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Water Demand and Supply at Great Salt Lake: A Case Study

**Abstract**

Ecosystem services supply many kinds of benefits to people, and Great Salt Lake in Utah provides many of them. It supports numerous industries, provides habitat for wildlife, and protects the health of the region. However, this lake is currently at risk. Due to increased water demand from agriculture, other industries, and a growing population, there has been a significant reduction in the water inflow into the lake. The subsequent shrinking in area of the lake has caused loss of profit in many industries and led to an increase in dust storms. These dust storms are particularly important because they carry toxic chemicals, that were currently stored underwater in the lakebed, into populated areas causing a major health risk. Our study looks to determine where decreases in water demand in urban areas and agriculture may be most effective in improving water yield, and compares water supply levels currently and in future scenarios to historical levels. We found that reduction in water demand from agricultural industries was most effective in improving water supply, although there is promise for a cooperative effort. It was discovered that no amount of decrease in water demand approached historical levels of water supply, indicating a need for more research to determine a sustainable level of water consumption.

**Introduction**

Ecosystem services are incredibly important for the survival of people on all scales of life. They are defined as the benefits provided by ecosystems to humans, and in this way, they are primarily anthropogenically focused. They only exist when they are helping humans. The importance of these services depends not only on the natural system processes but also on social values, so that they cannot be analyzed from any one perspective. Ecosystem services exist on many different scales and in all different kinds of ecological organizations (Kinzig, 2009). Ecosystem services include carbon storage, water regulation and purification, crop pollination, and recreational opportunities. The value these services provide can be used to offer financial incentives for conservation. However, there is still a lack of knowledge on where ecosystem services come from, who benefits, and how they are valued, which makes decisions of resource management difficult (Rickets and Lonsdorf, 2013). For example, a watershed can provide water for agricultural and industrial use, which promotes the local and global economy. The water can also be used for residential purposes, which means it affects human health and safety. The watershed ecosystem can also be used as a recreation area, as many people may like to visit the ecosystems fed by the water system. All of these services clearly have value, but it is difficult to quantify exactly how much and to whom the value goes, and many decisions depend on this.

The Great Salt Lake is an ecosystem which provides many services to people. It provides about 7,706 local jobs and a total labor income of about $375.1 million dollars to the people of Salt Lake City, which is directly on the lakes Southeast corner, and about $1.32 billion dollars of economic output annually. The industries around GSL extract large amounts of magnesium and sulfate, with mining companies extracting about 2 million tons of minerals per year, as well as producing large amounts of brine shrimp (Great Salt Lake, n.d). The evaporation off the lake settles on nearby mountain provides about $1.8 billion in economic productivity and 20,000 jobs through skiing and other tourism industries, as well as fueling the snowmelt which provides water for most of the valley (Osborne, 2023). GSL is also an important recreational opportunity for local residents and tourists, with boating, hiking, swimming, and fishing opportunities. More than 7,000 migratory birds pass through the lake annually (Safdie, 2023). It hosts 10 million birds in total of more than 330 species that come to rest. Brine flies are a vital part of the food chain which feeds these birds (About the Lake, 2023).

These services are at risk because of the increasing demand for water from industries and residents. The peculiar geography of the lake makes it so that water is not replenished easily. What makes GSL so special is that it is a terminal lake, meaning there are no outlets from the lake to maintain a stable water resource. GSL is a wide flat lake, with an average depth of only 14 ft. This means that water level and temperature change quickly. Water temperature can vary from below freezing to 80 °F throughout the year. In a normal year, water levels can change by 2-3 ft. As the water levels change, the dynamics and interactions of ecosystems along the shoreline are also affected (Physical Characteristics of Great Salt Lake, 2014). The water, and all the salts and minerals that it carries, flows into the lake from the Jordan, Water, and Bear rivers (Flavelle & Tarnowski, 2022). It then stays in the lake until it evaporates, leaving all the salts and minerals behind, leading to salinity levels 3.5-8 times higher in the lake than in the ocean (Physical Characteristics of Great Salt Lake, 2014).

This is part of the problem which is currently affecting the lake. The growing population of the city and surrounding areas is causing increasing diversions of water from the tributaries, meaning far less water is reaching the lake. About 75% of the water is being diverted for agriculture, with the rest being lost to water transport, mineral extraction, and piped to cities (Osborne, 2023). Combining this with increasing droughts in the region, and the Great Salt Lake is drying up. The lake's surface has shrunk from 3,300 square miles in the 1980s to less than 1,000, and the salt content has risen from the usual 9-12%, far beyond to usual yearly variations. The soil which is exposed contains all of the salts and minerals carried into the lake by the rivers, including arsenic, antimony, copper, zirconium, and other heavy metals. Many of these are residues from the mining industry of the region. As the crust of the exposed lakebed is worn away, these metals can be picked up in dust storms and blown into populated areas (Flavelle & Tarnowski, 2022). The dust could cause increased risk of respiratory conditions, heart disease, lung disease, and cancers (Osborne, 2023). There is also the risk of loss of biodiversity and ecosystem collapse, because as the lake gets saltier the brine shrimp and flies which feed the ecosystem may no longer be able to survive, and therefore the birds can no longer inhabit the region (Safdie, 2023). The increasing rate of toxic dust storms, with risk to human health and safety, and the growing worry about water scarcity are the impetus for decisions being made around the lake.

Many people have a part in solving this problem and a stake in its outcomes. One major stakeholder is agricultural businesses who draw water out of the tributaries to water their crops. They use about three-quarters of Utah’s water, usually to grow alfalfa (Larsen, 2022). There are also other industries that use water from GSL, diverting about 7.5% of it (Alsever, 2022). The mining industry dredges water and the brine shrimp industry requires the lake itself to maintain production. The recreational and tourism industry requires a functioning ecosystem for tourists and consistent snow levels for skiing. Conservation scientists also play a part, doing research and advocating the government and the public for water conservation strategies (Abbott et al., 2023). All of these industries are at risk of water scarcity troubles. Then there are also the residents of Salt Lake City. They are exposed to the health risks posed by the dust storms, as well as the risk of industry collapse and water scarcity. However, the stakeholders with the biggest decision making power are the government factions. The Utah state governor can implement plans for watershed management and oversees water leasing, farmer compensation, water donations, and conveyance. The Utah state legislature is important in passing new laws for water conservation and in providing funding for the governor’s plans (Abbott et al., 2023). The Utah Division of Wildlife Resources is the institution that is in charge of the ecology and industry at GSL, who does work mostly in data collection and surveying (Great Salt Lake Ecosystem Program*,* 2023).

The objectives of managing the lake are many and varied. One main goal is to maintain industry levels around the lake. Agriculture, mining, skiing, recreation, and more are all important parts of the economy that depend on water that flows into the lake. However, several of these industries also depend on the lake not drying up and on it having a functioning ecosystem. The government also needs to make sure that the health of its citizens is protected, which requires either making sure the lakebed is covered in water or finding some other way of preventing dust storms. If nothing is done, the lake will continue to shrink, exposing even more of the lakebed. This will most likely increase the frequency and severity of the dust storms, further imposing risks on the health of the nearby city. There will also be the total collapse of the brine shrimp industry as the salinity levels rise beyond tolerable, and the mining industry will face even more difficulty with obtaining water for their operations. With the collapse of the brine shrimp population, and with further habitat destruction from the receding lake, the local wildlife will also face severe declines, damaging the recreational opportunities as well (Hassan et al. 2017).

To prevent this decline, a solution of how much water is used in the lake by businesses and residents, and how much must stay in the lake should be created. It should also be examined if agricultural is economically viable in this region, and if so, how much should be allowed considering the water demand from residents and other industries. This will require new laws and regulations which limit industry and residential consumption and provide alternative resources to help those industries adapt to new water levels. The government may impose water restrictions on the city which prevent citizens from unnecessary uses of water, such as watering lawns, and can produce incentives for people to buy water saving devices. The government can also create similar restrictions of agriculture, by preventing how much water may be diverted from the lake and create incentives for new technology to be implemented at farms which reduce the necessity for frequent high-loss watering. There may also be the potential for a water pipe-line which could provide water to farms while reducing strain on the watershed. Which option is taken, reducing water demand from agriculture vs urban areas, or if both are implemented, depends on which choice offers the largest benefit.

This study provided examples of reducing water demand for the city, for agriculture, and for both. The first scenario involved reducing the water demand for urban areas, which includes the Salt Lake City metropolitan area, by 50%. This would mimic strong water restrictions within urban areas to reduce water usage with little effort made outside of the city. The next scenario was reducing water demand for agriculture, both cultivated crops and hay/pasture, by 50% while not reducing it for urban areas. This would show restrictions on the farming industries while allowing free use within the city. The third scenario was cutting water demand for both urban areas and agriculture by 25% to determine how cooperation between regions could affect overall water supply. This number is plausibly much easier for both places to achieve. A historical model was also run, where all urban and agricultural land cover was removed and water yield determined, to determine a metric for water yield levels that were sustainable. With this in mind, a fourth scenario was run where urban areas reduced water demand by 50% and agricultural areas reduced water demand by 75%, to find how close to historical levels could be achieved with these land covers still present.

**Methods**

To evaluate our scenarios, we used InVEST, a software which maps ecosystem goods and services that benefit humans. We used the annual water yield model to predict water yield and resupply resulting from the different scenarios. This model predicts how much water enters the watershed, how much is consumed by the landscape, and how much will be left to enter the lake. This allows us to determine how changing water use for different kinds of land cover affects how much water is available to recharge the lake. We also used the InVEST scenario generator to artificially remove all agricultural land cover and urban land cover from the original land cover map and replaced it with shrubland, the most likely historical land cover (fig 1). We then used this new land cover map, representing historical land cover, in an annual water yield model with the original water demand biophysical table.

Map

Description automatically generatedMap

Description automatically generated  
a) b)

Fig 1. a) Map of Current Land Cover in Salt Lake Watershed, b) Map of Historical Land Cover in Salt Lake Watershed, with Urban and Agricultural Land Covers removed

For each of our scenarios, the input files remained the same, outside of the water demand table. This keeps all values equal except for changing water demand for agricultural and/or urban land covers represented on the map, mimicking the implementation of water restrictions. For our base run, we imputed all files as original and didn’t change land cover or water demand (table 1). For the first scenario we manually reduced water demand on the biophysical water demand table by 50% for the four urban land covers: Developed, Open Space; Developed, Low Intensity; Developed, Medium Intensity; and Developed, High Intensity (table 1). For the next scenario we left the urban water demand at its original values, and reduced water demand for Pasture/Hay and Cultivated Crops by 50% (table 1). For the third scenario, we reduced for all the previously listed land cover types from their original values by 25% (table 1). For our final scenario, we reduced the urban land cover water demand by 50% and the agricultural land cover water demand by 75% (table 1).

Table 1: Water Demand Biophysical Tables for the Baseline and Four Scenarios

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| lucode | land cover type | water demand: baseline | Water demand: scenario 1 | water demand: scenario 2 | water demand: scenario 3 | water demand: scenario 4 |
| 0 | Background | 0 | 0 | 0 | 0 | 0 |
| 11 | Open Water | 0 | 0 | 0 | 0 | 0 |
| 12 | Perennial Ice | 0 | 0 | 0 | 0 | 0 |
| 21 | Developed, Open Space | 40 | 20 | 40 | 30 | 20 |
| 22 | Developed, Low Intensity | 120 | 60 | 120 | 90 | 60 |
| 23 | Developed, Medium Intensity | 200 | 100 | 200 | 150 | 100 |
| 24 | Developed, High Intesity | 400 | 200 | 400 | 300 | 200 |
| 31 | Barren Land(Rock/Sand/Clay) | 4 | 4 | 4 | 4 | 4 |
| 41 | Deciduous Forest | 40 | 40 | 40 | 40 | 40 |
| 42 | Evergreen Forest | 40 | 40 | 40 | 40 | 40 |
| 43 | Mixed Forest | 40 | 40 | 40 | 40 | 40 |
| 52 | Shrub/Scrub | 40 | 40 | 40 | 40 | 40 |
| 71 | Grassland/Herbaceous | 40 | 40 | 40 | 40 | 40 |
| 81 | Pasture/Hay | 200 | 200 | 100 | 150 | 50 |
| 82 | Cultivated Crops | 600 | 600 | 300 | 450 | 150 |
| 90 | Woody Wetlands | 40 | 40 | 40 | 40 | 40 |
| 95 | Emergent Herbaceous Wetlands | 40 | 40 | 40 | 40 | 40 |

This model has several limitations. Firstly, this model was designed to estimate hydropower, and thus it is based on annual averages, which neglect temporal changes which could cause rapid changes in water yield. The model also does not consider the topography of the land. It simplifies consumptive demand to one value, while it may actually change drastically within a land cover type. It simplifies point sources of water intake, and doesn’t account for withdrawal from upstream. It also doesn’t capture water transport for irrigation. However, the model remains the best available option for providing preliminary understanding of water yield and supply in the watershed.

**Results**

In the base run, total realized water supply was 8,085,028,792m3. The total realized water supply for the historical run was 9,780, 154,324m3. For scenario one, the total realized water supply was 165,743,180m3 greater than the base and for scenario two the total realized water supply was 610,165,5003 greater than the base. Scenario three had a total water supply of 387,954,340m3 greater than the base. Scenario four had the greatest difference from the base, as was expected, at 1,080,991,430m3 (table 6). While all of these numbers represent a greater amount of water entering the lake than the current value, they are all significantly lower than the historical value.

Table 6. Water Yield Results of Scenario Models

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Scenario | Mean Water Yield (mm) | Total Volume of Water Yield (m^3) | Total Water Consumption (m^3) | Mean Water Consumption (m^3/ha) | Total Realized Water Supply (m^3) | Mean Realized Water Supply (m^3/ha) |
| Base | 162.921978 | 1.2104E+10 | 4019231668 | 48.6873727 | 8085028792 | 114.234606 |
| Historical | 167.510696 | 1.2445E+10 | 2665024148 | 32.2830418 | 9780154324 | 135.227654 |
| Scenario 1:  Reduced Urban Water Demand | 162.921978 | 1.2104E+10 | 3853488488 | 46.6796258 | 8250771972 | 116.242353 |
| Scenario 2: Reduced Ag Water Demand | 162.921978 | 1.2104E+10 | 3409066168 | 41.2960707 | 8695194292 | 121.625908 |
| Scenario 3: Reduced Both Water Demands | 162.921978 | 1.2104E+10 | 3631277328 | 43.9878483 | 8472983132 | 118.93413 |
| Scenario 4: Extreme Reduction in Water Demand | 162.921978 | 1.2104E+10 | 2938240238 | 35.5926728 | 9166020222 | 127.329306 |

The first three scenarios indicate that agricultural water demand plays the largest role in reducing water supply to the lake. When the two regions both reduce water demand by a moderate amount, it is insufficient to reach levels of water resupply that were gained by reducing water demand for agriculture by a significant amount. Scenario one indicates a significant loss in agricultural production while there is little loss in quality for other industries or in quality of life in urban areas. Scenario two shows the opposite, a potential significant decrease in production for urban based industries and a possible lowering in quality of life through lower water access. However, agricultural production would remain at current levels. Scenario three shows some loss of production in both agricultural and urban areas, although less loss for both areas than the previous two scenarios. Scenario four shows a significant loss in both agricultural and urban production and a lowering in quality of life, however it also brings the water supply levels the closest the historical level (table 6). Outside of scenario four, which may be considered unrealistic due to the high reduction in water demand, the scenario which reached the closest to historic water supply levels was scenario two. This indicates that agriculture will have to take the brunt of the reduction in water demand, as it contributes the most to water inflow decline. However, in order to reach sustainable water supply, it is likely that both areas will play a part in reducing water demand.

**Discussion**

A significant finding of our work was that no reduction in water demand for any area greatly approached that of the historical levels. This worryingly indicates that no amount of water demand reduction was enough to reach near sustainable levels. Any amount of human demand reduces water supply, and thereby moves the lake from past inflow levels. Although our results show that it is difficult, if not impossible, to approach historic levels of water resupply, another study has estimated that an increase in inflow of 24-29% may be enough to sustain the levels of the lake to the point where ecosystem services are still provided (Wurtsbaugh et al., 2017). Now it must be considered how this sustainable level could be reached. Reducing water demand was an important factor in improving total water supply to the watershed. This indicates that reducing water demand is a critical component of improving the situation involving the reduced lake area. We also determined that agriculture was the primary entity responsible for the loss of water entering the lake. Our scenarios indicated that reducing water demand from agriculture was far more effective at improving water supply than reducing water demand from urban areas or from both. A large reduction in water consumption from agriculture must be made in order to significantly improve water supply. However, our results also indicate that some amount of reduction in urban water demand can be helpful in improving water supply. Some compromise between the two regions is applicable.

Reducing the amount of water demand for agriculture is likely to have a strong negative impact on farm yields. There are currently not many affordable options for farmers to supplement their water supply (*Agriculture water use and economic value in the Great Salt Lake Basin, 2023)*. However, there would be strong positives to this with increased lake surface area providing benefits for other industries in the area. It would also be beneficial for the local wildlife, which provide not only recreational services but climate regulation and pollination services as well, and support human health. It would also benefit water regulation, as precipitation could continue to provide water and snow for the wider range. Reductions in urban water use would also provide these benefits, with likely a low cost in quality of life, but not to the extent that reduction of use in agriculture would. It could provide some respite from water restrictions in agriculture if urban water use was cut enough. Further work should be done which evaluates the level of water consumption which could be sustainable.

Studies show that increased reduction in the surface area of the lake would be catastrophic. The reasons for the decline of the lake are various and complicated, including far more besides consumptive water use. Climate change and droughts are also potential factors contributing to the condition of the lake. However, it has been shown that precipitation and evaporation have not yet changed significantly, as was also shown in our models, leaving direct human influence as the main factor in water level decline. If the lake continues to decline, it will demonstrate decreased resilience to climate change, so that there will be an even greater difficulty in restoring the lake (Hassan et al., 2022). Runoff is expected to decrease by 11-20% and lake evaporation will also climb. Combined with continued consumptive use, which currently causes reductions in inflow of about 40%, of which 63% is agriculture, the lake faces serious future decline. This puts the $1.32 billion per year industries of mineral extraction, brine shrimp farming, and recreation at risk, along with the health of the city populace with the increased risk of dust storms.

Our models, while significant in showing potential effects of water demand decline, are still rough estimates and should not be taken as concrete. The models do not show the amount of water that will flow into the lakes, rather they indicate a rough estimate of water availability in the region after consumptive use. They are also simplifications of various industries and do not represent the differences in ways that water demand could be reduced and what effects these will have on the land cover of the region. Further research should be conducted to determine viable ways of reducing water demand that are economical, especially for agricultural areas. Areas of study should be agricultural technologies that promote sustainability, such as drip irrigation, and what water incentives provided promote the best use of water. Other research should focus on what water laws are most effective in engaging residents and city businesses in using less water, such subsides for drought resistant lawns. There should also be a sustainable metric of water inflow that is determined beyond simple analysis of historical, pre-settlement inflow.

To save the numerous services provided by the lake, it may be necessary to induce significant cuts in agricultural production. It is also necessary to consider cutting water demand in all industries present, as any current reduction in water demand does not reach sustainable water yield in the region. Making decisions on what profits may be maintained at the expense of other industries will be difficult as it affects the livelihood of many communities, but the health of the lake must be addressed. At the current rate of decline, all industries will eventually be lost. Innovation and cooperation between many groups of people will be necessary to formulate solutions and make decisions about the future of industry and human health in the Salt Lake City Watershed.

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