Measuring Water Level Decline of the Great Salt Lake

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Abstract

The Great Salt Lake in Utah has slowly become lower and lower over the last few decades. This has had adverse effects on wildlife and will likely soon affect humans as well. This study used GIS software and remote sensing data to measure how mush area (in meters) the lake has lost between 09 July 1998 and 26 September 2021. Study results show that the lake lost between 1,436,483,700 and 1,540,779,300 square meters of water area in this time period. Due to multiple variables, this figure is not conclusive. However, it does give a reference of the scale of loss the lake has endured in recent times.

Utah is one of the arid states in the western United States of America. It is home to the worlds largest Mormon population and amazing geologic wonders, such as Arches National Park, Bryce Canyon (National Park), Zion (Canyon) National Park, and the Great Salt Lake. The Great Salt Lake is a large lake in northern Utah that is well known for its high salt content and immense size. Danial Bedford wrote in The Geographical Review that "[The lake] is a remnant of pluvial Lake Bonneville, a much larger, freshwater lake formed during a period of wetter conditions in the western United States around 25,000 B.P. The drying climate has left the present-day Great Salt Lake as essentially a giant puddle occupying a depression in the Salt Lake Valley just to the west of the Wasatch Mountains" (para. 3). The lake is a terminal lake, which means that streams and rivers only flow into the lake; none flow out. The Aral Sea on the Kazakhstan/Uzbekistan border and the Dead Sea on the Jordan/Israel/West Bank border are also terminal lakes. Both the Dead Sea and the Great Salt Lake are famous for their high salt content. Since the Great Salt Lake has no outflows, the only way for water to leave is by evaporation. This process leaves large beds (or "flats") of salt on the ground.

The Aral Sea and the Great Salt Lake were both historically huge inland bodies of water that local people used for farming and living purposes. According to Kacey Deamer of Live Science, "After the Great Lakes, Utah's Great Salt Lake is the largest body of water (by area) in the United States" (para. 2). In 1986 the lake became even bigger. It began to flood and rose to 4,211.6 feet above sea level, its highest level since 1873 (Peterson para. 10). Former New York Times reporter Iver Peterson wrote that the Weather Service attributed the extreme rise to "unusually heavy winter snowfalls in the mountains surrounding the lake and to cool and overcast summers that have prevented the normal warm-weather evaporation. The lake has no outflow, so evaporation is the only way for it to lose water" (para. 11). Because of the damage the flood caused to cities and towns nearby, the excess water was pumped into the desert, which created the Newfoundland Evaporation Basin.

Unfortunately, like the Aral Sea, the water level of the Great Salt Lake has been slowly declining in recent years. Ray Boren of the Universities Space Research Association wrote, “[The] Great Salt Lake is out of balance and shrinking in size and storage. This is due in part to climate change but more particularly, hydrologists and other researchers say, because of human damming and upstream diversion of its water sources for agriculture and urban uses” (para. 1). Human activity is one of the major reasons for the drop in lake water level. This decrease has had negative effects on all wildlife that live in and around the lake. Microbialites are coral-like structures built by cyanobacteria, organisms that live in the shallows of the lake in the microbialites. Microbialites must stay wet for the cyanobacteria to live. Cyanobacteria photosynthesize and produce algae mats. According to Lauren Leffer from the National Audubon Society:

> Invertebrates feed on the algae and birds, in turn, feed on the invertebrates, making microbialites critical to the lake’s food web. Great Salt Lake hit its lowest recorded water level ever this month, leaving many microbialiates out of the water. Exposed to the air and allowed to dry out, the algal mats die back, and lifeless, yellowing mineral skeletons are all that remain. (paras. 3 and 4)

Without these microbialites and Cyanobacteria, the food chain of the lake begins to break down. Conservation efforts have worked to preserve wildlife habitats, but there is no telling how low the lake will get in future years.

Objective

The objective of this study was to find how and where the water level of the Great Salt Lake has changed over 23 years by comparing images of the Great Salt Lake. This study only regards the lake proper and the deeper water bodies around the lake, and excludes shallow parts of the lake and other shallow water bodies around the lake.

Data

- One (1) Landsat 5 TM Tier 1 (Level-1 Precision Terrain) raster (.tif) image of the Great Salt Lake (path 39/row 31) from *09 July 1998*. Acquired *24 November 2021* from USGS EarthExplorer. Cloud cover 1.00, spatial resolution 30 meters, UTM zone 12, WGS84 datum and ellipsoid. See Figure 1.

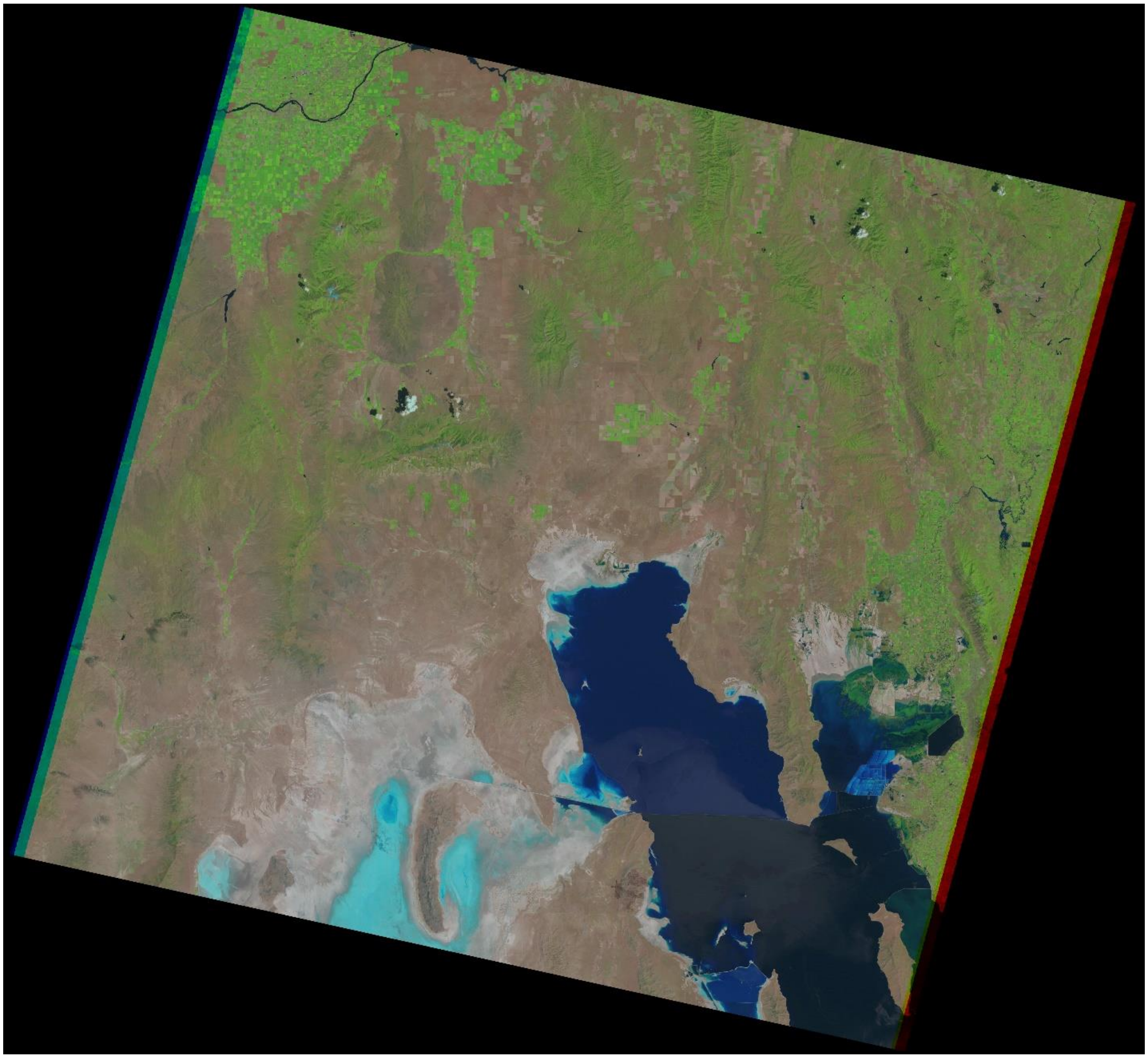

Figure 1. 26 September 2021image of the Great Salt Lake (EarthExplorer).

- One (1) Landsat 8 combined (OLI and TIRS data) Tier 1 (Level-1 Precision Terrain) raster (.tif) image of the Great Salt Lake (path 39/row 31) from *26 September 2021*. Acquired *24 November 2021* from USGS EarthExplorer. Cloud cover 4.96, spatial resolution 30 meters, UTM zone 12, WGS84 datum and ellipsoid. See Figure 2.

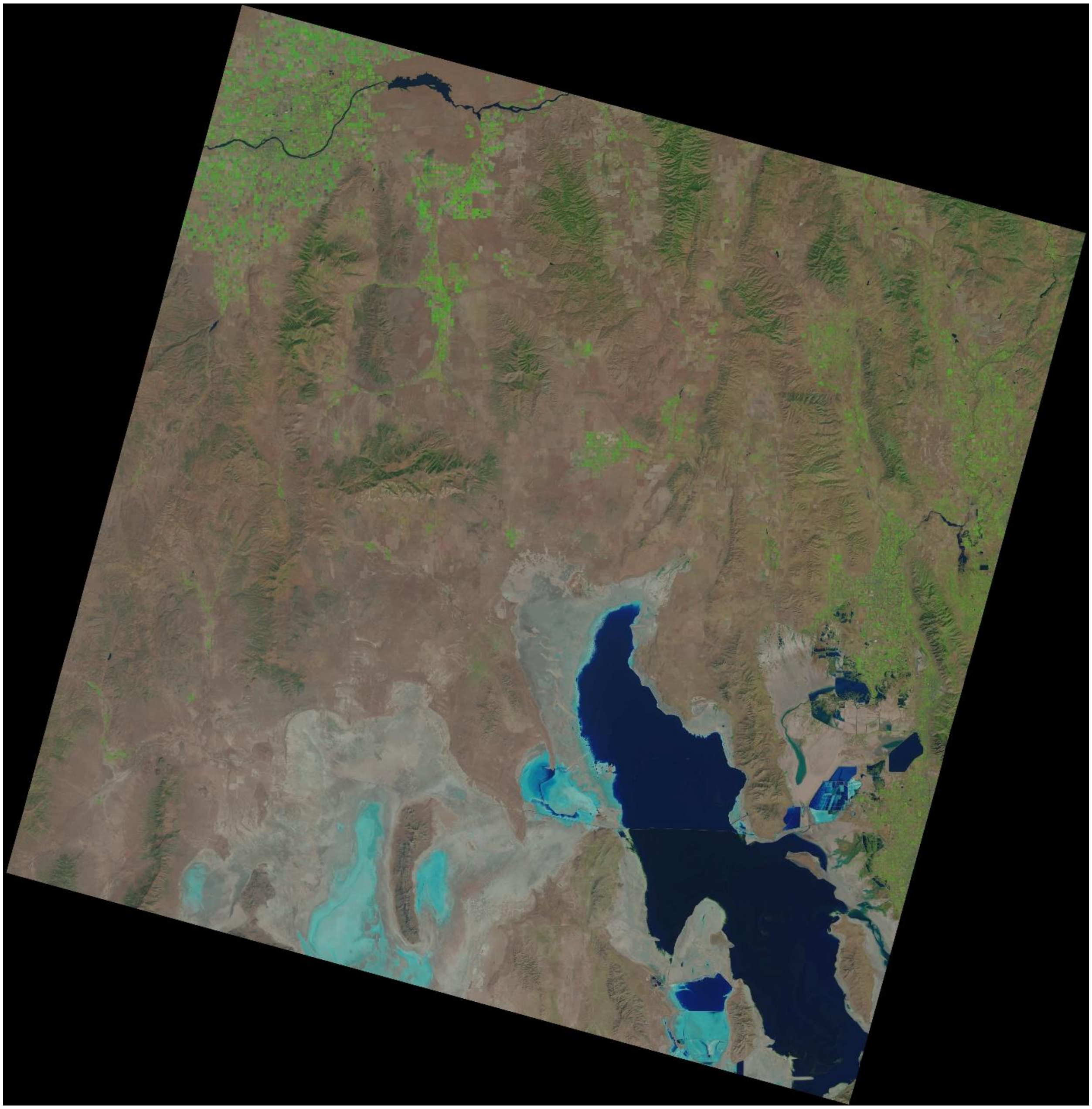

Figure 2. 26 September 2021 image of the Great Salt Lake (EarthExplorer).

Methods

1. After choosing to study the water level change of the Great Salt Lake, download a 2021 Landsat 8 and a 1998 Landsat 5 image of the lake from the USGS EarthExplorer website. Downloaded the images and load them onto QGIS Desktop.

2. Created a vector mask layer that encompass the bottom right corner of the image (which is the area containing the lake) and clip the Landsat images to the layer. Removed the mask and full-sized images, leaving only the clipped images.
3. The 1998 Landsat 5 image is a little darker than the 2021 image, so brighten it to make them about the same brightness.
4. Classified Training: Use the SCP plugin on QGIS to classified the 1998 image. Create a new training input and create five classes: water, shallow water, dry lakebed, dry soil, and cropland. Use eight training data polygons for each class. Run the classification program.
5. Next, again use the SCP plugin on QGIS to classify the 2021 image. Create a new training input and gave it the same five classes as the 1998 classification. Again use eight training data polygons for each class. Run the classification program.
6. Use the SCP plugin to perform a land cover change analysis. Enter in the proper information and run the program.

Results

Classification—1998:

The 1998 image came out fairly well. Not perfect, for it classified some areas of dry soil as cropland, and classified cities and a mountain as dry lakebed. It classified the deeper water very well, but because of spectral similarities between shallow water and some areas of dry lakebed, it classified some dry lakebed as shallow water. There were a couple areas where deeper water was classed as shallow and vice versa. Other than those, it came out well. Figure 3 shows the True Color image next to the classified image, and Table 1 shows the classification report for the 1998 image classification.

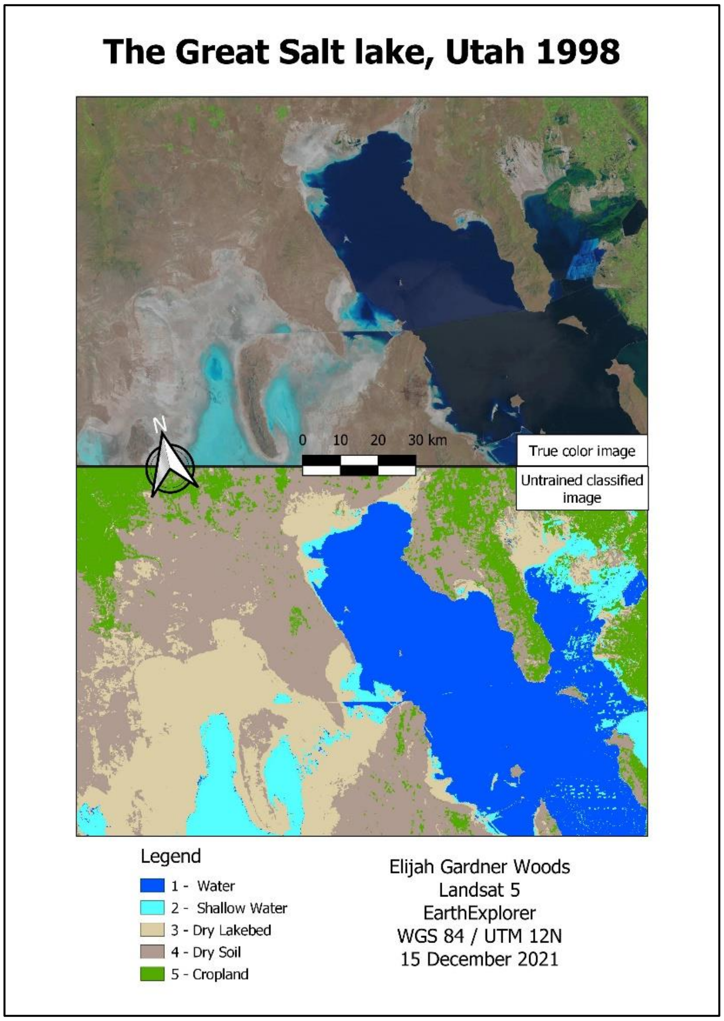

Figure 3, Great Salt Lake 1998 classification.

Class	Pixel Sum	Percentage %	Area [metre^2]
1 Water	4301260	25.59926238586297	3871134000
2 Shallow water	1289727	7.675904241810978	1160754300
3 Dry lakebed	3521758	20.959999419126486	3169582200
4 Dry soil	5182166	30.84203864939528	4663949400
5 Cropland	2507370	14.922795303804287	2256633000

Table 1, 1998 image classification report.

<u>Classification—2021</u>:

The 2021 image also came out fairly well. It also was not perfect, for it classified a few areas of cropland as dry soil, some mountainous regions as dry lakebed, and a couple shadowy mountain tops and the bridge across the lake as shallow water. It classified the deeper water very well, but because of spectral similarities between shallow water and some areas of dry lakebed, it classified some dry lakebed as shallow water. Figure 4 shows the True Color image next to the classified image, and Table 2 shows the classification report for the 2021 image classification.

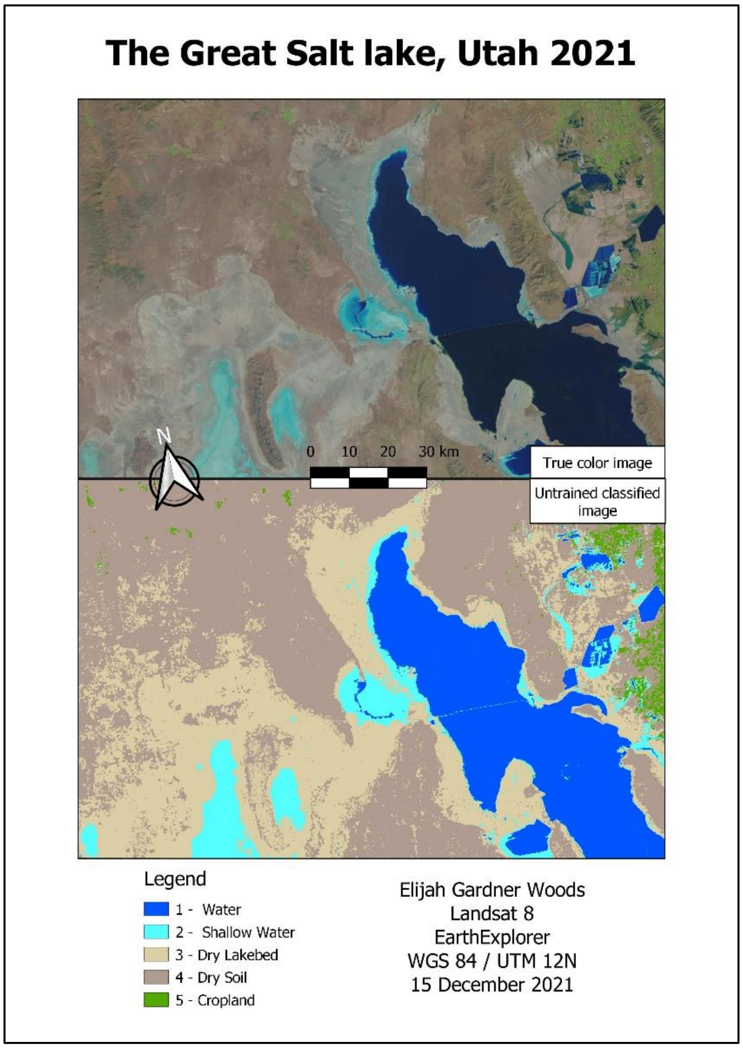

Figure 4, Great Salt Lake 2021 classification.

Class	Pixel Sum	Percentage %	Area [metre^2]
1 Water	2705167	16.099998565670933	2434650300
2 Shallow water	1047625	6.235016543289569	942862500
3 Dry lakebed	5044591	30.023251009788492	4540131900
4 Dry soil	7590417	45.17492000044518	6831375300
5 Cropland	414481	2.466813880805826	373032900

Table 2, 2021 image classification report.

<u>Land Cover Change Report</u>

Figure 5 shows the land cover change image and Table 3 shows the land cover change report for the 1998 and 2021 images of the Great Salt Lake. At the top and middle of the table, the Reference Class is the class (0 the black areas around image, 1 water, 2 shallow water, 3 dry lakebed, 4 dry soil, 5 cropland) that a region was classified as in the 1998 image. The New Classes show where the regions were classified in the 2021 image. Cross Class Code is the number assigned to the regions. Pixel Sum is how many pixels the table is referring to in each row, and Area is the size of the area in square meters.

At the bottom of the table under "LAND COVER CHANGE MATRIX", the V_Reference Class is the class (0 the black areas around image, 1 water, 2 shallow water, 3 dry lakebed, 4 dry soil, 5 cropland) that a region was classified as in the 1998 image. New Class show where the regions were classified in the 2021 image.

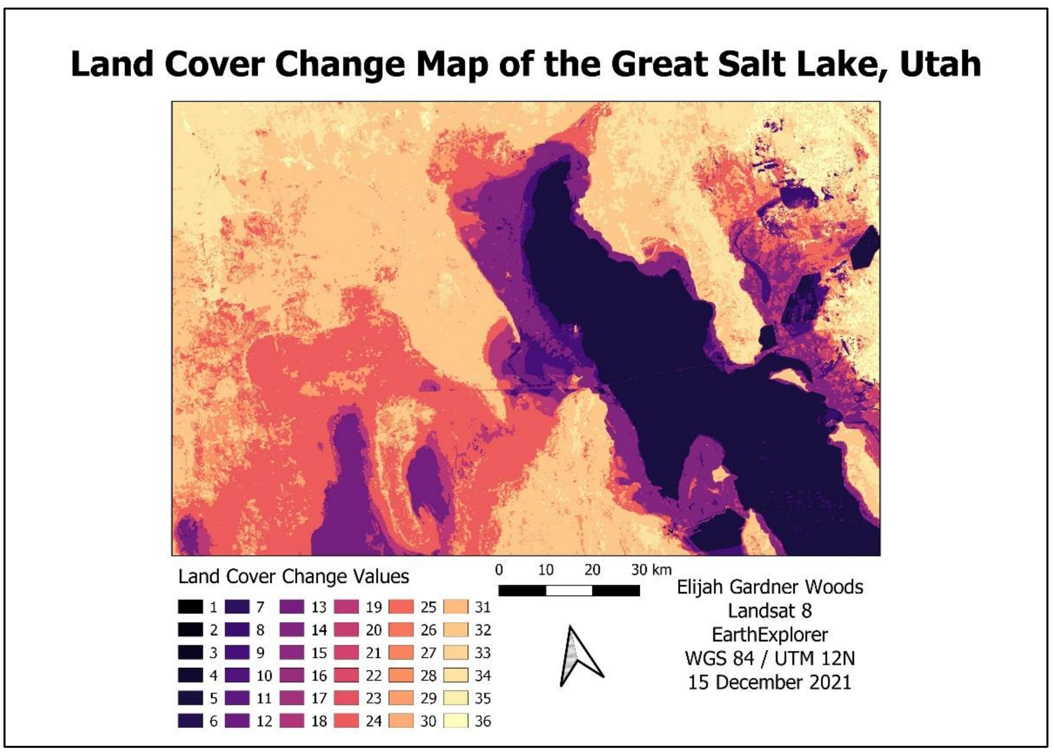

Figure 5, land cover change image.

CrossClassCoc	NewClass	ReferenceClass	PixelSum	Area [metre^2]
1	0	0	7958933	7163039700
5	1	1	2589283	2330354700
8	1	2	102557	92301300
12	1	3	7213	6491700
17	1	4	1113	1001700
22	1	5	5001	4500900
9	2	1	361658	325492200
13	2	2	578802	520921800
18	2	3	83666	75299400
23	2	4	5520	4968000
27	2	5	17979	16181100
14	3	1	1175851	1058265900
19	3	2	456894	411204600
24	3	3	2743671	2469303900
28	3	4	613720	552348000
31	3	5	54455	49009500
20	4	1	161443	145298700
25	4	2	136489	122840100
29	4	3	676488	608839200
32	4	4	4545552	4090996800
34	4	5	2070445	1863400500
26	5	1	13025	11722500
30	5	2	14985	13486500
33	5	3	10720	9648000
35	5	4	16261	14634900
36	5	5	359490	323541000

> LAND COVER CHANGE MATRIX [metre^2]
> NewClass

V_Reference Class	0	1	2	3	4	5	Total
0	7163039700	0	0	0	0	0	7163039700
1	0	2330354700	325492200	1058265900	145298700	11722500	3871134000
2	0	92301300	520921800	411204600	122840100	13486500	1160754300
3	0	6491700	75299400	2469303900	608839200	9648000	3169582200
4	0	1001700	4968000	552348000	4090996800	14634900	4663949400
5	0	4500900	16181100	49009500	1863400500	323541000	2256633000
Total	7163039700	2434650300	942862500	4540131900	6831375300	373032900	22285092600

Table 3, land cover change report.

Discussion

All tests performed in this study measure both the lake and the areas around the lake. Therefore, all water body measurements measure the lake and the smaller waterbodies around the lake. This study regards the lake and water around the lake, thus dry lakebed, dry soil, and cropland change will not be discussed. The shallow water category will also be excluded from this study because large areas of dry lakebed, particularly the Newfoundland Evaporation Basin west by southwest of the Great Salt Lake, are highly reflective and exhibit spectral signatures similar to shallow water areas. Because of this, the shallow water class contains both shallow water areas and areas of highly reflective dry lakebed. This was not realized until after the classification had been done, and due to time constraints, all initial data were kept and used for this study.

If one observes the images and raw data from the initial classifications, one can see a marked decrease in lake size between 09 July 1998 and 26 September 2021. In the 09 July 1998 image, the lake (excluding shallow areas) was about 3,871,134,000 square meters wide, and in the 26 September 2021 image, the lake was about 2,434,650,300 square meters wide. This is a loss of about 1,436,483,700 square meters of lake area. Using the land cover change matrix in Table 3, in class 1 (water, or deeper water), 2,330,354,700 square meters of area remained in class 1 and did not move to a different class. Meaning, 2,330,354,700 square meters of the study area contained water in both 1998 and 2021. These areas were likely the center and near center edges of the lake and the water bodies northeast of the lake. 325,492,200 square meters of class 1 area moved to class 2 in the 2021 image. This means 325,492,200 square meters of lake water disappeared and either became shallow water or highly reflective lakebed. 1,058,265,900 square meters of class 1 area moved to class 3 in the 2021 image. Therefore, 1,058,265,900 square meters of former lake water dried up, becoming a dry lakebed area. 145,298,700 square meters of class 1 area moved to class 4 in the 2021 image. Any water areas that dry up would become dry lakebed. These 145,298,700 square meters of area are places that are truly dry lakebed, but because of training polygon choice and spectral similarities between some dry lakebed and dry soil areas, the classification classed them as dry soil instead of dry lakebed. 11,722,500 square meters of class 1 area moved to class 5 in the 2021 image. These 11,722,500 square meters of area are likely places where open water has become wetland, such as the Ogden Bay Waterfowl Management Area east of the Great Salt Lake.

Adding the changed areas together, the results of this study show that the lake has contracted over 1,540,779,300 square meters between 1998 and 2021. This figure is greater than the 1,436,483,700 square meters calculated by the classification report. Unfortunately, there is yet no conclusive explanation for the discrepancy between the two figures. Either way, neither figure captures the true shrinkage of the lake because of the smaller water bodies around the lake and because a small part of the most southern part of the lake was not in the images that were studied. The images and analysis do show that major loss occurred in all areas of the lake, though the greatest loss occurred on the eastern arm of the lake. Though it does not show the true shrinkage of the lake, the research does show that the area around the lake has lost between 1,436,483,700 and 1,540,779,300 square meters of water area.

This study can be improved by measuring the entire lake area, isolating the classification area to the lake only, and by classifying the highly reflective dry lakebed areas as dry lakebed and not as shallow water.

Regarding Classification

A primary subject regarding classification is the shallow water category/class. As previously stated, this study only concerns the deeper regions of the lake. This distinction was made because large areas of the Newfoundland Evaporation Basin west by southwest of the Great Salt Lake are highly reflective and exhibit spectral signatures very similar to shallow water areas. Because of this, the shallow water class contains both shallow water areas and areas of highly reflective dry lakebed. Because of this, shallow water area was not used in this study.

As shown in figures 1 and 2, the 1998 and 2021 images had different amounts of dry lakebed, dry soil, and cropland. This was because of seasonal variations between the two images, the training polygon sites used to classify the images, and spectral similarities between areas in one image and not in the other. The 1998 image was taken by the Landsat 5 satellite on 09 July 1998 (in the summer), and the 2021 image was taken by the Landsat 8 satellite on 26 September 2021 (in the fall). Higher green vegetation levels in the summer and lower green vegetation levels in the fall is one reason for the differences in cropland and bare soil classification between the two images.

As noted in the Results area of this paper, the classification of the 1998 image classified some areas of dry soil as cropland and in the 2021 image it classified some areas of cropland as dry soil. The areas the researcher chose for the training polygons are one reason for this cropland/dry soil discrepancy. Both the 1998 and the 2021 images had areas of mixed crops and dry soil. In the 1998 image the researcher put more of these areas in cropland training polygons and in the 2021 image the researcher put more in dry soil polygons. The classification software also classified some mountainous regions in the 2021 image as dry lakebed because of training polygon location choices and spectral similarities between the mountain areas and dry lakebed areas.

References

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