# Emergency measures needed to rescue Great Salt Lake from ongoing collapse

Great Salt Lake is facing unprecedented danger. Without a dramatic increase in water flow to the lake in 2023 and 2024, its disappearance could cause immense damage to Utah's public health, environment, and economy. This briefing provides background and recommends emergency measures. The choices we make over the next few months will affect our state and ecosystems throughout the West for decades to come. We thank all those already working on solutions, and we thank you for considering this information.

Benjamin W. Abbott[1], Bonnie K. Baxter[2], Karoline Busche[1], Lynn de Freitas[3], Rebecca Frei[4], Teresa Gomez[1], Mary Anne Karren[3], Rachel L. Buck[1], Joseph Price[1], Sara Frutos[1], Robert B. Sowby[1], Janice Brahney[5], Bryan G. Hopkins[1], Matthew F. Bekker[1], Jeremy S. Bekker[1], Russell Rader[1], Brian Brown[1], Mary Proteau[1], Gregory T. Carling[1], Lafe Conner[6], Paul Alan Cox[7], Ethan McQuhae[1], Christopher Oscarson[1], Daren T. Nelson[8], R. Jeffrey Davis[9], Daniel Horns[8], Heather Dove[10], Tara Bishop[11], Adam Johnson[12], Kaye Nelson[12], John Bennion[12], Patrick Belmont[5]

[1]Brigham Young University, [2]Westminster College, [3]Friends of Great Salt Lake, [4]University of Alberta, [5]Utah State University, [6]Wasatch High School, [7]Brain Chemistry Labs, Jackson Hole, [8]Utah Valley University, [9]Integral Consulting, [10]Great Salt Lake Audubon, [11]Ph.D. Research Ecologist, [12]Conserve Utah Valley

**Figure 1.** A bridge where the Bear River used to flow into Great Salt Lake. Photo: EcoFlight.

First published on Wednesday, January 4th, 2023

# *Executive summary*

1. **Great Salt Lake is a keystone ecosystem in the Western Hemisphere**. The lake and its wetlands provide minerals for Utah's industries, thousands of local jobs, and habitat for 10 million migratory birds[1–4]. Fertilizer and brine shrimp from the lake feed millions of people worldwide[5,6]. The lake provides $2.5 billion in direct economic activity yearly[7–10], as well as increasing precipitation, suppressing toxic dust, and supporting 80% of Utah's wetlands[11–17].
2. **Excessive water use is destroying Great Salt Lake**. At 19 feet below its average natural level since 1850, the lake is in uncharted territory[18–22]. It has lost 73% of its water and 60% of its surface area[23–26]. Our unsustainable water use is desiccating habitat, exposing toxic dust, and driving salinity to levels incompatible with the lake's food webs[1,24,27–29]. The lake's drop has accelerated since 2020, with an average deficit of 1.2 million acre-feet per year. If this loss rate continues, the lake as we know it is on track to disappear in five years.
3. **We are underestimating the consequences of losing the lake.** Despite encouraging growth in legislative action and public awareness, most Utahns do not realize the urgency of this crisis. Examples from around the world show that saline lake loss triggers a long-term cycle of environmental, health, and economic suffering[30–35]. Without a coordinated rescue, we can expect widespread air and water pollution, numerous Endangered Species Act listings, and declines in agriculture, industry, and overall quality of life[1–4,36].
4. **The lake needs an additional million acre-feet per year to reverse its decline.** This would increase average streamflow to ~2.5 million acre-feet per year, beginning a gradual refilling. Depending on future weather conditions, achieving this level of flow will require cutting consumptive water use in the Great Salt Lake watershed by a third to a half. Recent efforts have returned less than 0.1 million acre-feet per year to the lake[37], with most conserved water held in reservoirs or delivered to other users rather than released to the lake.
5. **Water conservation is the way.** While water augmentation is often discussed (pipelines, cloud seeding, new reservoirs, and groundwater extraction, etc.), conservation is the only way to provide adequate water in time to save Great Salt Lake[33,38–41]. Conservation is also the most cost effective and resilient response[42,43], and there are successful examples throughout the region[44–48]. Ensuring financial, legislative, and technical support for conservation will pay huge dividends during this crisis and for decades to come[1,38,46,49].
6. **We need to increase trust and coordination.** New legislation allows users to return water to the lake while retaining rights[50]. However, lack of trust and cooperation between farmers, cities, managers, and policymakers is hobbling our response[33,38]. Users often have financial disincentives to conserve, and farmers often lack legal counsel to navigate policy changes.
7. **We call on the governor's office to implement a watershed-wide emergency rescue**. We recommend setting an emergency streamflow requirement of at least 2.5 million acre-feet per year until the lake reaches its minimum healthy elevation of 4,198 feet[51]. Executive leadership is needed for water leasing, farmer compensation, water donations, and conveyance[52]. Every major water user needs to be educated, empowered, and assured that their conserved water will be shepherded to Great Salt Lake. We need clear thresholds that trigger binding emergency conservation measures to stop the lake's collapse.
8. **We call on the legislature to fund and facilitate the rescue.** Recent bills have laid the groundwork, and a surge of funding is now needed to lease or purchase water and support farmers and cities to dramatically reduce consumption. Likewise, legislation is needed to put in place the policies, accounting, and monitoring for water shepherding to the lake and long-term sustainable water use[52].
9. **We call on every water user and manager to conserve water and support state efforts**. We are in an all-hands-on-deck emergency, and we need farmers, counties, cities, businesses, churches, universities, and other organizations to do everything in their power to reduce outdoor water use. We believe that our community is uniquely suited to face this challenge, but only if we implement a unified and pioneering rescue. By taking a "lake first" approach to water use, we can leave a legacy of wise stewardship for generations to come.

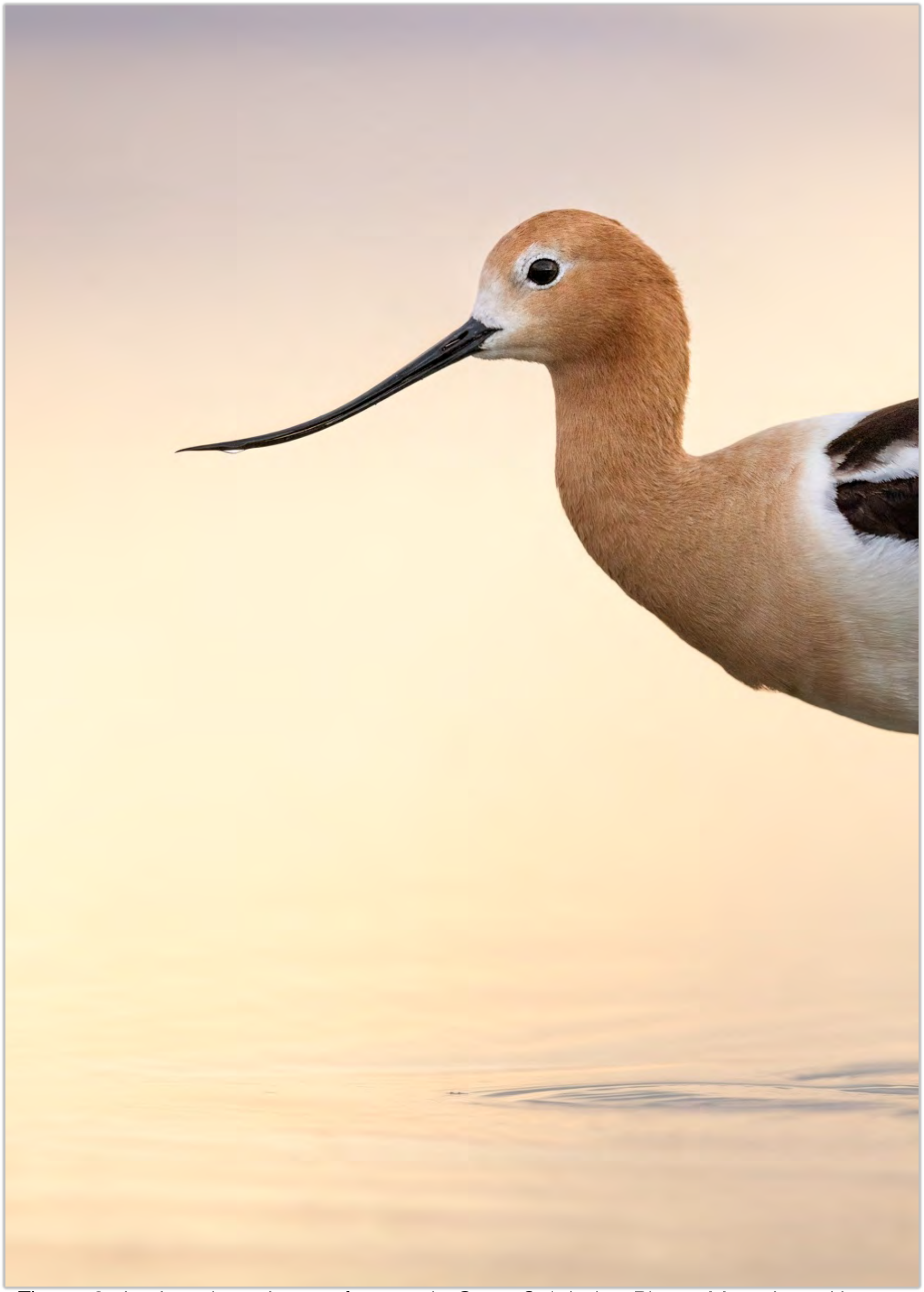

**Figure 2.** An American Avocet forages in Great Salt Lake. Photo: Mary Anne Karren.

## The lake's importance

Great Salt Lake is the largest saline lake in North America. The lake and its wetlands form a keystone ecosystem that supports biodiversity and human economy throughout the Western Hemisphere[1]. Terminal lakes like Great Salt Lake occur in semi-arid regions where there is enough precipitation to sustain surface water but not enough to erode a river channel to the ocean[53]. The lake directly provides ~$2.5 billion in economic productivity each year and supports ~9,000 jobs locally (Table 1)[7]. These direct benefits come primarily from mineral extraction, recreation, and brine shrimp harvesting[7–9]. Evaporation from Great Salt Lake increases annual snowfall in nearby mountains by 5-10%, supporting another 20,000 jobs and an additional $1.8 billion in annual economic activity[8,9,16,54].

**Table 1.** Direct economic value of Great Salt Lake

| | *Millions USD/year* | | | *Number* |
|---|---|---|---|---|
| **Sector** | **Economic output** | **Labor income** | **Total economic value** | **Jobs** |
| Industry | 1,549 | 424 | 1,973 | 5,400 |
| Recreation | 186 | 63 | 249 | 1,800 |
| Ski industry* | 110 | 53 | 163 | 1,000 |
| Aquaculture | 78 | 28 | 106 | 600 |
| **Total** | **1,923** | **568** | **2,491** | **8,800** |

**Estimates include 5% of Utah's ski industry—the approximate amount of Wasatch Front resort snowfall that comes from Great Salt Lake evaporation. Estimates are from [7–10] expressed in 2022 USD. These numbers should be considered as underestimates because they do not include the broader ecosystem services provided by the lake system.*

The lake is a vital link in the Pacific Flyway, providing food and habitat for more than 10 million migratory birds and wildlife throughout the Wasatch Front[1,4,36,55]. Almost 350 bird species depend on Great Salt Lake habitats, including globally significant numbers of Eared Grebes, Tundra Swans, Snowy Plovers, American Avocets, and multiple species of ducks, phalaropes, owls, and blackbirds (Fig. 3). The lake's diverse wetland, island, and open-water environments are becoming even more crucial as habitat is lost or degraded throughout the western US[56,57].

Great Salt Lake also provides numerous ecosystem services, including protection of air quality, removal of water pollution, and moderation of local weather[27,29,54,58]. As the namesake of the Salt Lake Valley, the lake is foundational to our cultural identity[59]. Its dramatic vistas have inspired countless scientists, pioneers, artists, writers, photographers, and recreationists[27,59]. We believe that our stewardship of the lake reflects our community's cultural values. Protecting the lake is not only a question of public health, economy, or environment; it shows our moral commitment to create a healthy home for ourselves, other living things, and future generations.

**Figure 3.** Ten of the 338 bird species known to feed, breed, or seek refuge at Great Salt Lake. Photos: Mary Anne Karren, Jeff Beck, Jeremy Bekker, Russell Hatch, Travis McCabe, Chuck Castleton.

## Causes of decline

After millennia of natural fluctuations, human water use has pushed Great Salt Lake into structural decline. Since 2020, the lake has lost just over one million acre-feet of water each year (Fig. 4), much more than predicted by current hydrographic models[20,60,61]. If this rate of water loss continues, the lake would be on track to disappear in the next five years. The lake is now 10 feet and 6.9 million acre-feet below its minimum healthy level, which has only been attained once since 2002 (Fig. 4)[51].

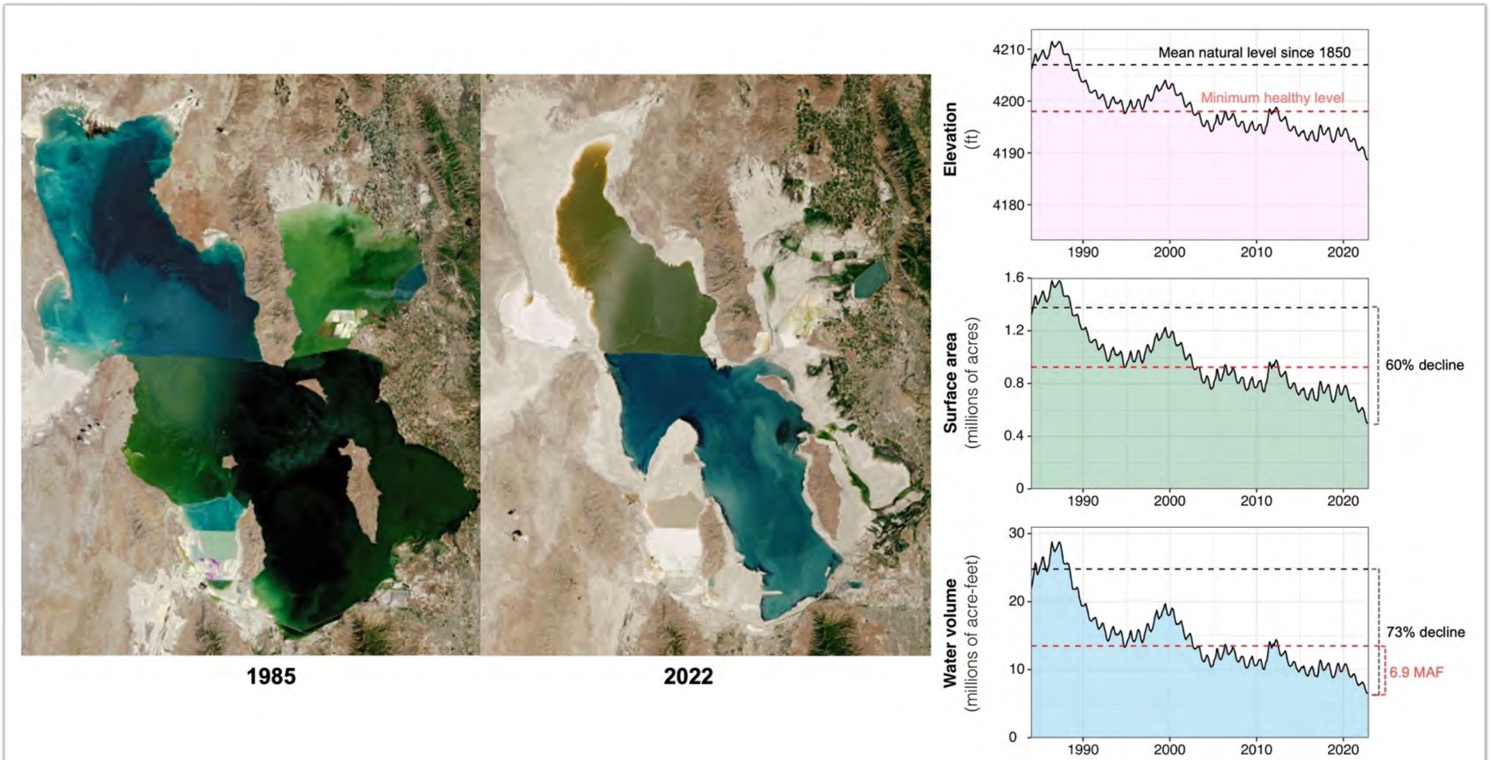


**Figure 4.** Elevation, extent, and volume of Great Salt Lake from 1985 to 2022. The mean natural values were determined from estimated 1850-2016 values without human water use[3]. The 1985 lake level is close to the long-term natural average of 4207’, providing a useful comparison. Data from USGS, NASA, and references [3,21,62].

Saline lakes are highly vulnerable to water overuse because they depend on a delicate balance between streamflow and evaporation. Consequently, there is a strong relationship between the area of irrigated agriculture in a saline lake’s watershed and the severity of its shrinkage[53]. Agriculture began affecting Great Salt Lake levels in the mid 1800s[38]. However, it wasn’t until the 1900s that humans became the dominant force controlling the lake[3,23,59]. Federal and state construction of dams, canals, and pipelines in the 1900s allowed more of the watershed’s natural runoff to be diverted for agricultural, industrial, and municipal use[3,38,53]. These subsidized water projects led to unsustainable water consumption[42,63] and plummeting lake levels through the 1960s[1,3]. An extremely uncommon wet period in the 1980s temporarily refilled the lake[1,23], but since peaking in 1987, it has been in steady decline (Fig. 4).

Over the last three years, the lake has received less than a third of its natural streamflow because of excessive water diversions (Fig. 5)[60]. In 2022, the lake dropped to a record elevation of 4188’—the lowest level on the state’s contingency charts[10,18,64]. The depletion of water is even more severe than it appears because groundwater is not included in these estimates. Approximately 26 million acre-feet have been lost from the lake itself, but twice that amount may have been lost from the aquifers around the lake due to water table drop[65]. These empty aquifers could slow the rate of rebound after runoff is increased.

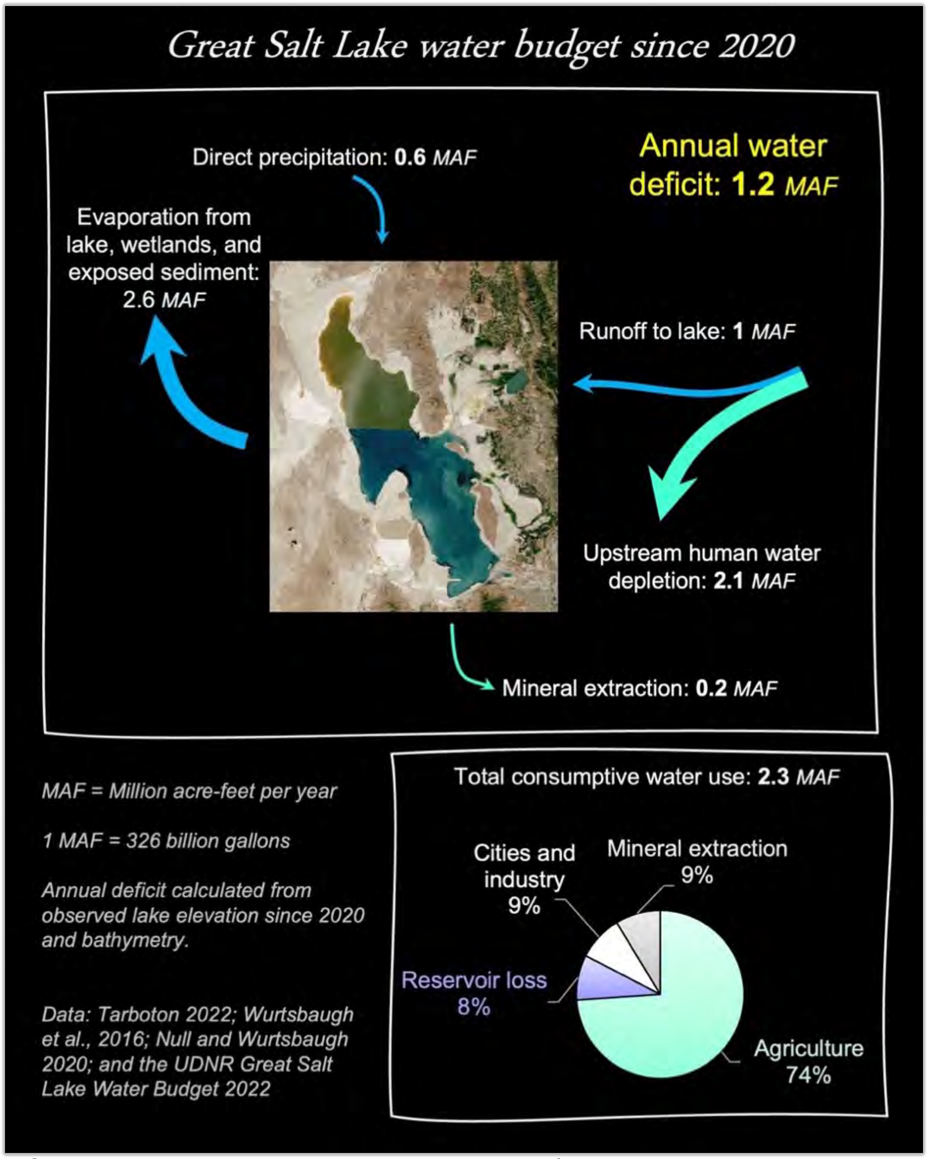


**Figure 5.** Great Salt Lake water budget, including a breakdown of consumptive water use. The reported numbers represent estimates from 2020-2022, the period of accelerated decline[1,3,25,60,62,66,67]. Because of inadequate monitoring and data availability, many of these estimates are uncertain.

Like most saline lakes, Great Salt Lake has a large watershed crossing multiple jurisdictions (Fig. 6)[2,30,68]. The 23-million-acre watershed is divided into four main basins, with the Bear, Jordan, and Weber watersheds contributing almost all surface water inflow (Fig. 6). Irrigated agriculture covers 1.4 million acres or 6% of the watershed. 63% of this agricultural land occurs in Utah, 31% in Idaho, 5% in Wyoming, and 1% in Nevada. Urban development covers 0.7 million acres or 3% of the watershed area, with 93% occurring in Utah.

Agriculture dominates water use in the Great Salt Lake watershed (Fig. 5)[25,26,69]. Irrigation of alfalfa and other crops directly accounts for around three quarters of total consumptive water use plus 5-10% indirectly through storage and transport losses such as reservoir evaporation[1,3,66]. Mineral extraction from the lake itself represents another 9% of water use (Fig. 7). Cities and industry account for the final 9% of consumptive water use, of which 90% is outdoor water use (irrigation for lawns and other decorative plants). The remainder of the consumptive use comes from thermoelectric power production, mining, and other industrial processes[25,70]. Indoor water use has little direct effect on lake level because ~95% is returned after wastewater treatment, though the storage, conveyance, and treatment of water used indoors does cause consumptive losses and degradation of water quality[25,71].

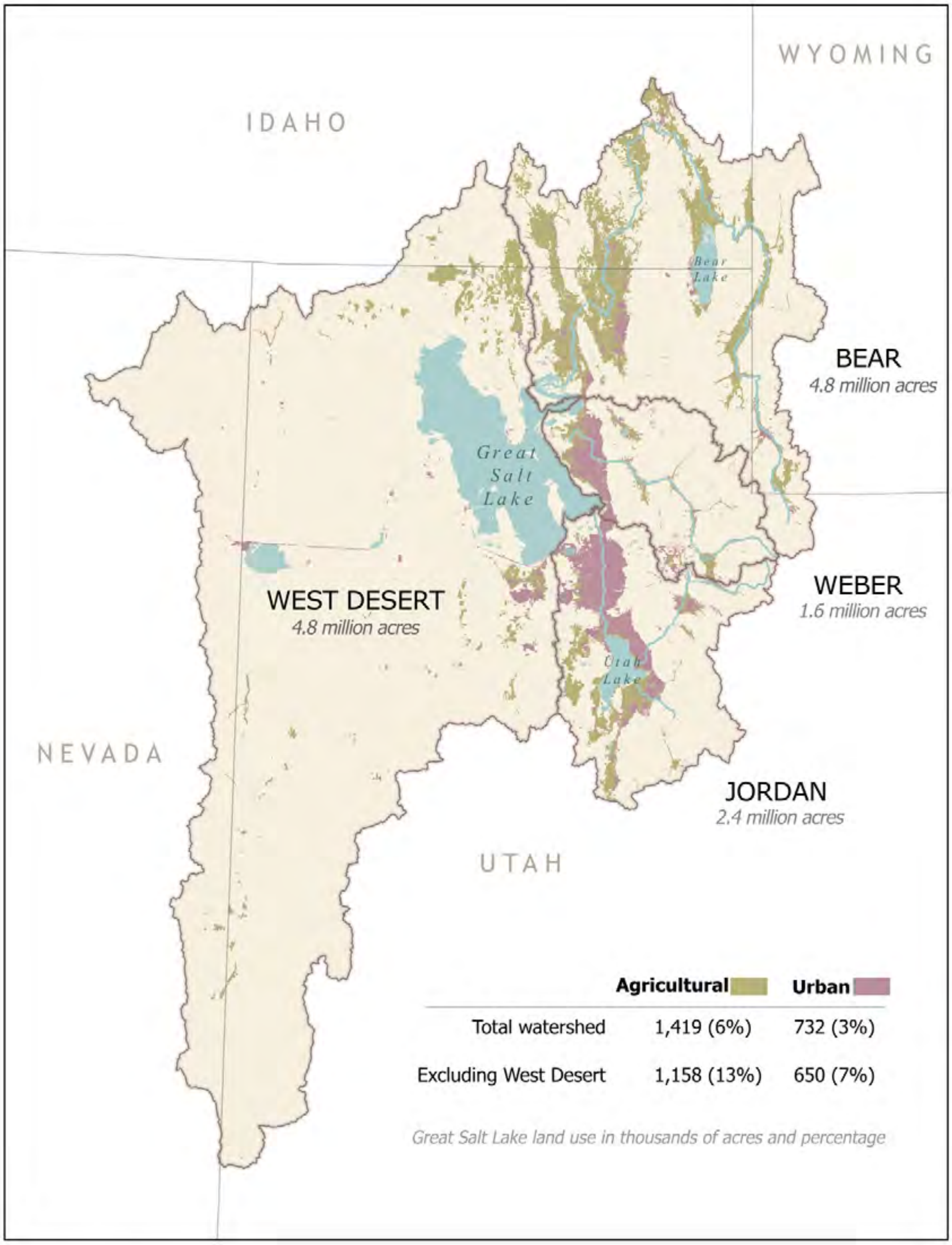


**Figure 6**. Map of the Great Salt Lake watershed, including the most extensive land uses (agricultural and urban).

Climate change is a secondary contributor to the decline of Great Salt Lake. Human greenhouse gas emissions have caused ~4°F of warming in northern Utah since 1900 and exacerbated drought in the southwestern U.S.[66,72–74]. This climate change has reduced runoff to Great Salt Lake and increased evaporation, accounting for ~9% of the lake's decline based on current estimates[2,23,43,66]. Streamflow is projected to decrease in the future, making water conservation even more important[66,75,76]. We need to plan for a drier Utah.

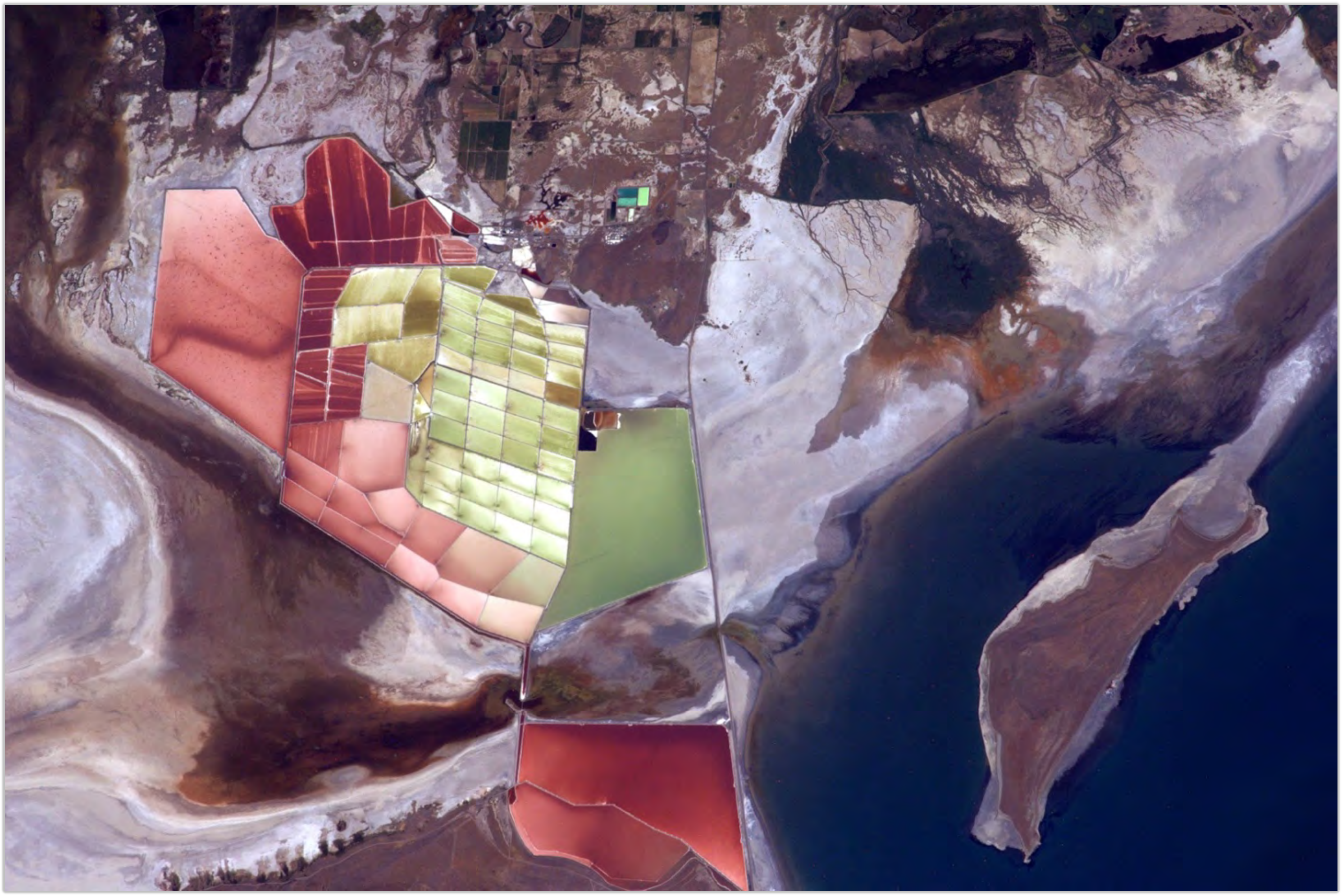

Figure 7. Evaporation ponds on the east side of the lake seen from the International Space Station. Water is taken from the lake to accelerate evaporation and extract potash fertilizer, magnesium, sulfate, table salt, and other minerals. Photo: Alexander Gerst, ESA.

## Consequences of losing the lake

Irrigated agriculture is destroying saline lakes on every continent except Antarctica[2,30,53,68]. Examples from around the world show potential consequences of Great Salt Lake collapse. The loss of a saline lake sets off a sequence of environmental and economic damage that is extremely difficult to reverse[2,30,33]. Specific consequences depend on local circumstances but often include air and water pollution, collapse of agricultural productivity, loss of industry, economic depression, and devastation of lake and wetland ecosystems[1,33,34,77–79].

Even when a lake is not completely lost, shrinkage can expose lakebed sediments laden with heavy metals and organic pollutants[1,80]. At the bottom of their large watersheds, saline lake sediments collect pollutants from human activities and natural sources including coal burning, mining, agriculture, and urban runoff. The following pollutants have been detected in Great Salt Lake sediment: arsenic, cadmium, mercury, nickel, chromium, lead, copper, selenium, organic contaminants, and cyanotoxins[12,13,32,81–87]. These pollutants can be transported by dust particles smaller than 10 microns (1/5$^{th}$ the width of a hair)[84]. Particulate matter from dried lakebeds can increase rates of chronic and acute diseases associated with air pollution, including reproductive disfunction, developmental defects, cognitive impairment, cardiovascular damage, and cancer[14,35,88,89]. Air pollution already causes 1-in-5 deaths globally—around 12.1 million premature deaths annually[88,90]—and dried lakebeds can erase air quality improvements that took decades to achieve[79,91–93]. Increased dust deposition in the watershed can also damage agricultural crops, degrade soil fertility, and cause premature snowmelt when deposited on snowpack (Fig. 8)[12,13,94].

**Figure 8.** Dust from drying saline lakes. Left: Mar Chiquita, Argentina (NASA, Jeff Schmaltz). Upper right: Owens Lake, California (Brian Russell). Lower right: dust darkens snowpack in the Rockies causing early melt (NASA).

Ecological damage from losing a saline lake is extreme[2,68]. Changes in water extent, depth, and chemistry can disrupt or destroy local food webs, often causing continental-scale impacts[1,2,28]. The loss of evaporation from the lake can modify nearby climate, producing more extreme temperature swings, desertification, and further reduction of runoff[49,81,95,96]. Together these effects can severely harm communities in the watershed of a shrinking lake, triggering abrupt crashes of lake industries, suppression of property values, mass migration, and social conflict associated with the loss of jobs, cultural identity, and quality of life[2,11,31,97].

**Figure 9.** A juvenile gull feeds on brine flies, which depend on microbialite habitat that is being destroyed by desiccation and salination. Photo: Mary Anne Karren.

Great Salt Lake is showing many of the symptoms of socioecological collapse, and these negative effects will grow more severe if water flow is not rapidly restored to the lake:

1. **Food web collapse**: The salinity of the main body of the lake has climbed to ~19%. At this level, the brine flies and brine shrimp cannot maintain their populations because of decreased primary productivity (i.e., loss of their food sources) and direct inhibition of their life cycles[98–102]. These invertebrates feed migratory birds and support much of the lake's industry[1]. Brine fly populations declined dramatically in 2022, and brine shrimp are expected to decline in 2023[28,103].
2. **Erosion of economic activity**: At levels the lake may reach in 2023 and 2024, withdrawing water from the lake for mineral extraction could be unviable. Additionally, if the lake's bird species are listed under the Endangered Species Act, economic activity may be stopped by federal regulation. In particular, Wilson's Phalaropes and Eared Grebes are threatened by Great Salt Lake's decline[28]. A recent economic analysis for the Great Salt Lake Advisory Council estimated that the drying lake could cost Utah $1.7 to $2.2 billion annually and destroy 6,600 jobs[10].
3. **Air pollution and dirty snow**: The salty crust deposited by the drying lake temporarily delays dust release. However, as more of the lakebed is exposed for longer, air pollution will increase throughout the Intermountain West[84]. Dust from Great Salt Lake has already been observed from southern Utah to Wyoming, and most of the dust in the Wasatch Front already comes from dry lakebed[12,13,84,104]. Saline lake dust causes acute local air pollution and harms crops and snowpack (Fig. 8)[12,13,94].

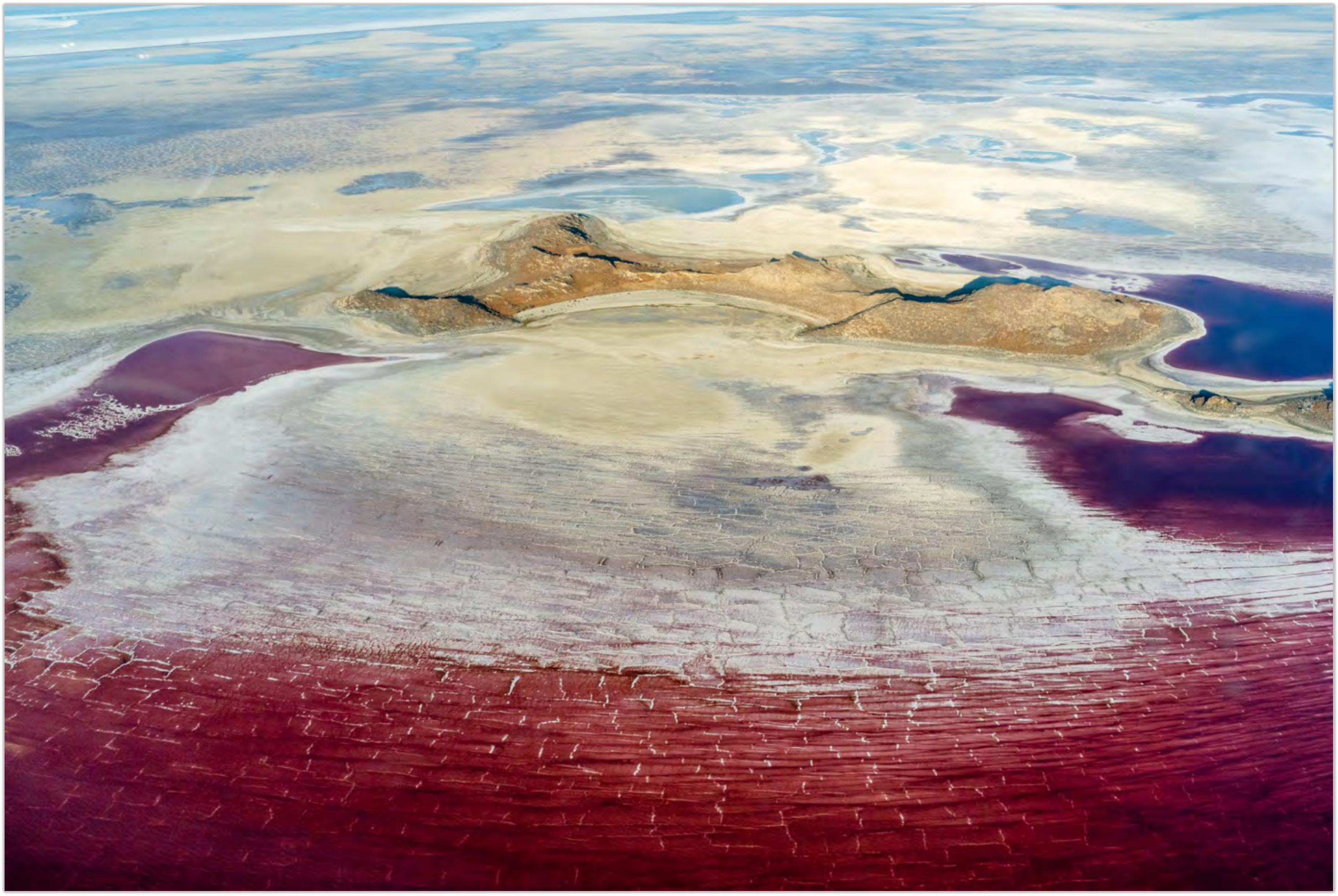

Figure 10. Gunnison Island and the receding hypersaline water of Great Salt Lake's North Arm. With the island connected to the mainland, predators can access the island's colony of American white pelicans, which is one of the largest in the world[105]. Photo: EcoFlight.

The lake's North Arm is a warning of what the future could hold unless streamflow is restored. Cut off by a railroad causeway in 1959, the North Arm receives almost no surface runoff[106,107]. The lack of freshwater flow caused salinity to reach saturation, killing the microbialites and algae that form the base of the lake's food web. The disrupted lake circulation temporarily caused the highest methylmercury levels in the country[1,108–113]. Water conservation could prevent this fate for the rest of the lake and restore health to the compromised North Arm.

## New conservation tools and commitments

Recent changes in water law and policy have created new tools for water conservation and conveyance to Great Salt Lake[22,50,114]. These improvements include designating instream flow and sovereign lands as beneficial uses, more funding for agricultural efficiency, and enhanced monitoring of water use (Table 2). These updates allow farmers and other water users to leave water in the streams and rivers without losing water rights. The 2022 legislative session committed record funds, and Governor Cox has called for an additional ~$350 million for Great-Salt-Lake-related measures in the 2023 budget[50,115]. Likewise, federal support has grown through grants, the Saline Lake Ecosystems Act, and the Great Salt Lake Recovery Act[114,116].

**Table 2.** Water legislation from 2022 pertinent to the Great Salt Lake emergency response

| Bill | Purpose | Significance |
|---|---|---|
| HB33: Instream Water Flow Amendments | Increases flexibility in use of water rights, designating instream flow for use on sovereign lands as beneficial | Allows water users to return rights to the lake without losing their shares up to 10 years at a time |
| HB410: Great Salt Lake Watershed Enhancement Program | $40 million trust to support voluntary transactions and projects to enhance or preserve water flows to the lake | Empowers FFSL to better study and manage the lake, including working with stakeholders |
| HB429: Integrated GSL Watershed Assessment | Produce a status, use, and conservation report by November 2022 | Could identify areas where further information is needed and guide water conservation efforts |
| HB168: Preferences of Water Rights | Enacts a provision for the use of water during a temporary water shortage emergency | Could allow the state to clarify how water rights should be administered during shortages |
| HB242: Secondary Water Metering | Requires nearly all providers of secondary water to install meters by 2030 | Could encourage conservation and potential pricing of secondary water |
| S. 1466: Saline Lake Ecosystems in the Great Basin States | Establishes a program through the USGS to assess, monitor, and improve management of saline lakes | Gathers information about Great Salt Lake hydrology and biodiversity, including shortcomings in current measurements and models |

*Legislation from other years overviewed in [22], and additional details for 2022 available in reference [50].*

In addition to legislative changes, many cities, counties, conservancy districts, businesses, and community organizations are implementing major water conservation measures[44–46,71]. Government, nonprofit, and private organizations are coming together, including the Utah Department of Natural Resources, the Utah Department of Environmental Quality, Great Salt Lake Advisory Council, the Utah Department of Agriculture and Food, the Natural Resources Conservation Service, the Great Salt Lake Strike Team, Friends of Great Salt Lake, and the Great Salt Lake Collaborative. Together, these and other groups have elevated public awareness for Great Salt Lake conservation through dozens of events and initiatives[28,66].

**Figure 11.** A child explores rock formations on the shore of Great Salt Lake. Photo: Angie Hatch.

While the changes above will likely contribute to water conservation in the coming decades, they are not adequate to help the lake through its current crisis. In fact, if legal, financial, and technical support is not provided for water users to implement these changes, the new policies could have little to no influence on Great Salt Lake in 2023 and 2024. For example, conservation in 2022 increased streamflow to the lake by less than 100,000 acre-feet, with most conserved water held in reservoirs or consumed elsewhere in the watershed[37,62].

## Call for a coordinated rescue

An emergency response plan needs to be put in action during the first half of this year to avoid catastrophic changes in the Great Salt Lake system. The lake is currently 10 feet below its minimum healthy elevation based on the state's management matrix, representing a shortfall of 6.9 million acre-feet (Fig. 4)[21,51]. Streamflow to the lake needs to be dramatically increased in 2023 and 2024 to reverse the lake's collapse.

Based on the best available hydrological and societal-impacts data[21,22,47,51,52,62], we recommend setting a minimum streamflow requirement of 2.5 million acre-feet per year. River flow at or above this threshold corresponds strongly with periods of lake elevation rise (Fig. 12). This is approximately one million acre-feet per year more than the annual average streamflow to the lake (1.6 million acre-feet per year since 2020)[21,60,62]. Depending on future weather conditions, this could require 0.7 to 1.2 million acre-feet per year of conservation, representing a 30 to 50% reduction in consumptive water use in the watershed (Fig. 5).

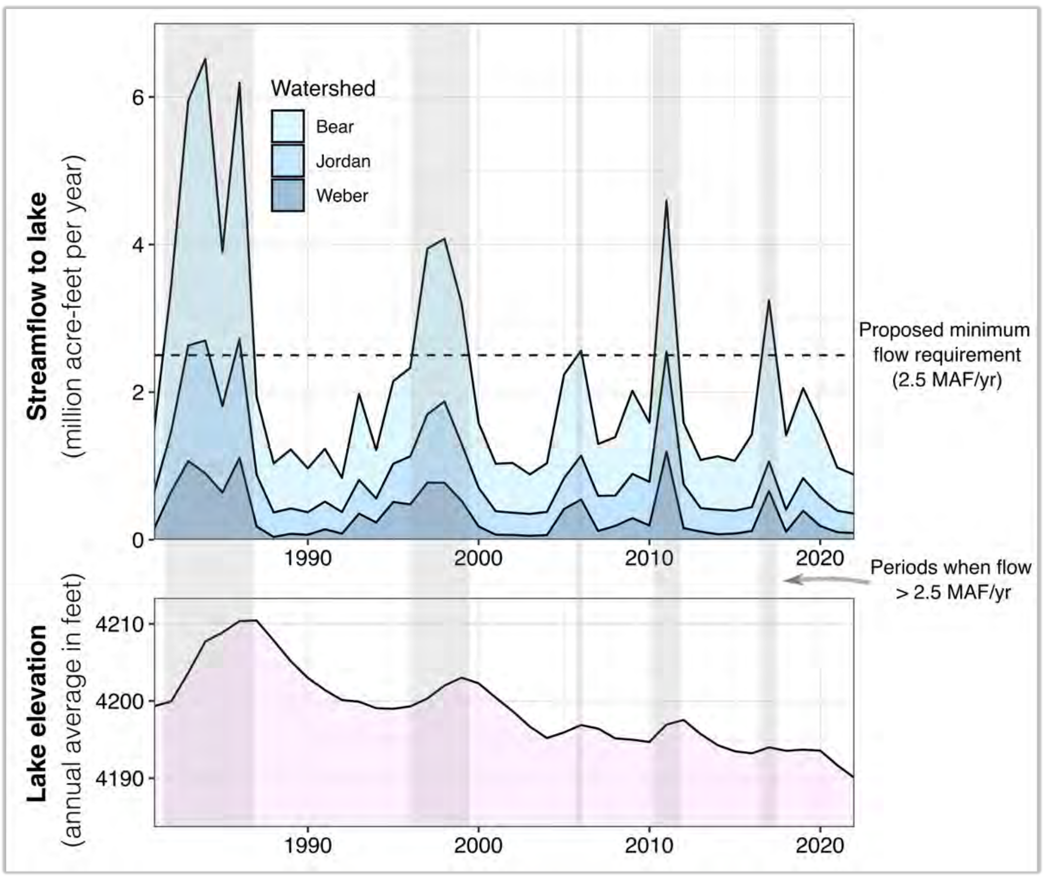


Figure 12. Streamflow to Great Salt Lake and annual lake elevation since 1981. The vertical shading shows years when streamflow equaled or exceeded our proposed minimum flow requirement of 2.5 million acre-feet per year.

The remainder of this report describes general approaches and specific actions to equip our community to face this challenge. No single intervention or organization can solve this crisis on its own, and we invite each person and institution to do all they can. Above-average snowfall this winter could provide a desperately needed jumpstart towards 2.5 million acre-feet, but only if we seize the day and make sure the water reaches the lake.

## Principles for sustainable water management

Over the past century, the fields of global hydrology and water security have generated important insights about resilient water management[38,42,49,75,117–119]. This includes a large body of literature on Great Salt Lake and similar saline lakes around the world (see references at the end of the report)[1,30,68]. In this section, we summarize a few of the general approaches we find most relevant to Great Salt Lake.

### *Learn > Conserve > Augment*

Water scarcity is the difference between demand and supply[120]. Our first instinct when faced with scarcity is often to increase supply through "hard-path" solutions like dams and pipelines. However, experience from around the world has shown that augmentation (increasing supply) should be a last resort[118,121]. Sustainable water management recommends the following prioritized steps to strengthen water security in a given region[42,122]:

1. **Learn**: Carefully study the physical, biological, and social dimensions of water
2. **Conserve**: Systematically eliminate water waste and overuse
3. **Augment**: Increase supply as little as necessary after exhausting steps 1 and 2

There are many ecological and economic reasons to follow this sequence. Large-scale water infrastructure is extremely expensive, and water projects are notorious for *"cost overruns, benefit shortfalls, and the systematic underestimation of risk"*[123]. Even when projects are completed as intended, they are often scaled incorrectly because of inadequate consideration of hydrological variability and changes in water demand[63,124]. This can cause water overallocation, leaving a community with more problems than before the project[123,125,126]. This is especially true in a world of rapid land use and climate change, where many water projects are obsolete before completion[43]. Finally, water augmentation in one region requires water depletion in another, shifting rather than resolving scarcity[31,49,127].

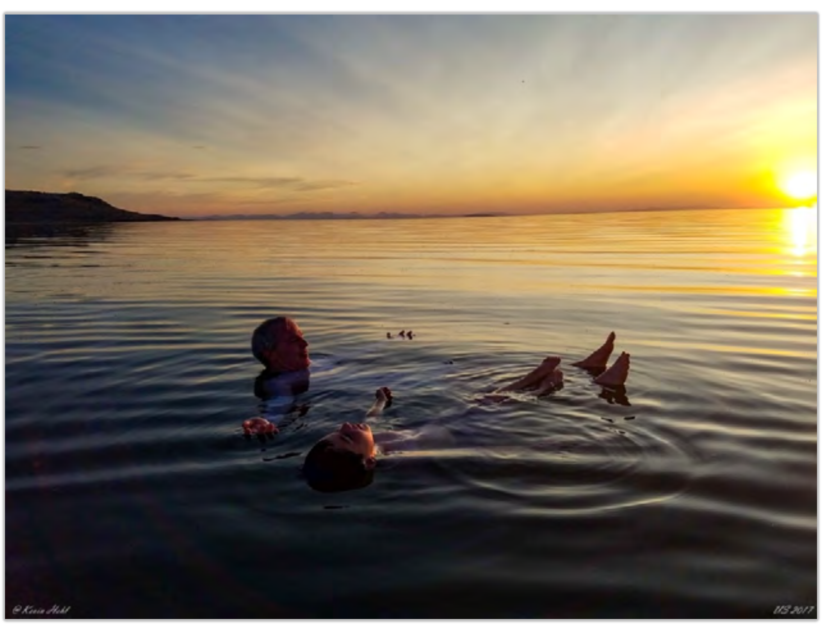

**Figure 13.** A family enjoys the buoyancy of Great Salt Lake's saline water. Photo: Kevin Hehl.

The Great Salt Lake watershed provides multiple examples of hard-path water compromises, including Bangerter's pumps, a federally-subsidized and oversized reservoir system whose storage and conveyance losses equal total municipal water use, and interbasin transfers that are accelerating the decline of the Colorado River while inducing local consumption[63,71,128–130]. Thankfully, wise managers and citizens have helped us dodge many silver bullet "solutions," including persistent proposals for new reservoirs and pipelines such as the Bear River Development and repeated attempts to fill in our watershed's freshwater lakes to reduce evaporation[3,71,131].

Rather than increasing supply, it is almost always more cost effective and resilient to decrease demand[39,122,132]. This is a hydrological application of the principle of **living within our means**. Conservation initiatives such as water pricing, water markets, and consumption caps often achieve their goals ahead of schedule and under budget[39,46,133]. For example, a recent analysis of water use in the Great Salt Lake watershed estimated that conservation could return adequate water to the lake for a total cost of $14 to $96 million—$5 to $32 per person in the watershed[132]. The use of open water markets where users can freely buy and sell available water could decrease the conservation cost even further to $6 to $48 million—$2 to $16 per person[39,132]. Even if these estimates are overly optimistic by an order of magnitude, they blow augmentation proposals' return-on-investment out of the water[134].

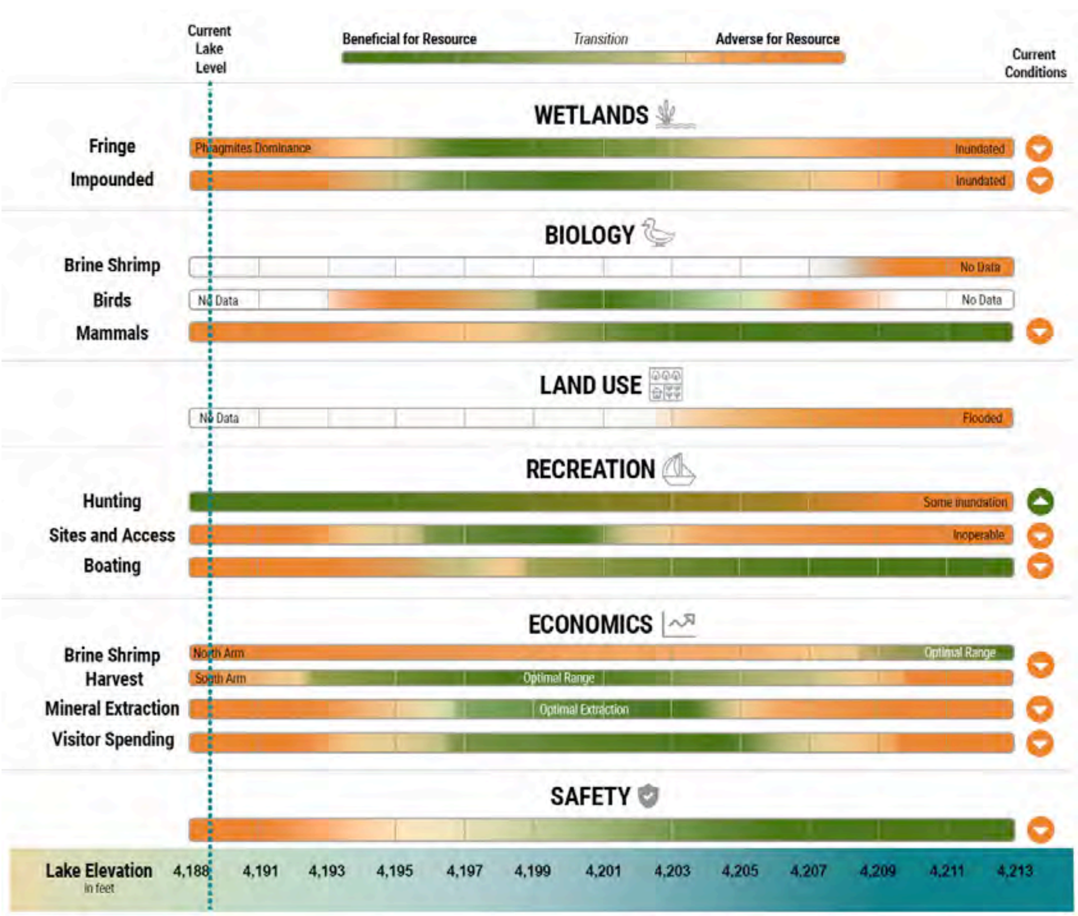


**Figure 14**. Simplified version of the state's Great Salt Lake elevation matrix from the USGS. The full matrix and report developed by Forestry, Fire, & State Lands is accessible here[51].

## *Nature is the model; naturalness is the goal*

The foremost law in ecology is "Nature knows best," or the law of unintended consequences[135]. This law has two major implications for water management. First, the more altered and artificial a system is, the more rigid and high maintenance it tends to be[136]. Second, more modification creates more negative tradeoffs and compromises[71,119]. The Great Salt Lake ecosystem is highly modified and managed[6,137]. From streamflow inputs to wetland water levels, almost every aspect of its hydrology and chemistry is controlled by people (Fig. 13). These changes were made with good intentions, but they contribute to the lake's current crisis[1,3,106,138].

A return to a "pristine" pre-human state is neither desirable nor possible[119], but we should use naturalness as an overarching management goal when implementing future changes[136]. This approach can increase the chances of success, decrease the likelihood of side effects, and lay the groundwork for a self-regulating system that is resilient to future natural and human pressures[118,139,140]. In practice, this principle should inform goals about the amount and timing of streamflow to the lake and the area of conservation buffer needed around the lake to allow natural fluctuation without undue infrastructure damage. For example, the target elevation range for the lake should be increased to include the lake's long-term natural level (4207 feet)[3,51]. By restoring more natural hydrology to Great Salt Lake, levels will rise and there will be major co-benefits for water and habitat quality in the upstream rivers, lakes, and wetlands (e.g., Utah Lake, Jordan River, Weber River, Logan River, and Farmington Bay)[71,136,141].

**Figure 15.** Complex dikes and flow control structures in the wetlands around the lake. Photo: EcoFlight.

## *A lake-first approach to water stewardship*

Water for the environment has historically been relegated to last place in western water law[142–145]. However, putting nature last neglects the fact that human flourishing depends on environmental health[78,88,146]. Shifting water among different users may treat symptoms of overuse, but it does not resolve the root problem[124,133]. To create a sound foundation for our state, we need to permanently allocate the lake its fair share of water. The water law concept of prior appropriations—*first in time, first in right*—could be highly useful to this end. The original beneficial use of water in our region is the lake itself and the soils, aquifers, and river networks that make up its watershed. As responsible stewards, we need to establish a binding environmental flow right for Great Salt Lake[133]. This right should be based on both lake level and annual streamflow, to avoid long-term catastrophe and ensure annual ecosystem health[51].

Though recognizing the lake's water right decreases the amount of water available for human use in a given year, it benefits water users by decreasing uncertainty[124]. For example, after the lake's share is met, remaining water could be distributed based on prior appropriation or a proportional reduction applied to all shares equally, as was recently approved in Nevada[147]. The prior option has the advantage of aligning with current water law in Utah, but the latter option is more equitable and could create more certainty and economic benefit for a greater number of users, particularly if coupled with water markets[132]. Certainty is extremely valuable when making agricultural and natural resources decisions, and water users might be supportive of changes that increase certainty even if it means less total water[124].

Recognizing Great Salt Lake's right to exist fills another need that is less tangible but perhaps more important. This respectful approach to God's creation is in line with the religious and cultural teachings of the Indigenous and immigrant peoples of Utah[148–151]. There is no better way to honor the legacy and foresight of our ancestors and Creator than acting as wise stewards of the watershed entrusted us.

**Figure 16.** Great Salt Lake and its watershed seen from the International Space Station. Photo: Alexander Gerst.

## Specific management options

### *Federal government*

1. Increase federal funds available for water conservation in the Great Salt Lake watershed through existing and new channels (e.g., WIFIA, ARPA, FEMA). We recommend some specific expenditures under the state government section.
2. Coordinate water use agreements across state lines. Because a third of the consumptive water use in the Great Salt Lake watershed occurs out of state (Fig. 4), federal facilitation of conservation may be necessary.
3. Expand monitoring of Great Salt Lake hydrology, including water use and climate. Current estimates are quite rough for surface and subsurface flow to the lake, evapotranspiration from the lake and surrounding wetlands, and water consumption throughout the watershed[60,62]. This hampers robust estimation of sustainable flow targets and our ability to measure progress[114].
4. Use existing human resources in federal agencies (e.g., BLM, NOAA, NPS, F&W, USGS, EPA, etc.) to strengthen coordination with state agencies managing the lake. Current efforts to monitor and manage lakebed, wetlands, and water conservation efforts suffer from incomplete communication and cooperation, partly because of not having enough personnel.

**Figure 17.** Livestock and water Infrastructure in the Heber Valley. Photo: Ben Abbott.

### *State government (executive, legislative, agencies)*

1. Authorize emergency water releases from reservoirs to increase streamflow to the lake this year and next. This could include water lease, purchase, or emergency mandate to stabilize Great Salt Lake and benefit impaired aquatic ecosystems throughout the watershed. Compensate water wholesalers for associated loss of revenue.
2. Establish a long-term target lake level and a short-term emergency release plan. The general framework for sustainable lake management has already been developed in state reports[22,51,52]. We now need timelines and milestones with legally binding actions informed by a detailed analysis of how many acre-feet each action will deliver.
3. Create a high-profile website that publicizes overall savings and highlights “water heroes” who are conserving the most. There could be a conservation goal set each winter before water is allocated and a progress bar showing water flow to the lake.
4. Use current state employees, temporary hires, and volunteers across divisions to contact every water user in the watershed to offer conservation resources, legal briefings on new laws, and an overview of available conservation programs[152]. Partner with trusted institutions to expand reach and credibility, such as Extension Services, church groups, and agricultural organizations.

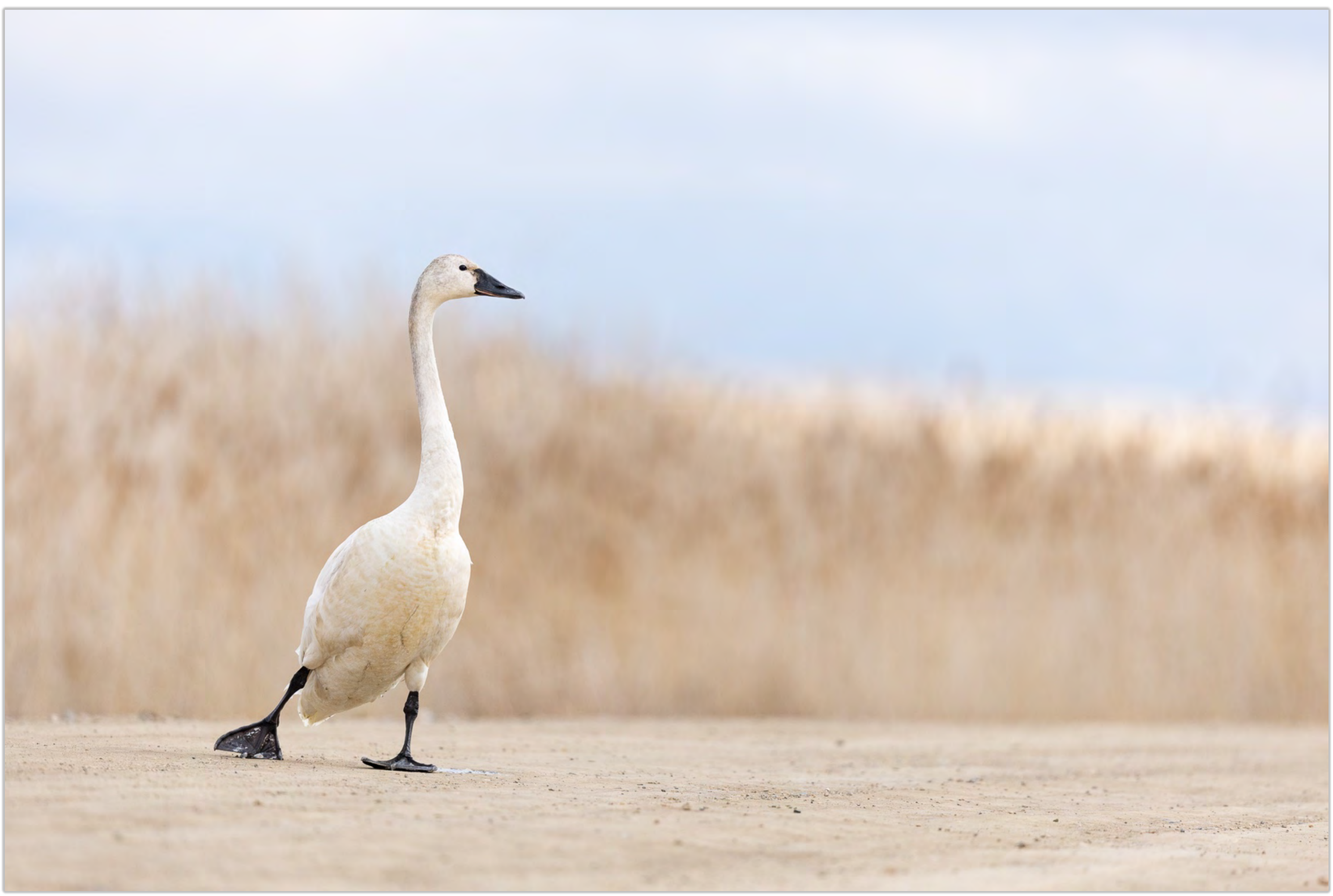

**Figure 18.** A Tundra Swan looks for water at the former shoreline of Great Salt Lake. Photo: Mary Anne Karren.

5. Offer compensation for not growing crops this year and next and support rapid transitions to less water-intensive crops. Fair compensation could be estimated based on avoided net profit and deficit irrigation adjustments[153].
6. Expand water markets (water banking) to the entire watershed following models developed for saline lake watersheds[39,132].
7. Work with the Utah Water Task Force, UDAF, and other trusted partners to convene water users and conservancy districts from each major watershed to establish a "law of the lake" framework with shortfall contingencies. This is how water conflicts were constructively resolved in the early 2000s in the upper Bear River basin[45].
8. Ensure that water saved by state and federal agricultural optimization programs is permanently designated for the lake. This is one of the mechanisms that allowed the June Sucker Recovery Implementation Program to acquire senior water rights for Utah Lake cooperatively with the watersheds agricultural community[46,71,154].
9. Expand urban/suburban turf removal programs, including making city and county incentives dependent on meeting conservation goals.
10. Hire additional agency employees across relevant DNR and DEQ divisions (e.g., FFSL and the Division of Water Rights). Investment in permanent conservation staffing is needed for the emergency response and long-term transitions.
11. Implement tiered water pricing and remove property tax subsidies for water use[155].

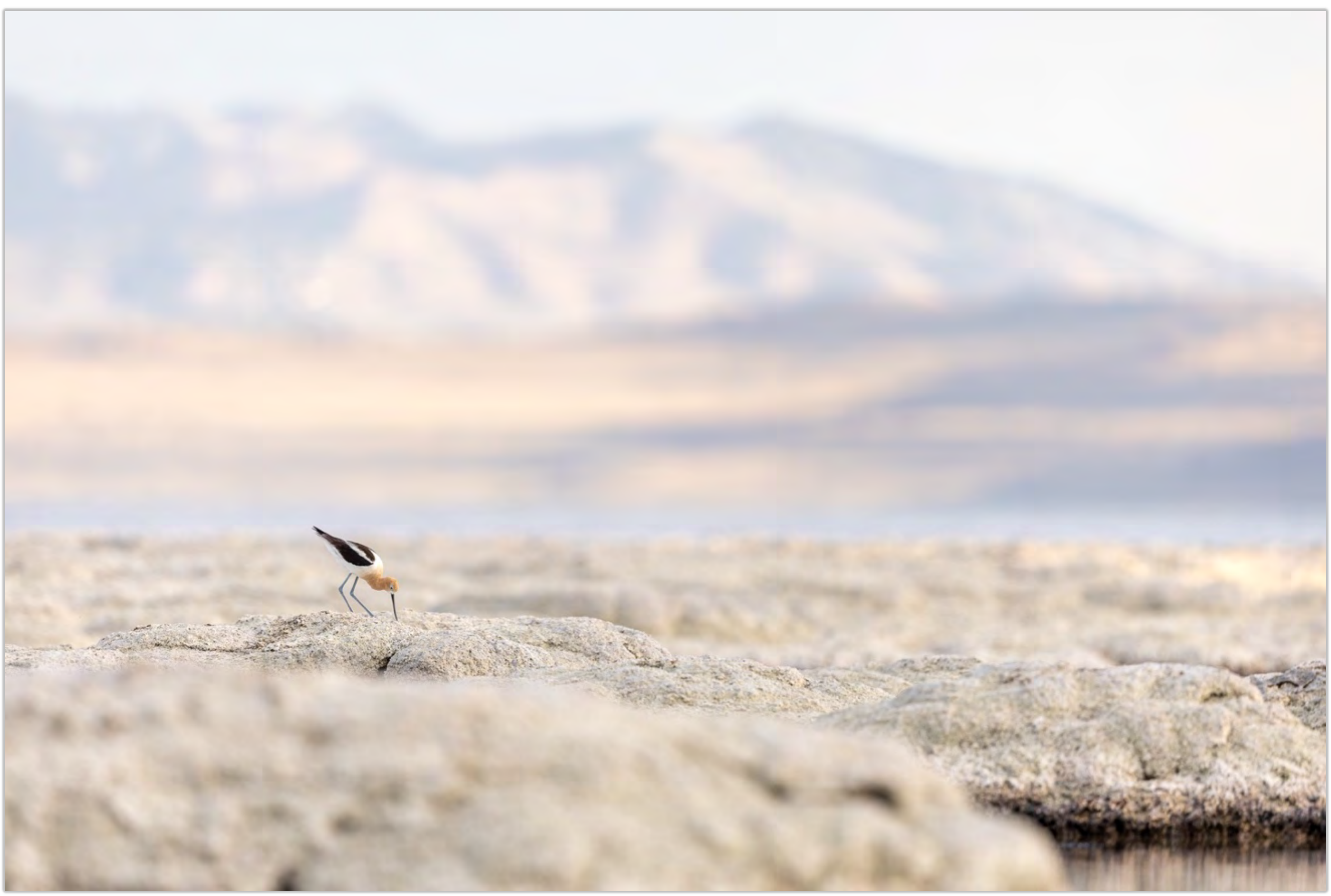

**Figure 19.** An American avocet forages for food among desiccated microbialites. Photo: Mary Anne Karren.

### *Local government (cities, counties, and conservancy districts)*

1. Coordinate with state and federal programs to expand awareness and adoption of water conservation measures at city, business, and individual levels (e.g., localscaping, turf removal, and sprinkler maintenance).
2. Convene homeowner and home builder associations for briefings on the Great Salt Lake situation. Ensure county, city, and neighborhood (e.g., HOA) rules and requirements are updated to encourage or require water conservation.
3. Collaborate with community groups to remove turf, plant native vegetation, and check for outdoor water waste. Use public assets (e.g., parks, buildings, turf strips, church lawns etc.) as examples of low water use.
4. Implement tiered water pricing with rates that increase for high use (e.g., low cost for the "indoor water use" tranche but ramped rates for high outdoor water use).
5. Expand water conservation curriculum and provide opportunities for community volunteers from schools, clubs, and civic groups.

### *Organizations and individuals (businesses, churches, nonprofits, etc.)*

1. Spread the word about Great Salt Lake and the megadrought generally. Create and share media on the topic and encourage your community groups to get involved.
2. Share water conservation information through formal and informal communication networks to increase trust and solidarity for those conserving water (e.g., newsletters, conversations, community events).
3. Convert outdoor vegetation to low or no-irrigation options.
4. Encourage city, county, state, and federal officials to adopt stringent conservation measures in 2023 and 2024 to reduce outdoor water use.
5. Maintain or remove leaking sprinklers.

**Figure 21.** Boaters, birders, and hunters access the lake's wetlands and shallow bays. Photo: Chandler Rosenberg.

**Figure 22.** An Eared Grebe looks to us for leadership. Photo: Mary Anne Karren.

## Things not to do

Not all water conservation efforts are created equal. Here are a few counterproductive interventions that we recommend avoiding:

1. **Artificially decrease evaporation in natural water bodies.** Evaporation from Utah Lake and Bear Lake is lumped into "reservoir losses" in state water budgets. Unlike artificial reservoirs, evaporation from natural water bodies serves important ecological functions, including nutrient removal, microclimate regulation, and downwind precipitation[71].
2. **Count on cloud seeding to solve our water shortage**. Despite decades of research, cloud seeding remains an experimental and unproven approach. Of the three valid randomized tests of cloud seeding, only one showed increased precipitation, and that study did not consider regional effects from upwind seeding[40,41,49]. Cloud seeding might redistribute snow marginally, but there is no evidence it will augment precipitation over a large region like the Great Salt Lake Watershed.

3. **Build more infrastructure**. There continue to be calls to build more reservoirs and pipelines as a response to the ongoing drought. However, our current situation is not caused by inadequate surface-water storage. In fact, reservoirs represent a major source of consumptive water use. We don't have enough water to keep current reservoirs full, and most suitable reservoir sites have already been developed.
4. **Wait for rain**. The last time the lake almost hit rock bottom, we were saved by a change in the weather. A series of wet years or "pluvial" in the 1980s increased runoff (Fig. 12). Archaeological evidence suggests that this was at least a thousand-year event[3,156], and two recent changes make another pluvial even less likely in the future. First, climate change has altered weather patterns, decreasing precipitation throughout the American southwest[74]. This has resulted in the most severe drought in the dendrochronological record—at least 1,200 years[72,73,76]. Based on previous megadroughts, this weather pattern could be the new normal until we restore Earth's climate[75,157–161]. Second, increased temperatures are reducing the amount of water available for human consumptive use. Climate change will reduce available runoff and groundwater flow to the lake more in the coming decades[66], making conservation even more important.
5. **Cut our losses**. There have been discussions of sacrificing the lake's North Arm to avoid reducing water consumption. This has been described as the "Aral Sea solution," referencing drastic measures taken by the Soviet Union and Kazakhstan to limit damage as that lake collapsed from excessive irrigation[1,38]. Closing the causeway would sacrifice the pelican colony on Gunnison Island, shut down mineral extraction in the North Arm, create a major source of toxic dust, and potentially trigger another period of mercury methylation as the waters recede[38,108,110].

**Figure 23.** Sunset over an exposed microbialite reef. Photo: Mary Anne Karren.

## What we need more than water

Perhaps the biggest deficit we have in facing this crisis is trust. Conservation measures have been taken throughout the watershed, but many water users and providers do not yet trust each other to shepherd conserved water to the lake. We desperately need transparency and shared sacrifice to reinforce trust and solidarity. We hope that this intention comes through in our writing. Many of us are currently involved in agriculture or have farmer heritage in the Great Salt Lake watershed. As farming families and communities will be most impacted by changes necessary to rescue the lake, we need to ensure financial, legal, and professional support for farmers during this transition.

Facing this crisis will require conservation measures unprecedented in living memory. Reversing the collapse of the Great Salt Lake system is perhaps the greatest challenge we have faced in the history of our state. However, history shows that our community is capable of just this kind of bold collective action. For example, our Indigenous and pioneer predecessors adapted to natural variability in weather and climate that would have extinguished most civilizations[72,151,162]. More recently, when excessive withdrawals caused Utah Lake to go dry in 1934 and 1935, emergency changes to infrastructure and water policy were made, allowing the lake to refill[71,163]. We invite all individual Utahns and all organizations in the state to do everything in your power to protect Great Salt Lake in this time of great need and risk.

**Figure 24.** A woman gazes across the lake. Photo: Jared Tamez.

## Additional resources

- *Legal Strategies for the Great Salt Lake* (Key policy document outlining future responses 2020)
- *Recommendations to Ensure Adequate Water Flows to Great Salt Lake and Its Wetlands* (report from the Great Salt Lake Resolution Steering Group (HCR-10) 2020; executive summary)
- *Friends of Great Salt Lake* (research, advocacy, and art about the lake 2022)
- *Great Salt Lake Comprehensive Management Plan* (Forestry, Fire & State Lands 2013)
- *Great Salt Lake Collaborative* (updates and news about the lake 2022)
- *Commonly asked Questions About Utah's Great Salt Lake and Ancient Lake Bonneville* (Overview of the lake's history and status by the Utah Geological Survey 2022)
- *Water Development, Consumptive Water Uses, and the Great Salt Lake* (Textbook chapter on water use and conservation options by Null and Wurtsbaugh 2020)
- *Exploring Utah's Water* (Extension report on water use in Utah 2016)
- *Economic Significance of the Great Salt Lake to the State of Utah* (Great Salt Lake Advisory Council economic assessment 2012)
- *Impacts of Water Development on Great Salt Lake and the Wasatch Front* (Report on water use impacts on lake level by Wurtsbaugh and others) 2016)
- *Water for Great Salt Lake* (Great Salt Lake Advisory Council report comparing strategies to increase lake level 2017)
- Utah Division of Water Resources (Lake overview and link to multiple resources 2022)
- *Conservation Impacts Study* (Great Salt Lake Advisory Council report on effectiveness of conservation 2020)
- *Utah Water Science Center* (United States Geological Survey resources on the Great Salt Lake 2022)
- *UDNR 2-pager on the Great Salt Lake* (2022)
- *Great Salt Lake Hydro Mapper* (Live data portal 2022)
- *Great Salt Lake Advisory Council Activities* (Compilation of reports)
- *Municipal and Industrial Water Use in Utah* (Detailed analysis of nonagricultural water use throughout the state 2010)
- *Great Salt Lake Ecosystem Program* (2022)

**Figure 25.** A Mallard looks for threats from the shore. Photo: Mary Anne Karren.

# Acknowledgements

We thank the thousands of dedicated workers in state, federal, nonprofit, and private sector positions who protect Great Salt and its watershed through study, management, education, industry, and recreation. We also thank the hundreds of committed leaders who have put in place policies and cultivated a culture of conservation surrounding Great Salt Lake over many generations. Thank you for your service and vision. We are grateful to more than a dozen independent experts who reviewed this report, primarily during the 2022 Christmas holiday. Thank you for using your expertise and time in the service of our community.

None of the coauthors of this report were paid for their efforts, several coauthors were able to donate their time thanks to support from the US National Science Foundation (grants EAR-2011439 and EAR-2012123) and state initiatives such as the Utah Department of Natural Resources Watershed Restoration Initiative.

**Figure 26.** An American avocet nestles into the lifegiving waters of Great Salt Lake. Photo: Mary Anne Karren.

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**Figure 27.** A flock of American white pelicans set off for a day of foraging. Photo: Chandler Rosenberg.