Lessons from the Desiccation of the World’s Saline Lakes: Is It Too Late For Great Salt Lake?

Friends of Great Salt Lake Forum
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“My friends are getting older... I guess I must be too.”

Greg Brown
Dream Cafe
Decline of the world’s saline lakes

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Many of the world’s saline lakes are shrinking at alarming rates, reducing waterbird habitat and economic benefits while threatening human health. Saline lakes are long-term basin-wide integrators of climatic conditions that shrink and grow with natural climatic variation. In contrast, water withdrawals for human use exert a sustained reduction in lake inflows and levels. Quantifying the relative contributions of natural variability and human impacts to lake inflows is needed to preserve these lakes. With a credible water balance, causes of lake decline from water diversions or climate variability can be identified and the inflow needed to maintain lake health can be defined. Without a water balance, natural variability can be an excuse for inaction. Here we describe the decline of several of the world’s large saline lakes and use a water balance for Great Salt Lake (USA) to demonstrate that consumptive water use rather than long-term climate change has greatly reduced its size. The inflow needed to maintain bird habitat, support lake-related industries and prevent dust storms that threaten human health and agriculture can be identified and provides the information to evaluate the difficult trade-offs between direct benefits of consumptive water use and ecosystem services provided by saline lakes.
Saline lakes are in trouble world-wide.
Problem Lake #1: Aral Sea in central Asia is the best-known case of the destruction of a salt lake

<table>
<thead>
<tr>
<th>Year</th>
<th>Lake Volume (km$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>23,000</td>
</tr>
<tr>
<td>2013</td>
<td>3,000</td>
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</tbody>
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Aral “Solution”—Dike off 5% of the lake so minimal water entering lake meets evaporative loss of this small system; maintain small fishery

Massive dust storms from dry lake bed

Major health problems for region

From: Philip Micklin (2014)
Problem Lake #2: Lake Urmia
A “sister” system of Great Salt Lake

Great Salt Lake

Lake Urmia

Area
4300 km$^2$
5100 km$^2$

Mean Depth
4.4 m
6 m

Elevation
1280 m
1275 m

Both have causeways dividing them; both have watersheds in 3 states.
After the western embargo, Iran has attempted to become self-sustaining in food production. Reservoir capacity & irrigated agriculture has increased tremendously.

- There is now more capacity in reservoirs (3.3 km³), than water in Lake Urmia (~2.5 km³)!
- The increase of irrigated agriculture in the basin is approximately equal to the area of the lake that has disappeared (substitution one evaporative area for another).
Currently, Lake Urmia is ~ 5% of its volume when full

Photo: Ali Chavoshian
Management Objectives:

1. Raise awareness of the values of the lake and satellite wetlands and enhance public participation in their management.

2. Sustainable management of water resources and land use.

3. Conservation of biodiversity and sustainable use of wetland resources

— $5 billion pledged
Solution? Find a lot of water to return to the lake

<table>
<thead>
<tr>
<th>Province</th>
<th>Potential Water Resources (m$^3 \times 10^6$)</th>
<th>Return to Lake Urmia (% of resource)</th>
<th>Million Acre Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Azerbaijan</td>
<td>1360</td>
<td>20%</td>
<td>1.10</td>
</tr>
<tr>
<td>West Azerbaijan</td>
<td>3982</td>
<td>47%</td>
<td>3.23</td>
</tr>
<tr>
<td>Kurdistan</td>
<td>1583</td>
<td>61%</td>
<td>1.28</td>
</tr>
<tr>
<td>Total</td>
<td>6925</td>
<td>45%</td>
<td>5.61</td>
</tr>
</tbody>
</table>


To date, there has been little success in restricting water usage in agriculture and returning more water to the lake. An “Aral Sea solution” (diking & greatly reduced lake size) seems likely.
Problem Lake #3: Owens Lake, California
Potential health and economic costs of dust storms are immense

Owens Lake, California: Water diversions to Los Angeles dried it up by 1940

- Dust storms have impacted communities in Inyo County. Los Angeles will spend $3.6 billion over 25 years on dust mitigation
Great Salt Lake - Can We Learn from Others?
Great Salt Lake Water Balance Analysis

There has been no significant long-term change in river flow coming out of mountains, nor has precipitation in SLC shown any long-term change. Variation yes, but no long-term change. Climate change has not been a factor (yet).

Water consumption (depletions) has increased significantly, and now represents 39% of river flow to the lake.

Agriculture is the primary user of water (63%), but other uses are significant.

Water use has decreased lake elevation (red) 11 feet. In contrast, when depleted water is added back in a hydrological model, long-term change is minimal, and we estimate that a natural lake would have had a mean elevation of 4,207 feet.
• Water use and drought has exposed ~50% of the lake bed.

• However, Bear River & Farmington Bay estuaries have been impacted much more
Effects of Water Use on Equilibrium Great Salt Lake Elevations: “Death by a Thousand Cuts”

 Estimates of Craig Miller, DWR (except Bear Lake’s 400,000 af)
Problems

Dry Marinas

Artemia franciscana

Gilbert Bay Salinities

Salinity Range for Brine Shrimp Growth & Survival

Limit 30% (230 g/L)

Salinity (%)

Problems: Dust

- Currently we do not understand the potential of the exposed Great Salt Lake playa to produce dust in the short term, or in the long term, as salts are leached from the playa back into the remaining lake—more research is needed.
Potential health issues & costs are alarming:

- Owens Lake: $3.6 billion over 25 years
- What might be the costs of remediation for dust if Great Salt Lake is dried up?
- Population of 5 counties adjacent to Great Salt Lake: 1,800,000
- Population in Inyo Co. near Owens Lake
How can we avoid the disasters of the Aral Sea, Lake Urmia, Owens Lake and others?

South shore of Great Salt Lake
1) Most logical and easiest way - Control population growth to decrease demand

With fixed levels of natural resources (water) these rates are not sustainable for either the Great Salt Lake or the Lake Urmia Basin. This has caused the problem, and continued growth will only make the problem worse.
River inflows (blue) and Target Inflows (green) for the recovery of three lakes

Target Elev. - 4199.4 ft

Can we save water and return some of what’s been lost to Great Salt Lake - Sure!

Utahans use 2.6 X more than the average of these other arid countries and 6.5 X more than Israelis

Conclusions

• Great Salt Lake is in much better condition than many of the world’s other saline lakes.
• We have time to act, and unlike Iran, we have the financial resources to avoid further degradation, or even to return water inflows to the lake.
• Water use in Utah is currently extremely high, so conservation efforts, especially in agriculture, could save huge amounts of water.
• We now have an extremely motivated conservation community and resource agencies knowledgeable about the issues.
• Now, the lake needs the support of the general public, and the political will so we can avoid the fate of other saline lakes of the world.
Questions?
2) Water conservation in urban and especially in the agricultural sector

1 Municipal water use
Gallons Per Capita per day

Denver: 171
Tucson: 117
Austin: 162
Albuquerque: 163
Los Angeles: 145
Phoenix: 174
Average Utah City: 295

We can calculate how future water development (or reduced use) will influence lake depth, area, volume and salinity: What sort of lake do we want?

Estimates of Craig Miller, DWR (except Bear Lake’s 400,000 af)
Birds

>2.5 million birds use the Great Salt Lake each year

Western Hemispheric Shorebird Reserve (1991)

RAMSAR Convention Wetland
Brine Shrimp in Gilbert Bay

Commercial harvest of brine shrimp cysts

Aquaculture industry (prawns & juvenile fish) $57 million
Mineral Extraction from Great Salt Lake

The most valuable industry
Climate change is often blamed for the demise of salt lakes. However, I will argue today that water development in arid basins generally represents a much larger and more immediate challenge. The Great Salt Lake is no exception.
Total Economic Effect ($ Millions) for humans
Total - $1,300 Million Dollars ($1.3 Billion per year)

Bioeconomics, Inc. (2012)
Hydrology and Salinity Issues
Major question: Is the decline in the level of Great Salt Lake the result of: (1) Natural cycles of drought & wet years? (2) climate change? (3) water withdrawals?

Great Salt Lake Elevation (1847-2014)
Bear River Compact Allocations

<table>
<thead>
<tr>
<th>State</th>
<th>Acre-Feet</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah</td>
<td>350,000</td>
<td>(220,000 current proposal)</td>
</tr>
<tr>
<td>Idaho</td>
<td>200,000</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>550,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

- **Full Bear River Compact (550,000 AF; +41%)**
- **Current proposed Bear River Development (220,000 AF; +16%)**
Lake Impacts of Additional Bear River Depletions
Utah Div. Water Resources (preliminary)

Additional Decline in Lake Level

- Bear River Development (220,000 af) 1.8 feet
- Bear River Compact Allowance (550,000 acre-feet) 4.5 feet
  - Expose a total of 680,000 acres of lakebed
  - Decrease the volume to 30% of natural
  - Increase salinities in the south arm of the lake (Gilbert Bay) to ~220 g/L, nearly eliminating Artemia from the lake

![Lake elevations graph]

-15.5 ft.
-4189.5 ft.
Great Salt Lake elevations (1847 - 2014)

Common perception:
The lake’s elevation is controlled by short-term climate fluctuations
Climate change?

A. Precipitation in Salt Lake City (1875–2014)

No Long-Term Trend In Precipitation

(http://w2.weather.gov/climate/xractis.php?wfo=slc)
River flow in mountains estimated from tree-ring widths

1) Core tree, measure annual growth increments

2) Derive relationship between ring widths and years of known discharge in rivers

\[ W = mx + b \]

3) Use the relationship and tree ring growth increments for up to 1000 years to estimate river discharge back in time before river flows were measured*

Water depletion is primarily due to agriculture

Agricultural (63% of loss)  Salt ponds (13%)

Logan River diversion

↑ Evaporation

Municipal (11% of loss)

↑ Evaporation

Impounded wetlands (10%)

Reservoir evaporation ↑ (3%)

One-half of municipal use is for landscaping (i.e. about 5% of total depletions), yet the vast amount of emphasis for the public is to control these losses. We won’t solve the problem that...
A model of what natural lake elevations would be without depletions indicates a mean of 4207’, with no long-term trend. Water use has lowered the lake ~ 11 feet.
Conclusion: Neither natural fluctuations or long-term climate change has caused the decline of Great Salt Lake. Rather, consumptive water use, primarily for agriculture has caused the decline. Additional planned development will lower it more.
Future Water Development and Great Salt Lake

**Bear River Compact**
- Agreement between Utah, Idaho, and Wyoming in 1958
- Amended in 1980
- Allocates water between the three states

**Bear River Development Project**
- Providing mechanisms for future water supply

[Image of Bear River in Utah]
3) Change archaic water right laws:\(^1,^2:\)

- Allow water banking & transfers from agriculture to urban use.
- Split Season Leases of Water Rights
- Legislative or Administrative Established Minimum Flow Requirements
  - Statutory Reservation (by Governor)
- Eminent Domain or Public Trust Doctrine

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Conclusions

• Although climate change has, and will continue to influence saline lakes, a more imminent threat to these ecosystems is water diversion for agriculture, urban and industrial uses, driven by population increases and an ever-increasing need for food production. Great Salt Lake, the Aral Sea and Lake Urmia are prominent examples.

• In some cases, water conservation and water marketing can shift water resources back to natural systems such as these salt lakes. This may be possible in developed, industrial countries where agriculture does not dominate economically, and high cultural values are placed on salt lakes.

• It is not too late for Great Salt Lake if we have the social and political will to save it.
The new President of Iran, Hassan Rouhani, campaigned that he would save Lake Urmia if elected.
Precipitation is apparently declining in the Lake Urmia Basin

2010-2015 data - ULRP
Curiously, elevations of other terminal lakes in the region have not declined.
• Freshwater Withdrawal by Country and Sector (2013 Update)
• Israel  268 m3/person/year
• US  1,518
• Portugal  792
• Spain  717
• Italy  755
• Greece  849
• Australia  2782
• All countries are in the data set
  • Utah  1750  m3/person/year
  • *Water use calculation for Utah vs world.xlsx*


“Utah, however, has a different distribution than the country on average. Withdrawals averaged 4.5 billion gallons per day in 2010, or about 1% of the country’s total. Irrigation accounted for 72% of the state’s withdrawals, with public supply (15%) and mining (6%) following.”

Water use per state: [https://pubs.usgs.gov/circ/1405/pdf/circ1405.pdf](https://pubs.usgs.gov/circ/1405/pdf/circ1405.pdf)
Great Salt Lake Watershed
493 mm/year*

‘Green’ is mostly forest

Water problems in both areas are from trying to grow crops in deserts

But: 120 day growing season in Great Salt Lake basin; 220 days in Urmia

Lake Urmia Watershed
235**mm/year (1967—2006)
372*** mm/ year (1964-1992)

‘Green’ is mostly agriculture

*** UNDP 2012. Lofti. A concise baseline report for L. Uromiyeh
Gilbert Bay (south arm)

Charles Uibel
Bear River Bay of Great Salt Lake
North Arm Great Salt Lake
Gilbert Bay

Charles Uibel
Gunnison Bay

Wayne Wurtsbaugh
The Spiral Jetty (Gunnison Bay)

Photo – Bob Grutzmacher, Wannabe-Photography
Gilbert Bay from Antelope Island

Thank You

Wayne Wurtsbaugh
Talked to here
Railroad causeway causes a deep brine layer in the south basin

Jones and Wurtsbaugh (2013)
Great Salt Lake Planning Matrix - What are the best lake elevations?

|---------------------------------| 70 Local Parts of the lake |

Lake Elevations (1277 m to 1284 m)

Orange = Bad

Green = Good Elevation
Microcosm Experiment to Determine Salinity Influences on Biotic Community

- 12 liter buckets
- 30-day experiment
- Salinities 10 - 275 g/L
- 2 replicates / salinity
- Inoculated with organisms from 0-275 g/L salinities

Pelagic (open water) Community Changed Markedly with Increasing Salinities

- **Copepods**
- **Corixid (predator)**
- **Artemia franciscana**
- **Fish (Gambusia)**
Brine Fly Length and Biomass Decreased with Increasing Salinities

- Reduction in larval length with increasing salinity
- Lower biomass of larvae and pupae at salinities >100 g/L
- However, brine fly larvae survived in the highest salinities, but most of them formed pupae
Great Salt Lake

- Western USA; State of Utah
- Area ~ 4200 km²
- Mean depth 4.4 m
- Salinity 10-330 g/L in different parts
- Mesotrophic-Hypereutrophic
Shrinkage of Lake Urmia

Currently, Lake Urmia is ~ 5% of its volume when full.
Both measured discharge and tree-ring reconstructions of river discharge indicated no significant long-term trend in flow from the upper tributaries of Great Salt Lake. That is, climate change has not yet influenced annual river flows from the mountains.
Water consumption (depletion), however, showed a significant long-term increase. Approximately 39% of the river flow towards the Great Salt Lake is now used for agriculture, industry, municipal use, and wetlands.
Major drop in lake elevation since 2000

Lake Urmia Surface Elevation

5 m (16 ft) decrease
2) Water conservation in urban and especially in the agricultural sector