



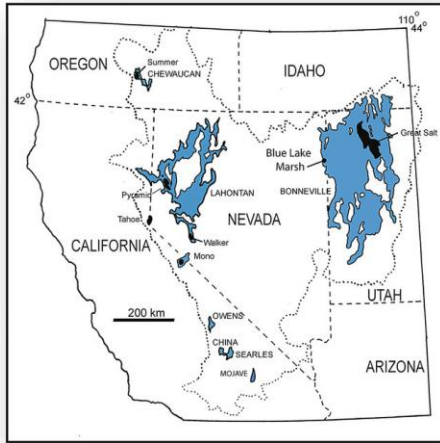
# **Salinity of Nevada's Terminal Lakes: History, Mystery, and Restoration**

**Kip K. Allander; Supervisory Hydrologist; NV Water Science Center  
([kalland@usgs.gov](mailto:kalland@usgs.gov))**

**2020 MSSC Summit:**

**February 27, 2020, Las Vegas NV**

# Nevada's Remnants of Lake Lahontan

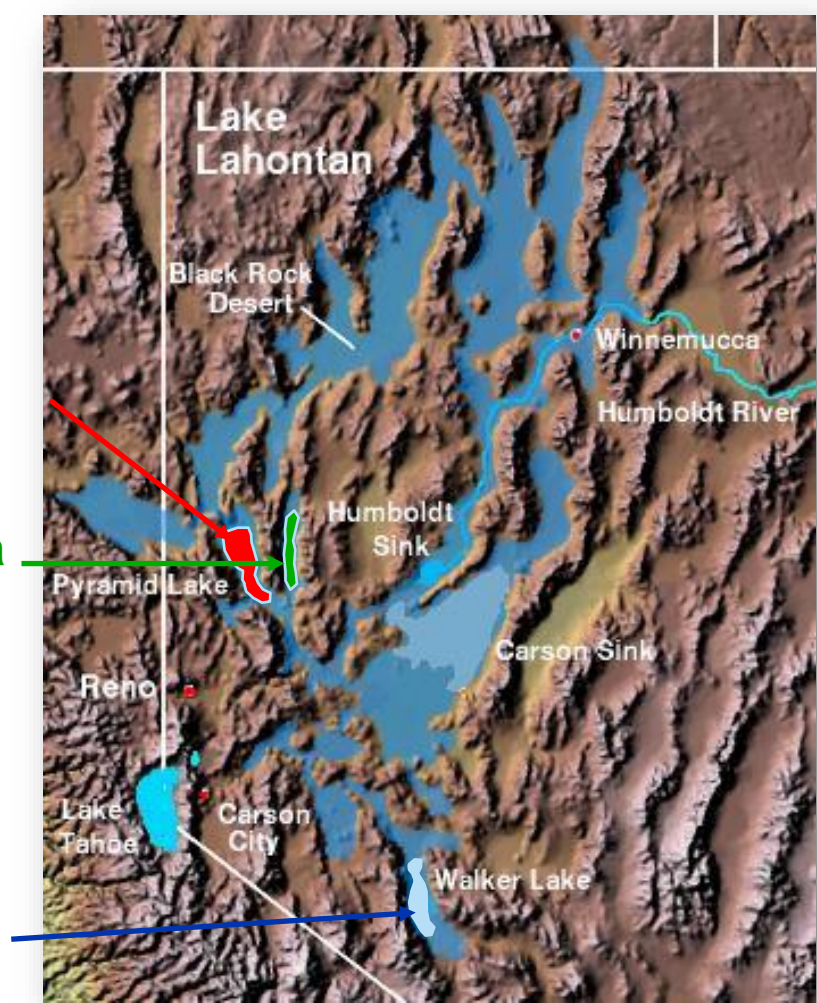


Benson (2013)

Pyramid Lake

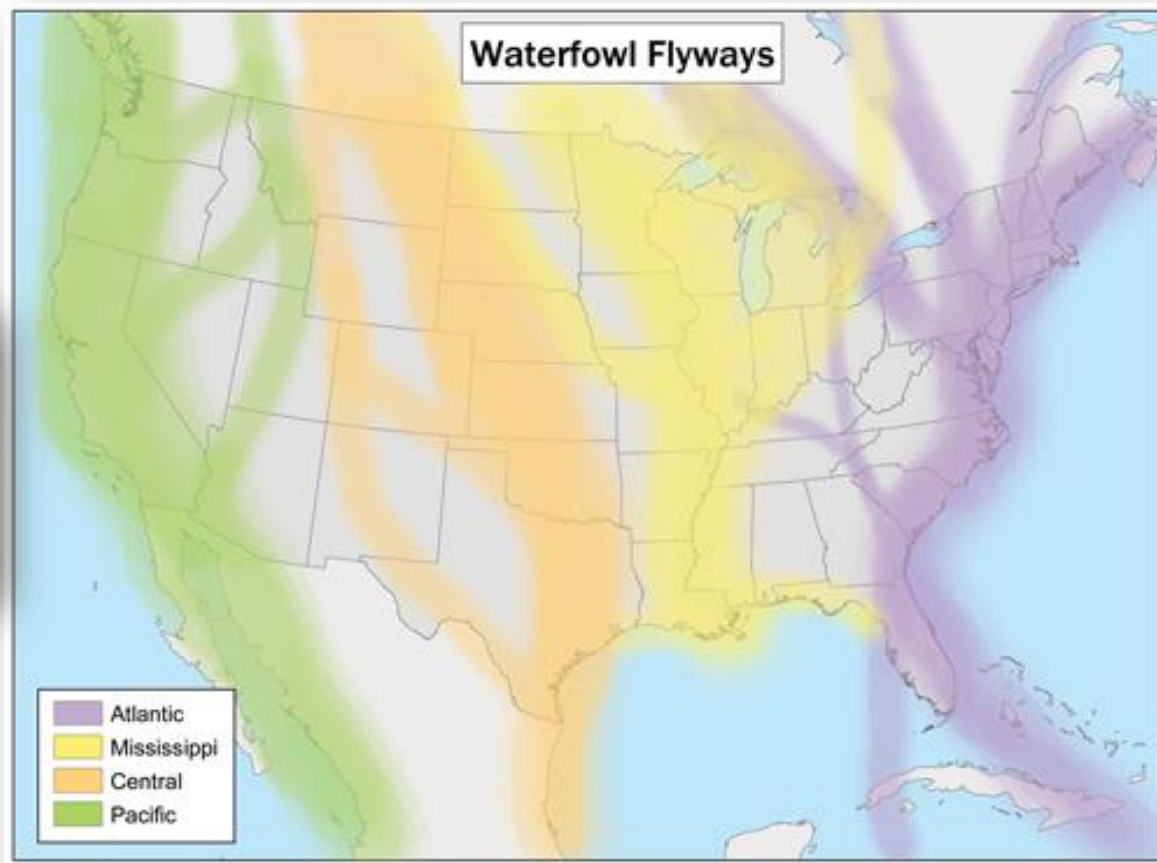
Winnemucca Lake

Walker Lake



Trump (2004)

# Pacific Flyway



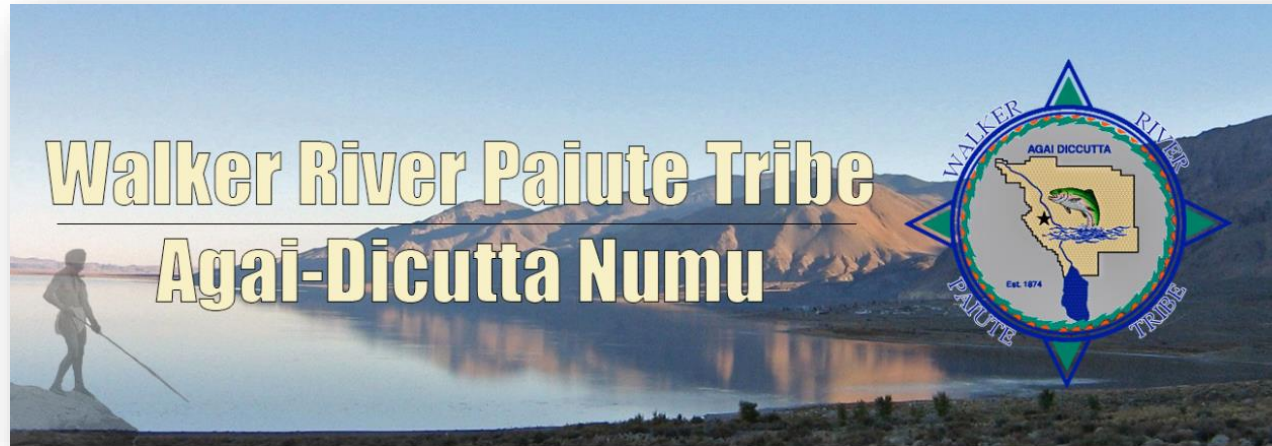
# Fisheries



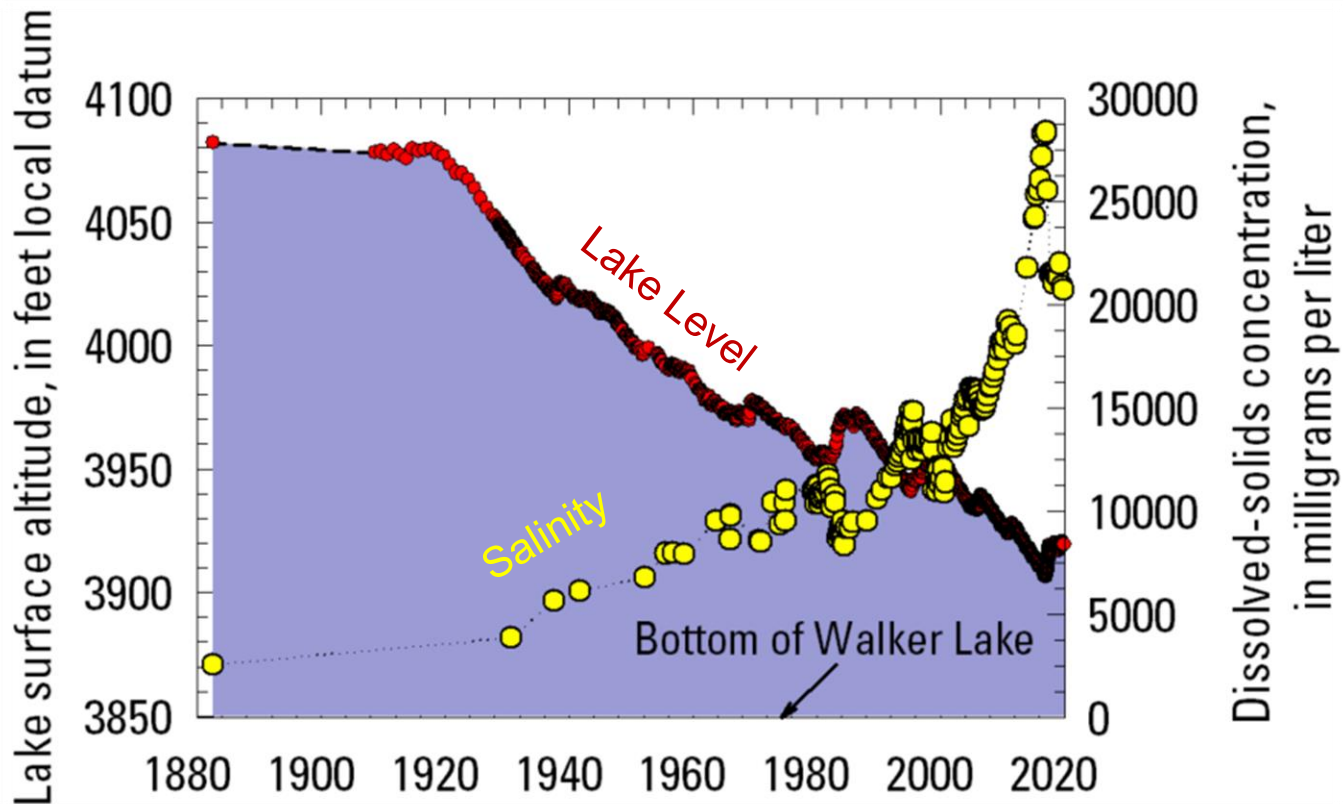
# Indigenous People and Culture



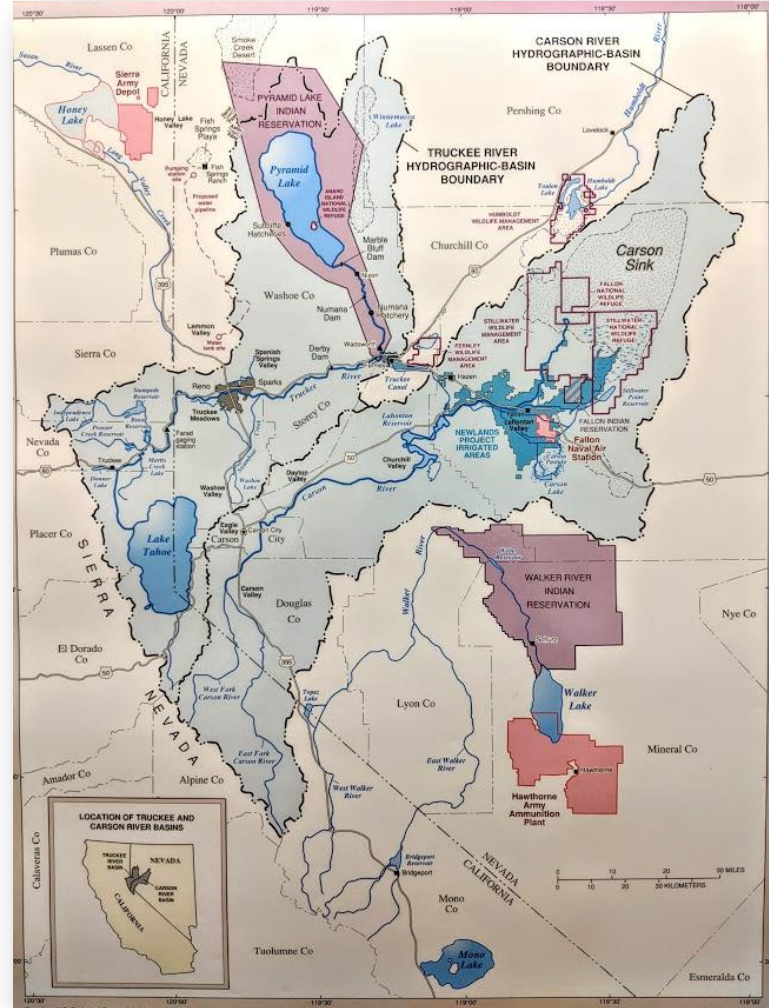
Cui-Ui Dicutta Numu (Pyramid Lake Paiute Tribe)



# Problem with Terminal Lakes. Salinity is highly sensitive to changes in storage.

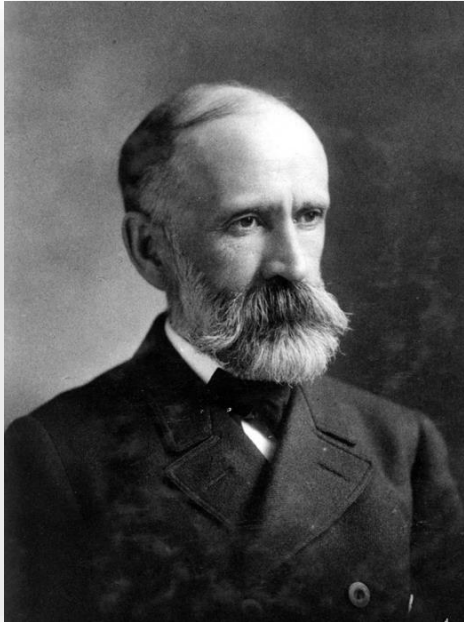


# Truckee, Carson, Walker River systems



Trionfante and Peltz (1993)

# Geologic Investigation by Israel C. Russell 1882 - 1883



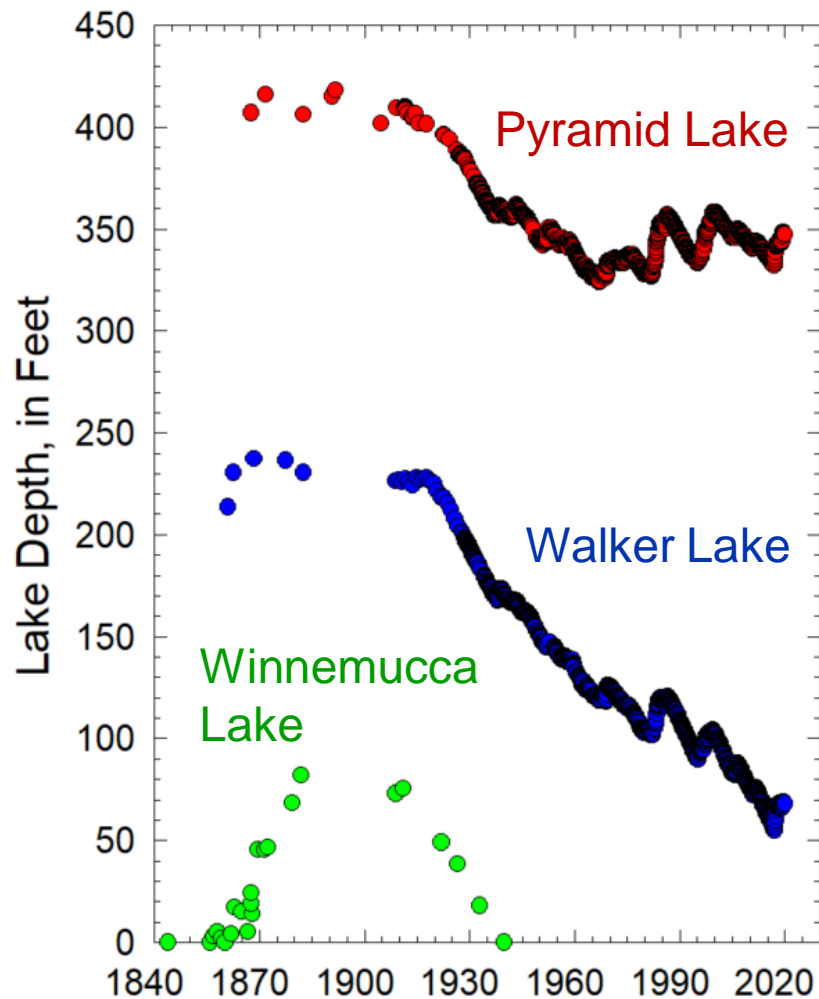
USGS



Russell (1885)



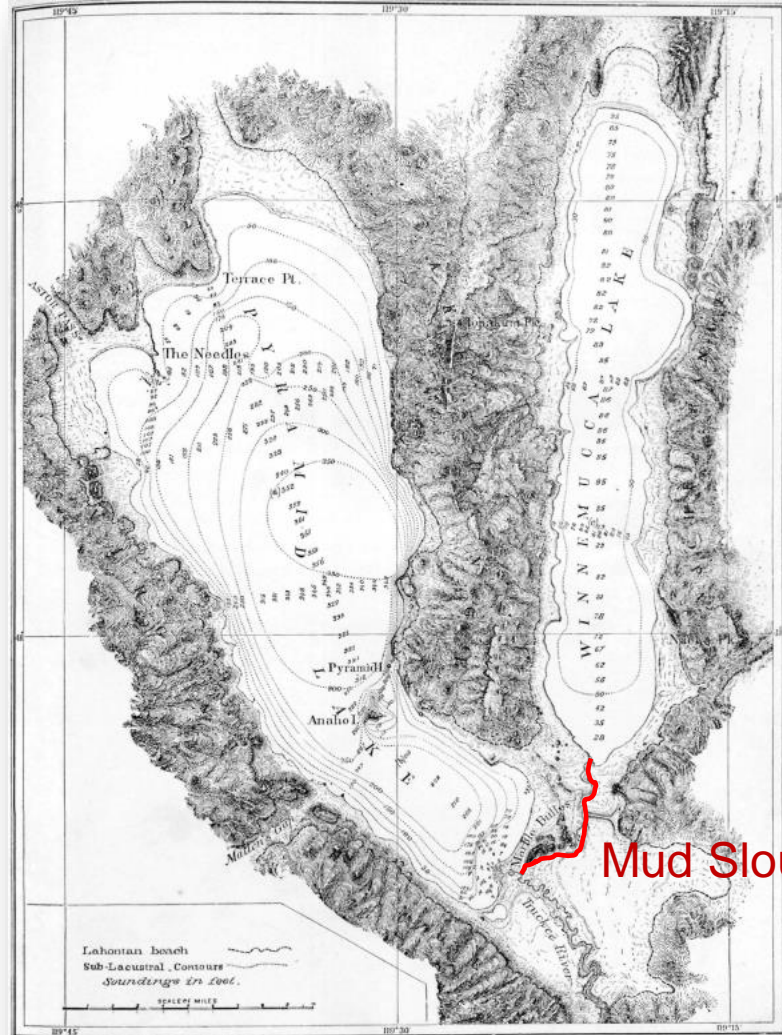
# Historic Lake Levels



# Pyramid and Winnemucca Lakes



Russell (1885)

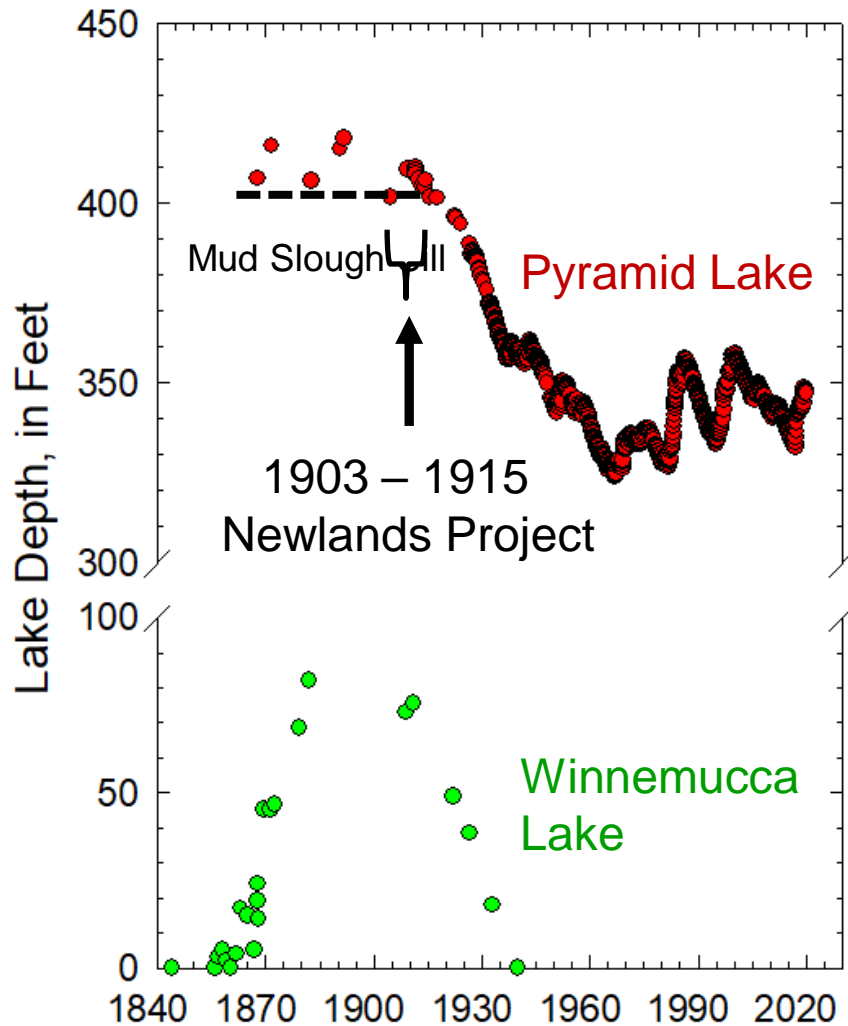


W. D. Johnson, Topographer.

PYRAMID AND WINNEMUCCA LAKES, NEVADA.

I. C. Russell, Geologist.

# Major events effecting water supply of Pyramid Lake



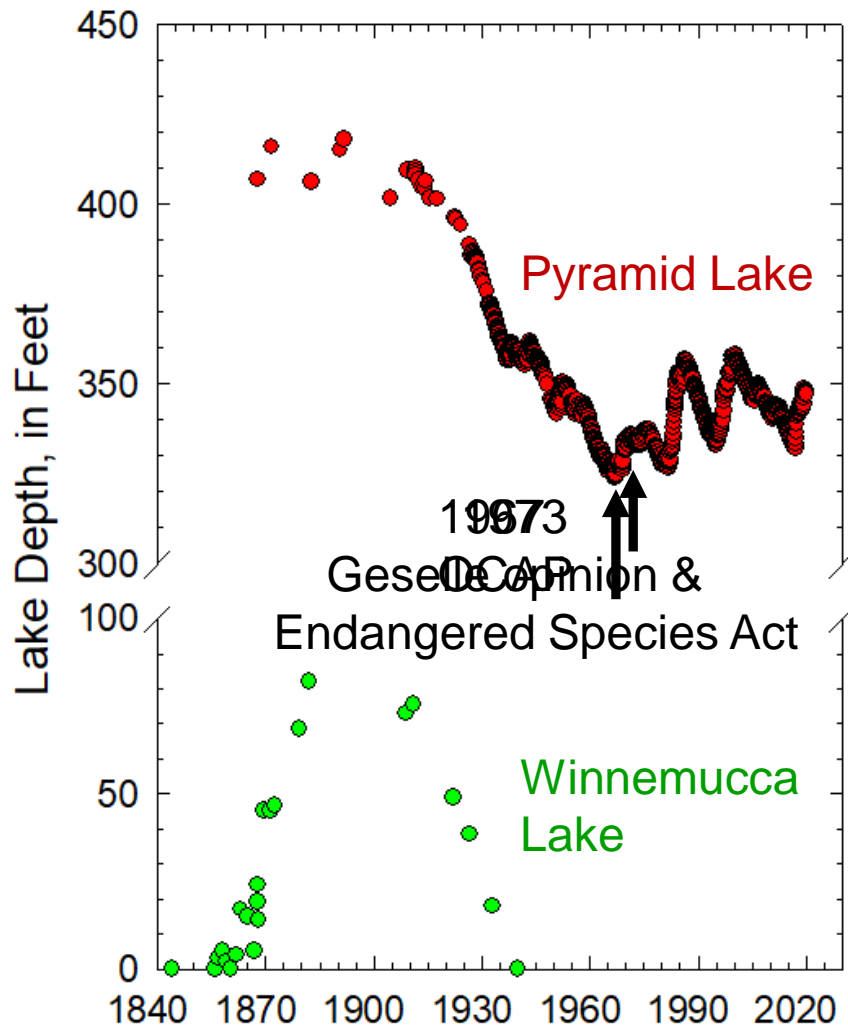
# Newlands Project



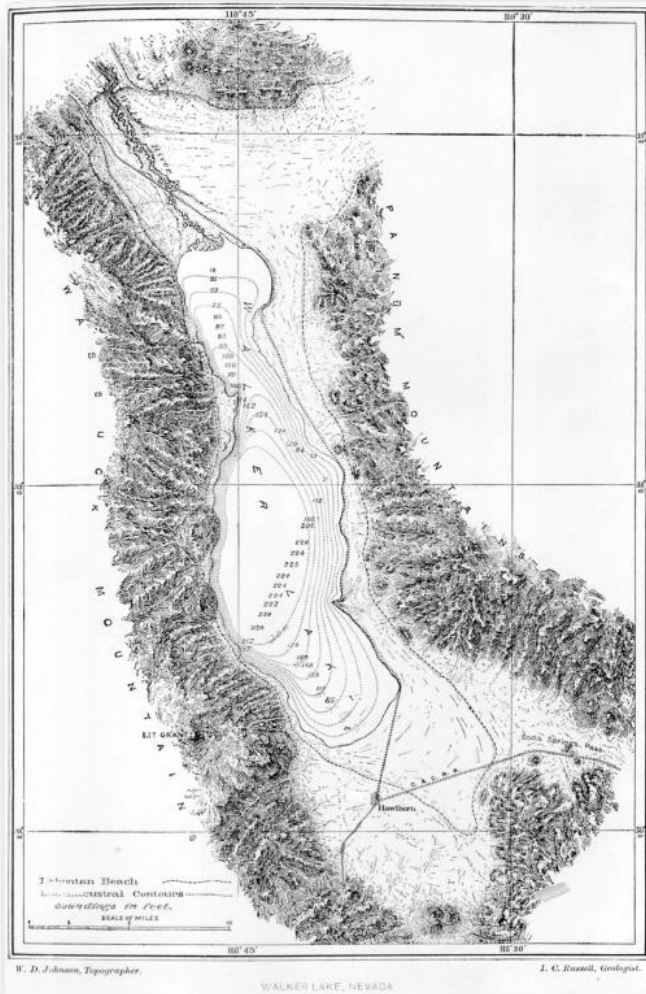
USBR

(Simpson and others, 2015)

# Major events effecting water supply of Pyramid Lake

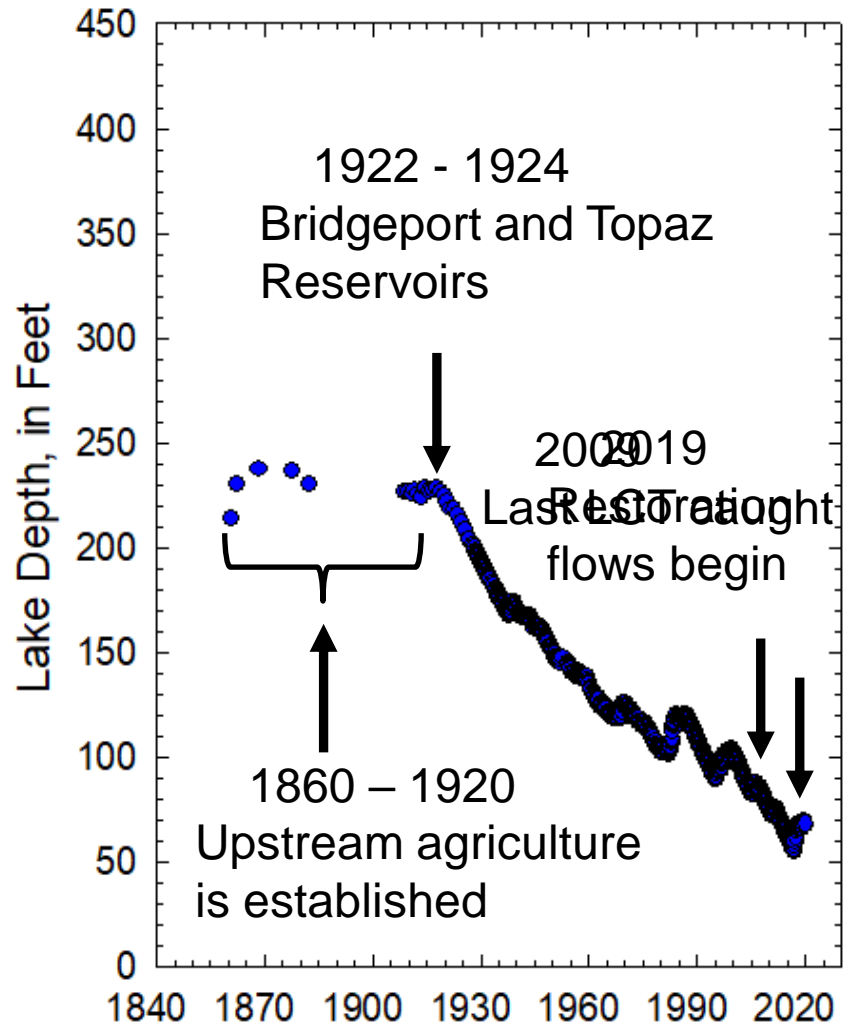


# Walker Lake



Russell (1885)

# Major events effecting water supply of Walker Lake





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Basin  
Conservancy

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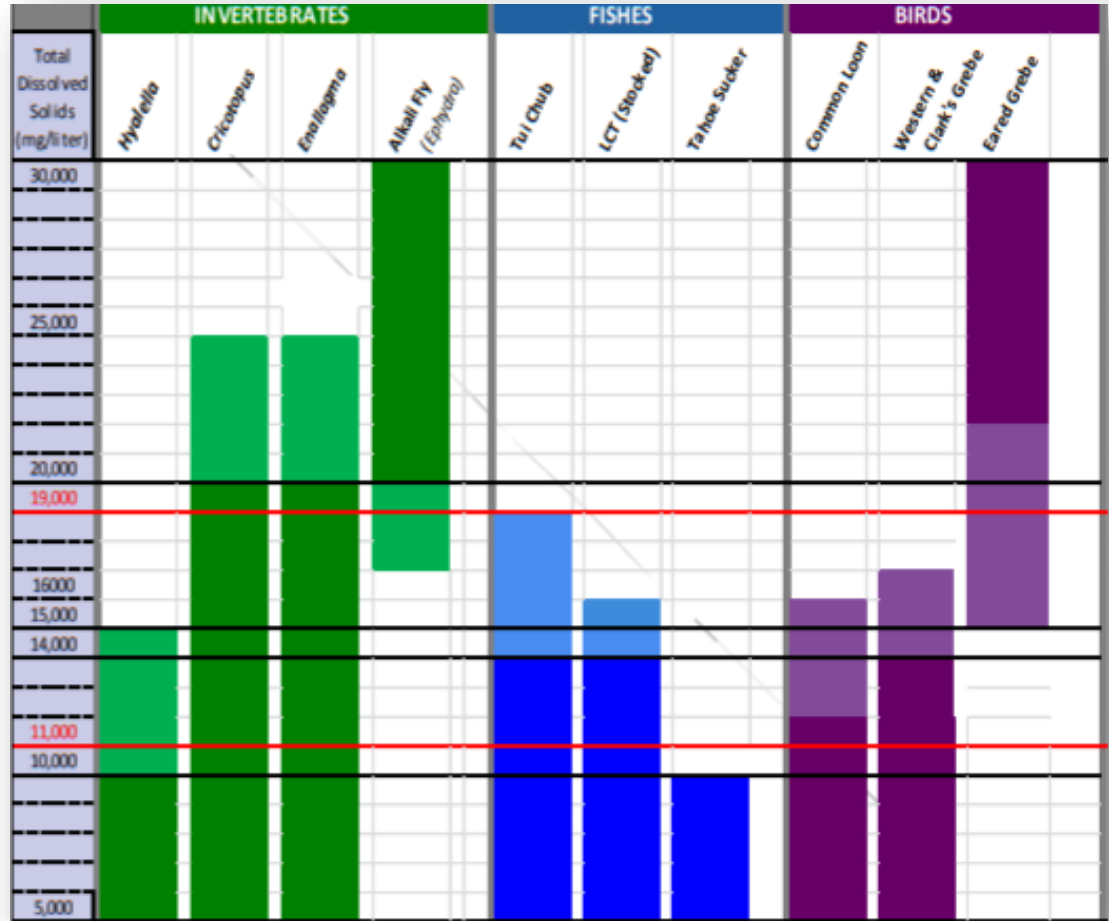
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# Walker Basin Restoration Program



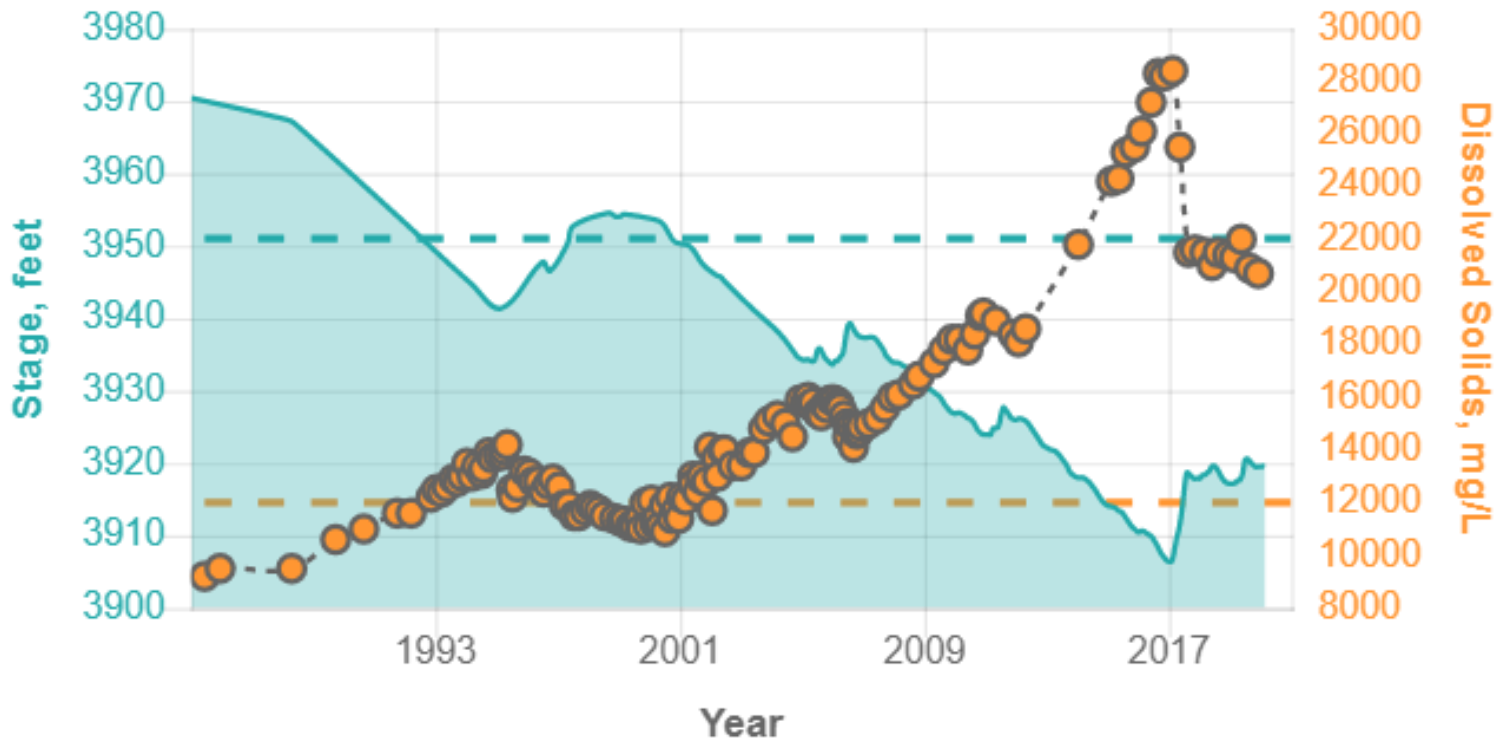


# Walker Lake Salinity Effects on Key Indicator Species

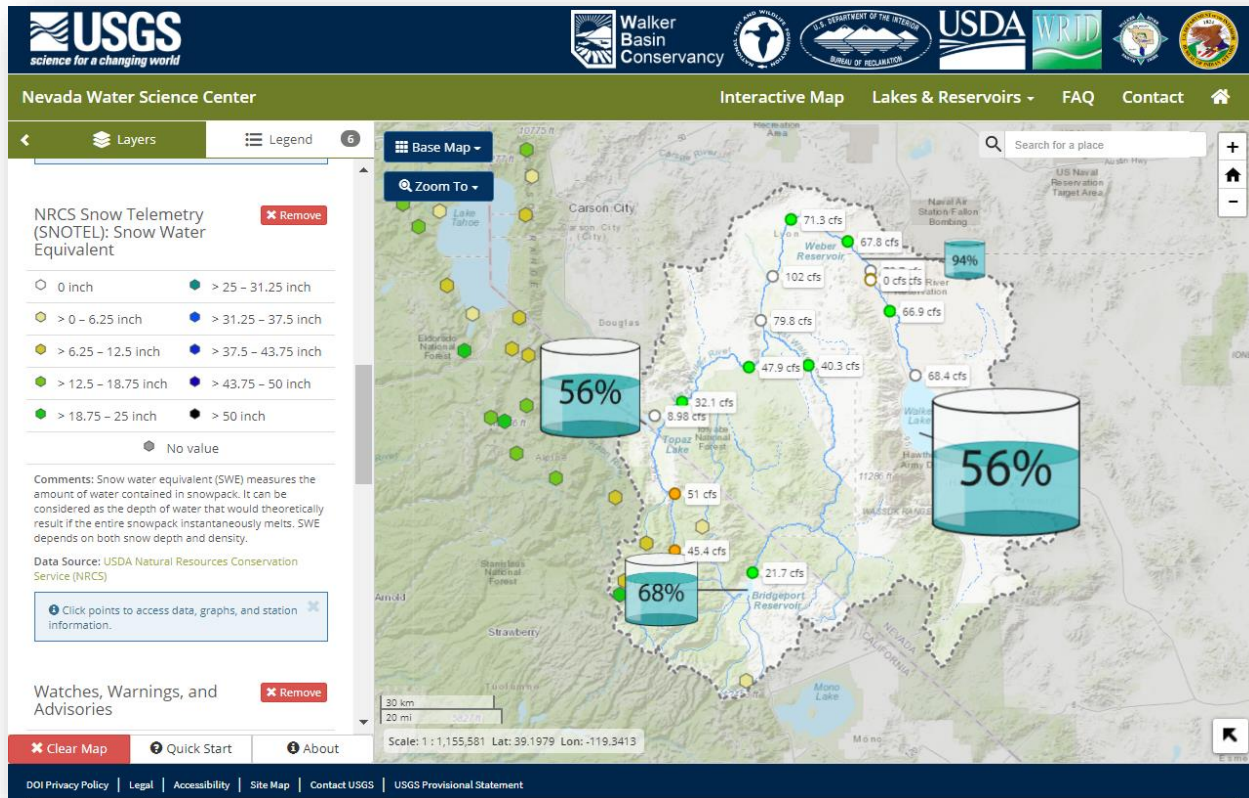


The Nature Conservancy (2013)

# Restoration targets: 12,000 mg/L TDS; 3,951 foot level



# Walker Basin Hydro Mapper



<https://webapps.usgs.gov/walkerbasinhydromapper>

# Walker Lake and the Mystery of the Missing Salt

## Walker Lake Salt Budget

$$WR_i + GW_i + PPT_i + LB_i + SL_i - (GW_o + PPT_o + LB_o + BIO_o + SL_o) = \Delta \text{ Salt Mass}$$

### Salt Inflows:

$WR_i$  - Walker River

$GW_i$  - Groundwater

$PPT_i$  - Precipitation

$LB_i$  - Lakebed sediments

$SL_i$  - Shoreline sediments

### Salt Outflows:

$GW_o$  - Groundwater

$PPT_o$  - Precipitation of salt minerals

$LB_o$  - Lakebed sediments

$BIO_o$  - Biologic processes (diatoms)

$SL_o$  - Shoreline sediments

# Salt Budget Estimate in 1995

+66,000 Tons/yr



U.S. Geological Survey  
Fact Sheet FS-115-95

## Water Budget and Salinity of Walker Lake, Western Nevada



Walker Lake (fig. 1) is one of the rare perennial, terminal lakes in the Great Basin of the western United States. The lake is the terminus for all surface-water and ground-water flow in the Walker River Basin Hydrographic Region (fig. 2) that is not consumed by evaporation, sublimation, or transpiration.

The concentration of dissolved solids (salts) in the lake and the lake-surface altitude fluctuate primarily in response to the amounts of water entering and evaporating from the lake. Because Walker Lake is a terminal sink—it has no documented surface- or ground-water outflow—dissolved solids that enter it accumulate as the lake water evaporates. Declining lake levels, owing to natural and anthropogenic processes, have resulted in most Great Basin terminal lakes being too saline to support fish. In Nevada, the only terminal lakes that contain fish are Pyramid Lake, Ruby Lake, and Walker Lake. Dissolved-solids concentration in Walker Lake increased from about 2,500 milligrams per liter (mg/L) in 1882 (Russell, 1885, p. 70) to 13,300 mg/L in July 1994 (U.S. Geological Survey analysis), as the lake-surface altitude declined from about 4,080 to 3,944 feet (ft) above sea level (fig. 3). This dramatic increase in dissolved-solids concentration threatens the Walker Lake ecosystem and the fish that depend on this ecosystem.

### Streamflow in Walker River Basin

In most years, Walker River is the primary source of water for Walker Lake. Flow in the river is mainly from precipitation in the eastern Sierra Nevada of California. Streamflow from the Sierra Nevada has averaged 327,000 acre-feet per year (acre-ft/yr) for 55 years, 1939-93 (table 1 and fig. 2, total for sites 1 and 5).

All flow data in table 1 are adjusted to the 55-year period of continuous record (1939-93) at site 4 (fig. 2), because,

although this site does not have the longest streamflow record, no upstream reservoirs or irrigation diversions exist and streamflow has been measured continuously at the site since 1939. Long-term average annual flows were estimated by comparing the average annual flow at a stream-gaging station with the average annual flow at site 4 for years of concurrent record. Then, this partial record was adjusted to a long-term average using the 55-year average at site 4.

Streamflow is measured approximately where the principal streams enter and exit each valley (fig. 2). Little ground water flows between valleys, so the difference between streamflow entering and exiting a valley can be used to estimate the consumption of surface water in the valley (table 2). Streamflow is consumed by evaporation and transpiration from irrigated crops and pasture land, natural vegetation, and water surfaces. River water also recharges ground-water aquifers.

In some valleys, local streams also contribute surface-water flow. Thus, estimates of surface-water consumption in table 2 are minimum values, because local streamflow in valleys may not have been measured. In Smith Valley, 8,700 acre-ft/yr of Desert Creek flow has been included in the water budget. In Antelope Valley, the contribution from Mill and Sinkard Creeks is unknown, so the difference of 15,000 acre-ft between average inflow and outflow underestimates total surface-water consumption.

### Water Budget for Walker Lake

Walker Lake volume decreased from 8,660,000 acre-ft in 1908 to 2,060,000 acre-ft in 1994—an average 76,000 acre-ft/yr. Walker Lake lost an average of 59,000 acre-ft/yr during 1939-93—less than during 1908-94 mainly because of decreasing lake-surface area.

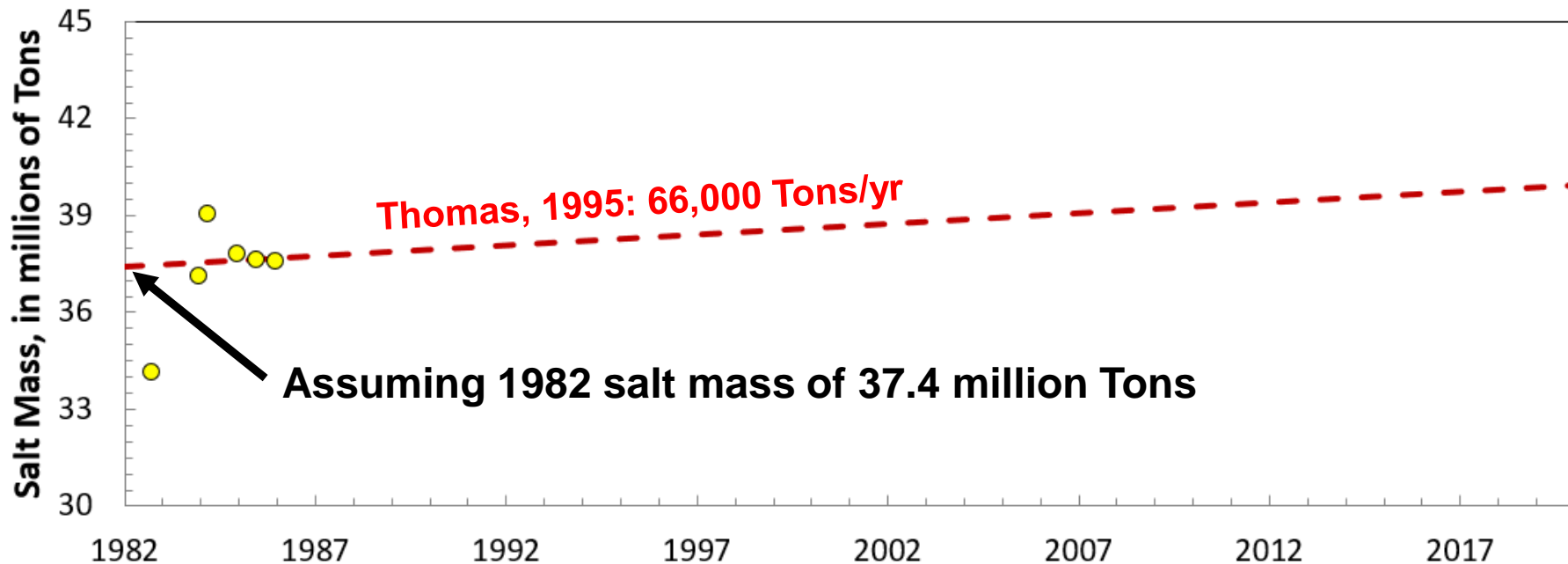
The average annual volume of water entering Walker Lake from Walker River during 1939-93 was estimated to be



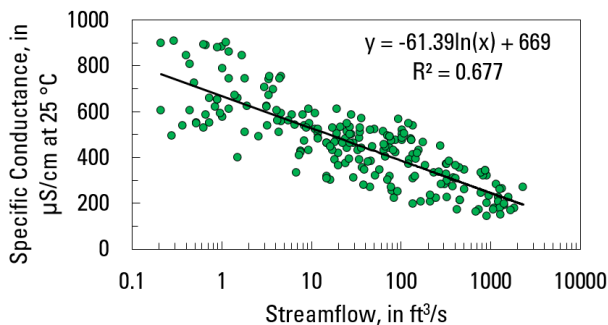
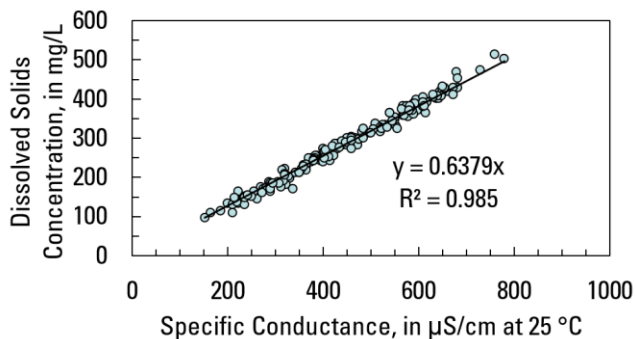
Figure 1. Walker Lake, June 1971; southward view from west shore; lake-surface altitude, 3,074 feet (30 feet above level of July 1994). Photograph by Steve Van Denburgh, U.S. Geological Survey.

Thomas, 1995

# Estimated Trend of Salt Mass in Walker Lake



# Revised Salt Budget Estimate in 2015



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## Walker Lake Salt Budget and the Mystery of the Missing Salt

By Kip K. Allander (kallander@usgs.gov), U.S. Geological Survey, Nevada Water Science Center, Carson City, Nevada  
James M. Thomas, Desert Research Institute, Reno, Nevada

### Problem

- Walker Lake (Figure 1) is a terminal lake in northern (Figure 2).
- Increasing lake salinity threatens fish lake restoration (Figure 2).
- Previous salt budget estimates are based on a 60,000-ton salt input into the lake each year (Thomas, 1993; Thomas and others, 1993; Nevada Department of Environmental Protection, 2005).
- Observed salt losses are 27.2 million tons (Figure 2).
- Restoration of full stream to Walker Lake requires an significant increase in salt input estimated about 1982 (large lake zone in Figure 2; Allander and others, 2014).
- Salt content should have increased by 7% over 13 year period (1982 – 2012) (observed line in Figure 2).
- Fracture response time or range of salt components are not well understood or recognized.
- Walker Lake salt budget has implications for estimates of fresh water needed to reduce dissolved solids (DS) concentrations.
- The lake restoration commission plan for Walker Lake is 27% concentration of 10 g/L on land and is currently estimated to be achieved with lake level of 1360 feet.

### Outlines

- DS in surface through groundwater outflow, PPT is precipitation of salt minerals.
- DS is observed difference of salt mass (dissolved solids), DS is input of salt by biological processes.
- DS is observed precipitation of salts during the lake level.

### Salt Flux Rate

DS flux rate is change in salt mass and theoretical salt flux.

**Revised Salt Budget estimate:**

- Original salt budget estimate was developed from best available information at the time (1997).
- Major water budget components were not well understood.
- Salt budget is reconstructed from data for period (1982 – 2012) to outside full period of full stream flow in Figure 1 (Table 1).
- Total inflow to Walker Lake from 1982 – 2012 (Table 1) was calculated from the Lower Walker River Basin Hydrologic Model (LWR, Allander and others, 2014).
- Inferred inflow from 1982 – 2012 was nearly 20,000 tons that greater than estimated by Thomas (1997) – which was for the period 1980 – 1993.
- WRB (revised DS concentration) to estimated using relative DS (specific conductance and DS concentration in Walker Lake) (Figure 4), and relative between discharge and specific conductance of lake (Figure 5).
- Assumed salt DS concentration for DS PPT is used by Thomas and others (1993) with revised PPT from LWR, SR.
- Assumed salt DS used by Thomas and others (1993).
- DS assumed by salt budget lake is estimated total at end of 2012 or 1982 – 2012 period (Figure 2).
- DS assumed by salt budget lake is estimated using relative DS (specific conductance and DS concentration in Walker Lake) (Figure 4), and relative between discharge and specific conductance of lake (Figure 5).
- PPT is precipitation of salts and evaporation salts from lake (DS).
- DS is estimated to be at lake site as Thomas and others (1997), DS is modeled average salt lake.
- DS is salt loss by stream.
- DS is salt loss.

Figure 1. Location of Walker Lake and Walker River basin, west central Nevada, USA.

Figure 2. Observed lake level (dashed) and dissolved solids concentration (solid) in Walker Lake.

Figure 3. Observed and theoretical salt mass in Walker Lake 1982 – 2012.

Figure 4. Relation between specific conductance and dissolved solids concentration in Walker Lake.

Figure 5. Relation between specific conductance and amount of lateral DS input.

Figure 6. Discharge diagram of Walker Lake showing discharge area (dashed) hypothetical of current average salt.

Budget Component	Estimated water quantity (acre foot/year)	DS flux (ton/year)
Inflow	104,500	24,000
PPT	7,400	14,000
DS	13,400	100
DS	-	14,000
DS	-	100
Total Inflow	125,300	48,100
Outflow	910	0
PPT	14,000	14,000
DS	-	14,000
DS	-	14,000
DS	-	14,000
Total Outflow	28,000	28,000
DS Net	-	20,100

Figure 7. Photo of Walker Lake water originating from Walker Lake discharge providing evidence of discharge and storage (photo credit: Mike Davidson, DRI, April 2015).

### Summary

- Dissolved Solids salt budget and observed salt budget do not agree (Figure 2).
- High degree of uncertainty of all salt budget components.
- Salt budgeting using discharge (DS) to lake (relative to discharge) is not salt or discharge while data were originating from discharge area (Figure 5). This is not a modification of salt budget estimate by Thomas and others (2012) for a relative salt value in the NAD83 datum (NAD 83, USA).
- Differences between theoretical salt flux and observed change in salt mass (Figure 2) is missing salt and potential estimate of DS.
- Estimates of discharge area show Walker Lake was last at a DS concentration of 10 g/L (December 1988) and 2012 is about 1300 acres (Figure 6).
- Discharge area was 700,000 tons of salt (27,400 tons/year) over 24 years of salt stored in discharge area between 2012 lake level and 10 g/L salt concentration level (Figure 6).

### Implications

- Restoration lake is discharge current vegetation growth, making riparian discharge area more susceptible to salt and soil modification, potentially diminishing its ability to accommodate current Walker Lake.
- Salt mass along discharge may be available for re-adsorption during lake restoration and could result in greater quantity of water needed to reduce lake DS concentration to lake restoration goal of 10 g/L.
- As of end of 2012, if salt storage along discharge is negligible, salt mass needed during lake restoration, Walker Lake would need an increase in volume of 17.4 million acre feet to restore DS concentration to 10 g/L (assuming that restoration lake goal of 1,360 ft).
- Discharge salt has been accumulating along the discharge and is readily discharged during lake rise. Walker Lake could need an additional 14,000 tons of salt to restore DS concentration to 10 g/L (assuming that restoration lake level goal of 1,360 ft).

### References

Allander, K. K., Anderson, R. L., and James, A. L., 2014. Restoration of the Walker Lake Basin, Nevada. U.S. Geological Survey, Nevada Water Science Center, Carson City, Nevada. <https://pubs.usgs.gov/ofr/2014/ofr2014-100/>.

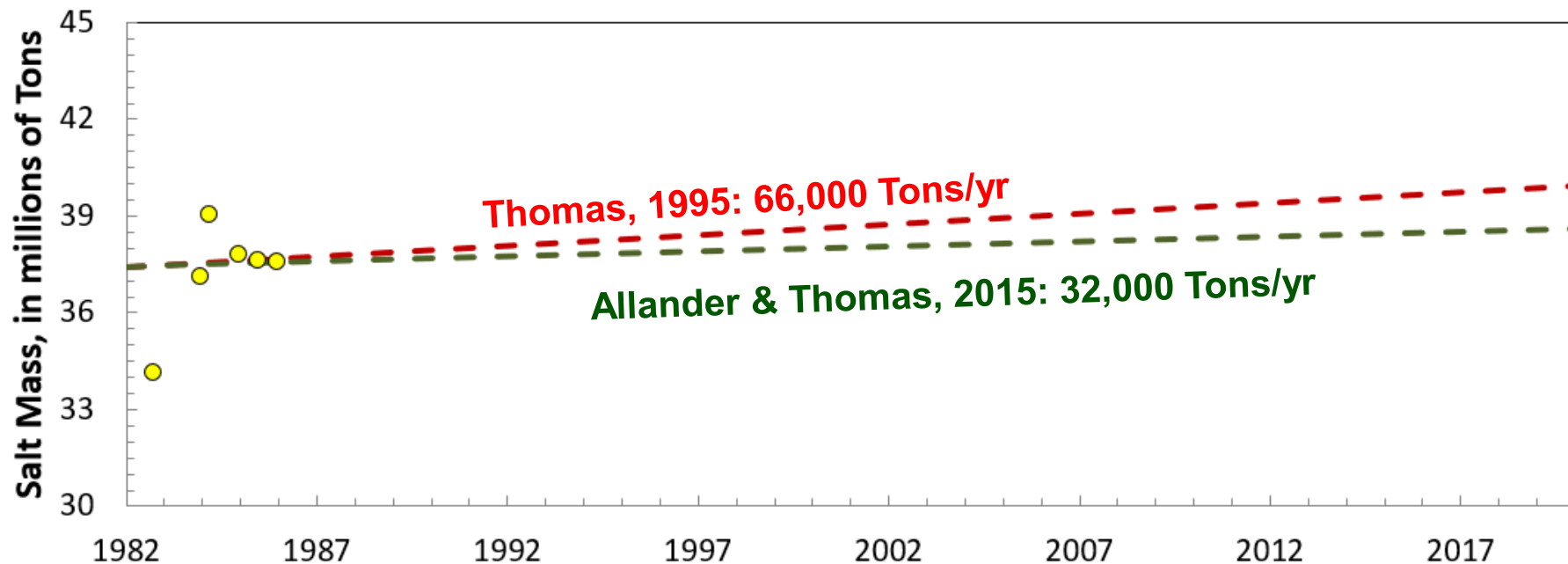
Thomas, J. M., and others, 1993. Final discharge budget for Walker Lake, Nevada. U.S. Geological Survey, Nevada Water Science Center, Carson City, Nevada. <https://pubs.usgs.gov/ofr/1993/ofr93-10/>.

Thomas, J. M., and others, 1997. Final discharge budget for Walker Lake, Nevada. U.S. Geological Survey, Nevada Water Science Center, Carson City, Nevada. <https://pubs.usgs.gov/ofr/1997/ofr97-10/>.

Thomas, J. M., and others, 2014. Final discharge budget for Walker Lake, Nevada. U.S. Geological Survey, Nevada Water Science Center, Carson City, Nevada. <https://pubs.usgs.gov/ofr/2014/ofr2014-100/>.

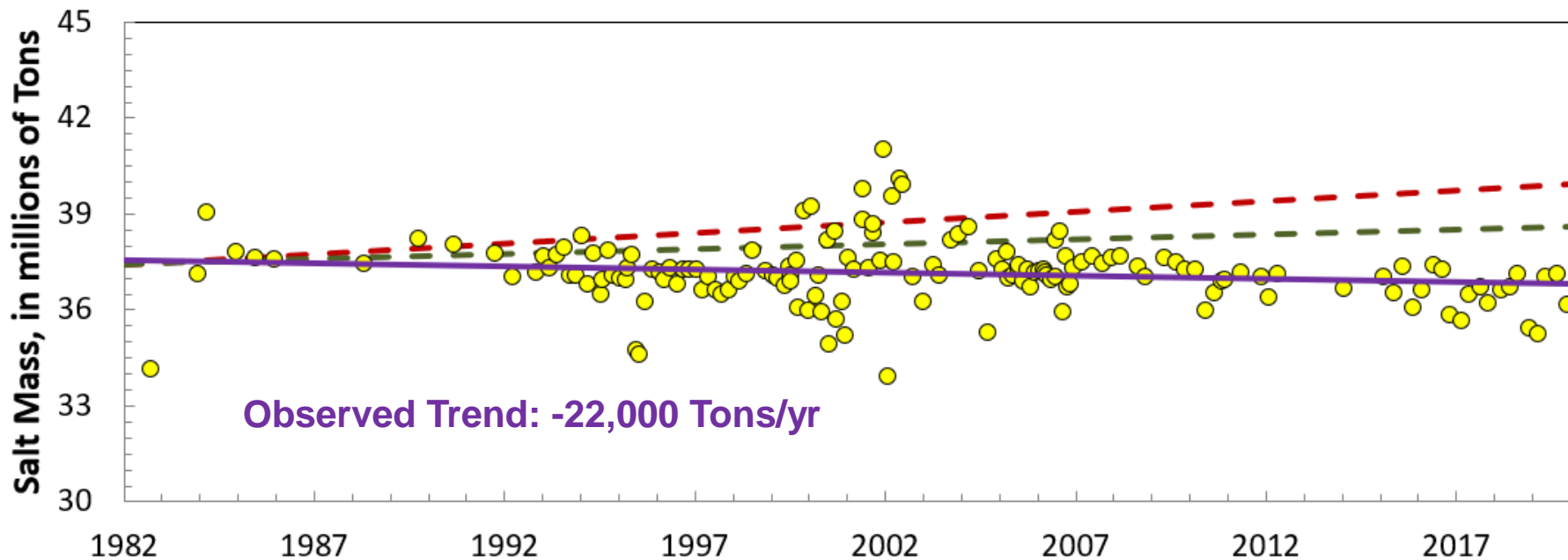
Thomas, J. M., and others, 2014. Final discharge budget for Walker Lake, Nevada. U.S. Geological Survey, Nevada Water Science Center, Carson City, Nevada. <https://pubs.usgs.gov/ofr/2014/ofr2014-100/>.

# Estimated Trend of Salt Mass in Walker Lake





# Observed Trend of Salt Mass in Walker Lake



# Walker Lake and the Mystery of the Missing Salt

Walker Lake is losing ~50,000 Tons/yr more salt than expected.

Unknown chemical precipitation?

Is it shoreline deposition?

Will salt re-dissolve when lake level's rise?



# Summary

- Nevada's remaining Terminal Lakes are important to migratory water fowl, fisheries, and Native American Cultures.
- Pyramid Lake levels and function has stabilized.
- Winnemucca Lake is really an ephemeral lake and virtually no chance it will return in modern times.
- Walker Lake fishery is gone but may recover to a viable fishery again someday.
- Salt mass in Walker Lake is decreasing but unknown where salt is going and if it will effect restoration.

Thank You.



# References

- Allander, K.K., Thomas, J.M., 2015, Walker Lake Salt Budget and the Mystery of the Missing Salt: Sixth International Limnogeology Congress, Reno NV, June 15 – 19, 2015. <https://doi.org/10.13140/RG.2.2.21904.81920>.
- Benson, L., Smoot, J., Lund, S., Mensing, S., Foit, F., Rye, R., 2013, Insights from a synthesis of old and new climate-proxy data from the Pyramid and Winnemucca lake basins, for the period 48 to 11.5ka: Quaternary International, V 310, P. 62–82. <https://doi.org/10.1016/j.quaint.2012.02.040>.
- Russell, I.C., 1885, Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U.S. Geological Survey Monograph 11, 288 p. <https://doi.org/10.3133/m11>.
- Simpson, K., Sterle, K., Singletary, L., McCarthy, M., Kauneckis, D., Dettinger, M., 2015, Role of Collaborative Modeling and Participatory Research in Understanding Challenges that Water Scarcity in a Changing Climate Pose for Agriculture: [ISEA, Nigde, Turkey; May 22, 2015](#).
- Thomas, J.M., 1995, Water budget and salinity of Walker Lake, Western Nevada: U.S. Geological Survey Fact Sheet FS–115–95, 4 p. <https://doi.org/10.3133/fs11595>
- Trionfante, J.V., Peltz, L.A., 1993, Hydrologic Features of the Truckee and Carson River Basins and Adjacent Areas, Western Nevada and Eastern California: U.S. Geological Survey OFR 93-368, 1 map. <https://doi.org/10.3133/ofr93368>
- The Nature Conservancy, 2013, Conservation Assessment for Walker Lake in Mineral County, Nevada: The Nature Conservancy, 50 p. <https://www.walkerbasin.org/resources-and-reports>.