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Consequences of Drying Lake Systems around the World

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Executive Summary

Great Salt Lake has significance from local to global levels, given its standing as the largest salt water lake in the Western Hemisphere, the eighth-largest terminal lake in the world, and the $1.3 billion it contributes to the local economy on the basis of its industrial, recreational, aesthetic and quality of life characteristics. Complementing this is a rich, diverse and unique ecosystem that boasts premier wetlands, immense populations of migratory birds, and a wealth of other terrestrial and aquatic wildlife. However, this vitally important resource, and the wetlands associated with it, is threatened by sustained, declining water levels that will continue to severely and adversely impact the ecological integrity of the resource, and the economic viability and quality of life of those who rely upon it.

Great Salt Lake and other significant saline lakes around the world are drying at alarming rates. Although saline lakes naturally shrink and grow with natural climatic variation, human impacts (such as diversions) can cause desiccation that may not be possible to reverse without intervention. Saline lakes provide a diverse range of ecological, sociological, and economic benefits. Saline lakes have a concentration of salts and other dissolved minerals significantly higher than most lakes (at least 3 grams of salt per liter).

To better understand the implications of a drying of Great Salt Lake, a review of the economic, social and environmental consequences of “drying” lakes around the world was conducted for the Utah Department of Natural Resources, Division of Forestry, Fire and State Lands and the Great Salt Lake Advisory Council. While there are more than 25 significant lakes drying around the world, this study focused on eight terminal saline lakes that share characteristics with Great Salt Lake, namely: Lake Urmia, Aral Sea, Lake Poopó, Owens Lake, Salton Sea, Dead Sea, Bakhtegan Lake, and Mono Lake.

This report, based upon an extensive literature review, provides a descriptive inventory of each of these drying lake systems, with a focus on the associated economic, social, and environmental consequences. Context for each lake’s drying (also referred to as “desiccation”) is also provided through a review of such items as causes and duration, contributing demographic factors, and mitigation and restoration measures that have been undertaken. This is followed by a brief discussion of relevance to Great Salt Lake.

As noted within, saline lakes provide an array of economic benefits as they typically support tourism, mining, aquaculture, and tourism industries. Social benefits include recreational opportunities, dust mitigation, and climate-moderating benefits. In some cases, saline lakes can buffer temperature and humidity changes in nearby agricultural fields, enabling farmers to harvest earlier. Great Salt Lake benefits nearby ski resorts by influencing the local climate and weather, producing “lake effect” snowstorms. Saline lakes also provide environmental benefits, both for aquatic habitat and organisms, as well as for migratory shorebirds and waterfowl that use saline lakes for nesting and feeding grounds. As desiccation occurs, adverse economic, social, and environmental consequences result.

Industries supported by saline lakes

Mineral extraction is a major economic benefit associated with many saline lakes. Mineral extraction from the Dead Sea, for example, directly employs 4,000 people and returns $800 million (2019$) in revenue annually (Becker and Katz, 2006). While increasing saline concentrations associated with lake desiccation can benefit the industry, the receding shorelines of saline lakes can make mineral extraction more costly (Wurtsbaugh et al., 2017).

In addition to mining operations, many saline lakes support aquatic activities, such as commercial fishing or harvesting of brine shrimp eggs. Prior to desiccation, the commercial fishing industry in the Aral Sea, for example, once supported 60,000 fishermen jobs (Wurtsbaugh et al., 2017).

Besides open water, the ecosystems of saline lakes include emergent marsh, mudflats, and playa. Due to their unique ecosystems that frequently host rare flora and fauna, saline lakes support tremendous tourism industries. Tourism in the Dead Sea basin employs 11,000 directly and more indirectly (Becker and Katz, 2006). Prior to desiccation, the Salton Sea’s annual recreational value was $550 million (Cohen et al., 1999) but, as of 2007, recreation had dwindled to an annual value of $26.5 million, less than 5 percent of what it once was (U.S. Department of the Interior, 2007).

Critical habitat

Saline lakes are critical habitats for migratory birds, and provide those populations with exclusive access to an important food source: dense invertebrate populations. As a result, many saline lakes around the world have been designated as Ramsar Wetlands of International Importance or as Western Hemispheric Shorebird Reserve sites (Wurtsbaugh et al., 2017).

Ecosystems within saline lake basins also host substantial biodiversity. The Great Salt Lake supports between 2 and 5 million shorebirds and hundreds of thousands of waterfowl during spring and fall migration (USGS, 2013). The ecological benefits associated with shoreline and near shoreline habitats surrounding Salton Sea are estimated to be $2.0 - $2.8 billion (Cohen, 2014).

Waterbirds and shorebirds feed on a variety of invertebrates at saline lakes, including invertebrates found in wetlands and mudflats along the shores depending on the ecosystem, though not all species feed on brine shrimp or brine flies and their larvae. Some shorebirds may feed on corixids, chironomids, and pile worms found in the wetlands, mudflats and shorelines. As desiccation occurs, salinity levels may increase to a degree that reduces the density of brine shrimp and their reproductive abilities, thereby threatening their survival. In Lake Urmia, for example, migratory bird populations that feed on brine shrimp have been reduced substantially and thousands of birds have died in recent years from starvation (Hassanzadeh et al., 2012).

Saline dust storms

Saline lakes around the world are drying as a result of several causes, including water diversion for irrigation and urban demand, and climatic changes (Oren, 2018). When dry, they leave behind fine-grained saline dust which can be transported up to 300 miles due to the general lack of vegetation which commonly mitigates wind erosion, and the loose texture of the salt-laden sediment (Abuduwali et al., 2010; Micklin, 2007). The distance dust can travel depends on the geography of the location. These saline dust storms are an environmental phenomenon in arid and semiarid regions that result from dust stirred up from the sediments of dried lakebeds (Abuduwali et al., 2010; Gholampour et al., 2015).

In general, terminal lakes in arid regions are the lowest elevation in the region and, as a result, accumulate high concentrations of chemical substances, increasing the toxicity of the dust. The dust contains high concentrations of fine-grain saline and alkaline material, including sodium sulfate, sodium chloride and other toxins which pose a threat to human health and natural ecosystems (Gholampour et al., 2015).

Saline dust storms decrease regional air quality and threaten public health. Saline dust is fine grained and generally considered to be particulate matter with a diameter of fewer than 10 micrometers (PM_{10}), a form of wind-blown dust. PM_{10} is dangerous due to its tendency to settle deep into a person's lungs, posing a danger to those with lung and chronic obstructive pulmonary diseases (Los Angeles Aqueduct Digital Platform, 2014). In addition, wind-blown dust (PM) can increase asthma attacks, asthma severity, hospitalizations, lung diseases and symptoms, and infections. PM can also impair the ability to fight off infections (Johnston and Farzan, 2016).

Saline dust storms are a substantial consequence of dried lake beds, and result in secondary salt deserts. Saline dust storms resulting from wind erosion of dry lakebeds increase soil salinization that adversely affects respiration and photosynthesis of plants, compromising vegetative growth (Abuduwali et al., 2010). As agricultural efficiency dwindles so does profitability, threatening the livelihood of farmers in the region (Jeihouni et al., 2017). Agricultural output near Aral Sea, for example, has declined by 30-50 percent as a result of salinity, water deficiency, climate change, and reduced labor productivity due to associated health challenges (Ataniyazova, 2003). Also, 70 percent of the irrigated land in Karakalpakstan is impacted by salinity that is deposited from dust storms (Ataniyazova, 2003).

Mitigation and reclamation measures are typically costly. The primary methods to control saline dust storms include shallow flooding, managed vegetation, and gravel blanket, as has been the case with Owens Lake (Abuduwali, 2010). For example, dust mitigation measures surrounding Owens Lake are estimated at $3.6 billion; Salton Sea measures are expected to cost up to $16.9 billion; and efforts to reclaim the Aral Sea are estimated to be more than $33.6 billion through 2025, with additional ongoing costs thereafter.

Summary

Saline lakes and associated wetlands are unique ecosystems that host tremendous biodiversity and support valuable tourism, mining, and aquaculture industries. The economic, social, and environmental benefits of these lake systems are diverse and substantial (Wurtsbaugh et al., 2017). As desiccation occurs, adverse impacts are pervasive, not only for the flora and fauna of these lake systems, but for the social well-being and health of residents, workers and visitors. In addition to adverse impacts on employment opportunities (e.g., farming, recreation, tourism, industry, and aquaculture) and overall economic health, desiccation of these lake systems has adverse impacts on public health. When dry, saline lakebeds present a public health hazard as they become sources of fine dust that can be transported significant distances in dust storms. Mitigation and restoration measures are needed to return drying lakes to a more stable condition that retains their substantial economic, social and environmental benefits. Such measures can be costly and, therefore, should be selected, designed and implemented strategically to maximize return on investment. A summary of the economic, social, and environmental consequences of drying for each lake system is provided in Table 0-1.

Table 0-1: Summary of economic, social, and environmental consequences of lake desiccation

1. Lake Urmia	Economic Consequences	Social Consequences	Environmental Consequences
Watershed Area (square miles): 20,100	$1.4B for restoration program	Public health impacts from dust storms (PM_{10})	86% of the lake became a salt desert
Watershed Population: 6.4M Salinity: 21 – 24%	$56M to transfer water from Kani Sib River	Displaced farmers	Migratory birds have been reduced and thousands have died from starvation
Largest lake in Iran	$1.6M recreation value		Threatened brine shrimp survival
2nd largest hypersaline lake in the world	Agricultural damages		

2. Aral Sea	Economic Consequences	Social Consequences	Environmental Consequences
Watershed Area (square miles): 700,000	$24.4B to $33.6B to improve irrigation & drainage systems	Public health impacts from dust storms (PM_{10})	Desertification in the region; salt flats on portions of lake bed
Watershed Population: 60M Salinity: +10%	More than $270M for restoration projects	High levels of esophageal cancer, respiratory illnesses, and eye problems in the surrounding region	Mammal and bird species reduced by half
	70% of irrigated land impacted by salinity from dust storms		Threatened permanent and migratory birds
	60,000 people lost their livelihood when fishery was lost		Native plants replaced by plants adapted to dry, saline conditions

3. Lake Poopó	Economic Consequences	Social Consequences	Environmental Consequences
Watershed Area (square miles): 360,000	Complete loss of fishing industry	Displaced fishermen and indigenous people that depended on the lake	Millions of dead fish
Watershed Population: 10,000			Mass die off of hundreds of birds
Size of dry lakebed (square miles): 380			Loss of wildlife in surrounding areas

4. Owens Lake	Economic Consequences	Social Consequences	Environmental Consequences
Watershed Area (square miles): 1,000	$3.6B for mitigation through 2025	Public health impacts from dust storms (PM_{10})	Rehydration efforts have provided habitat for 100,000 shorebirds annually
Size of dry lakebed (square miles): 110	$5M in noncompliance fees	USEPA declared the dry lakebed to be the source of the worst dust problem in the U.S.	
Salinity: 6 – 7%			

5. Salton Sea	Economic Consequences	Social Consequences	Environmental Consequences
Watershed Area (square miles): 8,400	Up to $16.9 billion for restoration $472 million for Phase 1 habitat & dust suppression	Public health impacts from dust storms estimated at $40 billion	$2.8 billion annual ecological benefits is declining as sea shrinks
Watershed Population: 650,000	$550M reduced to an annual recreational value of $26.5M and visitors reduced to 340,000 annually	Emergency room visits for children are over twice the statewide average in California	Fish populations declined by over 95%

5. Salton Sea	Economic Consequences	Social Consequences	Environmental Consequences
Salinity: +6%	Loss of commercial and sport fishing industry	Childhood asthma hospitalization rates are the highest in CA and 3 times the state's average	One of the few remaining wetland habitats for avian species in California
	Loss of $1.9 billion agricultural industry		
	Property value loss up to $7 billion		

6. Dead Sea	Economic Consequences	Social Consequences	Environmental Consequences
Watershed Area (square miles): 17,000	$11 billion to construct reclamation project, $440M for annual O&M	Sink holes causing serious injuries	Threat to biodiversity and ecosystem
Salinity: 34%	Without reclamation, potential loss of $265M in annual revenue to the region	Sink holes threaten tourism industry, the main livelihood of the region	Environmental hazards, such as steep slopes and earthquake-associated landslides
	$800M annual revenue for mineral extraction		
	Infrastructure and property damage from 1,000 sinkholes		

7. Bakhtegan Lake	Economic Consequences	Social Consequences	Environmental Consequences
Watershed Area (square miles): 12,200	Threatened tourism industry	Potential loss of agricultural and tourism jobs	Threatened wetland habitat; designated protected zone and wildlife sanctuary

7. Bakhtegan Lake	Economic Consequences	Social Consequences	Environmental Consequences
Second largest lake in Iran	Water scarcity threatens the agricultural sector (loss of $2.4B from severe drought)	Water scarcity could stimulate social conflicts	High number of bird mortalities

8. Mono Lake	Economic Consequences	Social Consequences	Environmental Consequences
Watershed Area (square miles): 800	Threated tourism industry	Public health impacts from dust storms (PM_{10})	Largest breeding ground for California Gulls in California
Population: 14,000			Threated brine shrimp populations
Salinity: 5 – 10%			Loss of wetland habitat

Note: M = million and B = billion

Note: To facilitate comparisons among the studies, values obtained from the literature are normalized to U.S. dollars with a 2019 base year using the Office of Management and Budget's GDP deflator.

I. Introduction

Great Salt Lake elevations have demonstrated a distinct downward trend over time. It has been estimated that Great Salt Lake has dropped 11 feet due to human impacts and diversions, and the lake volume has decreased by 48 percent (Wurtsbaugh et al., 2015). There have neither been significant long-term changes in regional precipitation nor have there been changes in water supply from mountain tributaries since 1847 (Wurtsbaugh et al. 2016). Human consumption has been found to be a leading cause of Great Salt Lake's desiccation (Wurtsbaugh et al., 2016). Residents in the region annually divert 871 million gallons of water from the streams that feed the lake (Deroin, 2017). As a result, water diversions for consumption have reduced the net river inflow to the lake by 39 percent and exposed 48 percent of its lakebed (Wurtsbaugh et al., 2015).

Salinity is characterized by the amount of salt dissolved in a body of water and the salinity level is an important factor in determining the biological processes of lake systems. Saline lakes provide a diverse range of ecological, sociological, and economic benefits, though they are difficult to monetize (Wurtsbaugh et al., 2017). Saline lakes around the world are drying at alarming rates as a result of several causes, including water diversion for irrigation and urban demand, and climatic changes (Oren, 2018). When lakes are dry, it leaves behind fine-grained saline dust, which can be transported significant distances by wind erosion and create dust storms, which have negative ecological, social, and economic impacts.

To better understand the drying of Great Salt Lake, this report reviews studies of drying saline lakes around the world, and presents the economic, social, and environmental consequences from literature as well as relevant mitigation and restoration measures that may be relevant to Great Salt Lake. While there are more than 25 significant lakes drying around the world, this study focused on eight terminal saline lakes that share characteristics with Great Salt Lake, namely:

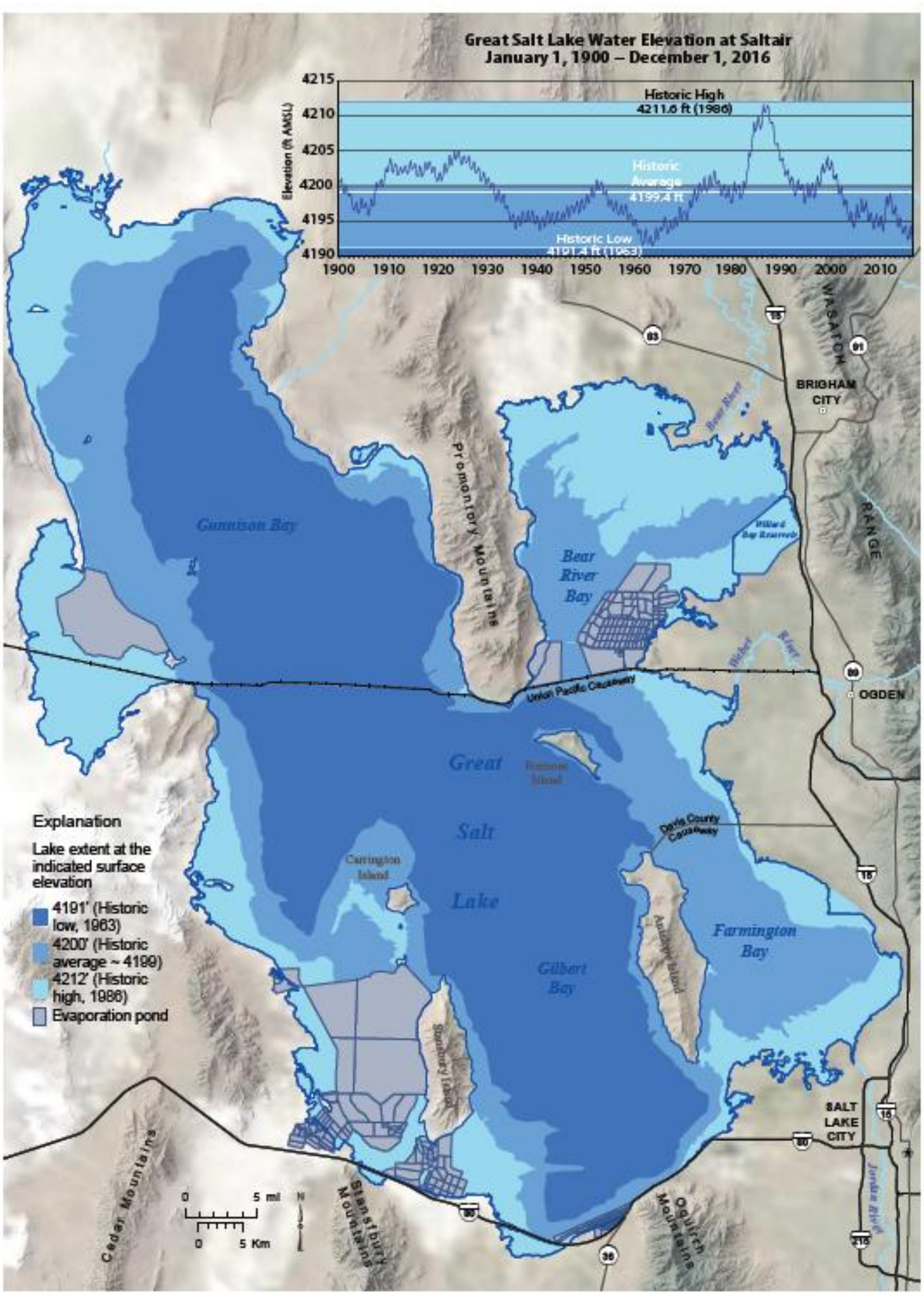
1. Lake Urmia in Iran;
2. Aral Sea between Kazakhstan and Uzbekistan;
3. Lake Poopó in Bolivia;
4. Owens Lake in California;
5. Salton Sea in California;
6. Dead Sea in Israel and Jordan;
7. Bakhtegan Lake in Iran; and
8. Mono Lake in California.

II. Context

Great Salt Lake is a terminal lake (meaning that it lacks an outlet) with an average elevation of 4,193 feet above mean sea level (U.S. Geological Survey, 2017) which equates to an area covering approximately 656,000 acres (1,050 square miles) (SWCA, 2017). Originating in the western end of the Unita Mountains, major rivers that drain into Great Salt Lake are the Bear, the Weber, and the Provo / Jordan. The maximum water depth ranges from 18 feet to 25 feet, depending on the water elevation level (Belovsky et al., 2011). As a result, salinity levels of Great Salt Lake also vary considerably. Over time, the lake's salinity has ranged from 5 to 28 percent, depending on the level of the lake (Belovsky et al., 2011).

The construction of causeways across the lake to accommodate rail and vehicular traffic has divided the lake into four main portions with distinct salinity levels. The smaller Bear River Bay and the Farmington Bay, both on the east side of the lake, have salinity levels ranging from 0 to 9 percent (Barnes and Wurtsbaugh, 2015). The two main portions of the Lake are Gunnison Bay to the north and Gilbert Bay to the south. The salinity levels of Gilbert Bay range from 10 to 18 percent, while the salinity level of the Gunnison Bay is more constant at 33 percent (Barnes and Wurtsbaugh, 2015). An overview of Great Salt Lake is portrayed in Figure II-1.

Figure II-1: Great Salt Lake's bays and water levels



Source: UT DNR, 2017

Great Salt Lake has significant output as an economic and cultural resource. The aggregate annual economic output of the lake is $1.32 billion (2010$) for mineral extraction, brine shrimp cyst production and harvesting, and recreation, including hunting, birding, boating, and other uses (Bioeconomics, 2012).

As a saline ecosystem, Great Salt Lake is host to phytoplankton (algae) and invertebrates, including brine shrimp and brine flies. These invertebrates and phytoplankton serve as the base of the aquatic food web. E.O. Wilson claimed that human life could not persist beyond a few months if invertebrates disappeared (1987).

Great Salt Lake and it's wetlands is of environmental and ecological importance for migratory birds, as a third of all western U.S. waterfowl passes through Great Salt Lake during their fall and spring migrations (Belovsky et al., 2011). Migratory birds are the primary predators of the invertebrates of the lake and associated wetlands, making the ecosystem an opportune feeding ground (Barnes and Wurtsbaugh, 2015).

As previously described, water diversions for consumptive use have significantly lowered the water level of Great Salt Lake. While urban per capita water use has been reduced by 18 percent in the region, overall municipal water use has increased 5 percent due to population growth (Wurtsbaugh et al., 2015).

Table II-1breaks down the contributing causes of Great Salt Lake's falling water levels by sector.

Table II-1: Great Salt Lake water diversion by sector

Sector	Water Use
Agriculture	63%
Consumption / Industry	11%
Evaporation	3%
Salt pond mineral extraction	13%

Source: Wurtsbaugh et al., 2017

A careful, literature-based examination of the social, environmental and economic consequences of selected drying lakes around the world will help characterize concerns associated with Great Salt Lake and inform any prospective mitigation and restoration measures.

III. Approach

The literature review follows a case study approach that includes research of drying lakes around the world with similar characteristics to Great Salt Lake. The economic, social, and environmental consequences of these drying lakes are examined, along with their relevance to Great Salt Lake. This study was focused on the following eight saline lakes: 1) Lake Urmia in Iran; 2) Aral Sea between Kazakhstan and Uzbekistan; 3) Lake Poopó in Bolivia; 4) Owens Lake in California; 5) Salton Sea in California; 6) Dead Sea in Israel and Jordan; 7) Bakhtegan Lake in Iran; and 8) Mono Lake in California. Following the case studies, the economic, social, and environmental consequences ascertained from each study are discussed.

Sources reviewed include studies and data from federal entities, international entities, relevant non-governmental organizations, peer-reviewed literature, and reports commissioned by the Great Salt Lake Advisory Council. Over 100 credible sources of relevant information were reviewed pertaining to the eight case studies (see Section VII).

In addition to searching all the major economic and ecological journals for the latest peer-reviewed information, the Economics of Ecosystems and Biodiversity (TEEB) Valuation Database was searched for empirical studies related to the economic, social, and environmental valuation of natural resources from the selected drying lakes. This was complemented by information available from the World Bank, USAID, World Large Lakes Conference archives, and related AECOM studies. To facilitate comparisons among the studies, values obtained from the literature are normalized to U.S. dollars with a 2019 base year using the Office of Management and Budget's GDP deflator.

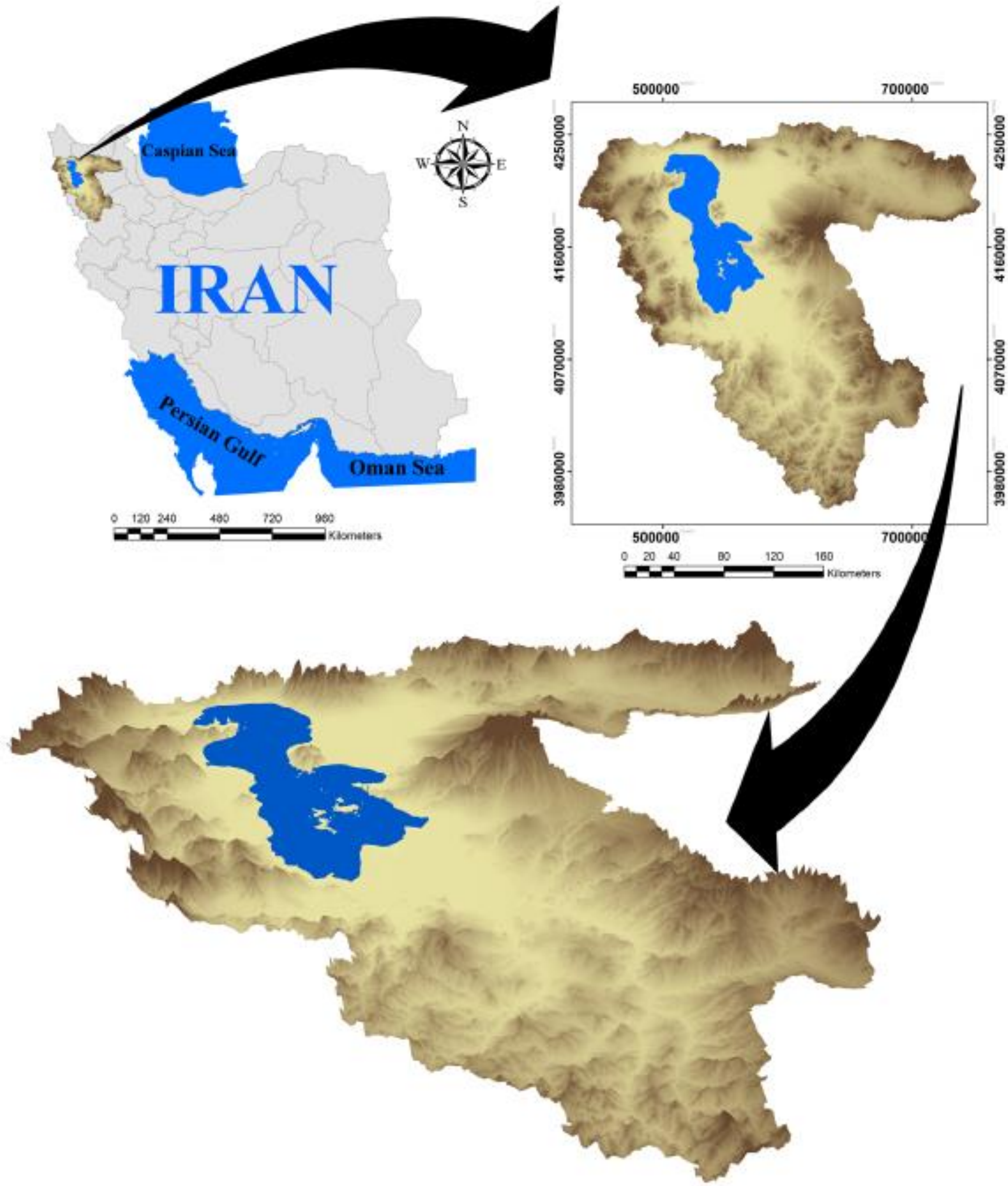
IV. Case Studies of Drying Lake Systems

The following section reviews selected drying lake systems around the world. The reviews include an overview of lake characteristics and a discussion of the economic, social, and environmental consequences of the drying lake systems. Lastly, the relevance of each drying lake system to Great Salt Lake is discussed.

1. Lake Urmia

Lake Urmia is the largest lake in Iran and the second largest hypersaline lake in the world (Sima et al., 2013). Lake Urmia was listed as a Ramsar site and UNESCO Biosphere Reserve (Zarghami, 2011). Lake Urmia is located in northwest Iran at an elevation of 5,900 feet above sea level (Nouri et al., 2017). The lake is situated on the eastern side of the Zagros Mountains and the local climate is continental, supporting Irano-Turanian steppe vegetation (Stevens et al., 2012). An overview of Lake Urmia is portrayed in Figure IV-1.

Figure IV-1: Location of Lake Urmia in the basin



Source: Jeihouni et al., 2017.

a) Overview of Lake Characteristics

Prior to the start of its desiccation, Lake Urmia had a land area of over 2,400 square miles and a depth of 52 feet (Nouri et al., 2017; Stevens et al., 2012). The lake is sourced by direct precipitation, multiple springs, and thirteen permanent rivers, though the Zarinneh Rud and Simineh Rud account for nearly half of the lake's inflow (Stevens et al., 2012). While the rivers that source Lake Urmia are fresh, the springs that feed it typically have high concentrations of solutes (Stevens et al., 2012). As a terminal lake, groundwater does not flow from Lake Urmia into nearby aquifers. Therefore, evaporation is the only outflow from the lake (Hassanzadeh et al., 2012).

The lake is highly saline (i.e., hypersaline), with concentrations ranging between 21 and 24 percent (Stevens et al., 2012). Lake Urmia is surrounded by extensive brackish marshes, which is an important staging area for migratory waterbirds. The flora and fauna within the lake includes algae, brine shrimp (*Artemia urmiana*), flamingo, ducks, pelicans, and mammals (Nouri et al., 2017). The ecological zone of the lake contains 547 herbaceous species, 27 mammal species, 21 fish species, 212 bird species, and 41 reptile species (Bagherzadeh, 2012). The lake's unique ecosystem is of considerable ecological value.

Development pressures, particularly irrigation for agriculture, have led to the rapid shrinking of the lake's size. Between 1995 and 2013, Lake Urmia shrank from 2,400 square miles to 400 square miles (Nouri et al., 2017). From 1980 to 2007, land used for agriculture in the Lake Urmia basin increased from 150,000 hectares to 400,000 hectares and, in that time, water usage in the agricultural sector increased from 64 billion cubic feet to 194 billion cubic feet (Nouri et al., 2017).

The watershed of Lake Urmia is 20,100 square miles and has a population of 6.4 million, which equates to 320 residents per square mile. Development pressures are particularly high in Urmia County, along the western side of the lake, which has a population density of over 620 residents per square mile (Nouri et al., 2017).

Furthermore, the damming and creation of reservoirs in Urmia County has reduced historical water flows by 17 percent (Nouri et al., 2017). Consequences of climate change are an additional cause of Lake Urmia's desiccation. Between 1996 and 2007, annual precipitation rates decreased by 17 percent and temperatures increased by nearly 17 percent between 1996 and 2006 (Hassanzadeh, 2012).

Table IV-1 summarizes lake characteristics for Lake Urmia prior to desiccation.

Table IV-1: Summary of lake characteristics for Lake Urmia prior to desiccation

Lake Characteristic	Value
Lake Area (square miles)	2,400
Watershed Area (square miles)	20,100
Watershed Population	6,400,000
Maximum Depth (feet)	52
Saline Concentration Range (percent)	21.7 – 23.5

Note: Current estimate of watershed population, not prior to desiccation.

b) Economic Consequences

As a National Park in Iran, economists believe Lake Urmia has the potential to develop a tourism industry due to its unique ecosystem (Bagherzadeh, 2012). According to

Bagherzadeh (2012), the estimated annual recreation value of the lake's ecosystem is 2.7 million Iranian Rials or an estimated $1.6 million USD (2019$).[1] This value was estimated by evaluating the price visitors pay to travel to Lake Urmia (e.g., travel time, car rental costs, accommodation and food).

Lake Urmia is known for its natural attractions, such as beautiful beaches, cypress trees, wild pistachio, and mountainous almonds. Lake Urmia hosts 547 herbaceous species, 27 mammal species, 21 fish species, 212 bird species, and 41 reptile species. On the islands there are rams, ewes, and Iranian yellow elks. Also, the saline water and black mud have been helpful for different diseases (Bagherzadeh, 2012). The continued desiccation of Lake Urmia would jeopardize the potential tourism industry in the region.

The desiccation of the lake has increased the size of the salt deserts around the lake significantly; 86 percent of the lake became a salt desert between 1998 and 2014 (Jeihouni et al., 2017). As the lake dries, it leaves behind fine-grained salt, resulting in saline dust storms. The dust storms that ensue deposit salt on the agricultural land, which increases soil salinization and reduces soil productivity. As agricultural efficiency dwindles so does profitability, threatening the livelihood of farmers in the region (Jeihouni et al., 2017).

The Government of Japan has donated $5 million USD over 5 years (since 2014) to the United Nations Development Programme (UNDP) to support the restoration of Lake Urmia, called the Conservation of Iranian Wetlands Project. The restoration project is specifically designed to raise awareness among the local communities and farmers and promote sustainable agriculture by building trust among local communities, training farmers to use a technique called Integrated Participatory Crop Management (IPCM), launching social media campaigns, encouraging alternative livelihood, and setting up women micro-credit funds. So far, this project has reduced water use by 35 percent, which allows more retention of water in Lake Urmia. Also, the use of fertilizers and pesticides has been reduced by 40 percent (UNDP, 2018).

The Urmia Lake Restoration Program (ULRP) was set up in 2013 to restore the lake. Phase 1 was intended to stabilize the lake's water level and was completed in September 2016. The goal of Phase 2 is to implement solutions supplying the entire lake water demand and gradually increasing the lake level. The purpose of Phase 3 is to establish required enforcement for final restoration and stabilization of revived condition (ULRP, 2015). The budget for ULRP is over $500 million, although the full estimated cost for the restoration program is nearly $1.4 billion (2019$) (Hecht, 2014).

Currently, a project is underway to transfer water from Kani Sib River to Urmia Lake through a 22 mile tunnel. The project is expected to be completed by March 2020 and the total cost is approximately $56 million (2019$) (Iran Water and Power Resources Development Co, 2015).

c) Social Consequences

Consequences from the drying of Lake Urmia extend beyond northwestern Iran and into southern Caucasia, eastern Turkey, and northern Iraq (Jeihouni et al., 2017). The saline

[1] The ratio of US to Iran GDP per capita was calculated using 2012 values from the World Bank's World Development Indicators database to capture the relative significance of Lake Urmia on Iran's economy, before adjusting to 2019 US Dollars.

dust storms that result from the lake's desiccation carry toxins from the lakebed, which decreases air quality and threatens public health across the region (Jeihouni et al., 2017). The dust is a known carcinogenic, and poses a hazard to public health and the emitted particulate matter (PM) can present significant public health hazards. Saline dust is fine grained PM, generally with a diameter of fewer than 10 micrometers, which classifies it as PM_{10}. PM_{10} is dangerous because of its tendency to settle deep into a person's lungs, posing danger to those with lung disease and chronic obstructive pulmonary disease (Los Angeles Aqueduct Digital Platform, 2014).

If the dust storms render the nearby agricultural lands unusable, rural farmers in the area would be displaced and forced to migrate to search for work (Hassanzadeh et al., 2012).

While not a direct result of Lake Urmia's desiccation, the use of large quantities of pesticides nearby to support agriculture have polluted one quarter of the lake (Hassanzadeh et al., 2012). Should the lake dry up completely, contamination from pesticides would increase the toxicity of the dust and exacerbate the public health implications associated with dust storms.

d) Environmental Consequences

Lake Urmia's water salinity has increased substantially; it is supersaturated with brine and this trend is expected to continue as the lake shrinks (Hassanzadeh et al., 2012). The increased salinity has decreased the density of brine shrimp and threatened their survival in the ecosystem (Hassanzadeh et al., 2012). Furthermore, migratory birds that feed on brine shrimp have been reduced and thousands have died in recent years from starvation (Hassanzadeh et al., 2012). Migratory birds include large flamingo populations (Hassanzadeh et al., 2012).

e) Relevance to Great Salt Lake

Similar to the drying of Great Salt Lake, the drying of Lake Urmia poses threats to the economy, public health, and the environment. The desiccation of Lake Urmia is a result of development pressures in the surrounding region. Population growth and increased land used for agriculture in the Lake Urmia basin have increased water diversion from Lake Urmia's sources. As Lake Urmia dries, the populations of brine shrimp and migratory birds are threatened. The same could be expected with Great Salt Lake drying, but worse consequences for the millions of birds and brine shrimp harvesting industry that the Great Salt Lake supports. The population density surrounding Great Salt Lake is far greater than that in the Lake Urmia watershed. Therefore, the socio-economic impacts of Great Salt Lake's desiccation could be far greater.

A summary of the economic, social, and environmental consequences of Lake Urmia desiccation that may be relevant to Great Salt Lake are presented in Table IV-2.

Table IV-2: Summary of consequences from the drying of Lake Urmia

Economic	Social	Environmental
$1.4 billion for restoration program	Public health impacts from dust storms (PM_{10})	Threatened brine shrimp survival
$1.6 M annual recreational value	Displaced farmers	Loss of thousands of migratory birds
$56 million to transfer water from Kani Sib River to Urmia Lake		
Agricultural damages		

2. Aral Sea

The Aral Sea is a terminal lake located in central Asia, to the south of Kazakhstan and to the north of Uzbekistan. The following sections describe the Aral Sea, and include an overview of lake characteristics as well as the economic, social, and environmental consequences of the drying lake. This is followed by a discussion of relevance to Great Salt Lake.

a) Overview of Lake Characteristics

The Aral Sea basin includes the drainage area of the Amudarya River in the south of the basin and the Syrdarya River in the north of the basin, which run through Afghanistan, Tajikistan, Kyrgyzstan, Turkmenistan, Uzbekistan, and Kazakhstan (IFAS, 2011). In its original state, the Aral Sea was situated approximately 160 feet above sea level and occupied an area of 26,000 square miles (which is larger than the state of West Virginia). Yet in general the lake was shallow, with a maximum depth of 180 feet (IFAS, 2011; Aral Sea, 2018). The Aral Sea Basin is portrayed in Figure IV-2.

Figure IV-2: Aral Sea basin

Source: Micklin, 2007.

The watershed of the Aral Sea occupies 700,000 square miles and experienced rapid population growth throughout the second half of the twentieth century (Micklin, 2007). From 1950 to 1988, the population grew from 13.3 million to 33.2 million and, by 2008, the basin's population exceeded 60 million (Thompson, 2008). The Soviet Union began a large-scale water diversion project in the 1960s which consisted of 20,000 miles of canals, 45 dams, and over 80 reservoirs diverting the Amudarya and the Syrdarya Rivers to support agriculture in the region (Howard, 2014). The total volume of water diverted in the Aral Sea Basin increased from 14.5 cubic miles to 27.9 cubic miles in the time period between 1960 and 1994 (Thompson, 2008).

As the lake dried up, its salinity increased. The salinity averaged 1.0 percent prior to desiccation and salinity levels now range from 1.0 percent to over 10 percent (Micklin, 2007). Prior to desiccation impacts, the Aral Sea largely supported freshwater species, including 12 species of fish and 160 species of invertebrates (Aladin et al., 2008). However, the ecosystem began changing in the 1920s, prior to the onset of desiccation impacts, with the anthropogenic introduction of non-native species (Aladin et al., 2008).

Between 1987 and 1989, the Aral Sea bisected into two water bodies, the "Small" Aral Sea in the north and the "Large" Aral Sea in the south. By 2008, the Aral Sea consisted of six separate waterbodies and, at present, is one-tenth of its original size (Aladin et al., 2008; Chen, 2018). The current fate of the Aral Sea remains uncertain; in 2014 it was reported that the Aral Sea was dry for the first time in 600 years. The South Aral Sea is almost completely desiccated. A small portion of the North Aral Sea has been revived but not completely restored (Howard, 2016; Chen 2018).

Table IV-3 summarizes lake characteristics for the Aral Sea prior to desiccation.

Table IV-3: Summary of lake characteristics for Aral Sea prior to desiccation

Lake Characteristic	Value
Lake Area (square miles)	26,000
Watershed Area (square miles)	700,000
Watershed Population	60,000,000
Maximum Depth (feet)	180
Saline Concentration Range (percent)	1 to 10+

Note: 2008 estimate of watershed population, not prior to desiccation.

b) Economic Consequences

Prior to desiccation impacts, the Aral Sea supported a substantial fishing industry in present-day Kazakhstan and Uzbekistan. However, the industries ended in the 1980s as increasing salinity levels and the loss of spawning and feeding areas led to the extinction of indigenous fish from the sea (Micklin, 2007). As a result, an estimated 60,000 fishermen lost their livelihood (Wurtsbaugh et al., 2017). Fishing and related activities previously provided half of the income of the Karakalpaks, an indigenous population located in the Karakalpakstan Republic within Uzbekistan (Ataniyazova, 2003).

The drying of the Aral Sea has also negatively impacted the agriculture sector in the region. The desiccation of the Aral Sea has intensified salinity levels, as 70 percent of the irrigated land in Karakalpakstan is impacted by salinity that is deposited from dust storms (Ataniyazova, 2003). Overall, agricultural output has declined by 30-50 percent as a result of salinity, water deficiency, climate change, and reduced labor productivity due to associated health challenges Ataniyazova, 2003).

In 2005, an 8 mile long earthen dyke was constructed to regulate the flow from the North Aral Sea to the large South Aral Sea, at a cost of $109 million (2019$), which preserved a portion of the North Aral Sea, approximately 5 percent of the size of the former Aral Sea (Wurtsbaugh et al., 2017). With support of the World Bank, the Kazakhstan Government is working toward a second phase of the Small Aral restoration project that would raise the water levels in the Gulf of Saryshaganak (Micklin, 2016). The cost of this project is estimated at $161.3 million (2019$) (World Bank, 2014). The total cost of the restoration work is estimated to be over $270.7 million (2019$).

Media reports indicate that the North Aral Sea is now 10 percent of its original size, and fishing harvests have increased from 1,400 tons in 2006 to 7,100 tons in 2016 (Chen, 2018). Still, the South Aral Sea has yet to rebound, which indicates reclamation efforts are not always effective.

The only realistic approach to substantially increasing flow to the Aral Sea is reducing consumptive use of water for irrigation in the drainage basin. Irrigation in the Aral Sea Basin is highly inefficient. Substantial technical, economic, and institutional improvements to the irrigation system could save considerable water. Some improvement measures are being implemented, however a comprehensive program to renovate the antiquated irrigation and drainage systems on 13.3 million acres is estimated to cost $24.4 to $33.6 billion USD (2019$). This would still not completely restore the Aral Sea. It is likely that the cost to renovate the irrigation and drainage systems is beyond the willingness, and perhaps ability, of the basin states to pay, even with major aid from international donors. Furthermore, the condition of the irrigation systems in the basin are steadily deteriorating owing to inadequate funding for, and lack of management responsibility over, operation and maintenance activities (Micklin, 2014).

c) Social Consequences

Dust from Aral Sea has been contaminated from agricultural runoff saturated with pesticides. The fine dust that lies along the dried lakebed contains high levels of salt and toxins and can be transported up to 300 miles in dust storms (Micklin, 2007). In addition to harming vegetation, the dust is a contributing factor to human health impacts in the region, which include high levels of esophageal cancer, respiratory illnesses, and eye problems in the near-Aral region (Micklin, 2007).

d) Environmental Consequences

In addition to contributing to the desiccation of the Aral Sea, poor agricultural practices have resulted in the degradation of water quality, which has reduced fish populations in the Aral Sea and damaged most flora and fauna (Ataniyazova, 2003). Desertification in the region has been expanding and intensifying due to reduced river flows and declining groundwater levels caused by the lowering levels of the Aral Sea (Micklin, 2007). Native vegetation have been replaced by plants that are adapted to growing in saline conditions (halophytes) and plants that need very little water (xerophytes), and salt flats have accumulated on some portions of the lake bed, inhibiting vegetation altogether (Micklin, 2003).

The desiccation of the Aral Sea has substantially reduced biodiversity in the region. Greater than 70 species of mammals and 319 species of birds lived in the river deltas prior to 1960, compared to 32 species of mammals and 160 species of birds by 2007 (Micklin, 2007). In addition to causing harm to natural vegetation and crops, the deterioration of the local ecology also threatens permanent and migratory waterfowl populations as well as wild and domestic animals. The true environmental costs associated with the desiccation of the Aral Sea have not been monetized (Wurtsbaugh et al., 2017).

e) Relevance to Great Salt Lake

The drying of the Aral Sea poses threats to the economy, public health, and the environment. The desiccation of the Aral Sea can be attributed to development pressures in the surrounding region. Both the Aral Sea and Great Salt Lake are in close proximity to large populations. Increased water diversions for agriculture also contribute to the drying of the Aral Sea.

A summary of the economic, social, and environmental consequences of Aral Sea desiccation that may be relevant to Great Salt Lake are presented in Table IV-4.

Table IV-4: Summary of consequences from the drying of Aral Sea

Economic	Social	Environmental
Cost to renovate the irrigation and drainage systems \$24.4 to \$33.6 billion	Public health impacts from dust storms from exposed lakebed (PM_{10}).	Mammal and bird species reduced by half
Restoration costs of \$270.7 million	High levels of esophageal cancer, respiratory illnesses, and eye problems in the surrounding region	Desertification and the associated impacts on flora and fauna
70% of irrigated land impacted by dust storms		Threatened permanent and migratory waterfowl
60,000 fishermen lost their livelihoods when fishery was lost		Native plants replaced by plants adapted to dry, saline conditions

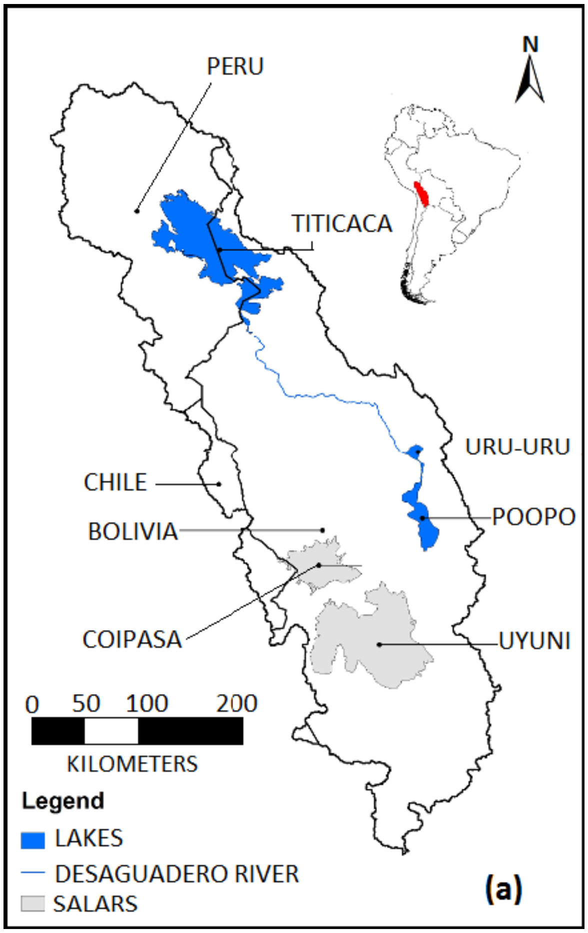
3. Lake Poopó

Lake Poopó is located in the Altiplano Mountains in Bolivia. With a watershed occupying 9,200 square miles, Lake Poopó had an area of 380 square miles prior to desiccation (Calizaya et al., 2008; Howard, 2016). Located 1,200 feet above sea level in Bolivia, Lake Poopó is remarkably shallow, with maximum depths of less than 10 feet (Arsen at al., 2014; Tewari, 2017). The following sections describe Lake Poopó, and include an overview of lake characteristics as well as the economic, social, and environmental consequences of the drying lake. This is followed by a discussion of relevance to Great Salt Lake.

a) Overview of Lake Characteristics

Lake Poopó is a saline lake located in the Altiplano Mountains, situated in a semi-arid climate. The salinity level of Lake Poopó was approximately 1.0 percent in 1985 (Iltis, 1993). Lake Poopó is classified as a terminal lake (Zola and Bengtsson, 2010). While 20 percent of the lake's inputs are sourced by precipitation, the remaining 80 percent are sourced by rivers (Abarca-Del-Rio et al., 2012). The Desaguadero River is the primary source for Lake Poopó, feeding the lake from Lake Titicaca to the north. The Marques and Sevaruyo Rivers also drain into Lake Poopó from the south (Abarca-Del-Rio, 2012; Munoz et al., 2013). A geographic overview of Lake Poopó, which includes Lake Titicaca basin to the north and the Desaguadero River, which connects the Lake Titicaca and Lake Poopó basins, is provided in Figure IV-3.

Figure IV-3: Geographic overview of Lake Poopó



Source: Arsen et al., 2014.

The Desaguadero River floodplain that surrounds the Lake Poopó basin is a water-land interface that fluctuates seasonally (Whitt, 2018). Much of the land remains dry in the winter months before groundwater recharge throughout the summer period between December and February (Whitt, 2018; Munoz et al., 2013). Prior to desiccation impacts, the variation in water levels of Lake Titicaca, which is connected to Lake Poopó via the Desaguadero River, frequently caused floods and droughts in the Lake Poopó basin (Munoz et al., 2013).

Lake Poopó has exhibited desiccation impacts for decades as a result of cyclical El Nino droughts and water diversions, and has dried several times in the past (Casey, 2016). Lake Poopó is known to have dried up between 1994 and 1997, and records show the lake was also dry between 1939 and 1944 and nearly dry between 1970 and 1972 (Zola and Bengtsson, 2010). Previously, the Andean glaciers would replenish Lake Poopó when the region suffered dry spells, although shrinking glaciers contribute to the desiccation of Lake Poopó. In addition, changes in precipitation patterns contribute to the lake's desiccation. Net annual rainfall is occurring over a shorter period of time, which limits water availability over the growing season while increasing flood risk (Whitt, 2018). Furthermore, temperature increases have raised the rate of evapotranspiration in the summer months, increasing water stress (Whitt, 2018).

Lake Poopó most recently dried up in December 2015 and, this time, recovery may not be possible (Valdez, 2016). The Andean glaciers previously helped source the lake, but the glacial retreat associated with climate change has limited the supply of glacial water and, as a result, the longevity of the lake is inhibited.

The area surrounding Lake Poopó had a population of 7,300 as of the official census in 2001, though the population was estimated to have grown to 10,000 by 2013 (Munoz et al., 2013). However, the watershed of Lake Poopó has an estimated population of 360,000 (Calizaya et al., 2008).

Table IV-5 summarizes lake characteristics for Lake Poopó prior to desiccation.

Table IV-5: Summary of lake characteristics for Lake Poopó

Lake Characteristic	Value
Lake Area (square miles)	380
Watershed Area (square miles)	9,200
Watershed Population	360,000
Maximum Depth (feet)	10
Saline Concentration (percent)	1.0

b) Economic Consequences

Prior to desiccation impacts, Lake Poopó had an active fishing industry (Munoz et al., 2013). After the loss of the fishing industry, the loss of income in the region resulted in the migration of up to thousands of residents from the region (Valdez, 2016).

c) Social Consequences

The Poopó region in the Oruro Department of Bolivia is poor and vulnerable to displacement. Together, the mining industry, agriculture, and livestock, largely supported by the lake, accounts for income for 90 percent of the area’s population (Ekdahl, no date). While records of population displacement due to the lake’s desiccation are limited, the water scarcity on the Bolivian Altiplano has led to a mass-migration of population toward more urban population centers, with estimates in the thousands. Furthermore, over 100 families in the lakeside village of Untavi sold their livestock and fishing equipment between 2013 and 2016, and approximately 3,250 people received humanitarian aid (Valdez, 2016).

d) Environmental Consequences

There is limited literature available on the environmental consequences of the desiccation of Lake Poopó. However, anecdotal evidence suggests catastrophic environmental consequences from the drying of the lake and, in particular, loss of fish and wildlife in surrounding areas. On November 18, 2014, millions of dead fish and hundreds of dead birds washed up on the lake shore, leaving behind a 19 mile long, 10 feet wide band (Whitt, 2018). The mass die off was a result of high winds that drove fish to low-oxygen waters where they suffocated; an event that demonstrates the fragility of the ecosystem (Whitt, 2018).

e) Relevance to Great Salt Lake

Similar to the drying of Great Salt Lake, the drying of Lake Poopó poses threats to the economy, public health, and the environment. The ecosystem of Lake Poopó is of ecological importance, and the lake's desiccation leaves fish and wildlife vulnerable to a catastrophic die-offs. A summary of the economic, social, and environmental consequences of the complete loss of Lake Poopó that may be relevant to Great Salt Lake are presented in Table IV-6.

Table IV-6: Summary of consequences from the drying of Lake Poopó

Economic	Social	Environmental
Complete loss of fishery and fishing industry	Displaced fishermen and indigenous people that depended on the lake	Millions of dead fish
		Mass die off of hundreds of birds
		Loss of wildlife in surrounding areas

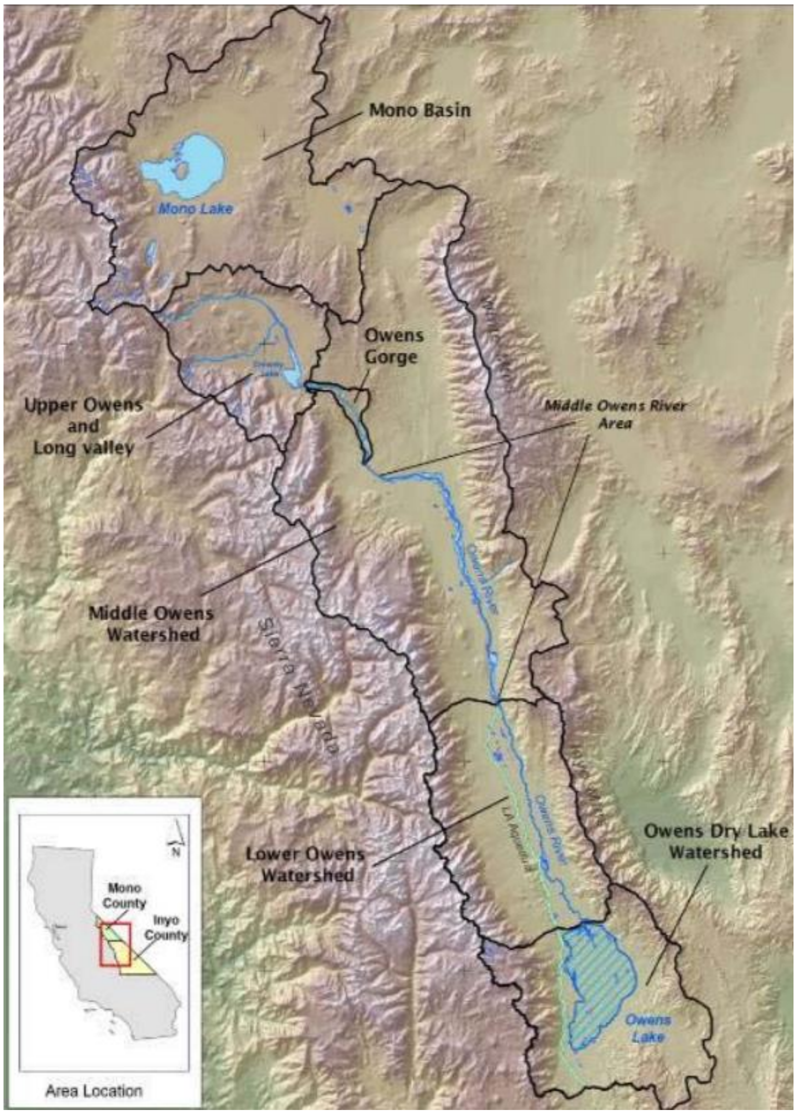
4. Owens Lake

The Los Angeles Aqueduct was constructed in 1913 to divert water from the Owens River. By 1925, the diversion caused Owens Lake levels to recede so rapidly that all that remains now is a dry lakebed and some mudflats (Piper, 2011). Located in Inyo County, California, the Owens Lakebed is 200 miles north of Los Angeles. The climate of Owens Valley is characterized as semi-arid to arid, with low precipitation, frequent winds, and high potential evapotranspiration (Cardoza and Rigby, 2016). The bed of Owens Lake is one of the highest sources of dust pollution in the United States (County of Inyo, 2008; Sapphos Environmental, 2007). The following sections describe Owens Lake and include an overview of lake characteristics as well as the economic, social, and environmental consequences of the drying lake. This is followed by a discussion of relevance to Great Salt Lake.

a) Overview of Lake Characteristics

Previously sourced by snowpack from the Sierra Nevada Mountains via the Owens River, Owens Lake held water for at least 800,000 years prior to the early twentieth century (Reheis, 1997). As the natural hydrologic sink of the Owens Valley, Owens Lake received water and dissolved salts coming from various sources within the watershed (Sapphos Environmental, 2007). Owens Lake occupied an area of approximately 110 square miles prior to desiccation impacts, and had typical depths ranging from 20 to 50 feet (Reheis, 1997). The Owens Lake basin occupies a land area of approximately 1,000 square miles (California Department of Water Resources, 2004). At an elevation of approximately 3,500 feet, the lakebed is surrounded by the southern Sierra Nevada to the west and the Inyo Mountains to the east (Herbst and Prather, 2014). Owens Lake was unique in that water evaporated from the lake faster than precipitation refilled it. As a result, the saline and alkaline concentrations naturally increased over time (Sapphos Environmental, 2007). The watershed of Owens Lake and the Owens River is displayed in Figure IV-4, in addition to the Mono Lake basin, which is described in Section IV-8.

Figure IV-4: Owens Lake watershed



Source: Los Angeles Department of Water and Power, 2012.

Prior to desiccation impacts, the salinity of the lake was approximately 1.5 times greater than that of seawater (Cardoza and Rigby, 2016). Water samples in 1876 and 1886 found saline concentrations to vary from 6.4 percent to 7.3 percent, with little change in lake volume during that time period (Herbst and Prather, 2014).

To meet the water demands of a growing city, the Los Angeles Aqueduct was constructed in 1913 to divert water from the Owens River (Piper, 2011). The diversion caused Owens Lake levels to recede rapidly and, by 1925, what remained were a dry lakebed and some mudflats, resulting in one of the largest sources of particulate matter in the United States (County of Inyo, 2008; Sapphos Environmental, 2007).

As Owens Lake has been dry for nearly a century, there is limited peer reviewed literature available on the ecological lake characteristics prior to the construction of the aqueduct. According to an 1876 land survey, the lake system could not support fish and mollusk populations due to the high saline and alkaline concentrations (Herbst and Prather, 2014). However, the lake did support lower forms of animal life, including infusoriae, brine shrimp (Artemia), and the larvae of insects (Herbst and Prather, 2014). The surveys also noted the presence of salt-tolerant green algae (*Ctenocladus circinnatus*) (Herbst and Prather, 2014).

Vegetation surrounding the lake included two salt plants (Bryzopyrum and Halostrachys) (Herbst and Prather, 2014). As an aquatic habitat, the ecosystem also supported large populations of waterfowl and shorebird, including avocets, phalaropes, and ducks (Herbst and Prather, 2014).

Table IV-7 summarizes lake characteristics for Owens Lake prior to desiccation.

Table IV-7: Summary of lake characteristics for Owens Lake

Lake Characteristic	Value
Lake Area (square miles)	110
Watershed Area (square miles)	1,000
Maximum Depth (feet)	50
Saline Concentration Range (percent)	6.4-7.3

b) Economic Consequences

After the City of Los Angeles built a 230 mile aqueduct in 1913, redirecting water from Owens Valley to the city, the Los Angeles Department of Water and Power (LADWP) purchased most of the land in Owens Valley. This created an economic hardship for those that remained in Owens Valley.

Merchants demanded reparations for lost business resulting from Los Angeles' acquisition of the valley's farm lands. As a result, California passed a state law permitting Los Angeles to purchase any commercial, residential, or agricultural property offered for sale. By 1933, Los Angeles had purchased 85 percent of the residential land in the valley, and 95 percent of the (largely farm and ranch) commercial property (County of Inyo, 2008). Following that, road improvements and an increased Southern California population led to a revival of Owens Valley as tourists began visiting the area. As the towns prospered, Los Angeles sold back some of the town property and leased some ranches for farming (Unrau, 1996).

In 1987, the US Environmental Protection Agency (USEPA) designated the southern Owens Valley as a non-attainment area for PM_{10} under the National Ambient Air Quality Standard (NAAQS) and, in 1993, it was reclassified as "serious nonattainment" for PM_{10}. The Owens Lakebed is considered to be an anthropogenic source of PM_{10}

because the City of Los Angeles' aqueduct diverts water that historically supplied the lake. In order to operate the aqueduct, the City of Los Angeles is required to provide a State Implementation Plan (SIP) to demonstrate how it will attain National Ambient Air Quality Standards (NAAQS) for PM_{10} as required by the Clean Air Act. The 2016 SIP was triggered by the USEPA's 2007 finding that the Owens Valley PM_{10} nonattainment area had failed to meet its December 31, 2006 deadline to attain the PM_{10} NAAQS (Docket ID number: EPA–R09–OAR–2016–0660; FRL–9958–80–Region 9). The Great Basin Unified Air Pollution Control District (GBUAPCD) ordered LADWP to pay fees associated with the development of dust control measures and legal costs to enforce Owens Lake air pollution control requirements. In 2012, Kern County's Judge Sidney P. Chapin ordered the LADWP to immediately pay fees of over $1.1 million to GBUAPCD (GBUAPCD, 2012). LADWP has had two noncompliance issues in the past year resulting in a notice of violation in the amount of about $1 million and an order to pay about $3 million to GBUAPCD.[2]

The 2016 SIP proposes a dust control strategy for the City of Los Angeles to continue to operate and maintain the 45 square miles of existing control measures on the Owens Lakebed and also requires control of the Keeler Dunes and the placement of Best Available Control Measures (BACM) on an additional 3.62 square miles of lakebed (GBUAPCD, 2016).

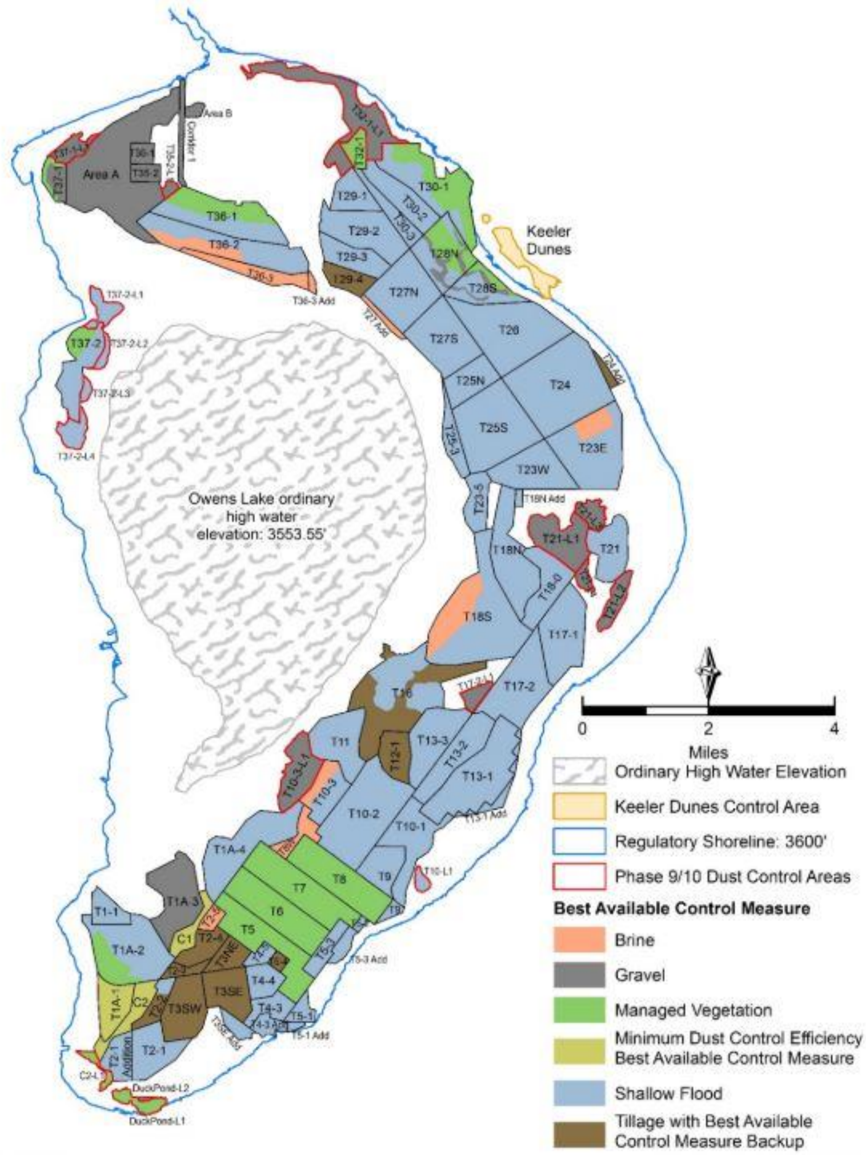
Three dust control mitigation measures that have been approved for use on the lake and are considered BACM:

- Shallow flooding (including brine and tillage with BACM shallow flooding backup);
- Managed vegetation; and
- Gravel blanket.

Dust control measures are shown in Figure IV-5.

[2] Communication with Phillip Kiddoo, Air Pollution Control Officer, Great Basin Unified Air Pollution Control District on January 9, 2019.

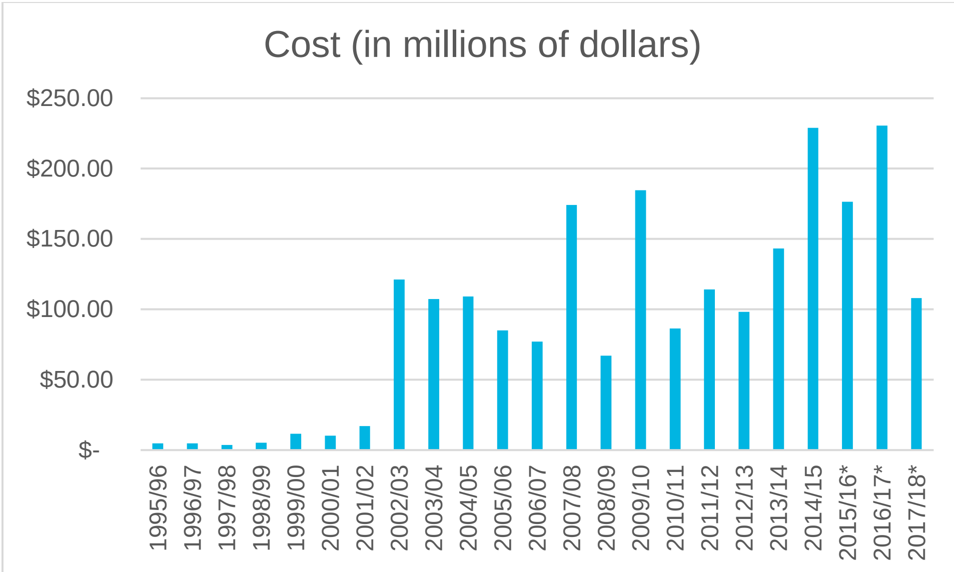
Figure IV-5: PM_{10} dust control measures map



Source: CARB, 2016

Mitigation costs, largely to mitigate the dust storms, have been substantial. LADWP has been operating the Owens Lake Dust Mitigation Program since 2001 (LADWP, 2015). Figure IV-6 shows a summary of the Owens Lake Dust Mitigation Program from July 1, 1995 through June 30, 2018. The total mitigation costs over that period are over $2.1 billion (LADWP, 2018). The dust control mitigation measures have been constructed on the lake bed over an area encompassing a total of 43 square miles or approximately 27,500 acres (CARB, 2016). Mitigation costs are expected to increase to $3.645 billion through 2025 (GBUAPCD, 2016).

Figure IV-6: Los Angeles Department of Water and Power (LADWP) mitigation expenditures



*Denotes LADWP anticipated expenditures as of June 30, 2015.
Source: Great Basin Unified Air Pollution Control District

The mitigation costs have a direct impact on the ratepayers in Los Angeles. Dust mitigation accounts for approximately 15 percent or nearly 2 months out of every Los Angeles ratepayer's annual water bill (LADWP, 2015).

c) Social Consequences

When rainfall occurs during cooler months, the dry lakebed becomes a toxic saturated brine pool of sediments. As the pools dry they leave behind a salt crust susceptible to erosion. Due to its fine grained nature, particulates from the dry lakebed can be transported significant distances. The dust includes PM_{10} dust particles and mineral dust aerosols from the lakebed, including pollution from the Cerro Gordo mine (Borlina and Renno, 2017). Furthermore, the unique drainage of the lake resulted in high concentrations of hazardous elements, including arsenic, cadmium, and chromium (Los Angeles Aqueduct Digital Platform, 2014).

In 1987, the USEPA declared the dry lakebed to be the source of the worst dust problem in the United States (Piper, 2011). That same year, the USEPA designated the Owens Valley Planning Area to be non-attainment for the NAAQS for PM_{10} (Sapphos Environmental, 2007).

The dust is a known carcinogenic, and the emitted particulate matter also poses a hazard to public health. The dry Owens Lakebed is one of the leading sources of PM_{10} emissions in the United States, with annual emissions greater than 80,000 tons (Sapphos Environmental, 2007). PM_{10} is dangerous because of its tendency to settle deep into a person's lungs, posing a particular danger to those with lung disease and chronic obstructive pulmonary disease (Los Angeles Aqueduct Digital Platform, 2014). As of the 2007 Ecological Risk Assessment, approximately 40,000 permanent residents are exposed to the dust of the lakebed each year.

d) Environmental Consequences

The remnants of the lake include a saturated brine pool occupying approximately 25.5 square miles in the western portion of the lakebed, and a significant source of dust pollution (Sapphos Environmental, 2007). Owens Lake has been a dormant habitat since it dried up, and the ecological values of the saline lake ecosystem have long been ignored (Herbst and Prather, 2014).

Rehydration efforts, largely in an effort to control dust, have resulted in the return of large numbers of migratory birds. A 2013 lake-wide survey found 20 species of shorebirds in addition to 600-700 adult snowy plovers, a California Species of Special Concern (Herbst and Prather, 2014). Recently, Owens Lake qualified as a Western Hemisphere Shorebird Reserve Network (WHSRN) site of International Importance – the 104th designated site and the 49th site in the U.S. Owens Lake now supports more than 100,000 shorebirds annually including more than one percent of the global populations of American Avocet (*Recurvirostra americana*) and Least Sandpiper (*Calidris minutilla*), and one percent of the Interior/Gulf Coast population of Snowy Plover (*Charadrius nivosus*) (WHSRN, 2018). Algae, brine flies, and brine shrimp are also known to live in the ecosystem, providing abundant food resources for wildlife.

e) Relevance to Great Salt Lake

Depending on water levels, the footprint of Great Salt Lake is on the order of 19 times the size of Owens Lake. At an elevation of 3,500 feet above sea level, the Owens Lakebed is approximately 700 feet below the elevation of Great Salt Lake (United States Geological Survey, no date). Counties in Great Salt Lake watersheds are less populated than Los Angeles County, therefore mitigation costs per capita could be much higher for Utah residents. Dust mitigation has cost Los Angeles rate-payers approximately $2.1 billion and that is expected to increase to over $3.6 billion through 2025 (LADWP, 2015).

The drying of Great Salt Lake has the potential to affect a much larger population. Great Salt Lake is in close proximity to millions of people, whereas approximately 40,000 residents are affected by the dust pollution of Owens Lake. LADWP has paid millions of dollars in court-ordered non-compliance fees. If Great Salt Lake follows a similar path, courts may intervene and usurp control over Great Salt Lake, imposing more significant costs.

Because it has been nearly a century since the desiccation of Owens Lake, the full economic, social, and environmental impacts are difficult to monetize. For instance, there is no evidence to suggest that there were recreation and brine shrimp industries prior to the desiccation of Owens Lake.

A summary of the economic, social, and environmental consequences of Owens Lake desiccation that may be relevant to Great Salt Lake are presented in Table IV-8.

Table IV-8: Summary of consequences from the drying of Owens Lake

Economic	Social	Environmental
Mitigation costs over $3.6 billion	Public health impacts from dust storms ($PM_{2.5}$)	Supports more than 100,000 shorebirds after rehydration efforts
$5M is noncompliance fees	USEPA declared the dry lakebed to be the source of the worst dust problem in the U.S.	

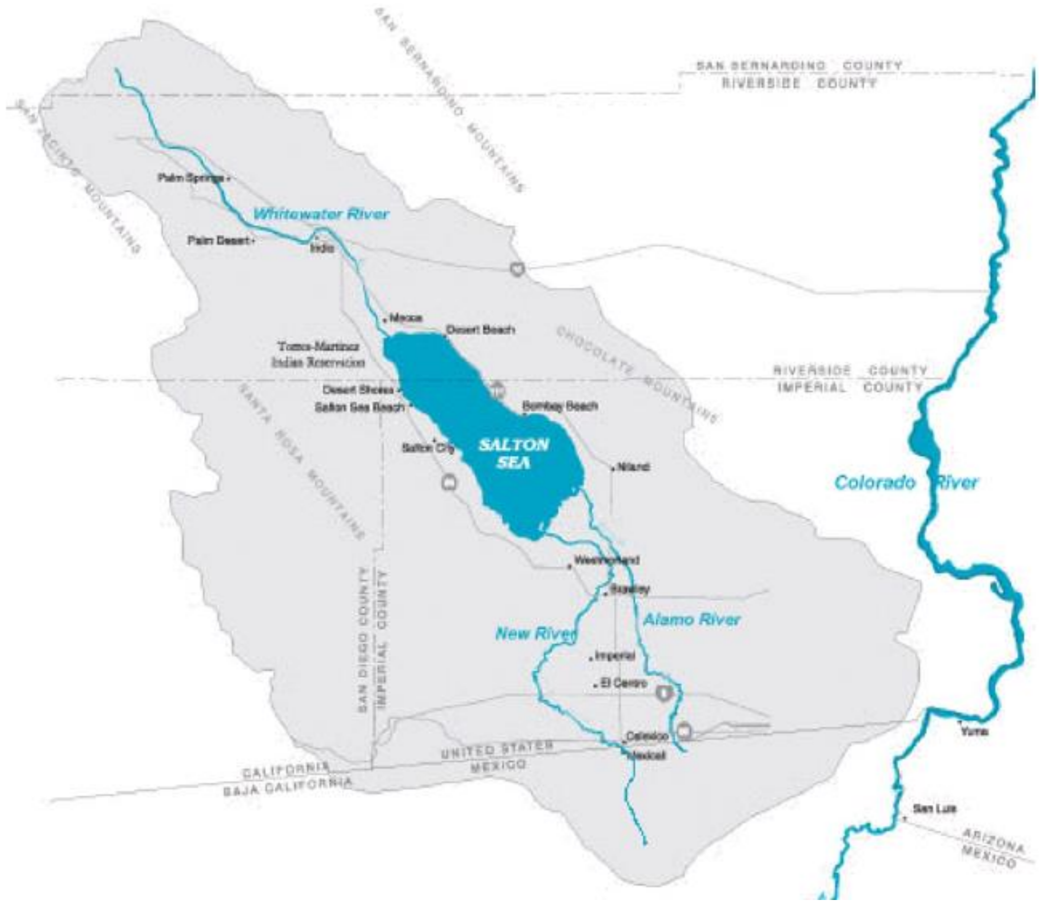
5. Salton Sea

The Salton Sea is a high saline terminal lake located in an arid-desert climate in the southeastern region of California, approximately 35 miles north of the U.S.-Mexico border. The following sections describe the Salton Sea, and include an overview of lake characteristics as well as the economic, social, and environmental consequences of the drying lake. This is followed by a discussion of relevance to Great Salt Lake.

a) Overview of Lake Characteristics

The Salton Sea, California's largest lake, has been flooded and dried several times over geologic history (Cohen and Hyun, 2006; Anderson, 2018). Its most recent formation resulted from the diversion of the Colorado River in 1905. The Salton Sea now covers an area of approximately 330 square miles and has a maximum depth of 20 feet (Pacific Institute, 2019). The Salton Sea watershed occupies 8,400 square miles (Cohen and Hyun, 2006). The Salton Sea is situated 200 feet below sea level and is sourced by the Alamo and New Rivers, which flow into the southern end of the basin, and the Whitewater River, which flows into the northern end of the basin. The Salton Sea watershed is displayed in Figure IV-7.

Figure IV-7: Salton Sea watershed



Source: Pacific Institute, 2006.

The Salton Sink or Salton Basin refers to the natural bowl geography of the area. The Salton Sea occupies the lowest elevation of the Salton Sink. The Salton Sink hosted a salt mining operation starting in 1884. The saline concentration of the Salton Sea has been increasing over the past century (King et al., 2011). The salinity of the lake has risen from 0.4 percent in 1905 to over 5.0 percent in recent years (Lyons et al., 2018). The Salton Sea is a wetland system of ecological importance, providing refuge for over 380 avian species (Lyons et al., 2018; Cohen et al., 1999). Piscivorous waterfowl (including pelicans, cormorants, gulls, and sterns) utilize the Salton Sea along their seasonal migrations (Lyons et al., 2018); however, pelican use is now dwindling with the shrinking Salton Sea and impacts to the fishery. Other species, including California Gulls, Caspian Terns, and Black Skimmers use the Salton Sea as nesting habitat (Lyons et al., 2018).

The Salton Sink is surrounded by the Imperial and Coachella Valleys, and is host to intense agricultural production (LeBlanc and Kuivila, 2008). In 1905, 10,000 people lived in the valleys, farming approximately 120,000 acres of land. As of 2018, more than 650,000 residents live within the Salton Sink area (Cohen et al., 1999; Audubon California, 2018). As of 1999, more than 75 percent of the water that entered the Salton Sea was U.S. agricultural drainage (Cohen et al., 1999).

In 2003 the Imperial Irrigation District agreed to the Quantification Settlement Agreement, in which the irrigation district agreed to transfer increasing volumes of water to San Diego and Los Angeles (Garza, 2017). Based on that Agreement, the Salton Sea was expected to drop five feet between 2006 and 2017 (Cohen and Hyun, 2006). The Imperial Irrigation District agreed to provide additional water (i.e., “mitigation water”) to the Salton Sea through 2017 to address the sea’s desiccation (Garza, 2017). The recent loss of mitigation water has accelerated changes in water levels and salinity.

Given that it has been just over one year since the Imperial Irrigation District stopped providing “mitigation water” to the Salton Sea, limited research is currently available on the impacts of the Quantification Settlement Agreement post-2017. However, a 2012 salinity survey by the U.S. Bureau of Reclamation estimated that the salinity would rise to 6 percent by the end of 2018 and 15 percent by 2045 (California Natural Resources Agency, 2017). Furthermore, the State of California anticipates an additional 77 square miles of dry lakebed will become exposed between 2018 and 2028 (Taylor, 2018).

Table IV-9 summarizes lake characteristics for the Salton Sea prior to desiccation impacts.

Table IV-9: Summary of lake characteristics for Salton Sea

Lake Characteristic	Value
Lake Area (square miles)	370
Watershed Area (square miles)	8,400
Watershed Population	650,000
Maximum Depth (feet)	50
Saline Concentration Range (percent)	0.4 – 6.0

b) Economic Consequences

Because of the warm winder climate, proximity to Southern California cities, large size and formerly active fishery, Salton Sea was a popular destination for tourism, fishing, and water sports (Taylor, 2018). Prior to desiccation impacts, the California Department of Fish and Wildlife stocked the Salton Sea with a variety of sport fish and Salton Sea supported a strong sport fishing industry (Taylor, 2018). In 1969, recreation activities around the lake contributed $550 million (2019$) to the local economy but, by 1987, the recreational use of the Sea had been reduced by half (Cohen et al., 1999). Tourism and recreation loss were due to episodes of flooding, fish die-offs, and other factors related to desiccation such as, the algae and nutrient in the Salton Sea often cause it to emit a sulfurous odor when temperatures are high (Taylor, 2018). As of 2007, the Salton Sea had annually attracted approximately 340,000 visitors for recreation purposes, contributing $26.5 million (2019$) annually to the state’s economy (U.S. Department of the Interior, 2007).

A report by the Pacific Institute estimated an annual loss of more than $6.5 million (2019$) in direct recreational revenue due to a reduction in visitor days (Cohen, 2014).

While subsequent reclamation efforts were expected to yield some recreation benefits, those benefits are expected to be far less than reclamation costs.

In addition to recreation, the Salton Sea hosted a thriving commercial fishing industry. However, increasing salinity levels have impaired the fishery of the Salton Sea (Cohen and Hyun, 2006). Furthermore, in 2006 the Coachella and Imperial valleys supported a $1.9 billion (2019$) agricultural industry (Cohen and Hyun, 2006).

Dust storms from the dry lakebed threaten property values within several miles of the lake. It is estimated that the loss of value for these properties is at least $400 million. Dust and noxious odors could also depress property values beyond the nearest few miles and impact businesses. The total impact on property values could be $7 billion (Cohen, 2014).

A 2007 report by the U.S. Department of Interior identified six possible projects to restore the Salton Sea ecosystem and protect vulnerable wildlife. The costs of the projects ranged from $4.2 billion to $16.9 billion (2019$), with annual maintenance costs ranging from $143.4 million to $283 million (2019$). Even the no-build project alternative would require $1.7 billion (2019$) in air quality mitigation costs. The selected alternative cost $11.09 billion to construct and over $283 million in annual maintenance costs (2019$) (U.S. Department of Interior, 2007). In the following years, a recession hit and the plan was subsequently deemed financially infeasible.

More recently, the Salton Sea Management Plan (SSMP) was developed to protect air quality and the ecosystem values at the Salton Sea (California Natural Resources Agency, 2017). Phase I of the SSMP provides for development of habitat and dust suppression projects on the exposed dry lakebed, using site logistics to determine the location of habitat projects (California Natural Resources Agency, 2017). Phase I of the project is expected to build 29,800 acres of habitat, reducing total exposed acres from 48,300 to 18,500 by 2028, at a cost of $427 million (2019$) (California Natural Resources Agency, 2017; Taylor, 2018).

While mitigation and management efforts of the Salton Sea have been chronically underfunded, funding for the SSMP is being pieced together. As of June 2018 approximately $730.1 million (2018$) of funding had been identified as authorized, which includes over $365.4 million in voter approved funding (Taylor, 2018).

California tax payers have approved considerable funding to support mitigation and management efforts of the Salton Sea, including: Proposition 12 in 2000 ($4.8 million); Proposition 50 in 2002 ($33.6 million); Proposition 84 in 2006 ($47.0 million); Proposition 1 in 2014 ($80.0 million); and Proposition 68 in 2018 ($200.0 million). In total, California tax payers approved over $365.4 million to support Salton Sea restoration efforts.

However, some of that funding has not yet been allocated to projects yet due to project delays and a lengthy state procurement process (Audubon California, 2018).

c) Social Consequences

The shrinking of the Salton Sea presents public health threats to the growing populations within the Imperial and Coachella valleys. As of 2006, a combined 400,000 people lived in the Imperial and Coachella valleys (Cohen and Hyun, 2006). The Imperial and Coachella valleys are within the Salton Sink. As of 2018, an estimated 650,000 residents lived in the Salton Sink (Audubon California, 2018).

As the Salton Sea shrinks it leaves behind fine-grained dust which presents a public health hazard, especially to sensitive populations. Increasing dust may increase other exposures to microbes (e.g., bacteria, fungi) and toxins. Salton Sea contains contaminants from agricultural runoff (i.e., fertilizers, pesticides, salt, toxic metals) that have collected in the sea over the years. Persistent organic pollutants include PDB, DDT/DDE, and toxic metals such as antimony, arsenic, cadmium, chromium, lead, and selenium (Johnston and Farzan, 2016).

Imperial County and the Coachella Valley air quality falls below state and federal standards due to high PM_{10} concentrations. PM_{10} has the potential to decrease growth and development of lung function in youth populations and can increase the potential for cardiac disease and heart attacks in adults (Cohen and Hyun, 2006). In addition, wind-blown dust (PM) can increase asthma attacks, asthma severity, hospitalizations, lung diseases and symptoms, and infections. With regard to the latter, PM can also impair the ability to fight off infections (Johnston and Farzan, 2016). The public health costs of not meeting the federal standards are estimated between $23 and $40 billion (2019$) through 2047 if no mitigation actions are taken (Cohen, 2014).

More than one-third of the residents (>10,000) living within 20 miles of Salton Sea are children. Other sensitive populations include elderly, asthmatics, and people who work or exercise outdoors. In 2016, one in five children from the communities of Imperial County (adjacent to the Salton Sea) suffered asthma, and emergency room visits for children ages 5 to 17 are over twice the statewide average in California (Audubon California, 2018). As water is diverted, dust may increase by 40 to 80 tons per day (Johnston and Farzan, 2016). Already the highest in California and three times the state's average, childhood asthma hospitalization rates in the Coachella and Imperial valleys could increase by exposing an additional 134 square miles of lakebed (Cohen and Hyun, 2006).

Fine-grained, wind-blown dust decreases the quality of life for residents within the Imperial and Coachella valleys because there is a risk of exposure and illness from spending time outdoors. There can also be reduced visibility during dust events that can make driving dangerous (Johnston and Farzan, 2016).

d) Environmental Consequences

As previously noted, agricultural runoff that feeds the Salton Sea has not supported stable saline levels (Lyons et al., 2018). As salinity increased to 4.0 percent, the fish community composition changed substantially. The four most abundant fish species in 1999-2000 were bairdiella, orangemouth corvine, sargo, and a hybrid tilapia strain; only the hybrid tilapia remains abundant (Lyons et al., 2018). However, recent monitoring research indicates that those populations have declined as the sea's salinity exceeds 6.0 percent (Lyons et al., 2018).

In 1999, the Salton Sea had a fishery. However, fish populations declined by over 95 percent in subsequent years due to low oxygen levels that resulted from increased nutrient concentrations from agricultural runoff (Cohen and Hyun, 2006).

The elimination of fish habitat and fish populations in the Salton Sea could threaten migratory bird populations that rely on the Salton Sea as a migratory stopover (Lyons et al., 2018). With increasing pressure on water resources in the Central Valley of California and the Colorado River Basin, the Salton Sea is of increasing significance for waterfowl species as other wetland habitats are disappearing (Lyons et al., 2018). More than 90 percent of California's wetlands disappeared during the twentieth century, making the Salton Sea one of the few remaining habitats for avian species in California (Cohen, 2000).

The ecological benefits associated with shoreline and near shoreline habitats surrounding Salton Sea are substantial, with an estimated range of $2.0 - $2.8 billion annually (2019$). These benefits have presumably been reduced as the lake dries and are expected to continue to decline absent mitigation measures (Cohen, 2014).

e) Relevance to Great Salt Lake

The shrinking of the Salton Sea poses threats to the economy, public health, and the environment of the watershed and its residents. Similarities with Great Salt Lake are as follows:

- With a lake area of 370 square miles, the Salton Sea is the second largest saline lake in the United States, second to Great Salt Lake at 1,050 square miles (Cohn, 2000; SWCA, 2017).
- The population density surrounding Great Salt Lake is far greater than that in the Imperial and Coachella valleys. Therefore, the socio-economic impacts of Great Salt Lake's desiccation could be far greater.

A summary of the economic, social, and environmental consequences of Salton Sea desiccation that may be relevant to Great Salt Lake are presented in Table IV-10.

Table IV-10: Summary of consequences from the drying of Salton Sea

Economic	Social	Environmental
Up to $16.9 billion for restoration; $472 million for 10YR Phase 1 habitat & dust suppression	Public health impacts from dust storms estimated at $40 billion	$2.8 billion annual ecological benefits is declining as sea shrinks
$550 million reduced to an annual recreational value of $26.5 million and visitors reduced to 340,000 annually	Emergency room visits for children are over twice the statewide average in California	Fish populations declined by over 95%

Economic	Social	Environmental
Loss of commercial and sport fishing industry	Childhood asthma hospitalization rates are the highest in CA and 3 times the state's average	One of the few remaining wetland habitats for avian species in California
Loss of $1.9 billion agricultural industry		
Property value loss up to $7 billion		

6. Dead Sea

A terminal lake, the Dead Sea is located on the border of Jordan and Israel in the Jordan Rift Valley. The following sections describe the Dead Sea, and include an overview of lake characteristics as well as the economic, social, and environmental consequences of the drying lake.

a) Overview of Lake Characteristics

At 1,400 feet below sea level, the Dead Sea is the lowest spot on earth (Shafir and Alpert, 2011). The Dead Sea consists of two basins, including a deeper northern basin and a southern basin, and covered an area of approximately 220 square miles in 2010, with a maximum depth of 1,000 feet (Wendt, 2016; Bodaker et al., 2010). The watershed of the Dead Sea covers approximately 17,000 square miles (Orthofer et al., 2004). The southern basin is currently dried up and is used for commercial mineral production (Wedyan et al., 2013). The northern basin is sourced by winter rain floods and the Jordan River, is dense with salt and minerals, and has a saline concentration of approximately 34 percent (Kis-Papo et al., 2003). Furthermore, the Dead Sea is located in a hot and dry climate, with approximately 1-2 inches of precipitation annually (Shafir and Alpert, 2011). The Dead Sea watershed is displayed in Figure IV-8.

Figure IV-8: Dead Sea watershed

Source: Frydman et al., 2008.

The Dead Sea has been shrinking since the early twentieth century, dropping more than 66 feet in that time period (Wedyan et al., 2013). The drying of the Dead Sea has accelerated more recently, dropping at an average rate of 3 feet per year over the past decade (Wedyan et al., 2013). While the sea was approximately 50 miles long in 1950, it had reduced to 30 miles long by 2005 (Hammer, 2005). The two primary causes of the Dead Sea's desiccation include the diversion of water by Israel, Jordan, and Syria for drinking, irrigation, and industrial use, and by pumping water out of the lake for mineral extraction (Oren, 2018). Diversions of the Jordan and Yarmuk Rivers upstream and their tributaries upstream of the Dead Sea account for approximately 75 percent of the Sea's loss (Becker and Katz, 2006). Another cause of desiccation is an evaporation rate that has increased by 20-25 percent annually from the 1960s to the 2000s (Shafir and Alpert, 2011).

Aquatic plant life reflects the extreme ecological conditions of the Dead Sea. The dominant species is green algae (*Dunaliella parva Lerche*), though the Sea also contains a diversity of filamentous fungi species (Kis-Papo et al., 2003). The ecosystem of the Dead Sea basin provides habitat to desert wildlife, which includes more than 450 species of plants and 150 species of animals (Becker and Katz, 2006).

Table IV-11 summarizes lake characteristics for the Dead Sea prior to desiccation.

Table IV-11: Summary of lake characteristics for Dead Sea

Lake Characteristic	Value
Lake Area (square miles)	220
Watershed Area (square miles)	17,000
Maximum Depth (feet)	1,000
Saline Concentration (percent)	34

b) Economic Consequences

The Dead Sea region hosts a substantial tourism industry, as tourists are drawn to the basin for the unique flora and fauna surrounding the sea, their ability to float in the water, and for its cultural and historical heritage. Tourism in the basin employs 11,000 directly and more indirectly (Becker and Katz, 2006). Mineral extraction from the Dead Sea directly employs 4,000 people and returns $800 million (2019$) in revenue annually (Becker and Katz, 2006).

The retreat of the shoreline and drying of the shallow Southern basin has developed sinkholes, mudflats, steep slopes and earthquake-associated landslides. There have been over 1,000 sinkholes, causing damage to roads, infrastructure, and private property (Becker and Katz, 2006). The rate of sinkhole formation is increasing as water levels continue to recede and exposed bottomlands increase.

A 2014 report by the World Bank indicated that annual lost revenues, in the absence of reclamation are in the range of $85 to $265 million (2019$) annually (Allan et al., 2014). The report also provided cost estimates for a series of reclamation remedies summarized in Table IV-12. The costs of reclamation range from $3.7 billion to $6.2 billion (USD).

Table IV-12: Cost estimates for reclamation efforts

Alternative / Project Description	Estimated Cost (2019$, in millions)
Alternative 1: Red Sea-Dead Sea Water Conveyance – Low Range	$3,700
Alternative 1: Red Sea-Dead Sea Water Conveyance – High Range	$6,200
Alternative 2: Mediterranean Sea-Dead Sea Water Conveyance – Low Range	$3,300
Alternative 2: Mediterranean Sea-Dead Sea Water Conveyance – High Range	$3,900
Alternative 3: Transfer of Water from Seyhan and Ceyhan Rivers in Turkey by Pipeline	$5,400

Alternative / Project Description	Estimated Cost (2019$, in millions)
Alternative 4: Transfer of Water from the Euphrates River in Iraq by Pipeline	Not Available

Source: Allan et al, 2014.

At the end of 2013, a Memorandum of Understanding was signed between Jordan, the Palestinian Authority, and Israel to begin the first phase of the Red Sea Desalination Project at Aqaba (RSDS). The purpose of the RSDS is to build a desalination facility in Jordan to transform the Red Sea water into potable water, while pumping the remaining brine water into the Dead Sea (Jordan Valley Authority, 2013). The total construction cost of RSDS is estimated at $11 billion (USD) with an annual operations and maintenance cost of $400 million (Markel and Beyth, 2013).

c) Social Consequences

There is limited peer reviewed literature available on the social consequences from the drying of the Dead Sea. However, the sinkholes that result from the drying of the Dead Sea present a threat to public safety. As of 2013, several serious injuries had occurred (Prince-Gibson, 2013). Furthermore, the sink holes that are a consequence of the drying of the Dead Sea present a threat to the tourism industry, which is the main livelihood of the entire Dead Sea region (Prince-Gibson, 2013).

d) Environmental Consequences

The Dead Sea supports a unique natural habitat of substantial biodiversity, which includes 450 species of plants and 150 species of animals (Becker and Katz, 2006). The drying of the Dead Sea presents an immediate threat to this biodiversity, as well as that of the overall basin ecosystem (Prince-Gibson, 2013). Furthermore, the drying of the Dead Sea has resulted in other environmental hazards in the area, including the formation of steep slopes and earthquake-associated landslides (Allan, 2014).

e) Relevance to Great Salt Lake

The drying of the Dead Sea poses threats to the economy, and the environment of the region and its residents. Similarities with Great Salt Lake are as follows:

- Dead Sea provides considerable economic value by supporting mining and tourism industries.
- Dead Sea is host to a unique ecosystem, which includes 450 species of plants and 150 species of animals, which is threatened by the Dead Sea's desiccation.

A summary of the economic, social, and environmental consequences of Dead Sea desiccation that may be relevant to Great Salt Lake are presented in Table IV-13.

Table IV-13: Summary of consequences from the drying of Dead Sea

Economic	Social	Environmental
$11 billion to construct reclamation project, $440 million for annual O&M	Sink holes causing serious injuries	Threat to biodiversity and ecosystem
Without reclamation, potential loss of $265 million in annual revenue to the region	Sink holes threaten tourism industry, the main livelihood of the region	Environmental hazards, such as steep slopes and earthquake-associated landslides
$800 million annual revenue for mineral extraction		
Infrastructure and property damage from 1,000 sinkholes		

7. Bakhtegan Lake

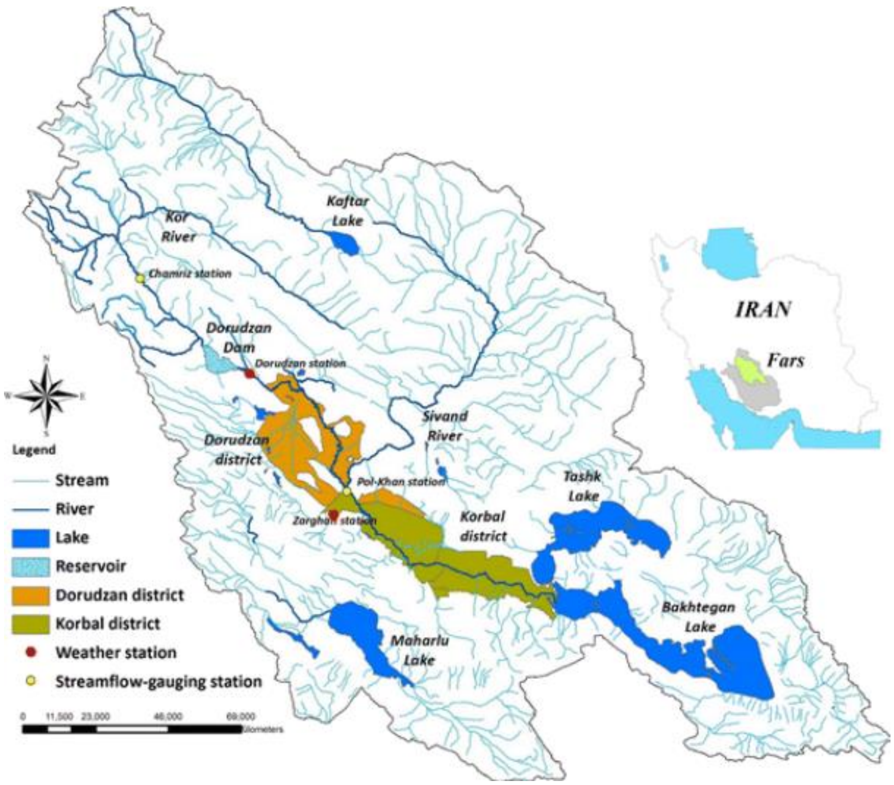
Bakhtegan Lake is a saline lake sourced by the Kor and Sivand Rivers. Located in Fars Province, Iran, it is characterized by a riverine system, terminal wetlands of ecological importance, a maximum depth of 10 feet, and a watershed of 12,200 square miles (Sajedipour et al., 2017). Bakhtegan Lake was the second largest lake in Iran, behind Lake Urmia; as such, much of the attention has focused on the latter (Arsanjani et al., 2015). The water levels of Lake Bakhtegan fluctuate according to the level of precipitation. During dry years (rainfall under average 14.4 inches), the lake dries out completely (Kiani et al., 2017). As lake waters recede, the salinity level increases, however the specific salinity level of Bakhtegan Lake was unfound. The following sections describe Bakhtegan Lake, and include an overview of lake characteristics as well as the economic, social, and environmental consequences of the drying lake. This is followed by a discussion of relevance to Great Salt Lake.

a) Overview of Lake Characteristics

Prior to desiccation impacts, Bakhtegan Lake was the second largest lake in Iran behind Lake Urmia (Sajedipour et al., 2017). However, satellite imagery from 1973 to 2013 indicates that the lake has been shrinking for the past several decades, reducing the lake's size from 320 square miles in 1986 to 140 square miles in 2013. Further, the lake was expected to shrink to an area of 80 square miles by 2017 (Arsanjani et al., 2015). The primary causes of the lake's desiccation include reduced precipitation, increased temperatures, and the construction of dams to divert surface water for agricultural irrigation (Arsanjani et al., 2015).

Bakhtegan Lake supports various algae (e.g., Chara, Ruppia, and Althenia), as well as fringing vegetation (e.g., Tamarix, Suaeda, Cressa, and Salicornia) (BirdLife International, 2018). In addition, the lake supports brine shrimp and saltwort (*Salsola*) (Sajedipour et al., 2017). The Lake Tashk-Bakhtegan basin supports large populations of waterfowl, including 120,000-140,000 surface-feeding ducks and 50,000 flamingos (Phoenicopterus ruber) (BirdLife International, 2018). In total, the lake ecosystem hosts 46 species of mammals, 218 avian species, 36 reptile species, and 23 species of fish (Sajedipour et al., 2017). The Bakhtegan Lake watershed is displayed in Figure IV-9.

Figure IV-9: Bakhtegan Lake watershed



Source: Narfarzadegan et al., 2018.

Table IV-14 summarizes lake characteristics for Bakhtegan Lake prior to desiccation impacts.

Table IV-14: Summary of lake characteristics for Bakhtegan Lake

Lake Characteristic	Value
Lake Area Prior to Desiccation (square miles)	320
Watershed Area (square miles)	12,200
Maximum Depth (feet)	10
Saline Concentration (percent)	NA

Note: NA = not available

b) Economic Consequences

Irrigated agriculture, primarily from the Kor River, is the dominant and highest yielding economic activity in the Lake Tashk-Bakhtegan basin (Mahabadi et al., 2018). Increased water scarcity threatens the agricultural sector, which plays a critical role in Iran's economy and consumes 90 percent of the water in Iran (Ghader, 2018).

Much of the literature regarding drying lakes in Iran focuses on Lake Urmia, and there is limited data available on the direct economic consequences associated with the drying of Bakhtegan Lake. However, water scarcity resulting from the natural hazard of a severe drought in 1999-2000 imposed a direct cost of $2.4 billion (2019$) to the agricultural sector of the Iran economy (Vitkovic and Soleimani, 2015).

Bakhtegan Lake hosts a substantial tourism industry, based on the aesthetic value of its dynamic landscape, biodiversity, and its natural beauty. The livelihood of the surrounding population is threatened not only by the decline in agriculture, but by the decline in tourism-based employment opportunities in recent years (Arsanjani et al., 2015).

c) Social Consequences

Limited literature exists on the social consequences of Bakhtegan Lake's desiccation. However, water is critical to support agricultural and tourism-based employment opportunities in the region, and is a critical input for food and job security. As a result, water scarcity could stimulate social conflicts (Mahabadi et al., 2018).

Existing literature on the drying of Bakhtegan Lake does not emphasize the potential public health externalities imposed by dust storms. However, drying of the lake is expected to be followed by adverse impacts, which include saline up-dust from the dried lakebed (Sajedipour et al., 2017).

d) Environmental Consequences

As a terminal wetland, Bakhtegan Lake provides substantial environmental value through biodiversity and ecosystem services. For those reasons, it was declared a protected zone in 1968. Also, in 1975 it was registered in Ramsar Convention's List of International Wetlands (Dashti, 2012; Sajedipour, 2017). Similar to other drying saline lakes, the ecosystem provides habitats for migratory birds. The loss of wetland habitat from the drying of Bakhtegan Lake resulted in a major mortality of flamingo chicks in 2007. In July 2017, approximately 1,000 flamingo chicks stuck in the salt marsh were rescued by locals and environmental officials (Sanjerehei et al., 2017; Hosseinpour, 2017).

e) Relevance to Great Salt Lake

The drying of Bakhtegan Lake poses threats to the economy, the environment of the region and its residents. Similarities with Great Salt Lake are as follows:

- Tourism and agriculture play an important role in the region's economy, and both are threatened by ongoing desiccation.
- Bakhtegan Lake hosts critical ecological habitat, and the loss of wetland habitat from the retreat of the lake threatens the health of the ecosystem and of migratory bird populations that depend on it.

The economic and ecological consequences from the drying of Bakhtegan Lake and Great Salt Lake are similar. A summary of the economic, social, and environmental consequences of Bakhtegan Lake desiccation that may be relevant to Great Salt Lake are presented in Table IV-15.

Table IV-15: Summary of consequences from the drying of Bakhtegan Lake

Economic	Social	Environmental
Threatened tourism industry	Potential loss of agricultural and tourism jobs	Threatened wetland habitat; designated protected zone and wildlife sanctuary
Water scarcity threatens the agricultural sector (loss of $2.4 B from severe drought)	Water scarcity could stimulate social conflicts	Major bird mortalities

8. Mono Lake

Mono Lake is located in east-central California, situated at the edge of the arid Great Basin and the Sierra Nevada mountains. The following sections describe Mono Lake and include an overview of lake characteristics as well as the economic, social, and environmental consequences of the drying lake. This is followed by a discussion of relevance to Great Salt Lake.

a) Overview of Lake Characteristics

A highly saline lake, Mono Lake was situated at an altitude of 6,400 feet before its water surface elevation began to drop due to water diversions (Mono Lake Committee, 2018). Mono Lake is at least 760,000 years old, making it one of the oldest lakes in North America (Mono Lake Committee, 2018). Mono Lake began shrinking in 1941 when the Los Angeles Department of Water and Power (LADWP) began diverting four of the lake’s tributary streams to address the water needs of Los Angeles (State of California, 1995).

Mono Lake has been a terminal lake for the past 60,000 years and, without an outlet, the concentration in mineral salts has gradually increased (van Breugel and Dickinson, 2017). The drying of the lake has raised salinity concentrations. Between 1941 and 1982, the salinity of the lake more than doubled from 5 percent to 10 percent, or about three times the salinity of the ocean (Mono Lake Committee, 2018; van Breugel and Dickinson, 2017). The maximum water depth of Mono Lake is 160 feet (Mono Lake Committee, 2001). The water diversions resulted in a 45 foot drop in the surface elevation of the lake between 1941 and 1982, resulting in a 30 percent reduction in surface area by the latter date, from 55,000 acres to 38,000 acres (90 square miles to 60 square miles) (State of California, 1995).

The Mono Lake watershed covers a land area of approximately 600 to 800 square miles (National Academy Press, 1987). The lake is located in Mono County, which had a population of 14,000 residents and a population density of 4.7 per square mile, as of the 2010 U.S. Census, and is expected to grow to 17,000 by 2040 (Mono County, 2018). The economy is largely based on the recreational opportunities and scenic values of the land surrounding Mono Lake (United States Department of Agriculture, 1989). An aerial image of Mono Lake is displayed in Figure IV-10.

Figure IV-10: Mono Lake

Source: NASA, 2017.

Mono Lake hosts large populations of Alkali flies, which are of ecological importance due to their ability to transform harsh saline environments into productive ecosystems (van Breugel and Dickinson, 2017). In addition to Alkali flies, the lake contains algae, bacteria, and brine shrimp. The ecosystem of the lake supports nearly 300 bird species, including 98 species of waterfowl (State of California, 1995). This includes large populations of migrating and nesting birds as well as large populations of waterfowl that include California Gulls, grebes, and phalaropes.

A series of lawsuits led to the State Water Resources Control Board's issuing the Mono Lake Basin Water Right Decision in 1994. The decision prohibited water exports until the water level of Mono Lake reached 6,377 feet above sea level, and restricted water exports to allow Mono Lake to raise to a level of 6,391 feet above sea level in 20 years (State of California, 1995).

As a result of this Decision, Mono Lake levels have been above the minimum level of 6,377 feet since 1995, and were at 6,382 feet in 2017 (Mono Lake Committee, 2018). Given limited data on pre-desiccation conditions, as well as the fact that the lake has been in recovery since 1995, it is difficult to quantify the economic, social, and environmental consequences of the lake's reduction in volume.

Table IV-16 summarizes lake characteristics for Mono Lake prior to desiccation.

Table IV-16: Summary of lake characteristics for Mono Lake prior to desiccation

Lake Characteristic	Value
Lake Area (square miles)	90
Watershed Area (square miles)	600-800
Maximum Depth (feet)	160
Saline Concentration Range (percent)	5.0 – 10.0

b) Economic Consequences

In the 1920s and 1930s, Mono Lake was a popular recreation spot which supported the tourism industry within the Mono Basin (State of California, 1995). However, the drying of the lake limited almost all boating to canoes and kayaks. With the lake's recovery, tourism remains a significant industry in Mono County.

No quantifiable information was found regarding the actual costs incurred by Los Angeles ratepayers to accommodate water diversion reductions. However, research by Loomis (1989) found that California residents and Mono Lake visitors would be willing to pay an additional $123 (2019$) annually on their water bill to reduce water diversions from Mono Lake by half. Furthermore, research found that respondents would be willing to pay an additional $120 (2019$) annually in their water bill to substantially restrict water diversions in order to maintain biologically optimum lake levels (Loomis, 1989).

c) Social Consequences

Due to saline dust that arises from the exposed lakebed, Mono County was designated as a non-attainment area for the state PM_{10} standard in 1993 (Mono County, 2018). As noted earlier, PM_{10} is dangerous due to its tendency to settle deep into a person's lungs, posing a danger to those with lung disease and chronic obstructive pulmonary disease (Los Angeles Aqueduct Digital Platform, 2014). However, PM_{10} concentrations in the Mono Basin remained relatively stable between 2000 and 2012 (Mono County, 2018). Mono Lake water levels have exceeded their minimum in that time frame, thereby reducing the impact of dust storms and associated consequences.

d) Environmental Consequences

Mono Lake is of particular environmental importance because it is the largest breeding ground for California Gulls in California (State of California, 1995). Little quantifiable data is available to describe the pre-diversion wildlife resources of the Mono Basin (State of California, 1995). However, the increased salinity concentrations that resulted from lowering the lake reduced the reproductive abilities of brine shrimp, a keystone species in the ecosystem. Furthermore, the reduction in lake volume reduced wetland habitat for the flora and fauna in the ecosystem. However, lake levels have stabilized since 1995 which, in turn, has resulted in stable saline concentrations and wetland habitat.

e) Relevance to Great Salt Lake

The drying of Mono Lake poses threats to the economy, public health, and the environment of the region and its residents. Similarities with Great Salt Lake are as follows:

- Mono Lake is a popular recreation spot and supports a strong tourism industry.
- The ecosystem of the lake provides critical bird habitat, and is host to large populations of migrating and nesting birds.
- Reductions in brine shrimp populations in Mono Lake present a potential threat to the aquaculture industry.

A summary of the economic, social, and environmental consequences of Mono Lake desiccation that may be relevant to Great Salt Lake are presented in Table IV-17.

Table IV-17: Summary of consequences from the drying of Mono Lake

Economic	Social	Environmental
Threated tourism industry	Public health impacts from dust storms (PM_{10})	Largest breeding ground for California Gulls in California
		Threated brine shrimp populations
		Loss of wetland habitat

V. Conclusion

Similar to many saline lakes around the world, which are shrinking at alarming rates, Great Salt Lake is drying. Delaying the restoration and mitigation of Great Salt Lake desiccation can have substantial economic, social, and environmental consequences for the Salt Lake City Valley.

There can be significant consequences of drying. The economic consequences of desiccation range from threatened losses to the mining, agricultural, tourism, and commercial fishing industries to complete losses of these industries supported by Great Salt Lake. For example, 60,000 fishermen completely lost their livelihood with the collapse of the Aral Sea fishery. The **$1.3 billion** Great Salt Lake contributes to the local economy could be lost completely.

Considering the proximity of Great Salt Lake to major populations, there is a substantial threat to property values from the desiccation of the lake. The property loss associated with the desiccation of Salton Sea has been estimated up to **$7 billion** and the watershed population is lower than that of the Great Salt Lake.

Saline lakes support unique ecosystems, host to tremendous biodiversity, which makes them of considerable value. It is common for migratory shorebirds and waterfowl to use saline lakes for nesting and feeding grounds. Many of the drying lakes studied have had massive losses of fish and birds. At Lake Urmia, migratory birds have been reduced and thousands have died from starvation. Mammal and bird species were reduced by half at Aral Sea. There were millions of dead fish and a mass die off of hundreds of birds at Lake Poopó. There were also large numbers of bird mortalities at Bakhtegan Lake. At Salton Sea, fish populations declined by over 95 percent. The ecological benefits of Salton Sea were estimated to be **$2.8 billion** but the benefits are declining as the lake dries and the flora and fauna that rely on the lake are threatened.

When dry, saline lakes present a public health hazard as they become sources of fine dust that can be transported significant distances in dust storms. PM_{10} from dry saline lakebeds can increase asthma attacks, asthma severity, hospitalizations, lung diseases and symptoms, and infections. In the region surrounding the Aral Sea, there are higher levels of esophageal cancer, respiratory illnesses, and eye problems. In the area surrounding Salton Sea, childhood hospitalization rates are the highest in California, and three times the state's average. Also, emergency room visits for children are over twice the statewide average in California. The public health impacts from Salton Sea dust storms is estimated at **$40 billion**, however, the population density surrounding Great Salt Lake is far greater than that in the Imperial and Coachella valleys. Therefore, the socio-economic impacts of Great Salt Lake's desiccation could be far greater.

Mitigation and restoration measures are needed to return drying lakes to a more stable condition that retains their substantial economic, social and environmental benefits. Such measures can be costly and, therefore, should be selected, designed and implemented strategically to maximize return on investment. Restoration costs tend to increase in accordance with the severity of lake desiccation. The highest restoration cost estimated was **$33.6 billion**, however this would still not completely restore the Aral Sea. It is likely that the cost is beyond the willingness, and perhaps ability, of the basin states to pay, even with major aid from international donors. There is an opportunity to protect and preserve the Great Salt Lake before restoration costs become too high to manage. Although the mitigation and restoration costs are high, the economic, social, and environmental consequences are likely much higher.

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