A Simulation Model for Evaluating Water Acquisitions to Reduce Total Dissolved Solids in Walker Lake

A technical report for

National Fish and Wildlife Foundation,

Walker Basin Restoration Program

September 2014

Erik Borgen*
Bruce Aylward*
Greg Pohll**
Amy McCoy*

***Ecosystem Economics LLC, Bend, Oregon**

****Desert Research Institute, Reno, Nevada**

ECOSYSTEM ECONOMICS

DRI
Desert Research Institute

Acknowledgements

We would like to acknowledge the contribution of Kip Allander of the US Geological Survey who has assisted our team by sharing his understanding of the Lower Walker River system and carefully reviewing previous versions of this paper. We also wish to thank Rick Felling of Nevada Department of Water Resources and Dwight Smith, consultant to the Walker River Paiute Tribe for reviewing a presentation on the paper and working with us to ensure we have accurately depicted basin hydrology and water rights. And, finally we wish to thank Joy Morris and David Yardas of NFWF for their review of prior versions of this paper. All errors and omissions remain the property of the authors.

Disclaimer

Please note that the model presented in this paper is intended to assist NFWF and stakeholders as the Walker Basin Restoration Program unfolds. As such it is intended to be a "living model" and thus by the time you read the paper, the paper will itself necessarily be out of date. This, as acquisitions under the Program and other developments continue apace in real-time. Therefore the paper should be used to gain an understanding of the model and its mechanics, as well as to review projections based on information available as of early to mid-2014. As time goes by and the program evolves, better information is obtained and factors beyond NFWF's control emerge, NFWF will issue updates to the projections provided in this paper as future model runs and additional scenarios are undertaken. As an example, this paper only reflects water right acquisitions NFWF had completed through FY13. Future updates will incorporate changes due to further acquisitions by NFWF.

Two specific developments subsequent to the preparation of this paper are as follows:

The USGS report on the Lower Walker River, which is cited in this paper as Allander et al. Forthcoming 2014, is now published. The full citation to the report is: Allander, K.K., Niswonger, R.G., and Jeton, A.E., 2014, Simulation of the Lower Walker River Basin hydrologic system, west-central Nevada, Using PRMS and MODFLOW models: U.S. Geological Survey Scientific Investigations Report 2014-5190, 93 p., http://dx.doi.org/10.3133/sir20145190. Due to ongoing communications with Mr. Allander (as referred to in the acknowledgements above) our paper should be consistent with the final published version of the USGS paper

Since this paper was finalized NFWF has begun using 16,000 mg/l TDS as the upper threshold limit instead of 14,000 mg/l TDS. This reflects the following statement by USFWS: "

> The USFWS will resume stocking [of Lahontan Cutthroat Trout] when [Walker Lake's] TDS level drops below 16,000 mg/l. The long-term maintenance of a TDS range…of an optimal 8,000 mg/l to a less optimal level of 12,000 mg/l is necessary to conserve Walker Lake and the array of native species it supports." (Walker Lake Ecosystem Research and Monitoring Summary Report 2006-2013. U.S. Fish and Wildlife Service, Lahontan National Fish Hatchery Complex, November 2013).

.

Contents

List of Figures

List of Tables

1. Introduction

Under Public Law 111-85, the Walker Basin Restoration Program (WBRP) is charged with restoring and maintaining Walker Lake, as well as protecting agricultural, environmental, and habitat interests consistent with that primary purpose. The WBRP includes priority initiatives in the area of water acquisitions from willing sellers, demonstration water leasing, conservation and stewardship, research and evaluation, and implementation support. The program is managed by the National Fish and Wildlife Foundation (NFWF), a federally chartered non-profit organization established in 1984 to further the conservation and management of the nation's fish, wildlife, plant and habitat resources for present and future generations. WBRP funds are provided to NFWF under a grant agreement with the Bureau of Reclamation (Reclamation) and its Desert Terminal Lakes (DTL) program.

Walker Lake is a natural desert lake in Nevada at the terminus of the Walker River stream system that originates in the Sierra Nevada of California. Historically, the lake was an oasis of freshwater and home to many freshwater species, most notable the now-threatened Lahontan Cutthroat Trout (LCT). The lake also was an important stopover for Common loons and other migratory waterfowl. Over the last century, as irrigation diversions and storage were developed upstream of the lake, freshwater inflows to the lake have been insufficient to maintain lake levels. The drop in lake elevation and decline in lake volume has led to increased total dissolved solids (salinity or TDS) levels and the loss of freshwater habitat and species. The WBRP aims to lower TDS by adding freshwater to the lake through water rights transactions with willing sellers, thereby reversing the ecological decline of Walker Lake. In this report the term “water rights” refers to surface water rights only, as explained further in Section 3.

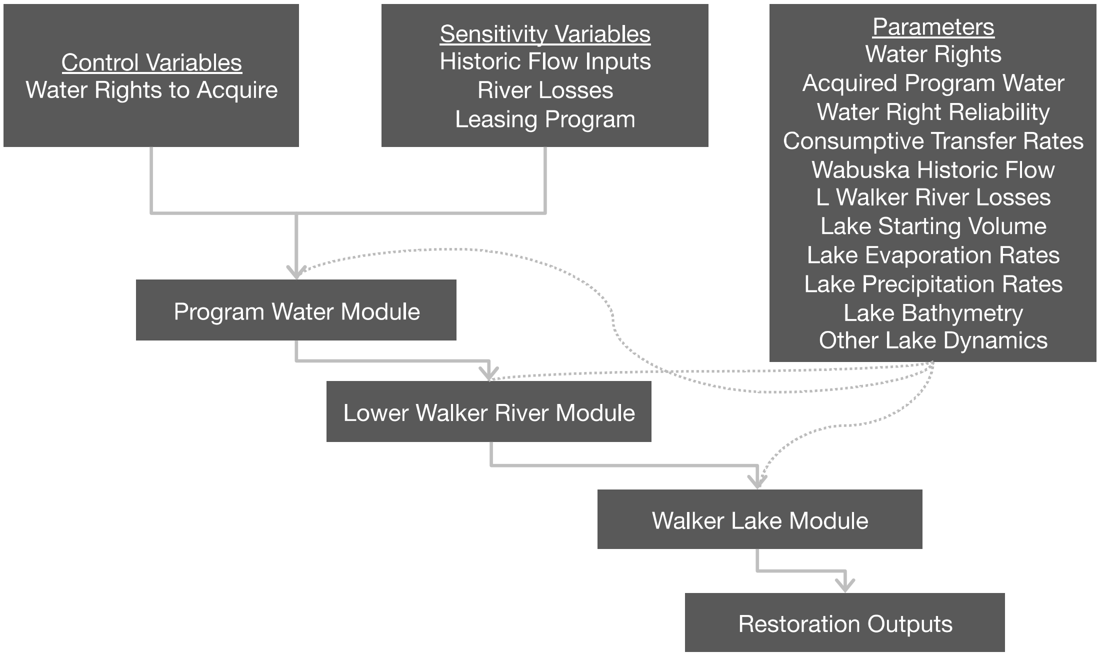
As part of the DTL program, and with funding from Reclamation and NFWF, the U.S. Geological Survey (USGS), the University of Nevada Reno (UNR) and the Desert Research Institute (DRI) have engaged in research, monitoring and planning efforts related to the acquisition of water rights in the Walker Basin since the mid-2000s. These efforts include a collaboration in the East, West, and Walker Rivers above the Wabuska Gage by UNR and DRI scientists on a suite of models forming a Walker Basin Decision Support Tool; and the development by USGS scientists of a Lower Walker River model, below the Wabuska Gage (Boyle *et al*. 2009: 2013; Minor *et al*. 2009; Allander *et al*. Forthcoming 2014).

Though valuable, detailed, and promising for the long term, these modeling efforts do not provide the WBRP with an integrated, basin-wide, planning-level simulation model that can be easily deployed to test the linkage between surface water acquisition efforts and TDS levels in Walker Lake. The model presented here attempts to fill that gap, drawing on the datasets, equations, and work of the USGS, UNR, and DRI.

This report provides a summary of the data, parameters and calculations used in the simulation model. The model simulates the long-term future impact on TDS in Walker Lake of ongoing efforts by the WBRP to purchase and lease surface water rights for delivery to the lake in accordance with all necessary approvals. The model allows the user to control a number of variables including the amount of water rights being purchased or leased and the corresponding amounts approved for change. Historic streamflow and water right reliability are then used to simulate the yield of these transactions and the stream losses experienced as that water flows downstream to Walker Lake. The basic model structure is outlined in Figure 1 below.

The user selected variables and parameters are the inputs to the calculations, which are divided up into a Program Water Module, Lower River Module and Walker Lake Module. The Program Water Module accounts for the acquisition and lease/transfer of WBRP water (i.e. Program Water) from the point of non-diversion to the Wabuska Gage. The Lower Walker River Module accounts for Program Water and non-Program Water from Wabuska down to Walker Lake. The Walker Lake Module accounts for the changes in storage in Walker Lake and resulting change in TDS.

Figure 1. Model Overview Flow Chart



The model is run using five basic scenarios:

- Scenario One – Business as Usual: this scenario models no change in flows to Walker Lake compared to current practices.
- Scenario Two – Return to Natural Conditions: under this scenario, no further irrigation occurs and all water currently diverted goes to support Walker Lake.
- Scenario Three – Restoration with Nevada Water Rights Only: under this scenario, eventual acquisition and transfer of 33% of all Nevada decree, associated supplemental storage, and New Land rights is modeled.
- Scenario Four – Restoration with Nevada and California Water Rights: This scenario models the purchase of 17% of remaining (not yet acquired) rights in California and Nevada resulting in total acquisitions under the Program of 20% of all decree rights (CA and NV) and 22% of all New Land (NV) rights.
- Scenario Five – Restoration to a Lesser Goal with Nevada Water Rights Only: This scenario models acquisition and transfer of 27% of all Nevada decree, associated supplemental storage, and New Land rights to demonstrate the amount of restoration needed to reach a mean TDS of 12,000 mg/L within 200 years.

In the short term, the model and this report will be reviewed by NFWF and interested parties. For the long term, the model and report are intended to be updated to account for new acquisitions, successful transfers and further changes in Walker Lake storage and TDS.

2. Ecology and Hydrology

This section briefly examines the interplay between water quality and ecological health of Walker Lake as well as the hydrologic conditions and practices that have influenced water quality.

2.1 Walker Lake Water Quality

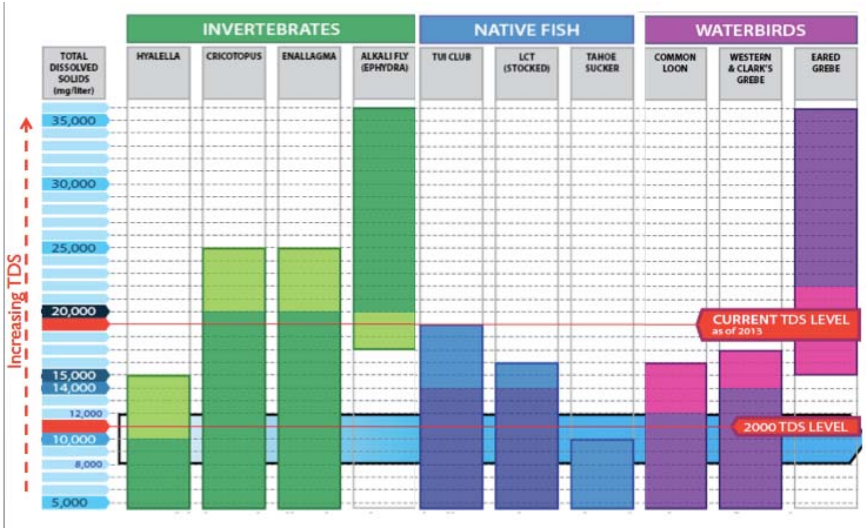
The ecological health in Walker Lake has declined over the past century. Prior to the late 1800s, the majority of flows in Walker River discharged into Walker Lake. With the growth and dispersion of agricultural diversions throughout the 1900s, most of the stream flow has been directed to agricultural production and flows to Walker Lake have decreased. As a result, salinity levels have steadily increased over the past several decades and affected the health and viability of populations of key fish and bird species.

To track conditions in the lake, several key indicators of ecological health and change have been selected (The Nature Conservancy 2013). Total dissolved solids (TDS) are the metric used for salinity. TDS has an inverse relationship to lake levels. In other words, as lake levels decline, salinity increases. TDS in the lake are currently almost 22,000 mg/L, a level at which native species, including LCT, cannot survive (see Figure 2 and Figure 3). Note that Figure 2 shows that lake TDS was below 20,000 mg/L in 2013 when The Nature Conservancy assessment was published, but that TDS levels have increased since that time. A preliminary water quality sample collected by the Nevada Science Center in January 2014 showed TDS levels at 21,800 mg/L. If no runoff reaches the lake, predictions suggest that TDS levels could increase to about 24,000 mg/L by the end of 2014.

In addition to TDS, invertebrate populations are also an indicator of water quality. As water quality in Walker Lake decreases, invertebrate populations shift toward species that can thrive in lower quality water. Surveying the decrease in abundance and variety of invertebrate species in the lake provides a proxy for other water quality indicators like TDS. Water quality changes that drive a decrease in invertebrate populations also cause a corresponding downward trend in the overall number and species of fish in the lake that can neither tolerate the TDS levels, nor survive on the shifting populations of insects. Likewise, as salt-tolerant insects increase and the diversity of fish species decrease, water bird populations shift towards species that can simultaneously tolerate higher TDS levels and thrive on a limited diversity of insects and fish. Figure 2 and Figure 3 illustrate these linked trends among TDS levels, invertebrates, native fish, and water birds.

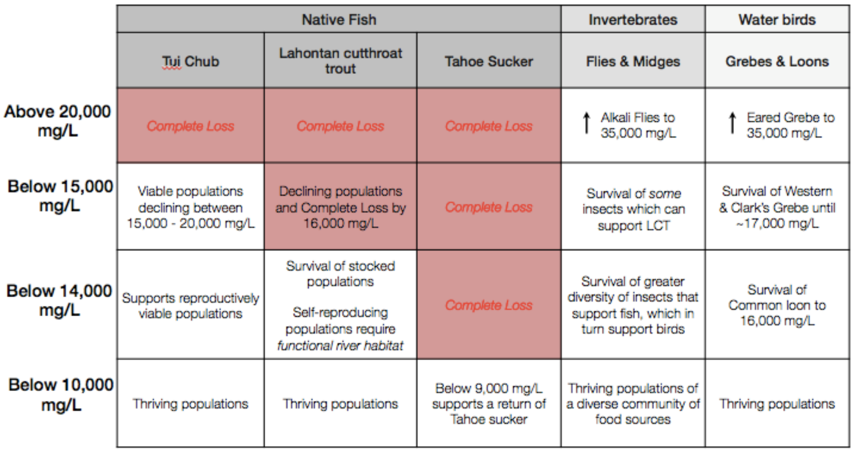
As a conservation goal, TDS levels of 8,000 – 12,000 mg/L are needed for optimal lake conditions and the viability of keystone species like the LCT, Tahoe sucker, and Tui chub.

Figure 2. Shifting Trends of key ecological indicators in relation to TDS.



Lighter shaded areas indicate a trend of decreasing abundance.
Source: The Nature Conservancy, 2013.

Figure 3. Impact of TDS levels on key indicators



	Native Fish			Invertebrates	Water birds
	Tui Chub	Lahontan cutthroat trout	Tahoe Sucker	Flies & Midges	Grebes & Loons
Above 20,000 mg/L	*Complete Loss*	*Complete Loss*	*Complete Loss*	↑ Alkali Flies to 35,000 mg/L	↑ Eared Grebe to 35,000 mg/L
Below 15,000 mg/L	Viable populations declining between 15,000 - 20,000 mg/L	Declining populations and Complete Loss by 16,000 mg/L	*Complete Loss*	Survival of *some* insects which can support LCT	Survival of Western & Clark's Grebe until ~17,000 mg/L
Below 14,000 mg/L	Supports reproductively viable populations	Survival of stocked populations Self-reproducing populations require *functional river habitat*	*Complete Loss*	Survival of greater diversity of insects that support fish, which in turn support birds	Survival of Common loon to 16,000 mg/L
Below 10,000 mg/L	Thriving populations	Thriving populations	Below 9,000 mg/L supports a return of Tahoe sucker	Thriving populations of a diverse community of food sources	Thriving populations

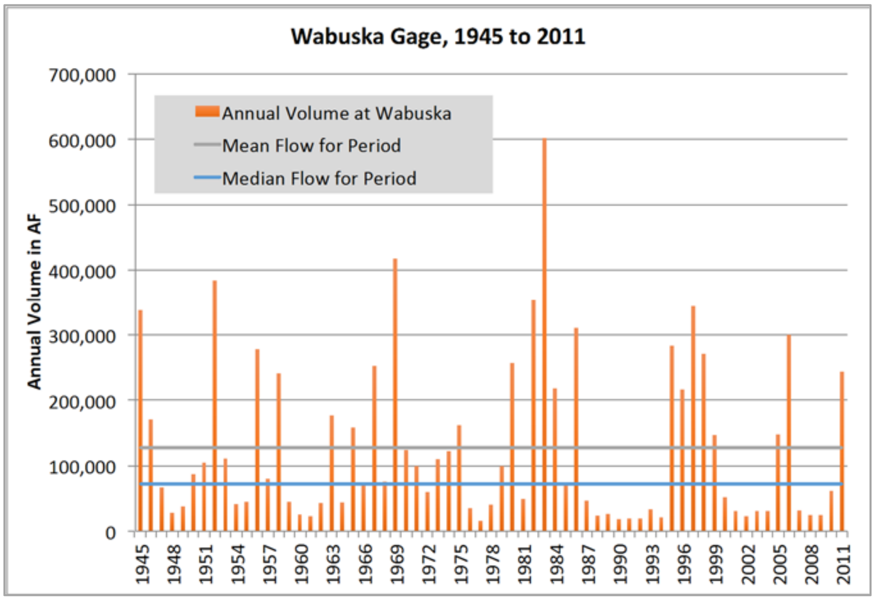
Source: The Nature Conservancy (2013)

2.2 Walker Basin Hydrology

Reducing TDS levels in Walker Lake requires diluting the existing saline environment by increasing freshwater inflows. Achieving the conservation goal of 8,000-12,000 mg/L TDS will take many years given the current saline environment of the lake. For this reason the WBRP is focused on the long-term annual volume of discharge to the lake and not on variability of flows within any given year.

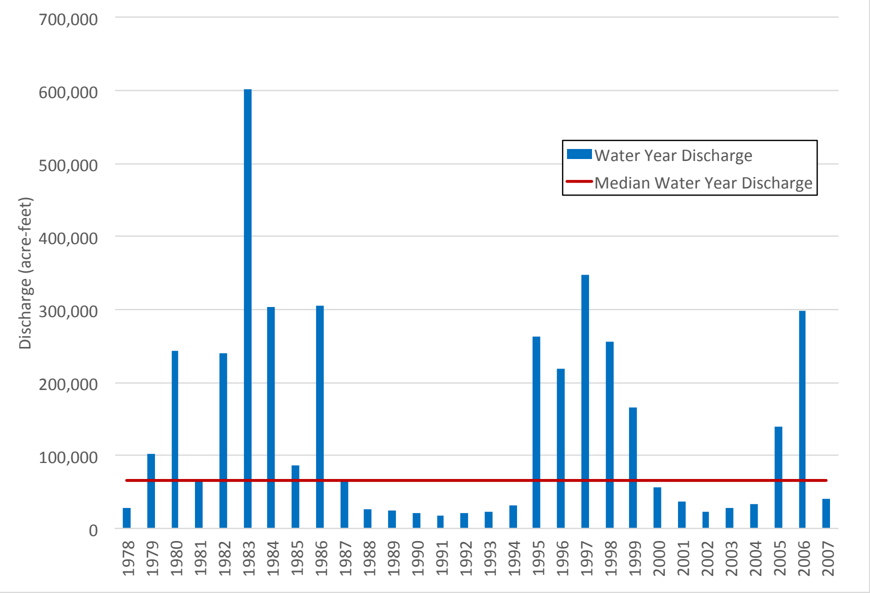
Walker River flows are highly variable from year to year, characterized by infrequent wet periods and extended dry periods. This extreme volatility not only affects the path to restoration of the lake but also poses issues for the modeling effort. Figure 4 presents annual flows at the Wabuska Gage from 1945-2011. This period is examined because it is the longest period of uninterrupted mean daily discharge data for the gage and because basin stakeholders consistently use it as the reference period for flows. Infrequent high flows skew the mean substantially higher than the median.

Figure 4. Wabuska Flows



As can be seen from Figure 4, the volume of water arriving at Wabuska in 1983 represents a significant outlier, producing almost 200,000 acre-feet more water than the next highest-volume wet year. The entire 1945-2011 period discussed above is not utilized in the simulation model because not all necessary data (including daily regulation data from the Federal Water Master) is available for the entire period. Instead, modeling is conducted by developing and repeating a representative thirty-year period for which the necessary information is available. This period, 1978-2007 is shown in Figure 5. A difficulty with using this period is that repeating the 1983 outlier year every 30 years would bias the long-term average above what might be expected over the long term. As a result the water year 1983 is replaced with water year 1995 in the model.

Figure 5. Annual non-Program water at Wabuska Gage, 1978 to 2007



In truing up the thirty-year period used in the model to be representative of the full historic record, the shorter period (with 1995 in place of 1983) must be adjusted to the longer period (with 1983). Table 1 below compares the mean annual discharge at the Wabuska Gage for the two periods being examined. Mean annual discharge is computed both with and without 1983, substituting 1995 for the "without" computations. To normalize the shorter 30-year sequence to be more similar to the longer 1945-2011 period, a correction factor was developed by dividing the mean for 1978-2007 by the mean for 1945-2011. As discussed above, 1983 is not used in the model, nor is it used in the 30-year mean for the calculating the correction factor; however, 1983 is used in the longer 66-year sequence to which the 30-year sequence is being normalized – the idea being that 1983 did indeed occur once in that 66-year period, but it is not being repeated. The resulting correction factor equals 0.9936. In the model, each year of historic total annual discharge at Wabuska is divided by the factor to get the "corrected" flow which is then used as an input in the Lower Walker River Module.

Table 1. Wabuska Flows, Period Comparison

Period	Wabuska Mean Annual Discharge (AF/year)		
	With 1983	Without 1983	Used for Long Term Correction Factor
1945-2011	127,581	122,846	127,581
1978-2007	137,346	126,771	126,771

2.3 Impact of Increased Streamflow on Walker Lake TDS Concentrations

Numerous researchers have investigated the impacts of increased freshwater inflows on Walker Lake elevation and TDS levels. Three of the more recent studies include Allander *et al.* (Forthcoming 2014), Bureau of Reclamation (2010), and Lopes and Allander (2009). Because each study used different hydrologic assessment tools and assumptions, results differ between studies.

Lopes and Allander (2009) calculated the expected change in the hydrologic budget for four lake stages. Each lake stage can be associated with a TDS concentration in the Walker Lake. Given fixed inflow rates, the main driver in the analysis is the net lake evaporation. Additional inflows were calculated to maintain a pre-specified lake stage and TDS concentration. TDS concentrations of 8,000, 10,000, 10,200, and 12,000 mg/L were evaluated with associated supplemental inflows to Walker Lake of 53,000, 36,000, 35,000, and 26,000 acre-ft/yr, respectively. The historical inflows were derived from the 1971-2000 period.

In the *Revised Environmental Impact Statement*, Bureau of Reclamation (2010) developed a water and TDS balance tool to estimate lake level and TDS changes. Steady surface water inflows representing high and low inflow scenarios were included with 50,000 acre-ft/yr of additional inflow at Walker Lake. The authors tested at least three different additional inflow rates (7,300, 32,300, and 50,000) but didn't adjust the additional inflow to achieve a pre-specified TDS target. Baseline inflows were selected to reflect high and low inflows and do not necessarily represent historical periods.

Allander *et al.* (Forthcoming 2014) developed a series of numerical models for the lower Walker River below the Wabuska gage to simulate the effects of increased streamflow on Walker Lake. A groundwater flow model that also simulates stream/aquifer interactions was used in combination with a TDS mass balance tool to estimate lake levels and TDS concentrations.

The key processes that control predictions of lake elevation and TDS levels include:

- precipitation on Walker Lake;

- evaporation from Walker Lake;
- hydrologic period of record;
- groundwater inflow to Walker Lake;
- local surface water flow (e.g. tributaries other than the Walker River);
- Walker River losses between the Wabuska gage and Walker Lake; and
- the relationship between Walker Lake storage volume and TDS concentration including whether or not salt mass within the lake is assumed constant.

Table 2 summarizes the results from the three studies in terms of input assumptions and predicted TDS concentrations at Walker Lake. The predicted TDS concentrations in Walker Lake vary from 12,000 to 13,500 mg/L. The variability in the TDS estimates is due to different underlying assumptions in the hydrology and TDS calculation method for the lake.

Lopes and Allander (2009) predict a TDS concentration of 12,000 mg/L with 26,000 acre-ft/yr of additional flow into Walker Lake. The supplemental inflows Lopes and Allander predict are required to achieve 12,000 mg/L are substantially lower than the other investigations, suggesting that the methodology may be overly simplistic. For example, the study relies on calculations of net evaporation based on lake stage rather than calculating the annual water balance and lake storage based on inflow rates.

Bureau of Reclamation (2010) estimated Walker Lake TDS concentrations ranging between 12,400 and 13,500 mg/L based on high and low surface water inflows. Details of the hydrology behind the calculations were not presented in the revised EIS so some of the terms had to be estimated for comparison purposes in Table 2. The results are less sensitive to the baseline flows because the net evaporation rates (evaporation less precipitation) were adjusted downward with decreased flows. Evaporation rates ranging between 3.7 and 4.0 ft/yr were used in the analysis while more recent data supports higher rates (4.4 ft/yr in Allander *et al.* Forthcoming 2014).

Allander *et al.* (Forthcoming 2014) predicted the largest supplemental flow rates needed to achieve TDS concentrations of 12,000 mg/L. In this study, evaporation rates were estimated at 4.4 ft/yr, decreasing the effectiveness of supplemental flows. The volumetric evaporation rate presented in Table 2 represents the results for the baseline simulation in which lake levels were significantly lower than other scenarios. The baseline flows to Walker Lake are approximately 86,000 acre-ft/yr in this study which is lower than estimates used in the other two studies. To some extent, the differences are due to increased seepage estimates between the Wabuska gage and Walker Lake. Baseline flow decreases can also be attributed to the fact that Allander *et al.* normalized the bias of the simulation period (two repetitions the 1981-2010 period) by replacing the extreme runoff year of 1983, which is unlikely to recur in any given 30 year period, with the large but more realistic streamflow observed in 1995.

Table 2. Streamflow-TDS Impact Study Results Comparison

Assumption	Lopes and Allander (2009)	Bureau of Reclamation (2010)		Allander et al (Forthcoming 2014)
		High Inflow	Low Inflow	
Precipitation on Walker Lake	14,100	146,500[4]	135,500[5]	9,400 [7]
Evaporation on Walker Lake	151,700			120,000 [8]
Evapotranspiration adjacent to Walker Lake	2,200	-	-	unknown [9]
Groundwater inflow	8,100	unknown	unknown	6,900
Local surface water flow	1,000 [1]	unknown	unknown	2,000
Wabuska to Walker Lake loss	n/a	10%	10%	model simulated [10]
TDS vs. Walker Lake storage	Regression[2]	Mass Based[5]	Mass Based[6]	Mass Based [11]
Supplemental Walker River inflow at Wabuska gage	n/a	55,600	55,600	65,000 [12]
Walker River inflow (at lake)				
Baseline	105,000	106,100	90,000	85,900
Supplemental	26,000	50,000	50,000	61,700 [13]
Walker Lake TDS Estimate (mg/L)	12,000 [3]	12,400 [6]	13,500 [6]	12,000 [12]

Notes:

Units are acre-ft/yr unless otherwise noted.

[1] Accounts for 2,000 acre-ft/yr of diverted local runoff

[2] Non-linear regression between lake stage and TDS (assumes a constant salt mass)

[3] Steady-state estimate of TDS concentration

[4] Evaporation - precipitation estimated based on net evaporation of 4.0 ft and lake area of 36,620 acres

[5] Assumes a time-varying TDS mass in lake

[6] TDS estimate at 2,200 mg/L

[7] Precipitation rate of 0.34 ft/yr used

[8] Evaporation rate of 4.4 ft/yr used, but volumetric estimates only presented for baseline simulation in which lake levels were significantly lower than other scenarios

[9] Model calculates ET over entire model but not but ET is not quantified separately for the area adjacent to Walker Lake

[10] Simulated directly by model but can be approximated as 95% of flows at Wabuska plus an additional 25,800 acre-ft/yr

[11] Assumes constant salt mass in lake

[12] Based in regressions developed in Figure 48 of Allander *et al.* (Forthcoming 2014)

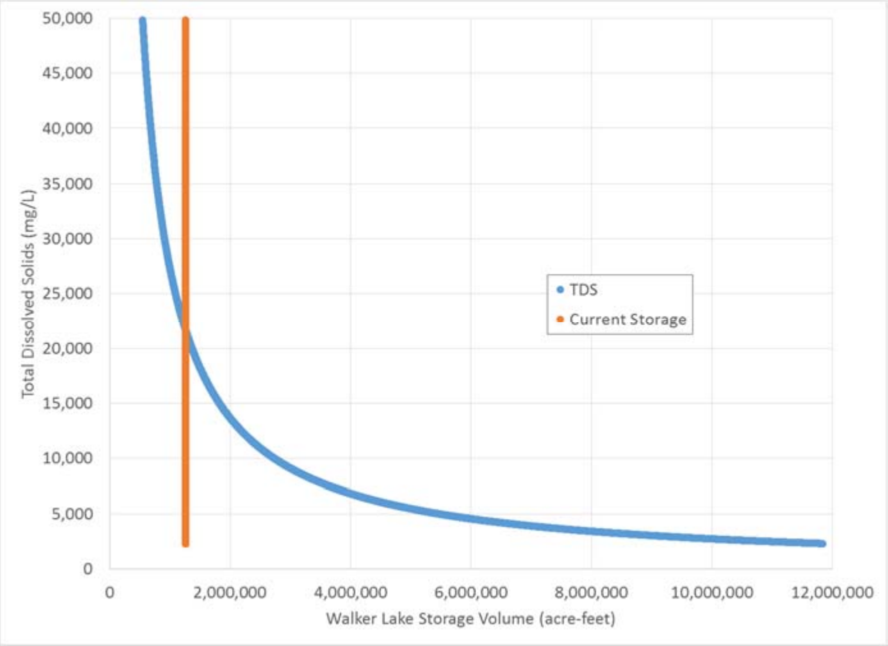
[13] Based on regression equation developed in Figure 44 Allander *et al.* (Forthcoming 2014)

2.4 Sensitivity of Walker Lake TDS to Volume Changes

At the current Walker Lake storage volumes, relatively small changes in water volume, particularly decreasing storage, leads to large changes in TDS. This is due to the large salt mass and the low volume of water present in the lake at this time. If Walker Lake storage volumes continue to decrease, TDS levels will increase more rapidly. Figure 6 shows that for changes in lake volumes that occur below a lake volume of 2 million acre-feet, the response of TDS is rapid. As water is added or subtracted beyond a lake volume of 4 million acre-feet, the response of TDS to change in lake volume is quite slow.

Figure 6 also shows that the first restoration threshold and the long-term restoration goal will be achieved in between these two ranges of responses, i.e. in the 2 to 4 million acre-feet lake volume range. However, the volatility of TDS levels due to the regular pattern of dry and wet years in the basin means that in any scenario the lake will be moving up and down this curve on a decadal time frame. Thus, when reviewing the model runs it is important to keep in mind that the relationship between adding freshwater and the change in TDS levels is not linear.

Figure 6. Walker Lake TDS by Storage Volume



2.5 Water Quality Objectives and Thresholds

Because the TDS levels can be so volatile, especially at the presently low lake volumes, achievements in lowering TDS levels could be short-lived. For example, if a certain quantity of water rights acquisitions achieves 12,000 mg/L sometime in the future, TDS will always fluctuate above and below that level.

The WBRP has set a long-term objective of lowering TDS to within the 8,000 to 12,000 mg/L TDS range mentioned in Section 2.1. Given the complexity and volatility, 10,000 mg/L was chosen as the target in this report because it is in the middle of that range. Additionally, once 10,000 mg/L is achieved, TDS will fluctuate above and below 10,000 mg/L. As a result, model Scenarios 3 & 4 (Section 4 of this report) which aim to determine how many acres of water rights need to be purchased to meet the lake restoration objectives, are set to achieve a long-term TDS mean of 10,000 mg/L during model years 170-200.

As Figure 2 and Figure 3 above illustrate, the lake could support invertebrates, fish and/or water birds at different levels of viability at TDS levels higher than 10,000 mg/L. Because of this and because the long-term TDS objective is so far in the future, two TDS “thresholds” are examined in order to highlight when water quality achieves milestones lesser than the ultimate objective. There are several important threshold distinctions between TDS levels of 14,000 and 15,000 mg/L. At 15,000 mg/L, water quality levels allow for acceptable survival rates of LCT that have been acclimated in a hatchery before being released into the lake, as well as the return of some invertebrate species that support LCT. However, Tui chub recruitment remains limited at these levels. As TDS levels approach 14,000 mg/L, Tui chub may begin to breed, thereby providing an important food source for the common loon and western and Clark's grebes.

In this TDS range, hatchery-raised, stocked LCT will likely have higher survival rates and grow to a larger size (The Nature Conservancy 2013).

In each model run developed in this report, two specific thresholds are highlighted. The first threshold is 14,000 mg/L, for the reasons stated above. The second threshold is 12,000 mg/L, which is the upper end of the long-term objective.

3. The Model

The model is constructed for the full Walker River Basin and has the potential to simulate the acquisition and transfer of water rights throughout the Walker Basin in California and Nevada including Antelope and Bridgeport Valleys in California, and the East Walker, Smith and Mason Valleys in Nevada. It is important to note that acquisitions (i.e., purchase or lease of water and related interests from willing sellers) in the Walker Basin in California are subject to the MOU between NFWF and Mono County (dated March 13, 2012), in which NFWF agreed to not pursue such acquisitions unless and until the Mono County Board of Supervisors had completed its own good-faith review and approval process and complied with its obligations under the California Environmental Quality Act (CEQA).

Due to variable hydrology and the amounts of water rights in the Walker River Basin, surface water rights are rarely fully served and often subject to curtailment based on priority. The assumption built into the model is that only a water right that is legally transferred to the Wabuska gage and from there downstream to Walker Lake will provide flow to Walker Lake that is additional to the flow that historically reached the lake. The model therefore includes only three types of water rights. The first are the Walker River C-125 “decree” rights that are natural flow rights in California and Nevada.

The second and third types of water rights are Walker River Irrigation District (WRID) storage rights from Bridgeport Reservoir and Topaz Lake and are available only in Nevada. Supplemental storage rights are apportioned by WRID according to the priority of the underlying decree right. For Nevada the model considers decree and supplemental rights jointly for the purposes of purchase and transfer. References to the acquisition of decree acres refers to the acquisition of the appurtenant decree and supplemental storage. New Land storage rights are the final type of water right and are primary storage rights that were assigned to lands without decree rights or that had very junior decree rights (permitted in 1907 or thereafter). New Land right acres are specified separately in the model from the decree and supplemental storage acres.

The three main river segments of the Walker River are the: East Walker, West Walker and the Walker River.

3.1 Inputs

The model relies on a large number of inputs. Some inputs are fixed parameters and others can be manipulated by the user. User-selected variables are figures in the model that are used in the model calculations but can be changed by the model user. They are typically in drop-down lists allowing the user to easily change the variable. Two types of user-selected variables are included in the model:

1. Control variables that the user can change in order to drive the model, i.e. to produce a scenario run.
2. Sensitivity variables that change underlying legal or hydrologic variables that will influence outcomes, i.e. to undertake a sensitivity analysis for variables that are uncertain.

Model parameters are fixed values or relationships that are used in the calculations at defined junctures in the model. Parameters are inputs that are relatively well established or represent values that are unlikely to vary much and thus are not manipulated in the scenario runs or examined in the sensitivity analysis.

User control variables and parameters are introduced below, under the relevant module.

Model calculations are divided into three modules: Program Water, Lower Walker River and Walker Lake. This section outlines the general steps taken to calculate results in each module. The Program Water and Walker Lake Modules have corresponding flow charts depicting the steps taken.

3.2 Program Water Module

The Program Water Module utilizes the user selected variables and parameters to simulate daily Program Water flows at Wabuska. Ultimately these daily flows are summed to produce an annual Program Water volume for each of the 200 years being simulated. A flow chart for how the calculations proceed is provided in Figure 7. The parameters and user control variables for this module are described in Table 3 and Table 4. A brief overview of the module is provided below.

At this stage, Program Water includes water from four types of water rights:

- Nevada decree natural flow;
- supplemental storage associated with Nevada decree natural flow;
- Nevada New Land storage; and
- California decree natural flow.

Nevada and California decree rights acres are converted into daily flows at Wabuska by:

- determining the extent of acres that would have been in priority on the corresponding day;
- converting the acres in priority to acre-feet by using the proper consumptive use factor based on reach;
- dividing the consumptive use volume by the number of days in the irrigation season and converting to cfs; and
- applying the proper reach-based loss factor.

For the determination of consumptive use rates associated with irrigation and the allocation of stream losses seven “sections” are defined in the model as illustrated in Figure 8. In Nevada State Engineer’s Ruling No. 6271 on Application No. 80700 a transfer of water rights from the Yerington Weir at the lowest section, the Main Section, is transferred as follows:

- the full amount of the water right is protected to the previous point of diversion
- the consumptive use portion of the water right is protected at the Wabuska Gage

The limitation at the Wabuska Gage is based on modeling that suggests that all the non-consumptive portion of the water right would return to the river at or above that point. Thus, as shown in Figure 8 water rights transferred from the Main Section are charged a 0% loss to consumptive use at the Wabuska Gage.

For sections higher up in the basin, the model follows a similar logic to that in Ruling No. 6271, but deducts expected stream losses between the bottom of each section and the Wabuska Gage. First, the consumptive use for each water right is derived based on the location of irrigation use and the net irrigation water requirements from Huntington and Allen (2010). Second, the total expected loss incurred during transit from the bottom of that section through to the Wabuska Gage is deducted based on loss figures from Lopes and Allander (2009). The consumptive use and loss figures in the lower-right inset box of Figure 8 show the consumptive use per acre and the total loss percentage for water, starting from the section named, to Wabuska. For example the consumptive use of a water right from Bridgeport Valley gets charged a 2% loss for going through E. Walker Valley and a 5% loss for going through Mason Valley, resulting in a total loss of 7% to get from the bottom of Bridgeport Valley to Wabuska. The consumptive use for a water right from the Main Section gets charged a 0% loss because it does not travel the complete distance through Mason Valley.

The losses and consumptive use estimates serve as input parameters in the model (Table 3). Section 4.6.3 below describes a sensitivity analysis conducted for these stream loss parameters to test their impact on model outcomes.

Storage water is held in the reservoirs until the end of the irrigation season. For each reservoir, the sum of the volumes for the supplemental storage (associated with the selected decree acres) and New Land acres is calculated. These sums are then adjusted by the historic reservoir yield for the corresponding water year. The total volume of storage water (for both reservoirs) held for release is then:

- divided by the days of release (as specified by the user);
- converted to cfs;
- adjusted by the appropriate streamflow loss factor; and
- assigned to successive days beginning November 1 until all held water has been released.

Program Water (decree and storage) is then summed by year at Wabuska.

Figure 7. Program Water Module Flow Chart

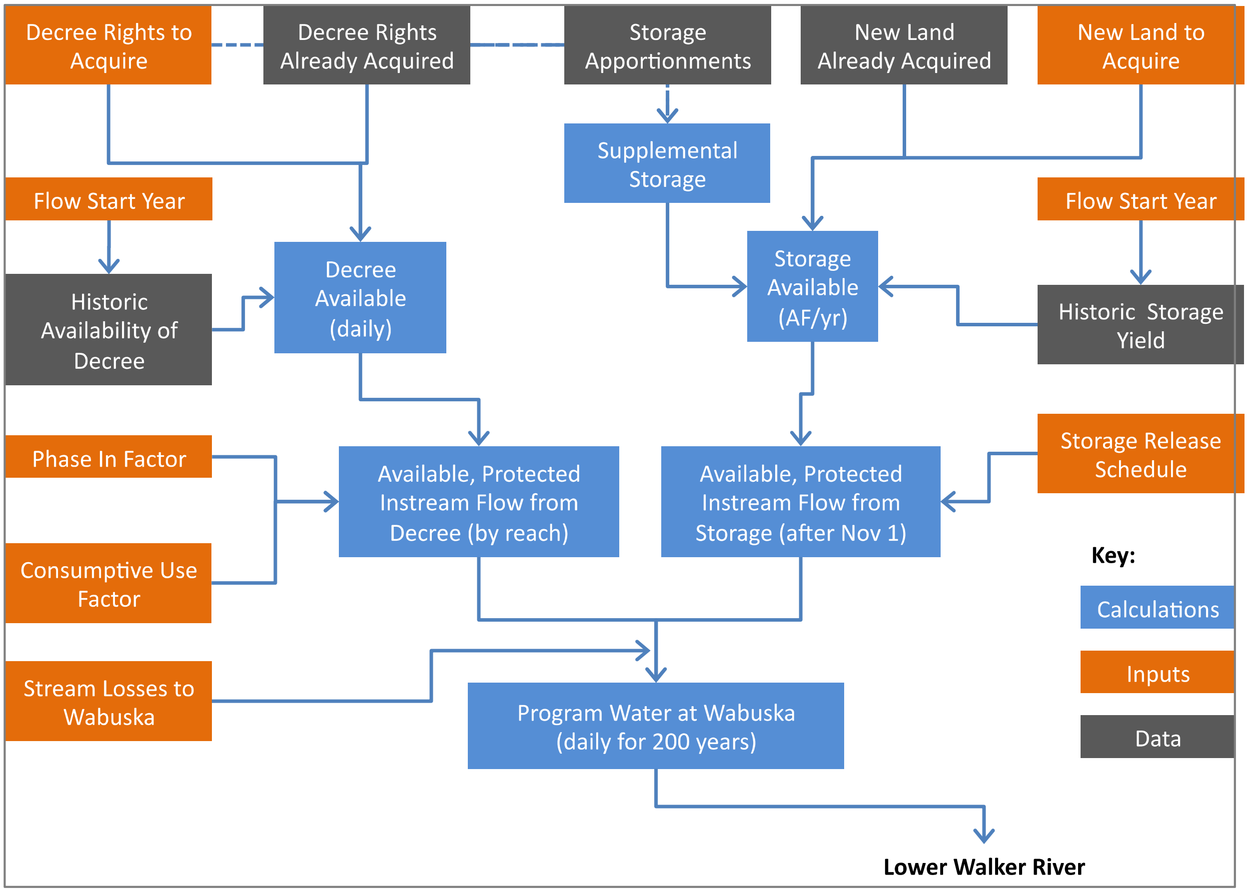
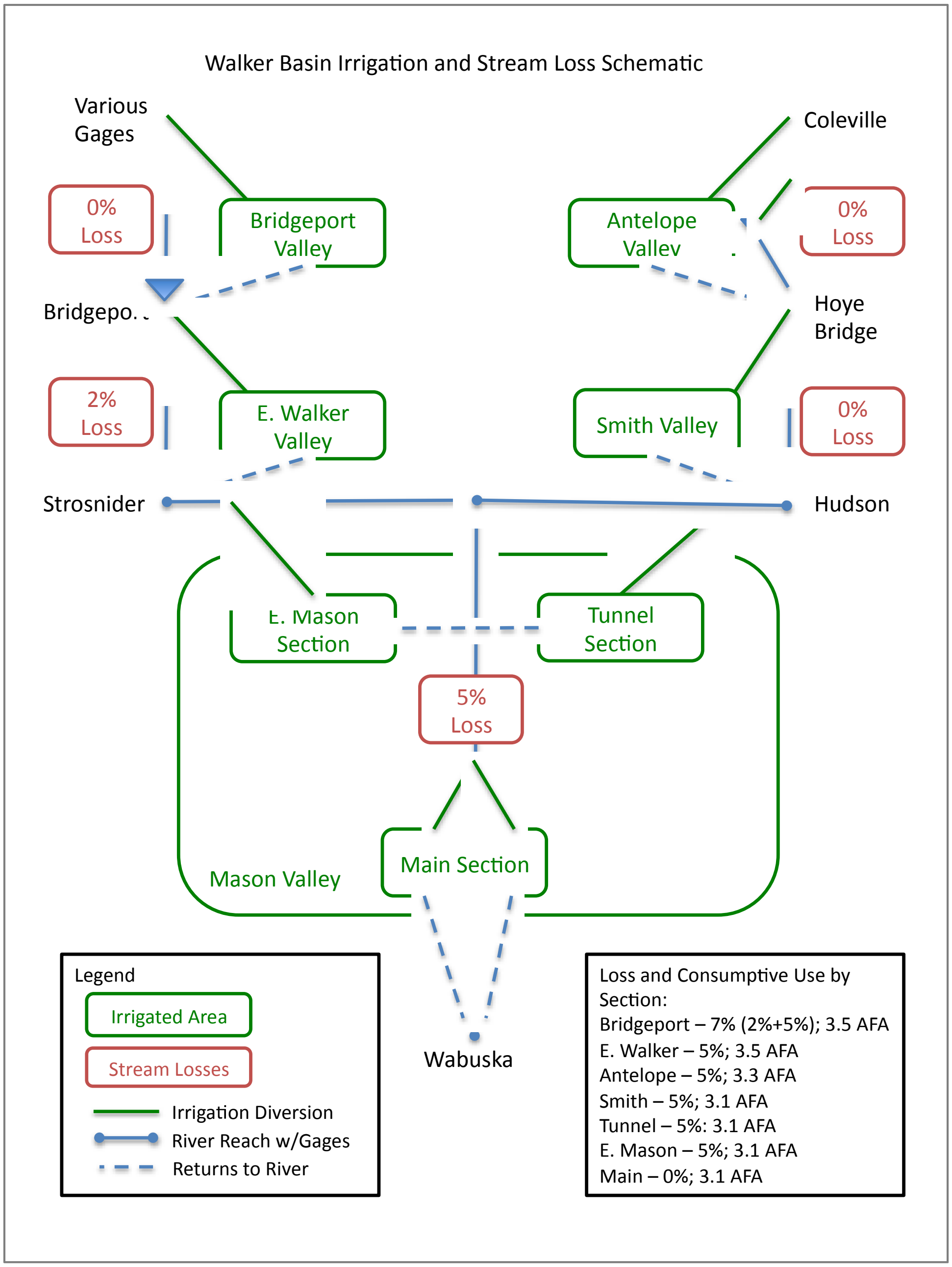


Figure 8. Consumptive Use and Streamflow Loss Estimates



Source: Consumptive use estimates from Huntington and Allen (2010); streamflow losses from Lopes and Allander (2009)

Table 3. Program Water Module Parameters

Variable	Value	Source	Comments
Walker River C-125 Decree Water Rights	total acres for decree rights by priority by river section for California and Nevada	Desert Research Institute (DRI) and Historical Mapping Service (see Minor et al. 2009)	checked against the C-125 decree and other available information by Ecosystem Economics (these acreages are in their respective spreadsheet tabs as indicated in the module description later in the report
WRID Storage Right Duties	annual amounts for supplemental storage and New Land primary rights in acre-feet/acre	Meyers (2001)	while this information is not deployed in the model itself it is used to derive the storage rights (in acre-feet)
WRID Supplemental Storage Amounts	total AF apportioned to decree rights in Nevada by priority and by river section	DRI and HMS (Minor et al. 2009)	
New Land Storage Rights	acres of New Land rights by river section	Meyers (2001)	used along with the storage right duty information to derive acre-feet of storage in Nevada by priority and river section
Acquired Program Water	totals for decree, supplemental storage and New Land rights by priority, by river section	NFWF	as of January 1, 2014; acquired as of the starting year for the model
Water Right Priorities Served	daily by river section (1978-2007)	Walker River Federal Water Master	
Storage Allocations	yearly (1978-2007)	email correspondence from Ken Spooner of WRID	
Consumptive Use (CU) Factor	acre-foot per acre amounts for Net Irrigation Water Requirements that are allowed to be transferred and protected instream for each valley	Nevada Department of Water Resources publication (Huntington and Allen 2010)	to obtain the instream rate, this volume is spread across the full irrigation season in cubic feet per second
Discharge at the Wabuska Gage	mean daily discharge (1978-2007) at the Wabuska Gage (USGS #10301500)	USGS website	

Table 4. Program Water Module User Control Variables

Variable	Value	Comments
Starting Year Model	selects the year to begin the modeling; to accommodate for future updates of the model.	default value is 2015
Water Rights to Acquire in Future	allows user to specify the amounts or % of water righted acres by river section to model for future acquisition (in years following the starting year for the model); input as acres or % of remaining decree natural flow, supplemental storage and New Land storage water rights (once acquired Program Water is deducted).	default value is zero
Future Program Water Phase-in	allows user to select when water acquired as of the start date of the model will be protected to Lake; inputted as the % of water acquired to be protected by year	see Appendix 2 for the default values
Days for Storage Release	allows the user to pick between 1 and 15 days to release leased stored Program Water at the end of the season	default value is 15 days

3.3 Lower Walker River Module

The inputs to the Lower Walker River Module are simply Program Water from each year simulated (from the Program Water Module as described above) and non-Program water for the corresponding year. Non-Program Water is defined as historic Wabuska discharge, adjusted by the long-term correction factor as described in Section 2.2.

The Lower Walker River Module combines Program and non-Program Water at Wabuska and conveys it to Walker Lake. Program water and non-Program Water at Wabuska are assigned losses on a proportional basis in order to derive the amount of Program and non-Program water that reaches Walker Lake. The losses from the Wabuska gage to Walker Lake are estimated through the use of a flow/loss equation developed by the USGS for this reach (Allander *et al.* Forthcoming 2014):

$$Q_{WL} = 0.9506Q_{Wab} -25,825$$

where Q_{WL} signifies annual volume of stream discharge at Walker Lake and Q_{Wab} signifies annual volume of stream flow at Wabuska.

The equation takes into account irrigation diversions by the Walker River Paiute Tribe below Weber Reservoir, Weber Reservoir storage evaporation, and other factors that contribute to the difference in the annual volume of flow between Wabuska and Walker Lake.

3.4 Walker Lake Module

The Walker Lake module simulates changes to lake storage volume and TDS on an annual basis. Walker Lake storage and stage from March 2014 are used as the starting point for the module. Each year, inflows and outflows are summed, resulting in a change in lake storage.

Inflows accounted for include:

- non-Program Water inflow, as calculated annually in model;
- Program Water inflow, as calculated annually in model;
- net local runoff to the lake (apart from that from the Walker River), as a fixed volume of water;
- lake precipitation, as calculated annually from fixed amount of feet per year and dynamic lake surface area for each year; and
- lake subsurface inflow, as a fixed volume of water.

Outflows accounted for include lake evaporation, calculated annually as a fixed amount of feet per year, and dynamic lake surface area for each year.

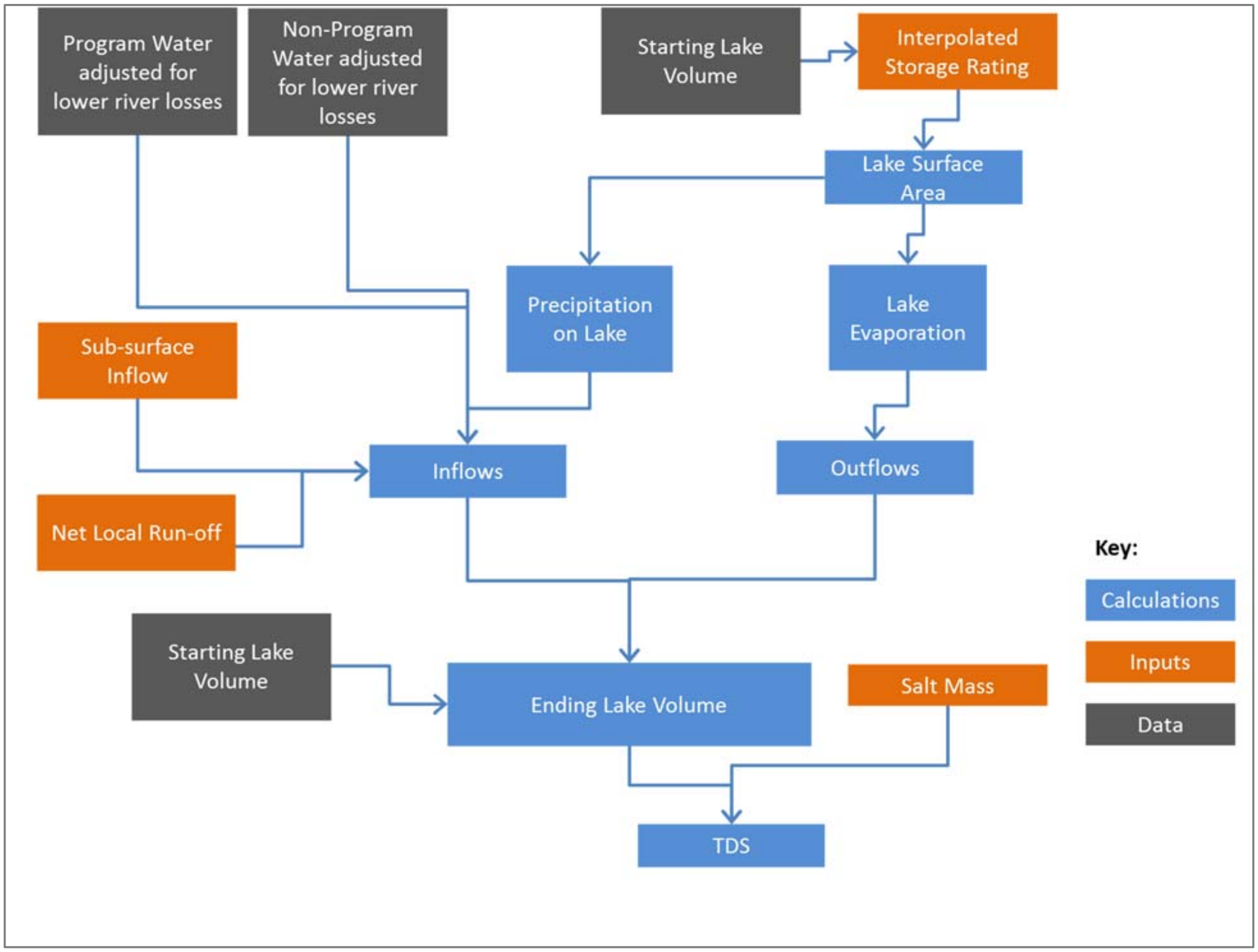
Parameters utilized for the simulated inflows and outflows are presented in Table 5.

Table 5. Walker Lake Module Parameters

Variable	Value	Source
Precipitation Rate	0.34 ft/year	draft USGS lower river model (Allander *et al.* Forthcoming 2014)
Evaporation Rate	-4.37 ft/year	Allander et al. Forthcoming 2014
Net Local Run-off	1,800 acre-feet/year	Allander et al. Forthcoming 2014
Sub-surface Inflows	2,250 acre-feet/year	Allander et al. Forthcoming 2014
Salt Mass	37.2 million tons	Allander et al. Forthcoming 2014
Storage & Stage for Walker Lake	mean daily stage and volume (1908 to 2013)	email correspondence with Kip Allander, USGS (in the 'Walker Lake Historic Estimates' tab, as used for output charts)
Interpolated Storage Rating for Walker Lake	storage and surface area at various stage levels	email correspondence with Kip Allander, USGS (in the 'Walker Interpolated Sto Rating' tab)

The TDS for the ending storage volume is calculated based on the salt-mass approach from Allander *et al.* (Forthcoming 2014) that is the fixed amount of salt divided by the changing lake volume. The lake volume is also converted to stage and surface area for calculations (precipitation, evaporation, etc.) for the following year.

Figure 9. Walker Lake Module Flow Chart



3.4.1 Walker Interpolated Storage Rating

The interpolated storage rating table supplied by USGS lists Walker Lake Stage in 0.1 foot increments and the corresponding lake surface area and volume (Personal Communication with Kip Allander of USGS, 2013). The table does not have any values for stages higher than 4,120 feet. In at least one of the scenarios explored in this paper the stage may exceed 4,120 feet as the lake is restored, so it is necessary to estimate the volumes and surface areas at higher stages. Walker Lake area was plotted versus volume at higher stage levels along with a linear trendline (Figure 10). The trendline equation was then used to estimate lake area at various lake volumes, above 4,120 ft stage. Values from the USGS table as well as the estimated values are plotted on Figure 11.

Figure 10. Walker Lake Area vs. Volume at High Stage, Regression Analysis

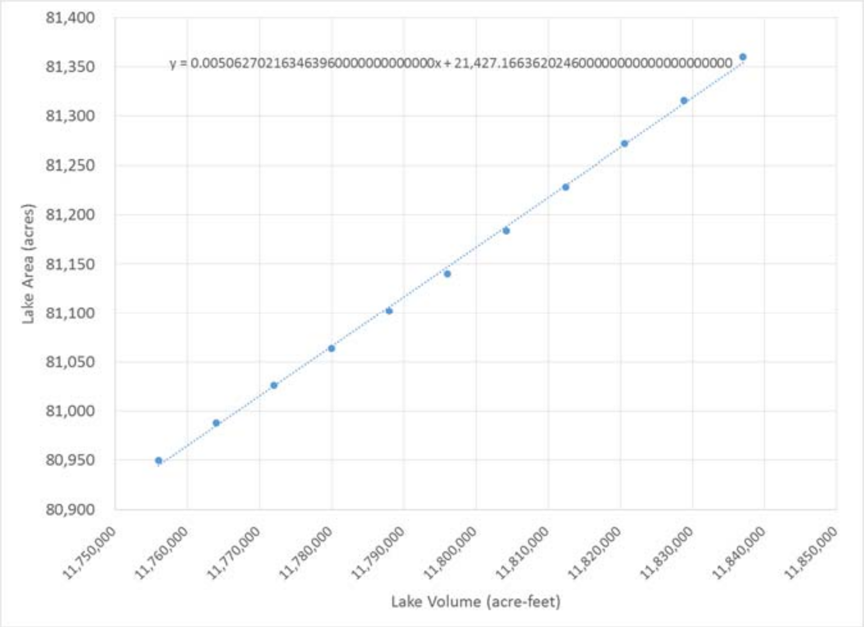
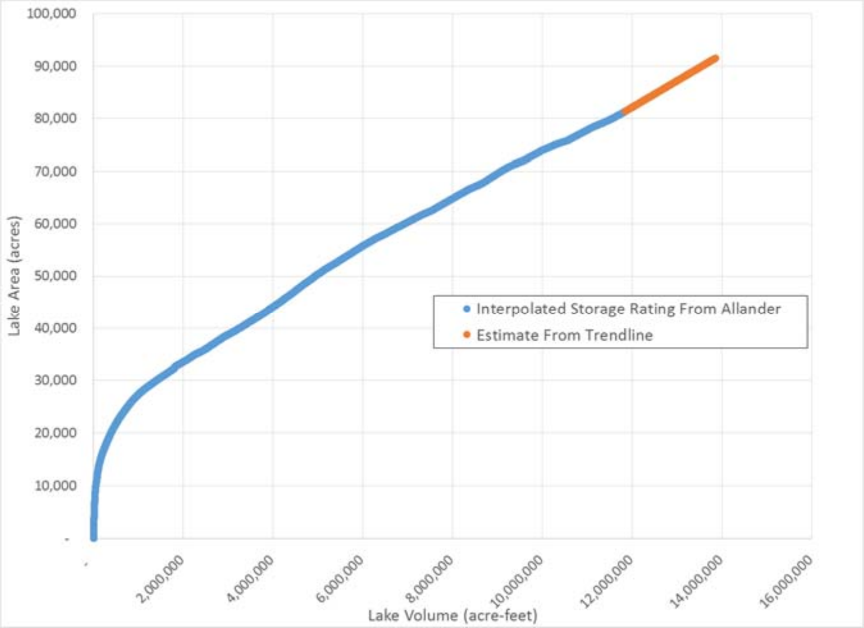


Figure 11. Walker Lake Area vs. Volume, With Estimates



4. Model Results

This section provides analysis and discussion of model scenario and sensitivity runs that were completed in order to examine outcomes in Walker Lake of varying levels of investment in water acquisitions. Five scenario model runs are presented here in order to portray the broad range of possible outcomes for Walker Lake volume and salinity levels:

Scenario 1 – Business as Usual: No water rights are transferred to Walker Lake. This scenario models the continued increase in Walker Lake salinity levels absent restoration efforts.

Scenario 2 – Return to Natural Condition: All irrigation diversion is ceased and all formerly diverted water flows to the lake. This scenario simulates what would occur if all the water rights were immediately transferred to Walker Lake.

Scenario 3 – Restoration with Nevada Water Rights Only: The purchase and transfer of Nevada water rights is used to meet the program objective. This scenario models the amount of Nevada water rights necessary to achieve and sustain a long-term (30-year) mean of 10,000 mg/L TDS.

Scenario 4 – Restoration with Nevada and California Water Rights: The purchase and transfer of California and Nevada water rights is used to meet the program objective. This scenario models the amount of California and Nevada water rights necessary to achieve and sustain a long-term mean of 10,000 mg/L TDS.

Scenario 5 – Restoration to a Lesser Goal with Nevada Water Rights Only: The purchase and transfer of Nevada water rights is used to meet a lowered program objective. This scenario models the amount of Nevada water rights necessary to achieve and sustain a long-term mean of 12,000 mg/L TDS.

Six additional model runs are presented exploring the sensitivity of the restoration scenarios to key uncertainties or assumptions in the model. Scenario 4 is used as the baseline run. Thus, the results of the sensitivity model runs are compared to the results of the Scenario 4 model run.

Four variables examined in the sensitivity analysis are:

- Variation in expected water supply – this analysis explores future outcomes if the historic water supply figures (i.e. non-Program Water at Wabuska) over- or under-estimates future conditions. For example, if climate change significantly alters the Lake's hydrology (note that changing this variable does not impact yield from transferred water rights).
- Higher streamflow losses – this analysis explores the possibility that streamflow losses are larger than estimated by Lopes and Allander (2009).
- Change in the historic flow start year – this analysis explores future outcomes if the starting year in the 30-year period of historic discharge and availability used in the analysis is not 1978, which represents a mixed dry/wet period over the first five years.
- WRID leasing program – this analysis explores the short-term impact on TDS levels if WRID successfully implements a three-year demonstration leasing program with WBRP funds over the period 2015-2017.

The sensitivity model runs used to test each of these variables are:

Sensitivity Run 1 – Lower Flows: In this run, non-Program Water flows at Wabuska are reduced by 10%. This should push achievement of restoration objectives further out in time and/or require more water rights to reach the same target.

Sensitivity Run 2 – Higher Flows: In this run, non-Program Water flows at Wabuska are increased by 10%; this should accelerate achievement of restoration objectives and/or require fewer acquired water rights to reach the same target.

Sensitivity Run 3 – Historic Flow Sequence Begins with a Dry Period: In this run, the starting year in the annual sequence of stream flows is changed from 1978 (the beginning of a mixed hydrological period) to 1990 (the beginning of a dry period). This should push achievement of restoration objectives further out in time.

Sensitivity Run 4 – Historic Flow Sequence Begins with a Wet Period: In this run, the starting year in the annual sequence of stream flows is changed to 1995 (the beginning of a wet period). This should bring achievement of restoration objectives forward in time.

Sensitivity Run 5 – Assign Higher Stream Flow Losses to Transferred Water: In this run, an additional 5% is added to the expected stream flow losses in each of the reaches above the Main Section. This should push achievement of restoration objectives out in time.

Sensitivity Run 6 – Include the WRID Leasing Program: In this run, the WRID leasing program occurs over the first 3 years of the program at 25,000, 50,000 and 50,000 AF of storage leased in program years 1, 2 and 3 respectively. These changes should bring achievement of restoration objectives forward in time.

Table 6. Variables tested and Sensitivity Run Numbers

Variable	Variation in expected water supply	Higher streamflow losses	Change in historic flow start year	WRID leasing program
Sensitivity Run	1, 2	5	3,4	6

For each model run a table and figure(s) are provided as well as a short text summary of the main inputs and results. The table provides numerical summary data for the results of each run. The figures are provided to illustrate each model run. The figures show the 14,000-mg/L initial threshold and the 12,000 mg/L second threshold. The first figure (included only for each of the scenario model runs) shows historical Walker Lake TDS and storage volume and the simulated TDS and storage volume from the model. This figure extends over a 200-year time span to ensure that a long-term equilibrium in TDS is reached. The second figure for each scenario model run shows only the simulated TDS and a ten-year moving average for the TDS (the smoothed line) over a 100 year time frame. This is meant to clearly illustrate the points at which TDS reaches the targets and also show how TDS fluctuates above and below the targets. For each of the sensitivity runs, a similar figure is provided, but with the simulated TDS from Scenario 4 inserted in place of the moving average so that the difference between the baseline Scenario 4 run and the sensitivity run is explicit.

4.1 Scenario 1: Business as Usual

The first scenario is a projection of lake storage and resulting TDS estimates with no change in the use of water in the basin. In other words, no additional water (over historic amounts of non-Program Water) is delivered to Walker Lake. With the historic flow start year set at 1978 the expectation is that a few good precipitation years serve to lower the TDS levels through 2024, before another dry spell drives the TDS to very high levels (Figure 12 and Figure 13). From there TDS levels demonstrate large volatility and rapid increases. TDS levels exceed 25,000 mg/L by 2030 and reach 30,000 mg/L – the salinity of seawater – by 2032.

The total water delivery efficiency represents the total amount of water passing the Wabuska Gage divided by the total amount of water delivered to Walker Lake as surface flow. This figure is 76% for the business as usual scenario. This figure does change as Program Water is added at Wabuska and at Walker Lake in the ensuing scenarios.

Table 7. Scenario 1 Results

Model Run	Water Rights Included (% of acres)			Mean Program Water (over 200 years)		Lower Walker R. Efficiency	Max TDS for Modeled Years (mg/L)	Year First Threshold Reached	Second Threshold TDS: 12,000 mg/L			Final 30 Years Modeled: 2185-2214
	Total	CA	NV	at Wabuska (AF/yr)	at Walker Lake (AF/yr)				Year Reached	TDS: 30-Year Period		
										Mean	Std Dev	Mean TDS
Scenario 1	0%	0%	0%	0	0	76%	67,069	n/a	n/a	n/a	n/a	37,819

Figure 12. Historic and Simulated Storage and TDS, Scenario 1

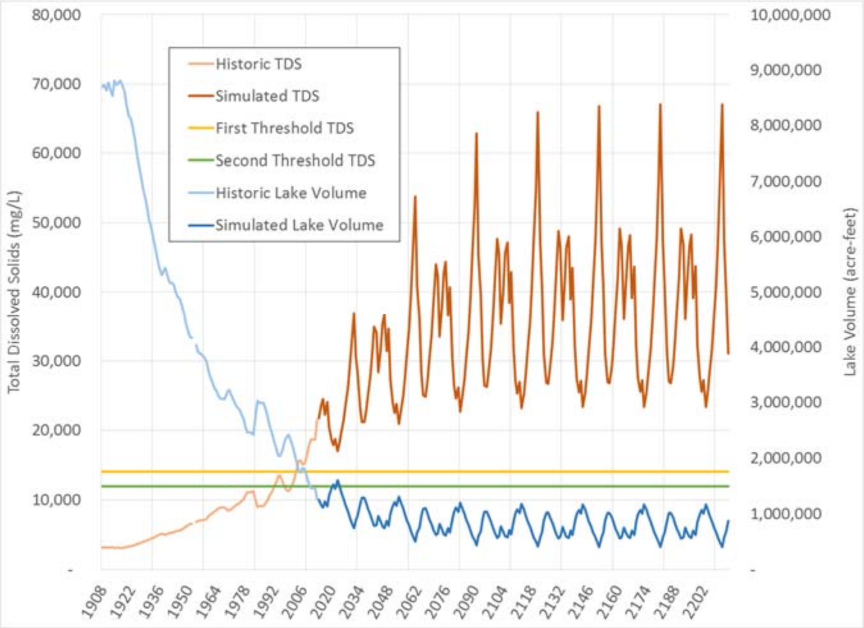
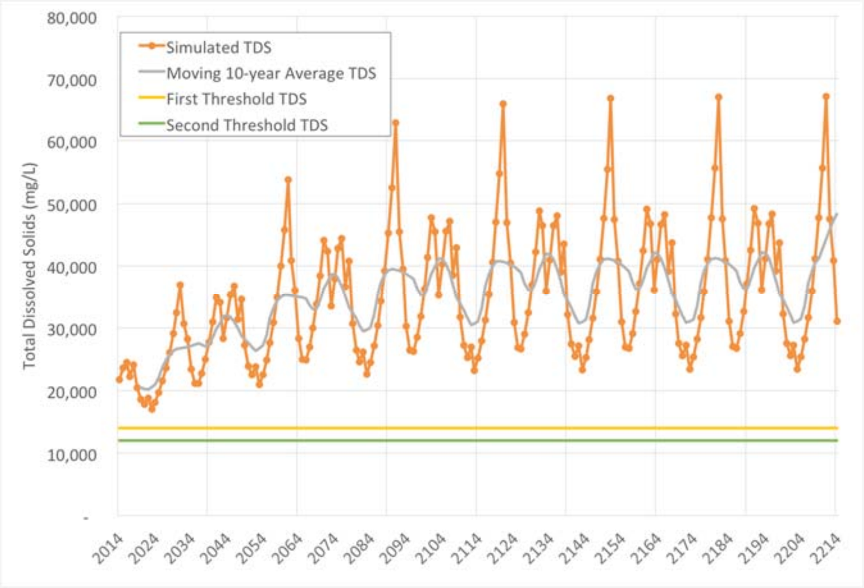


Figure 13. Simulated TDS, Scenario 1



4.2 Scenario 2: Return to Natural Conditions

The exact opposite scenario to the business as usual scenario would be to stop all irrigation and allow all the formerly diverted water to flow to Walker Lake. This scenario, therefore, simulates the purchase and transfer of all Walker Basin California and Nevada water rights at the beginning of the 2015 irrigation season. While this scenario is not a realistic outcome, it was chosen because it is the antithesis of Scenario 1 and it demonstrates the maximum potential water quality response. In this scenario, TDS levels immediately drop toward target levels. Under this scenario it would take only four years for the lake to drop down to the final TDS restoration goal (Figure 14 and Figure 15). Again, this is in part due to the favourable near term hydrology in the historic flow sequence. The 200-year simulation suggests that Walker Lake would reach and surpass its 1908 volume of 8 million acre-ft by 2050, effectively reversing a century of decline in less than 40 years.

Table 8. Scenario 2 Results

Model Run	Water Rights Included			Mean Program Water		Lower Walker R. Efficiency	Max TDS for Modeled Years (mg/L)	Year First Threshold Reached	Second Threshold TDS: 12,000			Final 30 Years Modeled: 2185-2214
	Total	CA	NV	at Wabuska (AF/yr)	at Walker Lake (AF/yr)				Year Reached	TDS: 30-Year Period after Reaching 12,000		
										Mean	Std Dev	Mean TDS
Scenario 2	100%	100%	100%	275,668	242,773	89%	18,563	2017	2018	5,811	1,831	2,082

Figure 14. Historic and Simulated Storage and TDS, Scenario 2

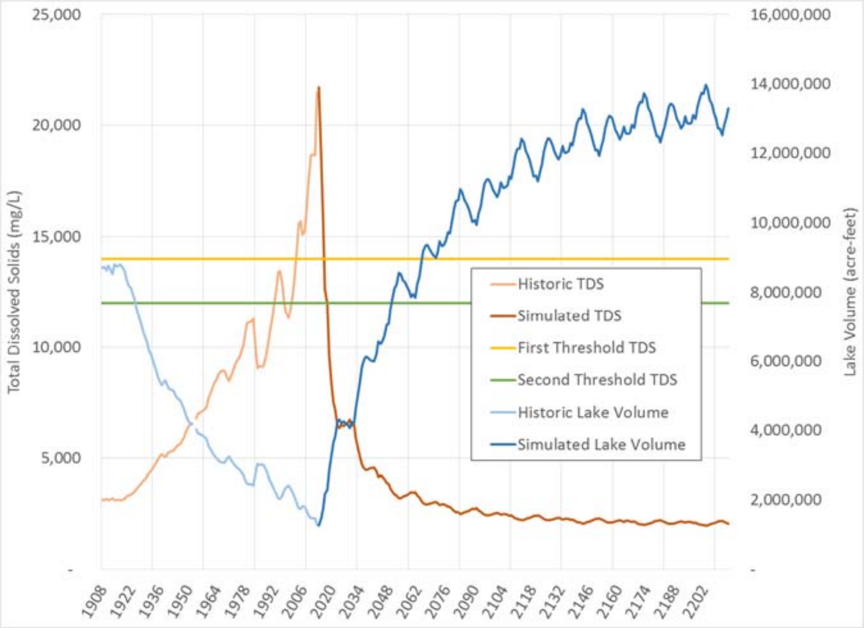
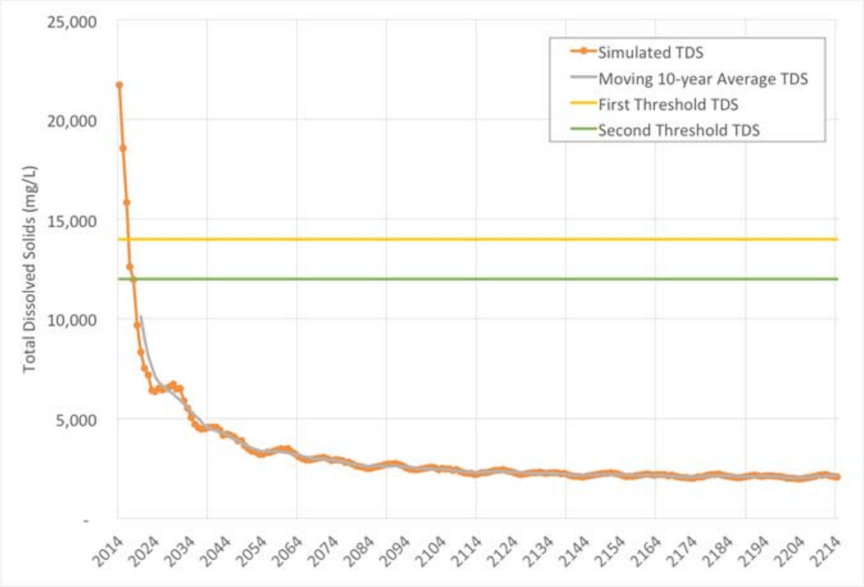


Figure 15. Simulated TDS, Scenario 2



4.3 Scenario 3: Restoration with Nevada Water Rights Only

To date the WBRP has only engaged in water transactions in Nevada. If this continues, the question is: How many of these surface water rights would need to be acquired in order to achieve and maintain the restoration objective of a long term TDS mean of 10,000 mg/L? The model predicts that by acquiring a total of 34% all Nevada decree (and associated supplemental storage) and New Land water righted acres, the first restoration threshold is achieved by 2023 and the second threshold by 2050 (Table 9). This amounts to acquiring a total of 20% of all water righted acres basin-wide. The 34% total for NV water rights include the NV water rights already acquired by the Program.

As shown in Figure 16 and Figure 17 the volatility of the TDS level remains a concern. During dry periods, the TDS levels rise above the restoration threshold and goal respectively for quite some time. However, the restoration goal is met over the final 30 years of the 200 years in the scenario.

Table 9. Scenario 3 Results

Model Run	Water Rights Included (% of acres)			Mean Program Water (over 200 years)		Lower Walker R. Efficiency	Max TDS for Modeled Years (mg/L)	Year First Threshold Reached	Second Threshold TDS: 12,000 mg/L			Final 30 Years Modeled: 2185-2214
	Total	CA	NV	at Wabuska (AF/yr)	at Walker Lake (AF/yr)				Year Reached	TDS: 30-Year Period after Reaching 12,000		
										Mean	Std Dev	Mean TDS
Scenario 3	22%	0%	32%	53,961	40,957	81%	24,292	2023	2050	12,209	1,251	10,000

Figure 16. Historic and Simulated Storage and TDS, Scenario 3

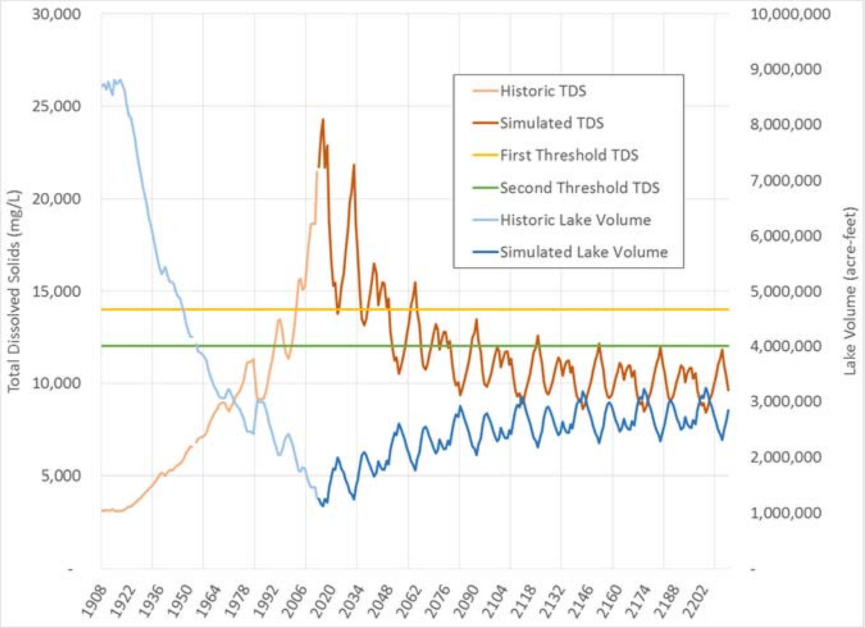
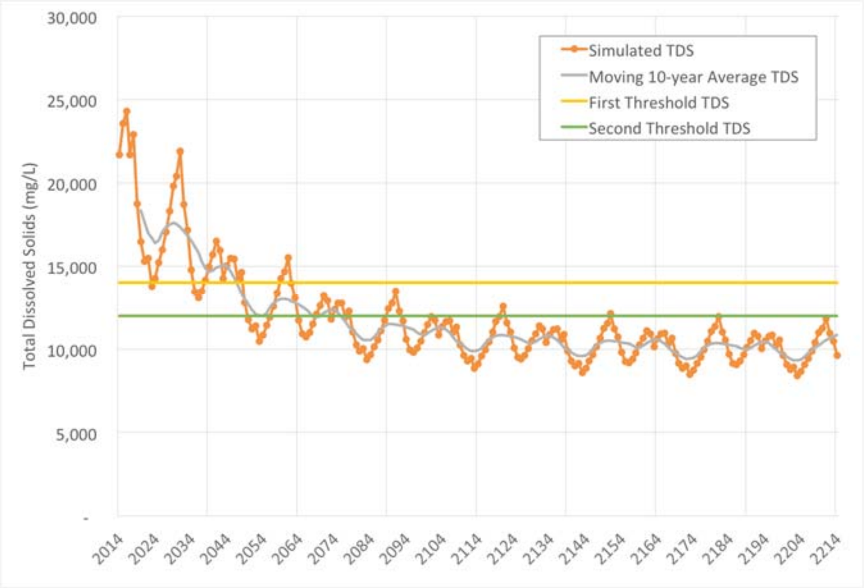


Figure 17. Simulated TDS, Scenario 3



4.4 Scenario 4: Restoration with California and Nevada Water Rights

Scenario 4 aims for the same restoration objectives as Scenario 3. The difference is that Scenario 4 seeks to meet these objectives by acquiring and transferring water rights from lands in Nevada *and* California. To achieve this, the model suggests that 21% of all water righted acres (which includes 17% of California decree acres, 24% of Nevada decree acres and their associated supplemental storage, and 22% of all Nevada New Land rights) must be acquired.

For both restoration scenarios it is worth noting that the average Program Water secured at Wabuska is 54,000 acre-ft/yr which amounts to around 41,000 acre-ft/yr at Walker Lake. These figures are not directly comparable to those presented earlier for other studies (Table 2) because these studies used higher TDS target concentrations (i.e. 12,000 mg/L).

Table 10. Scenario 4 Results

Model Run	Water Rights Included (% of acres)			Mean Program Water (over 200 years)		Lower Walker R. Efficiency	Max TDS for Modeled Years (mg/L)	Year First Threshold Reached	Second Threshold TDS: 12,000 mg/L			Final 30 Years Modeled: 2185-2214
	Total	CA	NV	at Wabuska (AF/yr)	at Walker Lake (AF/yr)				Year Reached	TDS: 30-Year Period after Reaching 12,000		
										Mean	Std Dev	Mean TDS
Scenario 4	20%	17%	22%	53,907	40,690	81%	24,292	2023	2050	12,216	1,229	10,001

Figure 18. Historic and Simulated Storage and TDS, Scenario 4

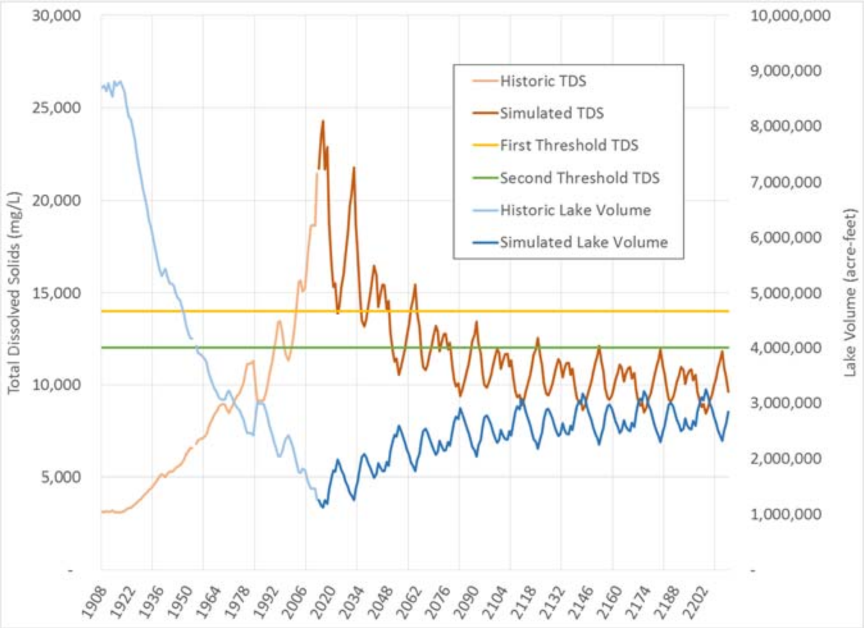
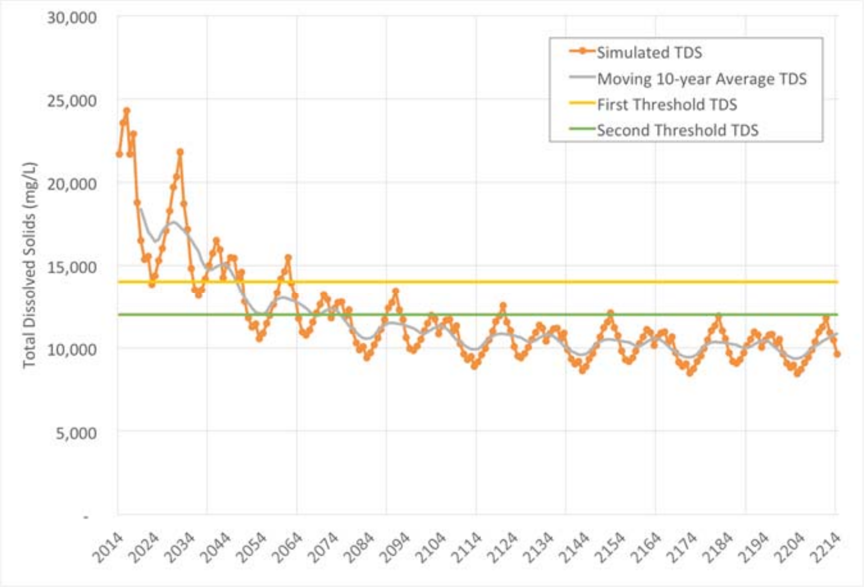


Figure 19. Simulated TDS, Scenario 4



4.5 Scenario 5: Restoration with Nevada Water Rights, Lesser Goal

This scenario is much like Scenario 3, except it examines the water rights needed to achieve a long-term mean TDS of 12,000 mg/L instead of the 10,000 mg/L in Scenario 3. By acquiring a total of 28% of all Nevada decree (and their associated supplemental storage) and New Land water righted acres, the first restoration threshold is achieved by 2023 and the second threshold, modified in this Scenario, is reached by 2053 (Table 11).

The amount of Program Water required at Wabuska is 44,000 acre-ft/yr, or 32,500 acre-ft/yr at Walker Lake. The non-Program Water at Walker Lake measures 105,600 acre-ft/yr for this scenario. In other words, a total of 138,100 acre-ft/year at Walker Lake is necessary to attain 12,000 mg/L TDS given the estimates of other lake inflows and outflows.

Table 11. Scenario 5 Results

Model Run	Water Rights Included (% of acres)			Mean Program Water (over 200 years)		Lower Walker R. Efficiency	Max TDS for Modeled Years (mg/L)	Year First Threshold Reached	Second Threshold TDS: 12,000 mg/L			Final 30 Years Modeled: 2185-2214
	Total	CA	NV	at Wabuska (AF/yr)	at Walker Lake (AF/yr)				Year Reached	TDS: 30-Year Period after Reaching 12,000		
										Mean	Std Dev	Mean TDS
Scenario 5	18%	0%	26%	43,921	32,536	80%	24,292	2050	2053	13,838	1,783	12,002

Figure 20. Historic and Simulated Storage and TDS, Scenario 5

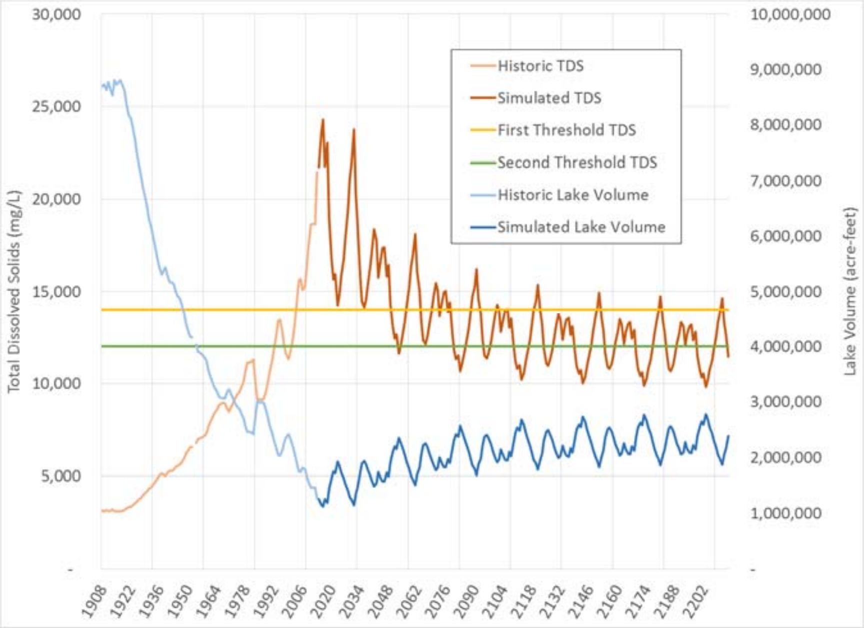
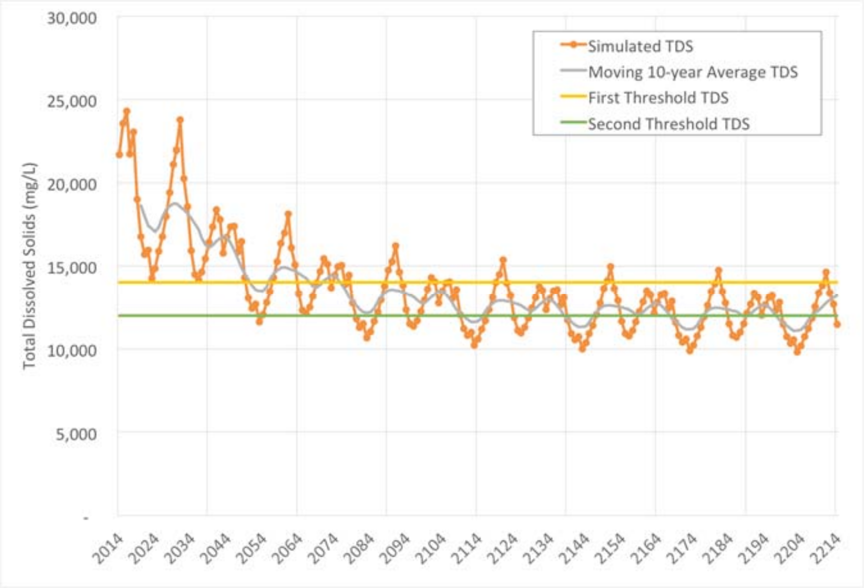


Figure 21. Simulated TDS, Scenario 5



4.6 Sensitivity Analysis

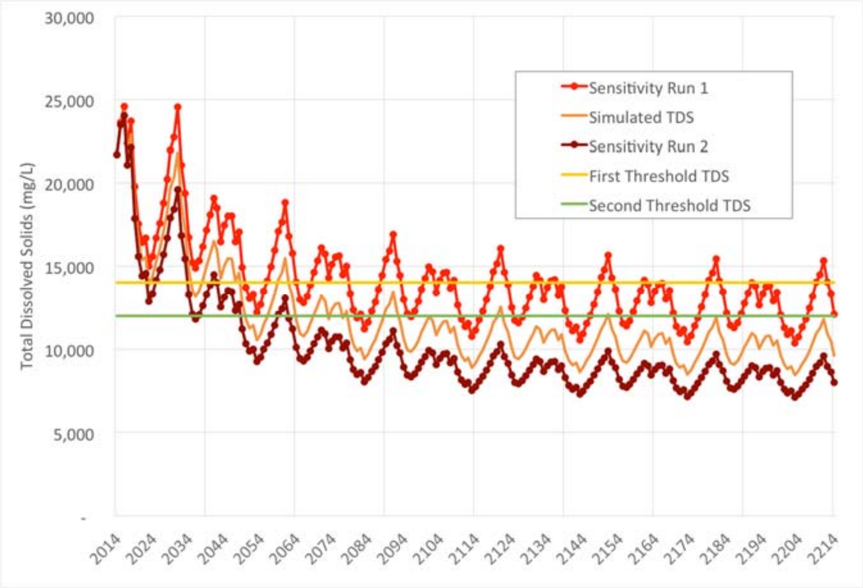
This section explores the sensitivity of the model results for Scenario 4 to the sensitivity variables explained earlier. Figure 22 shows the TDS levels for Scenario 4 and each sensitivity model run to facilitate comparison of the changes in outcomes between the model runs. The numeric results of the sensitivity runs are compared to those of Scenario 4 in Table 13.

4.6.1 Sensitivity Runs 1 & 2: Change in Walker River Flows

Sensitivity Runs 1 & 2 explore the impact to Walker Lake of changes in Walker River flows. In Sensitivity Run 1, lowering Wabuska flows (non-program water) by 10% raises TDS levels throughout the first 100 years as shown in Figure 22. During the last 30 years modeled, Scenario 4 TDS is expected to be 2,620 mg/L higher under these lower flow conditions.

Sensitivity Run 2 examines the opposite of Sensitivity Run 1: 10% higher flows at Wabuska. As one might expect, these higher flows result in lower TDS levels. During the last 30 years modeled, Scenario 4 TDS is expected to be 1,716 mg/L lower with these higher flow conditions.

Figure 22. Simulated TDS, Sensitivity Runs 1 & 2



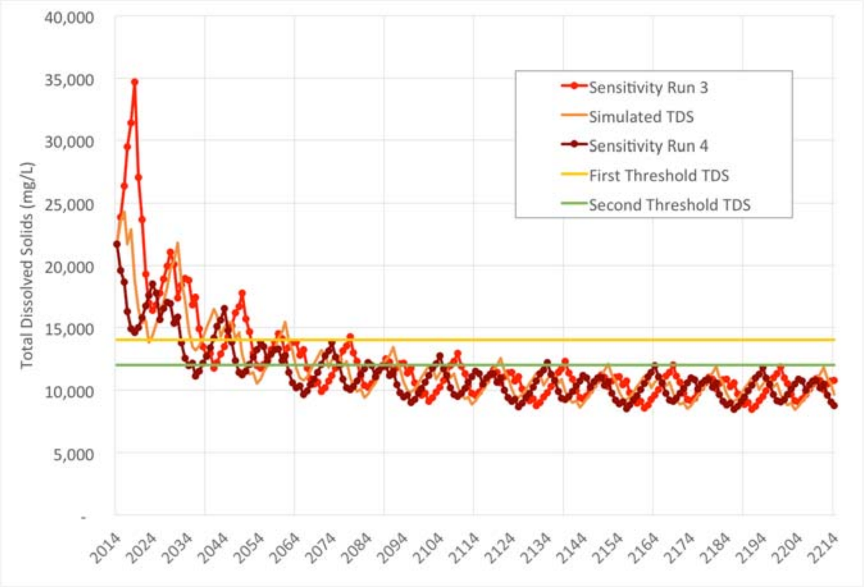
4.6.2 Sensitivity Runs 3 & 4: Historic Flow Sequence Begins with a Different Period

The starting year in the historic flow sequence used in the model run can be significant due to the large volatility of annual water supply in the Walker Basin and the presence of extended dry and wet periods. See Section 2.2 for discussion of the 30-year sequence used in the model to show the extent of this annual variation.

In Sensitivity Run 3 the 30-year flow sequence at Wabuska is altered so that it starts with 1990 (and not 1978). 1990 is the third year of a drought period. Given that the basin currently appears to be entering a dry period, this scenario is not unlikely. Figure 15 suggests that the short-term effects of this change in start year are significant. Instead of immediately falling, TDS levels rise, peaking at almost 35,000 mg/L by 2020. Such a deterioration of water quality in the lake would be of major concern. Longer-term prospects, however, are similar to Scenario 4. This reflects the fact that changing the start year does not change the long-term amount of water reaching the lake, just the sequencing of when this water reaches the lake. Given the current precarious nature of TDS levels in the lake, a near-term dry cycle may drive the lake quickly to TDS levels inhospitable to freshwater species.

Sensitivity Run 4 is a further test of the influence of the sequence of hydrological years used in the model to examine how Scenario 4 changes when a wet period occurs at the beginning of the model period. In this case 1995 is selected as the starting year. The results are immediate as the TDS level drops below the first restoration threshold by 2019 and to the second threshold by 2034, much faster than in Scenario 4. From there, however, the effects of this change net out as the long-term amount of water supplied has not changed. This illustrates, along with Sensitivity Run 2, how critical the short-term water outlook is for whether the lake declines or improves rapidly from its current precarious position on the storage volume-salt mass curve (see Figure 6).

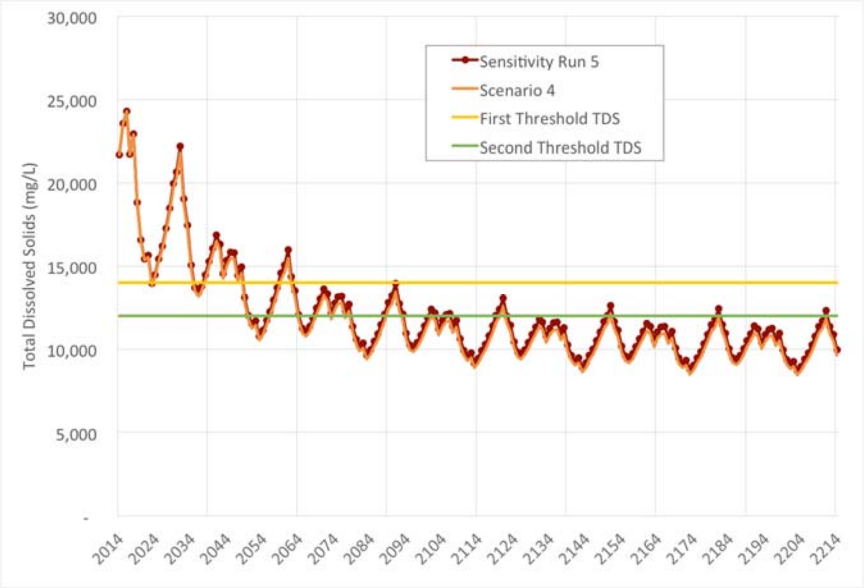
Figure 23. Simulated TDS, Sensitivity Runs 3 & 4



4.6.3 Sensitivity Run 5: Assign Higher Stream Flow Losses to Transferred Water

Stream loss factors used in the model above Wabuska Gage were taken from the USGS water balance work (Lopes and Allander 2009). These loss estimates are low when compared to ad hoc figures cited by WRID management and the Federal Water Master. Thus, in this sensitivity run, losses are uniformly increased by 5% on all the reaches except for the Main Section. The Main Section stays at a 0% loss because transfers from the Yerington Weir have the full amount of the non-consumptive portion of the water right to meet losses from the Weir to the Wabuska gage at the Federal Water Masters discretion as per the Nevada State Engineer’s Ruling No. 6271 on Application No. 80700. The results as shown in Table 13 and Figure 24 suggest little to no difference in achievement of the restoration threshold and goal in this sensitivity run. This can be explained by two factors. The first is that a large amount of the decree, supplemental storage and New Land water are acquired in Mason Valley at the weir (about one-third of the total acquired water rights) and this sensitivity run does not affect the contribution of these water rights to TDS levels. Second, such a marginal change is just that, marginal. For example a 5% increase in loss on two-thirds of 40,000 acre-ft of Program Water is about 1,300 acre-ft/yr, which in turn is less than 1% of total water delivered to Walker Lake.

Figure 24. Simulated TDS, Sensitivity Run 5

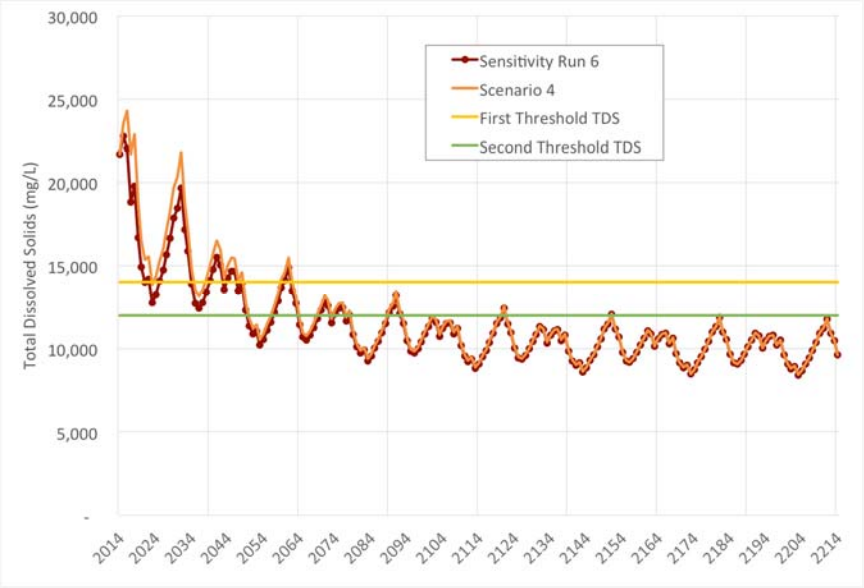


4.6.4 Sensitivity Run 6: WRID Leasing Program

A water leasing program operated by WRID was envisioned as part of the original WBRP legislation and a $25 million grant was specified for this purpose. To date the necessary permits and approvals have yet to be obtained and, thus, the feasibility of leasing large amounts of water is untested. The possibility of moving large amounts of water temporarily to the lake in the near term does, however, seem important given the potential danger of spiking TDS levels in the next few years if the current dry period continues. The results of such a leasing program – as shown in Figure 25 below – do show a short term "bump" downwards in TDS levels. However, it is neither substantial nor long lasting. The leasing program only moves achievement of the restoration goal up one year from 2051 to 2050.

A further question is whether a leasing program would assist in the near term if the near term will be a dry period, such as that simulated in Sensitivity Run 3. The answer to this question is yes. Combining the leasing program with Sensitivity Run 2 cuts the maximum TDS level seen in Sensitivity Run 3 from near 33,000 TDS down to just under 30,000 TDS. Whether such a gain is important to the lake in this case is debatable. However, the sensitivity runs certainly suggest that in the near term a large slug of water, whether from a leasing program or natural hydrology, may be valuable in preventing TDS levels from ascending to drastically high levels in the next few years.

Figure 25. Simulated TDS, Sensitivity Run 6



5. Comparison to Other Studies

This section briefly compares the model results to the other studies presented in Section 2.3 and Table 2.

5.1 Non-Program Water

In the model presented here, the average amount of water making it to Walker Lake (average over the repeating 30 year historic flow sequence) is almost 97,000 acre-ft/yr and is specifically demonstrated in Scenario 1. As shown earlier in Table 2, this figure compares well with the BOR (2010) results, but is 12,000 acre-ft/yr higher than the latest USGS figures (Allander *et al*. Forthcoming 2014). The lower inflows simulated by the USGS are due to the different hydrologic periods being simulated. Allander *et al.* (Forthcoming 2014) use the 1981 – 2010 period and replace 1983 with 1995, but do not "true" up the long-term average of this repeating 30-year cycle to the 1945-2011 period average. Simply replacing 1983 with 1995 in the 30-year cycle leads to a long-term average flow at Wabuska that is 10,000 AF less than the 1945-2011 period average. As a result, the difference between the model results here and Allander *et al.* (Forthcoming 2014) are due largely to this difference. The results presented here repeat the 1978 to 2007 hydrologic period (with 1983 replaced with 1995) adjusted by a correction factor to match the 1945-2011 (which does include 1983). Finally, the historical transient simulations performed by the USGS (Allander *et al*. Forthcoming 2014) show total inflow to Walker Lake of 99,300 acre-ft/yr, which is consistent with the 97,000 acre-ft/yr calculated here.

5.2 Walker Lake TDS Response

Scenario 3 shows that just under 147,000 acre-ft/year at Walker Lake is necessary to attain 10,000 mg/L TDS and Scenario 5 shows that a total of 138,100 acre-ft/year at Walker Lake is necessary to attain 12,000 mg/L TDS given the estimates of other lake inflows and outflows. These figures can be compared to those of previous studies, as summarized earlier in Table 2 and in further detail below in Table 12.

It is important to note that the TDS level targets for Scenarios 3 and 5 in the model presented are for the mean TDS over model years 170-200. The other studies refer to TDS at specific years in the future. To compare the results of the studies in proper context, the TDS estimates are grouped by common measurement period when possible in Table 12. Additionally, program water and non-program water below Wabuska are not differentiated in the table, as total water arriving at the Lake is what drives TDS levels. Allander *et al*. (Forthcoming 2014) uses a different method of assigning losses than the proportional method used in this model, so to avoid confusion, only total water at Walker Lake is shown in the table for each study.

Lopes and Allander (2009) projected a need for additional flows of 26,000 acre-ft/yr at Walker Lake on top of non-Program Water flows (105,000 acre-ft/yr) for a total of 131,000 acre-ft/yr of Walker River inflow to the lake. So the restoration model in this report produces higher requirements than Lopes and Allander (2009) although the results are not directly comparable because of the simplifying assumptions used to predict Walker Lake TDS concentrations in Lopes and Allander (2009).

The model results in this report suggest lower supplemental flow requirements than the Bureau of Reclamation (2010). Bureau of Reclamation (2010) estimated that 55,600 acre-ft/yr would be required at Wabuska to achieve 12,400 mg/L at Walker Lake. Further, the sum of water at Walker Lake was 156,100 of which 50,000 was from supplemental water (or Program Water). Both figures are substantially higher than the findings of the restoration model in this report. The large difference is due to Reclamation's assumption that the salt mass is increasing over time, instead of the assumption here – consistent with Allander *et al.* (Forthcoming 2014) – that the salt mass is constant.

Allander *et al*. (Forthcoming 2014) estimated that 65,000 acre-ft/yr of inflow at Wabuska is needed to achieve 12,000 mg/L at Walker Lake in model year 60. The USGS equated this to 61,700 acre-ft/yr inflow from Walker River at Walker Lake using their "pass-through" model. As noted earlier, these figures are based on a non-Program Water figure of 85,900 acre-ft/yr at the lake. So USGS is suggesting a total of 147,600 acre-ft/yr is needed at Walker Lake. This is similar to the Scenario 3 model run which suggests that 146,929 acre-ft/yr is needed to achieve 12,395 mg/L TDS at model year 60.

Thus the simulation model results reported here appear to fit well with those of other studies and are consistent with the latest USGS modeling results.

Table 12. Comparison to Other Studies

Metric	Lopes and Allander (2009)	Bureau of Reclamation		Allander et al (Forthcoming 2014)	Ecosystem Economics	
		High Inflow	Low Inflow		Scenario 3	Scenario 5
Lower Walker River Inflow (at Wabuska)						
Baseline (Non-Program Water)	n/a	n/a	n/a	n/a	127,587	127,587
Supplemental (Program Water)	n/a	55,600	55,600	65,000	53,961	43,921
Total at Wabuska	n/a	n/a	n/a	n/a	181,548	171,508
Walker River inflow (at lake)	131,000	156,100	140,000	147,600	146,929	137,364
Walker Lake TDS Estimates (mg/L)						
At 60 Years Modeled (Calendar Year 2074)	n/a	n/a	n/a	12,000	12,395	14,420
At 186 Years Modeled (Calendar Year 2200)	n/a	12,400	13,500	n/a	9,075	10,721
Mean Over Years 170-200 Modeled	12,000[1]	n/a	n/a	n/a	10,000	12,002
Efficiency	n/a	n/a	n/a	n/a	81%	80%

Units are acre-ft/yr unless otherwise noted.

[1] from long term steady state, not specifically mean over years 170-200

6. Conclusions

This report describes a model for evaluating how water acquisitions under the Walker Basin Restoration Program can be used to reduce TDS levels in Walker Lake, thereby aiding in the lake's ecological restoration. The model compiles a large amount of information on water rights and hydrology and provides a variety of user-controlled inputs that can simulate flows in the Walker River, water supply to Walker Lake, and TDS levels in the lake over a 200-year period in response to a program of water acquisitions.

A comparison of the primary inputs and outputs from the 10 different model runs are provided in Table 13. The principal findings of the scenario and sensitivity runs are as follows:

- Existing high levels of salt mass relative to water volume in the lake mean that salinity levels will react very rapidly to increases or decreases in water volumes in the near future;
- Continuing down a path of business as usual and relying on "unused" water to support the health of Walker Lake will drive salinity levels beyond the salinity of seawater (35,000 mg/L) within the next 20 years. TDS levels would continue to increase overall but fluctuate wildly into the future, making it difficult for the lake to support a viable ecology;
- Putting a hypothetical end to irrigation withdrawals would restore TDS levels to acceptable levels within five years and take these levels significantly lower in a short amount of time; while this scenario is not a practical alternative, it suggests that because this scenario quickly overshoots the goal, there should be a significant level of irrigation that would be consistent with restoring and maintaining both Walker Lake and the agricultural economy of the Walker River Basin; and
- Using either Nevada water rights alone, or in combination with California rights, the acquisition and transfer to the lake of an amount just over one-fifth of the total irrigation water right acreage in the basin would allow the lake to pass through the first restoration threshold of 14,000 mg/L within 8 years assuming a mix of dry and wet years, and reach and maintain the long-term restoration goal of 10,000 mg/L, subject to the following:
    - with a mixed dry/wet or wet period of years in the immediate future the threshold would be reached inside of 8 years and would stabilize by 2048, with the goal reached by 2050 or 2041, respectively;
    - a dry period in the immediate future does not significantly affect the long-term realization of the restoration objectives, however, it would lead to extremely high salinity levels in the coming decade;
    - should the WRID Leasing Program meet with success in addition to WBRP purchase and transfer of water rights, then the risk of a near term dry period would be ameliorated somewhat, but with little impact on the long term success of the larger restoration effort; and,
    - the model appears relatively stable in the face of selected default values and sensitivity values for river losses and the amounts of storage water that would be transferable to instream use and Walker Lake.

Finally, the strengths and originality of the model in this report lie with its simulation of surface water acquisitions and transfers from the valleys in the upper basin down to the Wabuska Gage in the Program Water Module. From there down to Walker Lake, the model uses published annual figures and flow/loss relationships established by USGS. Future efforts, therefore, to link the Program Water module directly to the USGS GSFlow model of the Lower Walker River would presumably provide higher confidence in the results. At this juncture, however, the model provides a useful bridge between acquisition activities above Wabuska and modeling of the response of the Lower Walker River and Walker Lake to these acquisitions, at least until the UNR/DRI's Walker Basin Decision Support Tool and the USGS' Lower Walker River model are ready for use in an integrated fashion.

Table 13. Summary of Model Run Results

Model Run	Water Rights Included (% of acres)			Mean Program Water (over 200 years)		Lower Walker R. Efficiency	Max TDS for Modeled Years (mg/L)	Year First Threshold Reached	Second Threshold TDS: 12,000 mg/L			Final 30 Years Modeled: 2185-2214
	Total	CA	NV	at Wabuska (AF/yr)	at Walker Lake (AF/yr)				Year Reached	TDS: 30-Year Period after Reaching		
										Mean	Std Dev	Mean TDS
Scenario 1	0%	0%	0%	0	0	76%	67,069	n/a	n/a	n/a	n/a	37,819
Scenario 2	100%	100%	100%	275,668	242,773	89%	18,563	2017	2018	5,811	1,831	2,082
Scenario 3	22%	0%	32%	53,961	40,957	81%	24,292	2023	2050	12,209	1,251	10,000
Scenario 4	20%	17%	22%	53,907	40,690	81%	24,292	2023	2050	12,216	1,229	10,001
Scenario 5	18%	0%	26%	43,921	32,536	80%	24,292	2050	2053	13,838	1,783	12,002
Sensitivity 1	Same as Scenario 4			53,907	40,110	80%	24,582	2050	2081	13,478	1,444	12,625
Sensitivity 2				53,907	41,208	82%	24,010	2023	2036	11,684	1,552	8,287
Sensitivity 3				54,102	40,820	81%	34,675	2038	2041	13,272	1,828	10,011
Sensitivity 4				54,280	41,082	81%	19,603	2032	2034	12,761	1,452	9,983
Sensitivity 5				51,745	38,861	81%	24,296	2023	2051	12,505	1,359	10,373
Sensitivity 6				54,936	41,530	81%	22,774	2021	2050	11,877	1,158	9,988

References

Allander, K.K., Niswonger, R.N. and A. E. Jeton. Forthcoming 2014. Simulation of the Lower Walker River Basin Hydrologic System, PRMS and MODFLOW models, West-Central Nevada: U.S. Geological Survey Scientific Investigations Report 20XX–XXX, XX. Reston: USGS.

Boyle, D.P., G. Pohll, S. Bassett, T.B. Minor, C. Garner, R. Carroll, D. McGraw, A. Knust, and C. Barth. 2009. Development of a Decision Support Tool in Support of Water Right Acquisitions in the Walker River Basin. In *Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin*, edited by M. W. Collopy and J. M. Thomas. Reno: UNR, NSHE, and DRI.

Boyle, D.P., C. Garner, E. Triana, T.B. Minor, G. Pohll, and S. Bassett. 2013. Walker River Decision Support Tool (version 2.0): Application and Analysis of National Fish and Wildlife Foundation Application No. 80700. Reno: University of Nevada, Reno and Desert Research Institute.

Bureau of Reclamation, 2010. Revised Draft Environmental Impact Statement, Walker River Basin Acquisition.

Huntington, J.L., and R.G. Allen. 2010. Evapotranspiration and Net Irrigation Water Requirements for Nevada. Carson City: Nevada Department of Water Resources.

Lopes, T.J., and K.K. Allander. 2009. Water Budgets of the Walker River basin and Walker Lake, California and Nevada. U.S. Geological Survey Scientific Investigations Report 2009–5157. Reston: USGS.

Meyers, T. 2001. An Assessment of Diversions and Water Rights Smith and Mason Valleys, NV. Prepared for Bureau of Land Management, Carson City, NV. Reno: Public Resource Associates.

Minor, T.B., A. Stroud, S. Bassett, M. Rincon, J. Saltenberger, D.P. Boyle, G. Pohll, C. Garner, R. Carroll, D. McGraw, and A. Knust. 2009. Development of a GIS Database in Support of Water Right Acquisitions in the Walker Basin. In *Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin*, edited by M. W. Collopy and J. M. Thomas. Reno: UNR, NSHE, and DRI.

The Nature Conservancy, 2013. Conservation Assessment for Walker Lake in Mineral County, Nevada.