecosystem services a combination of modeling, scientific literature review, land use change calculations, and comparative studies were used.

Selecting Models for Analysis

After deciding on which ecosystem services would be prioritized for this study, numerous models were considered to perform a baseline analysis and model possible variations due to climate change. The Natural Capital Project’s InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) was selected to carry-out these analyses. TNC has partnered with the Natural Capital project to design these modeling –often used in application for planning existing water markets and investment projects throughout the areas in which TNC works.

MODELING

Natural Capital Project

The Natural Capital project offers free, open-source modeling tools to be used to show spatial valuations of ecosystem services and processes. Within the Natural Capital project there is the main modeling toolbox InVEST which offers a variety of models. In addition, add-on model packages include RIOS, OPAL, PYGEOPROCESSING, and SCENARIO SUPPORT. For the sake of this analysis the InVEST Models for Seasonal Water Yield, Nutrient Delivery Ratios, and Sediment Delivery Ratios were used. Each of the InVEST models were modeled using existing data to establish a “baseline” as well as ran with data form existing climate models depicting climate change. Climate change models included cooler and wetter climate [CNRM-CM5], average [CanESM2], warmer and dryer [HadGEM2-ES] as well as climate scenarios with emissions peaking at 2040, then declining [RCP 4.5] and emissions continuing to rise strongly through 2050 till stabilizing in 2100 [RCP 8.5]. The main years considered for future climate models include 2050 and 2100.

INVEST MODELS – IN PRACTICE

After evaluating the available models in the Natural Capital, InVEST program three models were chosen to indicate seasonal water yield supply throughout the watersheds, nutrient delivery, as well as sediment loading. These three models get at the two predominant questions of water supply and water quality conditions throughout the watershed basins in respect to existing geologic, hydrologic, and land use conditions (**Table 8, Table 9, Table 10**). Each model requires different data inputs in the form of ArcGIS formatted raster datasets. Numerous, sometimes complex data gathering and transformation methods were also used to obtain these sources (Appendix C) supplied in full detail in supporting documentations. The following information provides a general methodology overview for each main model type selected.

Seasonal Water Yield (SWY) Model

Table 8. Seasonal Water Yield Model Inputs

Seasonal Water Yield		
Input	Description	Format/Units
<i>Watershed</i>	Shapefile delineating the boundary of the watershed to be modeled.	Polygon Shapefile
<i>Land-Use/Land-Cover (LULC)</i>	Raster of land use/land cover (LULC) for each pixel, where each unique integer represents a different land use/land cover class.	Raster
<i>Digital Elevation Model (DEM)</i>	Raster of elevation for each pixel. Floating point or integer values.	Raster [units: meters]
<i>Biophysical Table</i>	A CSV table containing biophysical coefficients corresponding to each of the land use classes in the LULC raster input. It contains the following fields: 1) <i>lucode</i> : Unique integer for each LULC class. 2) <i>CN_A, CN_B, CN_C, CN_D</i> : Integer curve number (CN) values for each combination of soil type and <i>lucode</i> class. 3) <i>Kc_1, Kc_2... Kc_11, Kc_12</i> : Floating point monthly crop/vegetation coefficient (Kc) values for each <i>lucode</i> . <i>Kc_1</i> corresponds to January, <i>Kc_2</i> February, etc.	CSV
<i>Precipitation Directory</i>	Folder containing 12 rasters of monthly precipitation for each pixel.	Raster Directory [units: mm]
<i>Evapotranspiration (ET) Directory</i>	Folder containing 12 rasters of monthly reference evapotranspiration for each pixel.	Raster Directory [units: mm]
<i>Rain Events Table</i>	A CSV table with 12 values of rain events, one per month. A rain event is defined as > 0.1 mm.	CSV
<i>Threshold Flow Accumulation Value</i>	The number of upstream cells that must flow into a cell before it is considered part of a stream, which is used to classify streams from the DEM.	Value
<i>alpha_m, beta_i, gamma Parameters</i>	Model parameters used for calibration and research purposes. <i>alpha_m</i> calculated for each month using the following equation, $P_{m,1}/P_{annual}$. Default values for <i>beta_i</i> and <i>gamma</i> were used; <i>beta_i</i> = 1 and <i>gamma</i> = 1.	Calibration Parameter

To run the seasonal water yield model input data (Table 8) includes raster files for the following: precipitation (mm/month) actual evapotranspiration directory (mm/month) – supplied from NASA satellite imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) downloaded using the MODIS ArcGIS toolbox, digital elevation model (DEM) supplied from the BASINS 4.1 software (m) and filled in using ArcGIS for continuity land use land cover data (LULC) taken from the National Land Cover Database (NLCD) 2016 and Multi-Resolution Land Characteristics Consortium (MRLC) and boundaries of each watershed were taken from BASINS 4.1 as shapefiles. In addition, a biophysical table needed to be prepared with a series of input constants for curve numbers (obtained from literature review) and soil erodibility k factors (calculated in ArcGIS). To calculate the k factor in ArcGIS the Enhanced Vegetation Index (EVI) raster obtained from NASA satellite and MODIS was overlain on the existing LULC file where average EVI was calculated for each land use type. In addition, values for rain events was arranged in an input table (mm), data was gathered from historical precipitation events with the National Weather Service Forecast Office of Reno, NV (2014-2018). Rain events were selected based on precipitation for any event over 0.1 mm of rainfall and averaged for each month.

The Threshold Flow Accumulation Value input was calculated using the existing DEM files for both the Carson and the Walker basins. Using ArcGIS tools, the data was filled to ensure continuity, flow direction was calculated using the geoprocessing tool (with the flow direction raster as an input), and the flow accumulation raster was then manipulated in order to visualize the stream network. Symbology was changed to show classified breaks,

the cell classes were divided into two categories, one category simulating where water accumulates and the others simulating land. Stream network simulated in ArcGIS was then compared to national hydrology dataset (NHD) river network obtained from BASINS 4.1 and threshold manipulated to match the main stem of the river visually.

The model was calibrated using a selection of calibration parameters as provided within the InVEST software models. As a function of precipitation seasonality, α was calculated by setting monthly values to the antecedent monthly precipitation values relative to the total precipitation using the following equation $P_m - 1 / \text{Annual}$. Beta and gamma parameters were set to default values, $\beta_i = 1$ and $\gamma = 1$ as instructed by the InVEST Modeling manual. β_i is a function of local topography and soils –for a given amount of upslope recharge, the amount of water used by a pixel is a function of the storage capacity. γ represents the fraction of pixel recharge that is available to downslope pixels. It is a function of soil properties and possibly topography. In the default parameterization, γ is constant over the landscape and plays a role similar to α .

The Seasonal Water Yield model was processed for Carson and Walker basin under normal conditions, and repeated for each run of the selected climate models.

Nutrient Delivery Ratio Model (Phosphorus & Nitrogen)

In addition to the data required for the Seasonal Water Yield model, the Nutrient Delivery Ratio Model requires data for the nutrient runoff proxy –a raster representing the spatial variability in runoff potential and the capacity to transport nutrients downstream (Table 9). Nitrogen and phosphorus loading raster were obtained the U.S. EPA EMAP-West Metric Browser and overlaid onto the existing LULC data to compute average nitrogen loadings per LULC type. The critical length factor was set to the cell size of 84 m by 84 m. For the calibration parameter of Borselli k , a parameter that determines the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the nutrient delivery ratio (percentage of nutrient that actually reaches the stream), the default value of 2 was chosen. The model was later calibrated by comparing outputs from the nutrient delivery ratio model to existing reports for phosphorus loadings in the watersheds –rather than a true calibration this process was referred to as a validation of existing results. The InVEST software is intended to be used in this case primarily for spatial, land use planning applications rather than direct values of nutrient loadings. The calibration process determined that the values modeled and actual records were of the same magnitude. With only a single value available for calibration this limited the model's ability to be more accurately tailored to the watershed beyond these means.

Table 9. Nutrient Delivery Ratio Model Inputs

Nutrient Delivery Ratio - Nitrogen and Phosphorus		
Input	Description	Format/Units
<i>Watershed</i>	Shapefile delineating the boundary of the watershed to be modeled.	Polygon Shapefile
<i>Land-Use/Land-Cover (LULC)</i>	Raster of land use/land cover (LULC) for each pixel, where each unique integer represents a different land use/land cover class.	Raster
<i>Digital Elevation Model (DEM)</i>	Raster of elevation for each pixel. Floating point or integer values.	Raster [units: meters]
<i>Biophysical Table</i>	<p>A CSV table containing biophysical coefficients corresponding to each of the land use classes in the LULC raster input. It contains the following fields:</p> <ol style="list-style-type: none"> 1) <i>lucode</i>: Unique integer for each LULC class. 2) <i>load_n</i> and/or <i>load_p</i>: The nutrient loading for each land use, given as decimal values with units of kg. ha-1 yr-1. Suffix <i>_n</i> stands for nitrogen, and <i>_p</i> for phosphorus. 3) <i>eff_n</i> and/or <i>eff_p</i>: The maximum retention efficiency for each LULC class, a floating point value between zero and 1. The nutrient retention capacity for a given vegetation type is expressed as a proportion of the amount of nutrient from upstream. 4) <i>crit_len_n</i> and <i>crit_len_p</i>: The distance after which it is assumed that a patch of a particular LULC type retains nutrient at its maximum capacity, given in meters. 	CSV
<i>Nutrient Runoff Proxy</i>	Raster dataset representing the spatial variability in runoff potential, i.e. the capacity to transport nutrient downstream. This raster was defined as a quickflow index from the InVEST seasonal water yield model output.	Raster [units: mm]
<i>Subsurface Retention Efficiency - Nitrogen or Phosphorus</i>	The maximum nutrient retention efficiency that can be reached through subsurface flow, a value between 0 and 1. This field characterizes the retention due to biochemical degradation in soils.	Value
<i>Subsurface Critical Length - Nitrogen or Phosphorus</i>	The distance (traveled subsurface and downslope) after which it is assumed that soil retains nutrient at its maximum capacity.	Value [units: meters]
<i>Threshold Flow Accumulation Value</i>	The number of upstream cells that must flow into a cell before it is considered part of a stream, which is used to classify streams from the DEM.	Value
<i>Borselli k Parameter</i>	Calibration parameter that determines the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream). Default value used; 2.	Calibration Parameter

Sediment Delivery Ratio Model

In addition to values computed and prepared for the Seasonal Water Yield model the Sediment Delivery Ratio Model (Table 10) required additional inputs in that of a rainfall erosivity index (R) given in units of MJ*mm/ha*h*yr. and obtained from the European Commission Global Rainfall Erosivity raster, the soil erodibility (K) factor retrieved from BASINS software, as well as additional aspects of the biophysical table. This biophysical table also contained the cover management factor (c) and support practice factor (p) for the USLE raster obtained from U.S. EPA EMAP-West Metric Browser which were overlaid on existing LULC data to determine averages by land use type. This model contains two calibration parameters of kb and ICO used to determine the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream). The default values of kb set to 2 and ICO set to 0.5 were chosen and later calibrated and validated by altering these values and assessing changes in magnitude of results against existing real-world data. The SDRmax value the maximum SDR that a pixel can reach, a function of the soil texture and defined as the fraction of topsoil particles finer than coarse sand, was set to 0.8.

Table 10. Sediment Delivery Ratio Model Inputs

Sediment Delivery Ratio		
Input	Description	Format/Units
<i>Watershed</i>	Shapefile delineating the boundary of the watershed to be modeled.	Polygon Shapefile
<i>Land-Use/Land-Cover (LULC)</i>	Raster of land use/land cover (LULC) for each pixel, where each unique integer represents a different land use/land cover class.	Raster
<i>Digital Elevation Model (DEM)</i>	A GIS raster dataset with an elevation value for each cell. Make sure the DEM is corrected by filling in sinks, and compare the output stream maps with hydrographic maps of the area. To ensure proper flow routing, the DEM should extend beyond the watersheds of interest, rather than being clipped to the watershed edge.	Raster [units: meters]
<i>Biophysical Table</i>	A CSV table containing biophysical coefficients corresponding to each of the land use classes in the LULC raster input. It contains the following fields: 1) <i>lucode</i> : Unique integer for each LULC class. 2) <i>usle_c</i> : Cover-management factor for the Universal Soil Loss Equation (USLE), a floating point value between 0 and 1. 3) <i>usle_p</i> : Support practice factor for the Universal Soil Loss Equation (USLE), a floating point value between 0 and 1.	CSV
<i>Rainfall Erosivity Index (R)</i>	Raster dataset, with an erosivity index value for each cell. This variable depends on the intensity and duration of rainfall in the area; the greater the intensity and duration of the rain storm, the higher the erosion potential.	Raster [units: MJ·mm ³ ·(ha·h·yr) ⁻¹]
<i>Soil Erodibility (K)</i>	Raster dataset, with a soil erodibility value for each cell. Soil erodibility, K, is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff.	Raster [units: tons·ha·h ³ ·(ha·MJ·mm) ⁻¹]
<i>Threshold Flow Accumulation Value</i>	The number of upstream cells that must flow into a cell before it is considered part of a stream, which is used to classify streams from the DEM.	Value
<i>k_b and IC₀</i>	Calibration parameters that determine the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream; cf. Figure 3). Default values used; k _b = 2 and IC ₀ = 0.5.	Calibration Parameter
<i>SDR_{max}</i>	The maximum SDR that a pixel can reach, which is a function of the soil texture. Default value used; 0.8.	Calibration Parameter

All raster files used throughout the InVEST modeling process were set to the specifications of cell size 84-84 m, spatial reference NAD_1983_UTM_Zone11N, the same extent (Top: 4,512,385 m, left: 55,798 m, right: 701,105 m, Bottom: 4,117,906 m), and saved in TIFF format.

MODELING FUTURE SCENARIOS

Future scenarios were modeled for RCP 4.5 (emissions peaking in 2040 then declining) for the years 2050 and 2100, RCP 8.5 (emissions continue to rise strongly through 2050 and plateau around 2100) for years 2050 and 2100. Future climate data used in modeled scenarios was obtained from the CanESM2 (Average) climate model (and compared against other available data sources for validation check).

Raster manipulation and updates for future modeled scenarios included altering precipitation and actual evapotranspiration using a percent change from baseline (Table 11) and recalculated using the following equations by means of the ArcGIS Raster Calculator tool:

$$\text{Future Scenario Precip} = \text{Baseline Precip} * (1 + \% \text{change from baseline})$$

$$\text{Future Scenario AET} = \text{Baseline AET} * (1 + \% \text{change from baseline})$$

Table 11. Precipitation (mm) and Actual Evapotranspiration (mm) Percent Change from Baseline Scenarios Using CanESM2 (Average) Future Climate Model. Note: Values for 2050 are averaged over 2045 to 2055 and values for 2100 are averaged over 2090 and 2100.

CanESM2 (Average)			
2050		Precipitation	AET
	RCP45	-0.033	0.099
	RCP85	-0.187	-0.084
2100		Precipitation	AET
	RCP45	-0.024	0.104
	RCP85	-0.354	-0.280

PRIORITY AREAS

After the current baseline and future projections for water availability (baseflow contribution) and quality (nitrogen and phosphorus export) parameters were modeled using InVEST, estimates for the amount that these parameters would be altered in the future as a result of climate change were determined. The top 25% of areas that would experience the most change in each of the three-water availability and quality parameters were mapped for each watershed. These areas were then overlaid onto a single map to determine if there were overlap areas that may experience the most change of multiple parameters affecting water availability and quality. This map was then evaluated to determine if there were priority areas that were affecting multiple water availability and quality parameters that could be addressed simultaneously through management actions, resulting in the greatest results for the least amount of management effort.

SENSITIVITY ANALYSIS

A sensitivity analysis was performed on the InVEST modeling results to determine how they would change given different future scenarios for global greenhouse gas emissions. The possible range of results for baseflow contribution, nitrogen export, and phosphorus export were evaluated based on two representative concentration pathways (RCPs) scenarios: RCP4.5 and RCP8.5. The RCP8.5 climate scenario represents a maximum of this

range where the global average temperature is expected to increase by approximately 4.9 °C by 2100 (Wayne, 2013). The RCP4.5 climate scenario represents a potential minimum of this range (generally assumes achievement of the Paris Climate Agreement goals) and would result in an increase in global average temperature of approximately 2.4 °C.

MARKET FEASIBILITY STUDY

The Nature Conservancy and its partners are looking to see which market mechanism(s) are most feasible in this region. Markets can often be used as effective tools in helping to both manage and mitigate changes to ecosystem services. Throughout this study a market feasibility analysis was conducted to analyze which markets would be most viable in this area. This process involved identify existing market actions and trends, compare case studies to inform management recommendations and ultimately presenting a prioritized list of options.

The market feasibility analysis identifies which ecosystem services have the largest potential for implementing a market solution (e.g., payment for ecosystem services, temporary or permanent water right transfers, and innovative funding mechanisms for conservation or restoration). This feasibility study was completed by 1) analyzing existing market strategies for similar watersheds 2) comparing ecosystem service valuation change based on percent of ecosystem service improvement or degradation under different scenarios of or relating to climate change 3) comparing investment horizons and possible stakeholder contributions through various funding mechanisms, and 4) recommending future action for greatest success to client.

A robust literature review was conducted looking at Water Fund case studies implemented across Latin America as well as pilot projects in the U.S., existing water rights structure in Nevada, water transfer records, as well as historic accounts of other market studies. In addition, stakeholders including ranchers, locals, tribe members, conservation easement firms, community officials, and water resource managers were interviewed by team members to identify possible interests in future investment options. Published literature including additional interview results were used in quantifying these interests in addition to the anecdotal information received by remembers from on-the-ground interactions.

To compare these market mechanisms, a rubric of essential components for success (in the case of each market option) was prepared. Based on what resources, investment interests, and legal structure are present in the area these rubrics were filled in for each market type – indicating resources available and structure in place. After comparing barriers and resources needed for success, market types were ranked based on most viable.

CASE STUDIES & MARKET OPTIONS

Utilizing market mechanisms for conservation efforts and restoration work is becoming a more popular option amongst water resource managers throughout the western states of America as well as throughout the world. In particular, TNC and their partners have been focusing on creating and stewarding Water Funds in Latin America in recent years, with 13 Water Funds either implemented or in development in the North Andes as of 2011 (Goldman et al, 2011).

Irrigators who require verified quantities of water to conduct their business, often employing water leasing, temporary water trades, and water rights sales may aid in procuring the water they need to go about their business, especially for agriculture dominated regions. In addition, numerous conservation groups and agencies concerned with instream-flow and environmental stewardship around rivers, lakes, and streams often make use of water transactions and market mechanism to further their restoration and preservation goals by returning flow and buying up water to remain in-stream.

Market feasibility depends on numerous factors including but not limited to political climate, legislation and legal framework facilitating transfers, the nature of state's water rights, stakeholders invested interest in participating, and general need. This "necessity" factor can sometimes be paramount in moving beyond existing legal and political barriers – when water situations become dire individuals are forced to act and get creative.

Water market mechanisms are still evolving in their application and innovation; however, for the sake of this study the following market mechanisms were considered: water funds, water market transactions (trades, transfers, and leasing), water banking, and payments for ecosystem services.

WATER FUNDS

Water funds act as a crowd-sourcing form of sustainable funding, where beneficiaries (usually downstream users) pay into a central fund that is managed and used to back conservation projects throughout the watershed (**Figure 10**). Stakeholders including farmers, ranchers, recreationists, municipalities, agencies and locals among others can support a local fund (gaining interest on the endowment) that benefits their entire watershed with select projects such as meadow restoration, riparian corridor management, as well as payments for returned water flow when needed.

Quito, Ecuador

TNC first participated in the creation of a water fund project in 2000 with the "fund for the protection of water", el Fondo para la Protección del Agua, (FONAG) located in Quito Ecuador (Goldman et al, 2011). This project covered over 500,000 HA of land and was estimated to be benefiting 2,093,000 individuals (population services) as of 2008 (Goldman

et al, 2011). The first and one of the largest water funds created by TNC to date, this project endowment yielded roughly \$690,000 in 2008 (Goldman et al, 2011). The Quito (FONAG) water fund is sustained by nearly 90% of its funding coming from a mandated ordinance to Quito's water company, requiring 2% of the company's annual budget

There are now seven Water Fund projects set in Ecuador, six in Columbia, as well as new additions in the Asia Pacific, Africa, and North America (Goldman et al, 2011, **Table 12**). Under TNC's management and partnership there are a listed total of 35 water funds in operation worldwide and over 30 more in development (TNC, 2019). In North America there are currently 8 water funds in operation and 10 new funds under development (TNC, 2019). A few key examples of water funds applied in the United States include the Brandywine-Christina Revolving Water Fund, Edwards Aquifer Protection Program, the Rio Grande Water Fund, and the Savannah River Clean Water Fund, Georgia.

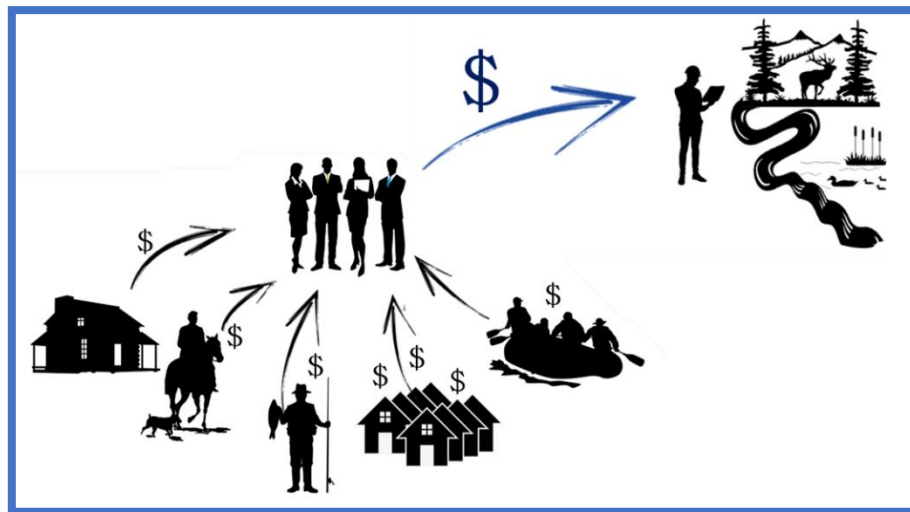


Figure 10. Water Fund Market Mechanism Diagram.

Table 12. Thirteen Water Funds Created by TNC in the Northern Andes, Adapted from "Water Funds" Source Goldman et al, 2011.

Date Created	Water Fund Name	Watershed/City	Beneficiaries (# People)	Fund \$\$\$ (2008)
2000	FONAG	Quito, Ecuador	2,093,000	\$ 6,500,000
2006	Pro-cuencas	Zamora, Ecuador	25,000	\$ 36,000
2008	Espindola	Amaluza, Ecuador	15,000	\$ 6,000
2008	FONAPA	Paute, Ecuador	800,000	\$ 490,000
2009	Tugurahua	Ambato, Ecuador	350,000	\$ 460,000
2009	Agua por la vida y la sostenibilidad	East Cauca Valley, Colombia	920,000	\$ 1,800,000
In Progress	Bogota	Bogota, Colombia	6,840,116	\$ 1,500,000
In Progress	Medellin	Medellin, Colombia	2,700,000	NA
In Progress	Cartagena	Cartagena, Colombia	892,545	\$ 220,000
In Progress	Cali	Cali, Colombia	2,100,000	NA
In Progress	Santa Marta	Sierra Nevada de Santa Marta, Colombia	600,000	NA
In Progress	Catamayo	Catamayo-chira, Ecuador-Peru	NA	NA
In Progress	Ayampe	Puerto Lopez, Ecuador	20,000	NA

Brandywine-Christina Revolving Water Fund

The Brandywine-Christina watershed runs across Delaware and Pennsylvania covering nearly 600 square miles. Providing ~60% of Delaware's drinking water supply to residents and spread across agriculture, forested, wetlands, and urban land use types; TNC began considering the Brandywine-Christina watershed for a water fund to coordinate projects for improved water quality efforts. Annually local non-profit groups, municipalities, state and federal agencies all work independently on conservation projects throughout the watershed. Without effective coordination, funding for projects tends to be limited to grants and private donors with little improvement seen in the watershed as a whole. Efforts are dispersed rather than joined for a more forceful impact overall.

The fund project now in effect derives funding from municipal stormwater and regulatory drinking water utility investments and has plans to create marketable "Environmental Impact Units" which could be sold for additional funding revenue in a revolving fund system (TNC, 2019). Beneficiaries in this fund include water providers from Delaware and Pennsylvania as well as cities with multiple-separate-storm-sewer (MS4) regulation concerns. Current funders also include government agencies and the William Penn Foundation (TNC, 2017 & 2019). Initial conservation projects slated to use these funds include BMP placement for fencing and riparian buffers around agricultural areas.

Edwards Aquifer Protection Program

Serving nearly two million residents in Texas and crossing 12 counties the Edwards Aquifer supports agricultural, industrial and recreational services. (TNC, 2019). For the past few decades, these counties have supported (successful) bond elections to purchase conservation easements across the aquifer --with a total of over 100,000 acres conserved and \$700 million (USD) or more in contributed funds (TNC, 2019). This fund was primarily financed by citizen-approved public investments with the City of San Antonio acting as lead administrator of the projects and funding (TNC, 2019).

Rio Grande Water Fund

In the Rio Grande region, climate change effects and the increased risk of wildfires prompted TNC and their partners to establish the fund in 2014 (TNC, 2019). These efforts were aimed primarily at treating forested acres prone to fire. The fund is administrated by a collaborative charter and executive steering committee with 76 signatories signed on across public and private interests. The fund is expected to generate sustainable project money for the next two decades to aid forest restoration efforts in high-risk areas across the local watershed.

Savannah River Clean Water Fund, Georgia

The Savannah River Clean Water Fund (SRCWF) covered a 2.8-million-acre area including five municipalities with a combined 550,000 residents. Both Georgia and South Carolina administrators are participating in the creation of this water fund. The primary motivations behind this fund were once again water quality and protection future drinking water supply. Facilitation of this fund was also driven by an opportunity to manage the basin covered by nearly 78% forested land and 19% already protect lands with landowner interest in establishing more. The fund managers and TNC partners plan to protect 8,000 acres per year for 15 years with the funding procured by this market mechanism –driven primarily by water users and municipality contributions (TNC, 2019).

Water Fund Major Take-Aways

Enabling conditions for all of these water funds are dependent on the population densities requiring increase (or more secure) water supplies and improved water quality conditions the most successful funds have large contributions coming in from water agencies and purveyors who would otherwise be spending their money on similar, more disperse projects. By pooling these resources into a central fund and coordinating distribution efforts with a targeted systematic approach returns on investment may be high and the ecosystem services presented in each watershed preserved or heightened in quality.

WATER MARKETS – TRADES & TRANSFERS

Records indicate that actively trading water rights for environmental uses specifically, first gained traction in the 1990s in Oregon and the north western united states with the Oregon Water Trust (Szeptycki et al. 2015). A dataset prepared by the Bren school in using water transaction data published by the “Water Strategist” and “Water Intelligence Monthly” from 1987 to 2010, (**Table 13**) indicate that on average roughly 9 water sales, leases, and other exchanges occurred annually with leases only lasting for 1 duration on average (Donohue, Libecap 2010).

Accompanying price data indicate that an average of \$177 (USD) in 2010, roughly was paid to each acre-foot committed during a transaction (Donohue, Libecap 2010). Based on these numbers, which were only adjusted to 2010 values, the lowest price paid for acre foot of water committed was roughly \$42 (USD) and the highest roughly \$603 (USD) (Donohue, Libecap 2010). It is important to remember that these values are based on transactions across the entire state of Nevada and that the market price of water will vary by region and seasonality.

Nearby in the Truckee watershed, the Truckee Meadows Water Authority (TMWA) policy agreements with developers facilitated a surface water rights market. Once designating

surface water and paying a metering fee (\$1,830/AF) developers either designate or purchase water based on necessary increased demands for drought storage on paper and in their reservoirs. Prices in this water market have ranged from \$5,264/AF (2004) to major highs of \$32,848/AF (2006) and have remained around \$7,500 for the past decade (data available from 2010 - 2017) based on available market data compiled.

Table 13. Water Market Transactions in Nevada (1987-2009) Source: Donohue, Libecap 2010.

State	Year	Average Annual AF	Average of Total Price (USD)	Count of Sale	Count of Lease	Count of Exchange	Count of Lease Duration	Average of Inflation Adjusted Price per Committed AF (USD)	Average of Inflation Adjusted Price per Annual AF(USD)
NV	1987	1430.533333	\$ 2,159,564.29	15	15	15	1	\$ 77.12	\$ 1,495.13
	1988	255.25	\$ 476,390.00	8	8	8	NA	\$ 70.01	\$ 1,400.10
	1989	124.3076923	\$ 42,804.25	13	13	13	NA	\$ 94.48	\$ 1,889.65
	1990	415.25	\$ 75,934.33	8	8	8	NA	\$ 71.12	\$ 1,422.43
	1991	2592.5	NA	4	4	4	NA	NA	NA
	1992	12380	\$ 1,303,894.50	5	5	5	1	\$ 118.12	\$ 2,362.49
	1993	6343	\$ 51,000.00	4	4	4	1	\$ 47.17	\$ 47.17
	1994	7440.7	NA	3	3	3	1	NA	NA
	1995	2694.79	\$ 128,572.75	6	6	6	1	\$ 42.35	\$ 843.43
	1997	852	\$ 2,428,200.00	1	1	1	NA	\$ 100.86	\$ 2,017.20
	1998	3889.2	\$ 9,975,928.60	5	5	5	1	\$ 159.55	\$ 2,348.21
	1999	3998.875	\$ 39,120,922.71	8	8	8	NA	\$ 143.81	\$ 2,876.14
	2000	504.8	\$ 1,412,909.67	5	5	5	NA	\$ 99.31	\$ 1,986.16
	2001	777.3333333	\$ 2,131,487.00	6	6	6	1	\$ 115.16	\$ 2,303.26
	2002	816	\$ 3,171,000.00	5	5	5	NA	\$ 119.19	\$ 2,383.77
	2003	544.1111111	\$ 500,118.00	9	9	9	NA	\$ 77.75	\$ 1,555.09
	2004	3171.184444	\$ 3,035,875.83	9	9	9	NA	\$ 168.18	\$ 3,363.63
	2005	1766.825684	\$ 14,598,064.30	19	19	19	NA	\$ 217.46	\$ 4,349.17
	2006	1666.397476	\$ 4,593,543.84	21	21	21	1	\$ 787.51	\$ 15,676.35
	2007	339.5274667	\$ 3,986,814.80	15	15	15	NA	\$ 602.65	\$ 12,053.01
2008	234.512	\$ 1,664,290.24	21	20	18	NA	\$ 217.82	\$ 4,269.27	
2009	181.0366667	\$ 1,316,815.59	8	1	NA	1	\$ 219.46	\$ 4,335.21	
NV Total		1702.714194	\$ 5,798,371.67	198	190	187	9	\$ 238.69	\$ 4,703.97

WATER BANKING

Water banks often help facilitate trades, leases, and transfers between groups. A water bank is an institutional mechanism used to facilitate the exchange of surface water, groundwater, and storage of these water sources –essentially serving as middleman between multiple buyers and sellers. These institutions vary greatly between examples and structuring; however, typical functions and duties may include 1) matching buyers and sellers’ goods 2) setting prices 3) administrating water transfer turnovers, as well as validating water rights and setting rules of trade.

Washington Water Trust

In Washington, the Washington Water Trust acts as a facilitation entity where water supply from water rights holders is certified, priced, and matched by the water bank before going on to help the buyers –typically used for mitigating new water users or restoring instream flow to rivers (Washington Water Trust, 2019). Recent water banking projects include the Dugess Water Exchange, Kittitas Basin, and Walla Walla Basin projects. Walla Walla County and the Washington Department of Ecology set up the (Walla Walla Water)

exchange based on new implementation of the 2007 Instream Flow Rule and an initial purchase of water which was transferred to the State Trust Water Program (Washington Water Trust, 2019). The exchange has been in operation since 2008 and works to ensure instream flows for the environment are occurring without detriment to the economy.

Arizona Water Banking Authority

Established back in 1996, the Arizona Water Bank acts to develop long-term storage credits for Arizona's allocation of their Colorado River entitlement (Arizona Water Banking Authority, 2019). The Arizona Water Banking Authority stores unused Colorado river water by paying for the delivery and storage costs to transfer water through the Central Arizona Project Canal, where it is stored in existing aquifers via direct recharge (Arizona Water Banking Authority, 2019). Each acre-foot in storage earns credit that can be redeemed in the future as back-up water supplies. This is a bit of a unique fund structuring due to the management activities (recharging existing aquifers for direct groundwater banking) and access for interstate banking between Nevada and California.

Colorado River Bank Feasibility Study & Pilot Projects

The well-known and highly politicized Colorado River Basin is currently undergoing the pilot-project phase of setting up their water bank. With calls to create contingency plans for lower-basin shortages that are more likely each year with changing water demands and climate conditions, the Colorado River District and their partners participated in a joint round-table study considering the status of water demands. After this initial planning they formed a water bank work-group out of which came two separate feasibility reports 1) initial phasing on water demand and water rights holding currently held and 2) project site identifications, rubric criteria for priority rankings, and pilot project implementation recommendations. As of April 2017, the pilot is expected to cost \$2 million over the course of two years with up to around ~1,000 acres participating (Colorado River District, 2019). Many discussions on payment schemes and communication efforts for longer term scaling-up are still in progress.

Water Banking Major Take-Aways

When facilitated by existing water rights and policy structures, water banking market mechanisms are effective tools in transferring water for instream benefits for wildlife, storing water for later use, and facilitating cross-basin coordination of water supplies. Differing from a water fund, water banks act as mediators between water transfers or managing entities of actual stored water and its accounting. The preference for one market mechanism over another depends on stakeholder interest, possible investment opportunities, and how well different groups across the basin can coordinate their work be it through restoration projects or water banking options.

PAYMENTS FOR ECOSYSTEM SERVICES (PES)

Payments for ecosystem services are often coupled with the other market mechanisms previously listed. For example, stakeholder groups such as ranchers may be compensated for changes in their behavior such as employing water conservation techniques or new management strategies (e.g. switching irrigation from flood to drip, using fences to prevent cows from crossing over riparian corridors) or watershed benefactors pay in response to receiving benefits (e.g. recreationists and park fees). Being that payments for ecosystem services are fairly common with more examples than is feasible to mention here specifically they are discussed throughout the paper at length in other sections.

RESULTS

Efforts to quantify water supply and water quality markers, establish an ecosystem service baseline, model possible changes due to climate variations, identify priority areas for future projects, and recommend most applicable market structure to facilitate these projects are described in detail in the following section as well as supplemented by Appendix A, Appendix B, and the separate Market Feasibility Report documents prepared for Douglas County Water Resource Managers.

HISTORIC WATER QUANTITY & QUALITY TRENDS

Annual Average Daily Maximum and Minimum Temperatures

An increase in temperature at the Carson and Walker basins headwaters could potentially affect snowpack accumulation and melting, the dominant processes that control the water level of the Carson and Walker Rivers. To determine the trend in annual average daily maximum and minimum temperatures, a linear regression model was fitted for the years 1980 to 2018 (**Figure 11**).

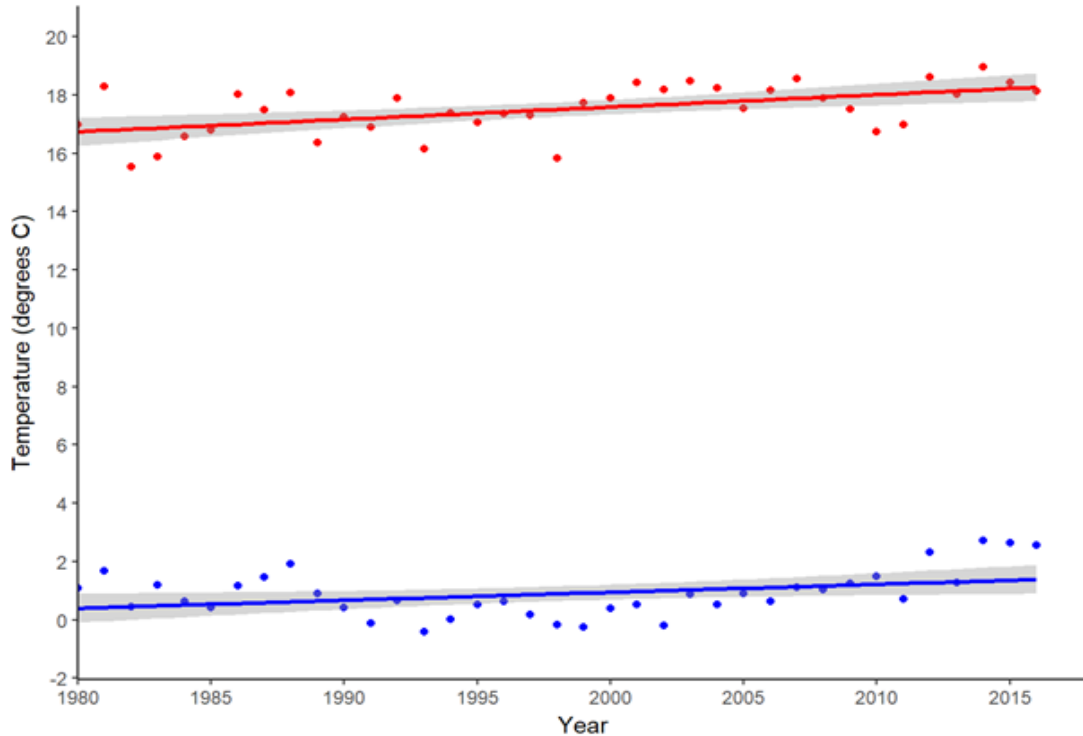


Figure 11. Annual average daily maximum and minimum temperatures in the Carson and Walker River headwaters (1980-2018).

In **Figure 11**, the red points represent the average annual daily maximum per year, the red line denotes the maximum temperature linear regression model ($F(1, 35) = 13.96$, $p < 0.001$, $R^2 = 0.27$, $\alpha = 0.05$, and Kendall's $\tau = 0.38$), and the grey shadow represents a 95% confidence interval. The blue points represent the average annual daily minimum per year, the blue line denotes the minimum temperature linear regression model ($F(1, 35) = 5.47$, $p = 0.03$, $R^2 = 0.11$, $\alpha = 0.05$, and Kendall's $\tau = 0.23$), and the grey shadow represents a 95% confidence interval. Data Source: Thorton et al., 2016.

Based on these models, there was a weak but significant increase in the annual average daily maximum temperature by about $0.04\text{ }^{\circ}\text{C}/\text{year}$ over the last 38 years ($F(1, 35) = 13.96$, $p < 0.001$, $R^2 = 0.27$, $\alpha = 0.05$, and Kendall's $\tau = 0.38$). Additionally, there was a weak but significant increase in annual average daily minimum temperature by approximately $0.03\text{ }^{\circ}\text{C}/\text{year}$ over this time period ($F(1, 35) = 5.47$, $p = 0.03$, $R^2 = 0.11$, $\alpha = 0.05$, and Kendall's $\tau = 0.23$).

Furthermore, the average annual daily maximum temperature was significantly greater ($t(34.9) = -4.25$, $p < 0.001$, $\alpha = 0.05$) more recently (2001-2018) than historically (1980-2000). Similarly, the average annual daily minimum temperature was significantly greater ($t(26.76) = -2.59$, $p = 0.01$, $\alpha = 0.05$) and increased at a faster rate of approximately 0.16

°C/year ($F(1, 14) = 40.12, p < 0.001, R^2 = 0.72, \alpha = 0.05$) from 2001-2018 than from 1980-2000.

Total Annual Precipitation

To determine if climate change would affect local precipitation (snow and rain) in the Carson and Walker basins headwaters, a linear regression model for annual total precipitation was used (**Figure 12**). The model revealed that there was no significant trend of change to total annual precipitation over time ($F(1, 36) = 1.26, p = 0.27, R^2 = 0.007, \alpha = 0.05$, and Kendall's $\tau = -0.10$).

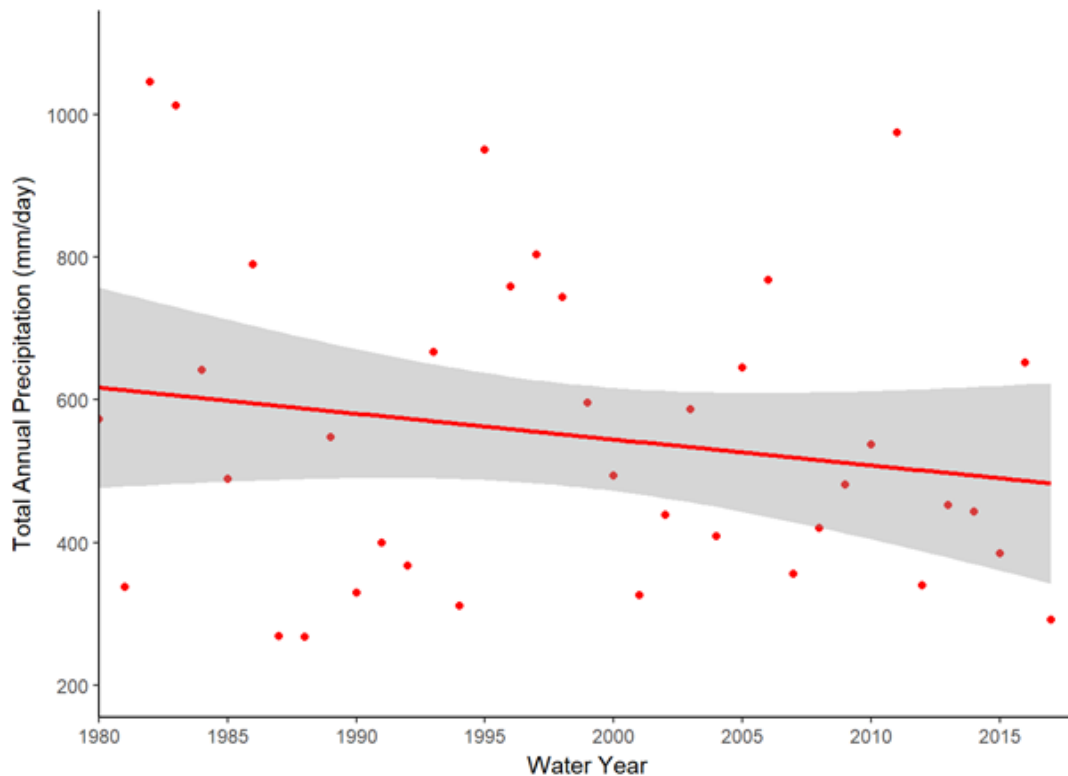


Figure 12. Total annual precipitation in the Carson and Walker River headwaters (1980-2018).

In **Figure 12**, the red points represent the total annual precipitation, the red line denotes the linear regression model, and the grey shadow represents a 95% confidence interval. The model revealed that there was no significant trend in total annual precipitation ($F(1, 36) = 1.26, p = 0.27, R^2 = 0.007, \alpha = 0.05$, and Kendall's $\tau = -0.10$). Data Source: Thornton et al., 2016.

Annual Maximum and Average Snowpack

Although there was no significant trend in precipitation, water levels could still be affected by climate change if the rising temperature trends described above cause changes in

snowmelt amount and timing. A linear model was used to investigate changes in annual maximum snowpack. A Mann Kendall test revealed that there was a significant decreasing trend in maximum SWE of the snowpack over 1980-2018 (Kendall's $\tau = -0.24$, $p=0.04$, $\alpha = 0.05$), but the model showed that this significance was borderline ($F(1, 36) = 3.34$, $p = 0.07$, $R^2 = 0.08$, $\alpha = 0.05$) (**Figure 12**).

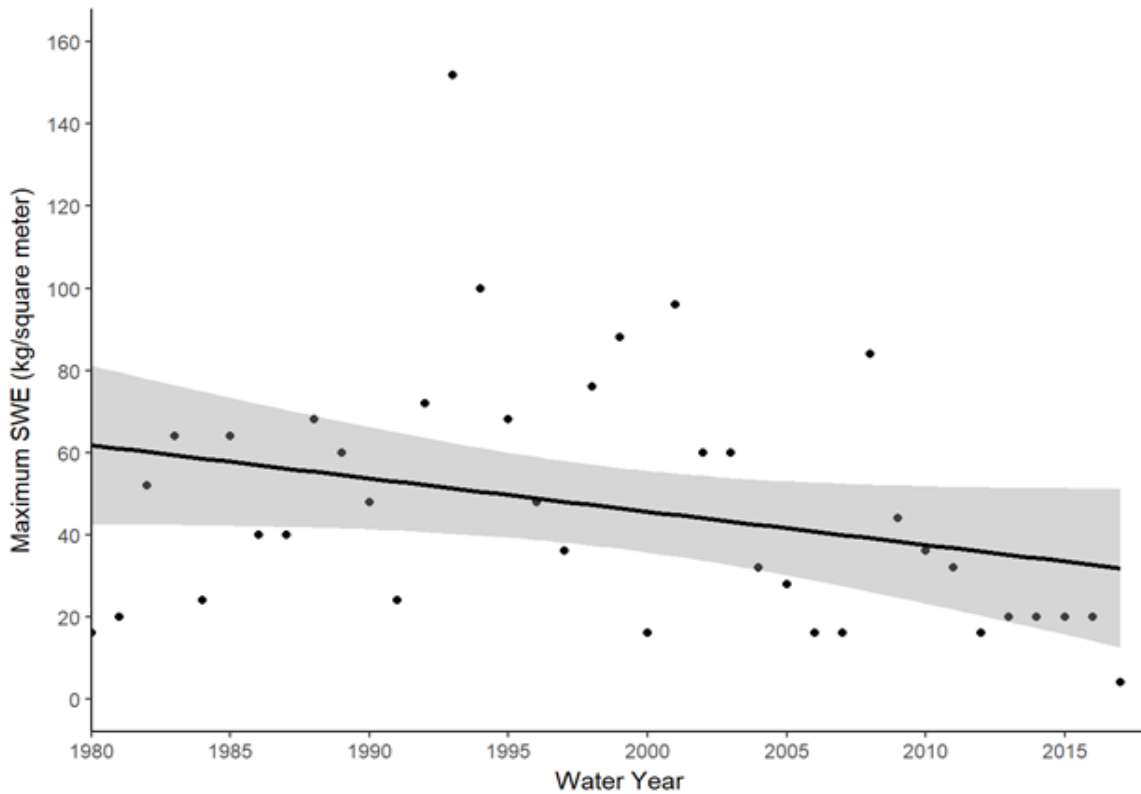


Figure 13. Maximum Snow Water Equivalent (SWE) (kg/m²) of snowpack in the Carson and Walker River headwaters (1980-2018).

In **Figure 13**, the black points represent the SWE for a given year, the black line denotes the linear regression model, and the grey shadow represents a 95% confidence interval. This model showed a borderline significant decreasing trend ($F(1, 36) = 3.34$, $p = 0.07$, $R^2 = 0.08$, $\alpha = 0.05$). However, a Mann Kendall test resulted in a significant decreasing trend in maximum SWE over this period (Kendall's $\tau = -0.24$, $p=0.04$, $\alpha = 0.05$). Data Source: Thorton et al., 2016.

However, more recently (1991-2018), the decreasing trend was significant, with a 2.69 kg/m² decrease in maximum SWE per year ($F(1,25) = 14.85$, $p < 0.001$, $R^2 = 0.37$, $\alpha = 0.05$) (**Figure 13**). Similarly, the average SWE of the snowpack from 1980-2018 only

showed a borderline significant decreasing trend ($F(1,36) = 3.30$, $p = 0.08$, $R^2 = 0.08$, $\alpha = 0.05$), but more recently (1991-2018) the trend was significant with a 1.35 kg/m² decrease in average SWE per year ($F(1,25) = 10.51$, $p < 0.01$, $R^2 = 0.30$, $\alpha = 0.05$).

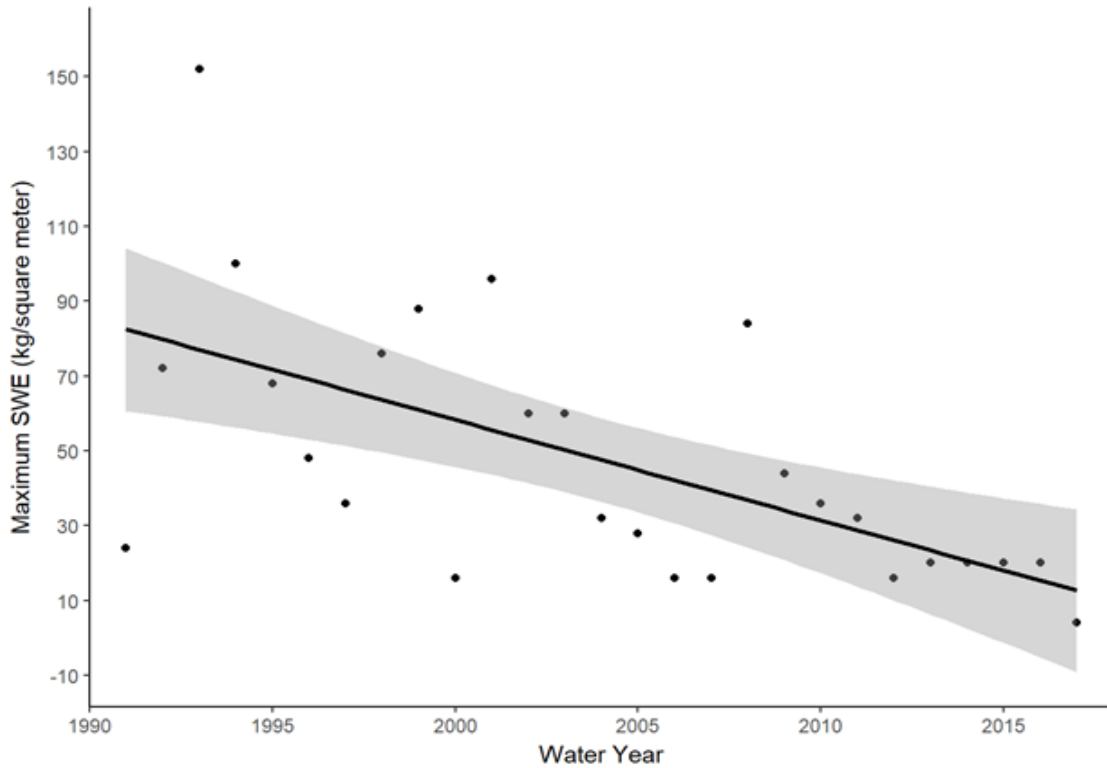


Figure 14. Maximum Snow Water Equivalent (SWE) (kg/m²) of snowpack in the Carson and Walker River headwaters for a recent subset of years (1990-2018).

In **Figure 14**, the black points represent the SWE for a given year, the black line denotes the linear regression model, and the grey shadow represents a 95% confidence interval. This model showed a significant decreasing trend in SWE over 1990-2018 ($F(1,25) = 14.85$, $p < 0.001$, $R^2 = 0.37$, $\alpha = 0.05$). Data Source: Thornton et al., 2016.

Historical Climate Trend Discussion and Conclusions

This report provides a trend analysis of important climatic variables (temperature, precipitation, and SWE) for the Carson River headwaters from 1980 to 2018. Major findings include:

- Annual average minimum temperature had a significant upward trend - increasingly so more recently (2001-2018)

- Annual average maximum temperature had a significant upward trend from 1980-2018, but the trend was not significant over just the more recent time period (2001-2018)
- Annual total precipitation had no significant trend
- Annual maximum and average SWE significantly decreased more recently (1991-2018)

Even though there is not a significant trend in total annual precipitation (rain and snow), the amount and timing of water availability in the Carson and Walker River headwaters are still being affected by significant trends in temperature and SWE. Rising daily maximum and minimum temperatures could result in less snow, more rain, and an earlier melting of the snowpack (Scalzitti, Strong, & Kochanski, 2016). This would likely cause lower river levels in the later summer months because the snowpack will not be able to store as much water due to higher temperatures and an earlier peak melting. This could lead to water shortages in the area affecting urban, agricultural, and wildlife water uses.

WALKER AND CARSON BASIN MAJOR TRENDS & CONCERNS

Water Supply – Hydrographs

The following hydrographs (**Figure 15, Figure 16**) represent two hydrologic attributes and their corresponding 10th 50th and 90th percentiles. The first being Snow Water Equivalency or the amount of water you would get from melting a given quantity of snow instantaneously, which is represented by the black curves. The second is streamflow, a measurement of how much water is passing through a river or stream and it is represented by the blue shaded area with the upper and lower bounds representing the 90th and 10th percentiles while the white line is the 50th percentile. It is convenient that the water cycle for both the basins fits into a standard October to September water year. In early October precipitation begins to fall as mixed rain/snow events, but as November arrives the temperatures consistently remain below freezing enabling each consecutive storm to build a deeper snowpack. This process more or less continues until April 1st, which is when peak SWE is measured in the Sierra Nevada mountains. After April 1st a clear transition begins into warmer temperatures, longer days, and higher solar zeniths, all of which are contributing factors to accelerated snow melt. By May 1st stream flow has rapidly increased in conjunction with rapid snowpack ablation.

Walker:

As presented in **Figure 15**, the Walker River is incredibly consistent with its flows and this is because Walker has multiple reservoirs taming its annual discharge. Water delivery is manipulated to better accommodate the water intensive livelihoods of people who live in that valley. Therefore, there is no natural extremes in stream pulses because storage solutions (dams/reservoirs) have been constructed to remove this unpredictability even

though the precipitation delivery and snow ablation for the river is nearly identical to the Carson.

Carson:

The percent of total discharge by month for Carson shows the true nature of rivers/streams on the East side of the Sierra Nevada. Basins are located in rain shadows where they receive very little wet precipitation from May-October. Therefore, flows are insignificant for the majority of the year. However, once that reservoir of snow begins to break during spring the surrounding valleys receive a deluge of runoff from high alpine mountains. So nearly 2/3 of the river's annual water budget flushes down in 1/4 of the year. This is how water delivery naturally occurs and it conveniently coincides with the time of year humans require the most water.

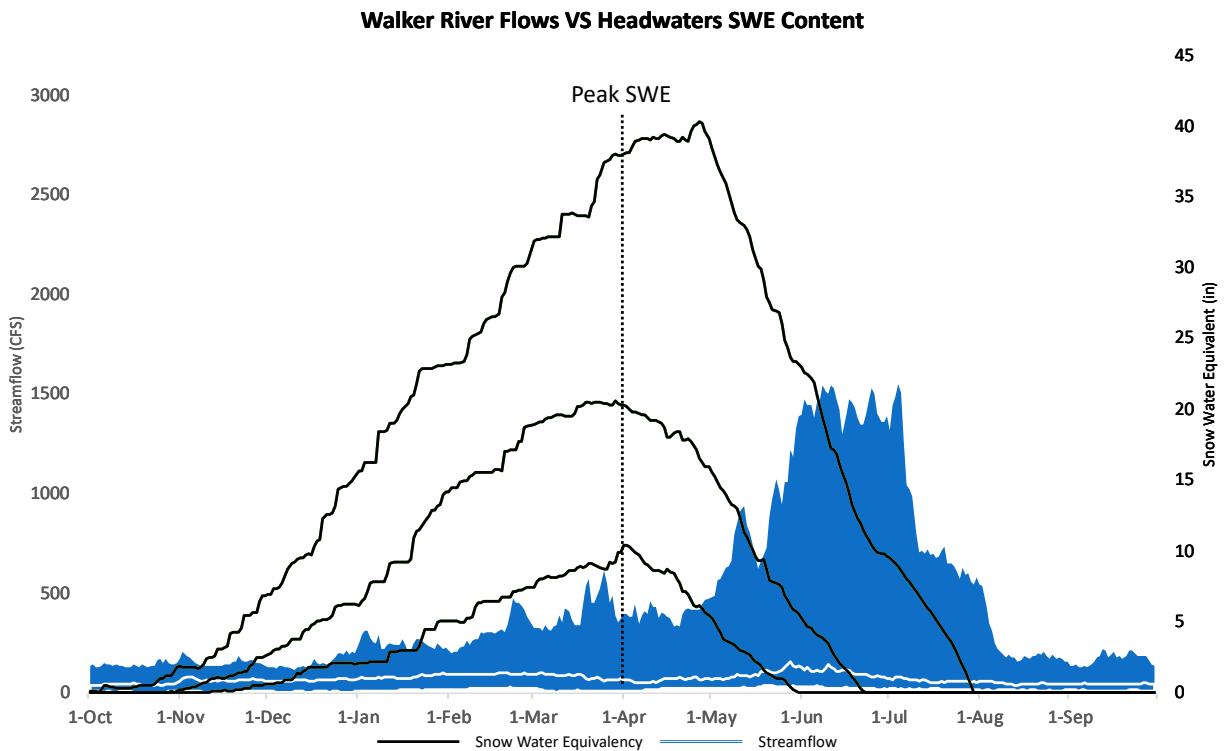


Figure 15. Walker River Hydrograph Results.

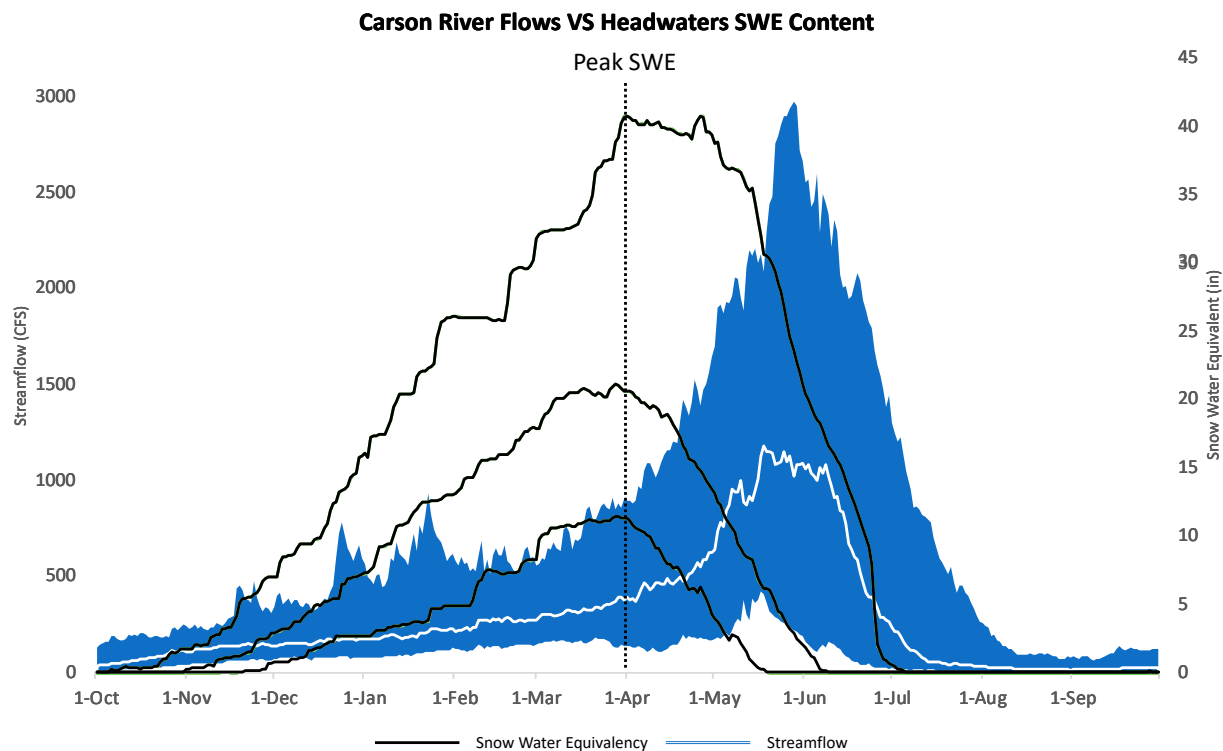


Figure 16. Carson River Hydrograph Results.

FUTURE PROJECTIONS

To assess trends in streamflow across the 20th and 21st centuries, historical and future precipitation (in millimeters [mm]/day) and surface air temperature (degrees Celsius) projections from the three selected GCMs (CanESM2, CNRM-CM5, and HadGEM2-ES) from the KNMI Climate Explorer database were used in a simple analytical model to estimate future streamflow in the Carson and Walker basins. Projections were focused on the headwaters of the Carson River and Walker River basins in the Sierra Nevada Mountain Range (latitude 38.854591 to 38.041064, longitude -120.054010 to -119.282672). Projections under RCP4.5, and RCP8.5 were downloaded for each model.

The climate model data was aggregated monthly and annually to determine actual evapotranspiration and resultant streamflow using the Thornthwaite and Budyko equations. The Thornthwaite equation uses the daily average sunlight hours based on latitude and temperature data from the GCMs to estimate the potential evapotranspiration (PET). The Budyko equation takes the PET output from the Thornthwaite equation and precipitation data from the GCMs to empirically determine the actual evapotranspiration (AET). This simplified model then predicts the annual streamflow quantity by subtracting the AET from the precipitation data in the GCMs.

The relative change in streamflow was calculated by dividing projected future streamflow by the reference streamflow (from 1940 to 2020). As a result, the annual streamflow quantity for the project 80 future years (from 2020 through 2100) is shown as a fraction of the historical reference average streamflow from the preceding 80 years from 1940 to 2020. Where streamflow < 1 means less predicted streamflow for that year than the historical reference streamflow, streamflow > 1 means more predicted streamflow for that year than the historical reference streamflow, and streamflow $= 1$ means the predicted streamflow for that year is the same as the historical reference streamflow.

As with actual historic annual streamflow levels, the GCMs projections for future streamflow can vary substantially from year to year due to the estimated changes in precipitation and temperature by the GCMs. To better illustrate the projected streamflow trend with these climatic fluctuations a linear regression was conducted on both climate scenarios, RCP4.5 and RCP8.5 for each GCM. Additionally, a 95% confidence interval was computed based on the GCMs yearly projections to determine the potential variation in the projected future streamflow trend.

Annual Streamflow Projection Results

The range of results of the projected annual reference streamflow levels captures variation and uncertainty from three sources: 1) uncertainty of future global GHG emissions accounted for by the two RCPs, 2) variation in different modeling approaches and accuracy for this region accounted for by the three GCMs, and 3) uncertainty of the linear model fits based on the data variation for each GCM accounted for with the 95% confidence intervals for the linear models.

In 2050 the linear models predict a range of approximately 60% to 110% of reference streamflow annual quantities (based on the period from 1940 to 2020). The uncertainty of these linear models ranges from about 40% to 120% of reference streamflow annual quantities for 2050. In 2100 the linear models estimate a range of approximately 25% to 150% of reference streamflow annual quantities. The uncertainty associated with these linear models ranges from about 20% to 170% of reference streamflow annual quantities by 2100 (**Figure 17** and **Figure 18**).

These results demonstrate a considerable range of uncertainty using this simple analytical model to estimate annual streamflow quantity changes. However, the majority of the linear models and the 95% confidence interval ranges for these linear models for both analysis years (2050 and 2100) are below the reference streamflow annual quantities from 1940 to 2020. This indicates a somewhat greater likelihood of decreased annual streamflow quantity in 2050 and 2100 compared to the reference period (1940 to 2020).

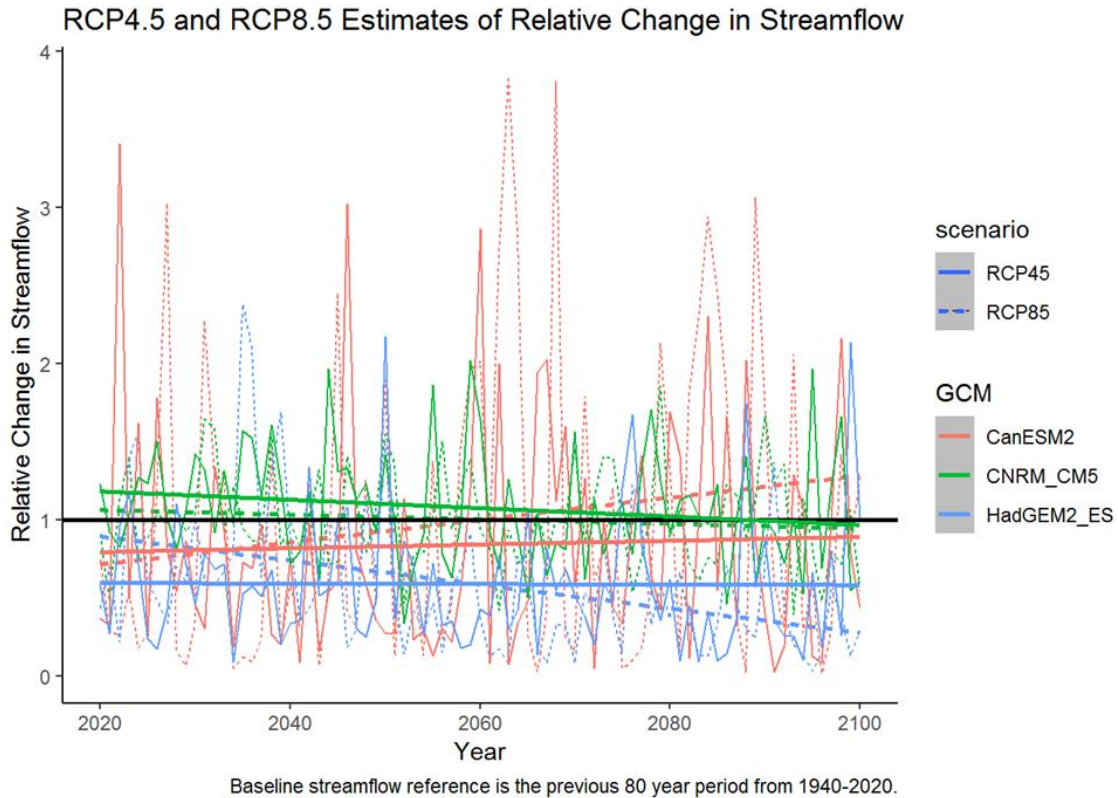


Figure 17. Three GCM Estimates of Relative Change in Annual Streamflow in the Carson River and Walker River Basins Headwaters (2020-2100).

The relative change in streamflow plot values represent the predicted streamflow amount for the 80 year period from 2020 to 2080 compared to the average streamflow during the historical 80 year reference period from 1940 to 2020 (streamflow < 1 means less predicted streamflow for that year than the historical reference streamflow, streamflow > 1 means more predicted streamflow for that year than the historical reference streamflow, and streamflow = 1 means the predicted streamflow for that year is the same as the historical reference streamflow). Based on a simple analytical model using the Thornthwaite and Budyko equations. All data displayed is from three GCMs: CanESM2 (red), CNRM-CM5 (green), and HadGEM2-ES (blue). Regular lines represent projections for the RCP4.5 scenario, and dotted lines represent projections for the RCP8.5 scenario. The black line represents the average streamflow over the baseline reference period from 1940 to 2020. Data Source: KNMI Climate Explorer database.

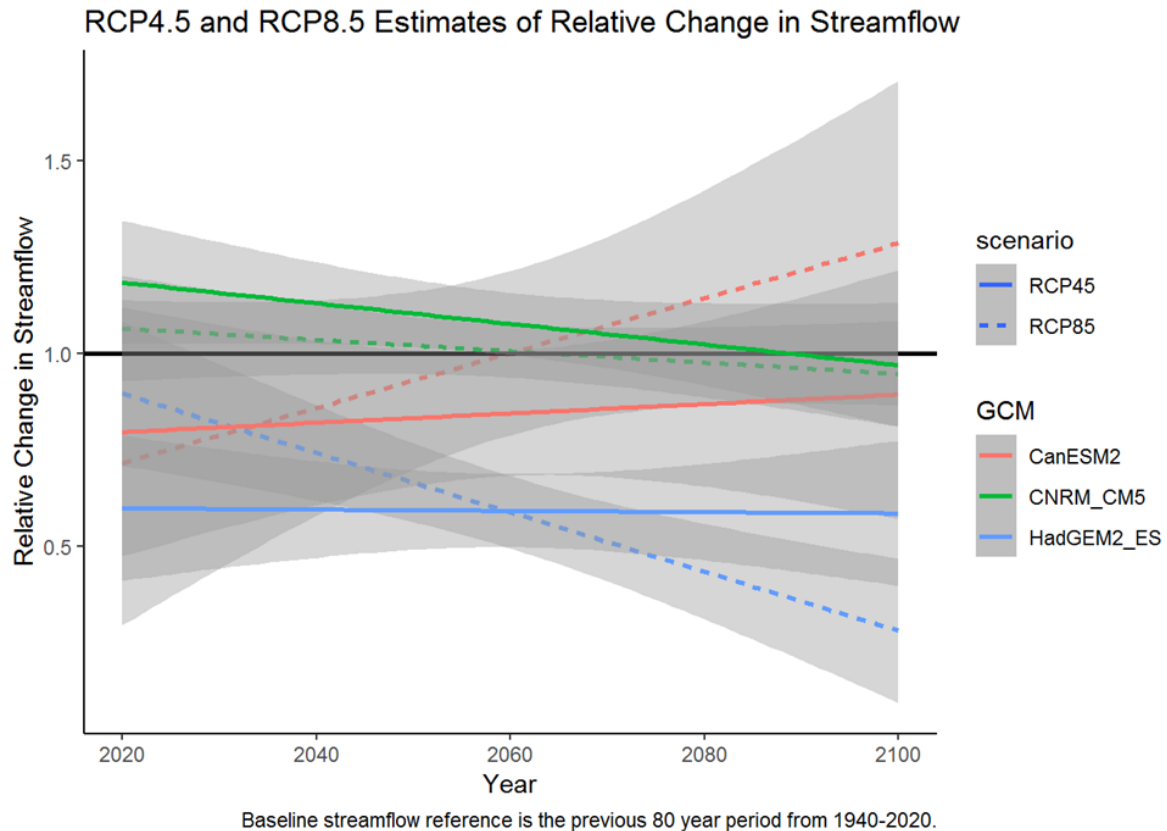


Figure 18. Linear Models and Confidence Intervals of Three GCM Estimates of Relative Change in Annual Streamflow in the Carson River and Walker River Basins Headwaters (2020-2100).

The values presented in this plot, represent linear models for the predicted streamflow amount for the 80 year period from 2020 to 2080 compared to the average streamflow during the historical 80 year reference period from 1940 to 2020 (streamflow < 1 means less predicted streamflow for that year than the historical reference streamflow, streamflow > 1 means more predicted streamflow for that year than the historical reference streamflow, and streamflow = 1 means the predicted streamflow for that year is the same as the historical reference streamflow). Based on a simple analytical model using the Thornthwaite and Budyko equations. All data displayed is from three GCMs: CanESM2 (red), CNRM-CM5 (green), and HadGEM2-ES (blue). Regular lines represent projections for the RCP4.5 scenario, and dotted lines represent projections for the RCP8.5 scenario. The gray areas represent 95% confidence intervals for the linear models. The black line represents the average streamflow over the baseline reference period from 1940 to 2020. Data source: KNMI Climate Explorer database.

MODEL RESULTS – BASELINE

Current Baseline

The first step in our analysis was to evaluate what the current baseline water supply and water quality conditions are in the Walker and Carson basins. This analysis used InVEST to quantify the contribution of each area to baseflow (to represent water supply) and major water quality pollutants (i.e., nitrogen, phosphorus, and sediment) in the Walker and Carson Rivers.

BASEFLOW

The current baseflow conditions in each basin were quantified to determine what areas are the primary contributors to baseflow in both the Walker and Carson Rivers. For the Carson River baseflow contributions are largest in the headwater areas of the upper watershed. These are high elevation areas in the eastern Sierra Nevada that receive most of the precipitation for the Carson basin as both snow and rain. Due to the rain shadow effect of the Sierra Nevada, the middle and lower watershed areas that are at lower elevations do not receive as much precipitation. As a result, their contributions to baseflow in the Carson basin are smaller than the headwater areas. The majority (80%) of baseflow contributions throughout the Carson basin range from 0 to 356 mm/year, with a maximum baseflow of 1,892 mm/year. The average baseflow in the Carson basin for the current baseline is 279 mm with the entire basin having a total baseflow contribution of 2.99×10^8 mm/year (**Figure 19**).

Carson River Watershed Baseflow

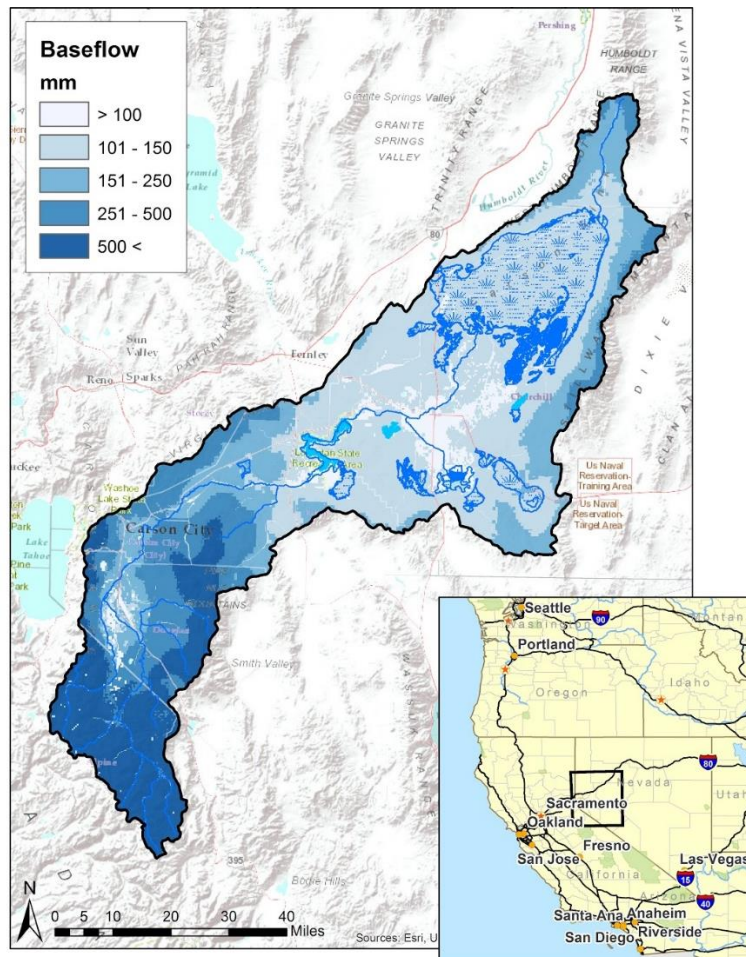


Figure 19. Baseflow contribution throughout the Carson River Watershed. Baseflow is determined by a pixel’s water delivery to the Carson River.

The Walker basin current baseline contributions to baseflow show a similar pattern to the Carson basin. The largest contributing areas to baseflow are located in the high elevation headwaters while the lower elevation valley areas have smaller contributions to baseflow. The contributions to baseflow for most (80%) of the Walker basin range from 0 to 462 mm/year with a maximum baseflow contribution of 1998 mm/year. The average baseflow contribution in the Walker basin is 381 mm/year with a total baseflow contribution for the entire Walker basin of 4.04×10^8 mm/year (**Figure 20**).

Walker River Watershed Baseflow

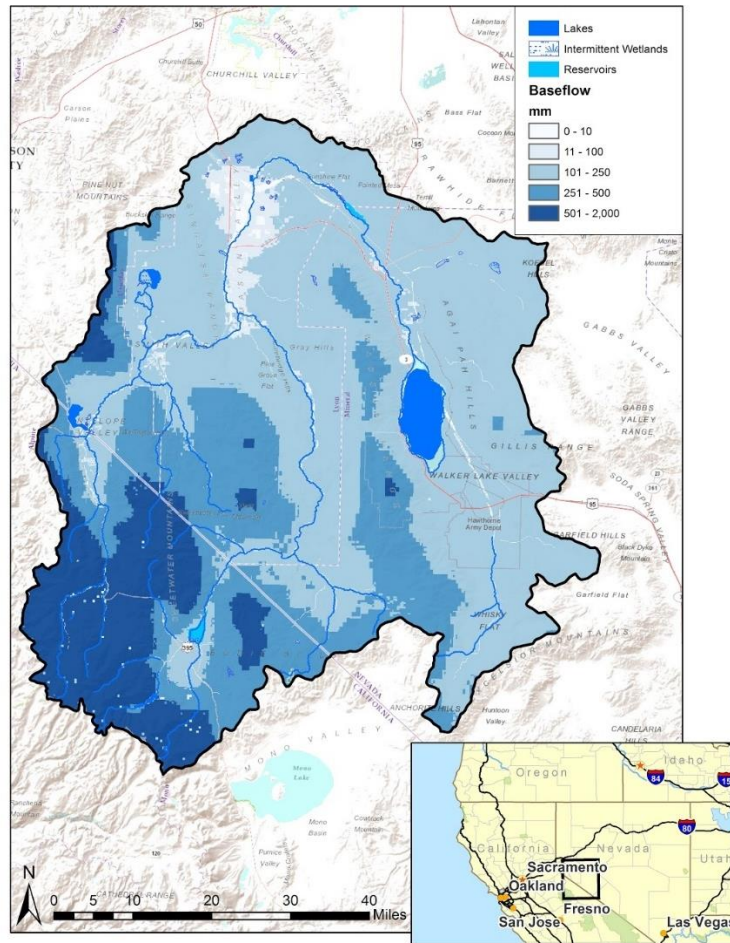


Figure 20. Baseflow contribution throughout the Walker River Watershed. Baseflow is determined by a pixel's water delivery to the Walker River.

NITROGEN EXPORT

Nitrogen export within each basin was analyzed for the current baseline condition to determine the origin of nutrients within the Carson and Walker Rivers. It was found that nitrogen in the Carson basin primarily originates from farming areas and from steep mountain peaks in the Sierra Nevada. The eastern Sierra Nevada has been found to have localized hot spots of nitrogen south of Lake Tahoe. These hot spots are characterized by a lack of plant roots and summer droughts. The nitrogen, rather than being uptaken by plants, is instead mineralized and runs off during precipitation events. High nitrogen export was also observed in the agricultural regions near Genoa and Fallon. During rain events, fertilizer runs off from the fields and pastures and into the Carson River. Nitrogen export

rates in the majority of the Carson basin range from 0 to 78 kg/km²/year with a maximum of 1,247 kg/km²/year (**Figure 21**).

Carson River Watershed Nitrogen Export

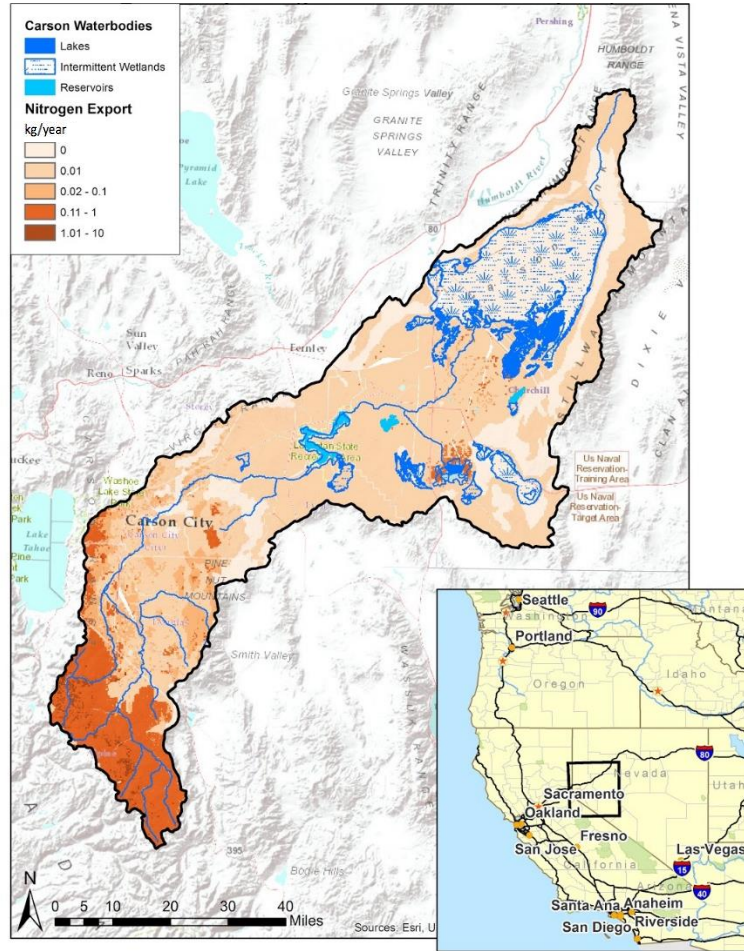


Figure 21. Nitrogen loading throughout the Carson River Watershed. Nitrogen export is determined by a pixel’s nitrogen delivery to the Carson River.

In the Walker Basin, nitrogen export follows a similar pattern to that seen in the Carson Basin. The primary nitrogen source is the headwaters, where steep slope areas with sparse vegetation result in natural accumulation of nitrogen in the soil that runs off during rain and snowmelt events. There was some nutrient contribution from agricultural operations within the Smith Valley, but due to the basin’s overall lack of population and human influenced landscape nitrogen primarily originated on the steep slopes of the Sierra Nevada in areas of high precipitation. Nitrogen export rates in most of the basin (80%) range from 0 to 76 kg/km²/year with a maximum nitrogen export rate of 2,770 kg/km²/year (**Figure 22**).

Walker River Watershed Nitrogen Export

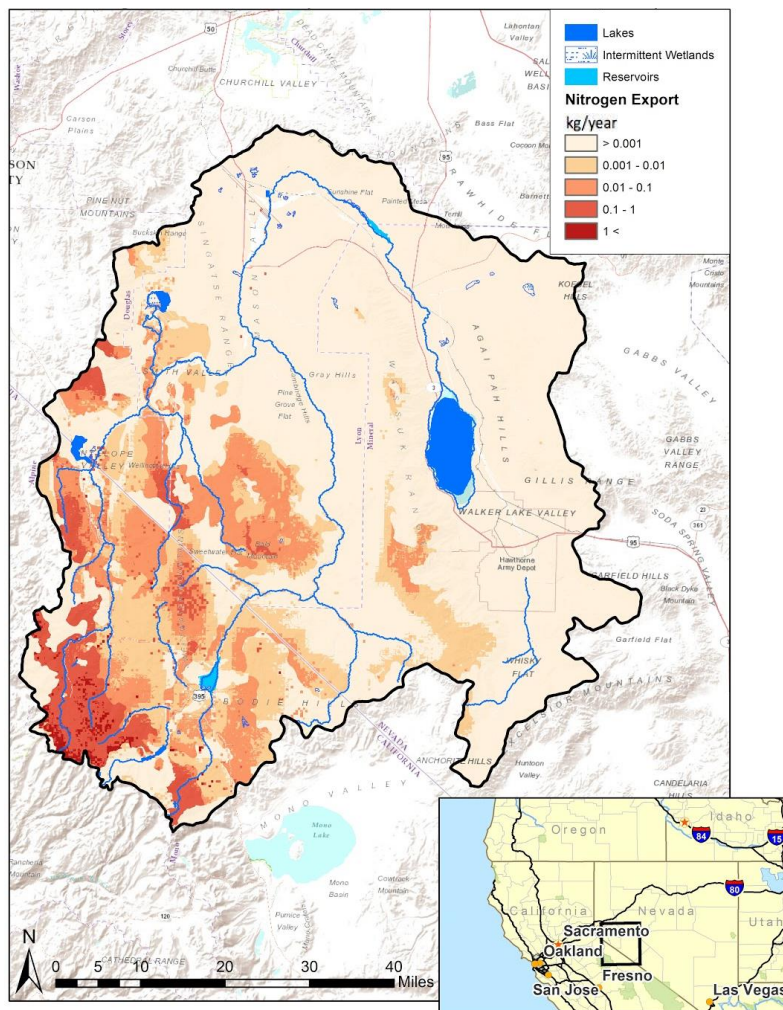


Figure 22. Nitrogen loading throughout the Walker River Watershed. Nitrogen export is determined by a pixel's nitrogen delivery to the Walker River.

PHOSPHORUS EXPORT

Similar to nitrogen, phosphorus export was evaluated to determine the sources of nutrient pollution in the Walker and Carson basins. In the Carson basin the largest phosphorus sources are in the headwaters and in the agricultural areas. The major phosphorus sources in the headwaters occur near mountain peaks that have sparse vegetation cover. As a result, phosphorus is not taken up due to the lack of vegetation. These headwater areas are also characterized by steep slopes and receive most of the precipitation in the basin, causing higher rates of runoff during precipitation events. Agricultural areas, primarily in the Carson Valley and the Newlands Project near Fallon, have high rates of phosphorus export

due to the use of phosphorus fertilizers that can runoff into the Carson River during irrigation or precipitation events. The majority (80%) of the Carson basin has a phosphorus export rate that ranges from 0 to 8.7 kg/km²/year with a maximum phosphorus export rate of 137.9 kg/km²/year. (**Figure 23**).

Carson River Watershed Phosphorus Export

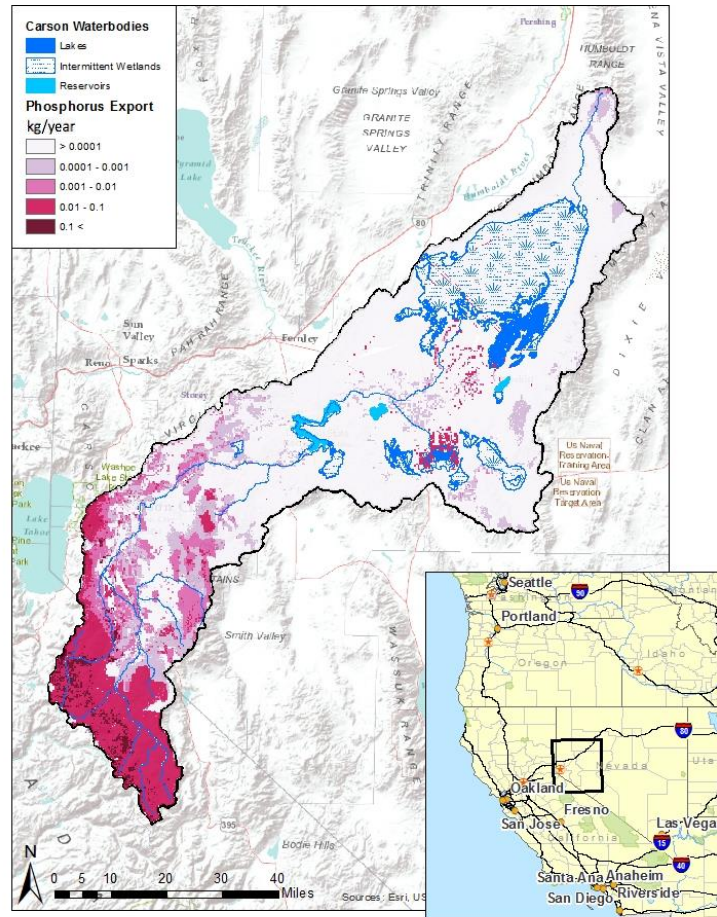


Figure 23. Phosphorus loading throughout the Carson River Watershed. Phosphorus export is determined by a pixel’s nitrogen delivery to the Carson River.

In the Walker basin phosphorus export is primarily concentrated in the headwater areas due to the steep topography, large amount of precipitation, and unvegetated mountain peak areas that decrease phosphorus uptake by plants and increase erodibility. High phosphorus export rates also occur in the agricultural areas near Topaz Reservoir and in the Smith Valley. Phosphorus export rates in most (80%) of the Walker basin ranges from 0 to 10.4 kg/km²/year, with a maximum phosphorus export rate of 441.8 kg/km²/year (**Figure 24**).

Walker River Watershed Phosphorus Export

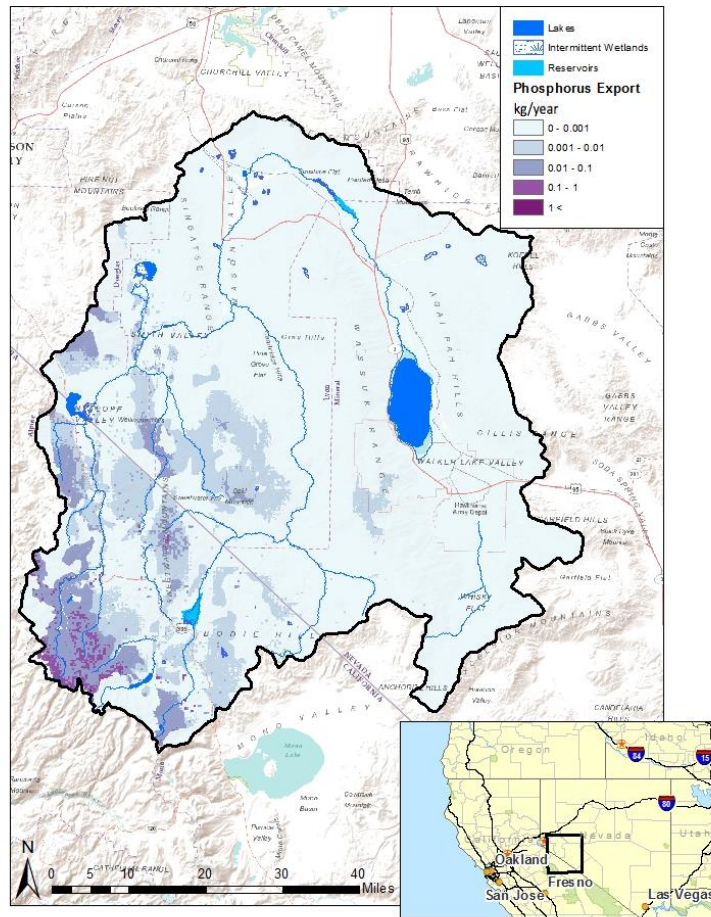


Figure 24. Phosphorus loading throughout the Walker River Watershed. Phosphorus export is determined by a pixel’s nitrogen delivery to the Walker River.

SEDIMENT EXPORT

Sediment export in both the Walker and Carson basins were evaluated for the current baseline conditions to determine what areas were contributing the most to sediment runoff into surface water bodies (e.g., Carson and Walker Rivers) in the basins. The major contributing areas to sediment export in the Carson basin were located in areas of steep slopes that increase soil erodibility and in areas of high elevation where higher precipitation rates can result in larger amounts of erosion and runoff. Specifically, these areas in the Carson basin include the headwater areas in the eastern Sierra Nevada, the Pine Nut Mountains and Virginia Range steep slope areas in the middle watershed, and the steep topography areas of the Stillwater Mountains and West Humboldt Range in the lower watershed. Sediment export from these areas ranges from 1,887 to 1,116,417 tons/km²/year. The flatter valley areas in the Carson

basin that comprise the majority (60%) of the watershed showed much lower levels of sediment export, typically below 581 tons/km²/year (**Figure 25**).

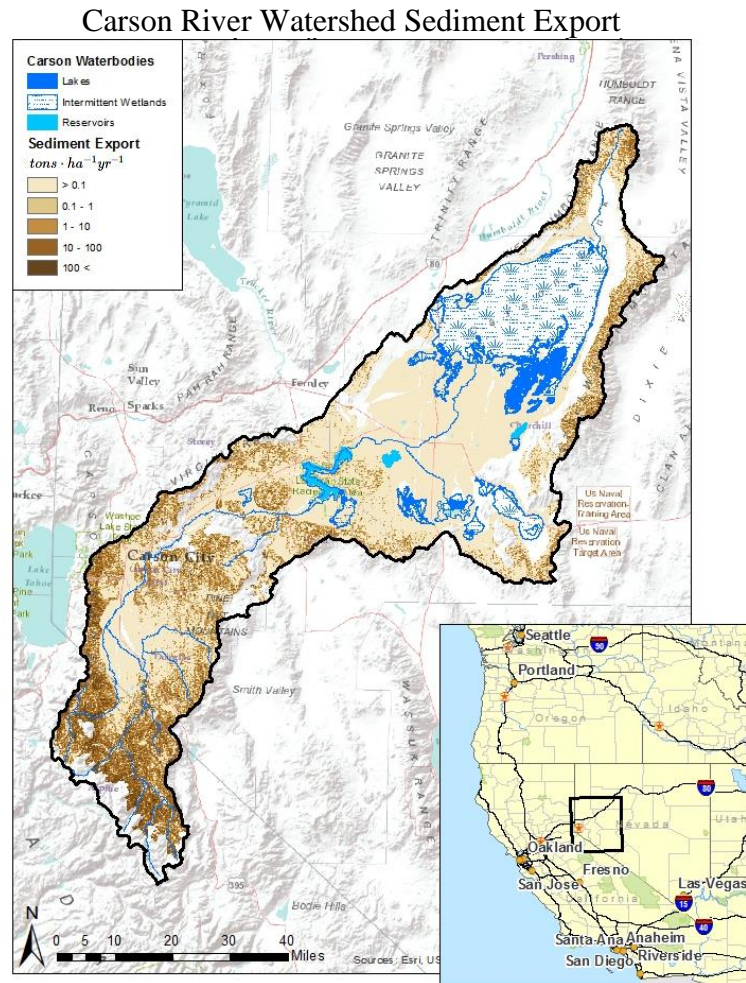


Figure 25. Sediment loading throughout the Carson River Watershed. Sediment export is determined by a pixel’s nitrogen delivery to the Carson River.

Sediment export in the Walker basin followed a similar pattern to the Carson basin. The high elevation areas that receive much of the basin’s precipitation that also have steep slopes that increase erodibility were found to have larger sediment export quantities ranging from 1,306 to 455,073 tons/km²/year. These include the eastern Sierra Nevada, Sweetwater Mountains, and Bodie Hills areas in the upper watershed; the Pine Nut Mountains and Singatse Range in the middle watershed; and the Wassuk Range and Gillis Range in the lower watershed. The majority (60%) of the Walker basin has lower sediment export amounts (less than 435 tons/km²/year) due to the lack of precipitation and flatter topography in these valley areas (**Figure 26**).

Walker River Watershed Sediment Export

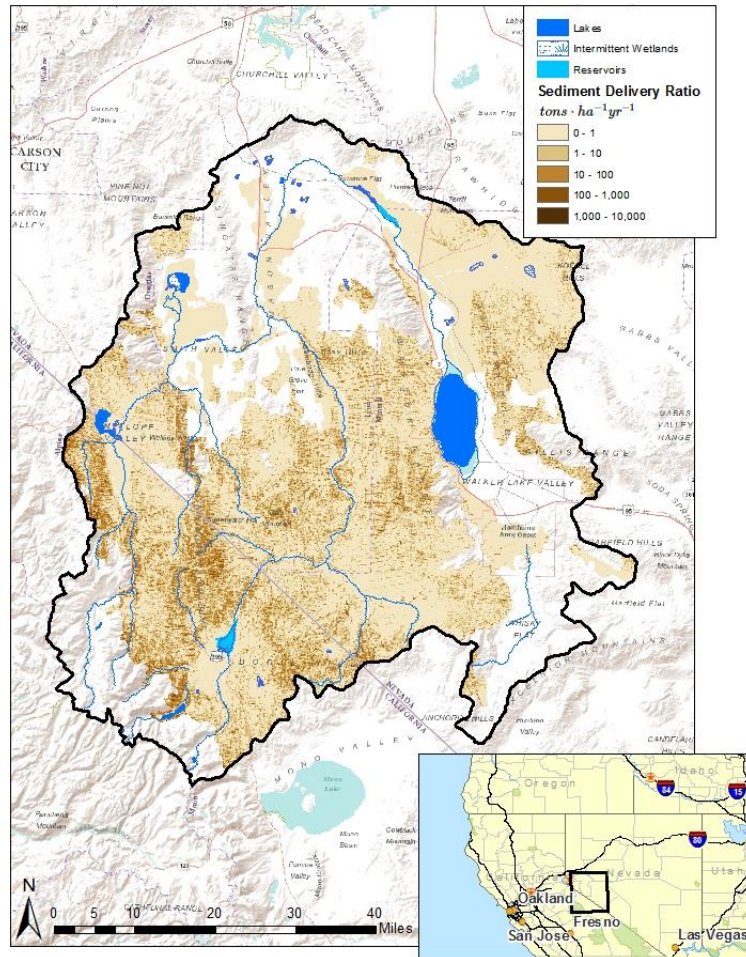


Figure 26. Sediment loading throughout the Walker River Watershed. Sediment export is determined by a pixel's nitrogen delivery to the Walker River.

CURRENT BASELINE SUMMARY

To identify patterns and overlapping areas of high contribution to the water supply and water quality parameters analyzed for the current baseline conditions (i.e., baseflow contribution, nitrogen export, and phosphorus export¹) the largest 25% of contributors to each of these factors were individually mapped and then overlaid onto a single map (**Figure 27**).

With the top 25% of contributing areas for baseflow contribution, nitrogen export, and phosphorus export overlaid, it is possible to identify regions that are large contributors to

¹ Sediment export was not analyzed for overlap with the other water supply and water quality factors due to data gaps in the results, particularly in the very high elevation portions of both the Carson and Walker basins.

more than one factor affecting water supply and water quality in both of the basins. For example, if an area is only a top contributor to baseflow it is shown in cyan (light blue), if an area is a top contributor for both nitrogen and phosphorus it is shown in red, and if an area is a top contributor for all three factors it is shown in black in (Figure 27).

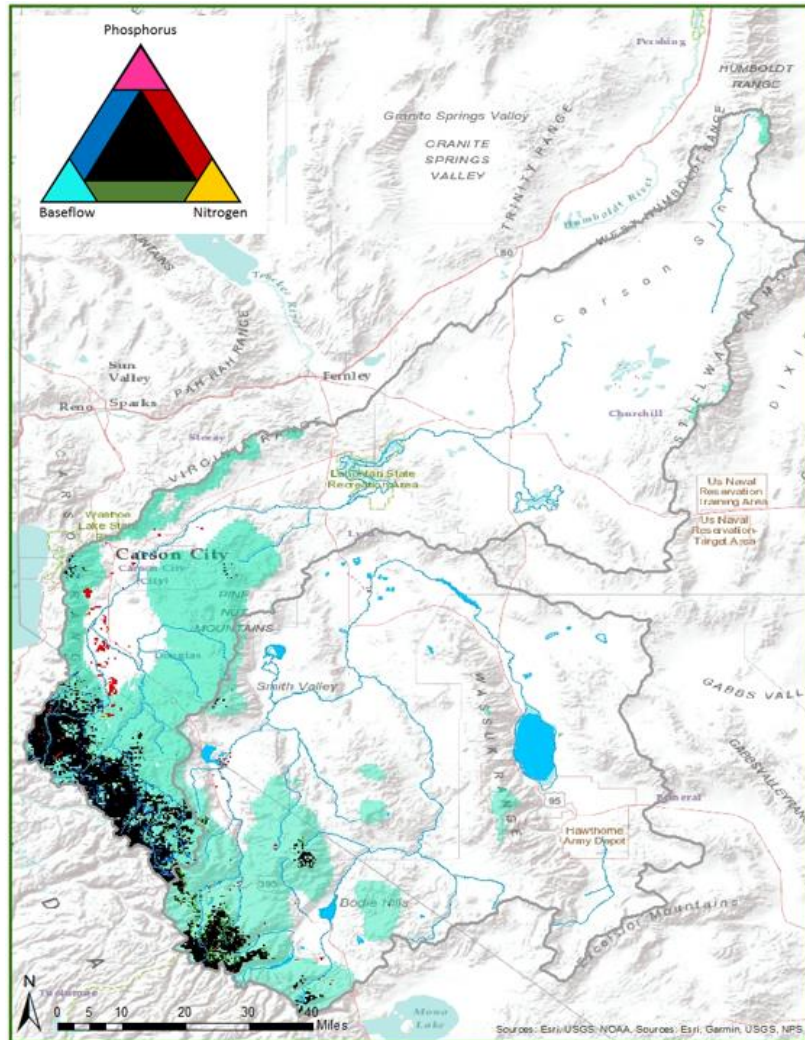


Figure 27. Priority Areas; Combination Map of Contributing Land from Baseflow, Nitrogen Export and Phosphorus Export in the Carson River Basin.

This analysis provides an overall understanding of both the Walker and Carson basins for these water supply and water quality parameters. In both basins there are large portions of the headwaters and other high elevation areas in the upper and middle watersheds that are the primary contributors to baseflow (shown in cyan). There are scattered areas in the high elevation headwaters and more concentrated areas in the valley areas where large amounts of agriculture are present that are the top contributors for both nitrogen and phosphorus. In

the Carson basin these areas include the Carson Valley and the Newlands Project near Fallon, while in the Walker basin the agricultural area near Topaz Reservoir was shown as a top contributor for both nitrogen and phosphorus export. Also, in the headwaters are a few areas near steep mountain peaks that are top contributing areas for all three factors (i.e., baseflow contribution, nitrogen export, and phosphorus export) that were analyzed for their impact on water supply and water quality in the basins.

MODEL RESULTS – FUTURE APPLICATION & PRIORITY AREAS

2050 Future Change from Baseline (CanESM2 & RCP8.5)

To determine how water supply and water quality parameters would be altered in the future by climate change, the change in baseflow contribution, nitrogen export, and phosphorus export² were estimated in 2050 using InVEST. The results presented here were calculated using temperature and precipitation data for the CanESM2 global circulation model that was determined to represent an average precipitation and temperature future. This model was run using the RCP8.5 scenario, which represents future global greenhouse gas levels with a business as usual projection for population, land use, and economic growth. Results for other global circulation models and representative concentration pathways are presented in a separate sensitivity analysis section. These future (2050) results were then compared to the current baseline results to generate maps showing the projected change in the chosen water supply and water quality parameters.

FUTURE BASEFLOW CHANGE (RCP 8.5)

The projected change in baseflow contribution for the Carson and Walker basins was determined by comparing the future baseflow contribution in 2050 to the current baseline baseflow contribution. In the Carson basin, the entire watershed would either experience a negligible change or decrease in baseflow contribution by 2050. Decreases in baseflow contribution could have adverse impacts on the basin due to decreased streamflow that supports municipal, agricultural, and environmental water uses. The areas where baseflow contribution would decrease the most are located in the high elevation areas, primarily in the headwaters of the eastern Sierra Nevada. These areas could experience a decrease in baseflow contribution between 60 and 320 mm/year or an approximately 17% decrease in baseflow (**Figure 28**). This means that the headwater and high elevation areas in the Carson basin are both the areas that are currently contributing the most to baseflow and that are projected to see the largest decrease in baseflow contribution by 2050. These reductions in future baseflow are a result of changing climate variables: a projected decrease in precipitation and estimated increase in temperature that subsequently increase evapotranspiration, reducing the amount of water that makes it into the Carson River.

² InVEST's Sediment Delivery Ratio model only accounts for changes in land use, not different climate parameters. As such, sediment export was not modeled for 2050.

Carson River Watershed Predicted Change in
Baseflow
RCP 8.5, Year 2050

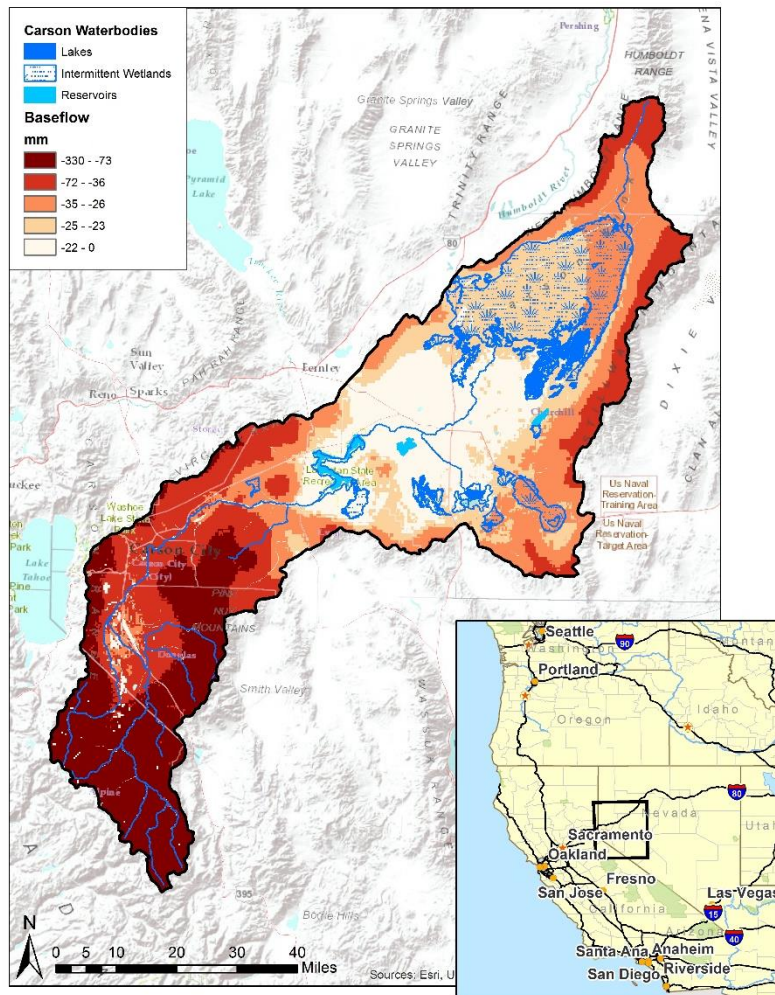


Figure 28. Carson River Watershed, Predicted Change in Baseflow 2050; RCP 8.5.

Similarly, the entire Walker basin would also experience a negligible change or a decrease in baseflow contribution that would likely result in reduced streamflow in the Walker River by 2050. The areas that would experience the largest decrease in baseflow are primarily the high elevation areas, particularly in the headwaters where the areas of greatest baseflow contribution are currently located. These areas are projected to experience a reduction of 106 to 353 mm/year or an approximately 17% to 23% decrease in baseflow contribution due to lower precipitation rates and higher evapotranspiration rates as a result of climate change by 2050 (**Figure 29**).

Walker River Watershed Predicted Change in Baseflow
RCP 8.5, Year 2050

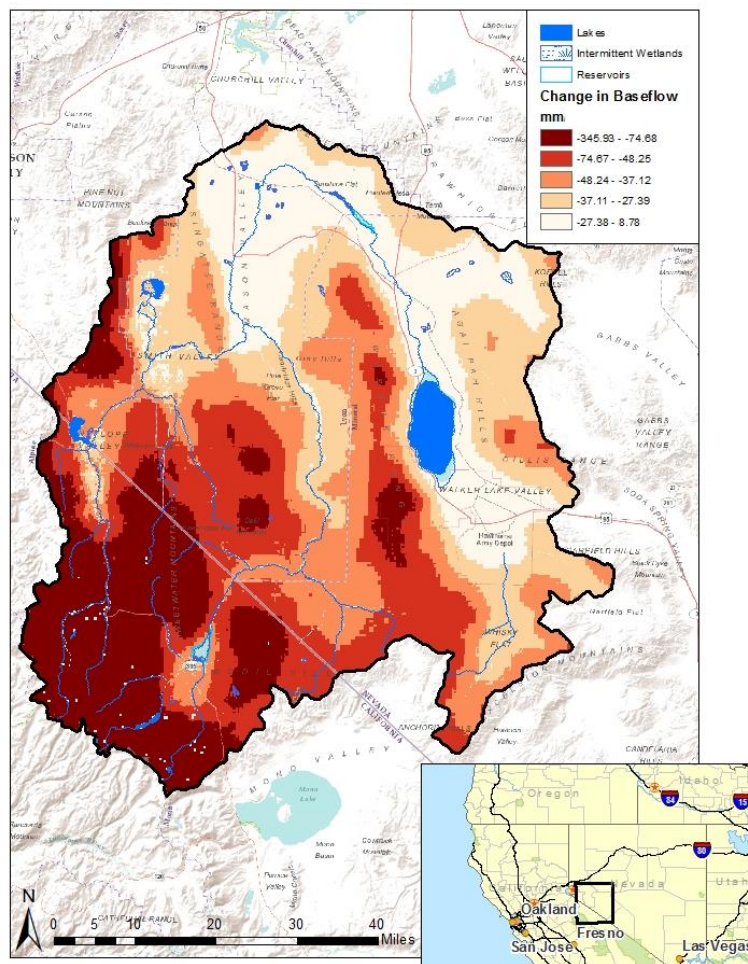


Figure 29. Walker River Watershed, Predicted Change in Baseflow 2050; RCP 8.5.

FUTURE NITROGEN EXPORT CHANGE (RCP 8.5)

The change in future nitrogen export was also calculated by comparing the results for 2050 to the current baseline. In the Carson basin, the majority of the watershed would experience negligible or no change in nitrogen export. Some high elevation areas would experience small to medium decreases in nitrogen export (shown in green in **Figure 30**). This would occur in many of the high elevation areas in the headwaters of the eastern Sierra Nevada and the Pine Nut Mountains because of a projected decrease in future precipitation in these areas that would reduce the amount of nitrogen runoff.

However, a few smaller areas in the headwaters and large agricultural portions of the basin would experience large increases in nitrogen export (shown in red in **Figure 30**). These areas

of increased nitrogen export are located around mountain peaks in the headwaters that have sparse vegetation cover. As a result, there is very little uptake of nitrogen by plants in these areas and their steep slopes increase the potential erodibility of nitrogen that could runoff during precipitation events in these areas. The agricultural areas in the Carson Valley and in the Newlands Project agricultural area near Fallon would also experience large increases in nitrogen export due to fertilizer use for agricultural operations.

Carson River Watershed Predicted Change in Rate of Nitrogen Export
RCP 8.5, Year 2050

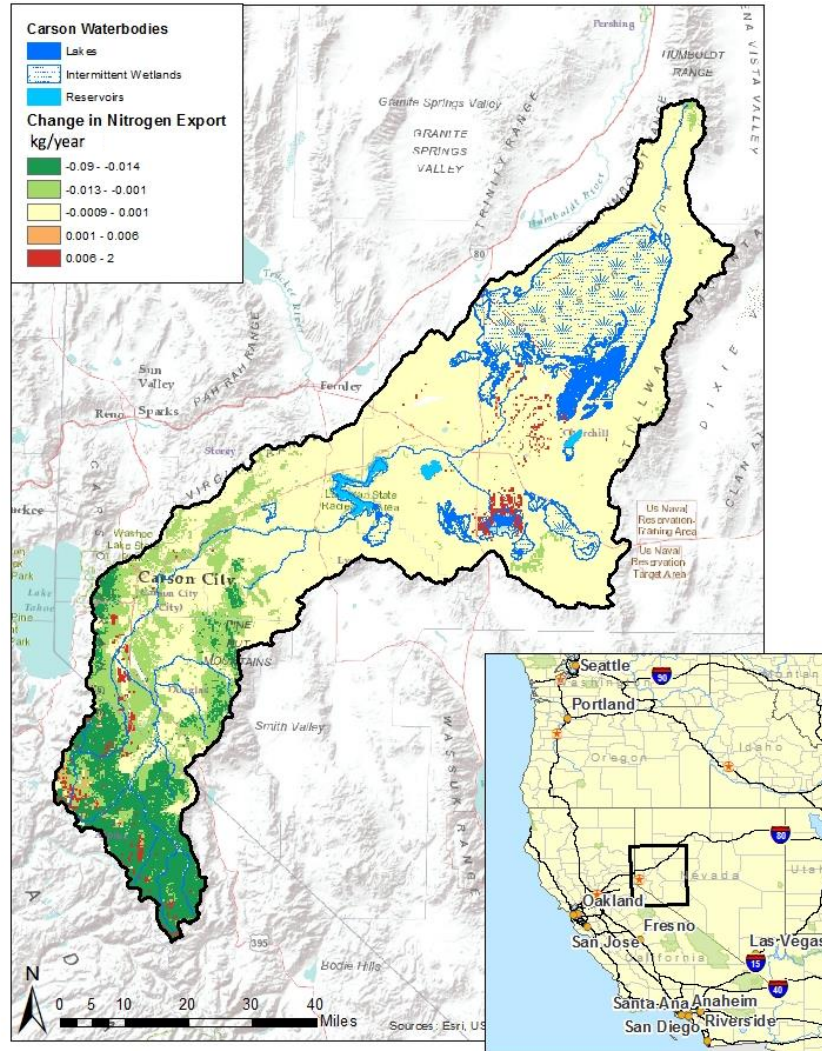


Figure 30. Carson River Watershed, Predicted Change in Nitrogen Export 2050; RCP 8.5.

The Walker basin exhibits a similar projected change in nitrogen export as a result of climate change in the watershed. For most of the Walker basin nitrogen export will either have negligible or no change in nitrogen export. Some high elevation areas where precipitation is likely to decrease would experience decreases in nitrogen export (shown in green in **Figure**

31). These areas are located in the eastern Sierra Nevada headwaters of the basin and along the Sweetwater Mountains. However, nitrogen export is projected to increase in the steep slope, sparsely vegetated mountain peaks in the Sierra Nevada headwaters and in the agricultural area near Topaz Reservoir. These areas could see increases in nitrogen export (shown in red on **Figure 31**) of 19 to 673 kg/km²/year or an approximately 24.3% increase.

Walker River Watershed Predicted Change in Rate of Nitrogen Export
RCP 8.5, Year 2050

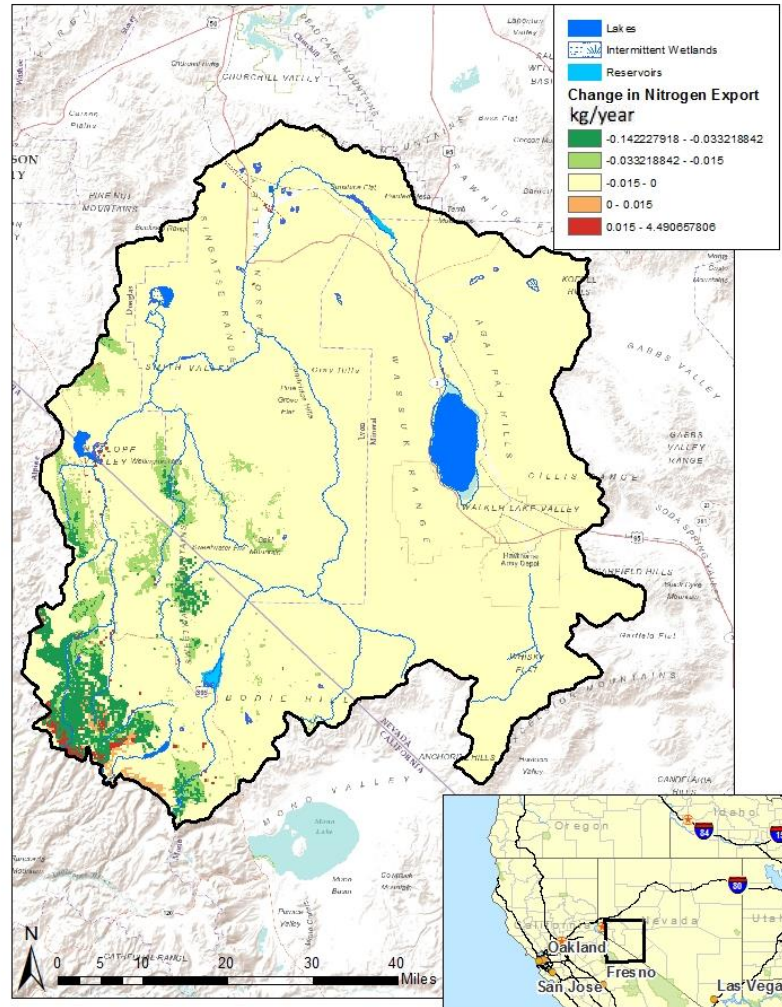


Figure 31. Walker River Watershed, Predicted Change in Nitrogen Export 2050; RCP 8.5.

FUTURE PHOSPHORUS EXPORT CHANGE (RCP 8.5)

Phosphorus export changes for both the Walker and Carson basins follows a similar pattern as nitrogen export. In the Carson basin most of the basin would experience negligible or no change in phosphorus export with some higher elevation areas in the Sierra Nevada

Walker River Watershed Predicted Change in Rate of Phosphorus Export
RCP 8.5, Year 2050

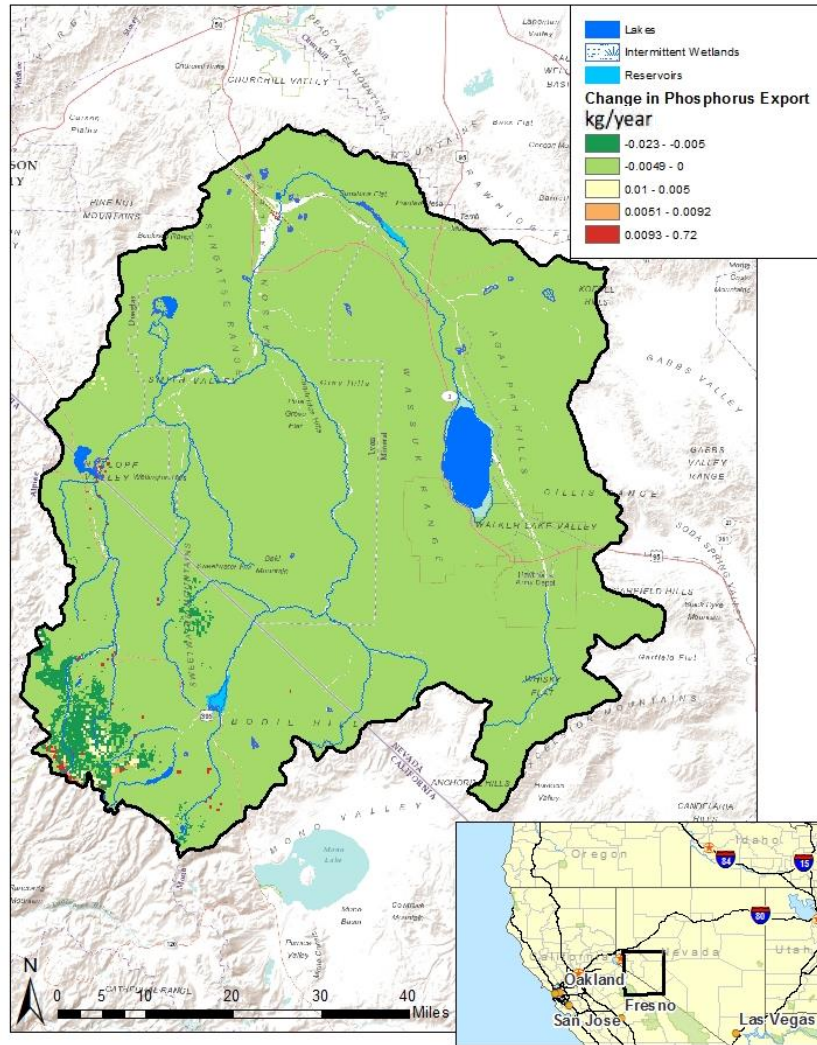


Figure 33. Walker River Watershed, Predicted Change in Phosphorus Export 2050; RCP 8.5.

PRIORITY MANAGEMENT AREAS

After determining the current baseline conditions and how water supply (i.e., baseflow contribution) and water quality (i.e., nitrogen and phosphorus export) would be altered in the future (2050) by climate change, priority areas for management could be identified to attempt to counteract the adverse effects of climate change. To identify priority areas for management the areas that would experience the largest 25% of adverse changes due to climate change

were individually determined for each of the study parameters (i.e., baseflow contribution, nitrogen export, and phosphorus export) and then overlaid together on a single map. Adverse changes were defined as a decrease in baseflow contribution (that would reduce water supply and streamflow) or an increase in nitrogen and phosphorus export (that worsen water quality in surface water bodies in the basins).

With the top 25% of areas experience adverse changes in baseflow contribution, nitrogen export, and phosphorus export overlaid, it is possible to identify regions that are most vulnerable to adverse future changes in one or more parameters. For example, if an area is experiencing a top 25% decrease in baseflow it is shown in cyan, if an area is projected to have increases in both nitrogen and phosphorus export it is shown in red, and if an area is in the top 25% of adverse changes for all three factors it is shown in black (**Figure 34, Figure 35**).

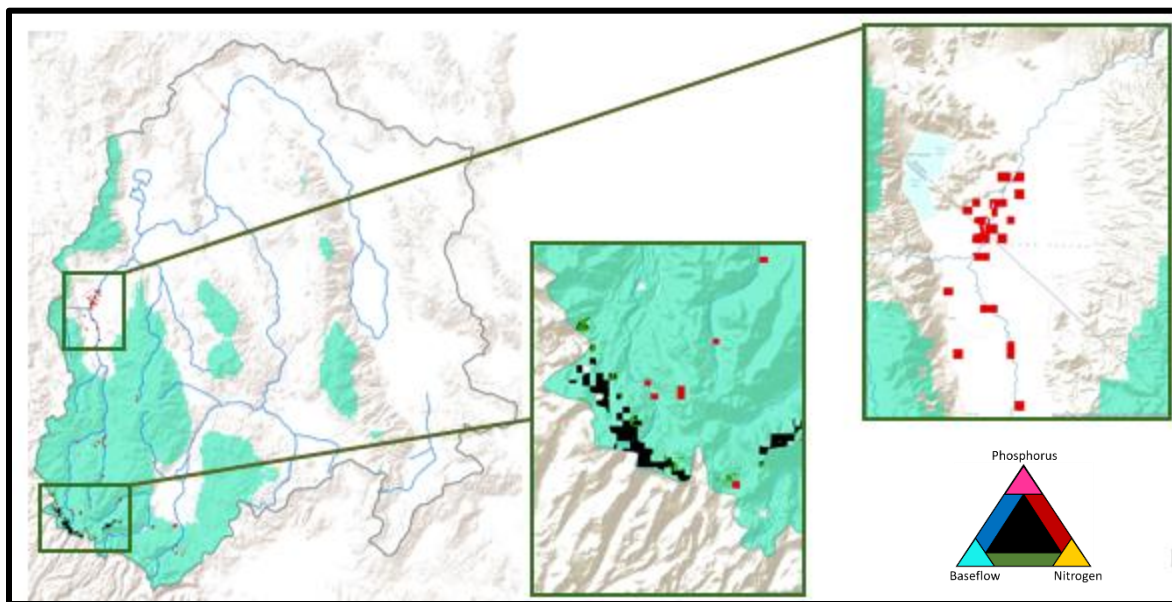


Figure 34. Walker Basin Change by 2050, Priority Area Mapping Based on Top 25% Contribution Mapping.

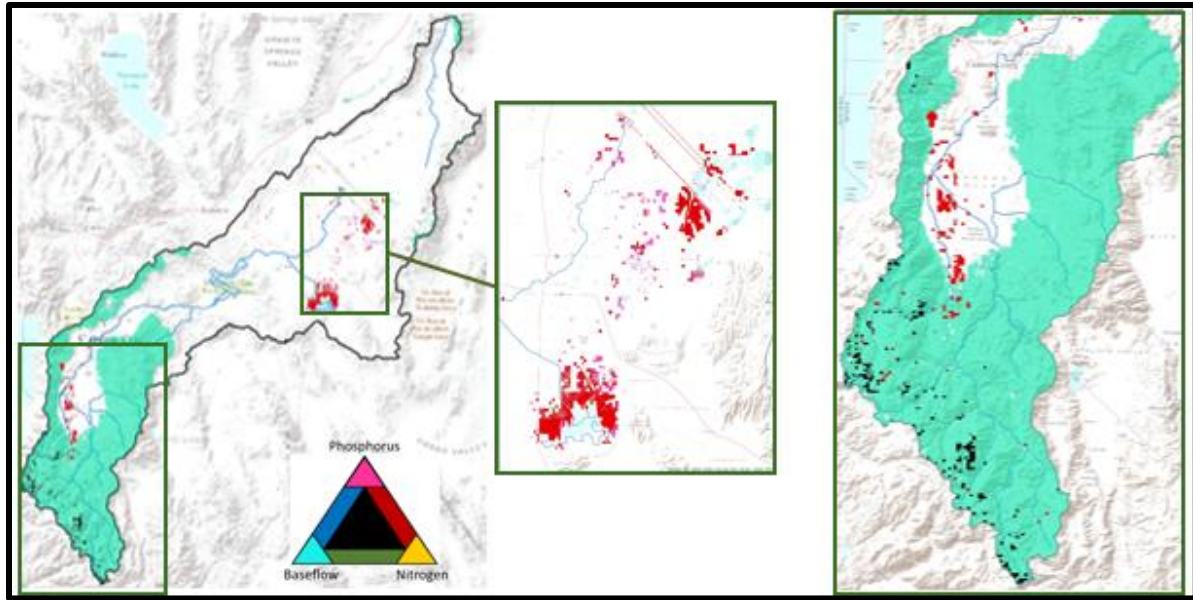


Figure 35. Carson Basin Change by 2050, Priority Area Mapping Based on Top 25% Contribution Mapping.

In both basins, large areas in the Sierra Nevada headwaters would experience the most decrease in baseflow as a result of climate change (shown in cyan). A few scattered areas in the headwaters of both basins would also experience the largest increases in both nitrogen and phosphorus export in the future (shown in red). This large increase in nitrogen and phosphorus export would also occur in the agricultural regions in both basins including the Carson Valley and Newlands Project near Fallon in the Carson basin and near the Topaz Reservoir in the Walker basin. Additionally, in the high elevation, steep slope, and sparsely vegetated areas near the mountain peaks in the headwaters of both basins would experience adverse changes in all three-water supply and water quality parameters (shown in black).

As a result of this analysis, three general priority areas for management have been identified for the Carson basin based on their adverse future changes in water supply and water quality parameters: the headwaters in the Sierra Nevada (large decrease in baseflow and adverse changes for all three parameters), the Carson Valley agricultural area (large increases in phosphorus and nitrogen export), and the Newlands Project agricultural area near Fallon (large increases in phosphorus and nitrogen). In the Walker basin two general priority areas have been identified that would experience the most adverse changes to water supply and water quality as a result of climate change: the headwaters in the Sierra Nevada (large decrease in baseflow and adverse changes for all three parameters) and the agricultural area near Topaz Reservoir (large increases in phosphorus and nitrogen export). These areas are both the largest current baseline contributors to water supply and water quality in both basins and the areas that would experience the most adverse changes to water supply and water quality in the future due to climate change.

LAND USE AND OWNERSHIP OF PRIORITY MANAGEMENT AREAS

With the priority management areas identified, it is possible to further characterized these locations to determine their potential for implementation of different management actions. A critical component of determining the potential for management in these areas are the existing land use and ownership/jurisdictional entity for the identified properties.

The priority management areas for both the Carson and Walker basins are primarily comprise of shrublands (Walker 23.6% of priority area, Carson 46.29% of priority area), forests (Walker 7.39% of priority area, Carson 28.33% of priority area), and barren (Walker 63.43% of priority area, Carson 14.26% of priority area) land uses (**Table 14, Table 15, Figure 36, Figure 37, Figure 38**). The prevalence of these land uses in the priority management areas is due to these areas being primarily located in the high elevation headwaters and the agricultural areas of both basins. As a result, to appropriately manage these priority areas, the management actions chosen for implementation in these priority areas should be tailored to the existing land uses.

Forest and meadow land covers in the high elevation headwater priority management areas that have projected adverse changes for baseflow, nitrogen and phosphorus would be a possible candidate for forest restoration (underbrush thinning and/or tree planting) and meadow restoration (contouring and revegetation to restore a natural hydrologic regime) to address the projected decrease in baseflow and increase in nutrients originating in these areas. Agricultural land uses in the priority management areas that are projected to have large increases in nitrogen and phosphorus export could implement riparian buffers or convert to conservation easements to promote native vegetation that can reduce runoff of nutrients and sediment erosion.

Table 14. Walker Basin Priority Area Land Use Percentages.

Walker River			
Habitat Type	LULC Code	Total Area (Square Meters)	Percent Area
Open Water	11	56006	0.51
Low Intensity Residential	21	225	0.00
High Intensity Residential	22	4882	0.04
Commercial/Industrial	23	1268	0.01
Bare Rock	31	6936850	63.43
Evergreen Forest	42	802807	7.34
Shrubland	52	2580921	23.60
Grasslands	71	542865	4.96
Non-Forested Wetland	95	9671	0.09

Table 15. Carson Basin Priority Area Land Use Percentages.

Carson River			
Habitat Type	LULC Code	Total Area (Square Meters)	Percent Area
Open Water	11	12453	0.03
Low Intensity Residential	21	485423	1.23
High Intensity Residential	22	185428	0.47
Commercial	23	29511	0.07
Industrial Land	24	1264	0.00
Bare Rock	31	5643825	14.26
Deciduous Forest	41	32843	0.08
Evergreen Forest	42	11215617	28.33
Shrubland	52	18325367	46.29
Grasslands	71	3322400	8.39
Non-Forested Wetland	95	337018	0.85

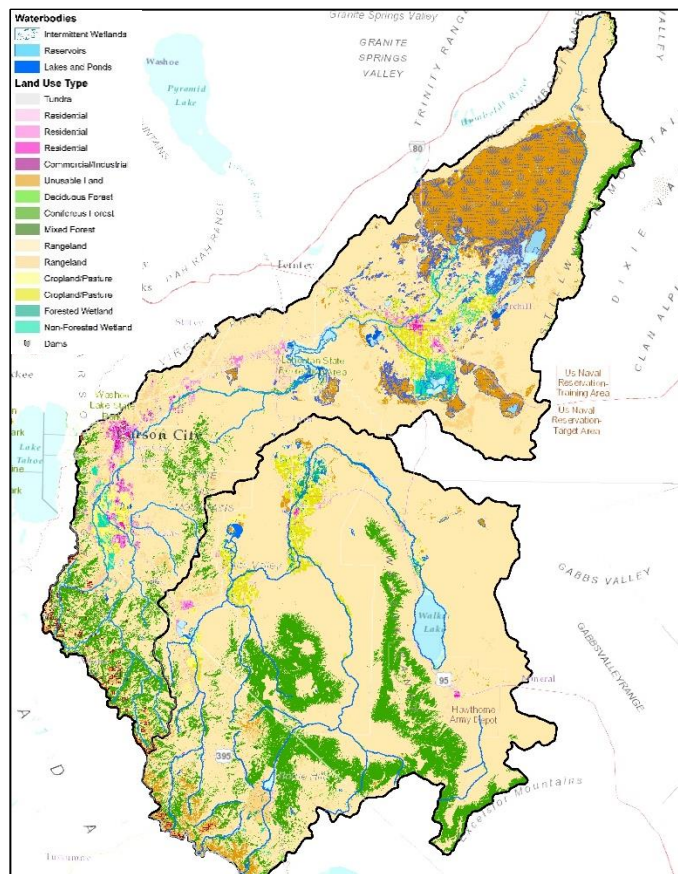


Figure 36. Carson and Walker River Land Use, See Figure 37 and Figure 38 for Enlarged.

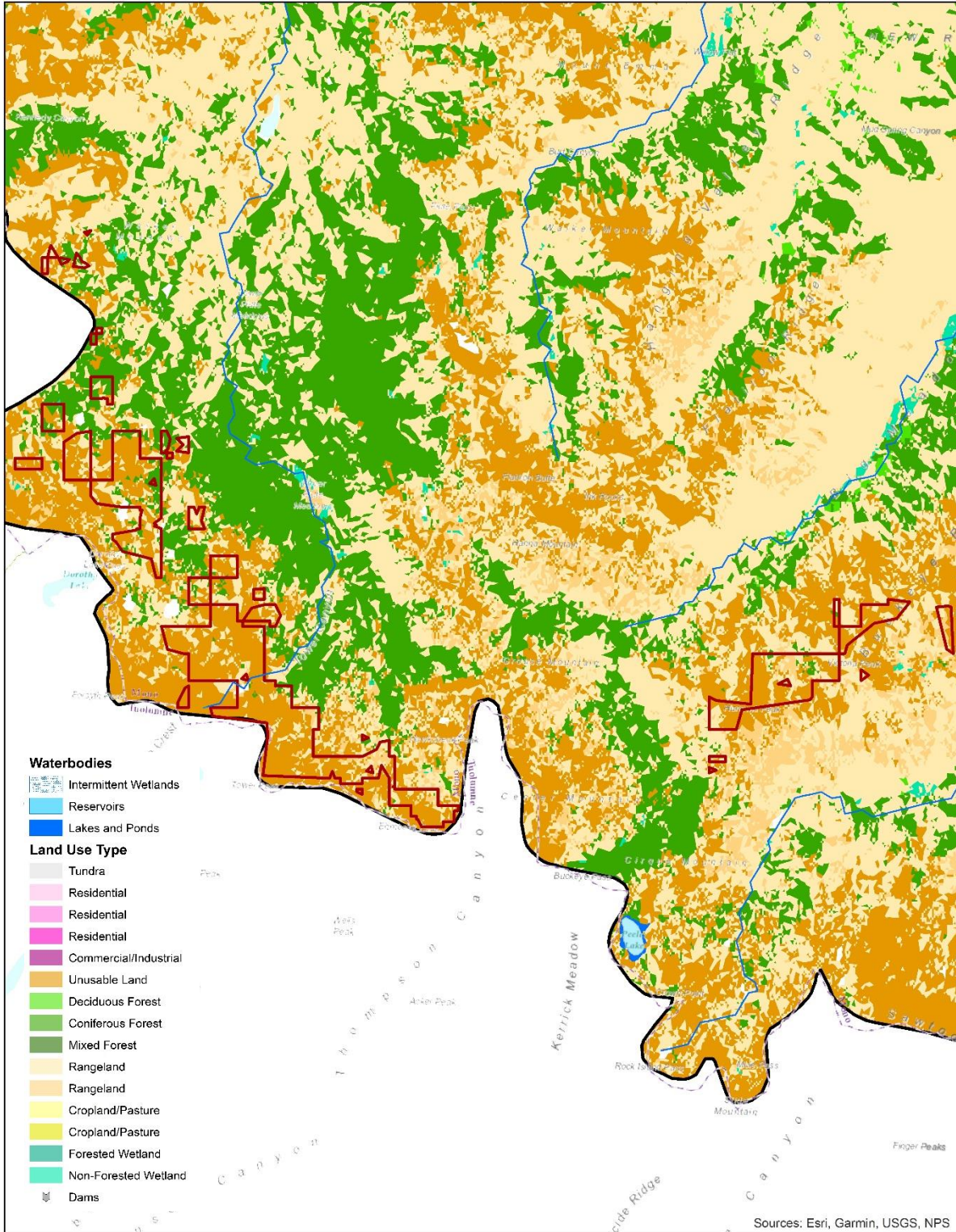


Figure 37. Walker Basin Headwater, Priority Areas (Enlarged). Red Outlines Indicate Calculated Priority Areas.

The method for implementing the appropriate management actions in the priority management areas also depends on the ownership (private or public) of the property and government entities (federal bureau or local municipality) that have jurisdiction over the property. For the priority management areas in the Walker basin private lands are contained on the western side of the basin up by Smith Valley and by Hawthorne Depot, while the Carson basins the ownership with private lands consist mainly on the middle and lower stretches of the river on the western side of the basin (**Figure 39, Figure 40**). Private ownership in the priority management areas could result in different management actions (e.g., water rights transfers and land purchases) and funding mechanisms than public ownership (e.g., pooling federal funding for programs).

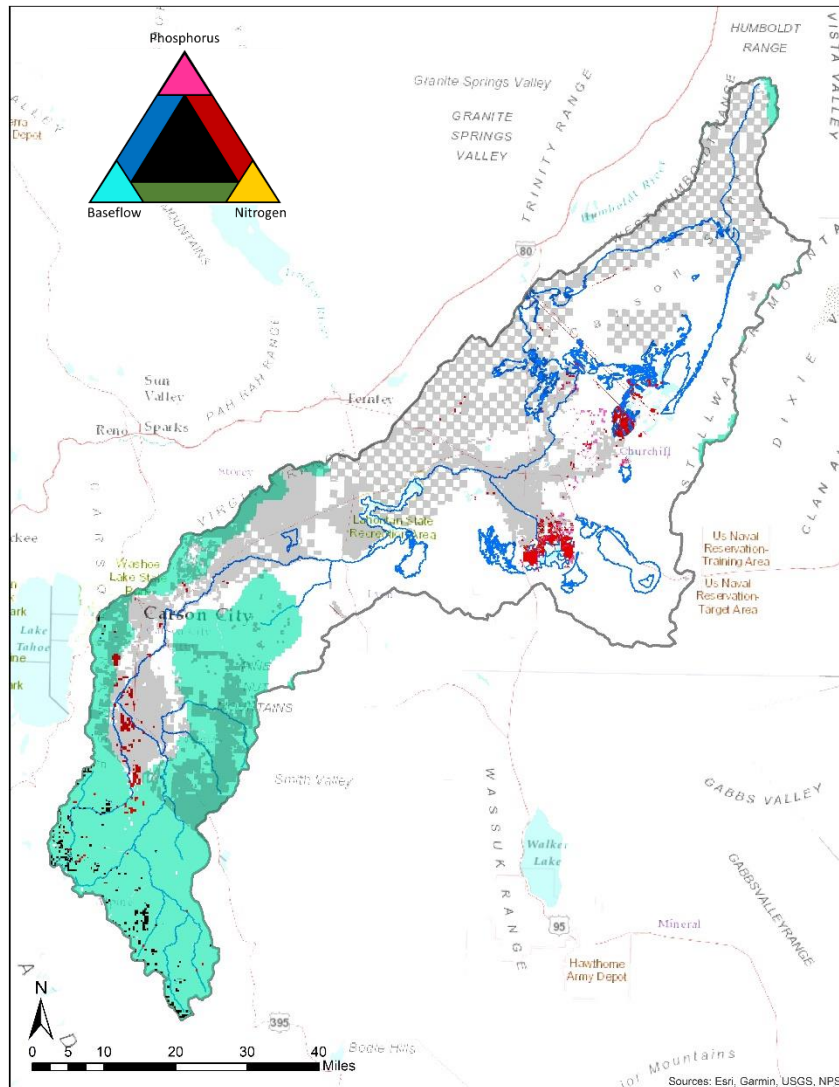


Figure 39. Carson Basin 2050 Change Priority Areas, Shaded Areas in Grey Are Private Lands.

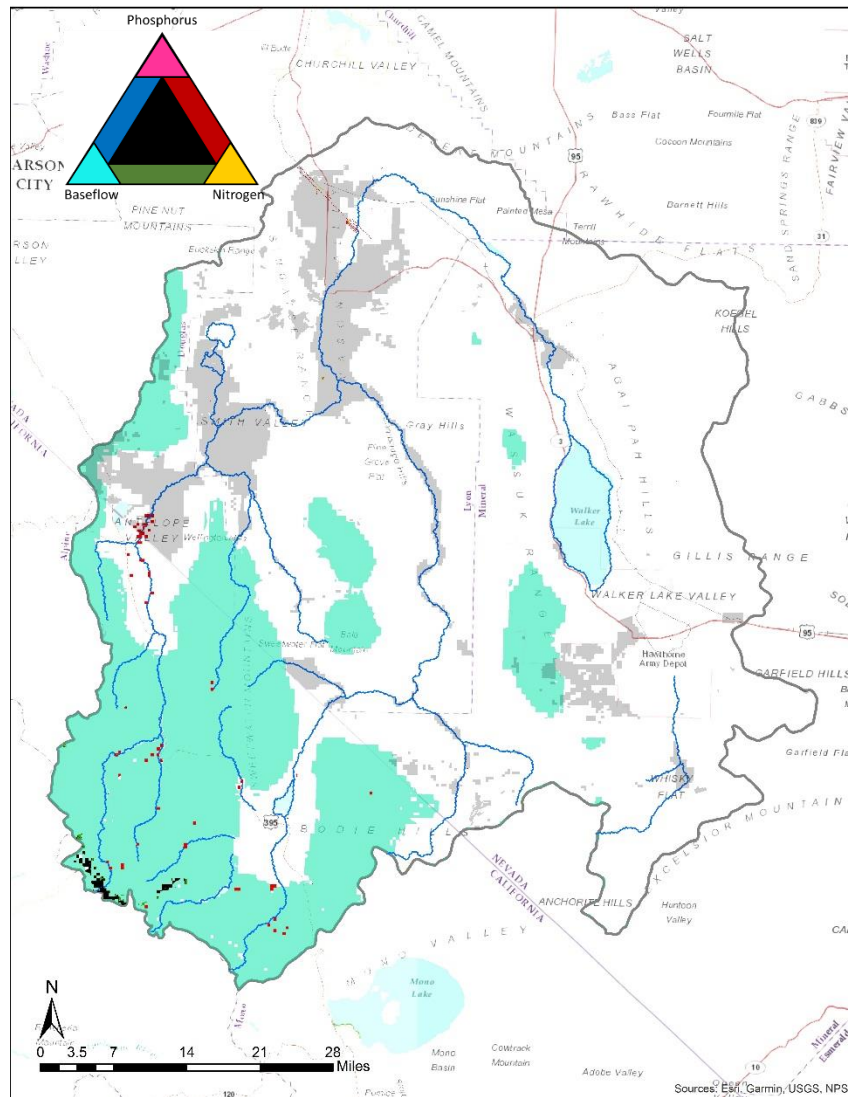


Figure 40. Walker Basin 2050 Change Priority Areas, Shaded Areas in Grey Are Private Lands.

Existing Conservation Easements and Priority Management Areas

Although this analysis has identified particular potential management areas throughout both the Carson and Walker basins, there may be different levels of priority for implementing management actions in these areas based on their ability to connect with and have reciprocal benefits with existing conservation and management areas. To determine the potential for reciprocal benefits in the priority management areas from this analysis, they were mapped with the known conservation easements in both the Carson and Walker basins.

Approximately 3,964 acres of existing conservation easements are located within the priority the boundaries of Douglas County with 18,320.94 acres of additional Southern Nevada Public Lands Management Act sensitive land acquisitions located throughout (**Figure 41**; Douglas

County, 2019). Together these conservation easements are listed as having 73% placed within the Carson River floodplain. Priority areas near these existing conservation easements could be given top priority when implementing management actions to maximize the reciprocal benefits of linking habitat and management areas.

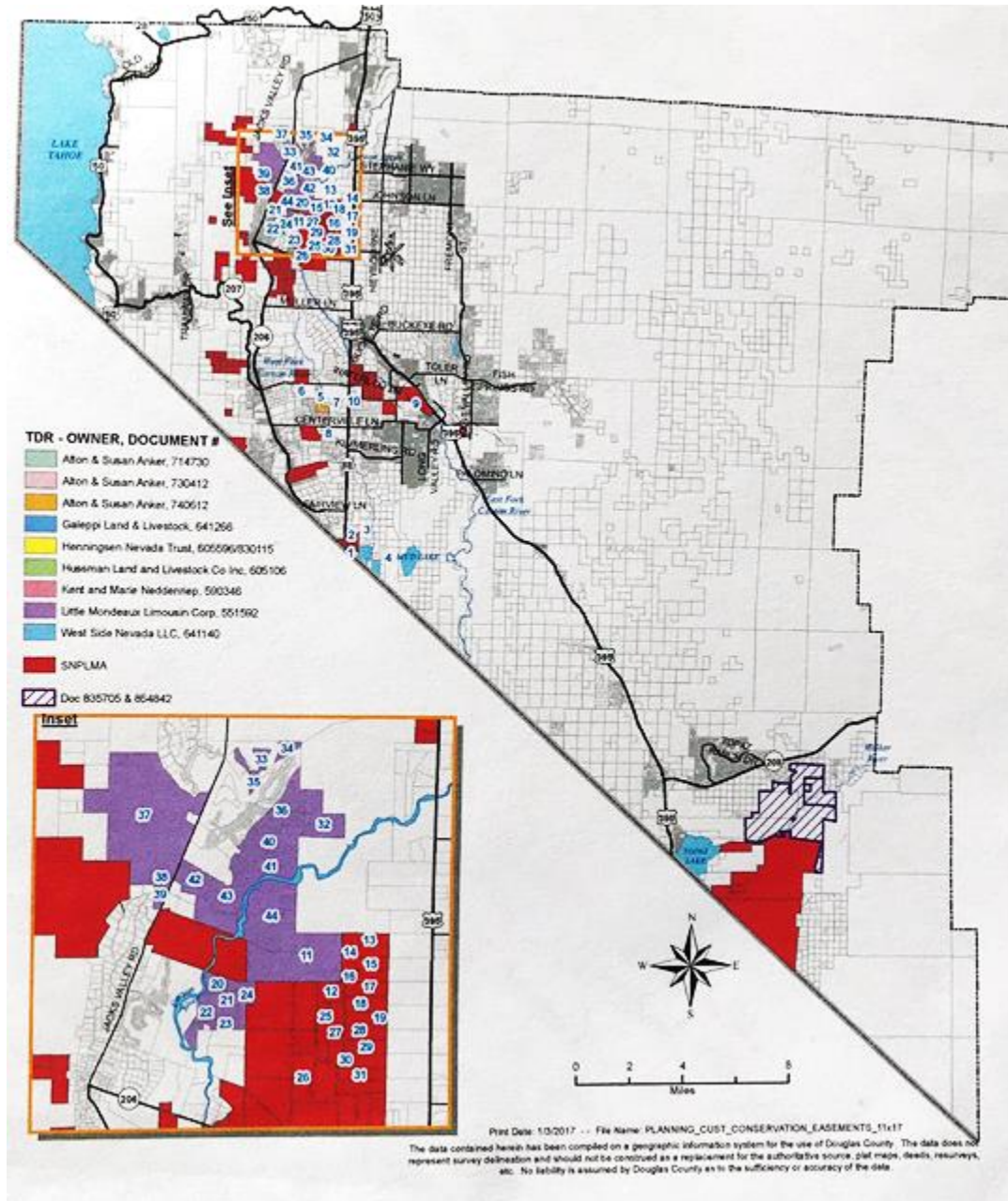


Figure 41. Douglas County Existing Conservation Easements, Taken Directly from Douglas County Official Documents (Douglas County, 2017) Note* Numbers correspond to conservation easement list of acquired TDR properties.

RESULTS FURTHER EXPLORED - SENSITIVITY ANALYSIS

There are many potential sources of uncertainty in the analysis results for baseflow contribution, nitrogen export, and phosphorus export. However, the largest source of uncertainty in this analysis is the projection of future climate parameters (e.g., temperature and precipitation). This includes both the use of different global circulation models (GCMs) and representative concentration pathways (RCPs). Therefore, this sensitivity analysis is intended to quantify the uncertainty in the analysis results (both the projected percent change from baseline for baseflow, nitrogen, and phosphorus as well as the shift in priority management area locations) associated with projecting future climate parameters.

CLIMATE SCENARIO SENSITIVITY

The InVEST modeling results shown in Section “Modeled Results – Future Application and Priority Areas” above, were analyzed using the CanESM2 (representing an average climate - precipitation, temperature, and their associated variability - future) GCM and RCP8.5 climate scenario. This climate scenario represents a “business as usual” future where factors such as population growth, land use, and economic activity continue to increase of greenhouse gas emissions through 2100 (Wayne, 2013). Under the RCP8.5 climate scenario, this level of greenhouse gases (1370 parts per million [ppm] CO₂ equivalent) is expected to increase the global average temperature by approximately 4.9 °C (radiative forcing of 8.5 Watts/m²) by 2100 (Wayne, 2013). This RCP (and the CanESM2 GCM) was used to represent the potential upper bound (i.e., worst case) of what could happen to baseflow contribution, nitrogen export, and phosphorus export as a result of climate change.

However, there are other RCPs that represent futures with different levels of greenhouse gas emissions. The results of our analysis could change depending on how future population, land use, and economic activity changes. To determine how the results for baseflow contribution, nitrogen export, and phosphorus export may change in the Carson and Walker basins due to the uncertainty in future population, land use, and economic activity InVEST modeling was also completed using RCP4.5. RCP4.5 represents a future where greenhouse gas emissions stabilize by 2100 (at 650 ppm CO₂ equivalent), resulting in an estimated global average temperature increase of 2.4 °C (radiative forcing of 4.5 Watts/m²) (Wayne, 2013). This RCP is considered to be generally consistent with the world’s nations meeting the goals of the Paris Climate Agreement and was used as a potential lower bound (i.e., best case) of what could happen to baseflow contribution, nitrogen export, and phosphorus export as a result of climate change.

CHANGE IN BASEFLOW CONTRIBUTION, NITROGEN EXPORT, AND PHOSPHORUS EXPORT AMOUNTS

To determine how the baseflow contribution, nitrogen export, and phosphorus export absolute amounts differ based on a range of future climate scenarios (using RCP4.5 and

RCP8.5 as the lower and upper bounds, respectively) the quintiles for these three factors were calculated for both RCP4.5 and RCP8.5 using the CanESM2 GCM. The quintiles represent the minimum, 20th percentile, 40th percentile, 60th percentile, 80th percentile, and maximum values for baseflow contribution, nitrogen export, and phosphorus export amounts. Comparing quintiles provides a general understanding on how the distribution of baseflow contribution, nitrogen export, and phosphorus export absolute amounts are different for the two climate scenarios used in this sensitivity analysis. The quintiles were compared for the future years of 2050 and 2100 to further understand differences and potential uncertainty in the results due to the future climate scenario used in the analysis.

Baseflow Contribution Sensitivity (RCP4.5 and RCP8.5)

To assess the sensitivity of baseflow contribution results to different RCPs the percent change from baseline for each quintile was calculated for both RCP8.5 (presented as the results RCP4.5 and. The difference in the respective percent changes in baseline for these RCPs was determined and indicates the potential variation in the results due to different future climate scenarios (i.e., RCPs).

In the Carson basin in 2050 under RCP4.5 baseflow contributions are estimated to decrease by about 1% from baseline for each quintile compared to a decrease of 16.9% for each quintile under RCP8.5. This represents a potential 15.9% difference in baseflow contribution from baseline for each quintile is due to different future climate scenarios (i.e., RCPs) (**Table 16**). In 2100, the basin baseflow contributions under RCP4.5 are projected to have a 0.2% decrease compared to baseline for each quintile, while RCP8.5 is projected to result in a 34.1% decrease in baseflow contribution from baseline. As such, a potential 33.9% difference in baseflow contribution from baseline can be attributed to possible different future climate scenarios.

Table 16. Carson Basin Climate Scenario Sensitivity – Baseflow Contribution.

Quintile	Baseline (mm/year)	2050				
		RCP4.5 (mm/year)	% Change ¹	RCP8.5 (mm/year)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0%
1	134	132	-1.0%	111	-16.9%	15.9%
2	171	169	-1.0%	142	-16.9%	15.9%
3	230	228	-1.0%	191	-16.9%	15.9%
4	356	352	-1.0%	296	-16.9%	15.9%
Maximum	1,892	1,873	-1.0%	1,572	-16.9%	15.9%
Quintile	Baseline (mm/year)	2100				
		RCP4.5 (mm/year)	% Change ¹	RCP8.5 (mm/year)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0%
1	134	133	-0.2%	88	-34.1%	33.9%
2	171	170	-0.2%	112	-34.1%	33.9%
3	230	230	-0.2%	152	-34.1%	33.9%
4	356	355	-0.2%	235	-34.1%	33.9%
Maximum	1,892	1,888	-0.2%	1,241	-34.4%	33.9%

Notes: ¹ % change between baseline and future RCP4.5 scenario.

² % change between baseline and future RCP8.5 scenario.

³ Difference between future RCP4.5 and RCP8.5 scenarios.

In the Walker basin in 2050 under RCP4.5 baseflow contributions are estimated to decrease by about 1.9% to 8.2% from baseline for each quintile compared to a decrease of 17.6% to 22.9% for each quintile under RCP8.5. This represents a potential difference in baseflow contribution from baseline due to different future climate scenarios ranging from 14.7% to 15.7% for each quintile (**Table 17**). In 2100 the basin baseflow contributions under RCP4.5 are projected to range from a 1.1% to 7.4% decrease compared to baseline for each quintile, while RCP8.5 is projected to result in a 34.4% to 38.9% decrease in baseflow contribution from baseline. As such, a potential range of 31.9% to 33.3% difference in baseflow contribution from baseline can be attributed to possible different future climate scenarios.

Table 17. Walker Basin Climate Scenario Sensitivity – Baseflow Contribution.

Quintile	Baseline (mm/year)	2050				
		RCP4.5 (mm/year)	% Change ¹	RCP8.5 (mm/year)	% Change ²	% Change Difference ³
Minimum	0	0	0	0	0	0%
1	149	139	-6.7	117	-21.7	15.0%
2	196	185	-5.5	155	-20.6	15.2%
3	266	247	-7.3	207	-22.2	14.9%
4	462	424	-8.2	356	-22.9	14.7%
Maximum	1,998	1,960	-1.9	1,645	-17.6	15.7%
Quintile	Baseline (mm/year)	2100				
		RCP4.5 (mm/year)	% Change ¹	RCP8.5 (mm/year)	% Change ²	% Change Difference ³
Minimum	0	0	0	0	0	0%
1	149	140	-5.9	93	-37.9	31.9%
2	196	187	-4.7	123	-37.0	32.4%
3	266	249	-6.5	164	-38.3	31.7%
4	462	428	-7.4	283	-38.9	31.4%
Maximum	1,998	1,977	-1.1	1,311	-34.4	33.3%

Notes: ¹ % change between baseline and future RCP4.5 scenario.

² % change between baseline and future RCP8.5 scenario.

³ Difference between future RCP4.5 and RCP8.5 scenarios.

Nitrogen Export Sensitivity (RCP4.5 and RCP8.5)

To assess the sensitivity of nitrogen export results to different RCPs the percent change from baseline for each quintile was calculated for both RCP8.5 (presented as the results RCP4.5 and. The difference in the respective percent changes in baseline for these RCPs was determined and indicates the potential variation in the results due to different future climate scenarios (i.e., RCPs).

In the Carson basin in 2050 under RCP4.5 nitrogen export is estimated to decrease by a range of 3.0% to 3.4% from baseline for each quintile compared to an increase of 0% to 23.8% for each quintile under RCP8.5. This represents a potential difference between RCP8.5 and RCP4.5 in nitrogen export from baseline of -20.4% to 3.4% for each quintile (**Table 18**). In 2100 the change in the basin’s nitrogen export under RCP4.5 is projected to have a range of -3.9% to 2.5% compared to baseline for each quintile, while RCP8.5 is projected to result in a range of -0.9% to 58% change in nitrogen export from baseline. As such, a potential -55.5% to 3.4% difference in nitrogen from baseline can be attributed to possible different future climate scenarios.

Table 18. Carson Basin Climate Scenario Sensitivity – Nitrogen Export.

Quintile	Baseline (mm/year)	2050				
		RCP4.5 (kg/km ² /year)	% Change ¹	RCP8.5 (kg/km ² /year)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0%
1	0	0	0%	0	0%	0%
2	14.7	15.2	-3.4%	18.2	23.8%	-20.4%
3	39.1	40.5	-3.4%	39.1	0.0%	3.4%
4	78.2	75.9	3.0%	78.2	0.0%	-3.0%
Maximum	1,246.8	1,289.7	-3.4%	1,246.8	0.0%	3.4%
Quintile	Baseline (mm/year)	2100				
		RCP4.5 (kg/km ² /year)	% Change ¹	RCP8.5 (kg/km ² /year)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0%
1	134	0	0%	0	0%	0%
2	171	15.0	2.5%	15.5	5.7%	-3.2%
3	230	40.1	2.5%	38.8	-0.9%	3.4%
4	356	75.2	-3.9%	77.6	-0.9%	-3.0%
Maximum	1,892	1,277.6	2.5%	1,969.8	58.0%	-55.5%

Notes: ¹ % change between baseline and future RCP4.5 scenario.

² % change between baseline and future RCP8.5 scenario.

³ Difference between future RCP4.5 and RCP8.5 scenarios.

In the Walker basin in 2050 under RCP4.5 nitrogen export is estimated to increase by a range of 0% to 3.6% from baseline for each quintile compared to an increase of 0% to 24.3% for each quintile under RCP8.5. This represents a potential difference between RCP8.5 and RCP4.5 in nitrogen export from baseline of 0% to -20.7% for each quintile (**Table 19**). In 2100 the change in the basin’s nitrogen export under RCP4.5 is projected to have a range of 0% to 2.6% compared to baseline for each quintile, while RCP8.5 is projected to result in a range of 0% to 57.5% change in nitrogen export from baseline. As such, a potential -54.9% to 0% difference in nitrogen export from baseline can be attributed to possible different future climate scenarios.

Table 19. Walker Basin Climate Scenario Sensitivity – Nitrogen Export.

Quintile	Baseline (mm/year)	2050				
		RCP4.5 (kg/km ² /year)	% Change ¹	RCP8.5 (kg/km ² /year)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0
1	0	0	0%	0	0%	0
2	10.9	11.3	3.6%	13.5	24.3%	-20.7
3	32.6	33.8	3.6%	40.5	24.3%	-20.7
4	76.0	78.8	3.6%	94.5	24.3%	-20.7
Maximum	2,770.3	2,869.9	3.6%	3,443.9	24.3%	-20.7
Quintile	Baseline (mm/year)	2100				
		RCP4.5 (kg/km ² /year)	% Change ¹	RCP8.5 (kg/km ² /year)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0
1	0	0	0%	0	0%	0
2	10.9	11.1	2.6%	17.1	57.5%	-54.9
3	32.6	33.4	2.6%	51.3	57.5%	-54.9
4	76.0	78.0	2.6%	102.7	35.0%	-32.4
Maximum	2,770.3	2,842.1	2.6%	4,363.8	57.5%	-54.9

Notes: ¹ % change between baseline and future RCP4.5 scenario.

² % change between baseline and future RCP8.5 scenario.

³ Difference between future RCP4.5 and RCP8.5 scenarios.

Phosphorus Export Sensitivity (RCP4.5 and RCP8.5)

To assess the sensitivity of phosphorus export results to different RCPs the percent change from baseline for each quintile was calculated for both RCP8.5 (presented as the results RCP4.5 and. The difference in the respective percent changes in baseline for these RCPs was determined and indicates the potential variation in the results due to different future climate scenarios (i.e., RCPs).

In the Carson basin in 2050 under RCP4.5 phosphorus export is estimated to decrease by a range of 0% to 3.4% from baseline for each quintile compared to an increase of 0% to 23.8% for each quintile under RCP8.5. This represents a potential difference between RCP8.5 and RCP4.5 in phosphorus export from baseline of -20.3% to 2.9% for each quintile (**Table 20**). In 2100 the change in the basin’s phosphorus export under RCP4.5 is projected to have a range of 0% to 2.5% compared to baseline for each quintile, while RCP8.5 is projected to result in a range of 0% to 58.6% change in phosphorus export from baseline. As such, a potential -56.1% to 0% difference in phosphorus export from baseline can be attributed to possible different future climate scenarios.

Table 20. Carson Basin Climate Scenario Sensitivity – Phosphorus Export.

Quintile	Baseline (mm/year)	2050				
		RCP4.5 (kg/km ² /year)	% Change ¹	RCP8.5 (kg/km ² /y ear)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0%
1	0	0	0%	0	0%	0%
2	1.6	1.7	3.4%	2.0	23.8%	-20.3%
3	4.3	4.5	3.4%	4.7	8.3%	-4.9%
4	8.7	8.9	3.4%	8.7	0.6%	2.9%
Maximum	137.9	142.6	3.4%	170.7	23.8%	-20.3%
Quintile	Baseline (mm/year)	2100				
		RCP4.5 (kg/km ² /year)	% Change ¹	RCP8.5 (kg/km ² /y ear)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0%
1	0	0	0%	0	0%	0%
2	1.6	1.7	2.5%	2.6	58.6%	-56.1%
3	4.3	4.4	2.5%	5.1	19.0%	-16.5%
4	8.7	8.9	2.5%	9.4	9.0%	-6.6%
Maximum	137.9	141.3	2.5%	218.7	58.6%	-56.1%

Notes: ¹ % change between baseline and future RCP4.5 scenario.

² % change between baseline and future RCP8.5 scenario.

³ Difference between future RCP4.5 and RCP8.5 scenarios.

In the Walker basin in 2050 under RCP4.5 phosphorus export is estimated to decrease by a range of 0% to 3.6% from baseline for each quintile compared to an increase of 0% to 24.3% for each quintile under RCP8.5. This represents a potential difference between RCP8.5 and RCP4.5 in phosphorus export from baseline of -20.7% to 0% for each quintile (**Table 21**). In 2100 the change in the basin’s phosphorus export under RCP4.5 is projected to have a range of -0.2% to 2.6% compared to baseline for each quintile, while RCP8.5 is projected to result in a range of 0% to 57.5% change in phosphorus export from baseline. As such, a potential -54.9% to 0% difference in phosphorus export from baseline can be attributed to possible different future climate scenarios.

Table 21. Walker Basin Climate Scenario Sensitivity – Phosphorus Export.

Quintile	Baseline (mm/year)	2050				
		RCP4.5 (kg/km ² /year)	% Change ¹	RCP8.5 (kg/km ² /year)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0%
1	0	0	0%	0	0%	0%
2	1.7	1.8	3.6%	2.2	24.3%	-20.7%
3	5.3	5.4	0.8%	6.5	20.9%	-20.2%
4	10.4	10.8	3.6%	12.9	24.3%	-20.7%
Maximum	441.8	457.7	3.6%	549.2	24.3%	-20.7%
Quintile	Baseline (mm/year)	2100				
		RCP4.5 (kg/km ² /year)	% Change ¹	RCP8.5 (kg/km ² /year)	% Change ²	% Change Difference ³
Minimum	0	0	0%	0	0%	0%
1	0	0	0%	0	0%	0%
2	1.7	1.8	2.6%	2.7	57.5%	-54.9%
3	5.3	5.3	-0.2%	5.5	2.2%	-2.4%
4	10.4	10.7	2.6%	13.6	31.3%	-28.7%
Maximum	441.8	453.2	2.6%	695.9	57.5%	-54.9%

Notes: ¹ % change between baseline and future RCP4.5 scenario.

² % change between baseline and future RCP8.5 scenario.

³ Difference between future RCP4.5 and RCP8.5 scenarios.

DISCUSSION & LIMITATIONS

In order to complete the objectives of this research project a watershed analysis was conducted for both the Walker Basin and Carson Basin watersheds, ecosystem services were evaluated through the course of an in-depth literature review as well as modeling using the Natural Capitals InVEST software, a sensitivity analysis reviewing these changes was conducted, and an initial market-feasibility report was prepared. Throughout these processes different scenarios and assumptions were applied based on available data options, model scenarios, and the purpose of conducting certain analysis. Where existing reports may go further in-depth modeling specific changes to hydrologic processes, our research sought to identify priority areas for ongoing conservation easement placement and identify key steps needed to apply market mechanisms to further these project efforts.

INVEST IN PRACTICE: LIMITATIONS AND VALIDATION

The InVEST models available through the Natural Capital project are fairly universal and thorough in data application; however as with any models there are a number of limitations in using this model over other choices that may exist. In previous studies comparing models' strengths and weaknesses between InVEST (Annual Water Yield), LUCI (Flood Interception), and ARIES (Flow and Use) common limitations include certain factors are not considered such as hydropower reduction, the placement of infrastructure, and do not account for surface-groundwater interactions

(Sharps et al, 2017). In addition, nutrient values are highly dependent on the accuracy of the export coefficient values which depend fully on the robustness of the literature reviews used to obtain them which may vary from a few cases of samples to dozens (Sharps et al, 2017). Overall, these comparison studies between models found that discrepancies between reality and export coefficients based on variations in land management “may be expected to average out at larger scales” (Sharps et al, 2017). Reported strengths on the InVEST modeling tools over other similar options include its widespread adoption, a comprehensive user manual, biophysical outputs that show variations based on user inputs, and the ability to highlight or priorities areas for provisioning particular services (Sharps et al, 2017). In conducting our own modeling efforts, we also experienced additional limitations and lessons learned, the following of which are reported below along with a validation practice serving as proxy to a true calibration.

LIMITATIONS

While InVEST is an incredibly robust software for ecosystem services analysis, it possesses several limitations. A major limitation within InVEST is that it is not intended to estimate actual values for detailed hydrologic analysis, but instead is intended to estimate relative values in order to provide information on areas that will be most heavily impacted as variables change (Natural Capital Project, 2015). Furthermore, each model is based on annual averages and therefore does not consider the maximums and minimums that may occur throughout the year. Therefore, InVEST results should only be used to inform selection of priority areas, and not to inform detailed water plans that require detailed hydrologic information as well as high resolution temporal information.

Another limitation to InVEST is that it assumes that all water reaches the watershed outlet and does not consider surface water - groundwater interactions. Therefore, InVEST should not be utilized in regions where there are high amounts of surface water - groundwater interactions such as areas of karst geology (Tallis et al., 2011). However, relative contributions of yield/export throughout the watershed are still valid.

Models in InVEST determine the human contribution of consumptive water use based on the land use land class (LULC) coefficients provided. However, this is an oversimplification of the water use from each land parcel, as a land parcel of one particular LULC could consume a different amount than another parcel of the same LULC. Furthermore, while one parcel of land may contribute a certain amount to consumptive use, the water use could actually occur further upstream rather than on that particular parcel of land. Therefore, the spatial accuracy of InVEST outputs may be partially skewed.

Several parameters within the models (α , β , γ) describe complex climatic, hydrological, and topographical features of the watershed using only singular values. Alpha describes precipitation seasonality, beta describes the water storage capacity of the soils, and gamma describes the fraction of recharge available for downslope pixels. Under the default values, those parameters are constant over the entire basin and therefore do not consider differences throughout the watershed. This oversimplification of such complex processes may lead to error within the models.

Lastly, the analysis is performed on a pixel-by-pixel basis (~84 meters x 84 meters for this analysis). These pixels were treated as contiguous pieces of land that possessed the same properties

throughout. Therefore, InVEST is best used as a basin-wide analysis rather than analysis of a particular parcel of land, and the spatial accuracy is largely limited by the resolution of the data available.

VALIDATION

Although InVEST was not utilized in this study to perform a detailed analysis of the watershed, a validation procedure was performed in order to determine the magnitude of error. Using USGS stream gauges throughout both the Carson and Walker Basin, the percent differences between InVEST model output values and real-world values were calculated (**Table 22, Table 23, Table 24**). Ten USGS stream gauge stations were selected based on availability of data as well as spatial dispersion throughout each watershed.

The results of the analysis revealed that the Seasonal Water Yield model produced an average percent error in baseflow of 16.948% in the Carson Basin and -10.466% in the Walker Basin. The sources of error could be due to spatial and temporal errors in estimates, lack of consideration for surface water - groundwater interactions, and finally oversimplification of complex climatic, hydrologic, and topographical variables. The relatively small magnitude of error suggests that the models provided valid estimates.

Further validation analysis was performed on the Nutrient Delivery Ratio model phosphorus export output in the Carson Basin. The validation was performed utilizing a study conducted by USGS on sources of phosphorus to the Carson River (USGS, 2004). The results revealed a slightly higher magnitude of difference in the phosphorus results than the baseflow results, with an average percent error of -30.3323%. The increased error could be due to the fact that the Nutrient Delivery Ratio model utilized an output from the Seasonal Water Yield model as an input (runoff calculated from the Seasonal Water Yield model was utilized as the nutrient runoff proxy raster for the Nutrient Delivery Ratio model). Although the Seasonal Water Yield model produced outputs with relatively small errors, those errors were likely magnified within the Nutrient Delivery Ratio model outputs. Despite the much larger magnitude of error, the results still provide adequate estimates to be used for selection of priority areas.

Table 22. Calculation of percent difference between InVEST Seasonal Water Yield baseflow outputs and USGS station gauge heights for the Carson Basin. Source: USGS.

Carson Basin						
	Station ID	USGS Gauge Height (ft)	USGS Gauge Height (mm)	InVEST Baseflow (mm/pixel)	InVEST Baseflow (mm)	% Difference
1	10309000	8.476	2583.558	3312.477	3312.477	28.214%
2	10310400	0.828	252.435	332.457	332.457	31.700%
3	10311000	2.913	887.730	944.081	944.081	6.348%
4	10312000	4.360	1329.016	1563.718	1563.718	17.660%
5	10312275	4.063	1238.454	1248.592	1248.592	0.819%
					Average Difference (%)	16.948%

Table 23. Calculation of percent difference between InVEST Seasonal Water Yield baseflow outputs and USGS station gauge heights for the Walker Basin. Source: USGS.

Walker Basin						
	Station ID	USGS Gauge Height (ft)	USGS Gauge Height (mm)	InVEST Baseflow (mm/pixel)	InVEST Baseflow (mm)	% Difference
1	10296000	2.202	671.040	617.620	617.620	-7.961%
2	10293000	3.076	937.559	867.971	867.971	-7.422%
3	10300000	1.781	542.957	390.348	390.348	-28.107%
4	10301500	4.198	1279.678	1209.146	1209.146	-5.512%
5	10302025	4.583	1397.000	1350.527	1350.527	-3.327%
					Average Difference(%)	-10.466%

Table 24. Calculation of percent difference between InVEST Nutrient Delivery Ratio (Phosphorous) outputs and USGS station gauge heights for the Carson Basin. Source: USGS.

Carson Basin						
	Station ID	USGS Phosphorus Export (lb/acre/year)	USGS Phosphorus Export (kg/km2/year)	InVEST Phosphorus Export (kg/pixel/year)	InVEST Phosphorus Export (kg/km2/year)	% Difference
1	10310000	0.091	10.200	0.046	6.526	-36.021%
2	10309010	0.167	18.718	0.103	14.717	-21.378%
3	10311000	0.133	14.907	0.078	11.201	-24.859%
4	10311400	0.108	12.105	0.052	7.447	-38.484%
5	10312020	0.060	6.725	0.033	4.646	-30.917%
					Average Difference (%)	-30.332%

Validation of Nutrient Delivery Ratio was conducted for the Carson Basin using recorded Phosphorus loading calculations from the USGS. This validation serves as proxy for both the Nitrogen and Phosphorus values calculated on the Carson Basin. The remainder of the output validations were not performed due to a lack of nutrient export data at site specific locations for comparison. However, since this study only utilized relative values in order to provide information on priority areas, this was not necessary.

MARKET LIMITATIONS & KNOWN INVESTMENT INTERESTS

MARKET LIMITATIONS

Live and accurate market price data is difficult to come by without a central, open database to access. Market transactions databases do currently exist yet are subscription based, often requiring large annual fees for access, and may not contain live market data depending on the database administrator. Information and access differ regionally and across watersheds, and while this is the case for Carson and Walker, it is not for other basins with a more developed market presence and more state transactions being facilitated. There does exist; however, well documented price data for water transactions nearby along the Truckee River and for areas along the Walker River in terms of obtaining instream flows with the intention of returning to Walker Lake (these being facilitated by National Fish and Wildlife Foundation; NFWF).

Often both buyers and sellers are incentivized to hold this information close-to-chest in order to avoid unsavory effects on market pricing. Without a thorough accounting of investment interests

over the course of a few years, following up with the parties initially considered for applying market mechanism in these basins, it is difficult to recommend one single market option over others. In addition, the market mechanisms initially considered by TNC for feasibility scoping, a water fund, require certain criteria including 1) a central management entity or “champion” as described in most case studies, 2) enough funding supplied by downstream users, and 3) coordinated planning efforts for use of the funds available. The major hinderances and limitations for recommending a water fund in this area is the lack of continuous funding from a large body of downstream users. While the population of Douglas County has grown substantially in recent decades, the county Land Development sections of the Master Plan indicate that this growth is now carefully tacked with only certain acres of land available to be added each year.

INVESTMENT INTERESTS

In existing publications, researchers around the Truckee and Carson river basins indicated management interests by interviewing a representative sample of existing water managers to identify trends in management adaptation strategies and barriers. Based on these studies, involving multiple interviews conducted between 2015 and 2016, managers in the Carson Basin (and by proxy surrounding watersheds) showed an increased interest in collecting scientific-based information to inform management strategies, desires to explore modifications to existing water institutions, an increase in the option to collaborate and communicate between partnering groups, as well as more concerns addressing enhancing available water supplies (Sterle et al, 2017). The only category experiencing a decline in manager interests between the rounds of surveys was for managing water demands as some individuals have shift interest from conservation tactics to adaptive management solutions instead.

Major barriers presented through the same research indicate a now unanimous agreement that climate uncertainty is a barrier for water resource management (moving from 50% responding such in 2015 to 100% in 2016) (Sterle et al, 2017). Additional barriers indicate an increasing concern for existing water institutions, lack of communicating, and need for improved water delivery efforts (Sterle et al, 2017). Views on water scarcity remained consistent between 2015 and 2016 based on the reported responses. Based on these manager concerns there is a clear interest in increasing communication efforts between management groups as well as overcoming more barriers regarding climate change uncertainty.

Major Take Away

Existing water resource manager interest in adaptation strategies and recognition of barriers for success indicate that collective management action, facilitated by market mechanisms may be well perceived by acting authorities in the local area. Although, these mechanisms must be flushed out with continued communication efforts across all relevant parties with an emphasis on exactly which resources are most needed; including but not limited to communication, central authority groups, collective funding and management for similar projects, as well as additional consideration paid to scientific information regarding climate change.

RECOMMENDATIONS

Based on the modeled results, known investment interests, and resources available for utilization in these basins the following recommendations have been prepared. To account for climate change effects, future conservation easement placement and land acquisitions should be considered in priority areas which contribute most to baseflow, nutrient loadings, and sediment export. For existing conservation lands throughout the basin, managers should execute best management practices, where able, to improve water quality and quantity conditions. In addition, to move towards creating a sustainable market mechanism for ongoing conservation work it is recommended that TNC and their partners create working groups for additional feasibility meetings and pilot projects to further test which mechanisms will be most beneficial for the local stakeholders present in this area.

CONSERVATION EASEMENTS TO PRIORITIZE

Headwaters and Priority Areas

Climate change is expected to alter the characteristics of the Carson and Walker basins within the next 100 years. Under the projections of an RCP 8.5 scenario, our team has identified the regions which are expected to experience the largest drop in water availability and the largest increases in pollutants and have found these areas to be concentrated in high elevations in both the Carson and Walker basins. To preserve water quality and ensure a reliable supply, conservation efforts should be focused in the headwaters. The high slopes of the Sierra Nevada are the largest proportion of source water to Douglas County. Rainfall and snow deposit up to 1800mm of precipitation in this region, which runs off the bare granite rock characteristic of the area and feeds the Walker and Carson rivers. The rapid runoff and high precipitation levels mean that the area is sensitive to any increase in contaminants. By focusing conservation efforts in an area of the basin which is less than 50 square kilometers, TNC will be mitigating climate change impacts on land parcels in the top quantile of risk.

After identifying which parcels of land will be most sensitive to the impacts of climate change, the current conditions of the parcels were examined. A land use analysis has found that the area is primarily privately owned, and consists of either shrubland, barren rock lands, or evergreen forests. Since the land is under private rather than public management, it is recommended that TNC continue to preserve water quality and water supply through conservation easements. By partnering with land owners in high altitudes of the headwaters, TNC can ensure that land is being managed sustainably in the face of climate change. The relatively small area of the priority areas mean that conservation easements may be prohibitively expensive. Within these priority areas, focus should be paid to river restoration and sustainable land management. Landowners should be incentivized to pivot from nutrient excessive ranching operations through the use of riparian buffers, cattle fences, or mandating herd size and movement.

Cross-State Management Efforts

The identified priority areas are located mainly in the headwaters of the Carson and Walker basins. These headwaters cross over between both Nevada and California and cover mainly shrubland, forests, and barren land use types. Considering the nature and placement of these priority areas, it is recommended that management actions aimed at conserving lands that will be most sensitive to climate change impacts be conserved through interstate natural resource management partnerships. Meadowland, forestland, and other restoration projects should be expanded in these areas. Existing conservation projects and management actions are already placed in and around areas just below these headwater zones. The research provided from this modeling process leads our team to recommend additional consideration be placed on expanding projects and consideration in the Upper Carson river and areas surrounding the headwaters of each watershed.

BEST MANAGEMENT PRACTICES

To avoid complications with water quality and help increase water supply it is recommended that TNC and their partners apply known best management practices as recommended for this area. Given that conservation easements such as River Fork Ranch are based on 50-50 conservation habitat land use and agricultural lands agreements, to preserve and improve the integrity of riparian habitats it is recommended that managers and leaseholders consider the following recommended best management practices in addition to the work they are already doing.

CONSERVATION EASEMENT MANAGEMENT – AGRICULTURE LANDS

Formal Grazing Plans & Fencing Around Riparian Areas for Water Quality

Due to known reports of algae blooms and heavy nutrient loadings alongside existing cattle operations and stretches of the Carson river it is recommended that managers consider adding fencing to prevent cattle from crossing the stream and detrimentally impacting critical areas. Based on existing BMP documents prepared by the state of Nevada and agriculture land researchers, fences (either traditional barricades or modern electrical fences –where applicable with trained herds) be used to exclude wildlife from entering sensitive or critical areas (Freeman, M. C., 1994).

Research out of UC Davis has studied the relationship between livestock (fecal deposits) and associated pathogens detrimentally effecting drinking water services due to runoff into river bodies (Tate, K., & Atwill, R., 2017). These studies indicate that by setting stocking rates in balance with forage production sites may be more resilient to impacts on soil and vegetation, by distributing grazing and water across the landscape rather than in concentrated areas as well as actively managing intensity of grazing near critical hydrologic zones (at the base of the headwaters in the upper Carson) may reduce pollution risks (Tate, K., & Atwill, R., 2017).

In addition, these researchers prescribed grazing management with set-reports and schedules designed to be followed throughout the year, cross fencing, off-stream drinking water for the herds to avoid concentration in and around the areas, as well as riparian pastures and employing the use of vegetated buffer strips to aid in these efforts (Tate, K., & Atwill, R., 2017). Existing management

for the active cattle ranches includes rotating grazing areas annually and seasonally to reduce impact on grazing areas. However, additional fencing and off-stream water sources for cattle may drastically improve the existing water quality conditions along the Carson river.

Removal of Noxious Weeds

Noxious weeds are a known concern for surrounding conservation easement lands. Often during the early stages of the process, a lack of hands-on management of new lands may contribute to the spread and growth of noxious weeds. Based on the materials presented previously and on-the-ground knowledge, it is recommended that managers continue to address and control noxious weed problems as they are presented throughout the basins on conservation easement lands and on sites in general.

MARKET RECOMMENDATIONS: SCOPING, MARKET COALITIONS, AND COORDINATED MANAGEMENT EFFORTS

Additional Scoping

Based on the existing case studies available for water funds and water banking, it is recommended that additional scoping meetings be considered for these projects –should TNC wish to pursue them. As seen in the case for the Colorado Water Banking multiple feasibility phases were considered before caring out the actual project which is still under development. This report and supporting documentation outlines water demand needs, available resources, and initial investment interests; however, additional scoping meetings are required for best results. Given the smaller population sizes present in Douglas County compared to other water fund projects observed in the past and the budgeted funding of existing water purveyors, a variation of a water fund or group-package of other market mechanisms may be more beneficial than a large-scale fund for this particular area –when considering fund administration costs and transaction costs.

It is recommended that TNC organize meetings with their partners and major managers in the area to gauge interest in participating in a larger group-market effort to coordinate projects throughout the basins. At present, numerous restoration projects from a variety of managing sources and entities are already active an in place. Unfortunately, this means that resources and conservation efforts may at times be dispersed rather than pooled for greater benefits and returns on investment.

Participation in Existing Market Mechanisms

As mentioned in the background portions of this report and market case studies, market mechanisms regrading water transactions and PES are already in effect throughout both basins. These markets are more active along the neighboring Truckee River and lower segments of the Walker River than in Carson; however, the mechanisms are already in place and facilitated by existing policies. Due to the placement of numerous conservation easements throughout the basin, a large proportion of conservation funding money that would be available from beneficiaries has already been played out across the basin in other forms. Depending on future additional feasibility and scoping meeting with stakeholders it may be more beneficial to design a targeted plan to participating in existing market services throughout the basins rather than creating a new water fund or water banking program. That being considered, if a single managing entity can come forward and the main downstream

beneficiaries choose to participate (collectively) a water fund or banking program may be an effective mechanism to coordinate these management efforts and activities (e.g. meadow restoration, forest restoration, and riparian habitat projects down and throughout the basins.)

Recommended Creation of Market Coalitions and Workgroups

It is recommended that TNC facilitate the creation of market scoping and coalition groups to connect existing partners. Most conservation groups and entities working on restoration projects in the Carson and Walker river basins are aware of and actively partnering with each other. Partners to consider for these larger coalitions include the Walker Conservancy, the Carson Sub Conservancy District, Douglas County, Nevada Division on Environmental Protection, Nevada Rural Water Association, local water purveyors, conservation easements firms, the Washoe tribe, and local recreations. To go forward with any fund mechanism a central administrative entity should be created or nominated from existing groups.

Management Coordination for Existing Projects

The majority of stakeholders in the area are well connected with TNC based on years of previous trust-building and networking throughout the basins. The Bren research team recommends that in order to successfully create a larger, more integrated water fund or water banking system in the area, decisions should come from these partnering groups as a collective who to verify who would be participating in these efforts and how. There may be ways to coordinate these efforts without a formal fund being created or verify the need and structure best suited to the area, depending on the funding and resources available to these groups.

CONCLUDING STATEMENTS

Modeled results indicate that regardless of specific climate change scenarios baseflow is expected to decrease throughout both the Carson and Walker River basins over the next 30 years. Specifically, ecosystem services along the headwater areas as well as around existing concentrations of agriculture and ranching land use activities are expected to experience drastic changes in existing nutrient loading –which may detrimentally affect future water quality conditions.

Market mechanisms are already in practice in and around the Carson and Walker river basins of Douglas County, Nevada. Water resource managers in the region are interested in expanding communication and collaboration efforts for existing projects as well as working to overcome existing barriers to climate change uncertainty. Based on existing literature reviews of known water funds and case studies, it is recommended that water resource managers form a coalition group(s) to further develop these ideas and consider a package of management options to further conservation efforts in this area.

Funding from downstream users (typically obtained from drinking water providers) may be a limiting factor for establishing a water fund in the Carson and Walker river basins which have smaller populations than previously seen. Depending on how many partnering organizations wish to participate in joint-efforts and actively contribute to additional scoping efforts a water fund or water banking system may be possible despite these supposed limitations. Improvements to and additional funding for existing conservation efforts may be obtained through other efforts including

joint-projects and pooled funding sources. Regardless, it is recommended that existing TNC projects apply BMPs to existing conservation easements and work to establish communication channels connecting opportunities for additional projects between partnering stakeholders.

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