GIST 58 Final Project
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# The Shrinking of the Great Salt Lake, 1985–2022

## I. Introduction

The Great Salt Lake in northern Utah is one of the most saline inland bodies of water in the world. With no outflow to any other body of water, this terminal basin for the Bear, Weber, and Jordan rivers is the eighth-largest endorheic basin in the world and the largest inland body of salt water in the Western Hemisphere. However, the lake has been shrinking at an alarming rate. A report written by researchers from several academic and environmental institutions and issued by Brigham Young University in January 2023 says that the lake is on track to disappear in five years.

This exploratory study uses images from Landsat satellites 5 and 9 to investigate the shrinking of the Great Salt Lake between 1985 and 2022. The study uses visual inspection and supervised classification to show the change in the extent of lake surface and the concomitant growth in the dry lake bed. The study also highlights urban development and the resultant loss of natural vegetation.

## II. Background

The Great Salt Lake is significant ecologically, culturally, and economically. Ecologically, it supports almost 350 migratory bird species, protects air quality, and moderates the local weather. Culturally, it is important to Utah's large Mormon population, who settled in the area around the lake in the 1840s, seeing it as a promised land. Economically, the lake creates around 9,000 jobs locally in mineral extraction, recreation, and brine shrimp harvesting, and supports another 20,000 jobs in the ski industry as snowfall in nearby mountains depends on lake evaporation.

Despite its environmental, human, and economic importance, the lake is in imminent danger of disappearing. About 2.1 million acre feet (MAF), or 684.60 billion gallons, of water per year are diverted for agriculture and urban supply from the rivers that feed the lake. Consequently, the lake faces a shortfall of 1.2 million acre feet, or 391.20 billion gallons, of water each year. With streamflow in the tributary rivers decreasing due to climate change induced drought, this problem will get only worse in the coming years, accelerating the lake's shrinkage.

The history of other now-dry endorheic lakes provides a preview of what is in store. The best known of these vanished lakes is the former Aral Sea. Once the fourth-largest inland saline lake in the world, the Aral has become desertified, leading to ecosystem collapse. Pollutants that had been safely underwater have become airborne, leading to a high rate of cancer and respiratory diseases. Salt deposition has led to water shortages and crop destruction. The livelihood and cultural identity of those living in the Aral basin have been destroyed. A similar fate is foreseeable unless immediate mitigation measures are taken to replenish the Great Salt Lake.

## III. Methodology

I began by researching years of high and low rainfall in the Great Salt Lake basin, and the historic fluctuations in the lake's extent. The lake was at a historic high in the mid-1980s, because 1984 and 1987 were both exceptionally rainy. Based on that research, I chose 1985 as the terminus a quo for this study. Initially I thought I would choose the current year as the terminus ad quem. However, when I began the analysis, I realized that satellite images from January or February are not suitable for a land cover study in Utah, since cloud and snow cover make image acquisition and analysis difficult. So I settled on 2022 as the concluding year. The lake was at an all-time low that summer.

The large extent of the Great Salt Lake meant that a single Landsat image was insufficient to cover the lake. Images covering a user-defined area of interest polygon (i.e., the entire lake) were mosaicked. This meant that images could not be chosen from just a single day. Instead, median pixel values of images from the period June 1–August 31 of 1985, and July 2022, had to be used to yield composites that had less than 5% cloud cover for the entire region. It is worth noting that the shorter period needed in 2022 for such cloud-free images itself is a warning signal about climate change.

I conducted a visual inspection of the images in true color, enhancing the gamma and stretching the images to about 98% of their min and max pixel values. This immediately showed the shrinking of the lake's surface area, but other features such as vegetation or urban areas did not stand out. I then inspected two sets of false-color images: one using near-infrared, red, and green bands, the other shortwave infrared, near-infrared, and green bands. These enhanced the contrast between land and water. They also helped identify healthy vegetation and urban features. Since Landsat 9 has the coastal aerosol band while Landsat 5 does not, care had to be exercised in choosing corresponding bands between the two images. Even among the corresponding bands, the spectral range is not exact. Table 1 shows a band comparison:

**Table 1: Landsat 5 Thematic Mapper and Landsat 9 Operational Land Imager Bands**

| Band | Landsat 5 TM Band Number | Landsat 5 Wavelength (µm) | Landsat 9 OLI Band Number | Landsat 9 Wavelength (µm) | Referred to in this study as |
|---|---|---|---|---|---|
| **Blue** | 1 | 0.45-0.52 | 2 | 0.45-0.51 | Blue |
| **Green** | 2 | 0.52-0.60 | 3 | 0.53-0.59 | Green |
| **Red** | 3 | 0.63-0.69 | 4 | 0.64-0.67 | Red |
| **Near Infrared 1** | 4 | 0.76-0.90 | 5 | 0.85-0.88 | NIR |
| **NIR 2 / Short-wave IR 1** | 5 | 1.55-1.75 | 6 | 1.57-1.65 | SWIR |

After the visual inspection, I chose several polygons in six feature classes to perform a supervised classification using a Random Forest Classifier. The classes were: (1) water (2) vegetation and agriculture (3) bare soil (4) dry lake bed (5) urban development (6) salt deposits and evaporation pans. Choosing polygons and running the classifier was iterated until good accuracy and kappa measures were reached. No pixels were left unclassified. Table 2 shows that over iterations, the classification reached a very high reliability. Further details such as the RF Consumer's and Producer's accuracies or the Error Matrix can be furnished if desired.

**Table 2: Final Accuracy and Kappa Metrics for the Supervised Classification**

| Year | RF Overall Accuracy | RF Kappa |
|---|---|---|
| **1985** | 0.976 | 0.955 |
| **2022** | 0.998 | 0.996 |

Finally, the land cover area for each feature class was calculated using the pixel count of the six feature classes in the RF classified image.

## IV. Results and Analysis

Table 3 shows that the Great Salt Lake has indeed shrunk greatly over the past four decades. During the same period, salt deposits leached from the ground by rainfall have also shrunk. Vegetated areas have decreased while urban settlements have increased. All figures are in $km^2$.

**Table 3: Change in Land Cover in the Great Salt Lake Basin, 1985–2022**

| Feature Class | 1985 | 2022 | Percent Change |
|---|---|---|---|
| **Water** | 5781 | 2535 | -56% |
| **Vegetation and Agriculture** | 2240 | 1017 | -55% |
| **Bare Soil** | 5778 | 6889 | 16% |
| **Dry Lake Bed** | 873 | 4079 | 79% |
| **Urban Development** | 986 | 1435 | 31% |
| **Salt Deposits or Pans** | 829 | 529 | -56% |

The urban growth of 31% over the last four decades reflects the fact that Salt Lake City is the seventh fastest-growing metro area in the country. The 2021 census showed that the metro population has grown to a record 1.2 million.

The following pages show the images used in the analysis.

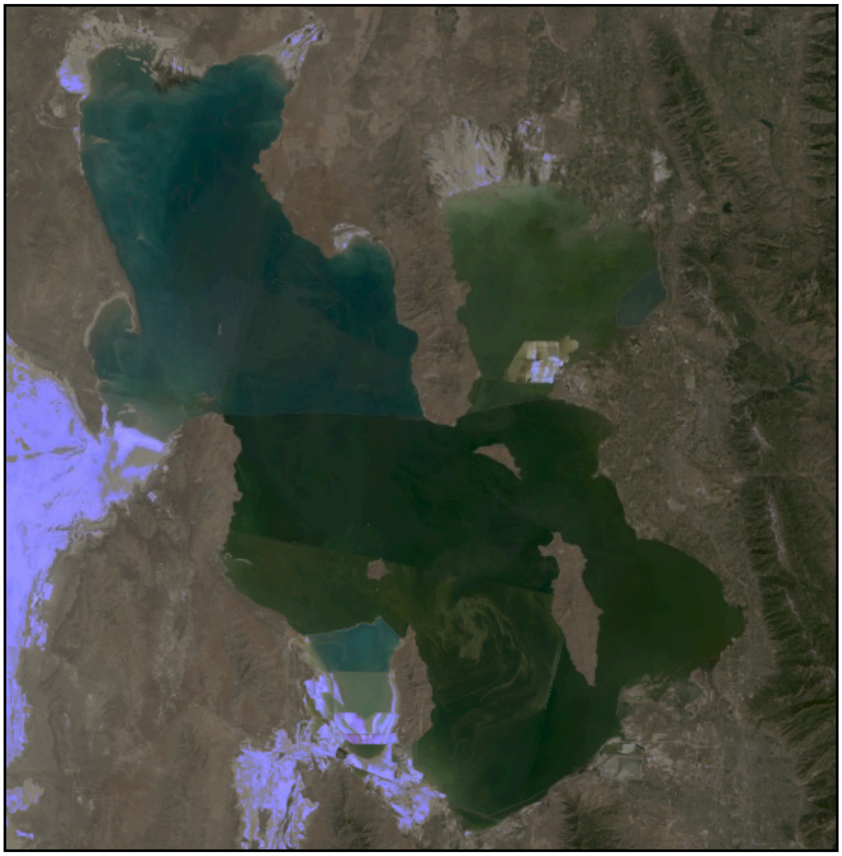


**Figure 1 (left). Top:** The Great Salt Lake and surroundings in 1985. The purple areas in the west are salt deposits caused by evaporated rainfall. The purple areas in the center right and the south show evaporation pans for potash, which have the same spectral signature as the salt deposits.

**Bottom**: The same area in 2022. A great extent of the dry lake bed is clearly visible around the water. The lake has long had different depths north and south of the Lucin Cutoff (a railroad causeway built in 1904), but the the brown appearance of the water above the Lucin Cutoff shows that water loss has rendered that portion considerably shallower. The salt deposits have shrunk, showing up as stark white due to lack of rainfall. The diagonal lines are mosaicking artifacts.

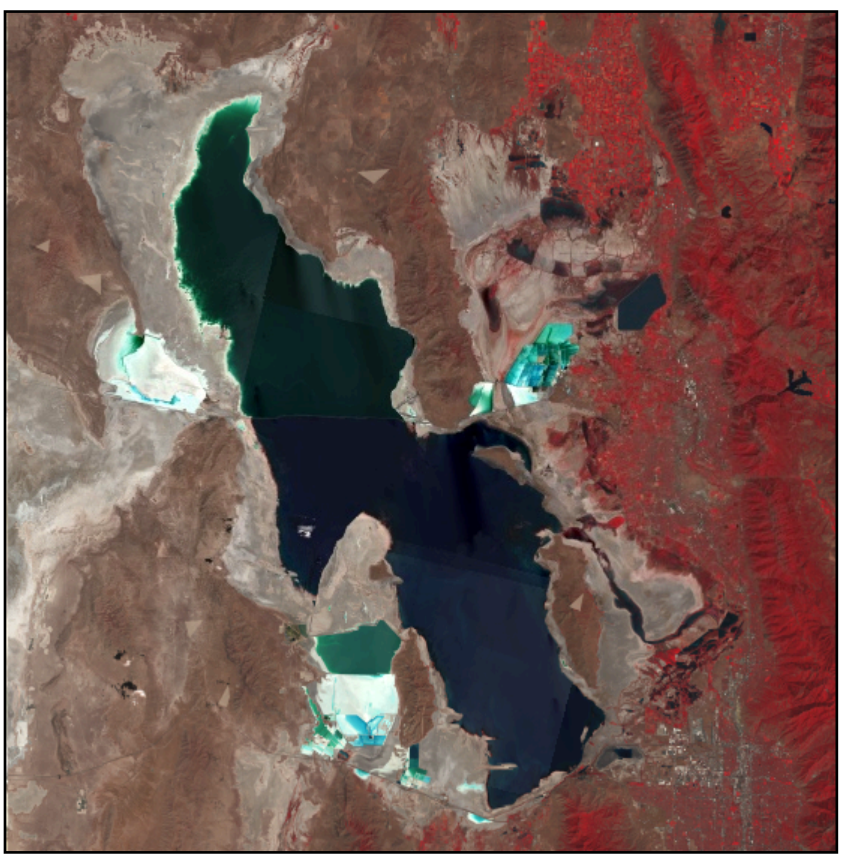


**Figure 2 (left). Top:** A false-color 1985 image showing the NIR, red, and green bands. The teal color differentiates the evaporation pans from the grayish-white salt deposits. Solid red indicates natural vegetation, whereas red specks interspersed with brown are agricultural land (northeast quadrant) or the lawns of metro Salt Lake City (east and south of the lake).

**Bottom:** a similar false-color image from 2022. The teal again shows the location of salt pans. The white areas show the surviving salt deposits. The large deposit extent to the east has become dry bed. Willard Bay Reservoir, not readily distinguishable from the lake in the 1985 image, is seen here as an isolated body of water, center right, just northeast of the salt pans.

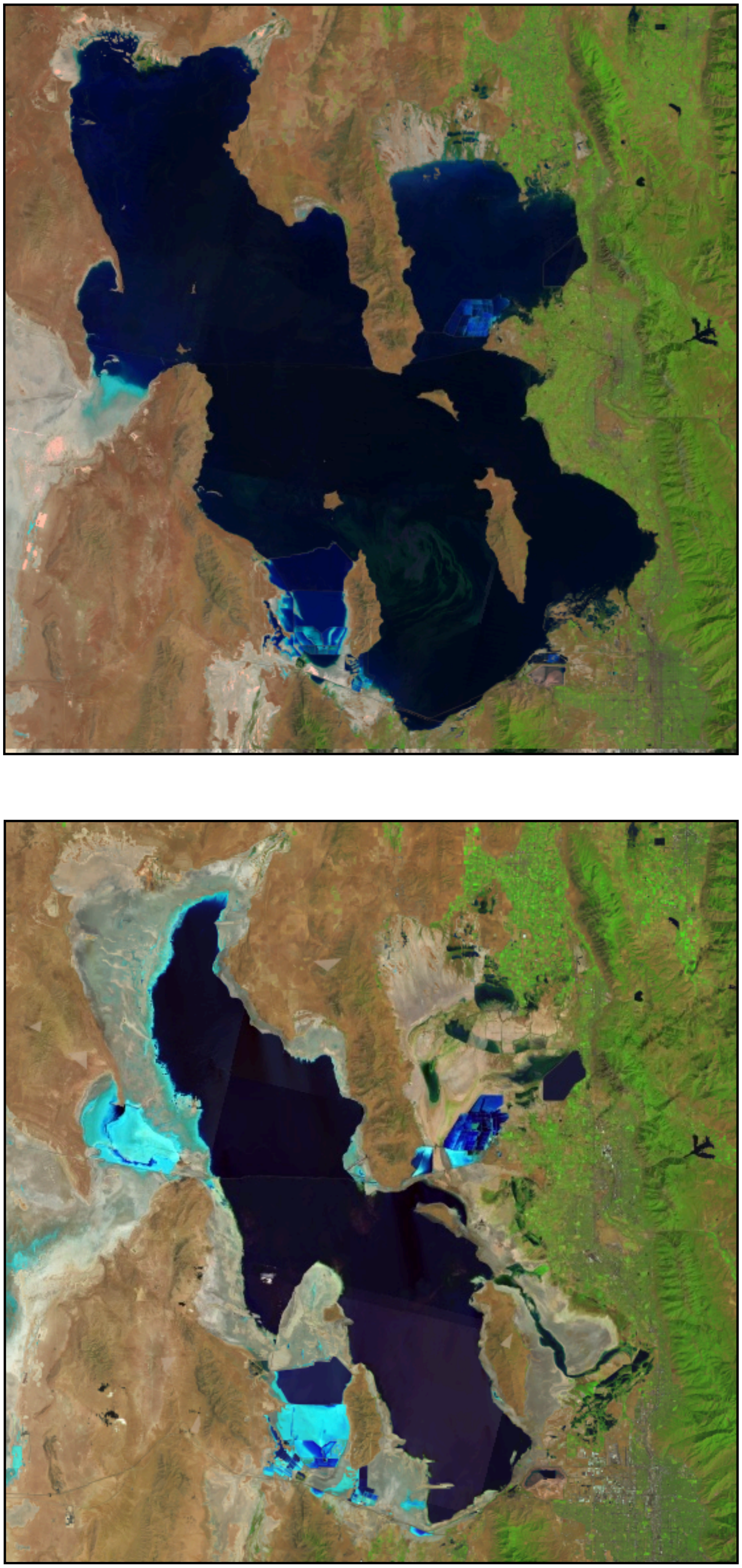


**Figure 3 (left). Top:** A false-color 1985 image using the SWIR, NIR, and green bands. Here too the salt pans, e.g., on the shore of the southwestern bay, are differentiated from the salt deposits in the west, though the RGB image (Figure 1) and classified image (Figure 4) do not make this difference visible.

**Bottom:** The corresponding image from 2022. The growth of Salt Lake City and environs is visible as grey-white squares or rectangles in a grid pattern to the east and southeast of the lake, with corresponding loss of natural vegetation shown by speckling in the vivid green compared to the 1985 image. This image also shows the Willard Bay reservoir distinct from the rest of the lake.

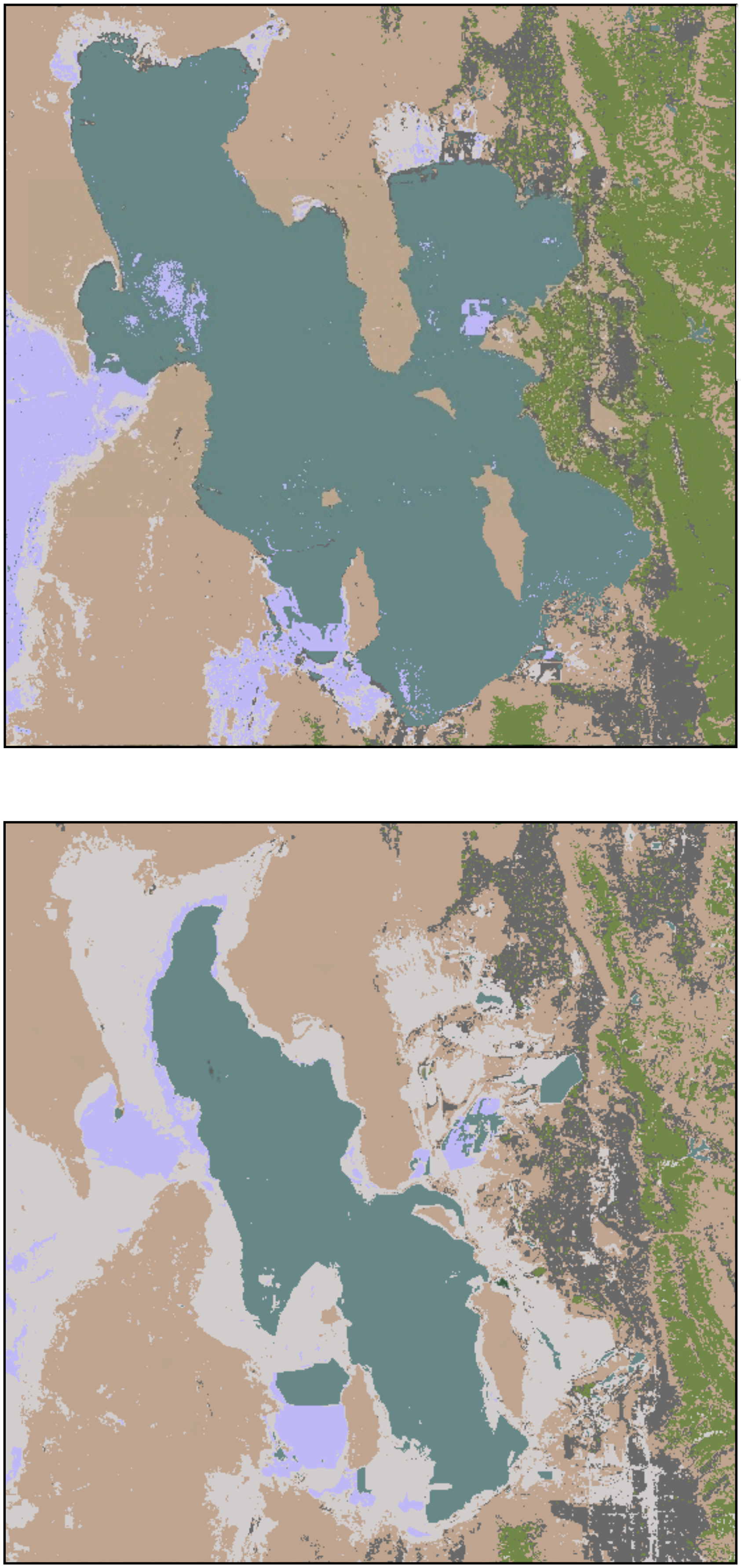



**Figure 4 (left). Top:** The RF classified image of the area in 1985. Salt deposits and evaporation pans are treated as a single class, as the classifier could not distinguish them accurately. A dense belt of vegetation is notable in the east.

**Bottom:** A similar image from 2022. The loss of lake surface area and salt deposits is clearly visible, as is the growth of the dry lake bed. To the east, the growth of urban features accompanies a concurrent loss of vegetation. The Willard Bay Reservoir is isolated from the rest of the lake.

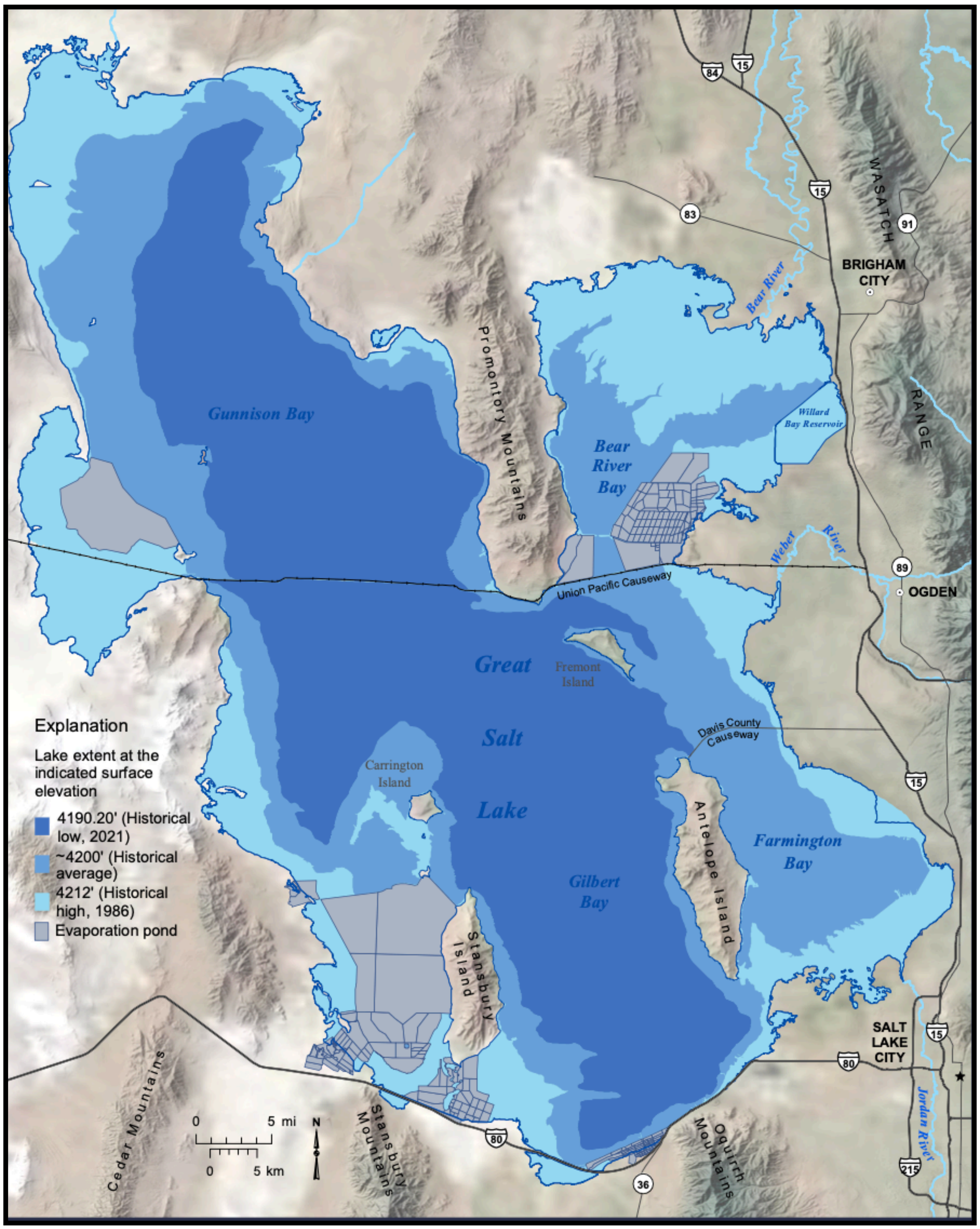
## VI. Conclusions

Both visual analysis of corresponding images from 1983 and 2022 across various bands, and supervised classification of land cover in the Great Salt Lake area, confirm the dire state of the lake. The calculation of lake extent loss done via the supervised classification (from 5781 $km^2$ to 2525 $km^2$, or 2232 $mi^2$ to 978 $mi^2$, a loss of 56%) is close to the 60% figure reported in the Brigham Young report mentioned above. The 4% discrepancy can be treated as part of this study's margin of error. This preliminary study has several limitations that contribute to error:

1. The classification treats *all* surface water as part of the lake, including the freshwater Willard Bay Reservoir, which was artificially separated from the lake in 1964. This certainly accounts for some of the 4% discrepancy.
2. Despite the high accuracy and kappa scores, the error matrix for the 1985 image shows that bare soil is not well distinguished from vegetation. About half the vegetation pixels are classified as bare soil. Attempts to reconfigure the vegetation polygons made the metrics worse. My hypothesis is that the nature of the vegetation in the desert hills means that many pixels in those areas do have the spectral signature of bare soil, and the chosen polygons cover not only the vegetation, but also the intervening bare soil.
3. As noted above, despite the spectral signature distinction between evaporation pans for potash manufacture and salt deposits that is visible very clearly in the false-color images, the classifier could not distinguish them. Ultimately the two classes were merged.
4. The mosaicking effect, visible most clearly in the true-color images, make visual interpretation and explanation difficult because of extraneous lines. For example, diagonal lines in the RGB 2022 photograph make it difficult to show the otherwise very clear separation between the water level north and south of the Lucin Causeway. It is possible that the mosaicking also affects the supervised classification by making correct assessment of pixel values difficult. But the high accuracy metrics cut against that possibility.

Within these limitations, this exploratory study is a useful confirmation of the dire predicament of the Great Salt Lake. Unless measures are urgently taken to curtail the water use that requires so much of the feeder stream water to be diverted, we are headed for another ecological, cultural, and economic disaster such as the one caused by the disappearance of the Aral Sea.

**Figure 5.** Areal extent and elevation of the Great Salt Lake at historical high, average, and historical low water levels. From Davis et al., 2022, p. 5.



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