The Great Shrinking Lake

How does population growth relate to the size of the Great Salt Lake?

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GES 381: Remote Sensing

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Image: Kevin Perry

The Great Salt Lake is shrinking.

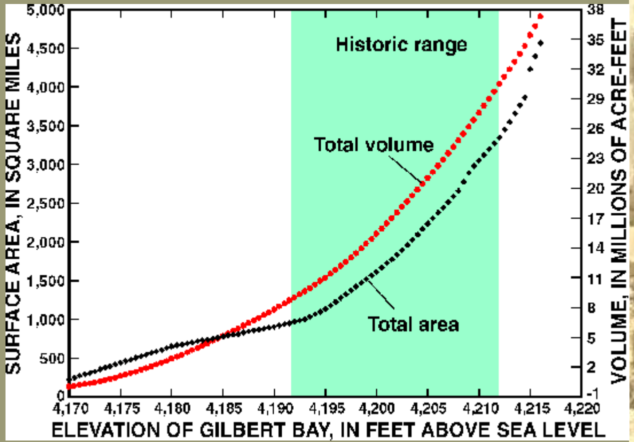
In 1986, the Lake reached a historic record elevation of **4,211.6 feet a.s.l.**

Since 1986, the Lake has lost water area every year, with a historic low level in 2021: **4,190.1 feet a.s.l.**

Using a hypsographic curve, volume and surface area can be estimated from surface elevation (below).

Using Google Earth Engine and R, the objective of this project is to demonstrate the relationship between **human population** and the **surface area of the Lake** over time.

Right: the hypsographic curve for the Great Salt Lake. (Utah Geologic Survey)
Far right: a true-color time series of the Great Salt Lake, 1986-2021.

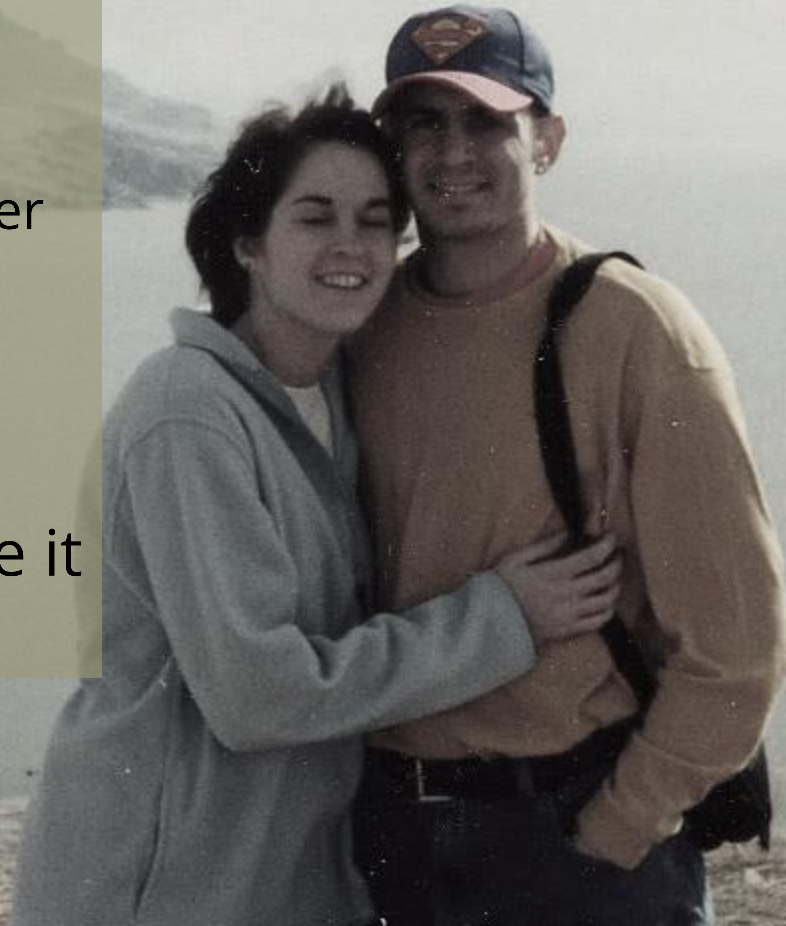


How can remote sensing help?

A hypsographic curve alone is not enough to determine the effects of shrinking water area.

- Where is the Lake shrinking?
- What habitats could this affect?
- Certain areas of lakebed are dustier than others, raising public health concerns.

By pinpointing areas more vulnerable to shrinkage, we can better protect the Lake and those it provides for.



My parents on **Antelope Island**, in the Great Salt Lake, 1999

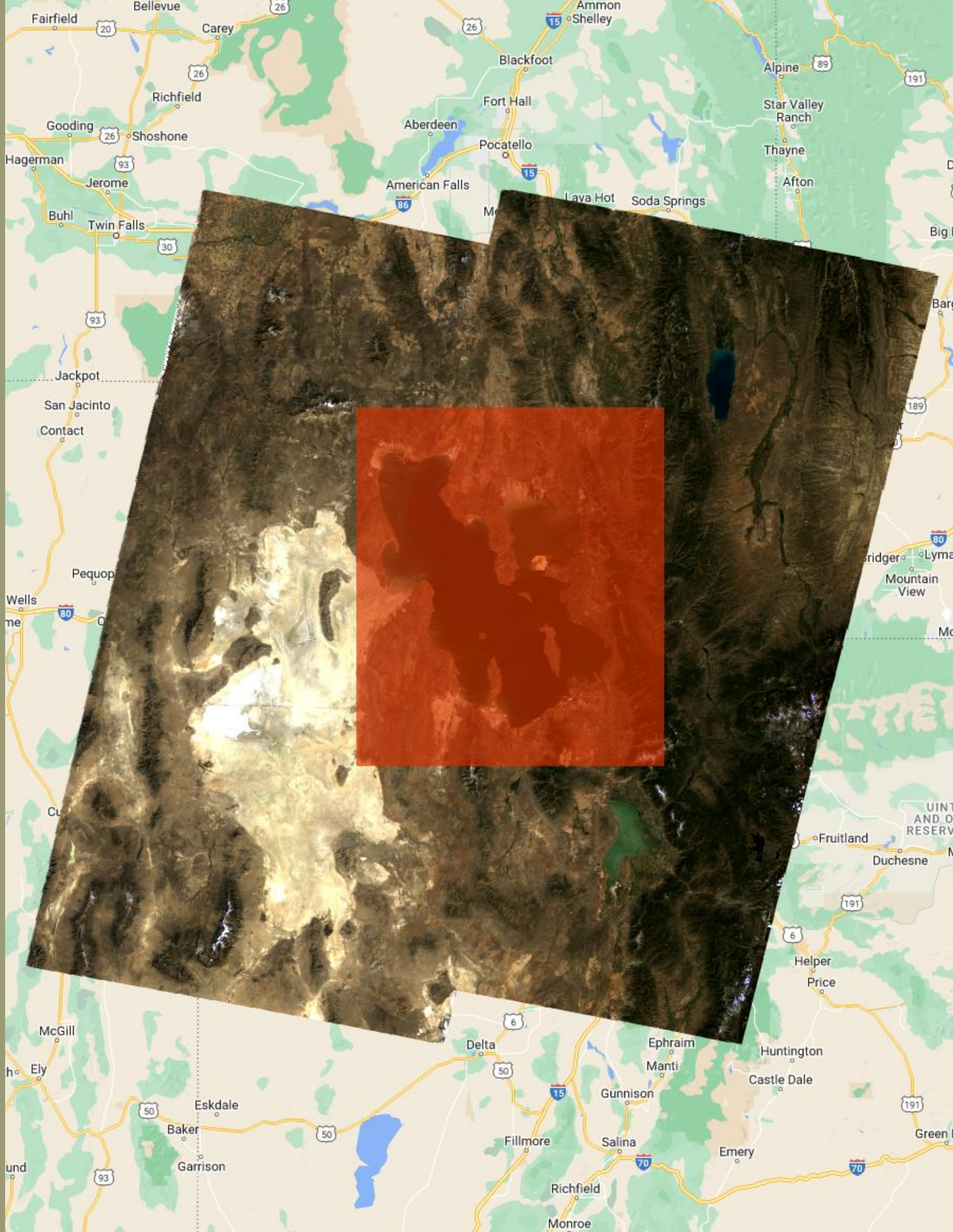
Data Sources

Since its historic high level in 1986, the Lake has been continuously monitored by Thematic Mapping (TM) sensors on Landsat 5, 7, and 8.

This means that I have access to **RGB, NIR, and SWIR** bands at a 30-meter spatial resolution for the Lake.

Since the Lake is an evaporative watershed, there is no surface flow output: thus, the lowest levels each year will occur when the baseflow of its input tributaries are lowest in autumn.

Imagery from Landsat 5, 7, and 8 was filtered for scenes with **less than 25% cloud cover** from July to November.



Right: Landsat scenes from 1986 are displayed under a red polygon delineating the region of interest.

Methodology (Earth Engine)

Median and Mosaic

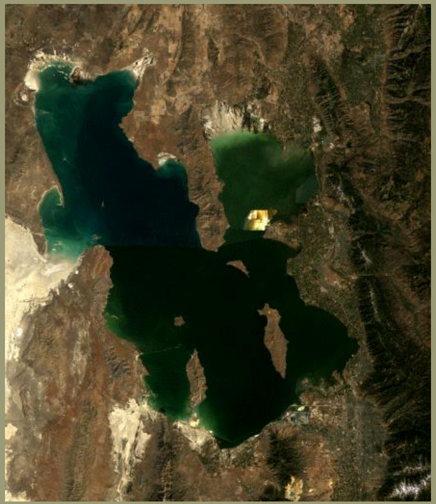
Since I requested Landsat data for several months, and Landsat has a 14- to 16-day recurrence interval, I had several images per year. I took the **median value** of these images for each pixel, then mosaiced the median values together to create a time series.

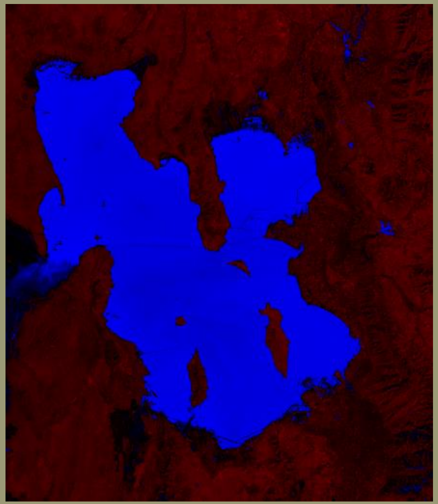
NDWI

I used the **Normalized Difference Water Index** for a water body, written as $\frac{green-NIR}{green+NIR}$, to monitor changes in water surface each year. Bluer areas in the animation below have higher NDWI values.

Threshold

I then used a threshold of $NDWI \geq 0.2$ to create a **binary image** showing areas where a pixel was likely to be water (shown in white below). I then used Earth Engine to calculate the area **within the historic maximum shoreline** of the Lake which was classified as water.





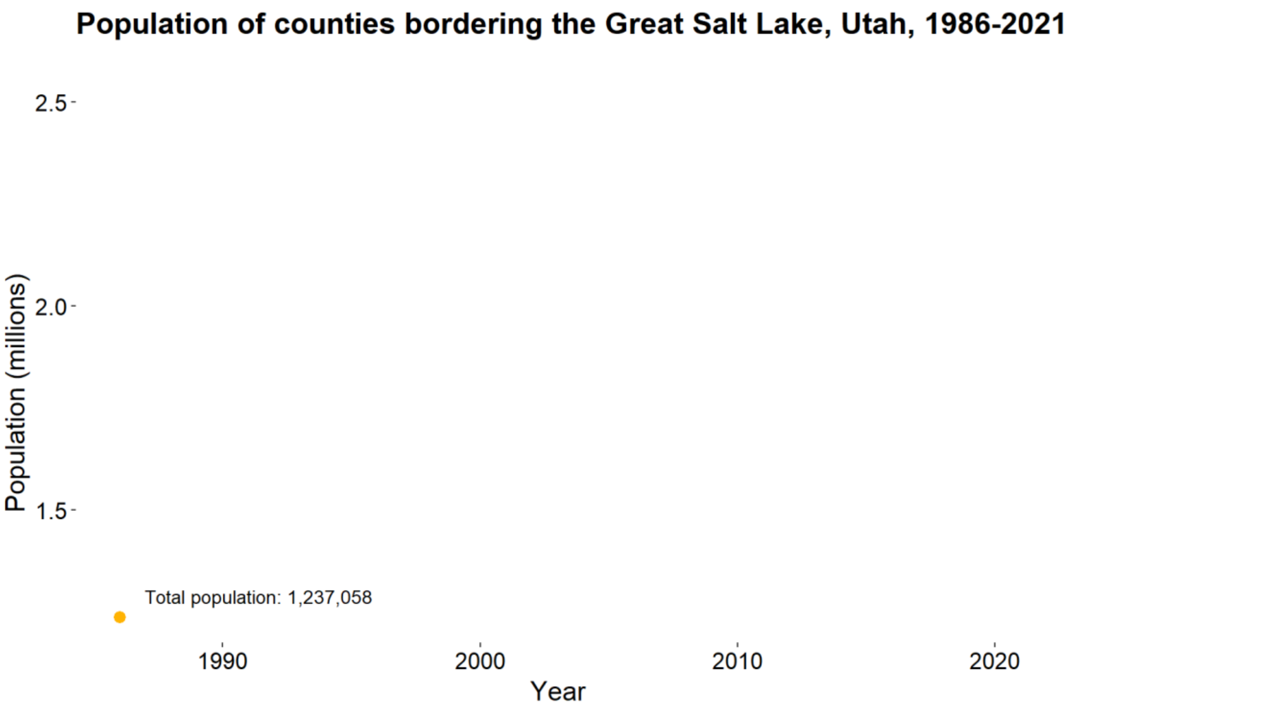
Methodology (R)

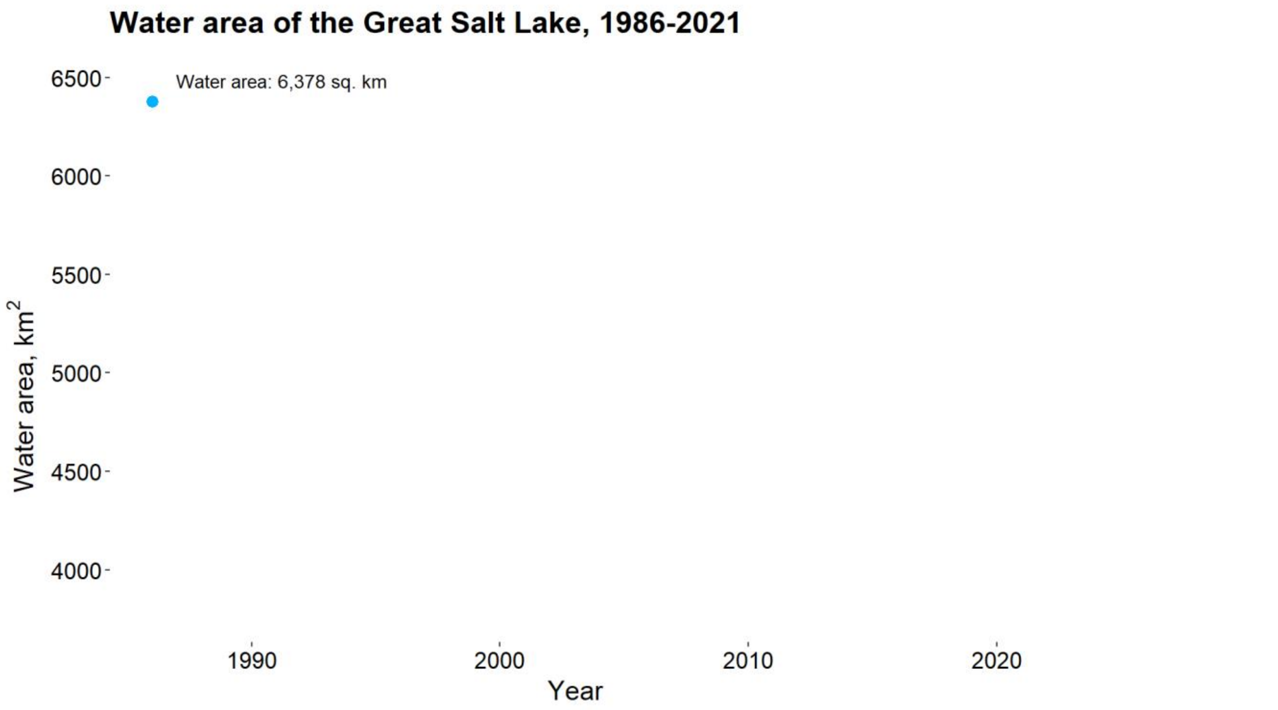
Using NHGIS IPUMS data, I collected population estimates for 1990-2020 normalized to 2010 census tracts. I performed a linear regression between decennial census years to estimate population from 1986-2009.

After 2009 I used the U.S. Census Bureau's ACS 5-year estimates to estimate population in the same counties.

Joining the data by year allowed me to create animated charts and investigate the relationship between population and surface area of the Lake.

Top: Animated chart showing the increase in population in counties bordering the Lake from 1986 to 2021.
Bottom: Animated chart showing the decrease in water surface of the Lake from 1986 to 2021.





Results

There is a significant ($p < 0.001$) negative correlation between the water surface of the Great Salt Lake and the total population of the counties bordering it.

With an **R^2 value of 0.7832**, this regression model is a reasonably good fit for our data, at least since 1986.

This relationship makes sense: in 2015, Utah ranked second in per-capita domestic water usage, according to the USGS. Since the saline Lake water isn't usable for domestic purposes, the water used must have been drawn from its tributaries.

Top: Summary statistics for the regression model.
Middle: Graph relating population to water area.
Bottom: The states with the highest domestic water usage, per capita (USGS).

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Residual standard error: 322.5 on 32 degrees of freedom
Multiple R-squared:  0.7832,    Adjusted R-squared:  0.7764
F-statistic: 115.6 on 1 and 32 DF,  p-value: 3.731e-12
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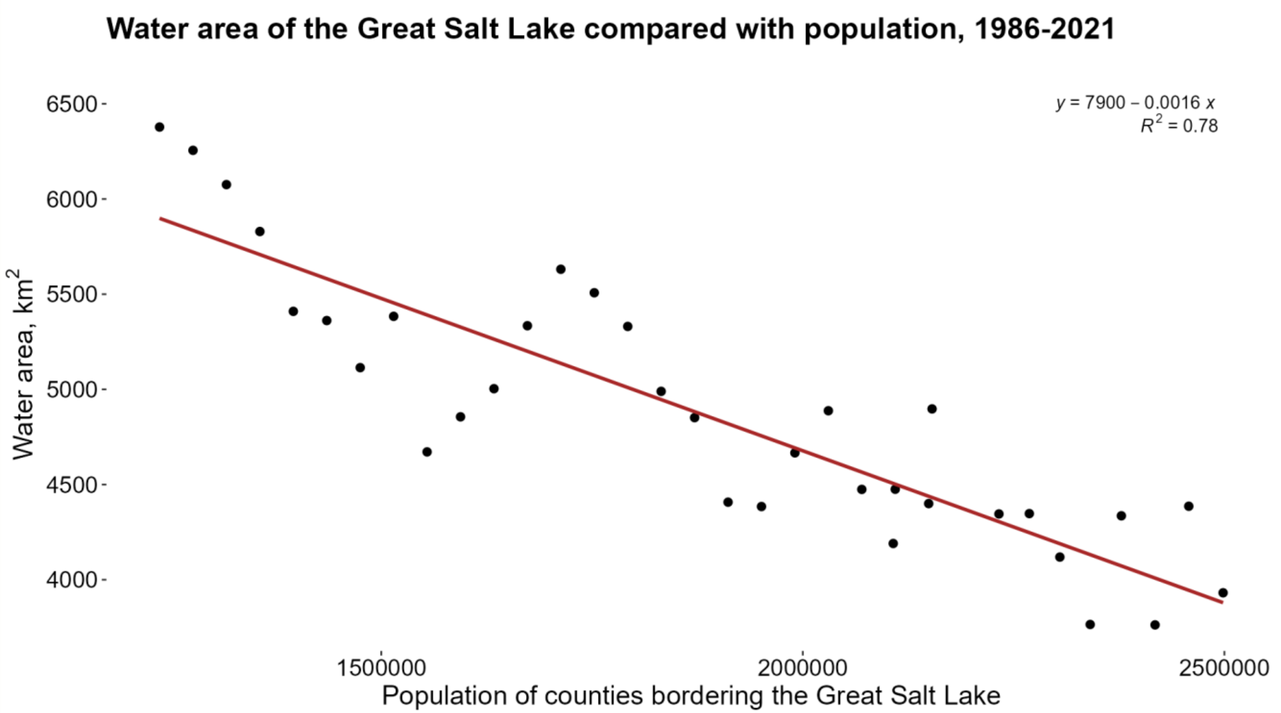


Rank	State	Population (2015)	Domestic per capita water use (gal/day)
1	Idaho	1,650,000	184
2	**Utah**	**3,000,000**	**169**
3	Wyoming	586,000	156
4	Arizona	2,980,000	145
5	Hawaii	1,430,000	144

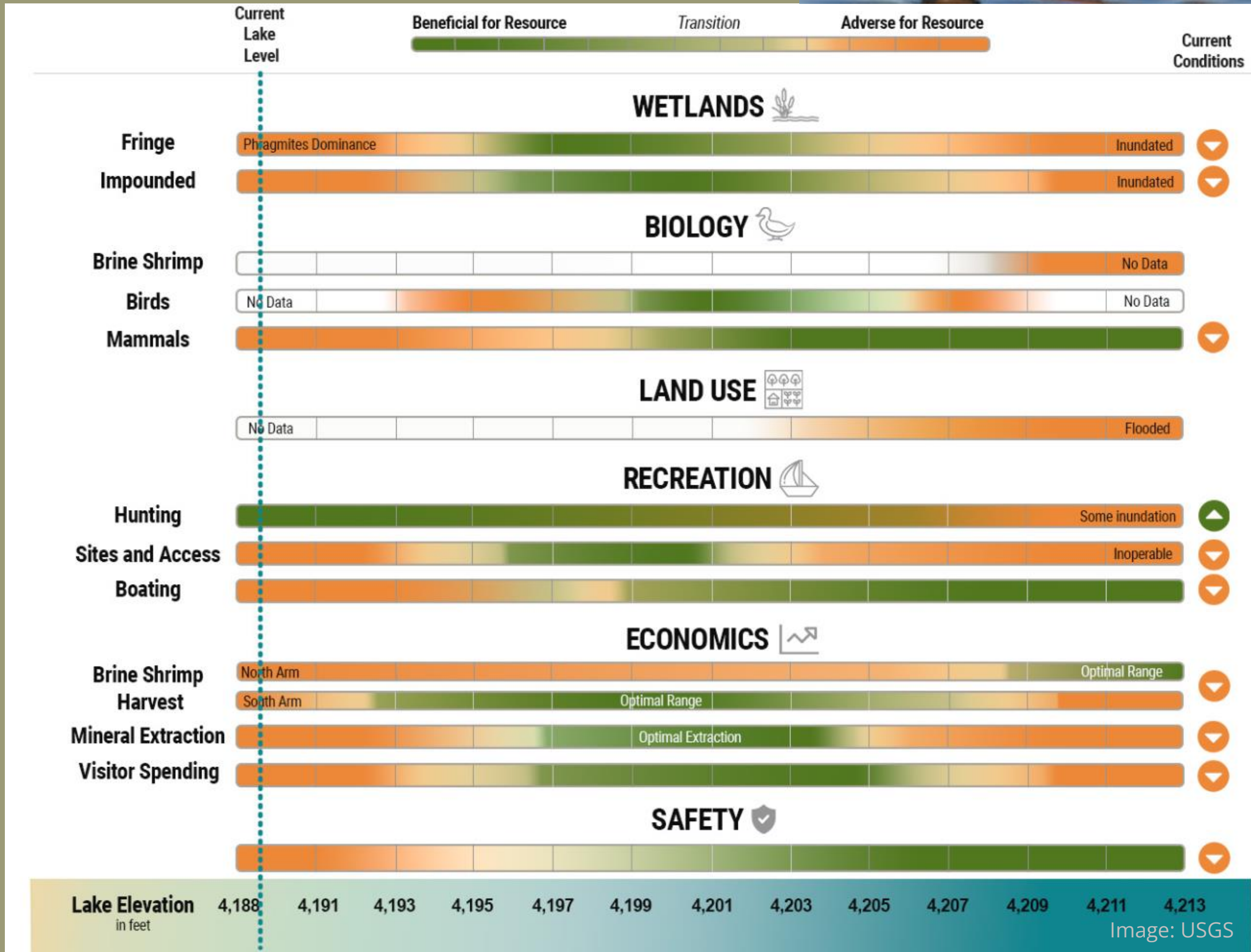
Conclusions

As the level of the lake decreases due to lower input volumes, multiple issues arise including increased salinity, altered habitat functionality, and raised public health concerns.

As water volume decreases but salt amounts remain constant, the **effective salinity of the water increases**. This means that the abundance of species which tolerate a narrow range of salinity levels will decrease, leading to ripple effects throughout the **trophic hierarchy**, and affecting larger species such as the California gull (*L. californicus*) and the eared grebe (*P. nigricollis*) (Roberts, 2013).

Right: Eared grebe (*P. nigricollis*) in the Great Salt Lake.

Below: Figure showing the effect of water surface levels on various ecosystem functionalities of the Great Salt Lake.



Conclusions (continued)

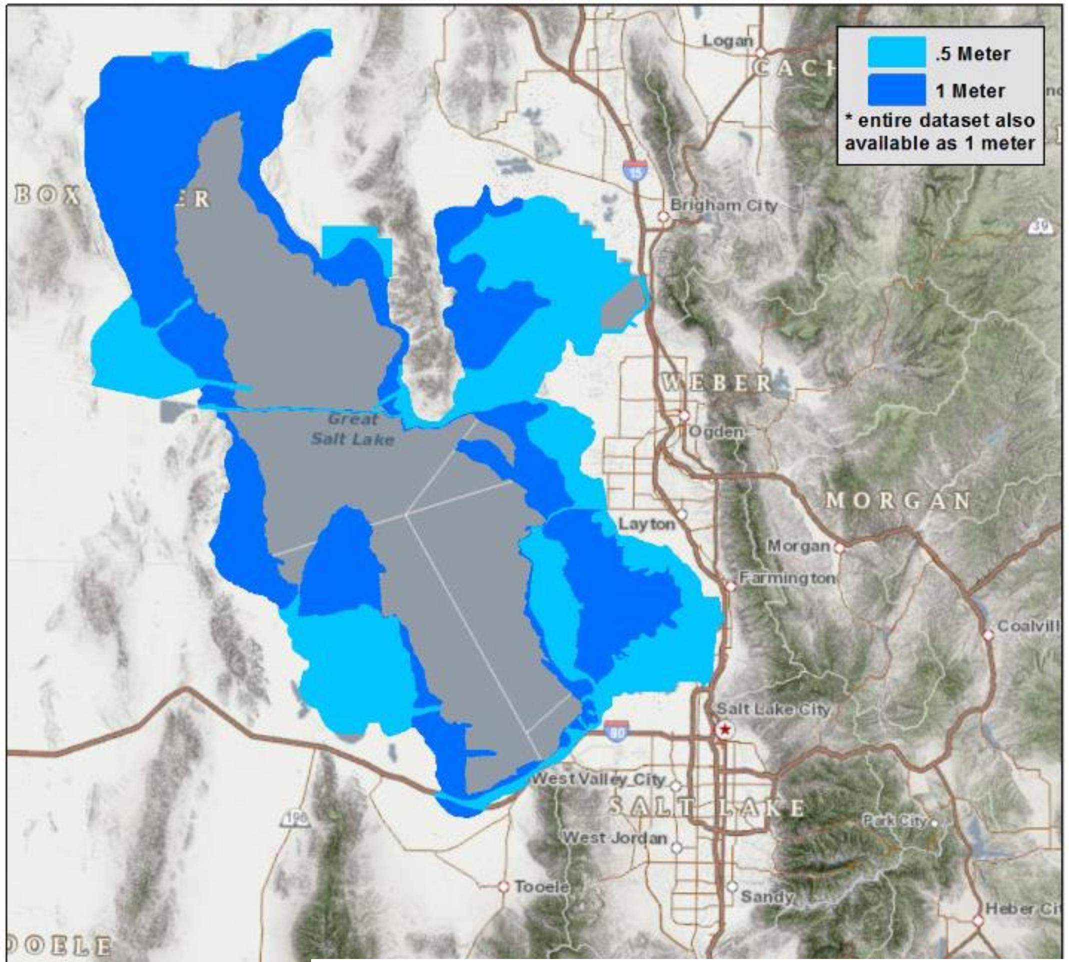
The Great Salt Lake is, on average, **14 feet deep**, with wide, flat plains near shorelines. As the elevation of the water surface and the water surface area decrease, new playa is created.

Playa is dry lakebed which was once submerged, and thus has different soil characteristics from land around it. According to Perry, Crosman, and Hoch (2019), there are dust hotspots throughout the four bays of the Lake which are likely to pose public health concerns as the lake level drops further. Loose particulate matter, which was trapped by the water, will be loose and create **dust storms**, posing a respiratory hazard.

Since different areas of the lake have different bathymetry, it's important to know where these hotspots will appear first to attempt to mitigate them.

Right: From Perry, Crosman, and Hoch (2019), the areas shown in blue have elevation data available and are not submerged (and are likely to contain dust storm hotspots). Table 5.2 shows elevations at which a given percentage of hotspots are submerged.

Great Salt Lake & Utah Lake LiDAR 2016



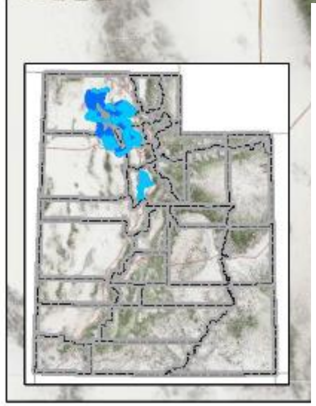


Table 5.2 Summary of GSL Elevation Impact on Dust Mitigation.

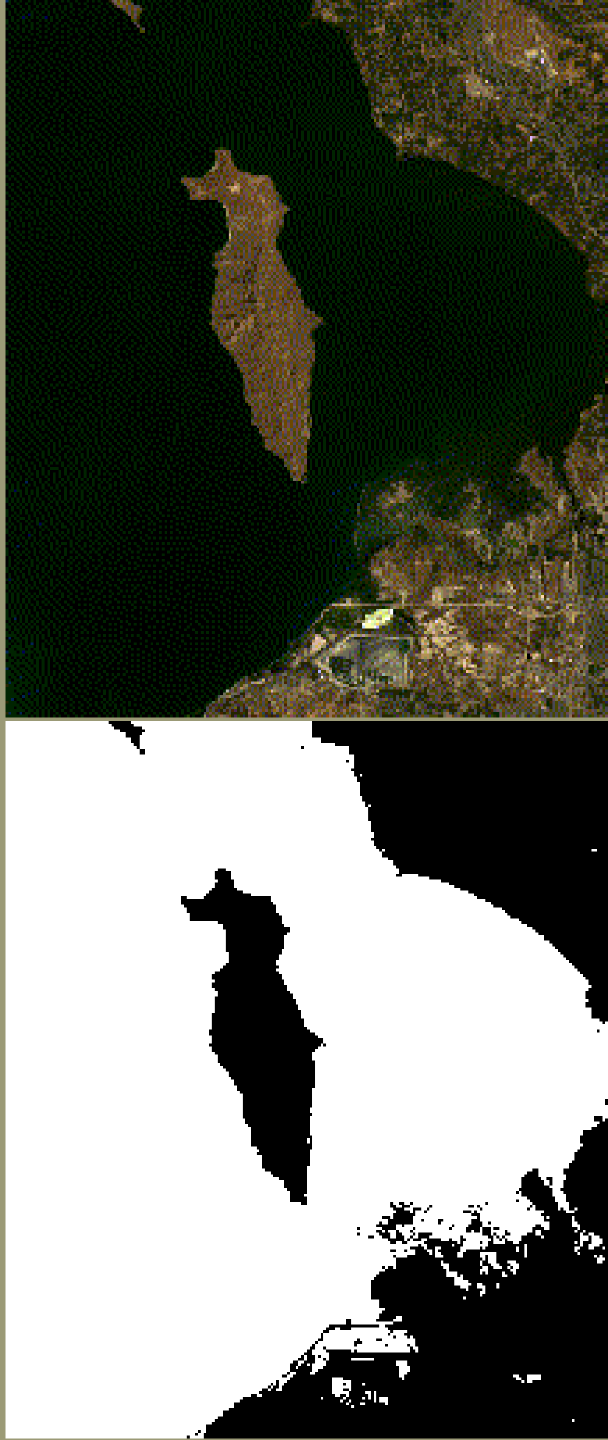
Quadrant	50% Mitigation Lake Level (feet)	80% Mitigation Lake Level (feet)	Slope (%/foot)
Farmington Bay	4198.3	4200.6	13.8
Bear River Bay	4204.2	4206.3	12.8
Gilbert Bay	4200.6	4202.8	11.7
Gunnison Bay	4201.2	4206.2	7.3

Final Conclusions

Decreasing water levels in the Great Salt Lake are caused by myriad factors: a warming climate, increasing domestic usage, and persistent drought all contribute.

The loss of water surface area poses a risk to nearly every function the lake provides to humans, animals, and local environmental processes — habitat is lost, trophic hierarchies are disrupted, and new public health concerns arise as the water level drops further.

The relationship between population and surface area of the lake is striking: without remotely sensed data, it would be nearly impossible to comprehend the danger posed by a continued loss of water from the Lake.



Right: a true-color (top) and NDWI threshold (bottom) time series of Antelope Island, in the southeastern section of the Lake.