GEOG 311 Final Project Paper

Modeling populations, vegetation, and snowpack areas affected by worsening toxic windblown dust from the Great Salt Lakebed

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Intermediate GIS 2024, Department of Geography BYU

A R T I C L E I N F O

Article history:
Received 22 April 2024

Keywords:
Great Salt Lake, Climate Change, Water Scarcity, Toxic Dust, Public Health, Agriculture, Water Conservation

A B S T R A C T

In the face of an ecological crisis as the water level of the Great Salt Lake quickly declines, concerns arise about toxic dust blown up from the now-exposed lakebed. This paper details three distribution models created in ArcGIS Pro which map the effects of potential toxic dust on human populations, different vegetation types, and snowpack along within the likely affected 100-mile range of the Great Salt Lake shoreline. The model exploring impact on human health found that there are over 1,000 K-12 schools with almost 570,000 students within the likely affected area of the lake. The model exploring impact on vegetation found almost 750,000 sq acres of wildlands in the affected area. The model exploring impact on snowpack found that all the Great Salt Lake's main tributaries watersheds would be affected, along with many of Utah's high Snow Water Equivalent areas. The authors suggest quick action to replenish the lake.

Background

Despite comprising 44% of the volume and 23% of the area of all lakes on earth, saline lakes are declining globally - resulting in disastrous ecological, economic, and health-related harm (Messager et al., 2016; Tussupova et al., 2020). As water levels decline, salinity rises and harms organisms that cannot withstand these changes (Great Salt Lake Advisory Council, 2019). Lakebed exposure also allows toxic chemicals to be released. Many of these chemicals are naturally occurring, but some (such as thallium, arsenic, and molybdenum) originate from mining, smelting, pesticide application, and other forms of anthropogenic activity (Putman et al., 2022).

The Great Salt Lake is steadily decreasing in area each year (Wurtsbaugh et al., 2017). This brings great cause for alarm as the Great Salt Lake provides various economic benefits to Utah, including brine shrimp harvesting and mineral extraction. It also supports wildlife, including around 10 million migratory waterfowl per year (Utah Division of Wildlife Resources). The collapse of this precious lake is an impending crisis, and one that is estimated to become real in as soon as five years if nothing is changed (BYU Great Salt Lake Briefing, 2023).

To help convey the severity of this issue, this project will utilize models from ArcGIS Pro to display the potential range and effects of dust pollution originating from the Great Salt Lake. The effects of windblown dust on human health, plant physiology, and snowpack in Utah will be examined separately, then discussed together to conclude.

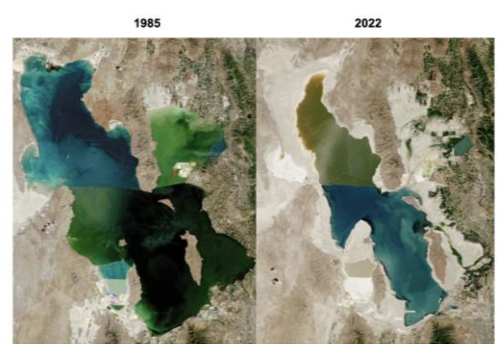

Figure 1: Satellite imagery of the lake extent in 1985 and 2022 (NASA). The lake has lost 74% of its water and 60% of its surface area (Abbott et al., 2023).

1. Impacts of Dust on Human Health

The toxic dust from Owens Lake and the Salton Sea have had horrible impacts on the surrounding residents. Two fallen saline lake ecosystems in California, these lakebeds now provide such a public health hazard that

California has spent millions on sprinkling water on the lakebed to avoid dust storms. In 1986 the Great Salt Lake covered 2,300 sq miles, making it significantly larger than Owens Lake and thus posing a much greater threat to public health. Replenishing the lake would require a much larger scale effort to protect people living within reach of the dust storms. A recent study found significant amounts of Great Salt Lake isotope tracers in urban dust found along Utah's Wasatch front, meaning lakebed dust falls directly onto the most heavily populated areas of the state. Specifically, those researchers found that up to 34% of the dust in urban areas of the Wasatch Front came directly from the lakebed (Carling et al., 2020). Concerningly, a study conducted by the International Agency for Research on Cancer found that particulate matter in outdoor air pollution, such as the larger PM 10 particles of which Great Salt Lake dust is a part, cause lung cancer (Loomis et al., 2013).

While the similarities between the situation of the Great Salt Lake drying up and the situation at Owens Lake or other declined saline lakes are still unclear, data collected from Owens Lake dust storms suggests that most of the Wasatch Front and the surrounding areas will be affected. Monitors from the Salton Sea show significantly more PM10 particulate matter within 100 miles of the lakebed versus outside 100 miles of the lakebed. Assuming that the spread of dust and pollutants affects those living within a 100-mile radius of the Great Salt Lake, that would mean that around 83% of Utah's population, or around 2.81 million people would have their health negatively impacted by the worsening air quality. This would put a huge strain on the healthcare system in the area and would generally have a very negative effect on the community.

While exposure to pollutants has a negative effect on all health outcomes, there are certain populations that are more at risk than others. According to the California Air Resources Board, there are certain groups, such as those with asthma, who are most likely to be negatively affected by the presence of harmful dust in the air. (Randolph & Liane, 2023). According to data from the Utah department of Health and Human services combined with the amount of people living within 100 miles of the Great Salt Lake,

Table A1: Exposed Playa and Pollution Outcomes -Particles within 500m

	(1) PM$_{10}$	(2) PM$_{10}$	(3) PM$_{10}$	(4) PM$_{2.5}$	(5) PM$_{2.5}$	(6) PM$_{2.5}$
Total particles	1.303***	1.405***	1.439***	0.823***	0.771***	0.769***
	(0.332)	(0.290)	(0.293)	(0.202)	(0.202)	(0.203)
Mean	43.288	43.288	43.288	10.747	10.747	10.747
Obs.	258,640	258,640	258,640	226,548	226,548	226,548
R-squared	0.112	0.139	0.153	0.259	0.288	0.292
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	No	Yes	Yes
Site by point FE	Yes	Yes	Yes	Yes	Yes	Yes
Day of week FE	No	No	Yes	No	No	Yes
Cluster level	Site	Site	Site	Site	Site	Site

Figure 3: PM10 and PM2.5 concentrations around the Salton Sea from 500m

Panel a) Monitors within 100 miles from the Salton Sea

	(1) PM$_{10}$	(2) PM$_{10}$	(3) PM$_{10}$	(4) PM$_{2.5}$	(5) PM$_{2.5}$	(6) PM$_{2.5}$
Total particles	1.269***	1.370***	1.405***	0.818***	0.766***	0.765***
	(0.326)	(0.282)	(0.284)	(0.200)	(0.200)	(0.200)
Mean	43.239	43.239	43.239	10.781	10.781	10.781
Obs.	264,815	264,815	264,815	231,010	231,010	231,010
R-squared	0.112	0.139	0.152	0.256	0.285	0.289
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	No	Yes	Yes
Site by point FE	Yes	Yes	Yes	Yes	Yes	Yes
Day of week FE	No	No	Yes	No	No	Yes
Cluster level	Site	Site	Site	Site	Site	Site

Panel b) Monitors farther than 100 miles from the Salton Sea

	(1) PM$_{10}$	(2) PM$_{10}$	(3) PM$_{10}$	(4) PM$_{2.5}$	(5) PM$_{2.5}$	(6) PM$_{2.5}$
Total particles	-1.322	0.906	0.704	1.208	-0.651	-0.547
	(1.362)	(0.741)	(0.566)	(1.331)	(0.704)	(0.674)
Mean	26.657	26.657	26.657	11.960	11.960	11.960
Obs.	277	277	277	758	758	758
R-squared	0.808	0.958	0.978	0.625	0.887	0.920
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	No	Yes	Yes
Site by point FE	Yes	Yes	Yes	Yes	Yes	Yes
Day of week FE	No	No	Yes	No	No	Yes
Cluster level	Site	Site	Site	Site	Site	Site

Figure 2: PM10 and PM2.5 concentrations within and outside 100 miles from the Salton Sea

around 256,000 people with asthma would be at risk of dust storms from the declining Great Salt Lake.

Methodology

Fig. 2 and 3 show the residence time of PM10 in the air after a dust storm or breeze. This shows that these harmful toxins can stay in the air for over an hour after the dust storm, meaning they can still be inhaled even after the air appears clearer. Given these data, the goal of this model was to identify the most affected populations around the Great Salt Lake. Due to the information from the Salton Sea monitors, a 100-mile buffer model was created from the Great Salt Lake. The purpose of this was to identify how many people were affected by dust at this range. Next, school data was used to identify where lots of children would be located, as they would be at high risk for negative health outcomes due to dust pollution.

It became clear that toxic dust from the Great Salt Lake may not just affect Utah, but also Idaho, Wyoming, and Nevada. All modeling data used was based off data found at utah.gis.gov. This modeling was done based solely on the address points and schools in Utah and did not include nearby states.

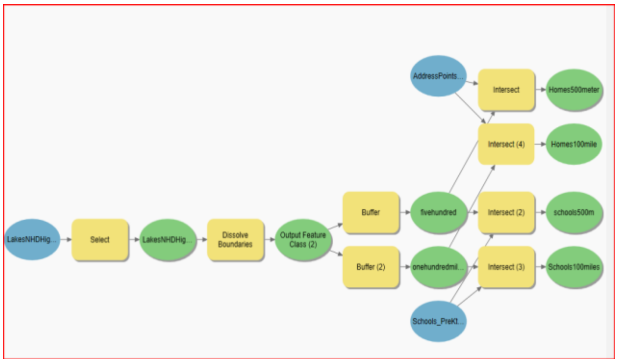

Figure 4: Workflow diagram showing the model for human health

All the data used were found at utah.gis.org, which has shapefiles created and approved by the state. First, the Lakes layers were added, then a Select was done to just have the Great Salt Lake. From here the boundaries were dissolved as some of the lake was split and the goal was to have one singular shoreline. After creating the shoreline, two buffers were made. One was 500 meters; the other was 100 miles from the Great Salt Lake shoreline. These two buffers formed the foundation for the rest of the project. Next, the other shapefiles such as addresses and schools were added to intersect with the buffers. This also could have been done with a Select by Location.

As a courtesy for everyone to have personalized data for their location, a web-map was created. The link below allows Utahns to search for their personal address to see what buffer zone they live in to know how long it is required to stay inside after a dust storm. The foundational buffers were needed to create the web map, which was then published on ArcGIS Online. Next, the API key was used to share the map after the search bar was coded in. Once the rest of the Web-map was coded, a video was created to show how the code could produce other working web maps. In addition, this data enabled us to run sum statistics to find a population number for children. This was all accomplished through the statistics in ArcGIS Pro.

This video shows an example web map: https://drive.google.com/file/d/1D-dmPcu_PCmhQjfVwmXnLr5LYtOlecDS/view

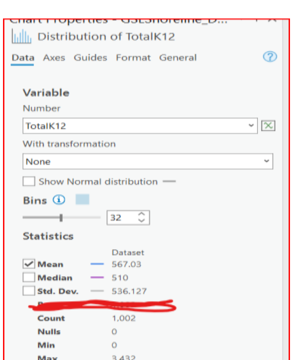

Figure 5

Results

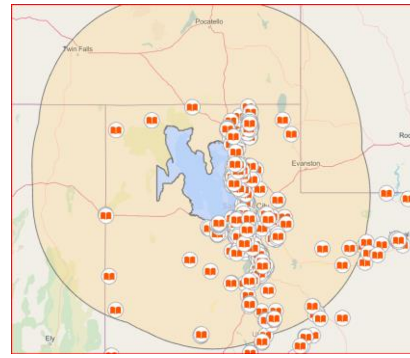

Figure 6: 100-mile buffer overlaid with school locations

There were seven schools within the most dangerous area, or 500 meters from the shoreline. These schools include Corinne Early Learning Center, Kay's Creek School, Jefferson Academy, Eagle Bay School, Canyon Creek School, Farmington High, and Foxboro School. If there was a dust storm and the children were released up to an hour afterward, they would be inhaling a large amount of PM10 pollution. Both the 500m and 100-mile buffers combined include 1,002 out of the 1,241 Utah K-12 schools. There were 568,164 children enrolled in these schools as of the 2020 school year data from the state of Utah. Another intersect of all the address points in Utah was completed. In total there are 1,411,864 address points in the entire state of Utah. In the 500-meter buffer around the Great Salt Lake shoreline there are 13,060 address points. Additionally, another 1,170,308 address points are within the 100-mile buffer from the shoreline, which in total is 83 percent of all of the address points in Utah.

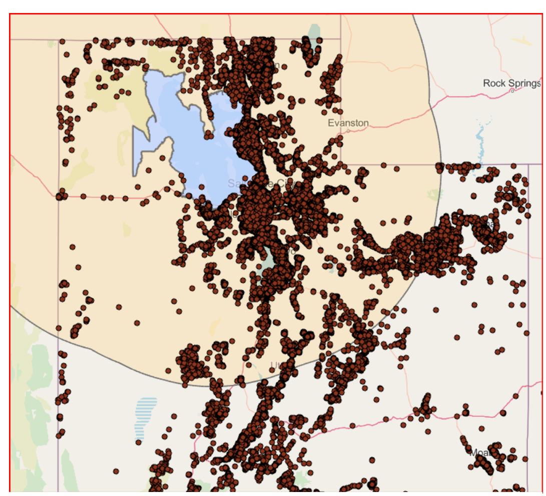

Figure 7: 100-mile shore buffer overlaid with Utah addresses

2. Impacts of Dust on Plant Physiology

Windblown dust has been proven to have a negative impact on plant physiology in several cases. Specifically, Sharifi et al. (1997) found that in cases of disturbed arid land shrub brush, photosynthesis was reduced from 21-58% depending on species of shrub affected. In addition, due to higher albedo, plant temperatures raised 2-3 degrees C. Finally, in a long-term study they found that dusted plants had lower leaf surface areas and lower water-use efficiencies compared to control plants.

In a study performed by Wang et al. (2016), grassland plant species were studied; these plants would be similar in physiology to plants throughout the Great Salt Lake watershed basin, therefore giving a clearer perspective to how dust would affect Utah grasslands. This study focused on coal dust, which would also reflect the chemical-laden attributes of Great Salt Lake lakebed dust. In addition to Sharifi et al., they also found that the photosynthesis rate was negatively affected. Interestingly, they also saw that in 80% of cases the dust inhibited root growth.

Dust doesn’t just impact the physiology of shrubs and grasses. In a very recent study, Moradi et al. (2024) tested the effects of dust on a range of Oak subspecies. They found that photosynthesis rates dropped to just 38-13% of original rates depending on the Oak subspecies tested. In addition to detriments to photosynthesis, they found decreased levels of chlorophyll and proline. At their lowest, chlorophyll levels dropped to 42% of their normal levels in the most affected species.

Dangerously, photosynthesis is not the only physiological process negatively impacted by windblown dust. In a study inspecting dust on corn plants, Barbastegan et al. (2015) found dust negatively impacted corn grain yield, stomatal conductance, substomatal CO2 concentration, maximum efficiency of photosystem, performance index of leaves, leaf temperature, transpiration rate, and physiological water use efficiency all in addition to decreased photosynthetic rate. This study is especially important to the Great Salt Lake watershed because there are many agricultural areas in close proximity to the lakebed.

Overall, these sources confirm that plant physiology is seriously negatively impacted by windblown dust accumulating on leaves. This decreases photosynthesis in shrubs, grasses, and deciduous trees, while potentially destroying crop yields in agricultural areas within range of the Great Salt Lake. The decrease in plants would not only decrease quality of life along the Wasatch Front, but it would also have the potential to destroy agricultural livelihoods.

Methodology

Two basic models were illustrated to understand the effect of dust on plant physiology. To create the first model, the 100-mile buffer assumed to be the most accurate according to data pulled from Salton Sea monitors (see fig. 2) was implemented. Next, shapefiles delineating wilderness areas according to the Bureau of Land Management and the U.S. Forest Service were downloaded from their respective websites and overlaid onto the buffer. This revealed designated wilderness areas most susceptible to photosynthetic obscurement via windblown dust (see fig. 8). To see the area affected, field statistics were calculated via the shapefile attribute table.

Because different wilderness areas play host to different vegetation types, a second model was calculated that would identify what types of plants lived in what areas of the state. Using raster data downloaded from the Bureau of Land Management, the four main vegetation types identified in the previous section were overlaid onto the 100-mile buffer. In this case, the four vegetation type areas were calculated using Raster Calculator.

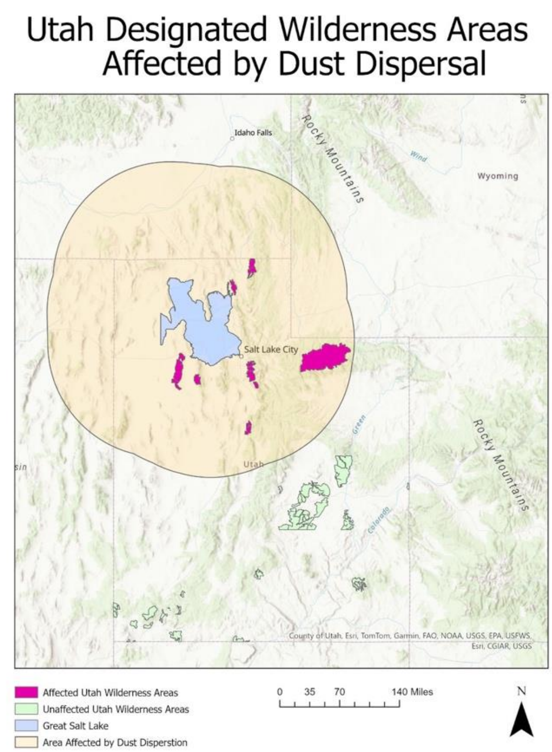

Figure 8: Pink areas are designated wilderness areas within the affected range

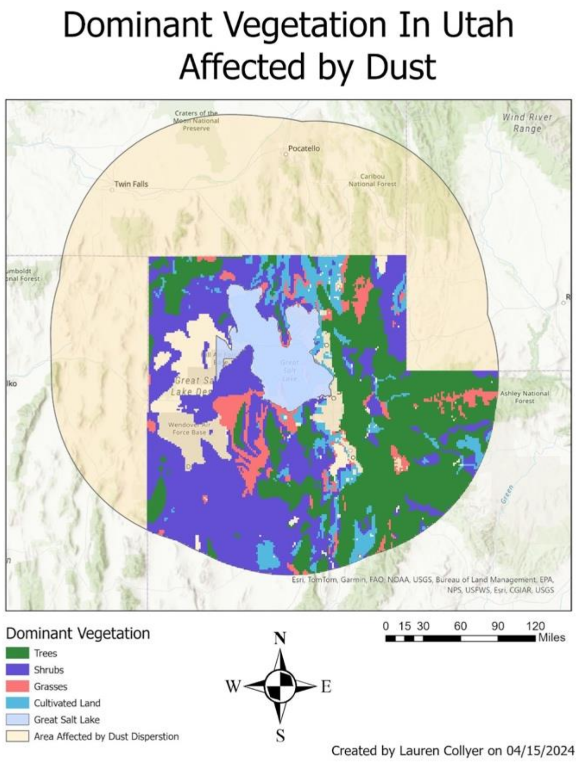

Figure 9: Each of the four identified vulnerable vegetation types overlaid on a 100-mile buffer

Results

Based on the first model, it was found that 745,589 acres of wilderness area in Utah alone will be affected by dust from the Great Salt Lake. Notably, winds typically blow eastward in Utah and the largest delineated section of wilderness within the affected range is directly east of the lake. This means that most of the dust blown up from the lake will move east, having a big impact on the large wilderness area in its path.

Based on the second model it was found that of the affected area, 49,806 sq km were trees, 51,515 sq km were shrubs, 9,440 sq km were grasses, and 11,448 sq km was cultivated land. It's concerning that the largest vegetation type by area was shrub, given that Sharifi et al. (1997) proved that plant temperatures raise 2-3 C on average when obscured with dust. This would most likely contribute to higher surface temperatures in the Utah west desert, and likely increase the chance of wildfire. However, though shrubs took up the highest area, most of the vegetation directly east of the lake are trees. They also followed closely behind shrubs as the second most prominent vegetation type in the effected range. Since Moradi et al. (2024) found that photosynthesis rates are sharply decreased when trees are faced with dust obscurement, Utahns can expect much higher tree mortality and lower productivity in the event of common dust storms.

3. Impacts of Dust on Snowpack

Windblown dust from the Great Salt Lake is already being studied in light of the dying ecosystem. Carling et al. (2020) tracked radioactive strontium isotopes fingerprinted from the Great Salt Lake lakebed to urban areas and snowpack in Utah mountains. He found that in the Uintah range, 11% of dust on snowpack came directly from the lakebed. Along the Wasatch range, 22% of dust on snowpack came directly from the lakebed. Looking back at snowpack, one of the main unique signatures that Great Salt Lake dust possessed was extreme seasonal variability, which is a reflection of seasonal runoff and water use within the Great Salt Lake watershed.

A lesser-known problem associated with windblown dust is increased dust enhanced energy absorption (DEAE). A recent report (Fassnacht et al. (2022)) found that not only did windblown dust accumulation quicken snowmelt, it also influenced other snowpack properties such as snowmelt timing. They concluded that DEAE, modeled clean snowmelt, and volume of snowmelt varied from year to year due to the frequency and size of windblown dust events. Therefore, Utahns should prepare for much faster snowmelt if the Great Salt Lake continues along its trajectory of decline.

Dust enhanced energy absorption (DEAE) is a subset of radiative forcing, a primary driver in climate change. Radiative forcing warms the earth's surface, leading to increased air temperatures and snowmelt, states Gleason et al. (2022). This study examined black carbon dust along the Rocky Mountains and its effect on radiative forcing leading to increased snowmelt. Although black carbon dust is much more potent than windblown dust in reducing snowpack, the study reaffirmed that dust is a prevalent driver of snowmelt.

In all, windblown dust not only has a major effect on snowpack in general, but also that it is accumulating on snow in Utah mountains. This presents a major climatic problem, as the Great Salt Lake is shrinking in part due to decreased snowpack over the winter season. A positive feedback loop is then established; as windblown dust decreases snowpack, less water is able to reach the lake, exposing more of the lakebed and generating increased amounts of said dust (Lang et al., 2023). Therefore, lakebed dust not only provides human health hazards, but ecological detriment as well.

Methodology

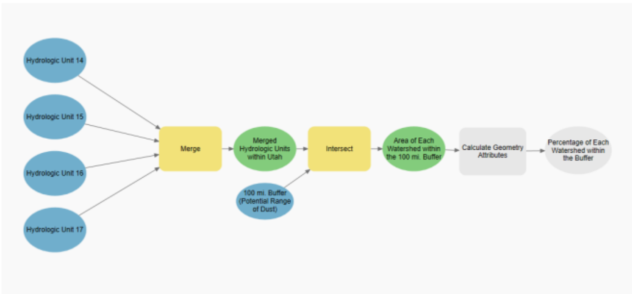

Figure 10: Workflow illustrating the model for potential affected snowpack

To display the potential harm dust pollution may have on snowpack within nearby watersheds, an analysis was performed to estimate how much each watershed may be affected. Due to the ability of dust accumulation to increase the rate of snowmelt, the hydrology of the watersheds will be altered by its presence (Lang et al., 2023). A 100 mi. buffer from the Great Salt Lake (the same used to estimate effects on human health and plant physiology) was used to display the potential range of dust pollution in ArcGIS Pro. The spatial data for the nearby watersheds was collected from Hydrologic Units 14, 15, 16, and 17 of the USGS Watershed Boundary Dataset (utilizing the USGS Data Download Application).

Once the layers for each Hydrologic Unit were added to a map, the Merge tool was used to combine them into one single layer. The area of each watershed affected by the buffer was calculated utilizing the Intersect tool and "Calculate Geometry Attributes" tool. The percentage of each watershed's affected area was then calculated by hand by dividing the affected area by the total area in square kilometers within the attribute table of the merged layer.

To assist in communicating the impact dust pollution could have on the area, the level of snow water equivalent measured by weather stations throughout Utah were displayed on a model created using the National Water and Climate Center's Interactive Map. The map displays snow water equivalent as of April 17, 2024 (by the end of the day).

Results

Based on the watershed model, the entirety of the Weber, Upper Bear, Lower Bear, and Jordan watersheds will be affected by emissions from the lake. Other watersheds within range of the lake's dust emissions include the Great Salt Lake (with the 100 mi buffer covering ~70% of the lakeshed), Upper Green (~23%), Lower Green (~28%), Escalante Desert-Sevier Lake (~24%), Humboldt (~3.4%), Upper Snake (~41%), and Central Nevada Desert (~7.4%). The SWE model indicates that many of Utah's areas containing the highest SWE values (31.5 inches and above) were within the estimated range of dust pollution as well (see fig. 12).

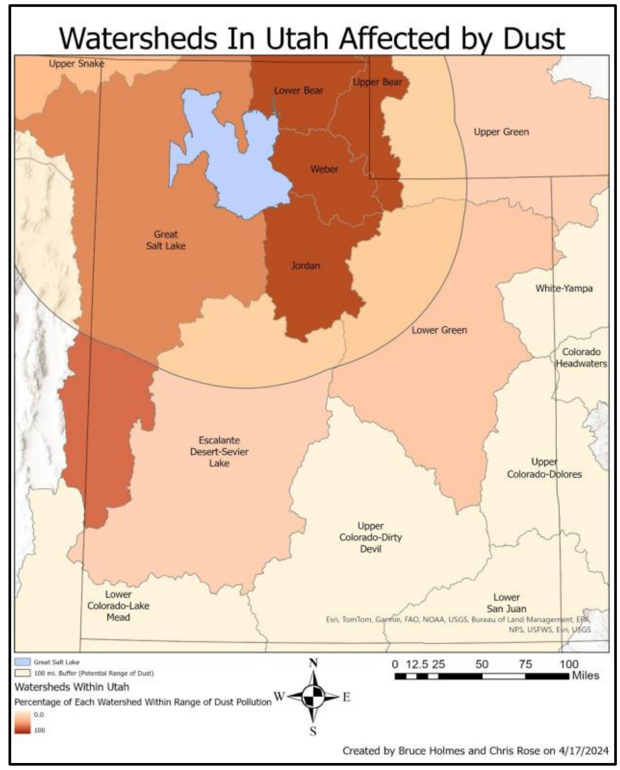

Figure 11: Illustration of dust polluting Great Salt Lake watersheds

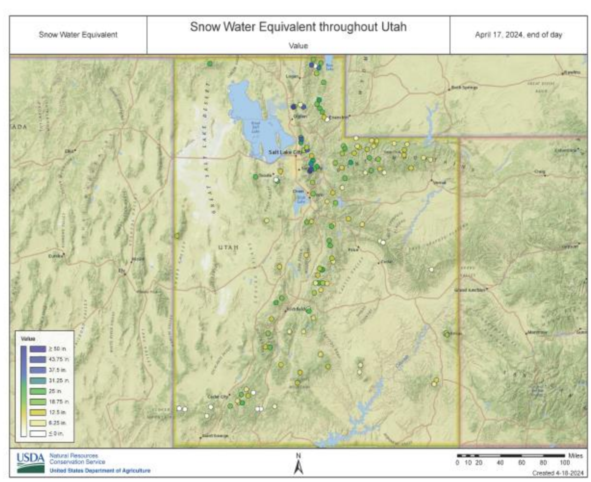

Figure 12: Illustration of Snow Water Equivalent measured by weather stations throughout Utah

Discussion

Due to the unique structure of this study, this discussion can be made by looking at the conclusions of all three explorations and putting them in context with each other. This study was put together in order for Utahns to become better informed about the status of their local environment. Because this study was intended to be public facing, the exploration into the impacts of dust on human health was the most comprehensive and included the web map explanation.

As was stated in the background, saline lakes are in steep declined globally. The Great Salt Lake stands to harm hundreds of thousands of people along Utah's Wasatch Front. Due to the fast-encroaching timeline set by Abbott et al. (2023), many Utahns won't know about this crisis until it is upon them. Many of these affected populations will be forced to upgrade home and automotive air filtration, as well as public and private buildings, stores, offices, and meetinghouses. Indoor recess for poor air quality will become the norm for Utah school children, and rates of childhood illness stand to increase.

Although a majority of the Great Salt Lake's upstream water diversions are from agricultural use, dust from the drying lakebed will start to define a vicious cycle. In the near future Utah may begin to see farmers who increase irrigation to help dying crops without realizing their water diversions may be causing the crops to die in the first place due to increased dust dispersion from the shrinking lake. As dust blows east from the lake, the Wasatch front receives the brunt of the pollution. The bulk of Utah's population and the mass of the forest areas in Utah conveniently fall directly downwind from the lakebed. In more rural areas of the 100-mile affected area, grasslands used for pasture will begin to lose vitality and decrease production. Shrubland in wild spaces will decrease in health as well, causing detriment to their local ecosystems.

Based on the potential range of dust pollution emitted from the Great Salt Lake, nine of the fifteen watersheds within Utah will be affected by the dust emissions. This will be problematic for each of these watersheds due to how dust can increase the rate of snowmelt and alter the hydrology of these areas. This is especially concerning for the Great Salt Lake's condition as its inflow originates from the Lower Bear, Weber, Jordan, and Great Salt Lake watersheds, with all but the latter being contained entirely within the estimated range of dust. Figure 12 displays how the areas with the highest Snow Water Equivalent are located within the estimated range of dust pollution. This worsens the possible threat of dust pollution as the areas responsible for much of Utah's water accumulation from snow could be affected.

The question remains of what it would look like for all these worst-case scenarios to play out. In short, it would sharply, quickly, and drastically decrease the quality of living within the affected area of Utah, or within 100 miles of the Great Salt Lake shoreline. Some of the symptoms of this decrease would include higher rates of childhood respiratory illness, or worse; it is known that the heavy metals found in the dust depositions can be carcinogenic. Strong economic downturn would ensue as farmers would see decreases in their crops due to lower production from decreased photosynthesis. Utah's infamous air quality would become even worse, making national headlines as Salt Lake City becomes a difficult place to live due to the air conditions. Finally, Utah's famous snowpack would decrease drastically, causing heavy financial burdens on local winter resorts as their ski season shrinks. Another possible outcome of the snowpack loss could be a reconsideration of Salt Lake City as the host of the 2034 Winter Olympics.

Vitally, it must be understood that the 100-mile buffer at the foundation of these studies is only based on preexisting data from monitoring stations around the Salton Sea. This means that the geographic range and residence time of airborne PM10 concentrations may be very different for the Great Salt Lake. In other words, the affected area could be smaller than 100 miles, or much wider.

What can be done about this issue? These studies have been performed as a what-if scenario in the event that the Great Salt Lake water level drops to the point where toxic dust storms become prevalent. Since the lake's record low water level in November 2022, Utah has seen two extremely high precipitation winters (Utah Division of Water Resources). This means that the Great Salt Lake is doing better than it was, but it's not in the clear yet. However, this means that the lake has possibly received some leeway since the publication of the 2023 Great Salt Lake Emergency Bulletin by Abbott et al. It seems that Utah has received a second chance at refilling the lake, which is vital now that it's better understood what would happen if that were not the case.

References

Abbott, B., Baxter, B., Busche, K., de Freitas, L., Frei, R., Gomez, T., Karen, M. A., Buck, R., Price, J., Frutos, S., Sowby, R., Brahney, J., Hopkins, B., Bekker, M., Bekker, J., Rader, R., Brown, B., Proteau, M., Carling, G., … Belmont, P. (2023). (rep.). *Emergency measures needed to rescue Great Salt Lake from ongoing collapse* (pp. 1–34). Provo, UT: BYU.

Abman, R., Edwards, E. C., & Hernandez-Cortez, D. (2023). (tech.). *Water, Dust, and Environmental Justice: The Case of Agricultural Water Diversions* (pp. 1–36). San Diego, California: San Diego State University.

Barbastegan, H., Saeidi, M., Nosratti, I., Honarmand, S., & Ghobadi, M. (2015). Dust Particles on Corn (Zea mays) Photosynthesis, Transpiration and Yield in Kermanshah, Iran. *Phillipine Agricultural Scientist*, *98*(3), 333–338.

Birds. Utah Division of Wildlife Resources. (2023). https://wildlife.utah.gov/gslep/wildlife/birds.html

Carling, G. T., Fernandez, D. P., Rey, K. A., Hale, C. A., Goodman, M. M., & Nelson, S. T. (2020). Using strontium isotopes to trace dust from a drying Great Salt Lake to adjacent urban areas and Mountain Snowpack. *Environmental Research Letters*, *15*(11), 114035. https://doi.org/10.1088/1748-9326/abbfc4

Fassnacht, S. R., Duncan, C. R., Pfohl, A. K., Webb, R. W., Derry, J. E., Sanford, W. E., Reimanis, D. C., & Doskocil, L. G. (2022). Drivers of dust-enhanced snowpack melt-out and streamflow timing. *Hydrology*, *9*(3), 47. https://doi.org/10.3390/hydrology9030047

Gleason, K. E., McConnell, J. R., Arienzo, M. M., Sexstone, G. A., & Rahimi, S. (2022). Black carbon dominated dust in recent radiative forcing on Rocky Mountain snowpacks. *Environmental Research Letters*, *17*(5), 054045. https://doi.org/10.1088/1748-9326/ac681b

Great Salt Lake & Lake Bonneville. Utah Geological Survey. (2023, October 17). https://geology.utah.gov/popular/great-salt-lake/

Great Salt Lake. Utah Division of Water Resources. (2023). https://water.utah.gov/great-salt-lake/#:~:text=Record%20Low%20Lake%20Levels,record%20low%20at%20that%20time.

Loomis, D., Grosse, Y., Lauby-Secretan, B., Ghissassi, F. E., Bouvard, V., Benbrahim-Tallaa, L., Guha, N., Baan, R., Mattock, H., & Straif, K. (2013). The carcinogenicity of outdoor air pollution. *The Lancet Oncology*, *14*(13), 1262–1263. https://doi.org/10.1016/s1470-2045(13)70487-x

Messager, M. L., Lehner, B., Grill, G., Nedeva, I., & Schmitt, O. (2016). Estimating the volume and age of water stored in Global Lakes using a geo-statistical approach. *Nature Communications*, *7*(1). https://doi.org/10.1038/ncomms13603

Moradi, A., Taheri Abkenar, K., Afshar Mohammadian, M., & Shabanian, N. (2017). Effects of dust on Forest Tree Health in Zagros Oak Forests. *Environmental Monitoring and Assessment*, *189*(11). https://doi.org/10.1007/s10661-017-6262-2

NWCC Interactive Map. Natural Resource Conservation Service. (n.d.). https://nwcc-apps.sc.egov.usda.gov/imap/#version=169&elements=&networks=!&states=!&counties=!&hucs=&minElevation=&maxElevation=&elementSelectType=any&activeOnly=true&activeForecastPointsOnly=false&hucLabels=false&hucIdLabels=false&hucParameterLabels=true&stationLabels=&overlays=&hucOverlays=&basinOpacity=75&basinNoDataOpacity=25&basemapOpacity=100&maskOpacity=0&mode=data&openSections=dataElement,parameter,date,basin,options,elements,location,networks&controlsOpen=true&popup=&popupMulti=&popupBasin=&base=esriNgwm&displayType=station&basinType=6&dataElement=WTEQ&depth=-8&parameter=PCTMED&frequency=DAILY&duration=I&customDuration=&dayPart=E&monthPart=E&forecastPubDay=1&forecastExceedance=50&useMixedPast=true&seqColor=1&divColor=7&scaleType=D&scaleMin=&scaleMax=&referencePeriodType=POR&referenceBegin=1991&referenceEnd=2020&minimumYears=20&hucAssociations=true&relativeDate=-1&lat=42.300&lon=-114.300&zoom=4.5

Putman, A. L., Jones, D. K., Blakowski, M. A., DiViesti, D., Hynek, S. A., Fernandez, D. P., & Mendoza, D. (2022). Industrial Particulate Pollution and historical land use contribute metals of concern to dust deposited in neighborhoods along the Wasatch Front, UT, USA. *GeoHealth*, *6*(11). https://doi.org/10.1029/2022gh000671

Randolph, L. (n.d.). *California Air Resources Board*. Inhalable Particulate Matter and Health (PM2.5 and PM10) | California Air Resources Board. https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health

Sharifi, M. R., Gibson, A. C., & Rundel, P. W. (1997). Surface dust impacts on gas exchange in Mojave Desert shrubs. *The Journal of Applied Ecology*, *34*(4), 837. https://doi.org/10.2307/2405275

State of Utah. (2021). *How many people in Utah have Asthma?*. Utah Department of Health and Human Services. https://health.utah.gov/asthma/data/

Tussupova, K., Anchita, A., Hjorth, P., & Moravej, M. (2020). Drying lakes: A review on the Applied Restoration Strategies and health conditions in contiguous areas. *Water*, *12*(3), 749. https://doi.org/10.3390/w12030749

Wurtsbaugh, W. A., Miller, C., Null, S. E., DeRose, R. J., Wilcock, P., Hahnenberger, M., Howe, F., & Moore, J. (2017). Decline of the world's Saline Lakes. *Nature Geoscience*, *10*(11), 816–821. https://doi.org/10.1038/ngeo3052

Zhan-Yi, W., Jia, H., Jian-Ying, G., Cheng-Jie, W., & Ming-Jiu, W. (2016). Coal dust reduce the rate of root growth and photosynthesis of five plant species in Inner Mongolian grassland. *Journal of Residuals Science & Technology*, *13*(2), 63–73. https://doi.org/10.12783/issn.1544-8053/13/2/s11