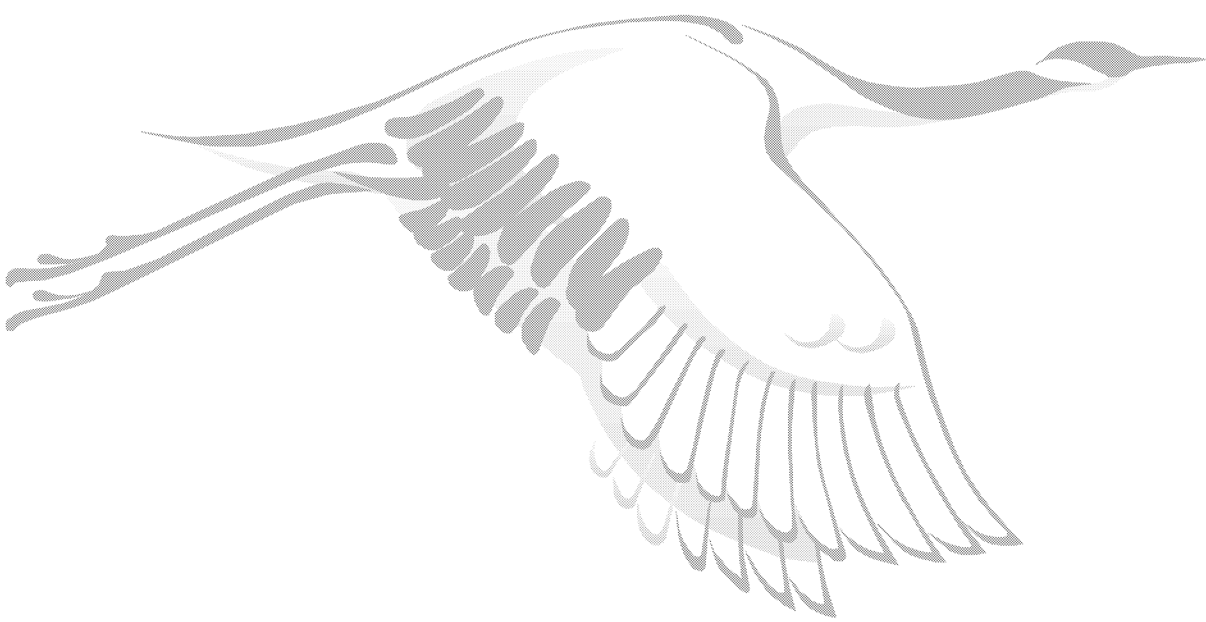
Great Salt Lake
Comprehensive Management Plan
Resource Document



Prepared by the Great Salt Lake Planning Team
Utah Department of Natural Resources

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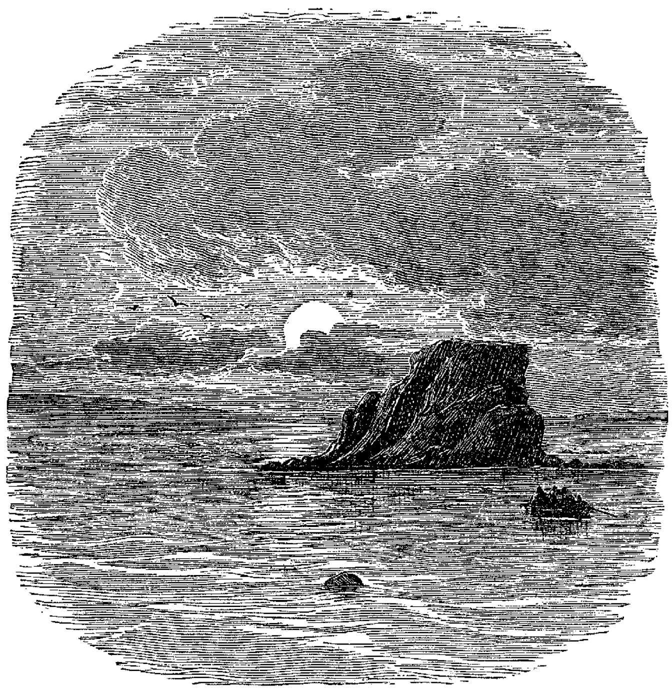

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Great Salt Lake Planning Team

Name, Title and Division	Role on the Team
Arthur W. DuFault, State Forester/Director Division of Forestry, Fire and State Lands	Team Leader
Karl F. Kappe, Strategic Planner Division of Forestry, Fire and State Lands	Sovereign Lands, Minerals, Diking, Agriculture, Public Involvement, Planning Team Coordinator
Brenda L. Landureth, GSL Analyst/Administrative Assistant, Administration	Open Space, Critical Lands, Visual Resources, Water Quality, Air Quality, Ecosystem, Public Involvement, Planning Team Coordinator
Lloyd H. Austin, Chief, Resource Inventories and Special Studies Section Division of Water Resources	Hydrology, Chemistry, Diking
Darin Bird, Assistant Director Administration	Public Involvement
Martin B. Bushman, Assistant Attorney General	Legal Advisor
Wally Gwynn, Salines Geologist Utah Geological Survey	Chemistry, Geology
William C. Perschon, GSL Ecosystem Project Coordinator Division of Wildlife Resources	Biology
Ann Price, Administrative Assistant, Division of Forestry, Fire and State Lands	Editor/Production
Bruce Ratzlaff, Natural Resource Analysis, Office of Energy and Resource Planning	Economic Team Coordinator, Economics, Recreation
William E. Schlotthauer, Hydrologic Engineer Division of Water Rights	Water Rights, Hydrology
Daniel K. Smith, Applications, Programmer, Analyst III Division of Oil, Gas and Mining	GIS Specialist
James K. Springer, Public Information Officer Division of Forestry, Fire and State Lands Division of Oil, Gas and Mining	Public Relations, Slide Presentation, Public Involvement, Media Relations
Garth C. Taylor, Antelope Island State Park Manager Division of Parks and Recreation	Recreation, Cultural Resources, Law Enforcement, Search and Rescue
Previous Planning Team Members	
James W. Carter, Director Division of Oil, Gas and Mining	Team Leader
Kimm M. Harty, Deputy Director Utah Geological Survey	Geologic Hazards, Chemistry, Transportation
Susan L. Jancart, Natural Resource Analyst Office of Energy and Resource Planning	Economics, Commercial, Industrial, Editing
Tim Smith, Antelope Island State Park Manager Southeast Regional Manager Division of Parks and Recreation	Recreation, Cultural Resources, Law Enforcement, Search and Rescue
Jeff Richards, Assistant Attorney Attorney General's Office	Legal Advisor

Department of Natural Resources **Great Salt Lake Board of Directors**
Kathleen Clarke, Executive Director
Sherman Hoskins, Deputy Director
Marty Ott, Deputy Director
Darin Bird, Special Assistant Policy and Inter-Governmental Relations
Art DuFault, State Forester/Director Division of Forestry, Fire and State Lands
Vacant as of 3/28/00, Director Utah Geological Survey
Robert L. Morgan, State Engineer/Director Division of Water Rights
John F. Kimball, Director Division of Wildlife Resources
Jeff Burks, Director Office of Energy and Resource Planning
Courtland Nelson, Director Division of Parks and Recreation
D. Larry Anderson, Director Division of Water Resources
Lowell Braxton, Director Division of Oil, Gas and Mining

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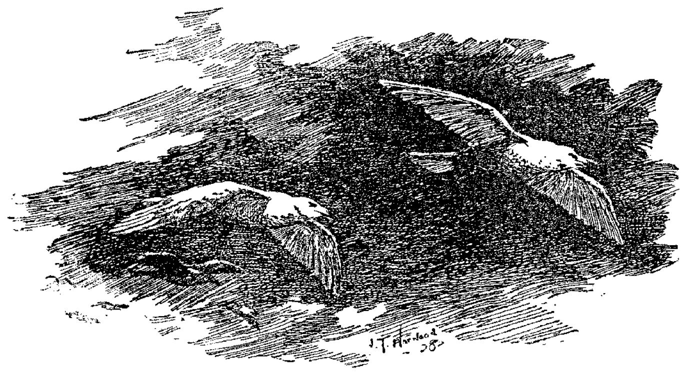
Introduction



Introduction

The Utah Department of Natural Resources (DNR) and the Utah Division of Forestry, Fire and State Lands (DFFSL) jointly sponsored the Great Salt Lake Planning Project to develop a coordinated natural resources management plan for the lands and resources of Great Salt Lake (GSL). Primary management responsibility for the lake's resources lies with DFFSL pursuant to Title 65A of the Utah Code, which governs management of all state lands. Specifically, Section 65A-10-8*, Great Salt Lake - Management Responsibilities of the Division*, requires the division to:

> "(1) Prepare and maintain a comprehensive plan for the lake which recognizes the following policies:
>
> (a) develop strategies to deal with a fluctuating lake level; (b) encourage development of the lake in a manner which will preserve the lake, encourage availability of brines to lake extraction industries, protect wildlife, and protect recreation facilities; (c) maintain the lake's flood plain as a hazard zone; (d) promote water quality management for the lake and its tributary streams; (e) promote the development of lake brines, minerals, chemicals, and petro-chemicals to aid the state's economy; (f) encourage the use of appropriate areas for the extraction of brines, minerals, chemicals, and petro-chemicals; (g) maintain the lake and the marshes as important to the waterfowl flyway system; (h) encourage the development of an integrated industrial complex; (i) promote and maintain recreation areas on and surrounding the lake; (j) encourage safe boating use of the lake; (k) maintain and protect state, federal, and private marshlands, rookeries, and wildlife refuges; (l) provide public access to the lake for recreation, hunting and fishing."

Section 65A-2-1 of the Utah Code provides; "The division [of Forestry, Fire and State Lands] shall administer state lands under comprehensive land management programs using multiple-use, sustained-yield principles." Briefly stated, the overarching management objectives of DFFSL and DNR are to protect and sustain the trust resources of, and to provide for reasonable beneficial uses of those resources, consistent with their long-term protection and conservation. This means that DFFSL will manage GSL and its resources under multiple-use sustained yield principles (Section 65A-2-1), implementing legislative policies (Section 65A-10-8) and accommodating public and private uses to the extent that those policies and uses do not compromise public trust obligations and sustainability is maintained. Any beneficial use of public trust resources is subsidiary to long-term conservation of resources.

Although primary lake planning and management responsibilities lie with DFFSL, the other divisions of DNR also have management responsibilities for resources on and around GSL. The Division of Wildlife Resources (DWR), for example, has plenary authority for managing wildlife in, on and around the lake. The Division of Parks and Recreation (DPR) manages Antelope Island State Park (AISP) and coordinates search and rescue and boating enforcement on the lake. The Division of Water Rights (DWRi) regulates the diversion and use of lake and tributary waters. The Division of Water Resources (DWRe) conducts studies, investigations and plans for water use, and operates the West Desert Pumping Project (WDPP). DNR divisions also regulate mineral extraction activities, conduct hydrologic research and identify and map geologic hazards around the lake.

In order to more specifically articulate DNR's management objectives for the resources of GSL, and to reconcile the diverse mandates of the divisions of DNR, the Great Salt Lake Planning Project was initiated.

The purposes of the Great Salt Lake Planning Project are:

(1) To establish unifying DNR management objectives and policies for GSL trust resources,

(2) To coordinate the management, planning and research activities of DNR divisions on GSL,

(3) To improve coordination among DNR divisions, establish a decision-making proposal review and appeal process, develop a sovereign land management plan for the lake that balances multiple-use and sustainability, resolves issues and improves management of the lake and its resources,

(4) To develop a sovereign lands and resources management plan, and

(5) To establish processes for plan implementation, monitoring, evaluation and amendment.

Planning Project Deliverables

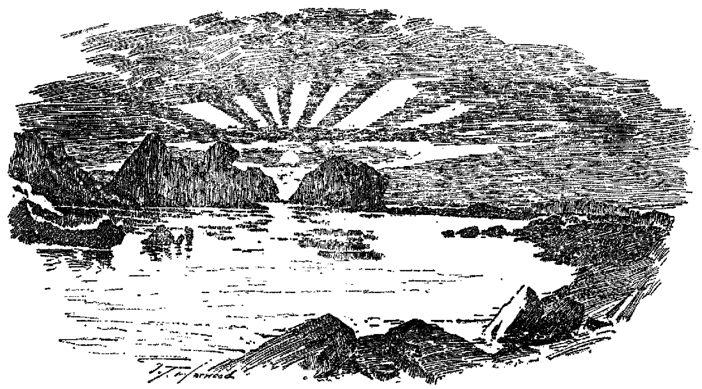
Decision Document

The Great Salt Lake Decision Document (GSLDD) contains an overview of the planning process, the record of decision, implementation activities, monitoring and research activities, and goals and objectives. Public comments in response to the Draft CMP are included with their responses.

Resource Document

This resource Document (GSLRD) will become the supporting reference for the decision document. The Statement of Current Conditions and Trends (SCCT) section was revised to reflect public comment recommendations. This inventory and other supporting information provides the framework for the GSLDD.

Statement of Current Conditions and Trends on Great Salt Lake



Overview

DNR has management programs in place for the resources of GSL. Those programs are designed to both conserve the lake's resources, and to make those resources available for beneficial uses. DNR's management of AISP and Farmington Bay Waterfowl Management Area (WMA), the regulation of commercial brine shrimping and sport hunting and the Mineral Leasing Plan (MLP) are examples of resource management programs currently in operation.

At the same time, factors exist which are affecting or have the potential to affect the lake, its resources and beneficial uses. Purposes of this planning process are to ensure that existing programs contribute optimally to DNR's management objectives for the lake and that emerging issues and demands are addressed in a coherent and comprehensive manner, consistent with overall management objectives.

The starting point for development of a comprehensive and consistent management plan is the assembly of relevant information and analyses into a resource inventory. Through a one-year internal and external scoping project, the GSL Planning Team identified the resource inventory information it believes is relevant to the good management of GSL. The inventory information was assembled by resource and use category, and was evaluated to develop descriptions of the current conditions of the lake's resources, and to discern trends which should be taken into account in future management. The information available on GSL and its resources is encyclopedic in scope and volume. Through internal and external scoping the team digested and presented it in the context of the key issues and needs identified. This statement represents a baseline picture of the current conditions and trends of GSL and its resources.

The SCCT is organized by resource category and includes hydrology, chemistry, land, mineral, cultural, and biological trust resources for which DNR is responsible. The SCCT also includes ecosystem, recreation, tourism, air and water quality, commercial and industrial, open space and critical lands, and visual resource management.

Geographic Setting

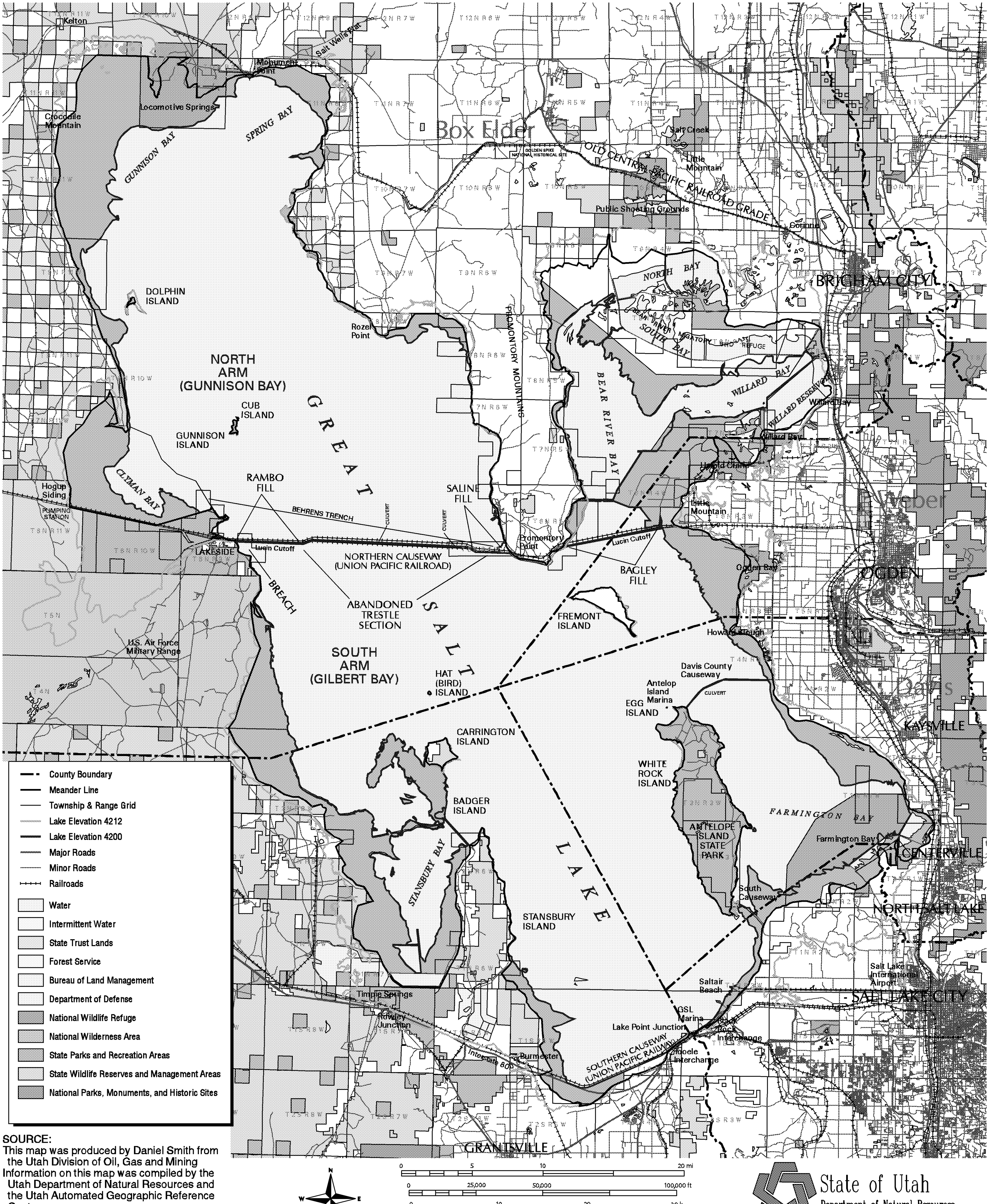
GSL is located in western North America at the eastern edge of the Great Basin of Utah (Exhibit 1, map of GSL). The Wasatch Range of the Rocky Mountains rises abruptly, forming the eastern boundary of the GSL valley. The east lake environment receives an average of 15 inches of moisture annually while the western lake environments receive less than 10 inches. The area is described as a cold desert where winter temperatures can fall below 0 degrees Fahrenheit and summer temperatures rise above 100 degrees Fahrenheit. Alkaline soil types dominate the landscape, influenced by the salts of the terminal lake basin. The long-term average lake elevation is 4202 (above sea level), but in historic time it has been as low as 4196 and as high as

4212. The lake is located within Box Elder, Weber, Davis, Salt Lake and Tooele counties. More than 50 percent of Utah's 1.8 million people live within 20 miles of the GSL and adjacent wetlands (DWR and the Great Salt Lake Site Assessment Team, 1998).

GSL is the remnant of ancient Lake Bonneville. After the Pleistocene, a warmer and dryer climate coupled with catastrophic flood through Red Rock Pass, Idaho drained much of Lake Bonneville and began the Great Salt Lake period some 12,000 years ago. GSL is a terminal basin which receives drainage water from several physiographic complexes, including the Uinta Mountains, the Wasatch Range, and the basin and range region (Great Salt Lake Site Assessment Team, 1998).

Exhibit 1 - Great Salt Lake Location Map

Plotted March 29, 2000



SOURCE:
This map was produced by Daniel Smith from the Utah Division of Oil, Gas and Mining
Information on this map was compiled by the Utah Department of Natural Resources and the Utah Automated Geographic Reference Center.
Official and detailed information is only available through DNR and AGRC.

Water - Hydrology

The "Hydrology" section addresses matters relating to the physical hydrology of GSL, including lake water level, inflows, flooding and diversions. The information collected during the scoping process highlighted three general areas of interest and concern with regard to the hydrology of the lake: lake level, including both low water levels and flooding potential; inflows to the lake, including flow quantities and locations; and diking and causeways in the lake, which affect currents and in-lake water conditions. Dikes and causeways have significant impacts on lake hydrology and water chemistry. The most significant resource impacts of dikes and causeways are more directly related to water chemistry than to other factors.

Based on the information gathered during scoping and the resource inventory, the planning team identified five major conditions and trends for the hydrology of the lake which are relevant to future management:

- **Continued reduction in inflows is anticipated. Studies of the lake hydrology indicate that 100,000 acre-feet of additional depletions per year would lower the average lake level approximately one foot.**

- **The statutory requirement to define the flood plain and develop strategies to deal with a fluctuating lake level needs to be addressed.**

- **The WDPP can presently be used for mitigation of flood impacts when the south arm lake level reaches 4208 by pumping north arm brines. The WDPP stands ready to be utilized for mitigation, but administrative barriers to its operation, external to DNR, now exist.**

- **Locomotive Springs is being impacted by decreasing water flows. This issue would require that DNR develop strategies to mitigate and remediate this inter-state situation.**

- **DNR is interested in establishing a policy regarding inter-island diking and freshwater embayments.**

Changes to Inflows

GSL is a remnant of Pleistocene Lake Bonneville, and occupies the lowest point in a 22,000 square mile drainage basin. The lake is a terminal lake with no outlet. This closed basin is formed by the drainages of the Bear, Weber and Jordan Rivers, plus drainage areas northwest and southwest of the lake (Exhibit 2). The average annual inflow to the lake, for the years from 1851 to 1996, has been approximately 3,684,500 acre-feet. Inflows originate from gaged or correlated stream flows (2,382,500 acre-feet); estimated un-gaged surface water (191,500 acre-feet); estimated un-gaged groundwater (107,500 acre-feet); and precipitation directly onto the lake surface (1,003,000 acre-feet) according to DWRe Great Salt Lake Simulation Model (1974a) (Exhibit 3). The average total annual evaporation equals average annual inflow, although inflow exceeds evaporation during cooler, wetter weather cycles, and evaporation exceeds inflow during hotter, dryer cycles. All water which is diverted from the lake (except the WDPP) is utilized for mineral extraction by evaporation and is included in the annual evaporation.

At the average water elevation of 4200 (above sea level), GSL has a surface area of 1,500 square miles, making it the fourth largest terminal lake in the world. GSL is hypersaline, with average total dissolved salt concentrations in its various arms ranging from about 8 percent to more than 26 percent. The average depth of the lake is approximately 14 feet, so that small changes in lake level either expose or inundate large areas of lake shoreline. For example, at a lake elevation of 4200 (above sea level), the lake's waters cover 1,079,259 acres. At 4204, lake waters inundate a total of approximately 1,223,000 acres. Seasonal and long-term fluctuations in lake level produce dramatic changes in the lake's shoreline. These fluctuations are an integral part of the lake ecosystem. Pumping from the lake would reduce peak elevations with minimal changes to natural lake level fluctuations.

The physical configuration of the lake and its high salinity create a "buffering" effect on the rate of evaporation of the lake. In general terms, as the lake rises, it increases significantly in surface area and declines in salinity. These factors contribute to an increase in annual lake water evaporation, and tend to slow the rise of lake level. Conversely, when the lake level drops, the surface area diminishes and the salinity increases, reducing the total annual evaporation. The lake, therefore, has a natural mechanism to prevent drying up and has a tendency to slow its own rate of rise. It has been suggested that a one-time removal of water from the lake, while noticeable at the time of removal, will eventually "heal" itself through this buffering effect, returning to pre-removal elevations. Long-term increases in diversions will, however, produce long-term changes in lake level.

Water Development Impacts on Lake Level

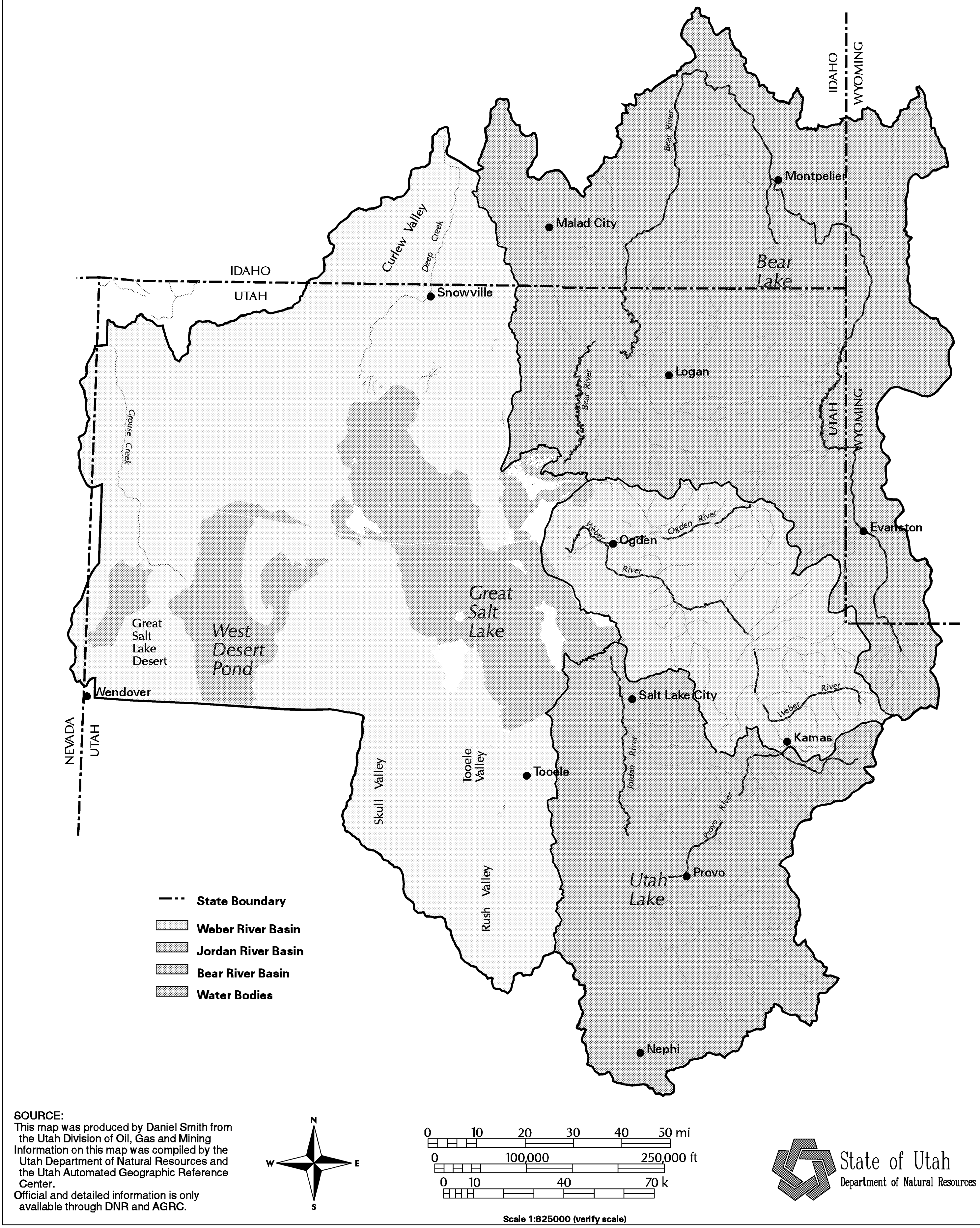
Over the last 20 to 30 years, studies have attempted to define the effects of water development and other human-caused water use on lake level. The studies indicate that with 100,000 acre-feet of annual depletion in the basin, the average level of the lake would be approximately one foot lower. The effect of this depletion on the lake elevation is greatest at low lake levels. The diversion of 100,000 acre-feet does not result in the depletion of 100,000 acre-feet if part of the diverted water returns to the lake. Water diverted for agricultural uses and for municipal (including drinking water) and industrial uses (M&I) is not entirely depleted, and significant quantities, approximately 60-70 percent (Jordan Valley Water Conservancy District, 2000a) are returned to the system as return flows. Also an average increase of 100,000 acre-feet of inflow per year to the lake would raise the average lake level by approximately one foot.

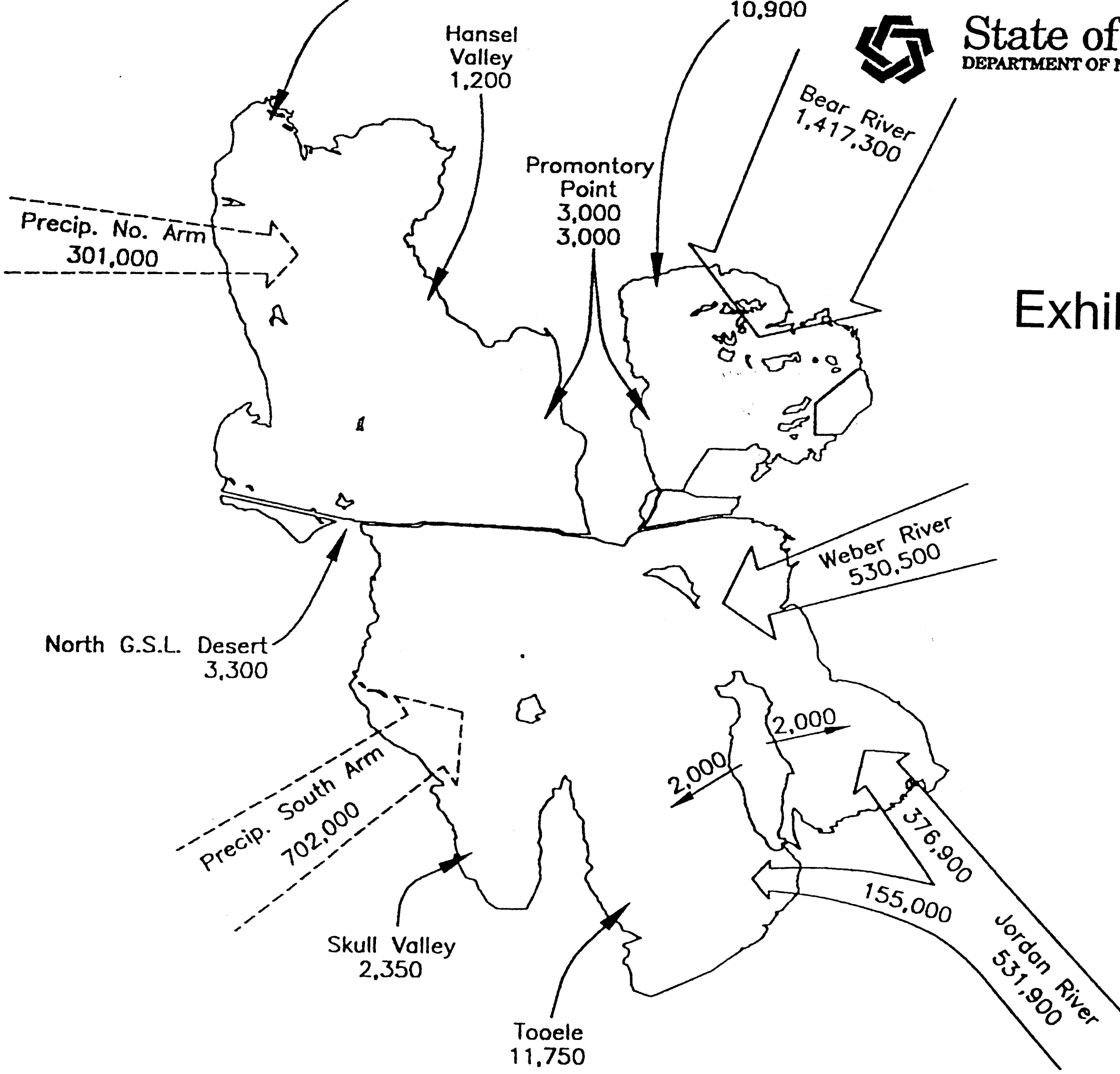
These studies have also shown that the lake would be approximately five feet higher without any human-caused depletions.

It is expected that depletions to the inflow of GSL from historical sources will continue through water development

Exhibit 2 - Great Salt Lake Drainage Basin

Plotted March 29, 2000





State of Utah
DEPARTMENT OF NATURAL RESOURCES

Exhibit 3

River Basin	Inflow Gaged	Ungaged	Ground Water	Total	%
Bear River	1,417,300	79,500	64,000	1,560,800	42
Weber River	482,400	26,600	21,500	530,500	14
Jordan River	482,800	27,100	22,000	531,900	14
Other		58,300 *		58,300	2
Subtotal	2,382,500	191,500	107,500	2,681,500	
Precipitation				1,003,000	27
Total				3,684,500	

* Includes Surface & Subsurface Flow

Source: Division of Water Resources – Great Salt Lake Simulation Model 1851–1996

Great Salt Lake Water Supply

on tributaries to the lake and other human-caused water uses. In the Jordan and Weber Basins, which have been highly developed by Weber Basin Water Conservancy District and Central Utah Water Conservancy District projects, it is expected that already diverted and developed water will be converted from agricultural uses to meet M&I demands, rather than large, new water projects being developed. M&I uses tend to consume similar quantities of water per acre as do agricultural uses. Another mitigating factor may be the importation of Uinta Basin water to the GSL Basin. The total estimated flow from the Uinta Basin, including the completion of the CUP, will be approximately 195,000 acre-feet per year (af/yr). Currently, approximately 95,000 af/yr enter the GSL Basin from the Uinta Basin. This inflow reduces human impact on lowering GSL.

In the Bear River Basin, it is expected that major new water diversions and developments will occur. Alternatives for development of water resources in the GSL drainage area have been documented in the Utah State Water Plans. These plans guide management and development of water resources in the GSL drainage basin, but are not for the purposes of managing inflow, level or surface area of GSL. These plans are available from DWRe.

Changes in Water Diversions from Great Salt Lake

Administration of Water Rights and Diversions

The diversion of water from GSL is governed by the same Utah water appropriation laws and regulations as the diversion of water from streams, springs or wells. Under Utah law, all waters of the state are the property of the public (Utah Code 73-1-1). A water right secures to an individual or entity the right to divert the water and place it to a recognized beneficial use. All water rights in the state are administered by the State Engineer with the assistance of DWRi staff.

Currently, Utah water law requires that water be distributed according to the priority date of the underlying water right. During dry periods, water rights for domestic use and public supply can be taken ahead of rights for other uses when the priority dates of the involved rights are equal. Any change to this arrangement will require legislative action (Utah Code 73-3-21).

A water right is acquired by filing an application with the State Engineer and receiving approval. If the application is approved, the applicant generally has three years to develop the project, place the water to beneficial use and submit proof of the beneficial use to the State Engineer. Extensions of time for filing proof can be requested. An unapproved water right is considered to be the personal property of the applicant. When the application has been approved it becomes real property. Once proof of beneficial use is submitted defining the quantity of water developed and the water uses, the State Engineer issues a Certificate of Appropriation which the applicant files with the local county recorder. At this point, the water right is said to be perfected.

For an application to be approved for development, the following conditions must exist: (1) there must be unappropriated water in the proposed source; (2) the proposed use must not interfere with existing rights or interfere with a more beneficial use of the water; (3) the proposed development must be physically and economically feasible and not detrimental to public welfare; (4) the applicant must have the financial ability to complete the proposed works; and (5) the application must be filed in good faith and not for speculation or monopoly 73-3-8 (Utah Code Annotated, 1953). If there is reason to believe that an application will interfere with a more beneficial use, unreasonably effect public recreation or the natural stream environment or will prove detrimental to public welfare, the State Engineer will withhold approval.

There is an additional requirement of the law which is important. To maintain a water right, the water must be diverted, or physically removed, from its natural source. The only exception to this rule is approved in-stream flow rights, which must be held by either DWR or DPR.

There are several reasons a water right may be terminated. An unperfected water right may be terminated by the State Engineer, (1) at the applicant's request, (2) if the applicant fails to meet the criteria for appropriation or the conditions of approval, or (3) the applicant fails to develop the project in the time allotted. Once a water right is perfected there are two reasons it may be terminated. The water right holder can file a statement of abandonment and forfeiture with the State Engineer and the local county recorder, or the courts may terminate the water right as part of a civil or criminal proceeding.

Tributary Water Rights

Except for the Bear River drainage, the West Desert and the lake itself, all surface waters of the GSL Basin are considered to be fully appropriated, except during high water years. On the Bear River, appropriations are still allowed, but there are factors which may restrict the amounts available. At present, the Board of Water Resources, by statute, is considering various alternatives for the development of Bear River water for use in various locations along the Wasatch Front. Development of the Bear River is subject to the limitations of the Bear River Compact.

Ground Water Rights

The Jordan River system, the Weber River drainage, and Tooele Valley are closed to new appropriations of ground water except for the shallow water table aquifers of Salt Lake Valley, Tooele Valley, and the Weber Delta. Groundwater is still available in the Bear River drainages and the west desert. In the Weber Delta and Bountiful sub-area, ground water from the deeper aquifers is still available for single-family domestic uses where no public water system exists. The Weber Delta is open to municipal appropriations on a case-by-case basis where an immediate need can be demonstrated.

For administrative purposes, the State Engineer has divided the GSL drainage basin into sub-basins. Each sub-basin has its own set of policies governing the appropriation and management of its water. GSL is open to appropriation. However, the siting of diversion facilities is dependent upon the applicant securing the proper easements and/or permits from the responsible regulatory agencies and landowner (Appendix F, Exhibit 1).

There are currently 11 perfected water rights to divert water from the lake, all owned by companies or individuals in the mineral extraction industry (Exhibit 4, locations of mineral extraction operations). The earliest priority date of these rights is 1940; the latest is 1986. Under these rights, if used to their fullest, it is possible for the rights holders to divert 362,306 af/yr. Due to economic limitations, climatic conditions and the available evaporative surface, only 95,000 to 180,000 af/yr is currently diverted. The vast majority of this water is evaporated, while very small amounts return to the lake through pond leakage and flushing.

There are six water rights applications which have been approved for development, one of which is non-consumptive. These rights, all owned by mineral extractors, represent a possible diversion of 444,562 af/yr for mineral extraction. The earliest priority date of these rights is 1962; the latest is 1993. Like the perfected rights, the majority of the water diverted under these applications would be consumed by evaporation.

There are 11 applications which have not been approved for development. Ten of these applications are owned by mineral extractors and one is owned by a quasi-governmental agency to provide cooling water for a proposed nuclear power plant. These applications represent a potential additional diversion of 657,565 af/yr, the great majority of which is for mineral extraction. The earliest priority date is 1964; the latest is 1995. The State Engineer has on file four unapproved applications which do not divert water from the lake, but which would have a large impact on it. All call for the diking of Farmington Bay and its use as a freshwater reservoir.

Under existing approved rights, an additional 627,000 to 712,000 acre-feet of brine per year could be diverted from GSL and consumed by evaporation. However, unless this diverted water is evaporated in ponds constructed outside the lake area, thereby increasing the effective surface area of the lake, such additional diversions should have no measurable effect on average lake level. Although this quantity is approximately 25 percent of the total annual inflow to the lake from all sources, the primary limiting factor on greatly increased water diversions from the lake under existing rights and applications is the amount of new land available and suitable for evaporation ponds. The possibility that all the water approved under existing applications will be diverted and consumed at some time in the near future is unlikely. It is, however, likely that existing mineral extraction operations will seek to expand their evaporation ponds and brine diversions.

Global and Regional Climatic Change

GSL and it’s watershed respond to global and regional climatic variability (precipitation, cloud cover, temperature and wind patterns). Understanding the relationship between lake and watershed hydrology and global climatic processes is important to understand changes in lake volume, salinity, and ecosystems behavior. (SRC, 1999c)

Many studies have focused on the relationship between lake volume, watershed processes and global climatic behavior. See Mann et al. (1995), Lall and Mann (1995), Moon and Lall (1996), Abarbanel et al. (1996), Lall et al. (1996) and Sangoyomi et al. (1996). (SRC, 1999c)

Flood Plain

DFFSL's statutory mandate is to define the lake's flood plain and the legislative policy is to maintain the lake's flood plain as a hazard zone. DNR considers the flood plain to extend to 4217. This is based on recent high lake level of roughly 4212, plus three feet for wind tide and two feet for wave action.

DNR has no regulatory authority over land it does not own in the flood plain. The regulatory framework is provided by local government planning and zoning, FEMA and U.S. Army Corps of Engineers (COE). DNR satisfies the legislative mandate and policy by defining the flood plain for planning purposes as lands below 4217 and discouraging development below that level. FEMA has mapped the flood plain to determine when flood insurance is required. Adherence to FEMA's demarcation is required if local communities want to participate in the National Flood Insurance Program. COE regulates placement of fill material in wetlands. If a wetland lies within the flood plain as determined by COE, an additional criterion is added to the permit decision-making process. Agencies do not always agree on the extent of the flood plain.

Flooding and the Operation of West Desert Pumping Project

Lake Level Fluctuations and Flooding

The historic hydrograph of GSL in Exhibit 5 is based on measurement at a series of lake gages since 1875 and on estimates of the lake level for the period prior to 1875. These estimates are based largely on interviews with stockmen who moved livestock to and from Antelope and Stansbury Islands from 1847 to 1875. The annual variations shown for this early period are the average of those measured since 1875. Although the major features of the pre-1875 hydrograph are real, the details are uncertain. For the period since 1875 a small but significant uncertainty exists in the elevation of the various gages used, and thus an uncertainty of several tenths of a foot exists in the absolute elevation of the lake level shown on the hydrograph for certain periods. Any analysis of the hydrograph should consider the uncertainties in the data upon which it is based.

GSL has historically (defined as the period from 1847 to the present), experienced wide cyclic fluctuations of its surface elevation. Since 1851, the total annual inflow (surface, ground water and precipitation directly on the lake surface) to the lake has ranged from approximately 1.1 to 9.0 million acre-feet. This wide range of inflow and changes in evaporation has caused the surface elevation to fluctuate within a 20 foot range. Historically, the surface elevation of the lake reached a high of 4211.5 in 1873 and a low of 4191.35 in 1963 (Exhibit 5). A new record high elevation of 4211.85 in (USGS Provisional Lake Level Records) the south arm was reached in 1986 and matched again in 1987.

From 1933 to 1983, the average elevation of the lake was 4196.77 (above mean sea level), with a maximum of 4202.25 and a standard deviation of 2.58 feet. During the 100-year period prior to 1983, the lake's average elevation was 4198.29 with a high of 4207 and a standard deviation of 3.60 feet. During the period 1983 to 1987, however, the lake rapidly rose 12.2 feet from 4199.65 to 4211.85 feet, causing extensive flooding. The result was millions of dollars in damages and many millions more spent for mitigation and protection from future damage.

Because GSL is a terminal lake in a closed basin, the surface level of the lake changes continuously. Short-term changes occur in an annual cycle of dry, hot summers and wet, cool winters. Long-term climatic changes occur with overlapping periods of about 20 to 120 years, and perhaps longer. The annual high-lake level, which normally occurs between May and July, is caused by spring-summer runoff. The annual low-lake level occurs in October or November at the end of the hot summer evaporation season. The average annual (pre-1983) fluctuation of the south arm of the lake, between high and low, was about 1.48 feet; the north arm fluctuation averaged 0.99 feet. The difference between the magnitude of the south and north arm fluctuations is due mainly to the flow-restrictive influence of the northern railroad causeway (formerly the Southern Pacific Railroad [SPRR] Causeway) and the lack of tributary inflow to the north arm. The highest recorded annual rise of the south arm, 5.05 feet, occurred in 1983. This exceptional rise in lake level was due to high snow pack and above-normal spring precipitation.

Because of the broad, shallow nature of GSL, its surface area expands rapidly as its elevation increases. Elevations 4200 and approximately 4212 represent a common average lake level and the historical high-lake elevation, respectively. Between these two elevations, the area of the lake increases more than 46 percent from about 1,079,259 to 1,572,000 acres. Within this range, the potential of flooding exists. Above-normal annual fluctuations, such as those experienced during 1983 and 1984, result in extensive flooding.

The low lying plain surrounding GSL is particularly susceptible to flooding and other related hazards. Regarding the flood plain, Lowe (1990a and 1990b) states the following: "Using the best available historical and scientific data on GSL, government policy-makers and lake experts have recommended that a beneficial development strategy should exist for lake-shore areas up to 4217 feet in elevation" (DCEM, 1985). This strategy establishes a Beneficial Development Area (BDA) along the shore of GSL between 4191.4 (the lake's historical low level in 1963) and 4217. The strategy recommends that, within the elevation interval between 4191.4 and 4217, development take place in a manner that will encourage the maximum use of the land for the people of Utah while avoiding unnecessary disaster losses. Pursuant to this strategy, (1) UGS would provide technical information and maps showing geologic hazards; (2) city-county surveyors would provide a BDA line which is at the 4217 elevation contour to the planning, zoning and permitting agencies of applicable city, county and state agencies.

The naturally occurring water level fluctuations of GSL are termed "flooding" when the level of the lake begins to adversely affect structures and developments which are located within the flood plain. However flooding is a natural process and is mostly beneficial to species adapted to this dynamic environment. The impact of flooding is greatest around the shores of the south arm of the lake where the majority of the recreational, industrial, wildlife management and transportation facilities have been built. To minimize the impact of flooding, the present and past elevations of the lake and its anticipated short- and long-term fluctuation (rises and falls) should serve as guides to determine "safe" construction areas. This should also identify areas which may be subjected to inundation, wind tides, ice damage or shallow ground water problems.

Long-term lake fluctuations result from a net gain or loss in lake elevation over a specified period of time. For example, between 1873 and 1963, the elevation of the lake fluctuated downward more than 20 feet, from 4212 to the historic low of 4191 feet. It then moved upward, while fluctuating within a 20-foot range, to the historic measured high of nearly 4212 in 1986.

For planning purposes, it is important to know the maximum movement that might be expected during a given period of time. Based on historic estimated and measured lake levels, it is estimated that during six-year blocks of time from 1847 through 1982, the maximum measured one-year upward fluctuation is about six feet. A notable exception to this was seen during 1983-84 when the level of the lake increased by nearly 12 feet during a five-year block. When the trend is downward, the maximum one-year downward fluctuation is about 2.5 feet.

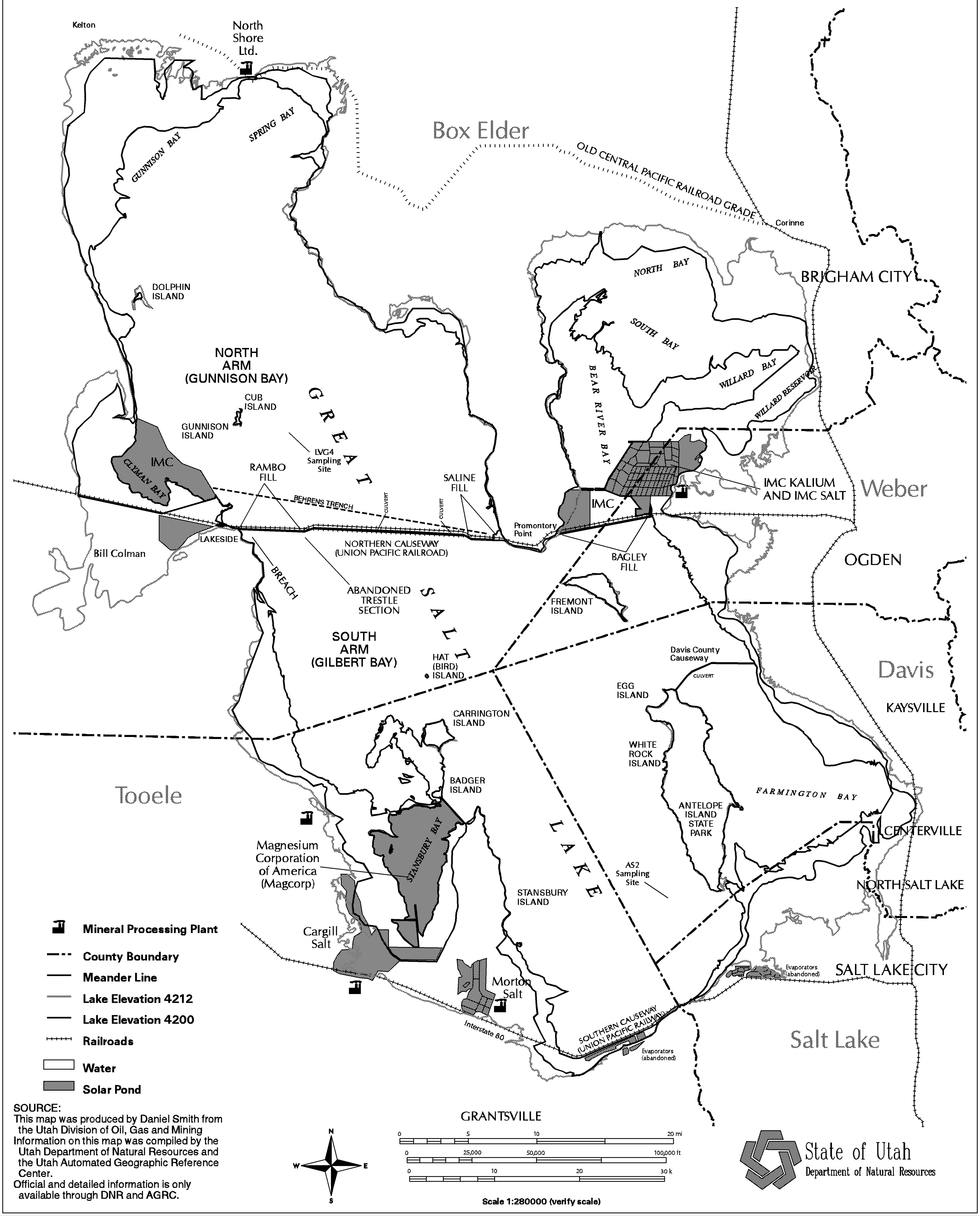
In addition to the historic record of lake level fluctuations, an extensive geologic record of prehistoric fluctuations is preserved as shorelines and other geomorphic evidence in the sediments underlying the lakebed and in the lagoons around the lake shore. This prehistoric record reveals that GSL has risen twice above the 4220 level in the last 10,000 years and numerous times to elevations between 4212 and 4217. The rises above the 4220 level are exceptional. They result from significant departures from what is considered normal climate for the Great Basin in non-glacial times. The rises to the 4217 level occur with climate that is "normal" for the region. They result from a series of years with precipitation above average, but normal for the region. An initial high lake level coupled with consecutive years of above average precipitation will result in a high lake level.

Great Salt Lake Planning Zones

The 1995 GSL CMP adopted seven four-foot elevation zones as a tool to aid in the planing process. These zones are shown in the following table (Table 1). Many of the exhibits used in this report show these zones along the elevation axis. Salinity ranges given in these zones are taken from the "Salinity

Exhibit 4 - Great Salt Lake Mineral Industries

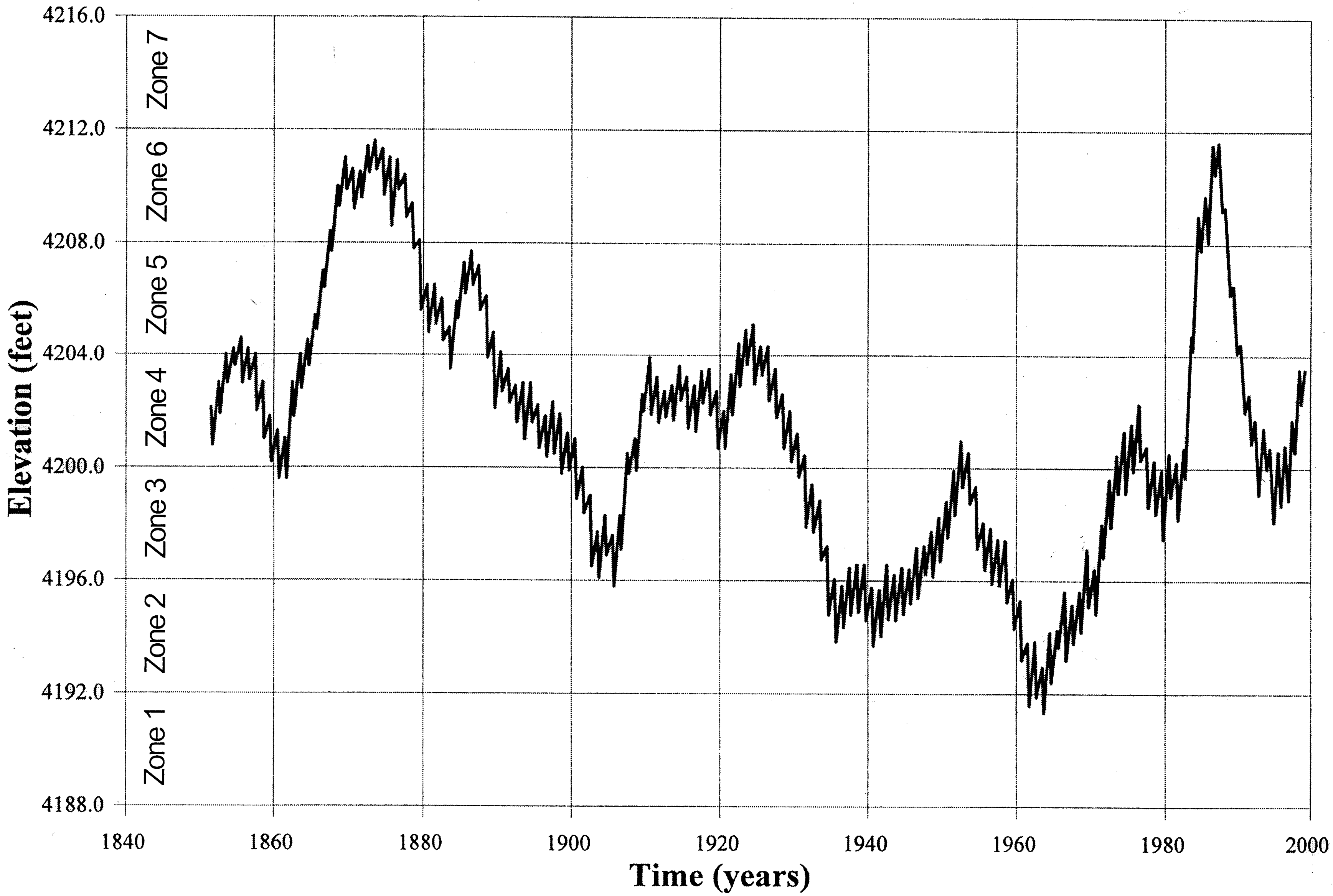
Plotted March 29, 2000



SOURCE:
This map was produced by Daniel Smith from the Utah Division of Oil, Gas and Mining
Information on this map was compiled by the Utah Department of Natural Resources and the Utah Automated Geographic Reference Center.
Official and detailed information is only available through DNR and AGRC.

Exhibit 5

HISTORICAL GREAT SALT LAKE HYDROGRAPH



vs South Arm Elevation - Breach at 4198 with Culverts" (Figure 7 in Appendix G for different management options).

Great Salt Lake Planning Zones

Zones	Elevation	Area Acres	Change in Area Acres	Volume Acre-feet	Probability* Percent
	4188	535,056		6,768,670	
1			66,805		1.4
	4192	601,861		9,030,560	
	4192	601,861		9,030,560	
2			171,103		7.6
	4196	772,964		11,749,730	
	4196	772,964		11,749,730	
3			306,295		23.0
	4200	1,079,259		15,370,180	
	4200	1,079,259		15,370,180	
4			143,741		33.0
	4204	1,223,000		20,040,700	
	4204	1,223,000		20,040,700	
5			187,000		24.0
	4208	1,410,000		25,074,700	
	4208	1,410,000		25,074,700	
6			162,000		8.3
	4212	1,572,000		30,669,000	
	4212	1,572,000		30,669,000	
7			656,000		1.7
	4216+	2,228,000		38,671,000	

Table 1 Great Salt Lake Planning Zones - *Log normal probability of annual peak lake elevations. The probability of the historical data indicates the percent of time the lake elevation would be in each zone.

Each agency having responsibilities on the lake should develop their planning and management activities for each of the seven four-foot zones. The information could be assembled by zone to provide plans and management options for a full range of lake levels. A general description of each zone is given below.

Zone 1. Elevation 4188-4192. The probability analysis indicates the lake would be in this zone about 1.4 percent of the time. Historically the lake was in this zone during the low levels in 1961, 1962 and 1963. While in this zone, the lake would be characterized with an average surface area and volume of 564,200 acres and 7,868,300 acre-feet, respectively. Access to the lake would be extremely limited for recreational and industrial purposes. A vast mudflat would be exposed around the lake. Managed wildlife areas around the lake may continue to operate, but other wildlife habitat may be severely impacted in this zone. These low lake levels and high salinity may either help or hurt mineral industries, depending on their location and salts they are harvesting. The salinity of the lake would be at saturation in the north arm. The south arm would vary from about 7 percent salt by weight to about 9 percent. Vast amounts of salts would precipitate and collect on the bottom of the north arm.

Zone 2. Elevation 4192-4196. The lake probability analysis indicates this would be in this zone 7.6 percent of the time. Historically, the lake was in this zone briefly in 1902, and from 1934 to 1946 (except 1937 to 1939 and 1943 to 1945, when the highs exceeded 4206), and from 1960 to 1968. While in this zone, the lake would be characterized with an average surface area and volume of 677,900 acres and 10,301,100 acre-feet, respectively. Access to the lake would still be difficult for recreational and industrial purposes because of extended mudflat areas and low lake elevations. The salinity of the lake would range from 9 to 10.5 percent salt by weight in the south arm but would be at saturation in the north arm. Large amounts of salts would be precipitated in the north arm of the lake while in this zone.

Zone 3. Elevation 4196-4200. The probability analysis indicates the lake would be in this zone about 23 percent of the time. Historically, the lake was in this zone from 1902 to 1906, from 1932 to 1939, from 1942 to 1951, from 1954 to 1959 and from 1969 to 1972. While in this zone, the lake would be characterized with an average surface area and volume of 890,000 acres and 13,422,000 acre-feet, respectively. Access to the lake should range from a problem at the lower part of the zone to a more normal nature in the rest of the zone. The salinity of the lake would range from about 10.5 to 12.5 percent salt by weight in the south arm and still be at saturation in the north arm. Salts would still precipitate in the north arm of the lake.

Zone 4. Elevation 4200-4204. The probability analysis indicates the lake would be in this zone about 33 percent of the time. The 1851 to 1994 average (south arm) level of the lake is 4201.3. Historically, the lake was in this zone from 1851 to 1853, from 1858 to 1863, from 1891 to 1901, from 1907 to 1921, from 1927 to 1931, from 1952 to 1953, from 1973 to 1982, and from 1991 to 1994. While in this zone, the lake would be characterized with an average surface area and volume of 1,175,000 acres and 17,641,000 acre-feet, respectively. Access to the lake would be good in the lower part of the zone but may start to be a problem in the upper part of the zone due to the high nature of the lake. Recreation, wildlife and other activities/facilities that operate close to the lake have experienced some flooding/damage in this zone. The salinity of the lake would range from about 11 to 12.5 percent salt by weight in the south arm and 21 to 28 percent salt by weight in the north arm.

Zone 5. Elevation 4204-4208. The probability analysis indicates the lake would be in this zone about 25 percent of the time. Historically, the lake was in this zone from 1863 to 1866, from 1880 to 1890, from 1922 to 1926, 1983, and from 1989 to 1990. While in this zone, the lake would be characterized with an average surface area and volume of 1,330,000 acres and 22,541,900 acre-feet respectively. This zone should also be characterized as the zone where major flooding and damages to facilities begins. This damage/flooding will occur to recreation facilities, wildlife areas (flooding of managed marshlands) and the Davis County Causeway (elevation of crest is 4208.75). Major transportation facilities (interstates and railroads), mineral industries and sewage treatment facilities that were generally protected above the 4208 during the 1983-87 flooding should remain protected to at least 4208. The salinity of the lake would range from about 9 to 11 percent salt by weight in the south arm and 16 to 21 percent salt by weight in the north arm.

Zone 6. Elevation 4208-4212. The probability analysis indicates the lake would be in this zone about 8.3 percent of the time. Historically, the lake was in this zone from 1867 to 1879 and from 1984 to 1988. The average surface area and volume are 1,490,000 acres and 27,607,300 acre-feet, respectively. This zone can be characterized as the major flood zone of the lake. Many facilities near the lake were damaged/wiped out during the 1984-88 period. It would be expected that many of the facilities around the lake that were protected during the 1983 to 1987 period would remain protected if the lake again rose to near 4212. It should also be expected that the facilities in this zone that were rebuilt after the lake lowered would be damaged/wiped out again. The salinity of the lake would range from about 8 to 9 percent salt by weight in the south arm to about 12.5 to 16 percent salt by weight in the north arm.

Zone 7. Elevation 4212-4216+. The probability analysis indicates the lake would be in this zone about 1.7 percent of the time. Historically, the lake has never been in the zone, although it reached a peak of 4211.6 in 1873 and a peak of 4211.85 in 1986 and again in 1987. Were the lake to reach the average elevation of this zone, the 1,900,000 acre surface area and 34,670,000 acre-feet volume would be over twice the average extent and size of the lake. Based on the flooding that occurred in 1986 and 1987, the two railroad causeways, Interstate 80 (I-80) along the southern part of the lake would be flooded by the time the lake reached 4213-4214. Also, as was happening in 1987, major flooding would be occurring in residential areas near Rose Park and places along the east of the lake, such as Plain City and Corinne. Protection to sewage treatment plants along the east shore area may also fail at these elevations. Although zones about elevation 4216 are not discussed, it goes without saying that major damages would continue to occur if the lake continued to rise. One area, Salt Lake City International Airport (SLCIA), needs to be noted. Studies during the 1983-87 period indicated the airport facilities are well protected and could continue to operate with elevations above 4216 (perhaps up to 4220) without major interruption to its operations. The salinity of the lake (assuming northern railroad causeway remained in place) would range 3 to 4 percent in the south arm and 13 to 15 percent in the north arm.

Current Status of Predicting Lake Levels

During the early 1980s when the lake rose to an elevation of 4211.85, there was a great deal of interest in predicting future levels of GSL. Although some of these forecasts, with hindsight, seemed to show some promise, there was a general consensus by researchers and climatologists, at the time, that predictions could not be made with any degree of assurance. Some researchers who made forecasts in the 1980s still believe they are able to make reasonably good short-term future forecasts of the GSL level. However, there still remains a general scepticism by researchers and climatologists that these forecasts can be made with any assurance.

Since 1990, one new forecasting model has been developed at the Utah State University Utah Water Research Laboratory (UWRL). This model is still being "fine-tuned" but has shown a reasonable good reliance to forecast short-term levels of GSL. Recent forecasts made using the water lab's model have matched the lake levels for 1998 and 1999. The model forecasts a rising lake level for at least another four years. If this or other models prove to be reliable in forecasting short-term future lake levels, they will be valuable tools for use with the GSL CMP.

Flooding Impacts

Flooding in the recent past has caused enormous financial damage and has required expensive mitigation. The lake flooding episode of 1983-87 is estimated to have caused over $240 million (1985 dollars) in damages. Had the lake level continued to rise and halt the operation of the northern and southern railroad causeways and I-80, it is estimated that the state could have suffered from $500 million to $1 billion (1985 dollars) in direct and consequential damages. Development and placement of structures in hazardous or flood-prone areas are the major causes of these high damage figures.

Most dikes on the lake are used and maintained for a particular purpose. Maintenance would ensure that these dikes would be able to withstand high lake levels (1980s).

Flooding of Interstate 80 and Other Access Roads

I-80 near GSL was adversely affected during the flooding period of 1983-87. Several sections had to be raised as much as eight feet, to an elevation of 4214, to make the freeway useable. The cost to do this work was approximately $20 million.

UDOT subsequently installed concrete pavement (final surface) from Burmester to the Tooele Interchange, replaced the bridge and modified Black Rock Interchange, all of which were completed in 1992. This section of I-80 is not expected to need attention, other than routine maintenance, until around 2002. Because of this construction, I-80 would not be flooded as long as the lake level does not rise above 4211.

The Davis County Causeway to Antelope Island was a state highway at the time of the severe flooding of the 1980s and was inundated. This highway was transferred to Davis County on May 17, 1991, was subsequently raised two feet, to 4208.75, and was paved during 1992. Use of the Davis County Causeway is adversely affected by lake levels of approximately 4204 and higher.

Flooding Impacts on the Southern Railroad Causeway

The southern railroad causeway (Union Pacific Railroad Causeway), located at the southern end of GSL, is a major rail line to the West Coast. It presently serves many chemical industries in this region and provides daily passenger service via Amtrak as part of an east/west rail corridor. In 1983, the rising lake began to effect the railroad track structure. Union Pacific raised the track in this area to protect it from the rising water. The elevation (top of the rail) through most of this area is 4221.0 feet, with the sub-grade (top of the embankment) at 4218.5 feet.

Flooding Impacts on the Northern Railroad Causeway

In 1906 Southern Pacific Transportation Company (SPTC) constructed the Rambo Fill, a wooden trestle and the Saline Fill between Lakeside and Promontory Point, to shorten the time required to go north around the lake. In 1959, SPTC completed the replacement of the original wooden trestle across the lake with a rock-fill and earthen causeway (Exhibit 4). The causeway was designed and constructed to have a minimum freeboard (vertical distance from maximum water level in the lake to the top of the causeway slope protection) of 10 feet. The slope protection design was based on the COE *Shore Protection Manual,* and was provided by utilizing very large one to three ton stones placed on a 1.5 to 1 slope. The thickness of the large stone layer was five feet. The causeway began to settle soon after construction and settles an average of two to four inches per year. Several areas of the causeway have experienced more settlement than the average, up to a half foot per year with a total settlement of up to 17 feet.

GSL is subject to sudden and violent storms, with winds over 70 mph. The winds generate waves that can reach eight feet in height and have 20 percent more energy than the ocean due to the higher density of lake waters. The height, length and period of wind-generated waves are determined by wind speed. The calculated "design wave," which is the average of the highest one-third of all waves, is 7.2 feet for the northern railroad causeway. High winds and waves can occur year round. However, most of the damaging wind and waves occur from the north, from April to July, and from the south, from July to August.

Prior to completion of the northern railroad causeway, the surface elevation throughout the lake was uniform. After completion of the causeway, however, an elevation difference began to develop between the two arms of the lake, with the south arm being higher. This elevation difference is due to two factors; the majority of the tributary inflow enters the south arm of the lake and the causeway restricts the movement of water from the south to the north arm of the lake.

From 1959 to 1982 the freeboard varied from 8 to 17 feet. During periods of the higher water elevations and low freeboard, the slope protection had some isolated areas that eroded and required repair. In January 1983, the average elevation of the crest of the causeway fill areas crossing the lake was 4209 to 4210 with some isolated areas as low as 4207. There were approximately 30 miles of fills crossing the lake and 60 miles of exposed slopes. By 1987, the fills crossing the expanding lake increased to 60 miles with over 105 miles of slopes to protect. The decision was made to utilize surplus and scrap box cars to create a "boxcar sea wall" on the north side of the causeway, which allowed the tracks and fill to be raised from about 4206 to 4217.

During the flood years, the causeway began to slough-off, settle and subside into the lake. It experienced five to six feet of subsidence along much of its length due to the weight of additional fill material. By spring 1984, very large inflows of freshwater into the south arm of the lake and restriction of flows to the north through the causeway fill, plus plugged causeway culverts, created a head differential of water levels. The higher elevation in the south arm added greatly to flooding problems on the south and east shores of the lake. The state constructed a 300-foot opening (breach) in the causeway, just off the west shore near Lakeside, to allow the rising waters to flow more freely into the north arm, thus reducing the large head differential and flood damage. The plugged causeway culverts and extremely high inflow created a head differential of water levels of nearly 3.5 feet between the north and south arms. The breach lowered the head differential between the lake arms to less than one foot.

Flooding Impacts on Recreation

Due to record high water of the early 1980s, millions of dollars of recreation facilities and user opportunities were lost. Antelope Island was isolated, marinas were forced to close and the southern sandy beaches were inundated by the waters of the lake. Recreation facilities on the lake generally begin to experience damage and interference with operations at lake levels of approximately 4205 and higher.

Flooding Impacts on Wildlife and Wetland Structures

Most WMAs around the lake were constructed in the 1930s to 1940s when lake level was relatively stable at 4198 above sea level. At these levels, annual production of waterfowl approached three-quarters of a million birds, with non-game production numbering in the multi-millions. Total bird use of the marshes on the lake exceeded 100 million use-days annually and recreationists would expend one-half million days each year afield. Marshes were managed for mean water depths of about 18 inches.

During the flood years of the 1980s, nearly 300,000 of the 400,000 acres of marsh around the lake were inundated or devegetated due to salt water intrusion. Damages to state-owned property, dikes, water control structures, parking facilities, fences, signs and gates were estimated at over $30 million. Similar damage occurred on the federal Bear River Migratory Bird Refuge (BRMBR).

During the floods, production of ducks and geese dropped by 80 percent and fall swan use decreased over 90 percent. Total bird use in marshes decreased nearly 90 percent and public use all but disappeared.

As the water depth increases, thousands of acres of brackish and freshwater marshes, as well as upland habitats, are flooded. This forces birds, particularly nesting species, to move to higher ground. In many areas around the lake, the upland buffer is no longer available because of human development. Either natural or anthropogenic flooding events could result in large population reductions of breeding birds, though there would again be some differences between long-term local events and short-term broad-scale events.

Although potentially damaging to structures in WMAs, fluctuations in lake water levels can be beneficial to wildlife. Periodic flooding and drying events keep wetlands in early successional stages and increase their productivity. Flooding impacts begin at lake elevation of 4198. Most lake-shore freshwater wetlands have been inundated with salt water when lake elevations exceed 4208.

The bulk of dike maintenance expenditures occurs in the lake level range 4200-4205. Regardless of which WDPP policy is implemented, dikes sustain the same amount of damage for that range. The current strategy for WMAs at this lake level range is to accept the rising lake and repair dikes after the lake recedes. It is very expensive to flood-proof dikes above 4205 and managers recognize the benefits associated with periodic flooding.

Flooding Impacts on Investor-Owned Public Utilities

Unless flooding is so severe as to enter established commercial and residential developments, damages to the telephone and gas utilities (US West and Questar [formerly Mountain Fuel], respectively) are minimal, even at lake elevations above 4208. Much more vulnerable to flooding are Pacificorp's (formerly Utah Power & Light) power lines. Much of the damage that occurred west of Bountiful and Centerville was caused by wind-blown ice which was able to reach the transmission lines due to high lake level. Utah Power & Light constructed a dike between the power lines and the open water to prevent ice damage to the power lines.

The anticipated loss at 4210 is $1.3 million (1993 dollars), adversely affecting several high-voltage transmission lines between SLCIA and Kaysville, two near Saltair, three more near Timpie Springs, a substation in Centerville and numerous service distribution lines. Damage costs would escalate to an expected level of $19.5 million (1993 dollars) if the lake level reached 4212. The construction of the third commercial runway at SLCIA required relocation of several major power transmission lines closer to the lake, which could make the damage estimates greater.

West Desert Pumping Project

Although the name West Desert Pumping Project implies a pumping project, it is actually a project which operates by expanding the surface area available to evaporate the flow into GSL by approximately 23 percent at 4208 lake level. The increased evaporation slows lake level increases and accelerates lake level declines during periods of pump operation.

The WDPP consists of a 10-mile access road along the former SPTC railroad causeway, a pumping station, two canals, trestles, dikes, a 37-mile natural gas pipeline and the West Pond in the desert west of the Newfoundland Mountains (Exhibit 6). The West Pond has a surface area of 320,000 acres, approximately 508 square miles, and a volume of 800,000 acre-feet at an elevation of 4216.5. Three large pumps lift up to 3,000 cubic feet per second of water from the north arm of the lake to a 4.1-mile outlet canal. The canal begins at 4224 (above sea level) and discharges water into the West Pond. The project is designed to pump approximately two million acre-feet of water a year into the West Pond to evaporate up to 825,000 net acre-feet of water each year.

A 24.4 mile dike with a maximum height of six feet retains the southwest portion of the evaporation pond and prevents water from the project from flooding I-80 and the famous Bonneville Speedway. A second dike 8.1 miles long with a maximum height of seven feet extends southeast from the southern tip of the Newfoundland Mountains and is used to contain the water and restrict the surface flooding of the U.S. Air Force (USAF) military range. A weir in the dike is used to regulate the pond's surface level between 4215 and 4217 and the return of concentrated brine to the lake. Return flow through the military range was not confined and flowed over the natural topography in an expansive path on its return to the lake.

Pumping started on April 10, 1987 and continued until June 30, 1989. During this period an estimated 2.73 million acre-feet of brines were pumped from the lake. The pumping was started too late to have a significant impact on the maximum lake level in 1987; however, the pumping project was successful in increasing the rate of decline of the lake and lowering the level of the lake some 15 inches. After pumping had ceased, the lake level continued to drop an additional two feet through the end of 1989. Precipitation dropped to average levels or below. The lake level continued to drop an additional four feet through the end of 1993.

Operating Consequences and Constraints

The design of the WDPP was modified prior to construction. The original design called for brine to be pumped from the fresher south arm of GSL. The final modification reduced the cost of the project and sped construction by pumping brine from the north arm. The use of more concentrated north arm brine reduced the evaporation potential of the project and resulted in more salt being left in the West Pond.

Part of the reason why 12 percent of the lake's salt was deposited in the west desert was the intentional continuation of pumping into the summer months (to provide feed stock to Magcorp's Knolls evaporation ponds). Had pumping been stopped in March or April of 1989 at the end of a planned cycle, or continued through the winter of 1990 to complete yet another full cycle, the salt loss to the west desert would have been greatly reduced.

In 1994, U.S. Geological Survey (USGS) published a report entitled "Salt Budget of the West Pond, Utah, April 1987 to June 1989." The report summarized the salt budget as follows:

"During operation of the West Desert pumping project, April 10, 1987, to June 30, 1989, data were collected as part of a monitoring program to evaluate the effects of pumping brine from GSL into West Pond in northern Utah. The removal of brine from GSL was part of an effort to lower the level of GSL when the water level was at a high in 1986. These data were used to prepare a salt budget that indicates about 695 million tons of salt or about 14.2 percent of salt contained in GSL was pumped into West Pond. Of the 695 million tons of salt pumped into West Pond, 315 million tons (45 percent) were dissolved in the pond, 71 million tons (10.2 percent) formed a salt crust at the bottom of the pond, 10 million tons (1.4 percent) infiltrated the subsurface areas inundated by storage in the pond, 88 million tons (12.7 percent) were withdrawn by Magnesium Corporation of American (Magcorp), and 123 million tons (17.7 percent) discharged from the pond through the Newfoundland Weir. About 88 million tons (13 percent) of the salt pumped from the lake could not be accounted for in the salt budget. About 94 million tons of salt (1.9 percent of the total salt in GSL) flowed back to Great Salt Lake."

Therefore at the end of pumping operations, approximately 484 million tons of salts were either in the pond or infiltrated into the subsurface. Another 211 million tons were withdrawn by Magcorp or discharged over the Newfoundland Weir. About 94 million tons of the 211 million tons had returned to the lake. Therefore approximately 600 million tons (as of 1989) had been pumped but not returned to the lake. Efforts are underway to estimate how much additional salt has returned to the lake since 1989.

It is presently believed that some portion of the precipitated salt, approximating 180 million tons, has been redissolved by rainfall and removed from the pond by either Magcorp or by flow over the weir. Much of this has not, however, returned to the lake. This removal of salt has had an impact on the overall salinity of the lake.

In its present configuration, the WDPP is capable of operating only at south arm lake levels of 4208 or higher (The WDPP operation is referenced to south arm lake elevation). The current configuration of the WDPP will allow the pumping of only north arm brines. Pumping the denser north arm brines reduces the efficiency of evaporation, in that less water can be extracted from the brines before salts begin to precipitate in the West Pond. Operation of the WDPP should begin in the early spring as the lake begins its seasonal rise and continue through the summer evaporation season. Pumping should continue through the fall and into the winter to redissolve the salts left during the summer and return them to the lake.

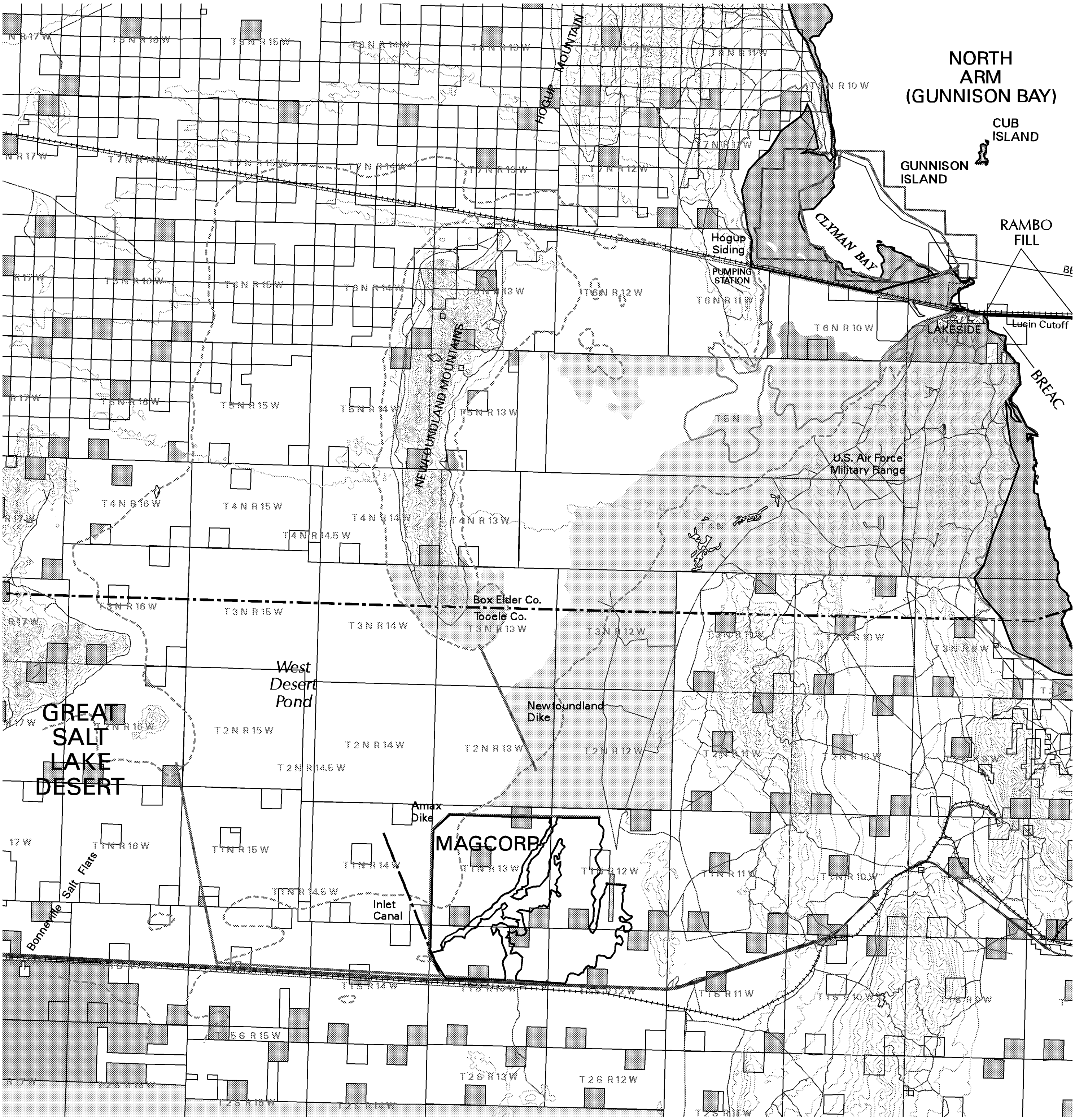
The relationship between lake levels, the pumping of brine from the north and south arms, and the build-up of salts in the West Pond are presented in Exhibit 7. The upper, more densely stippled shading shows the upper and lower limits of salt precipitation for north arm brines at varying lake level elevations. The lower, less densely stippled shading shows the same limits for south arm brines. Exhibit 7 shows that the WDPP could operate without precipitation of salts in the West Pond if operation is commenced only at lake elevations of 4210 (above sea level) and higher. With the current configuration of the inlet canal and West Pond, the WDPP can only be operated at lake levels above 4208, with feed brine pumped from the north arm of the lake. Unless the West Pond is significantly reduced in size, which would significantly reduce the effectiveness of the system, operation of the WDPP in its current configuration will result in precipitation of additional salts in the West Pond.

Administrative and Legal Considerations

As part of the WDPP, various rights-of-way, permits and memoranda of understanding (MOU) were executed among the State of Utah, BLM, USAF and COE. Several of these were long-term agreements to operate the WDPP, such as the right-of-way issued by BLM. Others were short term, temporary permission arising out of the emergency nature of the project. USAF never granted official approval for the use of the range in operation of the WDPP, but instead issued a letter of approval for temporary operation for the duration of the flooding emergency. In recent discussions, USAF notified the state that an environmental baseline study would

Exhibit 6 - West Desert Pumping Project

Plotted March 29, 2000



- County Boundary
- Meander Line
- Township & Range Grid
- Lake Elevation 4212
- Lake Elevation 4200
- Lake Elevation 4217
- Major Roads
- Minor Roads
- Railroads
- Mineral Lease Boundary
- Dikes
- Pump Canal
- State Trust Lands
- State Wildlife Reserves and Management Areas
- Bureau of Land Management
- Department of Defense
- Water
- Intermittent Water

SOURCE:
This map was produced by Daniel Smith from the Utah Division of Oil, Gas and Mining
Information on this map was compiled by the Utah Department of Natural Resources and the Utah Automated Geographic Reference Center.
Official and detailed information is only available through DNR and AGRC.

0 5 10 20 mi
0 25,000 50,000 100,000 ft
0 10 20 30 k

Scale 1:220000 (verify scale)

State of Utah
Department of Natural Resources

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DEPARTMENT OF NATURAL RESOURCES

Exhibit 7

West Desert Pumping Project with pumping rate vs. South Arm Elevation vs. Salinity.

LEGEND / NOTES:

① Max. weir elev./salt buildup boundary (4216.57 weir elev.)

② Min. weir elev./salt buildup boundary (4215.00 weir elev.)

③ Operating system above max., line allows for maximum pond size with no salt buildup in pond.

④ Operating system below max. line requires a reduction in pond size (resulting in loss of evap.) to not build up salts. Determination of the weir height can best be done using a computer model of the ponds.

⑤ Lowest limit (lowest level of weir setting) at which the system can be operated with no salt build up. System can be operated below min. line but not without salt build up.

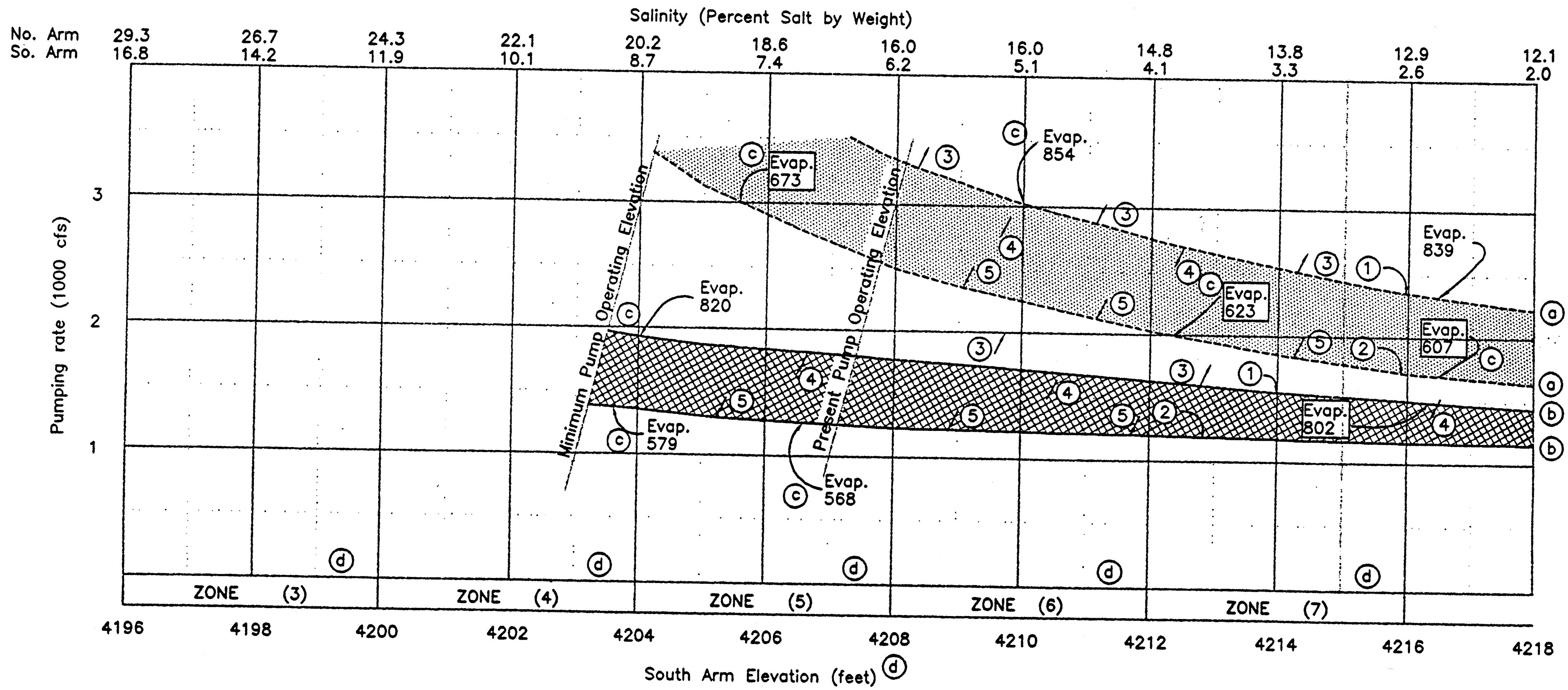
ⓐ ----- North Arm Brines

ⓑ —— South Arm Brines

ⓒ Pond evaporation in 1,000 Acre Feet.

ⓓ All elevations are referenced to South Arm Datum. A 0.9' amount was added to the North Arm gage reading (0.2' for gage correction and 0.7' for level difference), to adjust North Arm data to the South Arm Datum.

Source: Utah Division of Water Resources.



be required, and perhaps an update of the original project EIS, before Hill Air Force Base (HAFB) would grant permission to flood parts of the Utah Test and Training Range. HAFB has also indicated that a proposal to utilize the WDPP will require the state to address several HAFB concerns. Use of the WDPP raises several safety concerns such as the impact of the West Pond on fog levels and increased bird use, both of which affect flight safety. Presence of the West Pond will also affect planning for flying missions, operation of target complexes and conducting environmental clean-up activities. All of these concerns would have to be addressed before USAF would allow operation of the WDPP to resume. HAFB also indicated that a proposal to utilize the WDPP for lake levels below 4208 may make it more difficult to obtain USAF approval to pump GSL water into the West Desert.

COE has also raised a concern over the impacts the pumping project may have had on the ecology of GSL, (removal of salts from the lake). COE issued a Section 404 permit for construction of much of the WDPP, which also covers operations. COE has indicated that a resumption of pumping or a change in the use or protocols of the WDPP would likely trigger an evaluation of the state's performance under the permit in light of these concerns.

Locomotive Springs

The most critical issue facing Locomotive Springs is maintaining freshwater flow. From 1993 to 1997 DWRi has collected hydrologic data regarding the groundwater system in Curlew Valley. A report entitled *Hydrologic Data for Curlew Valley, Utah* (Atkin, 1998) was recently published containing this data. DWR cooperated with this data collection and installed and operated several gaging stations at Locomotive Springs.

The groundwater system in Curlew Valley is the source of water for Locomotive Springs. The basin is in both Idaho and Utah. The Utah portion of the valley has been closed to new groundwater applications, except single-family domestic wells, since 1976. However, it is reported that Idaho is still approving new applications. In addition, the data indicated that most of the water for Locomotive Springs comes from the Holbrook-Snowville Flow System. Most of the groundwater withdrawals from this flow system are in Idaho. Due to decreased hydrostatic pressure in this aquifer, the potential for salt water intrusion is another concern.

The State Engineer held a public meeting on March 3, 1999 in Snowville to discuss the current groundwater conditions in the valley. The data shows that the discharge from Locomotive Springs has dropped considerably during the last 40 years. The solution to this matter is complex and potentially very controversial—it will most likely take considerable effort to resolve.

Inter-Island Diking and Freshwater Embayment Proposals

Over the past hundred years, the state has received several significant proposals for major inter-island diking projects to create large freshwater embayments in GSL. The projects which have made a water right filing with the State Engineer are as follows:

Table 2. Water Rights Filings

Owner	Priority Date	Amount	Common Name
DWRe	March 31, 1971	1,510,000 af	
Glenn R. Maughan	May 5, 1989	5,000,000 af	Lake Maughan (Wasatch)
Davis County	January 6, 1993	800,000 af	Davis Lake
Western Water	March 31, 1999	450,000 af	Bonneville Reservoir

Lake Wasatch (1990), Lake Davis (1993) and Lake Bonneville (1996) are a few examples of recent proposals to create freshwater impoundments.

Sponsors of these projects listed the following potential benefits:

- Provide and enhance recreational and tourism opportunities—boating, fishing and water sports
- Provide year-round water storage to supply increasing municipal and irrigational demands
- Provide opportunities for economic development (industrial and residential) around these impoundments
- Protect wildlife and upgrade existing habitat (freshwater system)
- Provide transportation and utility corridors across these dikes
- Provide flood protection to facilities, industries, causeways and other areas bordering the lake
- Improve aesthetics, quality of life and enhance lifestyles
- Improve economy and provide additional revenue

"These proposals have been the subject of repeated, detailed and scientific studies. The studies have uniformly found the proposals unworkable for a variety of reasons . . . " (DFFSL, 1996). In 1996, the Utah Sovereign Lands Advisory Council along with Governor Michael Leavitt replied to the Bonneville proposal by stating that "The Bonneville Bay proposal could dramatically affect certain sovereign lands and would be similar to other concepts the state has repeatedly studied and rejected." In 1990, the Great Salt Lake Development Authority, as defined in Utah Code Ann. Section 17A-2-1603(9), rejected the Wasatch Lake proposal by stating that it "does not appear to be economically or environmentally feasible."

Some of the reasons that these proposals have been rejected are listed below:

- Did not appear to be economically or environmentally feasible
- Loss or damage to existing wetlands
- Impact on wetlands and other wildlife habitat
- Cost of diking, pumping and transportation facilities
- During flood events, it would require larger pump system
- Salinity problems
- Earthquake safety and dike stability concerns
- Studies showed the proposals could not provide water with quality adequate for agriculture or M&I uses

- Potential dam safety issue
  Water quality
  concerns—unacceptable for even irrigational purposes, recreation and residential waterfront uses and would require constant monitoring
  Possible offensive odors
  Fisheries may not be able to persist
  Water right concerns
  Water depth too shallow for recreational activities

Proposed locations for freshwater embayments would also conflict with sovereign land which the state legislature has authorized to be set side for wildlife purposes (23-21-5)(Appendix F, Exhibit 2).

There are no active proposals being considered at this time. However, establishing a DNR policy regarding how to address intra-lake proposals in the future would be advantageous since this issue arises nearly every three years. Small freshwater embayments may not possess some of these identified consequences.

The "Water Chemistry" section addresses the overall salinity and ion concentrations of the water of GSL. Biological and other chemical water constituents are briefly discussed in the "Water Quality" and "Biology" sections.

The water chemistry and salinity differentials and trends are significant to the aquatic and avian biology of GSL and to the extraction of mineral salts from lake brines. The impacts of varying water chemistries and salinities to the wildlife and mineral industries of the lake are discussed in the "Biology" and "Minerals and Hydrocarbon" extraction sections, respectively. This section focuses on the physical and chemical aspects of GSL, factors influencing nutrient inputs and losses from the lake and the lake hydrologic processes.

The planning team has identified the following lake water salinity and chemistry conditions and trends as relevant to lake management:

- **The continuation of separate and distinct salinity areas in GSL is an issue.**

- **There is an apparent change in the exchange of salts between the north and south arms. This has resulted in the south arm being less saline than before the high water years for a given elevation.**

- **There is a lack of an accurate accounting for the quantities and locations of salts in the lake system.**

- **There is a lack of knowledge regarding nutrient chemistry and its influence on biological productivity in the lake**.

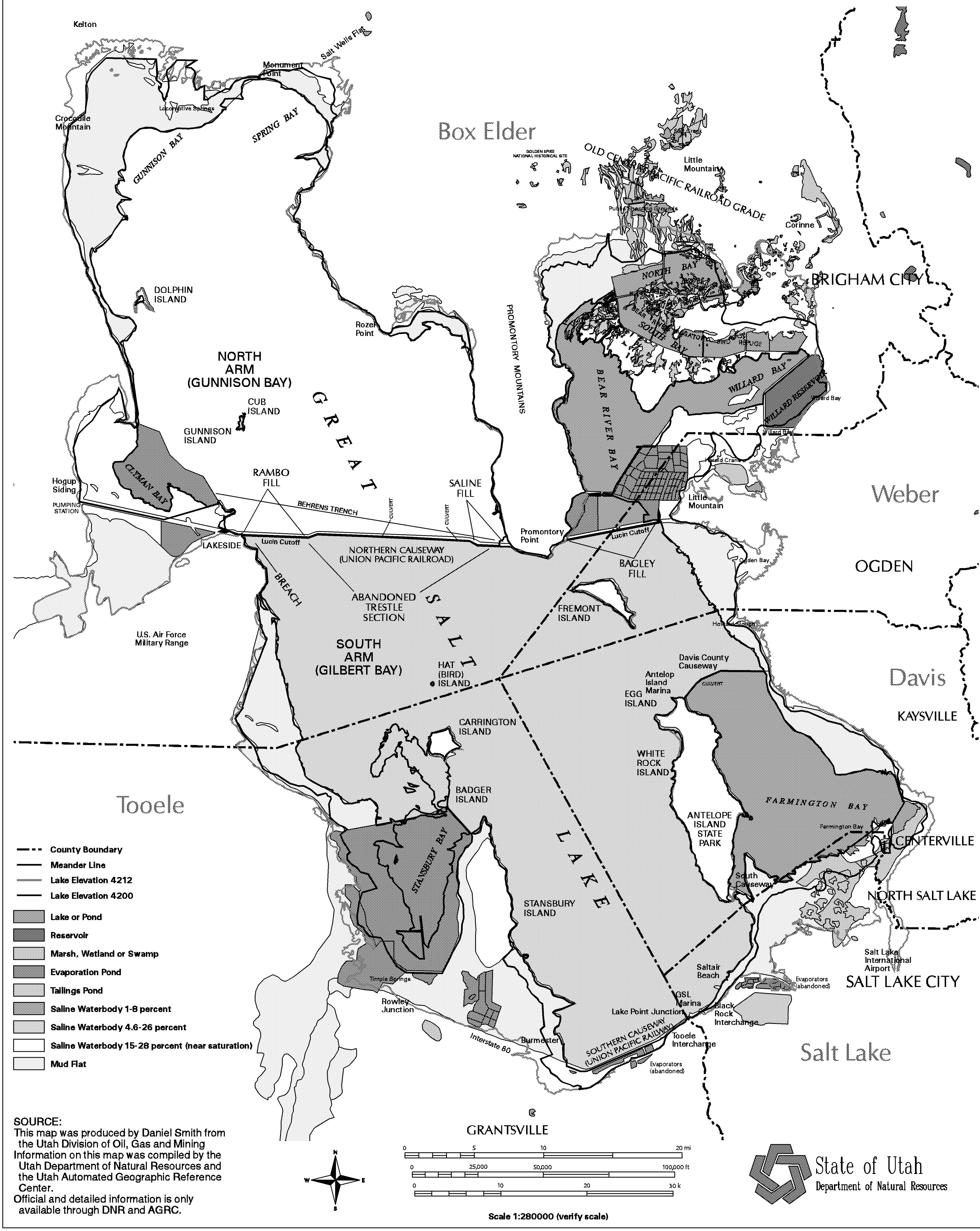
Separate Water Salinity Areas in the Great Salt Lake

It is believed that, prior to construction of dikes, causeways and mineral extraction facilities in GSL, lake brines were similar in composition and concentration throughout the lake (Appendix H). Since the early 1900s, dikes and causeways have been constructed in GSL for a variety of purposes. Several of these inhibited the unrestricted movement of lake brines among large areas of the lake. Coupled with the fact that most of the freshwater inflow to the lake occurs on the eastern shore, distinct salinity conditions have developed in four main areas of GSL. From freshest to most saline, they are; Bear River Bay, Farmington Bay, the main body of the lake (sometimes referred to as the "south arm" or Gilbert Bay) and Gunnison Bay, often referred to as the "north arm." Exhibit 8 shows the areas of salinity in GSL. Bear River Bay and Farmington Bay are both shown with salinities of 3-6 percent. Bear River Bay is generally fresher than Farmington Bay.

Bear River Bay is separated from the main body of the lake by IMC Kalium Ogden Corp.'s dike and the Bagley Fill which was constructed about 1900 and extends eastward from Promontory Point to Little Mountain. Construction on the northern railroad causeway began in

Exhibit 8 - Areas of Salinity

Plotted March 29, 2000



1956 and was completed in 1959. This rock-fill causeway separates the main body of the lake between Promontory Point to Lakeside and was known as the Southern Pacific Railroad Causeway. This causeway includes the Rambo and Saline Fills which were constructed about 1900. This created a separation between Bear River and Gunnison Bays from the main body of GSL.

With the completion of the causeway, the main body of GSL was now divided into two parts, the south and north arms. Even with the engineered permeability of the causeway and the incorporation of two 15-foot-wide by 20-foot-deep box culverts through the causeway, brine mixing was greatly diminished. Since 1960, the two main arms of the lake have developed different physical and chemical characteristics which vary as the lake level changes, and as changes are made to the structure.

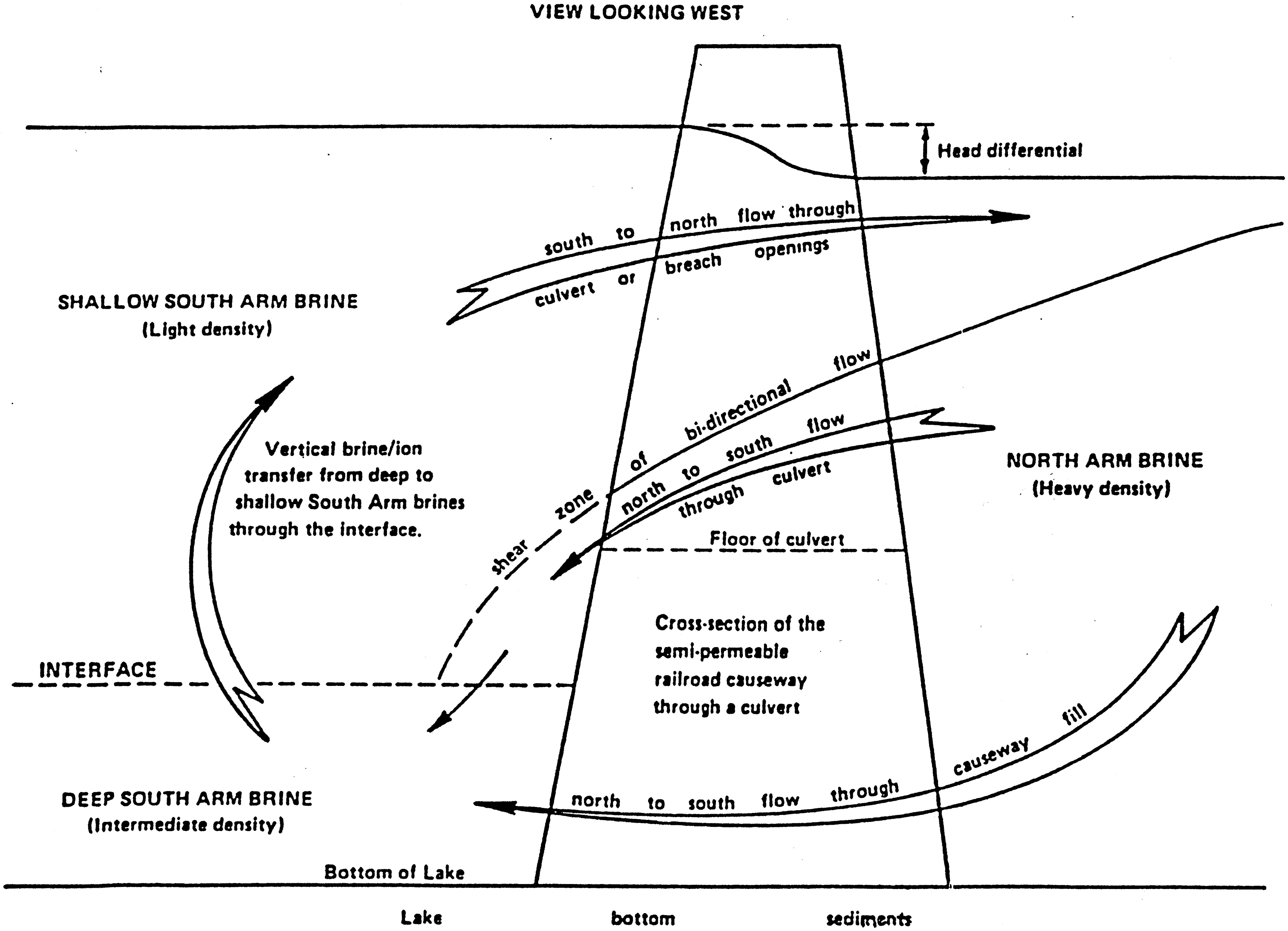
Farmington Bay was part of the main body of the south arm of GSL until it was isolated by the construction of two earthen causeways. The first causeway (southern fill) was built from the south end of Antelope Island southeastward to the mainland between 1951-1952. This structure inhibited water exchange between the main body of the lake and the bay at the south end of the island, and channeled the full flow of the Jordan River into Farmington Bay. The second causeway (Davis County) extending from the north end of Antelope Island eastward to the mainland, was constructed in 1969. With the construction of this causeway, Farmington Bay was essentially isolated from the main south arm of the lake, with the exception of two bridged openings, and mixing between the two bodies of water was severely restricted (Gwynn, 1998a).

Farmington Bay

Farmington Bay is isolated from the main body of GSL when its level is below the top elevation of the Davis County Causeway and the Antelope Island southern causeway fill. Because of the inflow of freshwater from the Jordan River and groundwater inflows, the lake brines tend to be "flushed" from the bay through openings in the Davis County Causeway. Periodically, denser brines from the main body of the lake flow back into Farmington Bay underneath the lighter, fresher brines from the bay. This phenomenon is known as "bi-directional flow," and prevents the waters of Farmington Bay from becoming completely fresh. Bi-directional flow occurs through the Davis County Causeway's bridged openings, and through a narrow culvert to the east which was installed in 1992. Bi-directional flow through these two openings is illustrated in Exhibit 9 and describes a similar dynamic occurring through the northern railroad causeway. When the lake's elevation is below 4208, the salinity of Farmington Bay is approximately half or less than that of the main body because of freshwater flows of the Jordan River into the bay. When the lake's elevation rises above 4208 and the causeway is over topped, the waters of Farmington Bay and the main body are free to mix (Gwynn, 1998a).

Brine returning to the bay from bi-directional flow tends to resist mixing with the fresher water, and remains in a fairly coherent "tongue" which extends some distance to the south underneath the lighter Jordan River/brine mixture. This forms a stratified brine condition

Exhibit 9



Schematic of bi-directional brine movement through the causeway within the Great Salt Lake, Utah (from Gwynn and Sturm, 1987).

within the central, deeper portions of Farmington Bay. The salt content of the upper Farmington Bay waters is maintained through vertical mixing of the tongue of denser, main body brine with the fresher water above it (Gwynn, 1998a).

Bear River Bay

Bear River Bay is similar to Farmington Bay as a brine system. It is separated from the main body of the lake by the rock-fill causeway which contains a mid-point, bridged opening through which bi-directional flow takes place. The brine is stratified within the deeper portions of Bear River Bay. The upper layer of water contains 1-2 percent salt. Below the upper layer of water lies a tongue of salty water which periodically moves into the bay by the bi-directional flow through the opening in the railroad causeway.

The salinity of the lower brine tongue is similar to that of the adjacent main body of the lake. The thickness of the tongue of denser brine and that of the overlying less-saline water depends upon the rate of inflow into the bay and on prevailing wind conditions. South winds raise the level of the lake at the causeway, forcing the tongue of main body brine farther into the bay, making it thicker. North winds lower the level of the south arm at the causeway, causing the brine to extend a shorter distance into the bay, and it becomes thinner. When the tongue of main body brine thickens and extends farther into the bay, the overlying fresher brine layer thins (Butts, 1998).

Gilbert Bay

The salinity (total-dissolved-solids) of Gilbert Bay varies inversely with lake elevation, and since 1966 has fluctuated from a high of 250 grams/liter in 1966 (approximately 21 percent salinity) to a low of about 50 grams/liter in 1986 (approximately 5 percent total salinity). The south arm of the lake receives nearly all of the freshwater inflow to the lake, including flows from the Jordan, Weber and Bear Rivers, and numerous, minor, east- and south-shore streams (Exhibit 3).

From 1966 until about mid-1991, the south arm of the lake was density-stratified into two brine layers. A dense, turbid, hydrogen sulfide-laden brine extended from an elevation of about 4180 to the bottom of the lake. A less dense, clearer, odor-free brine extended upwards from about 4180 to the surface. The two brines were separated by a relatively sharp transition zone. The deeper, denser brine layer disappeared in mid-1991, after the high-water years (1983-87). During the 1980s, the surface elevation of the lake rose from about 4200 to nearly 4212 by 1986-87. The disappearance of south-arm stratification is probably due to diminished north-to-south return flow through the causeway brought about by the apparent changes in the hydraulic conductivity (permeability) in the northern railroad causeway (Appendix H). Since mid-1991, brines of the south arm have been thoroughly mixed from top to bottom. This may have been caused by the addition of fill material used to increase the height of the causeway from 1983 through 1987 and subsequent compaction of the causeway. It may also have been influenced by the effect of the large head differential that existed between the two arms of the lake which minimized the potential for return-flow to the south arm.

The differences in salinity from east to west can be documented at the present time from the work being done by USGS in conjunction with DWR wherein samples are taken from a number of sites throughout the south arm within a day or so of each other. These differences are very minor (perhaps within a percent or two) compared to the dramatic differences that currently exist between the north and south arms of the lake (15+ percent).

Gunnison Bay

The salinity of the north arm does not exhibit as direct an inverse relationship with lake elevation as does the south arm. This is because the north arm receives small quantities of fresh surface water inflow and large quantities of salty water inflow from the south arm (Exhibit 3). Evaporation from the surface of the north arm is sufficient to maintain the north-arm salinity at a high concentration. From 1966 until about 1982, the salinity of the north arm remained within the 310-350 grams/liter range (25.7-28.4 percent). Due to this high salinity, a layer of sodium chloride precipitated on the lake's bottom during this time. North-arm salinity dropped to only 160-170 grams/liter in 1987 (14.5-15.3 percent), as evaporation was unable to keep up with increased, dilute inflows from the south arm. Since the high-water years, the north-arm salinity has climbed back into the 290-310 grams/liter range 24.3-25.7 percent or greater (Exhibit 10).

Brine stratification was not present in the north arm of the lake from 1966 until about 1983. When the lake began its rapid rise from about 4200 in 1983 to its historic high of 4211.85 in 1986-87, however, a layer of less-dense brine formed on top of the very-dense north arm brine. This was due to increased precipitation, and the enormous inflow of less-saline, south-arm water as the railroad causeway was breached in August 1984 (see later discussion), and the large, bi-directional exchange of brines between the north and south arms through the breach opening which followed (Exhibit 4). By mid-1991, the level of the lake had dropped below the 4199.5-foot bottom elevation of the breach opening. Because of this, the constant flow of south-arm brine into the upper light-brine layer in the north arm nearly ceased, and the stratified-brine condition in the north arm soon disappeared due to evaporation and vertical mixing.

Net Northward Movement of Dissolved Salts from the South Arm to the North Arm

To help alleviate the flooding of the 1980s, the state implemented two flood-control measures which affected the dissolved-salt distribution and the total salt load within the lake.

Northern Railroad Causeway

In August 1984, the state created a breach in the northern railroad causeway consisting of a 300-foot-long opening near Lakeside (Exhibit 4). At the time the breach was opened, the water elevation of the south arm of the lake was about 3.5 feet higher than the north arm. After the breach was opened, great quantities of less-concentrated south-arm brine flowed northward into the north arm. Within about two months large quantities or dense, north-arm brine began flowing southward into the depths of the south arm as bi-directional flow. As a result of this bi-directional interchange of brine,

Exhibit 10

State of Utah
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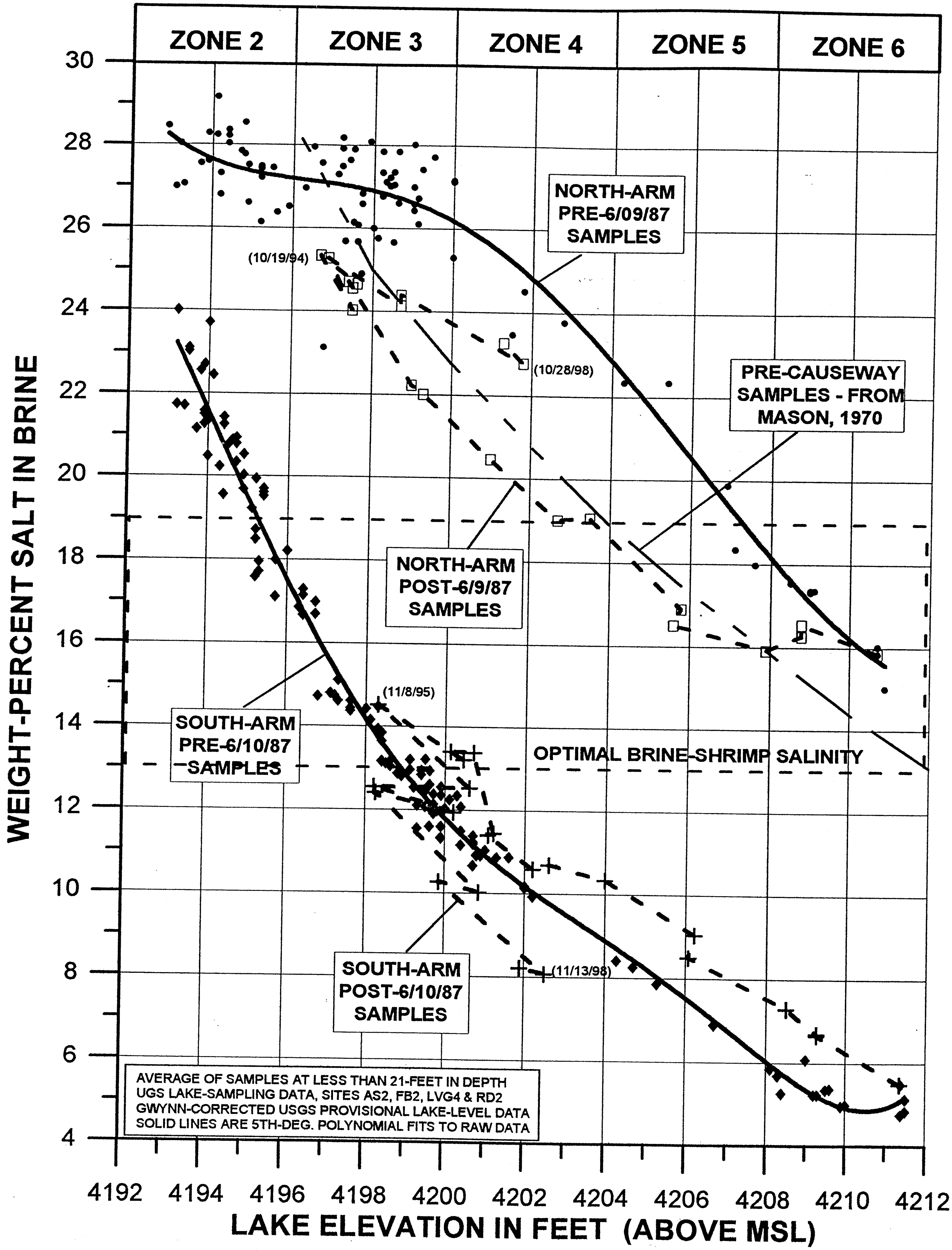

Trends in salinity versus lake elevation for the north and south arms of Great Salt Lake before and after the lake's 1986-1987 high (modified from Gwynn, 1998a).

the south arm density and salt load increased, while those of the north arm decreased. Bi-directional flow continued until the end of 1988 when the lake dropped to the point that return flow through the breach opening ceased. From that time until 1999, flow through the breach opening was mainly south-to-north which has resulted in a decrease in south-arm salt load and an increase in the north arm load. During some summer months, salt has precipitated on the floor of the north arm where it will remain until conditions change and the north-arm salinity decreases.

Early in 1999 there was very little bi-directional flow observed moving through the breach. Later in the year, however, as the level of the lake rose and the head differential across the causeway decreased, deep north-to-south, return flow was observed within the breach opening.

Two box culverts, each approximately 15 feet wide by 20 feet high, were installed when the causeway was built. These openings in the causeway contributed to water circulation and allowed for passage of small boats through the causeway. The culverts have settled as the causeway has settled. With the lake level substantially higher than when the causeway was built and with the settling, the culverts are now completely submerged. Under this circumstance, the culverts are useless for navigation but still contribute to water circulation. The importance of the culverts in the exchange of brine between the north and south arms is well known. At present lake levels, the culverts are at sufficient depth to allow dense north arm brine to flow into the south arm. Maintenance of the culvert openings is difficult because of their depth under water and the fact that they are frequently plugged by .5 to 2-inch gravel transported by storms.

In a recent engineering evaluation by PSOMAS, studies were reviewed that determined the effect of deepening the existing breach opening to 4193 or 4190. The evaluation included open and closed culvert scenarios. PSOMAS also proposed five alternatives as potentially workable solutions to the lack of bi-directional flow in GSL. The USGS water-salt balance model is a very important tool in this endeavor.

West Desert Pumping

The second emergency flood-control measure was implemented after the lake continued to rise, following the opening of the breach in the northern railroad causeway. This measure involved pumping water from the north arm of the lake out into the West Desert to increase the total evaporative surface area and to physically remove water from the lake. To accomplish this, three giant pumps (1,000 cfs each) were installed near Hogup Ridge (about 12 miles west of Lakeside). The water was pumped from Hogup Ridge by way of a 4.1-mile canal to the west desert where it was impounded in a 320,000-acre pond, contained by dikes (Exhibit 6). WDPP was successful in helping to lower the level of the lake from 1987 to 1989, but in the process 600 million tons of crystalline salt, representing 10-14 percent of the total salt-load of the lake, were precipitated and/or deposited on the pond floor when the project was suspended in 1989 (See discussion on "Operating Consequences and Constraints," page 26).

Ion Concentrations in Lake Brines

Unlike the lake's variable salinity (total grams of dissolved salt per liter of solution), its chemical composition (ratio of various dissolved ions to one another) is relatively constant throughout the north and south arms of the lake, and within Bear River and Farmington Bays. This chemical consistency exists because: (1) chemical homogeneity existed throughout the lake prior to the construction of the railroad and other causeways and (2) continual brine mixing, however limited, occurs among all portions of the lake. Slight, long-term changes in ion-ratios have been observed throughout the lake as a whole. Table 3 gives an average chemical composition of the dissolved salts in GSL waters on a dry-weight-percent basis, as contained in the UGS-GSL database. The compositions of typical ocean and Dead Sea waters are given for comparisons.

Table 3. Average chemical composition of the dissolved salts in the waters of GSL, Utah, typical ocean water, and Dead Sea water (dry-weight-percent basis).

Ion	GSL (%)	Ocean (%)	Dead Sea (%)
Sodium	32.1	30.8	12.3
Potassium	2.3	1.1	2.3
Magnesium	3.7	3.7	12.8
Calcium	0.3	1.2	5.2
Chloride	54.0	55.5	67.1
Sulfate	7.6	7.7	0.1
Bicarbonate*	0.62		

* Value from DWQ June 9, 1994 Lab Analysis Report for GSL Brine from UGS Sampling site AS

Table 4. In addition to the main ions listed above, the UGS database includes the three most abundant trace elements: lithium, bromine and boron. The average levels of these elements in the south and north brines are reported as follows in units of (mg/L).

Element	South Arm	North Arm
Lithium	24	45
Bromine	66	121
Boron	21	24

Table 5. The minor trace metals in GSL brines which are included in the DWQ's (June 9 and 22, 1994) Lab Analysis Reports.

Metal	Site AS2 (south arm) g/L	Site LVG4 (north arm) g/L
Arsenic	130	218
Cadmium	<3.0	<11
Chromium	<5	<5
Iron	<220	<220
Silver	<2	<2
Zinc	<330	360
Mercury	<.2	<.2
Barium	180	170
Copper	<220	<220
Lead	<30	<12
Manganese	<55	<55
Selenium	<12	31

(< = less than)

It has been postulated that the absolute quantities of the ions of magnesium, potassium, calcium and sulfates in lake brines is decreasing relative to sodium and chloride. Data collected by UGS since 1966 show a slight decline in the yearly average, south-arm dry weight percentages of magnesium, potassium, calcium and sulfates over time, while sodium and chloride show a slight increase (Gwynn, Work in Progress). During the low surface-elevation stages of the lake, from 1935 to 1945 and from 1959 to the mid-1960s, sodium chloride precipitated in Gilbert and in Gunnison Bays (the south and north arms respectively). Madison (1970) states that salt precipitated at lake elevations below 4195 and Whelan (1973) reports that some 1.21 billion metric tons of sodium chloride precipitated throughout the lake at those low elevations.

While the precipitated salt in the south arm had redissolved by mid-1972, it took until about 1986 before all the salt in the north arm had been redissolved (Wold et al., 1996). In 1992, salt again began to precipitate on the floor of the north arm during the summer months, and it is believed that precipitation continued through 1997. Dry-weight percentages of magnesium, potassium and calcium were increased during historic low lake levels because sodium chloride is the first salt to precipitate as the concentration of lake brine increases. Conversely, the concentrations of magnesium, potassium and calcium are believed to be recently decreasing relative to sodium because of the redissolution of sodium chloride from the lake bed, particularly in the south arm. Notwithstanding slight fluctuations in relative ion ratios in lake water with changes in lake elevation, it is not believed that the overall chemistry of lake brines has changed greatly. It is believed that the lake model currently being verified and calibrated by USGS will provide answers related to the salt-load balance between the two main arms of the lake and change in salinity and chemistry (Appendix G and H).

Accounting for Quantities and Locations of Salts

The location and amount of salts in the open lake are determined through water sampling and modeling (Appendix G). Data on locations and amounts of salts elsewhere are less available. Given recent attention to the salt balance in the lake and emerging disputes over mineral ownership, DFFSL would like to know more about locations and quantities of salts in the system. This information will be useful when considering potential recovery of the economic value of stockpiled and waste salt, and when planning for eventual reclamation.

Nutrient Chemistry

The biological productivity of the GSL is largely determined by the concentrations of plant nutrients in the water. Most often, nitrogen, phosphorous or combinations of these two nutrients control plant growth in freshwater lakes. Bioassay analyses of south-arm water of the lake have indicated that nitrogen concentrations most frequently control phytoplankton growth in the lake (Stephens and Gillespie, 1976). Unlike the conservative major ions discussed previously, the concentrations of nutrients in the lake are more dynamic and controlled both by nutrient loading from tributaries and the atmosphere, as well as hydrological and biotic processes in the lake. Upon entering the lake, dissolved forms of nutrients that limit plant growth will readily be taken up by the phytoplankton passed through the food web and repeatedly recycled until organic matter sedimentation buries it in the lake bottom. Nutrients entering in particulate form may settle out directly and not enter the lake's food web.

Relatively little information is available about the flux of nutrients into the lake and the concentrations present in the water. Studies conducted by Sturm (1980) and Wurtsbaugh (1995) reported high total phosphorus. Sturm (1980) also reported exceedingly high nitrate concentrations while a Wurtsbaugh (1988) study indicated algal nitrogen limitation. This discrepancy may be due to problems with measuring nutrient concentrations in the GSL's brines and/or different years when the measurements were made.

Anthropogenic factors undoubtedly have a large influence on the concentrations and distribution of nutrients in GSL. When tributary waters pass through wetlands prior to entering the lake, substantial portions of the nutrients may be removed (Horne and Goldman, 1994). Because most of the GSL's wetlands have been created or enhanced by diking, this likely results in a substantial loss of nutrients to the lake. Conversely, domestic sewage effluents and agricultural wastes from the watershed are possibly increasing the nutrient loading to the lake. In-lake diking greatly influences the distribution of nutrients.

The Davis County Causeway restricts water exchanges between Farmington Bay and the south arm. Because natural and anthropogenic loading into Farmington Bay is high, it is extremely productive and would be classed as eutrophic (Wurtsbaugh, 1995). Similarly, Bear River Bay receives a large portion of inflowing nutrients from the Bear and Ogden Rivers, but measurements of nutrients and biological productivity have not been made.

The northern railroad causeway influences nutrient distribution in the lake in two ways. As with the conservative major ions, nutrients are transported to the north arm, depleting the more productive south arm. Although limited measurements of nutrients have been made in the north arm, the limited available data (Sturm, 1980) found that nutrients there were often double the concentration of those in the south. However, limited bi-directional flow may also create a trap for nutrients in the south arm.

When dense underflow of highly saline water occurs, this layer does not mix readily with the overlying layer as prior to 1991. Sedimentation of phytoplankton and zooplankton carries nutrients into the deep-brine layer, thus removing them for months to years from the biological cycle. Phosphate, ammonia and total nitrogen and phosphorus concentrations in the deep brine layer were 10-100 times higher than the overlying, less-saline water (Wurtsbaugh and Berry, 1990), but it is not clear to what extent this difference was due to sedimentation of nutrients from the overlying water, and how much was due to the bi-directional flow transporting nutrients back from the north arm.

The amount of nutrient loading for the lake has not been determined. Excessive removal of nutrients would result in decreased brine shrimp and brine fly production and thus impact the bird community reliant on these food resources. Conversely, excessive nutrient loading from sewage and agricultural wastes entering the lake could produce intense and noxious blooms of algae that could be detrimental. The concentration of nutrients in Farmington Bay and the resulting biological production have produced eutrophic conditions that contribute to the odor problems in this area. Other salinity, chemistry and hydrology issues raised by the Scientific Review Committee (SRC) are addressed in Appendix H.

Water - Quality

Much of the earlier work on GSL addresses the water quality of the lake without distinguishing between the lake water's natural chemistry and the presence or absence of introduced contaminants which could affect the biology of the lake or its beneficial uses. The salinity and naturally occurring constituents of the water of GSL are discussed in the section entitled "Water - Chemistry." This section addresses biological and other chemical water constituents, nutrients and the regulation and impacts of introduced contaminants on the GSL system.

As an aquatic system, the function and usefulness of GSL is highly dependent upon the chemistry and quality of the lake water. As a terminal basin, the quality of the water in the lake is highly dependent upon the quality of water currently entering the lake, and upon the quality and nature of past inflows and discharges into the lake. A wide variety of organic and inorganic materials enter the lake by both natural and human-induced causes. The sources of potential lake water contaminants include:

- Surface and groundwater inflows to the lake
- Permitted discharges directly to the lake
- Spills/accidental discharges to the lake
- Lake sediments which contain non-naturally occurring contaminants
- Airborne particulates and precipitants

Because of the lake's high salinity and unique aquatic biology, some contaminants which are of great concern in fresher water systems may not be as problematic in GSL, and some may even help support the aquatic ecosystem. Others may be rendered harmless by the lake water's high salinity, but may become more bioavailable when lake water freshens. Despite a great deal of research on the lake's water chemistry and aquatic organisms, little work has been done directly on the effects of non-natural contaminants on the GSL ecosystem, or on the water quality effects of fluctuations in lake water chemistry.

The "Water Quality" section considers the presence and impacts of lake water constituents other than naturally occurring salts. Internal and external scoping identified five main areas of interest with regard to water quality.

- **Discharges to the lake and watersheds are managed by approval of discharge permits which are determined to be protective of primary and secondary contact recreation, aquatic wildlife and mineral extraction, and by development of non-point source management programs.**

- **The potential for future changes of lake water quality through loss of wetland function, spills or other accidental discharges and nonpoint source management initiatives are not well understood.**

- **The impacts of non-naturally occurring lake water contaminants**

on aquatic wildlife are not well understood.

- **Consider the possibility of establishing a DNR wetland strategy.**
- **Need to improve inter-agency coordination to protect water quality.**

Water Quality Management for Great Salt Lake

The Utah Water Quality Board and DWQ have been charged by the state legislature to maintain, protect and enhance the quality of Utah's surface water and groundwater resources. The statutory authorities of the board and division are located in Chapter 19-5 of the Utah Code. The overall program missions of the board and the division are to protect public health and all beneficial uses of water by maintaining and enhancing the chemical, physical and biological integrity of Utah's waters.

Facilities in Utah that produce, treat, dispose of or otherwise discharge waste water must obtain a discharge permit from the DWQ under the Utah Pollutant Discharge Elimination System (UPDES). UPDES permits are required for all industrial, municipal and federal facilities, except those located on Native American lands. After a discharge application is received, a wasteload evaluation is developed to determine specific discharge limitations, required treatment and monitoring. Each permit includes effluent limitations and requirements for monitoring, reporting and sludge use or disposal requirements. Permit duration is usually five years or less, with provision for renewal.

To establish discharge standards, the Utah Water Quality Board has classified the waters of the state based on their beneficial uses and has defined numerical and narrative standards to those waters to protect beneficial uses. The main water use classes are:

Class 1	Protected for use as a raw water source for domestic water systems.
Class 2	Protected for recreational use and aesthetics.
Class 3	Protected for use by aquatic wildlife.
Class 4	Protected for agriculture uses including irrigation of crops and stock watering.
Class 5	GSL. Protected for primary and secondary contact recreation, aquatic wildlife and mineral extraction.

Most of the main classes are divided into sub-classes which address specific pollutants and beneficial uses. GSL is in its own class (Class 5). Primary and secondary recreation, aquatic wildlife and mineral extraction are the defined beneficial uses of the lake's waters.

Numerical water quality standards have not been established for GSL. According to DEQ, numerical water quality standards may not provide the highest level of protection for GSL resources since dischargers would then be allowed to pollute up to these levels. Industry usually prefers the development of numeric criteria since this provides allowable effluent guidelines. Numerical standards make administration easier but reduce the ability to escalate discharge permit applications on a case-by-case basis. DWQ has established narrative standards for the lake and permits for wastewater discharges are established on a case-by-case basis. Applications for wastewater discharges are reviewed and regulated by the Water Quality Board to prevent the addition of pollutants which would be injurious to the defined uses. The general policy is that, to the extent feasible, no pollutants (discharges) should be delivered to the lake in amounts that result in concentrations greater than those already present in the lake. The Environmental Protection Agency (EPA) has approved DWQ's water quality standards for the lake. Some question if this is an effective policy.

Freshwater habitats are very important in a saline environment and wetlands have limited ability to effectively utilize and remove these nutrients. This is why DNR has recommended additional research and study to evaluate if a problem exists. The nitrogen and phosphorus in sewage effluents are not regulated by DWQ unless it can be shown that they are causing an impairment to the beneficial use in the receiving waters. DWQ has stated that significant cost implications are involved (public and industry) in ensuring the highest level of scientific information as a defensible basis to require nitrogen and phosphorous reduction/removal prior to discharging sewage effluent into the lake.

Dischargers are regulated by state and federal effluent limitations for total suspended solids (TSS), biochemical oxygen demand, coliforms, pH and some metals. A public notice process is followed to allow comment on any concerns.

Numerical standards would allow less flexibility in ensuring water quality protection. The cost and complications associated with attempting to develop numerical standards for a saline lake would first require a clearly identified problem.

Permitted Discharges to Great Salt Lake

Permitted discharges to GSL fall into three major classifications; municipal wastewater treatment facility discharges, mineral extraction facility discharges and other industrial facility discharges. Wastewater treatment facilities typically treat high levels of organic materials, which generate high biological oxygen demand (BOD) and bacteria. Nutrient levels (nitrogen and phosphorus) are also relatively high in these wastewater discharges and can lead to eutrophication in fresh waters. Mineral (salt) extraction industries produce bitterns or residual water from their solar evaporation ponds. These facilities withdraw water from GSL and then use solar evaporation to precipitate various salts from this water. Specific effluent guidelines and standards are applicable to discharges from salt extraction industries. The requirement is that the effluent contain only materials originally present in the intake water. Industrial discharges include effluent from the Kennecott Utah Copper (KUC) concentration and smelting operations and from oil refineries located in the North Salt Lake area. The copper mining and refining operations produce heavy metals, total and suspended solids and petroleum. Discharges from oil refineries have limitations on mass BOD, TSS, oil and grease, phenolic compounds, ammonia, sulfide and chromium.

Jordan Valley Water Conservancy District's (JVWCD) charge is to develop and deliver water supplies to meet growing population water demands. JVWCD anticipates a potential discharge from the treatment of Utah Lake/Jordan River water to meet these demands.

All dischargers, including KUC and oil refineries have specific discharge effluent limits, rigorous monitoring requirements and enforcement measures to ensure compliance. Baseline data collection is another requirement for instream and lake dischargers. If, or when, the state decides that numerical criteria are needed due to an identified problem, agencies and researchers with relevant experience will be involved. A listing of existing permits for discharges to GSL and its near-lake tributaries is in Appendix A.

Potential for Changes to Lake Water Quality

The overall quality of GSL water is good. From a biological standpoint, the lake's aquatic biological system is described as nitrogen-limited. Nitrates and phosphates, which are usually characterized as "pollutants" in freshwater aquatic systems, are almost completely consumed by lake organisms and do not pose problems in the open water of GSL that they otherwise can. In wetlands adjacent to the lake, nutrient loading may be adversely affecting buffering capability. Other factors on and near the lake, such as the wetland-marsh complexes on the east shore of the lake, are thought to be beneficial in "treating" nonpoint sources of potential pollution before they reach the lake. Some potential causes for water quality degradation are emergency spills and accidental discharges on and near the lake, possible contaminants in lake-bottom sediments and pollutants from nonpoint sources near the lake and entering tributaries. Managers do not fully understand how reductions in inflows and other water and land uses will affect population dynamics and species interactions.

Spills/Accidental Discharges

In the past, de-icing fluids at SLCIA have been controlled by disposal to a storm water collection area and then to wastewater treatment facilities. Due to a recent increase in the stringency of de-icing requirements imposed by the Federal Aviation Administration (FAA) regulations, the holding capacity is no longer adequate for proper containment and overloading of local treatment facilities has resulted in operational problems, including accidental discharges. The planned development of a process to recover and recycle glycols (the main component in deicing/anti-icing fluids) to eliminate the overflow discharge of contaminated storm water should be able to handle airport storm water and contaminants of concern. Biomonitoring is required where effluent toxicity is an existing or potential concern. SLCIA is considered a minor facility and its discharge is not likely to be toxic since the deicing/anti-icing diversion/recovery system is fully implemented and will not require biomonitoring.

Minor fuel spills involving less than 25 gallons must be contained by the party causing the spill. In the event that fuel reaches the storm sewer it can be removed by oil/water separators located at the discharge points to the City Drain, Surplus Canal and at the entrance to the aeration lagoon of the storm water pretreatment system. All material entering the storm sewer passes through these separators. Fuel spills greater than 25 gallons must be reported to the fire department, state Health Department, DWQ and the Salt Lake City County Health Department. Upon notification the responsible party will immediately begin containment of the spill and the Airport Authority Operations Division, Maintenance Division and the Airport Environmental Specialist will provide necessary assistance.

Reporting and Cleanup of Spills

With the proximity of large industrial, transportation and sewage treatment facilities to GSL, accidental unpermitted discharges to the lake and the lake environs have occurred in the past and are likely to occur in the future. Emergency spill reporting and response is handled by several agencies with different jurisdictional responsibilities. The unpermitted release of any substance which may pollute surface or ground water must be reported immediately to DEQ, followed by a written report summarizing the incident and remedial actions taken to respond. These include releases greater than 25 gallons of used oil, damaged radiation sources, lost or stolen radioactive materials spills or releases of radioactive materials to the environment or other events causing significant human exposure or property damage. This reporting is required by both state and federal statutes. If an incident involves potential health or environmental effects which require immediate action by local authorities, the local emergency response access number should also be called. Some spills also may require notification of the National Response Center (NRC), depending on the type and amount of the release. In addition, spills, leaks, fires and other events at oil or gas drilling or production facilities must be reported within 24 hours to the Division of Oil, Gas & Mining (DOGM) followed by a written report.

Releases involving oil causing a sheen on surface water, depositing sludge under the surface, or any substance that violates water quality standards must be reported to NRC. Releases to the sewer system in violation of a permit must be reported to the local sewer authority. The U.S. Fish and Wildlife Service (USFWS) receives notification through the NRC when a spill occurs that has implications for protected fish and wildlife resources.

DEQ and the Utah Department of Public Safety require that releases of substances or wastes which could be hazardous to human health or the environment must be cleaned up and the wastes disposed of, in accordance with applicable standards. This requirement includes releases which are below thresholds requiring notification to local, state or federal authorities. The conduct of response and cleanup of spills is governed by contingency plans developed cooperatively among the affected resource management agencies, and depends upon the type, extent and location of the spill. Federal and state agencies respond on site and consult with the on-scene coordinator.

Potential Flood and Drought Impacts on Water Quality

Lake levels above expected highs can adversely affect existing sewage treatment facilities around the lake.

During the flooding in the 1980s, several treatment plants were forced to take steps to protect their facilities from flooding. Substantial costs were incurred to protect facilities, keep them operating and prevent the discharge of millions of gallons of raw sewage into the lake. For example, the dikes of the Perry Lagoons were raised, rip rap was placed on the outside of the dikes to prevent erosion and a pump station was installed. The South Davis Sewer District built dikes around their plant and installed pumping facilities to lift the treated effluent into the lake. Although those protective structures remain in place, lakeside sewage treatment facilities are at risk from high lake levels. Also, some industries adjacent to the lake raised or relocated sediment and waste holding ponds. Magcorp relocated their wastewater holding pond further from the shoreline and put it behind a dike to provide additional protection.

Drought conditions may expose discharge effluent outfalls for longer periods due to low lake level. Effluents may be unable to mix with the lake and therefore expose pollutants to the environment and wildlife.

Lake Bottom Sediment Contaminants

Concerns that potential lake water contaminants may be contained in lake bottom sediments have occurred on several occasions due to past discharges to Farmington Bay, the south shore and other areas of the lake. Several studies have been initiated to determine the levels of heavy metals, organic pesticides, dioxin and furans by DEQ. The USFWS, USGS and Utah State University (USU) have also conducted studies related to lake bottom sediments and water quality (Discussions follow).

Farmington Bay

The Davis County Causeway, constructed in the 1960s, inhibited the free exchange of brines between Farmington Bay and the main arm of GSL, resulting in a gradual freshening of the brines in Farmington Bay. Because of the many years of discharge of untreated sewage into Farmington Bay, concerns emerged in the late 1960s that the freshening of the bay might allow aerobic bacteriological decomposition of organic materials previously "fixed" by the lake water's high salinity. In 1965, the Utah Department of Health reported "...positive evidence of sewage pollution in the [Farmington Bay] lake water to such an extent that bathing should not be approved of in any of these areas for this reason." A study completed in 1971 confirmed organics comprised up to 37 percent of some bottom sediment samples in the south end of the bay, and found unacceptably high counts of *E. coli* and other coliforms at salinities up to 5.5 percent (Carter, 1971). It was subsequently suggested that an accumulated sludge layer in the bottom of Farmington Bay could be a major water quality concern if sediments were disturbed or if the water continued to freshen (DWRe, 1974b).

In 1985, USU conducted an investigation to determine the potential for contamination of Farmington Bay water from bay sediments in different water freshening scenarios. The study suggested the potential for contamination exists in two sediment core samples which contained freshwater soluble heavy metal accumulations. The study also concluded that more information on the potential for release of toxic metals and organic materials should be gathered before any bay freshening proposals should be considered. It was suggested that if the salinity of Farmington Bay were lowered, the "consequences might be dramatic," and result in large algal blooms and resulting odors due to high nutrient levels.

Past sediment surface core sample analyses in Farmington Bay have indicated metal accumulations in bottom sediments. (USU Water Lab, 1988)

Initial results for Farmington Bay show generally low concentrations of contaminants. Lead concentrations peaked at 130 ppm about 1978 and have declined to near 70 ppm in recent years. This is likely due to declining use of leaded gasoline and lead shot for hunting.

South Arm

In 1994, USFWS conducted a limited evaluation of trace elements in brine shrimp and brine flies from the south arm of GSL. The report concluded that some trace elements are elevated to levels of concern and further study was recommended. Currently USFWS is evaluating contaminants including trace elements, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and pesticides in wetlands associated with the lake as well as its tributaries. Although sampling has focused on biota from these areas, some sediment samples have also been collected. This current study is also expanding on the study completed in 1994 to include sediment samples as well as brine shrimp to further characterize contaminants in the food chains of the south arm of the lake.

Bear River Bay

An investigation by USFWS near the BRMBR between 1989-90 discovered no indications of the presence of hazardous materials (DNR, 1995 and Waddell et al., 1990). There is currently underway a National Water Quality Assessment (NAWQA) study to determine trends in water quality using a variety of methods including sediment coring to determine magnitude and trends in contamination. This will be part of a wetlands study of chemical processes, and will include comparisons of sediment core samples taken at Red Butte Reservoir, a protected watershed, Farmington Bay, and Decker Lake, an urban flood control basin, to evaluate and detect peaks in pesticides, heavy metals and selected organics (USGS, 1998). GSL sediment core samples were collected (1995-96) for a global climate study to provide insight into GSL Basin climate changes and evaluate environmental signals which could provide information regarding anthropogenic influences and trends in lake level and climate over time. (USGS, 1999)

South Shore

During 1995, the U.S. Bureau of Reclamation was directed by EPA to conduct a soil and sediment sampling program to determine trace metal concentrations across the mud and alkali flats beach area of the south arm of GSL. The study area was located between Black Rock and the Davis-Salt Lake County line north of the C-7 Ditch and Goggin Drain. This study was a response to concerns regarding the migration of heavy trace metals to the south arm beaches. Other possible sources of heavy metals are the Jordan River and Goggin Drain, which flow through several active and inactive landfills, junk yards and several sewage treatment facilities. The purpose of this sampling program was to identify and determine the extent and the concentrations of heavy metals which might present a hazard to human health and the ecosystem. Arsenic and lead were targeted along with 22 other elements and this group wanted to identify the source of the metals. One hundred and twenty-five locations were sampled in a series of transects across the three main water channels, the C-7 ditch, Lee Creek and the Goggin Drain. The study concluded that concentrations of all contaminants of concern were below levels of biological concern.

Nonpoint Pollution Sources

A major source of pollution to all waters of the state, including GSL, is nonpoint source runoff, primarily from agricultural drainage and urban runoff. Because the lake receives overland flow and inflow from streams and irrigation/drainage ditches in addition to the three major river systems feeding the lake, nonpoint sources of water pollution are significant. Effective management of lake water quality is dependent upon effective nonpoint source management upstream.

In fiscal year 1999, a Phase II stormwater implementation component of the National Pollutant Discharge Elimination System (NPDES) will focus on reducing water pollution from urban runoff. The Total Maximum Daily Load (TMDL) is the quantity of pollutant allowable in a water body to meet water quality standards and avoid impairment of the water body's assigned beneficial uses. When TMDLs are established, the allowable pollutant loads will be allocated among all point and nonpoint sources to the water body in question. DEQ has determined that approximately 467 TMDLs will need to be developed during the next 12 years. Based on the proposed fiscal year 2000 303(d) list, there are 21 stream segments and 12 lakes/reservoirs which need to have TMDLs prepared in the GSL watershed (Pitkin, 2000).

Drinking Water

The Division of Drinking Water, in DEQ, is the state agency responsible for regulating and monitoring drinking water. Future development for drinking water depends on demand, supply, and cost effectiveness. Water uses associated with drinking water development projects could have GSL and tributary water quality implications. The primary responsibility for actions to conserve water and alleviate shortages resides with local government.

Establishment of a Department of Natural Resources' Wetland Strategy

COE regulates placement of fill in jurisdictional wetlands. DNR agencies generally enforce only COE permit requirements when issuing land use authorizations that affect wetlands. DNR is considering establishment of policy that goes beyond COE requirements. This could include actions such as mitigation requirements, grazing, burning, herbicide and pesticide application and actions in non-jurisdictional wetlands.

Inter-agency Coordination to Protect Water Quality

The planning team and DNR would like to improve coordination between local, state and federal entities in protecting water quality. According to statutory code requirements (Utah Code 65A-10-8), DFFSL is responsible to "promote water quality management for the lake and its tributary streams." However, the state's GSL jurisdiction includes below meander line and extends out to other adjacent state lands. DWQ focuses their efforts and resources on high priority streams and waters where the beneficial use is impaired. This is required by law under the *Clean Water Act*.

Protecting GSL water quality and ensuring public trust resource sustainability will require ongoing political support funding and enhanced coordination. DNR will focus resources to improve knowledge of water quality impacts on wildlife and other resources, improve understanding of chemistry and ecology to better understand lake processes and investigate how to define or determine appropriate effluent limits. This will help identify serious problems requiring response (lake and tributaries). Based on water quality monitoring results, DNR will consider GSL public trust beneficial uses and discharge effluent limits implications.

Introduction

Air quality is an important consideration for Wasatch Front residents' quality of life and protection of GSL ecosystem. Air quality degradation has the potential to impair the aesthetic values of this viewshed (sunsets, open spaces). Planners and resource managers have recognized the importance of air quality and pollutant transport along the Wasatch. This section addresses air quality issues and regulations relating to management of the GSL system.

The planning team identified the following resource concerns:

- **Air quality impacts on trust resources are not well understood.**
- **Coordination to protect trust resources is a concern.**

Air Quality Studies

The *GSL Air Basin Wind Study* was conducted by the Wasatch Front Regional Council (WFRC) in 1980 to determine the characteristics of regional wind circulation and its effect on pollution dispersion and transport. This information was combined with results from previous wind studies in developing an air basin concept for air circulation, considering air quality impacts to individual communities and area-wide concentrations along the Wasatch Front. The transport of toxic substances, radiological materials, odor, sound propagation and wind energy were other environmental considerations (WFRC, 1980).

This study concluded that the transport and diffusion of pollutants are severely limited during inversions. Also, pollutants emitted into the lower layers of the atmosphere are not usually dispersed on a daily basis and depend on large-scale weather mechanisms that are much stronger than the diurnal circulation patterns.

This study also developed recommendations for future industrial sites and the transport of toxic substances. The confining terrain, diurnal wind circulation and high inversion frequency requires that industrial sites be very carefully considered in this air basin. The impact of a given industry will depend on the transport properties of its emissions and the dispersion characteristic of the locality. This study also recommended that the use, storage and transport of toxic chemical, biological or radiological substances be carefully monitored since toxicity, dilution and other factors could be distributed easily resulting in a "critical transportation zone." Odors from industrial releases, sewage treatment facilities, wetland areas and decaying organic material in the lake are also easily transported. This study suggested that additional research be conducted on pollutants and their spatial and temporal emissions and completion of an inventory expanding on the existing database and sampling programs. This would include mixing heights and determining if an ozone cell exists to improve understanding of physical air quality systems in this basin (WFRC, 1980).

Existing Regulations

The *Clear Air Act Amendments of 1990* provide the policies regarding areas not currently meeting federal health standards for certain criteria pollutants. They also require that comprehensive state air quality plans be developed that will reduce pollutant concentrations to a safe level. The maximum allowable concentrations set by EPA for the criteria pollutants are known as the National Ambient Air Quality Standards (NAAQS). Areas failing to comply with these standards are considered nonattainment areas and can be classified as marginal, moderate, serious, severe or extreme. An area with a marginal rating will have less time to reach attainment than an extreme classification. Currently, Utah has, or is in the process of writing State Implementation Plans (SIPS) for several nonattainment areas; these include Davis, Salt Lake, Utah and Weber Counties. These counties are nonattainment areas for any single or combination of these pollutants:

Particulate matter (PM10)
Sulfur dioxide (SO_2)
Ozone (O_3)

Each state is responsible for developing plans to demonstrate how those standards will be achieved, maintained and enforced to protect public health, according to the *Clean Air Act* (42 U.S.C. Section 7401) requirements. These requirements set limits for maximum levels of pollutants in outdoor air. The SIPs and associated rules are enforced by the state and are subject to federal approval and compliance. These plans break down specific emission contributions from vehicles, industrial sources and human activities and also provide the framework for each state's program to protect air quality.

Portions of Davis, Salt Lake, Tooele, Utah and Weber Counties have exceeded the health standards for the pollutants CO, O_3, PM10 and SO_2 and Salt Lake, Ogden and Provo/Orem cities are nonattainment areas for carbon monoxide (CO) as shown by air monitoring station data and analysis. Once air quality compliance is accomplished, the implementation plan remains in effect and a maintenance plan is prepared to demonstrate how air quality will be maintained for at least the next 20 years.

Air Quality Monitoring

Twenty-five monitoring stations are strategically located across the Wasatch Front and collect representative data to determine how much of each pollutant is in the air. Air pollutant concentration models are used to assess area pollution levels and provide information for maintaining air quality standards (DEQ, 1999).

DAQ has studied smog and other aspects of air quality for over 30 years. Regional efforts are underway for visibility concerns. National air quality standards are based on human health. There is a considerable level of protection figured into these standards and should simultaneously address wildlife health impacts from an air quality perspective (not a food chain perspective).

DAQ has operated monitoring stations at Magna since 1969 and on the south shore beach since 1981. In 1995, 363 days out of 365 days, SO_2 concentrations were less than 0.04 ppm at Grantsville. A similar level of pollution was recorded for Grantsville over a four-year period.

Due to the 1983-84 flood, the beach monitoring station was relocated south of the freeway overpass near 2100 south. In response to public comments and pollution incident reports, DAQ relocated the monitoring station to GSL Marina (GSLM) three years ago. There has been only one notable accidental release from ruptured duct pipes at KUC. DAQ believes that episodic downwash conditions from the Oquirrh Mountains might contribute to air quality near GSL. DAQ has used a three-hour SO_2 monitoring standard to address this issue. EPA is currently investigating a five-minute standard for SO_2 monitoring standard to address this issue.

Air Quality Concerns

Ozone Formation

Light interacting with chlorine leads to the formation of unstable molecules that can enhance environmental conditions for ozone formation when catalysts are present. Two studies have been completed examining the effects of chlorine emissions (Hov, 1985 and Whitten, Johnson and Killus, 1982).

Chlorine Emissions

Magcorp operates a facility located approximately 60 miles from Salt Lake City on the west side of GSL. This facility emitted about 44,300 tons of chlorine and 440 tons of hydrochloric acid during 1988. However, Magcorp has significantly reduced chlorine emissions over the last ten years and has submitted a notice of intent to install new technology which is expected to reduce emissions by over 95 percent by 2003. An approval order would include monitoring requirements to document reductions and permit compliance. There has been a complete and thorough regulatory net to protect air quality and to dramatically reduce emissions. Stack testing, monitoring stations, health studies, dispersion studies and modeling, ozone and pollution studies have generated a massive amount of data indicating that there is no significant impact to the lake and wildlife.

Dioxin

Dioxin can cause a problem for the environment and wildlife, and DAQ is following up on these concerns. Approximately 19 months ago (November 1998) dioxin was identified in soil samples taken from Magcorp's wastewater ditch and ponds (DEQ, 1998). Dioxin levels in GSL near the waste ponds have been found to be within background levels. Dioxin is restricted to the wastewater ditch, scrubber discharge and from the stack at levels similar to municipal incinerator levels. Under DAQ oversight, Magcorp determined the likely process sources of dioxin and investigated the possible vectors by which dioxin contamination could leave the plant. DAQ did not find any dioxin in any of Magcorp's commercial products and test data confirm that there has been no significant contamination of the lake or the species of the lake. Dioxin levels in sediments from GSL near the plant are less than 50 parts per trillion (ppt), which is the generally agreed upon threshold that would require additional studies. Background levels of dioxin are also present in most soils due to industrial operations, incinerators and diesel engines.

Air Quality and Great Salt Lake Management

Air pollution along the Wasatch Front impacts visibility and GSL. Vehicles, industry and other air emissions are monitored. SIPs and other enforcement measures improve air quality conditions.

Air quality relates to management of the lake when trust resources are at risk or require protection. DEQ is currently (Spring 2000) coordinating with DNR and other state agencies. If contaminants are entering the lake and impacting wildlife or other trust resources, DNR would be interested in actively coordinating with DEQ and other agencies.

Air Quality Monitoring

DAQ will continue monitoring efforts and coordination with DNR. DAQ has considered installing an additional air quality monitoring station pending DNR and DPR approval on the south end of AISP when it becomes a little more developed. This would require an MOU. DAQ also suggested signs located at AISP and GSL Marina to provide a point of contact for air pollution incident reporting when air quality is poor. DAQ suggested that DPR could also help identify conditions that contribute to the problem by logging weather and air pollution information.

Biology

While the term "biology" encompasses all living things, the "Biology" section of the GSL plan focuses on the wildlife species for which DWR is responsible, and on the physical and biological habitats which support those resources. The volume of biological information the planning team identified in its resource inventory is enormous. The team has endeavored to identify and synthesize that information which is relevant to the management responsibilities of DNR. While a great deal is known about many of the species present in the GSL ecosystem, information about many species is not well known, and biological interrelationships and the effects of environmental stressors are not understood in many instances. The lack of information on natural systems was a primary reason for DWR forming the Great Salt Lake Ecosystem Project (GSLEP).

Based on the information received during internal and external scoping, the planning team identified four major areas of management interest and concern:

- **Existing DWR management programs need to be considered.**
- **Changes in lake brine salinities, with corresponding impacts to aquatic and avian populations and ecological interactions on GSL are significant concerns.**
- **Potential for changes in lake water quality and impacts to aquatic and avian wildlife are concerns.**
- **WMAs within the 39 townships identified by the Utah Code for that purpose have indefinite boundaries.**
- **The planning team has identified Ramsar designation as a resource concern in this planning process.**

Introduction

GSL and its environs support a number of diverse plant and animal species in a unique mosaic of upland, wetland, mudflat, river delta, brackish and freshwater marshes, ephemeral ponds and other habitat types. There are 250 species of birds which occur within the GSL ecosystem, of which 83 species are waterbirds that include 23 regularly occurring shorebirds and 11 that are seen occasionally. (Utah Ornithological Society, Bird Records Committee, 1998) GSL environs host 23 species or subspecies of fish which are found in impounded freshwater inflow areas, eight species of amphibians and 64 species or subspecies of mammals. From the federal listing, one threatened species (Bald eagle) and 15 sensitive species (which includes the American pelican and the Long-billed curlew) occur on and around GSL.

At least six uniquely productive wetland and water environments exist in the GSL ecosystems. These systems provide abundant and diverse habitat for the numerous wildlife species that use the lake system. These are:

- Open-water environments of varying salinities
- Island and upland habitats associated with the saline system
- Freshwater lacustrine wetlands associated with river and stream deltas
- Brackish-water areas of fresh and saline water interface
- Spring-fed isolated wetlands
- Mudflat/playa shoreline associated environments

While habitat attention generally focuses on the GSL's wetlands, adjacent upland areas are heavily used by wildlife and provide linking habitat types which create the highly productive marsh ecosystems. Upland areas provide an extraordinary amount of food, opportunities for cover, and buffer wetlands from expanding urban and industrial developments around the south and east sides of the lake. In addition, the lake is tied to the Wasatch Mountains by ribbons of riparian habitat which, in the desert west, are critical migratory and breeding habitats for a wide variety of wildlife, especially neotropical migrant songbirds, raptors and riverine mammals. The latitude of the lake makes it a significant wintering area for a number of species.

International, Hemispheric and National Significance of Great Salt Lake

The GSL wetland ecosystems have been recognized nationally, hemispherically and globally for their importance as a vital link in a migrational corridor for water birds which extends from South America to the Arctic. It has also been designated as a Hemispheric Reserve of the Western Hemispheric Shorebird Reserve Network (WHSRN), and is being considered for nomination by the Ramsar Convention on Wetlands of International Significance for listing.

Ramsar

An international convention was held in Ramsar, Iran, in 1971, to discuss the importance of wetland conservation worldwide. The name Ramsar was derived from the host city. The organizations that formed and support the Ramsar process are: the Asian Wetland Bureau, the International Waterfowl and Wetlands Research Bureau and Wetlands for Americas. The Ramsar Convention provides the framework for international cooperation for the conservation and wise use of wetlands (Ramsar, 1999a).

One outcome of the meeting was a process to offer special recognition to wetlands of international importance that met established criteria. A nomination process was put in place and recognition given to wetlands that qualified. Worldwide there are 113 Contracting Parties that have designated 957 sites for the Ramsar List, covering over 70.4 million hectares of wetlands (Ramsar, 1999c). There are 15 sites in the U.S. that recognize 1,163,690 hectares. Canada has 33 sites with 13,030,568 hectares.

Wetlands are selected on account of their international significance in terms of ecology, botany, zoology, limnology or hydrology (USFWS, 1999a). Ramsar sites meet at least one of the following criteria:

- Exemplify a specific wetland type characteristic of its region

Have special value as habitat for rare, vulnerable, endangered or endemic species or because of the quality and peculiarities of its flora and fauna
Support 20,000 waterfowl or substantial numbers from particular groups of waterfowl, shorebirds or waders indicative of wetland values, productivity or diversity. (Ramsar, 1999b)

The Ramsar Convention contracting parties are encouraged to develop national wetland policies and legislation to protect wetlands in their territory. Four main commitments for contracting parties include:

1. Listed sites. Wetlands are selected based on significancy in terms of ecology, botany, zoology, limnology or hydrology. Contracting parties develop specific criteria and guidelines for identifying sites that qualify for inclusion in the list of Wetlands of International Importance.

2. Wise use. General obligation to include wetland conservation considerations in land-use planning. Steps are taken to implement national planning that promotes the wise use or managing sustainable wetlands.

3. Reserves and training. Contracting parties establish reserves in wetlands whether or not they are on the Ramsar List and they are expected to promote wetland training.

4. International cooperation. Contracting parties consult with each other about implementation in regard to shared water systems, species and wetland linkages. (Ramsar, 1999b)

At least one site is designated for inclusion in the List of Wetlands of International Importance (Ramsar List). Ramsar List acceptance acknowledges the international importance and obliges the contracting party to take all steps necessary to ensure maintenance of the special ecological characteristics of the site, however management remains the responsibility of the contracting party. (Ramsar, 1999c)

According to the Ramsar website, this designation has played an important role in helping to prevent detrimental changes to wetland sites from:

dredging for a marina development in Canada.
mining in South Africa
agricultural development in Hungary (Ramsar, 1998)

Several years ago a nomination process was initiated to designate the lake as a Ramsar site. This was taken before RDCC and the process was tabled. The nomination was made by the National Audubon Society and perhaps others. GSL qualifies for this designation. However the convention also places general obligations on contracting parties relating to the conservation of wetlands and special obligations pertaining to those wetlands which are designated as Ramsar sites (Ramsar, 1999a). The planning team is concerned that this designation may not be compatible with the multiple-use management framework to the extent it can be implemented consistent with the Public Trust Doctrine.. The consequences of this designation and associated obligations could limit the states ability to respond to changing demand for public trust resources. Other Ramsar sites in the U.S. have a clear wildlife and habitat protection management focus. The state has broader management responsibilities, direction and objectives for the lake as a public trust resource.

A similar designation has been given to the lake recognizing its value to shorebirds. The WHSRN recognition carries no regulations or stipulations, simply a special recognition of the significant values.

The WHSRN was formed in 1985 to address serious concerns for shorebird population decline throughout North and South America. This group of government and private agencies is committed to shorebird conservation. The minimum criterion for designation is that the area must support more than 20,000 shorebirds or five percent of a flyway population. This international cooperative program is helping to protect key shorebird sites throughout the hemisphere. There are currently 40 reserves in the WHSRN network. GSL met the criterion for hemispheric reserve designation by supporting at least 500,000 shorebirds annually or 30 percent of the world population of an individual species. This is the highest designation within the WHSRN system. The designation highlights GSL's importance as a migration corridor line for millions of shorebirds. GSL is a significant refueling (feeding) station for shorebirds and, linked with other critical migration sites, forms a chain of such sites from northern breeding grounds in the Canadian Arctic to wintering places on remote coasts and wetlands of South America.

One reason cited for designation as a Hemispheric Reserve is that the 500,000 Wilson's phalaropes known to occur here represent the world's largest known concentration of the species. Wilson's phalaropes fly over 70 hours during their migration. These shorebirds nearly double in weight while feeding at GSL, storing the fat needed for fuel for their long flight.

Other Notable Species

Over 75 percent of the western population of Tundra swans and 25 percent of the continental Pintail population utilize the GSL area. The annual production of breeding waterfowl from the marshes adjacent to the lake is estimated to exceed 750,000 birds.

The largest nesting population of California gulls in the world is located on the lake and its environs. North America's largest staging concentrations of American avocets, Black-necked stilts, and Eared grebes occur at GSL, and the largest breeding population of White-faced ibis occurs in the wetlands around the lake. These are only a few examples of the importance of the lake system in terms of bird use and local, national and international recognition as an important bird area.

The aquaculture industry has spotlighted GSL due to the profitable brine shrimping industry. Brine shrimp *(Artemia*) are harvested, marketed and utilized on five continents. The GSL harvest provides a significant quantity of high quality brine shrimp cysts (also known as eggs) to the international market. Brine shrimp cysts and their nauplii (larval brine shrimp) provide the live feed and protein for marine finfish and crustacean hatcheries around the world. The aquaculture industry is rapidly becoming a primary food source for humans.

Aquatic Biology

GSL aquatic biology has adapted to various saline conditions of GSL ecosystems. The interactions and relationships of the species can be complicated by environmental conditions which are constantly changing in this terminal basin lake. Salinity is a very important factor. The lake has differing characteristics in each of its main bays, but the significant differences are seen contrasting the north arm to the rest of the lake.

The north arm receives limited freshwater inflow relative to the rest of the lake. The northern railroad causeway constructed between Promontory Point and Lakeside effectively separated Gunnison Bay from Gilbert Bay. The salinity of the north arm is significantly higher than the rest of the lake, and is currently close to saturation of sodium chloride. Currently there are six known algal species in this arm. There are few functioning brine shrimp populations in the north arm, and none of significance. Brine shrimp and cysts are washed in from the south arm, but are thought to soon perish due to high salinities. The cysts may persist longer, but may not hatch and grow to adults for the same reason. There may be local sites where freshwater springs discharge into the north arm that allow a small area of the bay to sustain brine shrimp populations because the salinity is locally favorable. As salinities vary, brine shrimp population abundance will change. Relative to the vigorous biota of the south arm, the north arm is comparatively depopulate.

The south arm, Farmington, Ogden and Bear River Bays receive nutrient input from drainages of the GSL watershed. Nutrient data are available for some of these drainages, but the sampling points are located upstream from the freshwater marshes surrounding the lake. The cycling and discharge of the nutrients from these marshes to the lake has not been quantified at this time. The nutrients in the lake water are utilized by algae and bacteria. There are more species of algae and bacteria present in these three bays of the lake than in the very saline north arm. The numbers of species present and their abundance fluctuate with lake salinity.

Algal production in the lake is, however, nitrogen limited (Stephens and Gillespie, 1976 and Wurtsbaugh, 1988), but Wurtsbaugh (1988) found that species (cyanobacteria) that can fix atmospheric N_2 and thus remove nitrogen limitation were limited by phosphorous. Both nitrogen and phosphorous are consequently of importance in regulating algal growth in GSL.

The primary consumers of the bacteria and algae are brine shrimp and two species of brine flies. The biomass of these organisms is significant. Brine shrimp and their eggs are eaten by birds and commercially harvested by humans. Brine flies are eaten by birds and other species in their various life stages. Dead shrimp, flies, algae, other organisms and the waste products from all, in return, are recycled through the system by decomposers as base nutrients.

Bacteria and Algae

There are many species of bacteria that inhabit the waters of GSL. Often, these organisms assist in the decomposition of dead algae, animals and organic wastes entering the lake by stream flow and wind. It was reported in 1966 by Flowers and Evans that GSL hosts eleven species of bacteria that tolerate moderate to high levels of dissolved salt concentrations. The north arm of the lake supports only two known genera of bacteria, *Halobacterium* and *Halococcus*, which are extreme halophiles present in numbers from 1,000,000 to 100,000,000 bacteria per milliliter. A pigment found in these bacteria gives the water in this portion of the lake a rose-purple hue.

Relative to a freshwater lake, there are few species of bacteria and algae that exist in the hypersaline waters of GSL. However, these organisms have the potential under favorable conditions to exist in great numbers and account for a significant amount of biomass. A taxonomic study of the algal flora of the lake was done between November 1975 and July 1978. The flora consisted of four blue-green algae, seven green algae, one dinoflagellate and 17 diatoms species (Felix and Rushforth, 1979). Two species of green algae, *Dunaliella viridis* and *Dunaliella salina* occur in the lake. During the winter months when there are no brine shrimp, these species typically thrive and the lake has a green hue. After brine shrimp populations are established by spring hatching, these species are grazed off. Brine shrimp population numbers cycle over the course of the summer. Low numbers of brine shrimp allow these species to rebound and the lake can again have a green hue. Both of these species rely upon salinity levels of approximately 13-19 percent to reproduce rapidly (Van Auken and McNulty, 1973). Research is being conducted by Dr. Gary Belovsky of USU and GSLEP to further examine habitat parameters and productivity of lake algae. At the time of this writing, the experiments are still in progress.

Diatom species in the lake seem to be more abundant at specific salinities. An abundance of these species gives the lake water a gold hue. Pennate diatoms are oblong in shape and have a silica covering. These diatoms are too large for brine shrimp nauplii to effectively forage upon them (Stephens, 1998). Brine shrimp numbers seem to diminish when the lake is dominated by diatoms. Laboratory experiments at USU demonstrated die offs of brine shrimp in lake water that contained high numbers of diatoms and low numbers of green algae. Shrimp were observed with black spots on their bodies. This occurs when nutrition is poor and the shrimp subsequently are affected by a virus (Belovsky, 1998).

Research must continue to understand the dynamics of algal populations in the lake and how brine shrimp populations relate to the changes in salinity. Brine shrimp populations diminish when salinities are low and evidence thus far suggests that forage is a significant cause. The current salinity levels of the north arm are too high for many species of algae. In a 1975-78 study which found 29 species of algae living in the lake, the authors reported only two in the north arm. "The findings of (their) study reveal that significant alterations have occurred in the algal flora of the GSL since the construction of the Southern Pacific Railroad Causeway (northern railroad causeway). The migration of dissolved minerals from the south arm into the north arm has reduced the salinity in the southern areas of the lake to the point where viable diatom flora and species of algae previously unknown to the lake have become established. Also the abundance and frequency of occurrence of previous reported algal species has been significantly altered" (Felix and Rushforth, 1979).

Brine Shrimp

Brine shrimp (*Artemia franciscana*) are found in all portions of GSL. Their occurrence is related to salinity levels and other environmental conditions. The annual life cycle of brine shrimp begins in early spring. Freshwater inflows to the lake from snowmelt and increasing water temperatures initiate egg (cyst) hatching in late February or early March. Hatching peaks in March or early April. Decreasing lake water salinity from freshwater inflow is an important mechanism in the hatching process. The cysts survive the winter in a semi-dehydrated state. When salinities decline, the cysts rehydrate, causing the shell to swell and crack, which allows the nauplii to emerge. As they mature, brine shrimp molt through as many as 15 different stages before they become adults and begin reproducing.

Brine shrimp reproduce by two methods. During the spring and summer many females give birth to live young that are hatched from eggs within their bodies. The other reproductive mechanism involves the formation of hard-walled eggs (cysts) which are cast into the water by the female. These cysts must then go through a period of dormancy before they hatch. Both of these mechanisms occur throughout the summer, although the birth of live young is more prevalent. In the fall, factors such as the lack of quality food, declining water temperature, decreasing day length and increasing salinity trigger the females to start producing primarily cysts. As many as three generations of shrimp may be produced in GSL during a single growing season. When water temperatures decline below 5º C (42º F), live brine shrimp perish. No adult brine shrimp survive the winter. The population is restarted from the cysts which persisted over winter either in or on the water or deposited on the beaches. As the lake rises in the spring due to inflow, some of the cysts which washed up on the shore during the winter may end up back in the lake.

Commercial harvesting of brine shrimp began in 1950 when adult brine shrimp were harvested for tropical fish food. Several years afterward, cysts were first harvested because they could be dried, packaged, and stored for long periods of time. The eggs could then be hatched as needed. Presently, only cysts are targeted by the harvest operations but there is a small market for the adult brine shrimp bycatch. Most of the harvested cysts are used as hatch out feeds in the aquaculture of shrimp and fish which are reared for human consumption.

Brine Flies

Often considered "noxious and insidious creatures" (Rawley et al., 1974) brine flies are actually harmless, do not bite or transmit disease and are a very important part of the overall ecology of GSL. Brine flies are the primary food source for many species of animals, spiders and birds living around the shores of the lake. A source of amazement is their sheer numbers, reported to be over 370 million flies per mile of sandy beach, for a total of over 110 billion flies plus 10 billion pupae on approximately 300 miles of beaches around GSL.

Brine fly abundance is variable from year to year, and depends upon changes in water chemistry and other environmental conditions. The lake's rise in the 1980s probably resulted in an enormous supply of brine flies when the bullrush was inundated and new pupation sites appeared. Wind direction and velocity seem to have a direct affect on their distribution. Brine fly numbers peak during July and August, and decrease as temperatures begin to drop (Vorhies, 1917).

There are two species of brine flies, *Ephydra gracilis* and the smallest and most abundant, *Ephydra hians*, the alkali fly. Brine flies play an essential role in converting organic material entering the lake into food for wildlife living along the lake's shoreline. By removing over 120,000 tons of organic matter each year from GSL, brine flies consume great quantities of algae, bacteria and organic refuse from brine shrimp and their own life processes. It would require a 78,000,000 gallon per day waste water treatment facility about the size of the Salt Lake City municipal treatment plant to remove this much organic waste from the lake. According to biology professor Dr. Robert N. Winget, "Without brine flies or additional water treatment, lake waters would become cloudy and foul smelling, sands would be clogged with algae and decomposing organic materials, and wild animals of the lake area would be starving."

The life cycle of the brine fly consists of four stages, egg, larva, pupa and adult. Each female lays approximately 75 eggs on the surface of the water or on floating debris consisting of brine fly pupal casings, dead brine shrimp or cysts. The eggs sink to the bottom of the lake before they hatch into larvae. They obtain oxygen from the water by diffusion, and feed on blue-green algae. They become free swimming after emergence, until they find suitable habitat such as algal bioherms or other stationary objects in shallow areas of the lake on which to pupate. Nearly 10 percent of the lake bottom is covered with algal bioherms (Cohenour, 1966).

Larvae and pupae have been found in water depths of between one and 20 feet, and can obtain oxygen from the water by use of tracheal gills located in a long forked anal tube. During warm weather, the larval stage also may pupate on the surface of the lake on floating masses of algae. The pupal cases split open on the back and fully develop into adult flies. Flies emerging from the bottom of the lake float to the surface in a bubble of air. The life cycle can be completed in 21-30 days, and may extend longer during cooler temperatures. Adult brine flies only live 3-4 days. Brine fly populations begin to expand rapidly in numbers during the first of June, and one or two generations of flies reach maturity each year. The flies survive the winter in immature stages.

Corixids

Corixids are small predatory aquatic insects that live in and around the edges of GSL. Their preferred habitat is water with salinity less than six percent along rocky shorelines (Belovsky and Mellison, 1998). Their diet includes, but is not limited to, brine shrimp. These insects have the ability to fly and are observed in the main body of the lake.

Wurtsbaugh (1992), working in Farmington Bay during the 1980s, reported that predation by corixids and copepods on brine shrimp may decrease shrimp population densities. This bay has lower salinity than the main body of the lake due to its being diked and freshwater inputs from the Jordan River. Gliwicz et al., (1995) suggested that similar salinity levels to those observed in Farmington Bay might allow corixids to decrease the brine shrimp population in the south arm of the lake during periods of lower salinity. This has led a brine shrimp harvester to argue that decreasing salinities in the south arm of the lake has led to a decline in brine shrimp populations.

Belovsky and Mellison (1998) have conducted experiments on predation by corixids on brine shrimp. This information, when combined with the corixid densities in the lake reported by Stephens (1998), indicated that corixid predation rate was 1-2 orders of magnitude less than the brine shrimp population growth rate and has negligible impact on the brine shrimp population in the south arm.

Research findings from Farmington Bay (Wurtsbaugh, 1992) are unlikely to apply to the south arm of the lake due to substantially different limnological conditions. If salinity in the south arm remains higher than six percent, conditions for corixids will be poor and their impact on brine shrimp will be negligible. Wurtsbaugh now considers corixid predation unable to decrease brine shrimp populations in the south arm without dramatic declines in salinity. Furthermore, Wurtsbaugh now considers that brine shrimp in Farmington Bay may have been reduced during his study by other factors (e.g. lack of abundance of high nutrition foods for brine shrimp) that were not examined (Belovsky, 1998).

If corixid numbers were to increase to the point of decreasing the shrimp population, there is no known remedy (e.g., insecticides) that would be environmentally acceptable. Current knowledge suggests that corixids do not limit the brine shrimp population in the lake and sampling programs will continue to monitor corixid abundance in the lake as salinity varies.

Fish

The current salinities of the north and south arms of GSL are too saline to support fishes. In shallow water areas near freshwater inflows, fish are also important—mostly carp, but sometimes Utah chub. (BRMBR, unpub. and SRC, 1999c) During high lake elevation cycles, the fishery has been known to persist for several years concurrently. Also, Weber River fish may enter GSL during high lake levels. Both of these bays receive substantial freshwater inputs from the Bear River and the Jordan River, respectively.

During the spring runoff period, fish are carried out into Bear River Bay from the adjacent freshwater marshes and waterways. In addition to carp, the Willard Spur portion of the Bear River now have a population of Gizzard shad, an introduced forage fish to Willard Bay Reservoir, which could have escaped into the Spur. This added fish population may be partly responsible for the increased number of fall staging American white pelicans and other fish eating birds at GSL in recent years. The salinity of this bay is very low. A tongue of saline water flows into the bay through IMC Kalium Ogden Corp.'s (formerly Great Salt Lake Minerals) causeway. This layer of salt water is usually found along the bottom of the bay, and its presence and depth is influenced by south winds and the amount of inflow from the Bear River. There is a layer of fresher water on top of the saline layer. This freshwater can sustain fish populations over time. Fish species in the marshes around the lake have not been extensively studied. Piscivorous bird species such as American white pelicans, Western grebes and Double-crested cormorants use the bay as a foraging area. A strong south wind has the ability to push saline water from the south side of the causeway up into the bay, causing significant fish kills at times.

These fish may be washed out of Bear River Bay into Gilbert Bay of GSL. Dead fish can be preserved to a degree in the saltwater, and are transported around the lake surface by winds and water currents. Observations of these fish in the main body of the lake and/or on the beaches of Fremont, Antelope and other islands leads some people to the assumption there are live fish in the main body of the lake.

Farmington Bay tends to be more saline than Bear River Bay. Salinity is often at 3.5 percent, which is too saline to support freshwater species of fish. The margins of the bay adjacent to the freshwater marsh outflows are sometimes fresh enough to sustain temporary populations of fish and the birds that eat them. However the winds frequently mix the water to the point that the fish cannot survive. Occasionally some fish wash out of Farmington Bay through the Davis County Causeway into the main lake. This phenomenon is not as common as fish from Bear River Bay, because the populations of fish in Farmington Bay are rarely as abundant.

There are times when layers of freshwater may be temporarily found on the surface and periphery of Gilbert Bay and may support fish. When lake levels rose in the mid-1980s, salinities declined to a point allowing fish to exist in shallow areas around the edges of the lake.

Terrestrial Biology

Plants

A great deal of work concerning plant life on the shores of the lake has been conducted by various investigators. (Flowers and Evans, 1966). GSL and its environs have a unique diversity of flora, due to the interface between fresh and saline marshes and soils. Halophytic species are found along and adjacent to the beaches of GSL. Freshwater from streams, drainage ditches and springs leaches some of the salt from the soils near the lake, and allows a greater diversity of plant species in some areas. Such areas are quite extensive in the deltas of the Jordan, Weber, and Bear Rivers, and smaller in other areas due to springs or seepage areas.

Playas are low flat depressions in the valley floor formed by bottom currents of ancient Lake Bonneville in its last stages of recession. The west desert is a vast complex of playas laced with irregular bars and local depressions. Salt-tolerant species found on GSL beaches are also found in some playas, depending upon soils, salt gradients and successional stage. Saline plains or uplands extend beyond the playas and beaches around the lake up to the bases of the mountains. The flora is very diverse and includes herbs and smaller scrubs. Their frequency and location depend on the character of the soil surface and rainfall. Slight depressions usually collect water in the spring and support localized changes in plant life.

Dunes are formed along the eastern shores of the lake and on the plains and foothills bordering the salt desert. Dunes near the lake are composed of white calcareous oolitic sand formed around mineral particles and fecal material. Beach flora is distinct in some areas but in others it is mixed. Vegetation is usually restricted to the upper edge of the shoreline where wave action is less and flooding by brine laden waters is limited in frequency. Mudflats are a special aquatic site and provide important habitat for some wildlife species, such as the Snowy plover, Willet and Long-billed curlew. These areas support pickleweed along the shores of the lake, an important fall and winter forage for geese and other waterfowl.

Vegetation on GSL islands is variable, and ranges from no vegetation to broad diversity on Antelope and Stansbury Islands. Some islands are mere sand bars with little vegetation or cover, some have a considerable amount of vegetation including desert shrubs, and others are quite rocky and devoid of vegetation.

The eastern shoreline of the lake is dominated by wetlands. This narrow strip of vegetation combined with shallow water is important habitat for wildlife and millions of waterfowl, shorebirds and migratory birds. Relatively small changes in lake level inundate or expose large areas of shoreline so lakeshore flora are characterized by multiple successions.

Lake level fluctuations and the shallow gradient of the lake bottom together have a profound affect on the flora and fauna found in this zone of influence. This natural phenomena is critical to maintaining the habitat requirements of many species of birds which inhabit the lake. This mechanism (lake level fluctuation) must be present to maintain this dynamic system.

Around the shores and private lands at the north end of the lake there are extensive stands of sagebrush and this is an important winter grazing area for domestic sheep and deer. Browse-type vegetation located in the Promontory Mountains includes Mountain mahogany, Serviceberry and Bitterbrush, which are valuable to wildlife as food and cover. These areas also have juniper growing on steep and rocky hillsides.

Perennial vegetation consists mainly of grasses and various shrubs such as sagebrush, rabbit brush, greasewood and shadscale, particularly along the west side of the lake. Upland and agricultural areas also provide important wildlife habitat and serve as critical habitat when lake levels are high.

Reptile and Amphibians

Limited work has been done on the amphibians and reptiles in the GSL ecosystem. Eight species of amphibians, two species of turtles, nine species of lizards and eight species of snakes were identified in the biological resource inventory and study at the request of the Utah Legislature prior to 1976 (Rawley et al., 1974). Some of these species occur on the islands in the lake. Locations and records of occurrence can be examined in *The Great Salt Lake Biotic System* (Rawley et al., 1974).

Mammals

A total of 64 species or subspecies of mammals have been identified around the lake and on islands in the main body of the lake. Many of the species are rodents. Other species present include bats, rabbits, porcupines, coyotes, foxes, bobcats, mountain lions and deer. DPR and DWR have established antelope and California bighorn sheep on Antelope Island. Locations and records of occurrence can be examined in *The Great Salt Lake Biotic System* (Rawley et al., 1974).

Birds

Avifauna associated with the lake and its environs are abundant and diverse. Groups include waterbirds, shorebirds and marsh-associated songbirds. Over 250 different species have been identified. Several million birds use the lake area in spring, summer and fall migration. Some unique winter visitors occur in the area including one of the largest concentrations of Bald eagles in the 48 contiguous United States. The lake is of hemispheric importance to many populations of birds.

Waterbirds on Great Salt Lake

GSL has extensive populations of colonial waterbirds. These species can be found on the lands or marshes adjacent to the lake, or on the islands and dikes/causeways within the lake. There are three primary habitat types utilized by these birds for nesting locations: upland/shoreline substrates, emergent vegetation and areas of woody vegetation.

During the years of 1997, 1998 and 1999, GSLEP conducted a lake-wide intensive waterbird survey. It was completed by 90 surveyors collecting information from 47 survey sites. The data from this concentrated effort during spring, summer and early fall provides an impressive picture of the ecosystem's importance to waterbirds. The total number of waterbird observations for the three years — 21,275,169. The survey will continue in 2000 and 2001 (DWR, unpublished, and 1997-1998).

Habitat Relationships

Upland/Shoreline Substrates

Some examples of ground nesters include California gulls, which nest on islands in the lake and on dikes or causeways that transect the lake. Egg Island and dikes at the IMC Kalium Ogden Corp. operation in Bear River Bay are sites for gull colonies. One of the world's largest nesting colonies of White pelicans occurs on Gunnison Island. This extremely remote island provides security from disturbance and predators. The pelicans fly from the island to forage for fish in the freshwater marshes and reservoirs, then return to bring food to their young. Adult pelicans leave the pod between 18-72 hours. Black-necked stilts and American avocets nest on mudflats and playas around the lake. These sites are adjacent to favored shallow water feeding areas. Snowy plovers select playas with little vegetation around the lake for nesting sites.

Emergent Vegetation

Birds which select the interface of open water areas and the beginning of the emergent vegetation (such as bulrush species) of the exterior marshes include

White-faced ibis, Franklin gulls and tern species, which are often found together in nesting colonies around the lake. Eared grebes also utilize this habitat type, although they are not necessarily nesting along with the species previously mentioned. The populations of these species are substantial. As lake level fluctuates, the location of the bulrush-open water interface constantly changes. The dynamic of the GSL shoreline helps to maintain pioneering stages in emergent vegetation types which are important in developing habitat edge and vegetation density. It allows for periodic open mudflats and playas important for certain bird species and breeding sites for invertebrates. Changing habitats are the key to wildlife diversity and abundance in GSL ecosystems.

Woody Vegetation

There is another group of species which utilize a relatively rare habitat type around the lake. This is woody vegetation in the form of trees and large shrubs. These are usually found along the waterways entering the marshes or planted along dikes and uplands by wildlife managers. All of the trees below lake elevation 4212 were killed by salt water and/or flooding during the mid-1980s. Some of the dead trees still persist and new trees have been planted or have naturally re-established. These woody plants are excellent nesting sites for such species as Great Blue herons, Snowy egrets, Black-crowned night herons and Double-crested cormorants. Other species such as raptors utilize these trees as well.

Pelagic Areas

The open or pelagic areas of the lake are very important to many birds. These areas are primarily used for either foraging or resting. Eared grebes and Red-necked phalaropes feed on brine shrimp in the open waters of the lake. Gulls are observed there as well. They feed upon dead brine shrimp and brine flies which collect in windrows (streaks) on open water.

Waterfowl

GSL is located on the eastern edge of the Pacific Flyway. These corridors are the major routes that populations of birds utilize when migrating north and south. These flyways were defined for administrative considerations primarily, not biological, and are utilized in the analysis of bird banding data. It was discovered that birds typically, although not exclusively, migrate in north-south corridors.

Many species of waterfowl have been documented on and around GSL. Over 75 percent of the western population of Tundra swans utilize the lake as a stopover and foraging area during their migration. As many as 60,000 birds have been observed at peak times. They utilize the large lake areas within state WMAs and the BRMBR. Sago pondweed grows in these units and is a preferred forage. Trumpeter swans also occasionally inhabit the area. USFWS and DWR have transplanted Trumpeter swans here from areas where populations have exceeded the food source as a means to broaden their wintering range across the west.

Breeding

A number of breeding ducks use marshes around the lake. The nesting habitat types used range from dry upland areas to emergent marshes (Table 6).

Table 6. Waterfowl Breeding

Species	Breeding pair #
Pintail	2,000
Gadwall	40,000
Cinnamon teal	40,000
Mallard	<65,000
Ruddy duck	15,000
Northern redhead	20,000
Northern shoveler	10,000
Canada geese	2,000

The total number of individuals is double the breeding pair number.

Migration

Waterfowl that are produced elsewhere, typically north of Utah, use marshes and GSL as a stopover point during their migration. Up to five million waterfowl migrate through Utah each year. Large numbers of green-winged teal and pintail use the lake each summer as a key molting area. They fly from other areas and use the large open water portion of the lake for security and foraging. During the waterfowl molt, the birds are flightless for a 3-4 week period. Pintail numbers in late summer historically reached about 1,000,000 birds. This is approximately 25 percent of the continental population of these birds. In the 1990s, pintail populations using GSL reached about 250,000. Green-wing teal numbers peak at 600,000 during the molting and staging period. Populations of the following species also utilize the lake during migration periods and peak at the following levels:

Table 7. Waterfowl Population Numbers

Species	Peak Population
Gadwall	100,000
Cinnamon teal	80,000
Mallard	500,000
Ruddy duck	60,000
Canada geese	50,000
Northern redhead	150,000
Canvasback	50,000
Northern shovelers	100,000

From 7,000 to 11,000 Canada geese annually molt along the west side of Bear River Bay.

Wintering populations of waterfowl are dependent upon habitat and climatic conditions, which change yearly. The amount of water which is not frozen and the availability of food are the primary factors governing abundance of birds during the winter. If the winter is severe and most of the marshes are frozen over and relatively deep snows cover the ground, birds migrate south where more favorable conditions are encountered. Mid-winter numbers of ducks range from 10,000-150,000, depending upon the weather.

DWR participates with other states and USFWS in the management of migrating waterfowl. Management of birds that can move in one day from state to state or even between countries require coordinated management. Utah conducts several bird surveys each year to determine population numbers. These counts are coordinated with other states so a continental population can be determined. For example, all states conduct mid-winter surveys between January 1-15 to establish wintering population data (Table 7).

Habitat Relationships

There are five major habitat types around the lake that are used by waterfowl species.

Uplands

This habitat is found at slightly higher levels than adjacent marshes, and is usually characterized by dry ground and species of grasses, forbs and shrubs that favor this condition. Uplands are the most limited types of habitat around the lake. These are the areas that are best suited to development, farming and other activities of humans. Many waterfowl species prefer to nest in upland sites, then lead their broods to the marshes to rear them.

Freshwater Marsh

There are approximately 400,000 acres of freshwater marsh wetlands around the lake, principally on the east side. The major surface water inflows to the lake run through these areas. Many impoundments have been constructed by DWR, USFWS and private land owners which include duck clubs and the wetlands mitigation sites of KUC and SLCIA. The Nature Conservancy (TNC) and the Utah Reclamation Mitigation and Conservation Commission (URMCC) also own emergent marsh wetlands. These areas are principally impounded water which support plants including bulrush and cattail. Other land types associated with this habitat include small ponds found within the emergent vegetation and large bodies of water where depth precludes the establishment of these species. Dikes and small islands are also found in these marshes. They are particularly important as nesting and resting sites because, as water levels change, they usually stay dry.

Mudflats and Playas

This major habitat type around the lake is characterized by a very low gradient. As the lake level fluctuates these areas become inundated and then dry out. The water levels can change due to runoff or winds. The lake is so wide and shallow that, as the wind blows across it, water is pushed to the windward side increasing water levels one foot or more due to this tide-like phenomenon. Precipitation or snow melt can also fill low spots in these areas, creating ephemeral pools which are excellent sites for invertebrates. The vegetation on mudflats and playas is often sparse and composed of plant species that are tolerant to high salinities. These include salt grass and pickleweed. Mudflats and playas are important to waterfowl for feeding and resting. Lack of vegetation provides visual security from predators.

Brackish-Water

These areas are located where the freshwater from the marshes flows into the saline water of GSL. The resultant mixing of the waters provides a range of salinities that allow a diverse groups of plants, invertebrates and sometimes fishes to exist. Water depths are often shallow and birds use these areas extensively for feeding.

Open Water or Pelagic

The main area of the lake provides this habitat type. When the surface water is relatively calm, huge numbers of waterfowl raft in these areas. Isolation from disturbance makes these open water areas attractive to birds. Open water areas also provide important foraging habitat for birds which eat brine shrimp, brine shrimp eggs, brine flies and algae. Brine flies are found on pieces of debris, vegetation, and brine shrimp cysts floating on the lake surface. Huge flocks of green-winged teal, Goldeneyes and Northern shovelers have been observed on the lake, presumably feeding on these resources, however research needs to document this information. During the winter there are other species of maritime waterfowl that are occasionally observed on these expansive open waters. These species include Oldsquaws and Scoters. Gulls and phalaropes also use open water areas.

Shorebirds

GSL has one of the largest shorebird concentrations in the world. Over 35 species of shorebirds are found in the Western Hemisphere (Sorensen, 1997). Many of these visit GSL each year and commonly include American avocet, Black-necked stilt and Killdeer.

Many of these birds undertake extraordinary migrations with some birds traveling up to 2,000-3,000 miles. Over 50 percent of the world population of Wilson's phalaropes (500,000), the largest staging population in the world, depends on GSL. The largest population of American avocets (250,000) and Black-necked stilts (65,000) in the Pacific flyway, and over 10 percent of all Red-necked phalaropes (280,000) stop over on GSL. The lake also hosts the world's largest assemblage of Snowy plovers (10,000), and the only inland staging area for Marbled godwits (30,000) in the interior of the United States. Observations of over 30,000 Long-billed dowitchers have been made on a single occasion.

The GSLEP has cooperated in the development of a national shorebird management plan. A local shorebird plan is being developed to help guide management of these birds around the lake. A working group comprised of government and non-government stakeholders is developing a GSL Shorebird Plan. This effort complements the national shorebird planning effort but focuses on the unique conditions and needs of GSL shorebird habitats and conservation.

Habitat Relationships

The most significant aspect of the GSL ecosystems is the great diversity of habitats created from the integration or close association of fresh and salt water systems which create a fluctuating "mosaic" of land forms, vegetative cover, water and salinity. Several habitat types, natural and human-made, are described below to illustrate the importance of each micro-habitat. Management and conservation efforts must consider each habitat type and the species that frequent these areas.

Estuaries

Fresh and salt water interfaces are created where freshwater enters directly into the lake such as the outflows of several small streams along the east shore. These areas provide important foraging areas for breeding, brooding, and staging shorebirds. These areas also remain ice-free in winter and provide habitat for waterfowl.

Playas/Ephemeral Pools

Salt playas, mudflats and other lake interfaces occur at numerous locations throughout the extremely shallow, low gradient GSL Basin. These environments shift seasonally and with lake level fluctuations. These areas are critical to Snowy plovers for nesting and provide foraging and staging areas for numerous shorebirds, including tens of thousands of Avocets and Stilts. The associated shoreline supports a robust population of brine flies which is a significant avian food source. The transitory nature of this habitat type introduces a constant dynamic state so that emergent vegetative stands are constantly shifting between early and late seral stages as the water levels advance and recede. A rich mosaic pattern of habitat types is the result. Some examples include Farmington Bay, Howard Slough and the areas west of existing WMAs and TNC's Layton Wetlands Preserve. There are numerous ephemeral pools that are associated with the mudflats and playas. They are resultant of slight changes in topography and precipitation, overland flow (runoff), wind tides from the main lake and receding lake levels. Small pools create critical habitats for waterfowl and shorebirds and create unique places for food production for invertebrates and vegetation species.

Salinity Variations

Salinity varies around the main body of the lake due to geographic location, basin configuration, geology and the presence of human-made structures. A variety of plants (halophytes) and animals (halophile) including invertebrates are dependent on these differing saline habitats. Each species has an optimum range of preferred salinity levels, and this wide spectrum of salinities provides unique and critical habitat for wildlife. Brine shrimp play a significant role in the GSL ecosystems and, along with brine flies, are the keystone species supporting many of the water and shorebird species that frequent the lake. A primary reason for the hemispherically important bird numbers at GSL is the lake's capacity to produce millions of pounds of easily foraged protein at the appropriate times for staging and molting migratory birds.

Generally, the north arm (Gunnison Bay) is extremely saline and only supports brine shrimp when the lake is at very high elevations. The north and west shorelines of the lake are important to wildlife there. The west and south shores are moderately saline, and support brine shrimp at high to average lake elevations. The northeast, east and southeast sides of the lake are less saline and support brine shrimp and other invertebrates during average and lower lake elevation years. These open lake and littoral zones are exceptionally important to phalaropes, Franklin and California gulls and Eared grebes. The east shore of the lake has many productive habitats due to the freshwater deltas of the Jordan, Weber and Bear Rivers, and numerous smaller Wasatch Front streams. The water from all these drainages has been totally or partially diverted through natural or managed wetlands adjacent to the lake. The historic Jordan and the Weber River Deltas have been abandoned and receive little or no natural flow. These are very productive areas for waterfowl, colonial nesters and many shorebirds, including Dowitchers, Yellowlegs, Godwits, Avocets and Stilts.

During the high lake years of the 1980s, the north arm provided the only substantial habitat for pelagically active

Eared-grebes, Wilson's and Red-necked phalaropes that occurred within the GSL ecosystem. This condition occurred because of the reduced salinity which, in turn, improved conditions for brine shrimp and brine fly survival.

Great Salt Lake Wetlands

GSL wetlands consist of a mosaic of habitat types including emergent marshes, playas and wet meadows. Wetlands around the lake are unique in North America because they cover a large expanse of inland alkaline and saline wetlands located in a cold desert. Approximately 400,000 acres of wetlands (at 4202 lake level) exist near the shores of GSL, which represents almost 75 percent of all the wetlands in Utah. GSL wetlands provide a variety of functions, including wildlife habitat, water quality enhancement, aquifer discharge, temporary water storage and nutrient cycling.

Managed Wetlands

Managed wetlands have created unique habitats with dikes, levies, headgate systems and diversion structures. These systems enhance the opportunities for active management by changing water depths, temperature and water dispersion patterns and by controlling nutrient flows over time. These managed wetland areas accommodate seasonal use and the needs of migrating and breeding water birds. Significant production of waterfowl also occurs in these areas.

Avian Surveys, Studies and Information

GSL is the largest permanent saline lake in the U.S. and is a critical habitat area for birds. There are many bird surveys conducted on and around GSL to answer specific questions such as total numbers present, peak season use, species use and habitat relationships. A waterbird survey conducted by DWR GSLEP is the most extensive to date. Approximately 90 volunteers assisted with the count. It began in 1997 and is projected to continue until 2001. The count examines total number of waterbirds over time and relates this data to habitats.

In addition, there is an enormous amount of information and research (published and non-published) available on the flora and fauna of GSL. A literature search has been completed by USU and GSLEP. The project searched for research papers on brine shrimp in natural systems, limnology of saline lakes, avifauna ecology of hypersaline lakes in the Western Hemisphere and research on GSL. A bibliography is will be available at the DNR Bookstore.

The Utah Natural Heritage Program is a central repository for information about Utah's biodiversity including animal and plant communities. This program was initiated by TNC in 1988. The program was transferred to the state in 1991 and is currently partially funded by DWR. The program's mission is to collect information about Utah species and plant communities in a standardized and easily retrievable way and provide this information for natural resource management decision-makers.

The Utah GAP analysis program is comprised of a geographic information system (GIS) that includes map layers of habitat types, vegetation, wildlife distribution and other resources. This information can be utilized to investigate spatial relationships of resources and to track changes or trends in wildlife distribution and habitat utilization. Many master's and doctoral dissertations have been completed on the ecology of GSL and are kept at the universities where the research was originally funded. These publications will be cited in the bibliography prepared by DWR and USU. Recently completed and ongoing research includes the following efforts:

Periodic Waterfowl Surveys on State WMAs (DWR)

Pacific Flyway Shorebird Project (Point Reyes Bird Observatory)
Bear River Migratory Bird Refuge Bird Abundance Surveys (USFWS)
Canada Goose Banding (DWR)
Pacific Flyway Duck Banding (DWR)
Great Salt Lake Botulism Study (USU)
Mechanisms for coexistence of two swan species at varying spatial scales (USU)
Interactive pathways in wetland ecosystems (USU)
Restoring breeding bird population to Bear River Migratory Bird Refuge (USU)
Brine Shrimp Population Dynamics (USU)
Brine Shrimp Populations and Lake Limnology (DWR & USGS)
Salinity Model/Patterns in the GSL (USGS, DNR, Tooele County)
Bioenergetics of the eared grebe (DWR, USU)
Population Status of the eared grebe (DWR)
Water Quality and Contaminant Research (USFWS & FFSL)
Food Chain Ecology on the Great Salt Lake (USU)
Mid-Winter Eagle Count
Snowy Plover Surveys (1996-Weekly/Summer; American Birding Association)
Spatial/Temporal Avian Census of the Great Salt Lake (DWR and cooperators)
Brine Shrimp Population and Harvest Census (DWR)
Brine Shrimp Ecology of Great Salt Lake Beaches (DWR)

A significant local effort is the National Audubon Society's *Feasibility Study for the South Shore Wetlands Ecological Reserve of the Great Salt Lake* (1995). This was an investigation of the potential of restoring the natural inflow of freshwater to the prehistoric river channel and delta of the Jordan River. The results of this study indicated that a state of the art ecosystem wetland habitat restoration effort would have a high likelihood of success. This is one example of an effort focusing on improving habitat for waterfowl, shorebirds and other water birds.

Research

As mentioned previously, in July 1996, DWR formed GSLEP. The purpose of this project is to exclusively dedicate personnel to research and management of the GSL ecosystems, focusing on the relationships of aquatic species of the lake to resident and migratory birds. As implementation of the project began, it became apparent that no one had previously attempted to manage a naturally occurring brine shrimp population or the bird populations that rely upon it. Therefore, the methodologies and techniques had to be developed for the first time to gain the necessary data.

GSLEP is staffed by the project leader, an aquatic biologist, a wildlife biologist, a wildlife technician and various biological aides hired seasonally. Law enforcement officers conduct field operations during the harvesting season and at other times as necessary to regulate the brine shrimp harvesters.

To address the broad ecological questions necessary for management of the ecosystem, DWR has contracted with a number of researchers. Dr. Gary Belovsky of the Department of Fisheries and Wildlife and Ecology Center at USU was contracted to research factors influencing the dynamics of the brine shrimp population and develop a population model. A preliminary model was developed using available data from the lake and pertinent literature. Model components included primary and secondary production in the lake as it influences the brine shrimp population dynamics and standing crop of shrimp, rate of shrimp consumption by harvesters and birds and the cycling of nutrients back to the system. Values from the literature were used in place of available GSL data when appropriate, however in many instances, no literature values were available for the required parameters. Many of the research endeavors of the GSLEP are targeted at these deficiencies. From the model, annual shrimp production in the lake, amount of forage required by the birds, quantity of cysts harvested and the amount of cysts that are needed to restart the population the following spring can be predicted.

Other brine shrimp related research projects currently underway at USU include determining the overwinter mortality of cysts within the lake, and a study of corixid predation on brine shrimp.

A research project on Eared grebe-brine shrimp interactions is underway. Dr. Michael Conover of USU is the contracted researcher. This research is geared toward understanding their reliance on brine shrimp as a food source. Eared-grebe reliance relates to brine shrimp densities, grebe energetics and other issues.

Dr. Doyle Stephens of USGS has been contracted to conduct field sampling of sites in the south arm of GSL and conduct laboratory analysis of these samples. This information will be input to the management population dynamics model developed by Dr. Belovsky.

In addition to this work, DWR and DFFSL have joined with other cooperators in funding data collection by USGS necessary to refine an existing water and salt balance model which predicts the transport of salts between the north and south arms of the lake (Appendix G). During the GSL planning effort, USGS was contracted to conduct a bathymetric study of the lakebottom topography near the northern railroad causeway culverts.

Dr. Susan Kilham, a noted diatom researcher from Drexel University, Pennsylvania, will be conducting a one-year sabbatical study on diatoms in GSL. It is hoped that this research will provide insights into the factors controlling algal community shifts within the lake.

GSLEP personnel are also conducting research that will assist with management directly or enable future inputs to the brine shrimp model. Some of the objectives of project research include:

- Conducting waterbird counts and determining seasonal use.
- Understanding the role of brine shrimp cysts in the diet of wintering ducks.
- Developing sampling techniques to quantify floating cyst streaks.
- Learning more about brine shrimp biology in the lake.
- Understanding the relevance of salinity to cyst characteristics.
- Understanding brine shrimp and algal population changes as they relate to salinity.
- Understanding brine shrimp cyst mortality in the lake over time.

An avian census program has been conducted for two years with the assistance of many volunteers. The objective of this research is to quantify timing and magnitude of bird use in various habitats around the south arm of the lake, Bear River Bay and Farmington Bay. This information will be critical input to the brine shrimp population model in understanding the needs of birds as they relate to brine shrimp. Other bird conservation needs will also be addressed. Additional work is underway with bird banding, specific grebe research and conservation planning. A Snowy plover research effort was partially supported by DWR in 1997. Study results indicate that Snowy plover population numbers were relatively unchanged from the initial study.

Existing Division of Wildlife Resources Management Programs

Functions of Division of Wildlife Resources and Wildlife Board

DWR has jurisdictional responsibility for all wildlife in the state pursuant to Section 23-15-2 of the Utah Code, which provides;

> "All wildlife within this state, including but not limited to wildlife on public or private land or in public or private waters within this state, shall fall within the jurisdiction of the Division of Wildlife Resources."

The division is "appointed as the trustee and custodian of protected wildlife..." and, subject to the broad policy making authority of the Wildlife Board, the division's responsibilities are to, "protect, propagate, manage, conserve, and distribute protected wildlife throughout the state" (Utah Code 23-14-1(2)).

The Wildlife Board's responsibility is to, "...establish the policies best designed to accomplish the purposes, and fulfill the intent of all laws pertaining to wildlife and the preservation, protection, conservation, perpetuation, introduction, and management of wildlife." The Wildlife Board relies on the division's determinations of fact, and on the recommendations of the Regional Advisory Councils (RACs) established under Section 23-14-2.6 of the Utah Code. Under Utah law, five RACs conduct hearings to collect public input, gather information from division staff, the public and government agencies and make recommendations to the Wildlife Board in an advisory capacity.

On and near GSL, DWR's responsibilities include: research on and management of wildlife species, regulation of hunting, regulation of commercial brine shrimping, management of state WMAs, cooperative management of Antelope Island's large ungulates with DPR, cooperation with USFWS in the management and research of migrating birds and cooperation with non-governmental and other governmental agencies in the conservation of wildlife habitats.

Great Salt Lake Waterfowl Management Areas

There are eight DWR WMAs on GSL. Six are located along the shoreline of the lake, and include Farmington Bay, Howard Slough, Ogden Bay, Harold Crane, Locomotive Springs and Timpie Springs (Exhibit 1). The others are within 10 miles of the lake and have a direct association with the lake environs. Salt Creek WMA, Bear River Access and Willard Bay are examples. A total of 87,244 acres are intensively managed by DWR. Some acres are managed under cooperative agreements with other state and federal agencies, such as DFFSL and BLM. Utah Code Section 23-21-5 identifies approximately 150,000 additional acres in the lake area which are authorized for administration by DWR for hunting, fishing and wildlife management purposes.

DWR is in the process of developing a habitat management plan for each management area. These plans describe each area, identify capital improvement needs and describe generalized management activities associated with identified goals and objectives.

General management actions include wildlife habitat enhancement through water control, agricultural practices, population monitoring, law enforcement, education and information sharing to support and build an appreciation for wildlife, habitat, wetlands, wildlife management and conservation.

WMAs can be affected by high lake water levels and have many common management issues and concerns. Important issues include securing future water supplies, access management, balancing the needs of user groups, funding to operate and maintain facilities, urban changes in the GSL flood plain, flooding of lower tributaries, water pollution, siltation and invasion of plant species such as Phragmites, Tamarisk and Purple loosestrife.

Acreages of different types of habitats were extracted from "*Evaluation of Existing Wetland Habitats in Utah*" (Jensen, 1974). The lake elevation was 4201 when this study was completed. The intent of stating acreages is to give the reader a sense of marsh habitat relationships. These figures have changed over time due to lake changes.

For ATV use and other WMA restrictions, refer to the current waterfowl hunting proclamation.

Farmington Bay Waterfowl Management Area

Farmington Bay WMA is located west of Interstate 15 between Centerville and Farmington. This area can easily be accessed from Glovers Lane west of the interstate and south along the access road. Duck clubs, city, county and private property outline the perimeter of the WMA. Farmington Bay is one of the most popular waterfowl hunting areas in Utah and also is an outstanding birding area. It is unique in that it provides important wetland and wildlife habitat based recreation close to an urban area. This 17,916 acre management area is one of the best places to observe the freshwater interface with GSL. The Jordan River is the primary water source for Farmington Bay. This area is managed primarily to provide habitat for water-dependent birds.

Farmington Bay has sufficient water rights. To protect their water rights from the potential of non-use forfeiture during the flood years, DWR filed Requests for "Extension of Time in Which to Submit Proof of Appropriation" on their uncertificated water rights and "Non-Use Applications" on their certificated water rights. Reestablishment of those water rights requires the submission of Proof of Appropriation for the uncertificated water rights and Proof of Resumption of Use for the certificated water rights by early 2000. DWR is currently preparing those proofs for submission to the State Engineer using funding obtained through the "Habitat Authorization" process.

The Farmington Bay WMA was constructed in 1935 to provide habitat for nesting and migratory waterfowl. It includes 12,000 acres impounded by dikes and another 15,000 acres of natural estuary wetlands. Habitat types include:

4,301 acres open water	6,277 acres marsh
6,174 acres mudflats	600 acres uplands

Farmington Bay WMA provides opportunities for hunting, bird watching, photography, nature study, hiking, biking and air boating. Currently, DWR is pursuing funding for enhanced visitor use development, which includes a visitor center on the north end of the management area to improve interpretive and education efforts.

WMA dikes and water control structures around GSL are impacted by natural lake level fluctuations. The outer dikes have top elevations varying between 4204 and 4208. At lake level elevations above 4204, the WMA loses the ability to impound shallow water. Farmington Bay dikes were designed to impound and spread shallow water at a lake level elevation of 4198. Lake level elevations higher than 4198 reduce management efficiency and increase loss of habitat units. At 4206, nearly 80 percent of this WMA is inundated, and above 4210 all created habitats are lost. Flooding impacts to the interior marshes occur incrementally between 4201 and 4212.

Birds relocate when lake level fluctuations inundate suitable habitat areas around GSL. In response to this natural dynamic, DWR has designed portable structures for walk ways, restrooms and office facilities. Approximately one million dollars was required to repair damages from the 1980s flooding event. The most significant management issue at Farmington Bay is future water quality and supply. Other important issues include providing additional access and balancing diverse user groups. Expansion of the Farmington Bay WMA has been discussed, but there appears to be a limited number of willing sellers from which to acquire additional property.

Harold Crane Waterfowl Management Area

Harold Crane WMA is located on the south-west corner of Willard Bay

Reservoir, and is approximately 11,300 acres of the following habitat types:

2,905 acres open water	3,805 acres marsh
3,210 acres mudflats	1,380 acres uplands

According to engineering data, lake flooding over the dikes occurs at elevations between 4207-4210. However, in the spring of 1999, some flooding damage did occur at locations below 4207.

This area was constructed in 1964 as mitigation for wetlands lost due to the construction of Willard Bay Reservoir. Additional lands acquired in 1990 doubled its size. Foot access is permitted between September 1 and March 1. The gate is open to vehicles and small boats during hunting season, but closed to motorized vehicles and boats the rest of the year. The area is closed from March 1 to September 1 during the bird nesting season.

Howard Slough Waterfowl Management Area

This WMA is located two miles west and one mile south of Hooper in Davis County. Howard Slough was established in 1958 to create wetlands from irrigation return flows before they entered the lake. This development was the first major wetland project along GSL in over 20 years and a subsequent 1990 expansion was Utah's first *North American Waterfowl Management Plan* cooperative acquisition. Major redesigning and restoration occurred at this time.

This area includes a total of 3,420 acres of the following habitat types:

600 acres open water	1,800 acres marsh
631 acres mudflats	389 acres uplands

According to engineering data, lake flooding over the dikes occurs at elevations between 4206-4208. However, flooding occurred at points along the dike in the spring of 1999 when lake elevations exceeded 4203.

Ogden Bay Waterfowl Management Area

Ogden Bay WMA is located on the Weber River delta of GSL, and, at over 21,000 acres, is the largest state waterfowl management area in Utah. The northwestern boundaries are indefinite. Land acquisition and development of Ogden Bay WMA started in 1937 with a cooperative project between DWR, Weber County Wildlife Federation, USFWS and the Civilian Conservation Corps. In 1938, following the passage of the *Pittman-Robertson Act*, Ogden Bay became the nation's first Federal Aid to Wildlife restoration project. It is located two miles west and one mile north of Hooper in Davis and Weber Counties. Ogden Bay WMA contains the following habitat types (acreage numbers are estimated):

4,998 acres open water	4,780 acres marsh
5,182 acres mudflats	3,800 acres uplands

Ogden Bay WMA is also known for wildlife-related recreation on GSL. During the production period, March 1 through August 1, approximately 15 miles of dikes are open to non-motorized use. Throughout the rest of the year, 45 miles of dikes are open to non-motorized use. Several air boat ramps and parking areas are available for public use at various lake levels during the hunting season. Ogden Bay WMA has approximately 70,000 visitors each year, 28,000 of which are waterfowl hunters and the rest are other wildlife enthusiasts. The most popular activities include wildlife watching and waterfowl hunting.

Ogden Bay WMA's wetland resource values are dependent on the water levels of GSL. A series of boat ramps which are useable at various lake levels improve access. Wetland habitat, wildlife use and public recreation opportunities are greatly reduced at high lake level elevations. During the 1980s flooding, wildlife and human use decreased by over 90 percent. Lake level begins to affect Ogden Bay WMA dikes at a lake level elevation of 4203, which occurred in 1998. Other dike elevations range from 4205-4212, with upland areas at an elevation of 4220. More than 80 percent of the area is flooded at a lake elevation of 4211. Flood damages to the diking system were close to $150,000 in the 1980s.

Important issues for Howard Slough and Ogden Bay WMAs include vulnerability to flooding from the Weber River and GSL. Other management issues include additional access for air boats, visitor conflicts, water quality and high levels of sediment entering via the Weber River. The water rights are sufficient since this is one of the oldest WMAs in Utah. Another concern is diminishing agricultural habitat and food sources for White-faced ibis, waterfowl and other agriculturally-dependent species due to residential housing development on the periphery of the management area.

Timpie Springs Waterfowl Management Area

Timpie Springs WMA is located one mile north of I-80 at Rowley Junction, 15 miles northwest of Grantsville in Tooele County. This WMA is comprised of 1,440 acres. The water source is a saline spring which feeds two water impoundments created by 3.5 miles of dike. The salinity of the water source limits the vegetation of the area to salt grass. Waterfowl, waterbirds and shorebirds utilize this area. It is important because there are few significant marshes and sources of fresher water around the southwest quadrant of the lake. Bass and mosquito fish may be found in the springs. There is a half-mile long road that provides access to the area from I-80. This road terminates in a parking lot where there are informational signs. Timpie Springs has approximately 400 annual visitors, of which approximately 300 are waterfowl hunters. Walking access to the area is available all year from the parking lot. Habitat types include:

350 acres open water	400 acres marsh
390 acres mudflats	300 acres uplands

Locomotive Springs Waterfowl Management Area

Locomotive Springs WMA is an isolated, spring-fed wetland located at the north end of GSL, east of Kelton. This 17,317 acre WMA is supported by six springs and provides a much needed oasis for wildlife in the middle of the west desert. Habitat types include the following:

1,370 acres open water	3,250 acres marsh
9,077 acres mudflats	1,455 acres uplands

The Civilian Conservation Corps created the Locomotive Springs WMA in 1931. DWR plans to expand the WMA by 2,600 acres to include protection of playas which are Snowy plover habitat. Wildlife viewing activities include some passerine and scrubland bird species. This WMA is open to public use during waterfowl hunting season, however access is allowed year round at the six springs. Vehicular use is restricted beyond designated parking areas. Bird watching, fishing and primitive camping are allowed year round. The entire WMA is accessible during hunting season. Locomotive Springs receives approximately 6,000 visitors a year, 5,000 of which enjoy hunting and fishing.

The most significant issue facing Locomotive Springs is maintaining water flow from the springs throughout the year. Since the early 1970s the spring flow has declined by 67 percent. This has resulted in diminishing wetlands by 5,000 acres in this WMA. Diminished flows have also resulted in higher salinities in the impounded waters of the marsh which affects vegetation.

Other Important State-Operated Wildlife Management Areas

Other WMAs located beyond the meander line of GSL provide a variety of different habitat types for many species that depend upon the GSL ecosystem. These areas are directly associated with the lake environs and become critically important when high lake levels inundate otherwise available habitats at lower elevations.

Public Shooting Grounds Waterfowl Management Area

Public Shooting Grounds WMA was perhaps the first area in the nation set aside specifically for hunting when it was established in 1929. It is located 10.5 miles west of Corinne on U-83 and is directly north of BRMBR. This 11,834 acre area includes cold desert upland plant species, extensive wetland vegetation, 11 developed ponds and mudflat areas providing great habitat diversity. Habitat types include:

2,305 acres open water	4,129 acres marsh
3,675 acres mudflats	1,455 acres uplands

This WMA is not accessible without permission except during waterfowl hunting season. Camping is allowed during this time period. No air boats or ATV use is allowed.

Bear River Access Wildlife Management Area

Bear River Access WMA was purchased in 1989 for fisherman access to the Bear River. This WMA is small, only five acres, but includes a parking area and a hardened launch ramp for easy access. The WMA is set in a riparian valley bottom at an elevation of 4220 feet, and is a diverse and productive area for waterfowl and wildlife. Camping, boating and fishing are the primary and popular recreational activities available in this area. Wildlife viewing opportunities include waterfowl during spring and fall, Bald eagles in the winter and a variety of other species.

Salt Creek Waterfowl Management Area

Salt Creek WMA is located eight miles west of Corinne on U-83 then north of Little Mountain. It was established in 1961 and has expanded from 1,389 acres to approximately 5,236 acres. The area provides semi-marsh habitat with open water ponds and extensive wetland vegetation. Elevations range between 4255 and 4270 feet. Upland areas include cold desert plant species. Habitat types in this area include the following:

1,208 acres open water	1,210 acres marsh
120 acres mudflats	2,006 acres uplands

Vehicle access is possible to Comptons Knoll throughout most of the year, but is difficult during winter months. However, all other access points are restricted except during the waterfowl hunting season.

Willard Bay Upland Game Wildlife Management Area

Willard Bay Upland Game WMA is located on the south side of Willard Reservoir, and consists of primarily upland habitat mixed with cultivated food plots. This provides habitat for many species of wildlife, and is particularly ideal for pheasants. Riparian wetland areas in this area are productive and attract a variety of wildlife species. Recreation activities include hunting, dog training and wildlife viewing of waterfowl and songbirds. This WMA contains 1,350 acres and is accessible along the south dike of Willard Bay just west of the south marina entrance.

State Parks

Antelope Island State Park

AISP is managed by DPR and provides habitat for an unusual array of wildlife. The most visible and well-known of the park's wildlife are bison. The island bison herd, which numbers over 700 after calving season, is one of the largest public herds in the nation. The herd is maintained within a managed carrying capacity via a roundup and sale of surplus animals and limited hunting permits. The sale of bison finances the park's wildlife program.

Pronghorn were reintroduced in 1993 through a cooperative effort between DPR and DWR. A similar cooperative effort resulted in the introduction of bighorn sheep. Antelope Island provides a disease-free environment as it relates to domestic sheep, which is a key consideration for bighorns. A program goal for the island's bighorn herd is to produce a surplus for reintroduction of bighorn sheep to other historic ranges. Mule deer, coyotes, bobcats and badgers as well as numerous small mammals also inhabit Antelope Island.

The island's east shore wetlands are proximal to the mainland marshes and provide additional water bird habitat. The island also provides important upland habitats adjacent to wetlands.

DPR established an independent Wildlife Advisory Committee to review management programs pertaining to range and wildlife issues. Outside research projects have been funded and focus on pronghorn, bighorn sheep and bison genetics. Staff monitors range conditions and trends, herd sizes and composition and assists DWR with shorebird census projects. Future research will study recreational impacts on wildlife populations.

Important Habitat Managed by Other Entities

Many areas around the lake are managed for habitat preservation and improvement by other entities such as conservation groups, duck clubs, counties and federal agencies.

Bear River Migratory Bird Refuge

BRMBR is located west of Brigham City in Box Elder County at the mouth of the Bear River. It is the largest national refuge specifically set aside for waterfowl and shorebird management. The Bear River Delta is considered one of the most valuable water bird and wetland areas in Utah. Waterfowl, water birds, migratory birds and wildlife depend on the refuge as an important breeding, wintering and staging area (USFWS, 1993).

The refuge was established in 1928 through an Executive Order by Herbert Hoover and the permission of the State of Utah. Today, BRMBR encompasses approximately 74,000 acres providing contiguous and diverse habitat areas for wildlife. The primary management goals of the refuge include protecting and enhancing habitat to maintain or increase threatened and endangered species, providing suitable production and migration habitat to benefit migratory birds and providing a biologically diverse suite of habitat types in various successional stages to maintain healthy wildlife and fish populations. Secondary management goals include providing opportunities for the public to enjoy wildlife and to better understand their role in the environment and ensuring protection for important archaeological, historical and cultural resources. Over 43 archeological sites have been recorded on the refuge.

A 12-mile driving or hiking tour is open year round and provides an excellent opportunity for wildlife viewing and environmental education. Hunting, trapping and warm water fishing on the main river channel are popular activities available seasonally. Over 40 percent of the refuge is open to waterfowl hunting. A 1990 study, to examine the economic value of the refuge, indicated that 20,000 visitors equates to over $180,000 to the local economy (Piper, 1990).

Water control structures are designed to regulate water flow into several management units to create diverse habitat areas to benefit wildlife. Approximately 18,937 acres of the refuge do not receive water from the Bear River. Water supplies are rarely at optimum levels. Flushing removes excess salts and drawdowns improve some habitat types. During the 1980s, GSL flooding caused over $42 million of flood damage including the loss of the visitor center, dikes, water control structures and roads. The outside dikes are presently at 4208.75 feet, which is a 0.75 foot increase from pre-flooding elevation.

BRMBR completed a *Long Range Water Management Plan* in 1993, to examine existing water management, enhance refuge habitat and improve future water supplies and management for maximum wildlife benefit. Important management concerns include water supply, water quality and disease management. Water shortages are very detrimental to wetlands and wildlife. USFWS would

like to augment natural flows of the Bear River during July and August. A project to supplement these low flows with Willard Bay water was negotiated, but the project was not constructed. Future water development projects on the Bear River are currently under consideration and include plans for the Honeyville area, but there is no authorization for this dam to date. Disease management focuses on botulism outbreaks and attempting to understand ideal conditions by linking losses with water conditions and habitat indicators. Peak avian botulism losses seem to occur during above-average water years,
according to USFWS. Water quality and sediment contamination have been investigated in BRMBR and in proposed acquisition areas. "Soil and water analysis from this study did not identify any toxic constituents, although further sampling of soil, water and fish tissues may be warranted in the Black Slough area to determine the source(s) or extent of DDT contamination," according to the contaminant study of Waddell et al. (1990). Also, salts were present in high levels in both water and sediments.

Layton Wetlands Preserve

Layton Wetlands Preserve is a mosaic of over 2,500 acres of wetlands, playa and upland habitats. It is owned and managed by TNC. An additional 1,000 acres of adjacent property is managed by TNC for URMCC. TNC continues to look for opportunities to protect important wetlands and uplands around GSL.

Management of the preserve is conducted within the context of identifying conservationally important species and communities, identifying stresses or threats to those conservation targets and developing strategies to minimize the stresses or threats. One of the primary conservation strategies outlined in the plan is to allow the dynamics of GSL to act naturally upon the landscape in this undiked area.

To address management issues on the preserve, TNC is also developing visitor management, weed management and community outreach plans. Wetland restoration activities are being conducted on the preserve. Much of the work is accomplished with volunteer help and the assistance of local experts.

Inland Sea Shorebird Reserve

This 3,889 acre reserve was developed by KUC to mitigate for the tailings modernization and expansion project completed in 1998. The reserve provides a large contiguous area for nesting and resting habitat for migratory shorebirds and waterfowl. The Inland Sea Shorebird Reserve is surrounded by private duck clubs, the Gillmor Wildlife Sanctuary and the SLCIA Mitigation Project, all of which provide wildlife habitat. The reserve has three water sources, including Goggin Drain, Lee Creek and the North Point Canal. They circulate brackish water through marshes and mudflats to maximize invertebrate populations as food for visiting birds. A unique sand dune environment exists on state sovereign lands adjacent to the reserve (Neville, 1998).

Once COE approves the mitigation project, which is expected in 2002, KUC plans to allow greater public access. Important issues for the Inland Sea Shorebird Reserve include access to sovereign lands and mosquito abatement practices.

Gillmor Wildlife Sanctuary

The land for the Gillmor Wildlife Sanctuary was donated to the National Audubon Society to help preserve the natural ecosystem of GSL. This 1,425 acre property has a variety of habitat types ranging from open water to playas and upland areas. It is located north of I-80 and west-northwest of the new SLCIA runway on the abandoned delta of the Jordan River. The *Feasibility Study for the South Shore Wetlands Ecological Reserve of the Great Salt Lake* was conducted with URMCC to investigate the possibility of restoration of the natural inflow of freshwater to this old river delta system. The hydrological study and analysis concluded that approximately 2,000 acres of potential wetland habitat could be developed or restored in this area to provide a mosaic of wetland and upland habitats for wildlife.

The goals of the adjacent property owners are compatible in developing a contiguous area of highly productive habitat suitable for breeding, nesting, foraging and resting for a wide range of species. A goal for this area is to acquire water for future improvement of wildlife habitat.

Salt Lake City International Airport Mitigation Site

The SLCIA runway expansion project required mitigation for wet meadow wetlands habitat loss. Most of this mitigation site is surrounded by private property, duck clubs and the Gillmor Wildlife Sanctuary. The mitigation site includes 1,500 acres of wetland habitat. SLCIA authorities plan to focus on increasing shorebird habitat by 70-80 acres by enhancing marginal wetlands and uplands. Issues facing this mitigation project include flooding impacts, changes in water use from agriculture to urban, non-native species invasion and future supplies of freshwater entering the mitigation site.

Great Salt Lake Duck Club Properties

According to the *South Shore Duck Club Study* (Dunstan and Martinson, 1995), 13 duck clubs exist on the south shore of GSL, with more than 16,791 acres managed as wetlands for waterfowl habitat. Many duck clubs also exist along the east and north areas around the lake. Private duck clubs develop additional habitat and actively manage and enhance existing habitat to increase wildlife use for the purpose of waterfowl hunting. Enhanced areas require active management to maintain wetland and wildlife functions. These efforts also improve habitat conditions for a variety of other species and, together with the efforts of adjacent landowners, provide a considerable amount of contiguous habitat for wildlife around GSL. The *South Shore Duck Club Study* conducted between 1994-95, examined the feasibility of a formal protection plan and the possibility of developing public support for these privately owned and managed wetland areas. This effort identified the importance of duck clubs in providing habitat for a variety of species.

Surface gradients in developed wetlands are so shallow, a one-inch change in water level can move pond shorelines hundreds of yards. Because of this gradient, water control is the primary means of managing vegetative growth and these wetlands have extensive, precise water control systems. One 3,346-acre duck club has 18 managed water levels, 88 water control structures, over 18 miles of channels and 21 miles of dikes. Precise water control is required to prevent avian botulism which can kill tens of thousands of birds, to minimize pond siltation and to control carp and other undesirable exotics.

Water shortages can cause vegetation damage and changes that may contribute to disease epidemics resulting in bird mortality. To maintain healthy marshlands, a flush of water is required to wash out toxins and provide salinity control during the spring.

Critical issues for duck club managers include securing adequate water supply, delivery timing and reliability and maintaining water quality. Flooding issues are significant since these properties are located at low elevations near the lake and most owners or managers rebuilt after the 1980s flooding. Other pressing issues include access, road maintenance, predator control, trespass grazing and non-native plant species invasions which require ongoing control and expensive eradication.

Important Island Habitat Areas

In addition to established WMAs and privately managed habitats, the islands of GSL provide isolated habitat for a variety of colonial and migratory birds. The following table was used in the *"Linking Communities, Wetlands and Migratory Birds*" document to describe the islands of the lake, access and wildlife use (Wetlands International, 1998) (Table 8).

Table 8. GSL Island Management, Acreages, Public Access and Wildlife Use

Island Name	Managing Agency	Acreage	Public Access	Wildlife Use
Antelope Island	DPR	28,240	Yes	Antelope, bison, deer, bighorn sheep, many birds and other wildlife species
Stansbury Island	BLM/Private	22,314	Partial	
Fremont Island	Private	2,945	No	Unknown
Carrington Island	BLM/Private	1,767	Yes	
Gunnison Island	DWR	163	No	Pelican rookery, gulls
Dolphin Island	Sovereign Land	60	Yes	
Bird or Hat Island	DWR	22	No	Gull and heron rookery
Badger Island	Sovereign Land	6	Yes	
Cub Island	BLM	1	Yes	
Egg Island	Sovereign Land	1	Yes	Gull rookery closed 4/1-7/31
White Rock Island	Sovereign Land	1	Yes	Gull rookery closed 4/1-7/31

Census work by DWR will better define wildlife use on the islands in the lake. Dependent upon lake elevation, there may be more or fewer islands than those listed above.

Changes in Lake Brine Salinities

Segregation of Great Salt Lake Waters into Distinct Salinity Areas

The waters of GSL are segregated into four areas of different salinity. (Bear River Bay, Farmington Bay, Gilbert Bay and Gunnison Bay) Each is influenced by differing water inflow and evaporation regimes, which results in changes to lake elevation and salinity.

In this discussion, the south arm of the lake is different from Farmington Bay and Bear River Bay. Salinities in the south arm have ranged from 5-21 percent in recent times. In August 1999, salinity was approximately eight percent. It is this portion of the lake that is being harvested for brine shrimp and supports abundant bird populations.

Farmington Bay is that portion of the lake east of Antelope Island and isolated from the rest of the lake by the Davis County Causeway and the Antelope Island Southern Causeway. Salinities of Farmington Bay fluctuate substantially due the inflow of freshwater from the Jordan River, and the causeway-inhibited exchange of salt water from the south arm. Salinity values have ranged from 2-6 percent in recent times. Commercial harvesting of brine shrimp is prohibited in this area to minimize impacts to bird populations, which are substantial.

Bear River Bay lies north of the causeway (Bagley Fill), on the east side of Promontory Point. Water salinity in this bay can also fluctuate substantially, but is usually very low (<2 percent). There is evidence that when the Bear River flows are very low, a layer of dense brine runs northward into the bay, especially during periods of south winds (Butts, 1998). Commercial harvesting of brine shrimp is also prohibited in this bay to minimize impacts to substantial bird populations, especially fish-eating birds.

The north arm of the lake (Gunnison Bay) lies north of the northern railroad causeway between Promontory Point and Lakeside. Salinities in this portion of the lake have ranged from 14.5-28.4 percent in recent times. In August 1999 salinity was approximately 23 percent. There has been very little harvesting of brine shrimp in this portion of the lake. The water of the north arm is too saline to sustain meaningful populations of shrimp. Periodically, some shrimp and cysts wash through the breach and culverts, and there are a few locations in the north arm where brine shrimp populations may occur, probably due to springs which dilute brine salinity. As salinities decrease, brine shrimp populations will increase. In fact, meaningful populations have historically existed and been harvested from the Gunnison Bay. Commercial brine shrimp harvesting is allowed in the north arm. In fact, most brine shrimp harvesting during 1999-2000 occurred only in the north arm of GSL. Bird use of the north arm of the lake has been severely limited because of the lack of viable brine shrimp populations, although some foraging occurs near the causeway breach and culverts. Gunnison Island is an important White pelican nesting area.

Aquatic Biota Differences

Of primary concern to wildlife managers is the current degree of difference in salinities between the north and south arms of GSL and the lack of brine shrimp productivity in the north arm and diminished cyst production in the south arm. Because brine shrimp are currently managed and considered a focus species, most of the research and attention has centered on brine shrimp. However, the same low productivity concerns extend to other aquatic species which are significant in the lake's food chain, such as algae and brine flies.

The northern railroad causeway from Promontory Point to Lakeside is inhibiting the exchange of lake brines between the north and south arms of the lake, and has caused a significant difference between the salinities of the north and south arms since its completion in the late 1950s. It is now thought that the differential, which has averaged between 10-13 percent, is increasing ("Water-Chemistry" section). Because brine shrimp and brine fly productivity in the north arm has been severely limited, and south arm production has declined, substantial negative impacts on avian species are suspected. Wildlife managers are concerned about the causeway's impact on the lake's ecology.

Brine shrimp populations flourished in the north arm of the lake during the mid-1980s, due primarily to high lake levels and resulting lower than average salinities in the north arm. It has been suggested that, at some lake levels, a differential in brine concentrations is beneficial because when the south arm is too dilute to support a healthy brine shrimp population, the north arm may be able to. At historically high lake levels, that appears to be the case.

In 1999, salinities in the south arm have diminished to the point where the brine shrimp population is stressed and substantially reduced, while salinities in the north arm continue to be high enough to prevent the establishment of a significant, viable brine shrimp population. The south arm has experienced reductions in brine shrimp harvest and salinity.

Table 9. Brine Shrimp Harvest and South Arm Salinity

Year	Harvest (million lbs.)	South Arm Salinity
1996	14.7	12-13%
1997	6.1	11-12.6%
1998	4.6	8.7%
1999	2.5*	7.3%

*The south arm was closed to harvesting during the 1999-2000 season. Most of the biomass was harvested from the north arm.

These salinity ranges occurred during the brine shrimp production season and were measured at a sample site located in the open water area of the south arm. This circumstance has resulted in a depressed shrimp population in the lake with negative impacts on bird populations and commercial harvesting of brine shrimp (Table 9).

Research on both the hydrology of the lake and the role of salinity in brine shrimp and other aquatic population ecology is continuing.

Lake Water Quality Impacts to Wildlife

A discussion of GSL water quality issues, studies and initiatives appears in the "Water-Quality" section of this statement. Little is known about the impacts of water contaminants on GSL wildlife. A research project sponsored by USFWS is expected to provide information focusing on Bear River Bay in the near future. That document will represent the latest understanding of the dynamics of water contaminants and will likely help chart the future of water quality research on GSL.

Lands Designated for Wildlife Management

Section 23-21-5 of the Utah Code provides;

> "The Wildlife Board is authorized to use any and all unsurveyed state-owned lands below the 1855 meander line of the GSL within the following townships for the creation, operation, maintenance and management of wildlife management areas, fishing waters and other recreational activities..."

The Code identifies all or part of 39 townships lying within the meander line of the lake (Appendix F, Exhibit 2). Some of the area within the identified townships has been formally placed within WMAs by the Board of Wildlife Resources, but much has not. The management status and responsibility for the lands identified as available for wildlife management by statute is unclear for those which have not yet been evaluated and acted upon by the Board of Wildlife Resources. DWR will initiate the process to consider the designation of these lands.

Ecosystem

Introduction

The Great Salt Lake ecosystem is of worldwide importance for migratory bird populations, brine shrimp and mineral extraction industries. GSL is one of the premier wetlands areas of the United States and is a major recreational and aesthetic resource for Utah. (SRC, 1999c)

The GSL ecosystem is comprised of many subsystems (SRC, 1999b and c) and each is strongly influenced by changing lake levels and lake chemistry. Shallow water, wetland areas and deep water portions of the lake are spatially and temporally dynamic in response to changing environmental conditions. Variations in precipitation and fresh water inflows together create a dynamic mosaic of habitat types along the shores of the lake. Variations in salinity affect species community composition and structure which also varies across all of the lake's ecosystems. There is a distinct difference in salinity between the north and south arms of GSL and this directly influences species distribution and abundance. There is also a strong east-to-west ecosystem gradient in regard to GSL habitat and productivity (SRC, 1999b). Natural and human-induced inputs and outputs occur via inflow, atmosphere and other mechanisms (SRC, 1999c). There are many other components and interactions which determine ecosystem function and productivity. GSL resources are inter-connected and human use influences ecosystem response. GSL components and interactions are closely associated, thus making the management of GSL ecosystems complex and challenging.

Great Salt Lake Subsystems

GSL and its watershed represent a complex web of interacting physical, socioeconomic and ecological systems and subsystems (SRC, 1999c). Current understanding of the complexity of GSL ecosystems and lake dynamics limits the ability to accurately describe and forecast the dynamics of the various system components (SRC, 1999c) such as hydrology, landscape, chemistry, biology, water and air. A subsystem analysis emphasizes the linkages between these components and human interactions from a large-scale perspective. Subsystems and their interactions are usually represented by using a Venn Diagram (Exhibit 11). The subsystems approach can be a management tool for resource planners and managers to identify issues, limitations and areas of uncertainty.

These linkages are best depicted by studying cause-and-effect chains (Exhibit 12 is a simplified example of GSL systems biological linkages). Understanding cause-and-effect chains and their interconnected linkages helps resource managers identify potential methods of altering conditions or managing a system.

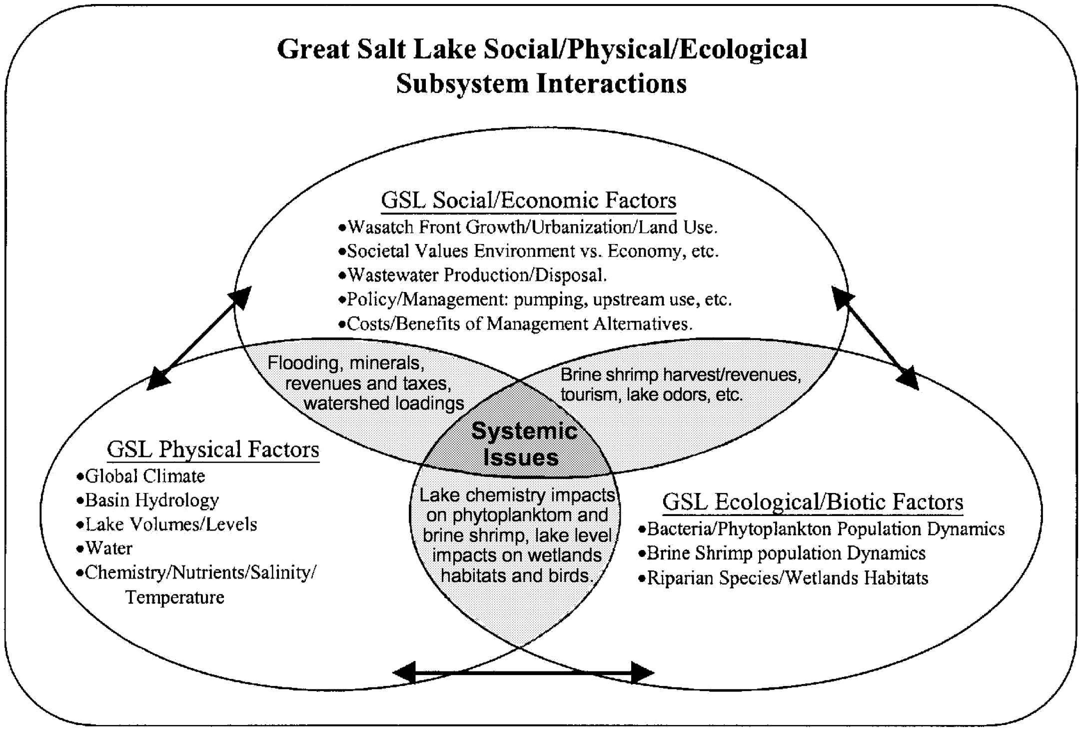

Exhibit 11: Great Salt Lake Subsystem Interactions and Management Problems (SRC, unpub.).

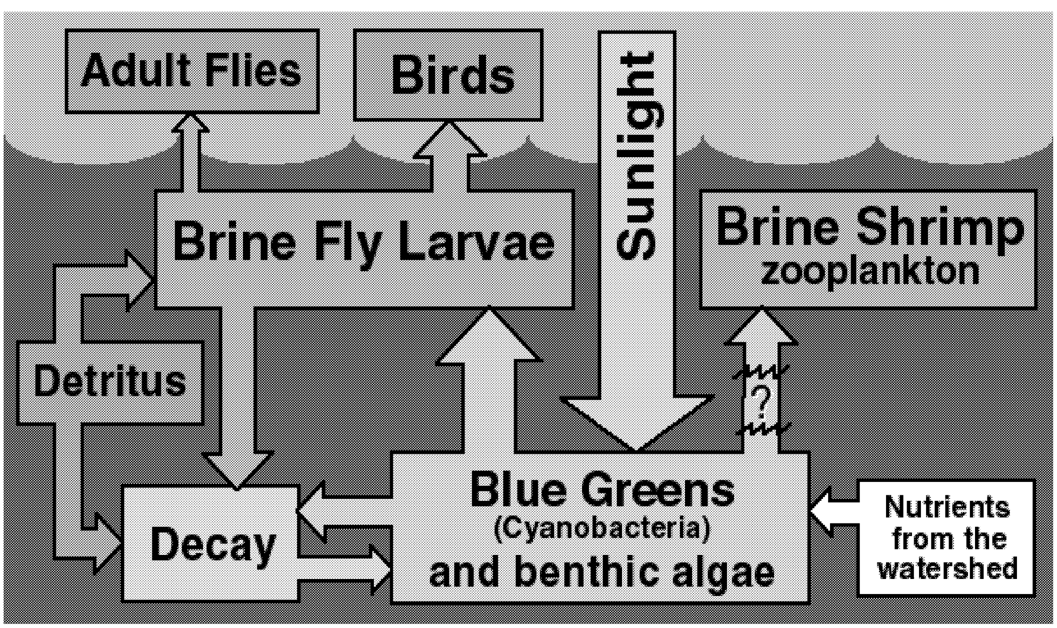

Exhibit 12: View of GSL Ecosystem (USGS, 1999)

Physical Subsystems

Physical subsystems are the physical environment or setting and include basin geology, global and local climate, hydrology, lake level fluctuation, hydrodynamics and lake chemistry. The geologic setting and geography of the landscape creates this watershed and terminal basin. These influence the behavior of other physical components. Lake geomorphology which includes the erosion, transport and distribution of sediments and their patterns in the ecosystem are not well understood (SRC, 1999b).

Hydrologic processes cause fluctuations of lake volume, lake level and salinity. All are strongly influenced by each other and respond to regional and global climatic factors ("Water-Hydrology" section). Climatic forces drive watershed response and lake level fluctuations at multi-year, decadal and longer time scales. The ability to predict these changes is very limited. Resource managers deal with uncertainty in the long-term behavior of lake hydrology and at best can predict lake levels in the short term (one-to-three years) along with some associated management implications and ramifications (SRC, 1999b).

Biological/Ecological Subsystems

These subsystems focus on biological and ecological interactions. Lake level fluctuations, salinity and water quality affect the dynamics of the lake's ecosystems. This has implications for wetland habitats and the population dynamics of brine shrimp, brine flies and birds. There are further implications for tourism and commercial brine shrimp harvesting. Nutrient availability, air and water quality have ecological consequences. Lake managers have yet to fully understand these interactions and the affect of lake chemistry on biota (some research is currently underway). The physical arrangement sets the stage for biological subsystems' ability to function. Temperature, light, salinity, nutrients and many other factors have an effect on shallow and open-water ecosystems which create dynamic biological systems and subsystems with their seasonal and annual variability (SRC, 1999c). There is limited information available to understand these interactions. Time scales of ecological subsystems behaviors range from diurnal to multi-year.

Socioeconomic Subsystems

Socioeconomic subsystems relate to human interactions that influence ecosystem response. This subsystem includes population, economic and other human-related interactions with a system. Salt extraction, mineral production, brine shrimp harvesting and oil and gas reserves are also important lake economic resources. Tourism and recreation are additional important lake uses.

Rapid urbanization and agricultural expansion is occurring in portions of the GSL uplands and the watershed. This area contributes the vast majority of fresh water inflows to the lake. These human-induced impacts change the amount and temporal distribution of runoff into the lake, as well as the quality of runoff water. These changes affect lake level, water chemistry and ultimately other subsystem components. Management strategies may also influence lake level and chemistry, air and water quality.

Upstream and watershed activities such as discharges, development and water allocation all interact with other lake ecosystems and all three conceptual subsystems. The political and economic arenas drive management actions within this subsystem. Activities within socioeconomic subsystems occur and affect the lake at seasonal to multi-year time scales.

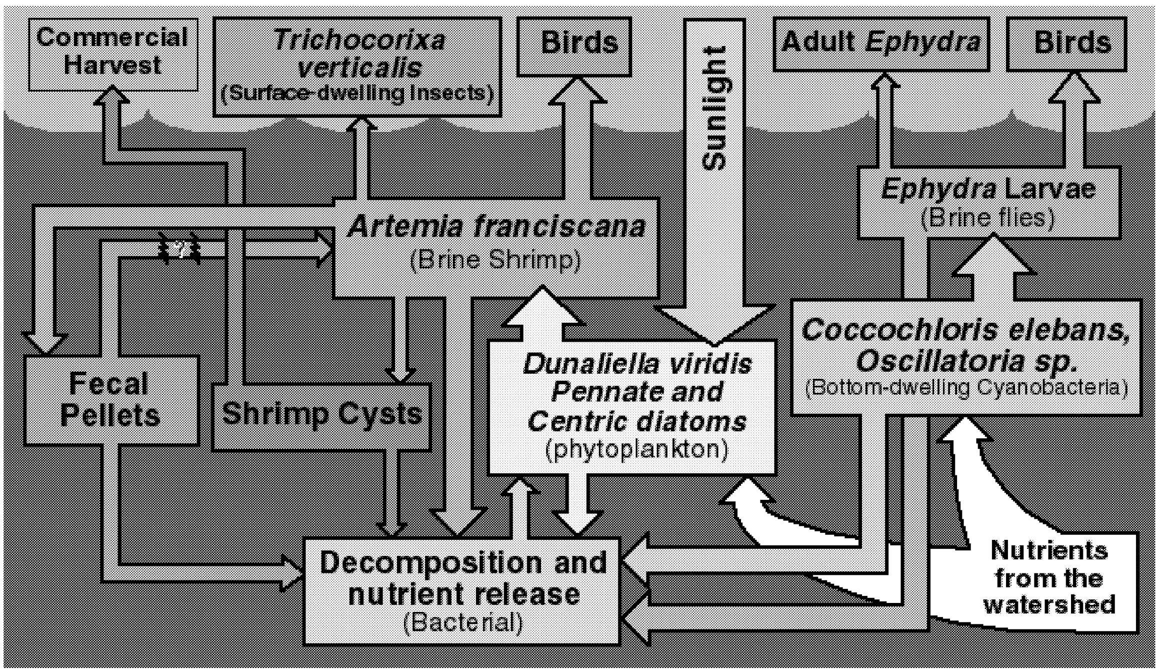

Exhibit 13. Components of GSL System (USGS, 1999)

Subsystems Management and Planning

Many management issues occur at the interface among these three subsystems (Exhibit 11). Each subsystem varies spatially, temporally and structurally and impacts each of the others. Management actions intended to influence environmental conditions in one subsystem may impact another. For example, high lake levels in the 1980s and flooding (physical system changes) impacted infrastructure and other major economic resources (socioeconomic system) around the lake. Physical subsystem changes, such as lake level fluctuations and salinity variability influence lake aquatic organisms (phytoplankton and brine shrimp populations). This also has implications on the quantity of wetland and riparian habitat available to migratory birds and other wildlife, thus demonstrating that GSL subsystems have many linkages and are dynamic and interactive (SRC, 1999c).

Lake managers currently recognize that:

> GSL dynamic subsystems operate at different spatial and temporal scales and interact with one another to produce complex nonlinear behaviors that are difficult to predict (1999c).
>
> Sufficient scientific understanding for management purposes is needed and includes the dynamics, complexity and uncertainty inherent in the behavior of lake subsystems (SRC, 1999c). Additional study and research is needed to better understand lake dynamics ("Monitoring and Research" section of the Great Salt Lake Comprehensive Management Plan and Decision Document).
>
> Lake level fluctuation and variability in lake salinity are important aspects of ecosystems function and are important management considerations.

Ecosystem/Biological Linkages

Invertebrates and fish in some areas are important links between the primary producers (algae and macrophytes) and the bird populations that make these ecosystems valuable and unique resources. Available information on these components (Huener and Kadlec, 1992, Osmundson, 1990, Flannery, 1988 and others), is marginal. Information for invertebrates in similar ecosystems exists (Murkin and Batt, 1987; SRC, 1999e).

In shallow and less saline regions of the lake, brine shrimp are not as abundant and different invertebrate communities are more prevalent. In marshes, brine flies are not abundant but midges are usually abundant and are the main food supply for avocets (Osmundson,1990) (SRC, 1999c).

This dynamic of interconnected GSL ecosystems creates a reliable resource (major concentration area) for many species and huge populations of birds. During high water years, birds relocate to other areas and resources. High bird population numbers today suggest that this has been an extremely productive ecosystem for a very long period of time. Food resources have been reliable for huge populations and many species of birds have developed migratory behavior that capitalizes on these resources. Variability within natural limits is good for ecosystem productivity (SRC, 1999c).

Sustainability and Ecosystem Health

Sustainability is "a system's ability to maintain its structure (organization) and function (vigor) over time in face of external stress (resilience)"(Costanza, 1992). A system responds to outside stresses and nature of the stress may even be more significant (Smol, 1995) (SRC, 1999c).

A well buffered system is able to maintain its structure and function (SRC, 1999c). Biodiversity is another important consideration for planners and managers.

A "healthy" ecosystem is one that existed before significant anthropogenic impact (Smol, 1992), but ecosystem health is difficult to define. As environmental conditions change, the system adjusts to these changes. Therefore an "unhealthy" condition is beyond the natural range of fluctuation due to conditions resulting from some human-induced modification of the system (SRC, 1999c).

Ecosystem Impacts

There are several types of environmental impacts that managers consider in planning and managing for important natural resources. Managers consider short- and long-term, immediate and site-specific impacts. There are also adverse, unavoidable, irreversible and irretrievable impacts.

Direct impacts are the result of circumstances or activities that occur at the same time and place and hence alter a system. Indirect impacts are further removed but are still reasonably foreseeable and influence a system. Cumulative impacts occur when there are multiple effects on the same values. Gradual impacts occur on resources when combined with past, present and future actions (BLM, 1998). There are many direct, indirect and cumulative impacts to GSL and its environs. The following list cites a few examples of human-related direct and indirect GSL impacts:

Dikes and causeways
Brine shrimp harvesting
Exotic species introduction
Mineral extraction
Oil and gas production
Lake level modification
Recreational activities
Grazing
Discharges/Accidental spills
Upstream water allocation
Water and air quality
Population growth
Wetland-nutrient loading
Loss of GSL wetlands
Agriculture activities
Road salts
Mosquito abatement
Trash and pollution

Some GSL impacts have a positive effect on lake resources, such as the creation of state and federal wildlife management areas and duck club habitat enhancements. These alterations enhance habitat resources and provide forage and cover for wildlife. Others may cause degradation over time. Ecosystem threats include population growth, water and air pollution, commercial and industrial development such as diking and mineral extraction pond conversion.

The sovereign land multiple-use and sustainable yield management framework requires that lake managers consider these and other impacts to lake resources.

Resource planners and managers consider impacts in lease permits, management activities and in protecting resource sustainability. Better monitoring and research adds to the information base and helps managers make good management decisions.

Cumulative impacts are often difficult to identify but will play an increasingly important role in lake management. As the knowledge base increases through monitoring and research, the consequences and mitigation measures to avoid cumulative impacts on lake resources will be better understood.

Great Salt Lake Impacts - Examples

Some areas of the lake are more susceptible to impacts due to their shallowness and proximity to large population centers. Farmington and Bear River Bays have very limited data to investigate the implications of possible or future impacts to these areas. Shallow water and wetland areas of the lake, especially on the north end and east side of the lake, are different both ecologically and in regard to the multitude of threats to these areas. These ecosystems are interfaces or buffers between the main body of the lake and surface and ground water inflows (SRC, 1999c).

Environmental conditions adjust to changes in water depth, salinity, volume and chemistry of inflows. Natural and human-induced changes in water levels and salinity have major impacts on the spatial and temporal distribution of the shallow lake and lake margin ecosystems. Variability is essential to GSL ecosystems function and productivity. Ecosystem changes are likely the result of changes in individual species biology (Foote, 1992 and Engelhardt, unpub.). Often, ecosystem changes are more or less predictable depending upon available species-specific information. Some species-specific information exists (Kadlec and Wentz, 1994, Foote, 1991 and Kantrud et al., 1989). Species tolerance to changing conditions within GSL ecosystems should be better understood (SRC, 1999c).

Lake hydrodynamics have been impacted. Water does not circulate freely throughout the system due to dikes or causeways resulting in several sub-ecosystems with different hydrologic and water chemistry characteristics. This limits the variability of lake levels, salinity and water circulation. Farmington and Bear River Bays' salinity conditions have some positive consequences for wildlife productivity.

The multiplicity of GSL ecosystems, lake dynamic interactions and lake level fluctuation makes it difficult for resource managers to detect undesirable changes and determine their causes. Gaps in the information base limit knowledge and understanding of the GSL ecosystem and its many sub-ecosystems. A well-designed monitoring and research program can help improve lake management, evaluate lake impacts and help protect sustainability while still allowing for a wide variety of multiple uses (SRC, 1999b and c).

Planning Team Ecosystem Health and Salinity Conclusions

The planning team has considered concerns regarding declining numbers of brine shrimp in the south arm (Gilbert Bay). Changes in salinity can change the abundance of brine shrimp (Stephens, 1998b). Brine shrimp are important consumers of algae and are also an important food source for GSL birds. Brine shrimp are also commercially harvested which complicates an ecosystem analysis. Brine shrimp population studies indicate that lower salinity levels in the south arm are impacting algal community compositions, specifically *Dunaliella virdis*. These green algae are a major food source for brine shrimp and are being replaced by larger pennate diatoms, which are difficult to digest (Stephens, 1998b). Reduced salinity appears to contribute to a higher winter loss of brine shrimp cysts, making it difficult for the population to restart when conditions are favorable in the spring. Research studies in 1998-99 identified this problem. However, other environmental variables may also impact brine shrimp population numbers, and according to the SRC, brine shrimp are not the best indicator of ecosystem health or of the overall condition of the lake (SRC, 1999c).

DNR resource managers are concerned that the south arm of the lake may be trending beyond its natural range of variability due to human-induced impacts to the lake. This concern raises a sustainability issue regarding ecosystem function. The northern railroad causeway has restricted flow between the north and south arms of the lake ("Water-Chemistry" and "Water-Hydrology" sections).

As resource managers, how should we then evaluate "ecosystem health?" The planning team has considered using brine shrimp as an indicator of ecosystem functioning. The SRC suggest that algae would be a good indicator since they are widespread and trackable in GSL sediments over time, plus are responsive to human-induced and environmental change. Some historical measurements of lake level and salinity are available and, along with future paleolimnological studies (SRC, 1999c), can be useful to assess the health of GSL ecosystems. An additional method would be to investigate a community or group of species response to ecosystem change, but historical data of this type are very limited. No single species is a reliable indicator of GSL ecosystem condition. The SRC suggests that we should also study other factors whose interactions and variability are less known, such as nitrogen, water transparency, temperature, brine shrimp harvesting, algae, diatoms, other primary producers, invertebrates and their interactions (SRC, 1999c).

Diatoms are often used as bio-indicators of environmental change (Dixit et al., 1992) and are well preserved in lake sediments. They can be used to indicate past environmental conditions (Moser et al., 1996). Other past limnological variables can be inferred from the sediment record. This makes diatoms a powerful and robust tool for ecosystem management. However, this information is either limited or not available at this time (SRC, 1999c).

The physical, socioeconomic and biological/ecological subsystems and their resulting interactions describe one approach to investigate the implications of salinity and human impacts on GSL ecosystems. The economic and political reality in the context of GSL "ecosystems" planning is that the railroad causeway is a human-induced change that is altering the function of GSL ecosystems. Brine shrimp populations are declining in both the south arm (low salinity and south arm industry concerns) and the north arm (high salinity). The northern railroad causeway has restricted natural lake hydrodynamics (lake circulation, level and salinity or the movement of fluid with in the lake) to a point at which environmental conditions have been noticeably altered (Appendix G and Appendix H).

A "focus species" is a species that for several reasons is a compass of changing conditions, economic and other human-induced change. The planning team believes that the GSL brine shrimp population is an indicator of the overall condition of the lake and reflects the socioeconomic factors related to recently observed salinity trends. Economic, political and environmental factors will be considered in view of ecosystem sustainability and health.

Great Salt Lake Ecosystem Management

The main ecosystem driving forces, lake level and salinity, are an integral part of the lake's ecosystems. DNR intends to allow for as much natural lake level fluctuation as reasonably possible to enhance ecosystem processes. It is also important to recognize when human-induced impacts are altering or restricting lake hydrodynamics and the ability of the lake to exist as a natural body of saline water.

Existing jurisdictional boundaries limit the ability of DNR and its divisions to consider GSL ecosystems beyond the meander line and champion or monitor GSL ecosystems. It is the intent of DNR to change this situation by improving coordination among the different divisions that have management authority on the lake. It is the role of this planning effort to initiate in-house collaborative coordination to resolve long-standing issues, integrate GSL management policies and to help determine gaps in information that require research or monitoring for this valuable local, state and world-wide resource.

The GSL plan will provide a framework and help guide this activity. However, initiating more comprehensive planning efforts for the lake and its watershed will require legislation and financial backing. Multi-agency collaborative efforts are essential to accomplish and support plan research and ecosystem monitoring objectives and to continue ongoing efforts.

This planning process in itself has improved coordination among the divisions of DNR. GSL management requires a coordinated front to address lake management issues. However, many issues transcend the state and private land boundaries and post-plan watershed coordination will also help protect long-term sustainability.

Sustainability and Development

"In order to achieve sustainable development, policies must be based on the precautionary principle. Environmental measures must anticipate, attack and prevent causes of environmental degradation where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" (Bergen Ministerial Declaration on Sustainable Development in the ECE Region, 1990). There is often industry and political opposition to the precautionary approach since it interferes with traditional ways of conducting business and the scientific process utilized to provide decision-making rationales (Buckingham-Hatfield and Evans, 1996). Traditional ways to conduct business may lead to over exploitation while waiting for better scientific data to be compiled. The planning team believes that the proposed salinity management preferred alternative is an example of a precautionary approach.

Jurisdictional boundaries of GSL systems for planning are limited by different land-based resource agencies which limits the effectiveness of government to plan for sustainable development. Other constraints include scientific/technical, economic factors, political and ideology and the lack of industry volunteerism. Managing for sustainability often requires a regulatory framework to protect public trust resources and to identify appropriate tradeoffs in balancing multiple-use and sustainability objectives. Sustainability is defined by societal and political values rather than a scientific based concept. The long-term viability of the resource is determined by the outcome of social values. However impacts on GSL systems cut across economic, social and political boundaries.

Sustainability is achieved by "knowing the state of the environment." This is the resource inventory and provides the baseline to evaluate monitoring and identify trends that are useful for formulating effective management policies. Managing for sustainability assumes that resource managers understand management actions and their consequences (impacts) on dynamic systems. Precise cause-and-effect observations are often vague and problematic since scientific information may have several different interpretations. Therefore research and monitoring objectives must be carefully designed.

Sustainable planning for GSL ecosystem should include "targets" or objectives for determining the effectiveness of multiple-use and sustainable management objectives in balancing development and maintaining environmental integrity. Management targets are based on scientific understanding of GSL ecosystems limits and tolerances to human-induced change. Management targets may be established at different scales and levels. (Buckingham-Hatfield and Evans, 1996). A few ideas to evaluate management objectives are:

1. Identify sustainability indicators or targets for resource management and decision-making.

2. Identify tradeoffs and determine if acceptable tradeoffs will maintain the integrity of GSL resources to ensure that each generation should at least inherit a similar natural environment.

3. Identify environmental quality or performance measures that are reportable and measurable over time.

4. Determine a conceptual approach for monitoring and assessing the state of the environment.

5. Identify information needed to assess the "state of the environment."

6. Identify vigorous monitoring strategies.

7. Design analysis and reporting strategies.

Sustainable use of GSL ecosystems means limiting the use of renewable natural resources at a pace where they can renew themselves through natural processes (Fischer and Black, 1995). Ecosystem management objectives should include and consider:

1. Allowance for reasonable multiple-uses to the extent they are consistent with the Public Trust Doctrine

2. Wise resource allocation to ensure long-term sustainability

3. Establishment of checks and balances to ensure an acceptable level of environmental protection

4. Minimizing negative impacts on GSL ecosystems

5. Engaging industry in ensuring sustainable resources by preventing and managing for crises in their operations and to help in monitoring impacts

These measures will allow for economic growth that is mindful of the limited natural resource base (Fischer and Black, 1995). It will be challenging to balance public needs and ensure long-term resource protection with projected population growth scenarios. Sustainable management ensures that GSL natural resources will be available for future uses.

Introduction

The state owns and manages the bed of GSL pursuant to the Equal Footing Doctrine. The boundary line of the bed of GSL is the surveyed “meander line.” The meander line follows no particular topographic contour or elevation, but is generally located between 4202- 4212 (above sea level) in most places around the lake. These lands within the meander line are referred to as “sovereign lands.” Sovereign lands also include the unsurveyed islands in GSL; Dolphin, Badger, Egg and White Rock Islands. Hat and Gunnison Islands are owned by DWR. Stansbury, Fremont, Carrington and Cub Islands are federally and privately owned.

In addition to the sovereign lands owned by the state, DNR has acquired lands in and around GSL including Antelope Island (DPR), wetlands and uplands associated with wildlife management areas and formerly private lands needed for the WDPP operation, all of which are managed for specific purposes.

The management of sovereign lands is the responsibility of DFFSL. One of the challenges in managing sovereign lands is that the biological and physical systems of GSL do not observe property boundaries, and management decisions on sovereign lands affect, and are affected by, uses and activities on adjoining lands.

The internal and external scoping conducted by the planning team identified these areas of interest and concern with regard to the management of sovereign and other state-owned lands on and around GSL. A listing of the existing leases and permits on sovereign lands is in Appendix B.

- **Disclosure has to be made of known geologic hazards.**

- **Impact assessment for diking proposals needs to be considered.**

- **A review of sovereign land is needed.**

- **Use of sovereign land for BRMBR expansion is a consideration.**

Land Uses Adjacent to Great Salt Lake

Land use around GSL consists of a mix of residential, commercial, agricultural, recreational and industrial uses common to population centers (Exhibit 1). The east side of the lake has the higher concentration and diversity of land uses. Population growth in Weber, Davis and Salt Lake Counties is resulting in the conversion of agricultural land to residential and commercial uses. Associated with this changing land use is a shift in water use from agriculture to M&I uses, with a resulting reduction in sub-irrigation ground water and return flows to lands adjacent to the lake. As development moves lakeward, the uplands no longer provide a buffer to the lake wetlands, and diminishing irrigation return flows affect the wetland ecosystem (Davis County Government et al., 1996). In addition, runoff from urban lands introduces water contaminants different from those of agricultural lands.

BLM manages nearly 40 percent of the total GSL shoreline. Approximately 70 percent of the shoreline above meander on the west side of GSL is managed by BLM. The USAF operates the Utah Test and Training Range on the west side of GSL.

A number of landowners adjacent to the lake are managing their holdings primarily for habitat protection. Approximately 150,000 acres of adjacent lands are within state and federal WMAs. In addition, approximately 10,000 acres of wetland and upland parcels are owned and managed by groups like TNC and the National Audubon Society for habitat preservation. Private hunting clubs own and manage over 50,000 additional acres on the east side of the lake, primarily adjacent to Bear River Bay and south of Farmington Bay.

Elsewhere around the east side of the lake agricultural uses predominate. Grazing and crop production from dry and irrigated acreage are the most common land uses around the north and west sides of the lake. The notable exceptions are the mineral evaporation ponds of Bear River and Clyman Bays and the south shore, and the bombing and gunnery range which lies on the western shore of the lake.

County Zoning Adjacent to Great Salt Lake

Box Elder County

Box Elder County covers approximately 800 square miles of GSL, the largest area and the longest shoreline of the five counties adjoining the lake. Several abandoned industrial ventures abut the lake, but brine shrimping is the only current lakeshore commercial activity other than mineral production. Only a portion of the lake shoreline is zoned. The area on the west side of the lake from Kelton to the southern county line is zoned M-160, multiple uses with 160 acre minimum lot size. The balance of the shoreline is not zoned.

Davis County

Zoning along the GSL shoreline in Davis County is controlled by three governmental entities; Davis County, Kaysville City and Centerville City. Most of the county-controlled land adjacent to the lake is zoned A-5 for agriculture and farm industry with a five acre minimum lot size. The A-5 zone is intended to promote and preserve agricultural uses and to maintain greenbelt open spaces. Primary uses include single-family dwellings, farm industry and agriculture. Several conditional uses include stables and dog kennels. Kaysville City abuts the lake for only a few hundred feet, and is also zoned A-5 with similar uses.

Davis County and others sponsored the development of the *Davis County Wetlands Conservation Plan*, published in December 1996, as a non-regulatory, multi-faceted program, “To conserve and enhance the integrity of Great Salt Lake wetland ecosystems in Davis County,...”

(Davis County Government et al., 1996). The purposes of the plan are to define a Davis County conservation zone adjacent to the lake, "...incorporating provisions for appropriate development, infrastructure needs, resident livelihoods and quality of life, while ensuring perpetuation of these important natural resources;..." While many of the plan implementation steps remain to be completed, the conservation plan establishes a blueprint for land management and use adjacent to GSL in Davis County.

Centerville City abuts the eastern shoreline of the lake for about two and one-half miles immediately to the east of the Farmington Bay WMA. City zoning in this area is A-1, agricultural or I-D, industrial development. The A-1 zone allows both standard agricultural activities and single-family dwellings on one-half acre lots. The I-D zone allows for a wide array of industrial and commercial uses.

Salt Lake County

The shoreline of GSL in Salt Lake County is generally unpopulated, and is zoned A-20, an agricultural zone with a 20 acre minimum lot size, or C-V, a commercial visitor zone. The A-20 zone provides for standard agricultural uses, but also allows solar evaporation ponds. It typically acts as a large-acre holding zone until a specific use is proposed, which can result in re-zoning for the use proposed. The C-V zone allows for commercial uses to accommodate the needs of visitors and travelers.

Tooele County

The shoreline of GSL is not specifically zoned in Tooele County, with land uses reviewed and approved on a case-by-case basis as conditional uses. Current uses include agricultural operations, brine mineral extraction and brine shrimping operations.

Weber County

Fifteen miles of GSL shoreline are within Weber County, and are zoned S-1, farming and recreation. Lands around Little Mountain are zoned M-3, manufacturing. The M-3 zone allows for the manufacture and testing of jet and missile engines, aircraft and spacecraft parts and similar heavy industry, and for the extraction and processing of brine minerals. Bordering the S-1 and M-3 zones on the east are agricultural zones A-1, A-2 and A-3.

Land Uses on Sovereign Lands

The framework for sovereign land management is found in the Utah Constitution (Article XX), state statute (primarily Chapter 65A-10), and administrative rule (R652). Commercial uses are allowed on sovereign lands only by permit.

Division rule allows for classification of sovereign lands based upon current and planned uses (R652-70-200. "Classification of Sovereign Lands" (Appendix F, Exhibit 3).

Class 1: Manage to protect existing resource development uses.

Class 2: Manage to protect potential resource development options.

Class 3: Manage as open for consideration of any use.

Class 4: Manage for resource inventory and analysis.

Class 5: Manage to protect potential resource preservation options.

Class 6: Manage to protect existing resource preservation uses.

The legislature has authorized DWR to use sovereign land in all or parts of 39 townships on GSL for the creation, operation, maintenance and management of WMAs, fishing waters and other recreational activities. This geographic area covers Bear River Bay, Ogden Bay, Farmington Bay, portions of the south shore area and the north end of Spring Bay. This statutory authorization is interpreted as establishing wildlife management and wildlife-related recreation as the primary intended land use, except for areas identified for other uses through a planning process. Land uses with significant adverse impacts on wildlife and recreation values may be prohibited, even though mitigation strategies are available. Some of this sovereign land is included in AISP and is managed by DPR. Some of the land has been sold or exchanged.

The most current statement of use classifications for the sovereign and other state lands of GSL appears in the 1995 plan. The 1995 plan recommended application of the use classifications set forth in R652-70-200 to areas of GSL as follows (Appendix F, Exhibit 3):

Class 1, managed to protect existing resource development.

Lands under this classification include the area around Antelope Island delegated to DPR for recreation management, the area around Saltair and GSL Marina, existing mineral extraction lease areas, and areas under special use lease for brine shrimp cyst harvest activities. These lands would be open to oil and gas leasing, but no surface occupancy will be allowed in the recreation areas.

Class 2, managed to protect potential resource development options.

This area includes the West Rozel oil field and shoreline areas from the north end of Stansbury Island south along the west side of the island and then north along the west side of the lake to the south line of Township 11 North, Salt Lake Base and Meridian (SLB&M). This area will be open to mineral leasing, developed recreation and other kinds of developments.

Class 5, managed to protect potential resource preservation options.

This classification includes lands which the legislature has authorized DWR to use for wildlife purposes under Section 23-21-5 (Appendix F, Exhibit 2), and a one-mile buffer zone around islands in the north arm of the lake. No surface occupancy for oil and gas exploration will be allowed in established WMAs or in the island buffer zones. Elsewhere, oil and gas surface occupancy constraints shall be determined in consultation with DWR (Appendix B, Exhibit 1 for Sovereign Land Surface Leases). Mitigation strategies for developments not related to wildlife management in these areas shall also be determined in consultation with DWR.

Class 6, managed to protect existing resource preservation uses.

This classification covers existing WMAs. Lands will be available for oil and gas leasing with no surface occupancy.

Class 3, managed as open for consideration of any use.

The remainder of the lake is recommended to be placed in Class 3.

Class 4, managed for resource inventory and analysis.

This is a temporary classification used while resource information is gathered pending a different classification. There are no Class 4 lands in the lake.

The mineral lease descriptions in the 1995 plan are revised by the 1996 MLP. The sovereign land mineral lease categories now in place are shown in Appendix F (Exhibits 5 and 6).

Geologic Hazards

State law requires DFFSL to disclose known geologic hazards affecting leased property. Information on known hazards is routinely provided to lessees but, in general, there is no follow-up activity.

Tectonic Subsidence

In the event of an earthquake within the Salt Lake Valley, the potential exists for the valley floor to drop relative to the adjacent Wasatch Range. Such movement would likely occur along the multi-segmented Wasatch fault zone. Keaton (1986) suggests that displacement could be approximately five feet at the fault line. The zero-subsidence line would be about 10-12 miles west of the fault. A drop and tilt of the valley floor of this magnitude would cause (1) waters of GSL to move east, and (2) a rise in the water table in low areas near the fault. These effects could vary depending on the surface elevation of the lake at the time and the amount of displacement along the fault.

Earthquakes could also cause movement along the numerous north-south faults within and adjacent to the lake. Such movement could cause damage to highways, railroads, dikes and other existing or proposed structures in and around the lake.

Surface Faulting

Surface faulting may accompany large earthquakes (greater than magnitude 6.0-6.5) on active faults in the bed of GSL. One fault trends northwest along the west side of the Promontory Mountains and Antelope Island. Other faults are present elsewhere beneath GSL, particularly in the north arm (Hecker, 1993). Because faults in GSL do not trend onshore, surface faulting resulting from an earthquake on one of these faults would not directly affect structures along the shoreline. However, surface faulting beneath the lake may rupture dikes or in-lake structures that straddle the faults, and may generate seiches which could indirectly damage both in-lake and shoreline structures by flooding. Little is known of the earthquake history of the faults in GSL, but evidence indicates some have been active in Holocene time.

Liquefaction and Ground Failure in Sensitive Clays

Lowe (1990a) states that "ground shaking tends to increase the pressure in the pore water between silt grains, which decreases the stresses between the grains. The loss of intergranular stress can cause the strength of some soils to decrease nearly to zero. When this happens, the soil behaves like a liquid, and therefore is said to have liquefied." Four types of ground failure can occur during liquefaction: loss of bearing strength, ground oscillation, lateral-spread landslides and flow landslides. The type and severity of the failure depends greatly on the surface slope. Under some conditions, clays can become unstable by leaching salts. These are referred to as sensitive clays. During earthquakes they can lose their strength, resulting in ground failures similar to those occurring during liquefaction.

Anderson and others (1982, 1986 and 1990) and Lowe (1990a and 1990b) suggest that large areas within Salt Lake, Davis and Weber Counties east of the lake have a moderate to high potential for liquefaction during earthquakes. These areas adjacent to the lake have sensitive clay soils susceptible to liquefaction. Regarding flooding related to local and distant earthquakes, liquefaction, and wind tides, Atwood and Mabey (1990) point out the following: "Engineered structures (such as dikes and causeway embankments) founded on the lakebed, particularly those designed to provide protection from the lake water, pose special engineering-geology problems." These problems include settling, flooding, soil compaction and erosion.

Shallow Ground Water

Ground water is, by definition, water beneath the surface of the ground which fills fractures and pore spaces in rocks and the voids between grains in unconsolidated sediments. Ground water is considered shallow when it occurs at depths less than 30 feet. Lowe (1990a and 1990b) suggests that ground water adjacent to the lake, at depths less than 10 feet, may cause flooding of basements and other related problems. In the vicinity of GSL, the water table, or the top of the saturated ground, fluctuates in response to the level of the lake. During times of high-lake levels, the water table is higher than during times of low-lake levels, and larger areas around the lake will be affected.

Wind Tides and Seiches

Sustained winds blowing across the surface of GSL push the water to the shore or dike and causeway where it "piles up," forming what is known as a wind tide or wind setup. The height or magnitude of the setup depends on the speed, direction, fetch, depth of lake at that point and duration of the wind. Wind setup exceeding two feet is not uncommon, and can cause localized increased flooding and damage. The combined effects of wind setup and high waves (wave runup) can produce adverse impacts to elevations five to seven feet above the static lake elevation and locally even higher. As these winds cease or diminish, the water begins to oscillate back and forth in the lake, similar to water sloshing from end to end in a bathtub. This movement is referred to as a seiche. The period of the oscillation, or the time it takes to move from high to low and back to high, is about six hours in the south arm (Lin, 1976, and Lin and Wang, 1978b) and shorter in the north arm. Earthquakes also have the potential to cause large-scale surges and seiches in the lake. During such surges and seiches, the elevated water may cause repeated, short-term flooding around the lake. The heights of earthquake-induced surges and seiches are unknown, but may well exceed the heights of wind tides and seiches. A 1909 earthquake is reported to have generated a surge that sent water over the railroad causeway and the pier at Saltair. The extent of flood damage in an earthquake affecting the lake will depend on the level of the lake at the time of the event.

Wind-Blown Ice

During the cold winter months, freshwater from the major tributaries to the lake flows out and over the heavier saline water of the south arm and also in Bear River Bay. If this water is not mixed, it freezes and can form large sheets of ice. As the winds blow, these sheets of ice are pushed around the lake and can destroy stationary objects within the lake and at its margins.

The *1995 Comprehensive Management Plan-Planning Process and Matrix* (the 1995 plan) recommended that all five counties on the lake should establish ordinances requiring that all structures built in and around the lake be designed for additional short-term lake elevations due to wind tides (and subsequent seiches), earthquake-induced seiches and waves. Wind tides can raise the lake an additional two to four feet. Structures should be built to withstand wind-blown ice in the southern part of the lake.

The 1995 plan recommended that site-specific studies be conducted, prior to development of proposed structures in and near the lake, to identify sensitive clays, soils susceptible to liquefaction, areas susceptible to earthquake-induced flooding and shallow ground water. In addition, the plan recommended that advice on geologic hazards and mitigation measures should be provided to applicable county planning, zoning and permitting agencies. UGS suggests that general hazard maps be made available to city and county planning, zoning and permitting agencies to identify where further site-specific studies are needed. Where such maps are not available, studies addressing all these potential hazards should be required for any development between the lake and the 4217 contour (or high elevation if required by the permitting agency). These studies should be reviewed for adequacy by the local government or their consultants (UGS performs such reviews), and steps should be taken by local government to ensure that recommended mitigation measures are implemented.

Sovereign Lands Boundaries

Uncertainties and Disputes

The meander line, which is the legal boundary between sovereign lands and adjacent lands, was established by a series of surveys over a period of years, and does not follow a topographical contour line around GSL. A number of the original survey markers and monuments have been obliterated, and the exact location of the sovereign/private boundary is uncertain in many areas. Specific areas of uncertainty and/or dispute include (Appendix B, Exhibit 2 for locations):

Bear River Duck Club (E1)
Ownership questions below meander need to be resolved.
Chesapeake Duck Club (E2)
Ownership questions below meander need to be resolved.
Canadian Goose Club (E3)
Ownership questions below meander need to be resolved.
Lands below the meander line in the proposed expansion of BRMBR
Lands below the meander line between Willard Bay and BRMBR

Boundary Resolution Strategies

Section 65A-10-3 requires DFFSL to consult with the attorney general and affected state agencies to develop plans for the resolution of disputes over the location of sovereign land boundaries. With respect to the areas identified above, the division has not yet prepared such a plan, but anticipates doing so in 2000 if the records search identifies potentially legitimate private ownership claims below meander.

Dikes and Causeways

Dikes and causeways in and around GSL serve a variety of purposes. Dikes are used to impound freshwater (e.g., BRMBR, WMAs, Willard Bay Reservoir), impound brine pumped from the lake or trap brine in the lake for brine extraction (e.g., Magcorp, IMC Kalium Ogden Corp., Morton) and protect facilities from high lake levels (wastewater treatment plants, sewage lagoons, power lines). Causeways are also used for transportation facilities along the shore or across the lake (I-80, northern and southern railroad causeways, Davis County Causeway).

Dikes and causeways influence lake level, salinity, habitat and the surface area of the lake. The influence of causeways on salinity is evident. Where dikes or causeways constrain the area over which the lake could expand in high water periods, the water depth along shores may be too deep for shorebird habitat. Similarly, the formation of wetlands along shoreline areas may be affected. Some dikes and causeways constrict lake hydrodynamics and tributary flows as the water moves toward the lake, thereby exacerbating local flooding.

With the exception of studies regarding proposed large freshwater impoundments (e.g., inter-island diking, Lake Davis, Lake Wasatch), assessments of effects have focused on the intended purposes of dikes and causeways. Effects beyond the immediate vicinity have received little attention in project planning.

Minerals and Hydrocarbons

Introduction

The state owns the minerals located in the bed and waters of GSL as public trust resources. The responsibility to manage the minerals of the lake, and of all sovereign state lands, has been assigned to the DFFSL by statute. The division has specific management responsibilities for minerals of GSL pursuant to Section 65A-10-18 of the Utah Code.

Internal and external scoping conducted by the planning team focused on the DFFSL MLP categories and policies.

Although GSL is renowned for its "salt" (sodium chloride or table salt), its waters actually contain other sodium, potassium (potash), calcium and magnesium salts. GSL contains salt from a variety of sources. Rain and snow in the mountains leached saline materials from soils and rocks and carried it in solution to streams that eventually flow into the lake (Miller, 1949). GSL may be as salty as it is because much of the salt was originally in the waters of Lake Bonneville and was concentrated as those waters evaporated (Trimmer, 1998). In addition, some believe that the lake's salts were leached from deposits of oceanic salt of Jurassic age which crop out extensively in Sanpete Valley within the GSL Drainage Basin (Eardley, 1938). Due to the terminal nature of GSL, salt delivered to it remains in the lake. Water entering the lake escapes by evaporation only. GSL presently contains 4.3 billion tons of salt in its system (Trimmer, 1998).
Other geological resources under and around the lake include mirabilite and epsomite, oil and gas, oolites and quartzite. Oil has been produced at Rozel and West Rozel oil fields and natural gas has been produced at Farmington Bay and Bear River Bay but commercial quantities of hydrocarbons have not yet been discovered.

Mirabilite and Epsomite

The most economically important salts in the lake are table salt, potash and magnesium chloride but mirabilite and epsomite are significant resources which have been produced from the lake. Mirabilite (sodium sulfate) is a mineral that is precipitated from highly concentrated lake brines during the cold winter months. This salt is not stable and redissolves as the brine warms in the spring except where it is enclosed in sediment at the bottom of the lake.

During the construction of the northern railroad causeway in about 1900, a deposit of mirabilite was discovered west of Promontory Point. Eardley (1963b) described the deposit as lying 15 to 25 feet below the bottom of the lake, interbedded with the soft lake-bottom clays, and having a maximum thickness of about 32 feet. The salt bed extends westward about 9.5 miles from a point one mile west of Promontory Point, and is bounded on the east by a fault.

When the pilings were driven during construction of the old Saltair resort on the southern end of the lake, a hard layer of mirabilite-cemented oolites was encountered. This layer was penetrated only by steam-jetting a hole for the pilings. Soon after the pilings were installed, natural recrystallization of the mirabilite solidly cemented the pilings in place. Mirabilite-cemented oolite beds have been found at numerous other places around the lake including: the South Shore Marina, the Antelope-Island Marina and the Morton Salt intake canal on the south end of Stansbury Island. They are probably present at many other areas around the lake. At one time, Great Salt Lake Minerals Corp. (now IMC Kalium Ogden Corp.) produced anhydrous sodium sulfate from winter-precipitated mirabilite. There is no current production of mirabilite.

Epsomite (magnesium sulfate) can be produced by the winter cooling of highly concentrated lake brines, such as those utilized by Magcorp in the production of magnesium metal and chlorine gas. Epsomite is not currently being produced from lake brines.

Rozel Point Oil Field

Naturally oozing tars have been collected from areas near Rozel Point, probably since pre-settlement times.

Shallow wells drilled near surface oil seeps at Rozel Point beginning in the early 1900s produced a small amount of oil from a fractured, Tertiary basalt reservoir. The field area lies on mudflats at the edge of the lake and is submerged at times of high lake levels. There are currently no active wells in the Rozel Point oil field. Cumulative production (to 1993) is 2,665 barrels of oil (Kendell, 1993a). The oil is thick with a high sulphur content making it difficult to produce and refine. Rozel Point field is discussed by Heylmun (1961b), Eardley (1956 and 1963a) and Kendell (1993a).

West Rozel Oil Field

Amoco Production Company drilled 15 wells in GSL, utilizing a floating barge-mounted drill rig, from mid-1978 to 1981. The drilling resulted in the discovery of the West Rozel field, a seismically defined structural feature, three miles west-southwest of the Rozel Point oil field. The structure is a faulted anticline about three miles long and more than a mile wide, covering about 2,300 acres. The discovery well produced two to five barrels of oil per hour during production testing from perforations located 2,280 to 2,410 feet below surface in Tertiary basalt. Cumulative production (to 1993) is 33,028 barrels of oil (Kendell, 1993b). The oil is very thick and high in sulfur, making it difficult to produce and refine. West Rozel is discussed by Bortz (1983 and 1987), Bortz and others (1985) and Kendell (1993b).

Additional Oil Shows

Additional oil shows were found in samples collected by Amoco during drilling in the south arm of the lake.

Farmington Gas Field

The Farmington gas field was discovered in 1891 near the shore of GSL about three miles southwest of Farmington. One well produced at a rate of 4.9 million cubic feet of gas per day from a depth of 850 feet. In 1985 a pipeline was built from the field to Salt Lake City and provided gas for 19 months until the gas was depleted or the wells sanded up. It is estimated that the field produced 150 million cubic feet of gas at a rate of 8.5 million cubic feet per month. The

Farmington gas field is discussed by Heylmun (1961a).

Bear River Gun Club

Natural gas has often been encountered while drilling shallow water wells on the Bear River delta. A water well drilled by the Bear River Gun Club was converted to gas production and provided natural gas for private use for many years until the well blew out. When attempts were made to plug the well, the gas flow cut away from the well bore and blew out through the soil. It took several days to control the flow which was estimated to be as large as a million cubic feet a day. There has never been any attempt to commercially exploit the gas resource from the delta.

Oolites

Oolitic sands are an unusual sediment type found in and around GSL at numerous locations. They are rounded, light-colored carbonate grains and range in shape from nearly spherical to cylindrical. Their surfaces are usually smooth, like a miniature pearl. The size of oolites ranges from 0.015 to 1.5 millimeters, with the average size being about 0.31 millimeters. The chemical composition of the outer shell consists mainly of calcium carbonate, though some calcium-magnesium carbonate (dolomite) is also present. The nucleus or central core is usually a mineral fragment or a brine-shrimp fecal pellet.

Some of the areas in which oolites are found include: (1) the west side of Stansbury Island in Stansbury Bay and the north end of the island extending northward past Badger Island, where beds up to 18 feet thick have been measured; (2) around Antelope Island, and especially in the area of the Bridger Bay bathing beaches, and (3) the southern shores of the lake.

Oolites have been used by Magcorp (and their facilities' prior owners) to neutralize the acidic gases produced during the processing of magnesium chloride brines into magnesium metal, and to produce calcium chloride which is used in the brine-desulfation process and as an industrial chemical. Oolites are also used as flux in mining operations and could also be used in most applications where limestone is used. Small amounts of oolitic sand are used to dry flowers.

Bioherms

Calcareous assemblages of flat, mounded algal deposits are called bioherms. These structures form as a result of calcium and magnesium carbonate by the blue-green colonial algae *Aphanothece packardii*. These unicellular algae are the most predominant algal bioherm builders. Bioherms are found in shallow water and near shore environments, where wave activity and subsequent circulation is strong, but algae must have a permanent base for attachment. Bioherms range from several inches to up to 12 feet deep. Bioherms are found along Stansbury Island, the north end of Antelope Island and along the west side of the Promontory Range (Eardley, 1938 and Cohenour, 1966).

Quartzite

Since about 1996 quartzite has been quarried on BLM land near the southwest end of Stansbury Island by McFarland Hullinger Company. The quartzite is sold to KUC for flux to assist copper smelting at Kennecott's Salt Lake Valley facility.

Mineral Industry Overview

Salt extraction is one of Utah's oldest industries and salt has been harvested from the waters of GSL for over 100 years (Miller, 1949). In addition, magnesium metal, chlorine and potassium salts are harvested through extraction processes. These newer industries began in the 1970s. Currently, all major ions contained in the lake water are extracted by solar evaporation in large pond systems (Trimmer, 1998).

There are currently six companies in the GSL minerals industry. These include IMC Kalium Ogden Corp., Magcorp, Cargill Salt, Morton Salt, IMC Salt and North Shore Limited (Appendix F, Exhibits 3 and 4). In 1997, existing aggregate data from DWRi indicate that in excess of 31 billion gallons of water were pumped from GSL by mineral harvesting companies (Hudon, 1998). Sodium chloride (NaCl, or table salt) is the first salt to be precipitated out as lake brines are concentrated, and it is either sold or is a waste product, depending on the focus of each company (Trimmer, 1998).

Magcorp produces magnesium metal from lake water at its electrolytic plant in Tooele County. Chlorine gas is also produced. The plant has a capacity to produce 40,000 metric tons of magnesium metal at 99.9 percent purity annually and is the fourth largest magnesium plant in the world as of 1996. Magcorp represents 28 percent of primary U.S. magnesium capacity (Kramer, 1998a). Magcorp sells some potassium-magnesium salts to IMC Kalium Ogden Corp. (Trimmer, 1998 and U.S. Bureau of Mines, 1996).

Morton and Cargill produce only sodium chloride and return bitterns, the concentrated brine that remains after sodium chloride has crystallized, to the lake. IMC Salt is the largest salt producer on the lake and buys salt from IMC Kalium Ogden Corp. IMC produces magnesium and potassium salts, primarily sulfate of potash (K_2SO_4) rather than muriate of potash (KCl). Sulfate of potash is a higher value product than KCl. IMC Kalium Ogden Corp. produces minerals such as kainite, schoenite and carnallite in its solar ponds which are then processed to remove magnesium, chloride and sodium ions, leaving potassium sulfate. Also, under certain conditions, potassium chloride is added directly to the process where it undergoes a base conversion into potassium sulfate. A significant portion of the sulfate of potash is exported to other countries. This company retains and sells the magnesium chloride brine, but flushes excess sodium chloride and some of the low-grade magnesium and potassium salts back into the lake. Sodium chloride build-up on evaporation pond floors is a problem for both IMC Kalium Ogden Corp. and Magcorp, although IMC is able to return some waste salts to the lake (Trimmer, 1998 and Gwynn, 1998b).

North Shore Limited produces magnesium chloride brines through solar evaporation. This product is sold for nutritional supplements (Trimmer, 1998) (Table 10).

Table 10. Mineral Table

Company	Production
IMC Kalium Ogden Corp.	Magnesium and Potassium Salts ($MgCl_2$, K_2SO_4)
Magnesium Corporation of America	Magnesium Metal (Mg), Chlorine Gas (Cl)
Cargill Salt	Salt (NaCl)
Morton Salt	Salt (NaCl)
IMC Salt	Salt (NaCl)
North Shore Limited	Magnesium Brines ($MgCl_2$)

(Trimmer, 1998 and Gwynn, 1998b)

Production Trends

The salt industry is characterized by high tonnage volumes at relatively low unit values and a product which is harvested far from markets. These products face intense competition within the industry both nationally and internationally (GSLTT and DSLF, 1995). Potassium sulfate is produced at a relatively high volume with higher value per ton, while magnesium metal is produced at a relatively low volume with a high value per ton (Trimmer, 1998). The estimated average price per metric ton of K_2O in 1997 is $140 (Searls, 1998). The estimated average price per metric ton of magnesium metal in 1997 is $2,700 (Kramer, 1998a).

Harvesting is also vulnerable to weather conditions and lake level changes. Cool and wet weather slows evaporation and concentration processes. Both low and high lake levels create problems for the mineral extraction industries. When lake levels are low, intake canals to pumps must be dredged and the pumps may need to be repositioned into deeper water (GSLTT and DSLF, 1995).

High lake levels, as experienced in the mid-1980s, are much more critical to the salt industries than low levels, due to the dilution of feed brines. The economic impact of increased erosion of dikes, dike failure and rebuilding or reinforcing of dikes at high lake levels can also cost millions of dollars (GSLTT and DSLF, 1995).

As the lake level rises and falls, the strength of the brine falls and rises. This inverse relationship is a result of a relatively fixed amount of dissolved solids within the lake coupled with a fluctuating amount of water. When inflow exceeds evaporation, the lake level rises and the extra water dilutes the lake brine. Dilute brine conditions require larger pond areas for a given tonnage of salt production. With a low lake level, brine strength is higher and therefore pumping and pond area requirements are lower for a given tonnage of salt, therefore producing a greater yield. This inverse relationship is particularly applicable to the south arm of the lake, although under some circumstances, similar impacts can result in the north arm of the lake as well (GSLTT and DSLF, 1995).

Salt and brine-derived products are the largest contributors to the value of industrial minerals in Utah. The production of salt and brine-derived products is expected to continue to expand over the next several years (U.S. Bureau of Mines, 1996). For instance, IMC Kalium Ogden Corp., the largest potassium sulfate producer in North America, plans to double current production (Warnick, 1998).

Value of Production

Because there are only six companies on the lake which harvest minerals, and only five mineral commodities are harvested, data on extraction must be presented in aggregate form. Therefore instead of reporting a unit value of the product, this section emphasizes the overall value of production of the minerals harvested. Although the dollar amounts of value of production of minerals extracted is held in confidence by DFFSL, general trends can be noted.

Overall, the value of production of potassium and magnesium salts has increased more than 12-fold since production began in 1973. The value of production of magnesium metal has increased 31-fold since production began in 1974, and the value of production of salt has increased 17-fold since 1970. These increases have not been steady however, as the value of production in all three categories declined periodically, particularly from 1986 to 1989 due to years of flooding. In total, minerals extraction from GSL amounted to a value of production of $231,611,752 in 1997 (Trimmer, 1998) (Figure 14).

Solar salt produced from GSL represents a significant and increasing share of total domestic solar salt production. The remainder of solar salt produced in the U.S. is primarily from California with some production from New Mexico. Solar salt competes in regional markets with rock salt for chemical and industrial, water conditioning and agricultural uses. Nationwide, the consumption of rock salt is four times that of solar salt. However, USGS data show that these markets are regional and, with respect to road salt, local. Solar salt dominates in western markets and appears to be increasing in certain Midwestern markets for certain end uses. DFFSL believes that the growth of regional solar salt markets, in

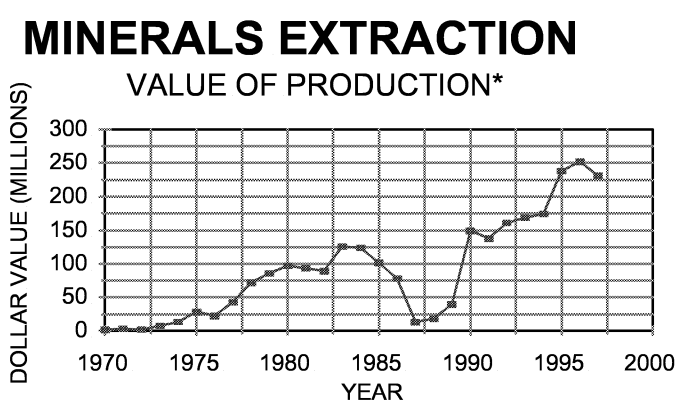

Figure 14 (Source: Utah Division of Forestry, Fire and State Lands)
* not adjusted for inflation

which Utah producers compete, could continue to grow at three percent per year over the next five years. This amounts to approximately 50,000 tons per year (Trimmer, 1996).

Production of magnesium metal in the U.S. declined by six percent in 1996 from 1995. World magnesium oversupply and high prices were primarily responsible. For the first time in 20 years, the U.S. imported more magnesium than it exported. However, the U.S. continued to lead the world in production and production capacity of primary magnesium (Kramer, 1998a). Utah magnesium production remained steady in 1996 while prices declined, primarily due to increased foreign competition (U.S. Bureau of Mines, 1996). Magnesium metal is used for aluminum alloying, diecasting, and automotive applications. However, demand for magnesium used in aluminum alloying dropped in 1996 and several U.S. auto manufacturers canceled some programs to incorporate more magnesium diecastings into domestic passenger vehicles due to rapidly changing magnesium costs (Kramer, 1998a).

The outlook for global use of magnesium diecastings in automotive applications is expected to continue to grow at 15-20 percent average annual growth rate. North America and Europe are expected to be the areas with largest growth. Although magnesium prices declined in 1996 through June 1997, they began to increase slowly from mid-year. Price fluctuations were not as widely varied as in recent history. From 1993 to 1995, prices fluctuated from $2,260 to $4,138 per metric ton (Kramer, 1998a).

U.S. production of magnesium compounds increased in 1996. Magnesium chloride was used mainly as a chemical intermediate. Magnesium chloride brines were used principally for road dust and ice control. $MgCl_2$ was used in agricultural, chemical, construction, environmental and industrial applications. Year-end magnesium compound prices in 1996 did not change from those at year-end 1995 (Kramer, 1998b).

The term potash denotes a variety of mined and manufactured salts, all containing the element potassium in water soluble form. The general term potash also includes potassium sulfate (K_2SO_4), which is produced in Utah (Searls, 1998 and Trimmer, 1998). Domestic potash production comes from New Mexico, Utah and California. Because it is a source of soluble potassium, potash is used primarily as an agricultural fertilizer. U.S. potash sales were approximately 88 percent to the fertilizer industry and approximately 12 percent to the chemical industry. Production of all types and grades of potash in the U.S. declined in 1996. Sales of all types and grades of U.S.-produced potash were unchanged from 1995 to 1996. Potash consumption was only slightly above the 1995 level in 1996 (Searls, 1998).

Royalties on State Minerals

Prior to February 1997, Cargill and Morton paid a $0.10 per ton royalty to DFFSL on salt extraction, while IMC's predecessor paid an *ad valorem* royalty of approximately two percent of the value of the salt. Currently, Cargill and Morton pay a $0.10 per ton royalty to DFFSL, with an additional amount paid into an escrow account which is controlled by the companies. DFFSL, which administers mineral leasing on

GSL, has adjusted the royalty rate to $0.50 per ton to be implemented over the next five to eight years. DFFSL reached a settlement with Morton Salt for a buyout of its outdated royalty agreement. This action is being contested by other mineral companies (Trimmer, 1998).

IMC Kalium Ogden Corp. pays an ad valorem royalty rate of 1.5-5 percent, increasing over time, on magnesium chloride and potassium sulfate. Magcorp pays a royalty rate of 0.1259-0.41967 percent, increasing over time, on sales of magnesium metal and chlorine gas. In 1986, these companies were allowed to roll back the royalty rate to year one due to flood damage. The royalty rate has continued to advance from this base rate since that time. North Shore Limited pays a royalty of five percent on the value of the brine with a $5,000 minimum royalty (Trimmer, 1998).

All of the above-listed royalties are put into the restricted Sovereign Lands Management Account. This money must be appropriated by the legislature for any use. To date, these funds have been used for DFFSL's operating costs associated with sovereign lands management and various sovereign lands projects such as the cooperative causeway salinity study with USGS and work related to Utah Lake, the Jordan River Corridor, Bear Lake and the Colorado River (Baker, 1998 and Kappe, 1998).

Royalty Revenues

Royalties paid to the state amounted to $1,056,367 in 1997. The percent of total value of production paid as royalties declined from 1970 to 1997 with the exception of the period from 1986-1987. Currently, approximately 0.61 percent of total production value is paid in royalties. For those companies that pay a fixed rate on salt harvesting, the percent of total value paid as royalties primarily declined during this time because the selling price increased (Trimmer, 1998).

Additional Research

More research might be useful in the areas of ion depletion and accumulation of waste salts.

Mineral Leasing Plan

On June, 27, 1996, DFFSL published its *Mineral Leasing Plan for Great Salt Lake*. Development of a mineral leasing plan was one of the key recommendations of the 1995 plan. The goals section of the MLP recites:

> "The purpose of the mineral leasing plan for the Great Salt Lake is to guide DSLF [now the Division of Forestry, Fire and State Lands] in accomplishing the following goals:

Integrate minerals resource planning with other resource planning.

> To create a framework for long-term policy direction for minerals management which also has flexibility to respond to the dynamic character of GSL
> To integrate management of GSL's mineral resources with the lake's other resources so that all resources are managed for the health and integrity of the GSL ecosystem
> To identify compatible uses and conflicts among mineral resource development and other resources on GSL and to provide for resolution of conflicts

To monitor impacts of minerals operations and to collect, analyze and use data to maintain health and integrity of the ecosystem, including its mineral resources

To monitor impacts of all diversion, dredging, causeway and diking operations and to collect, analyze and use data to maintain health and integrity of the ecosystem, including its mineral resources

Plan for leasing and efficient development of mineral resources.

To inventory and monitor GSL's mineral resources

To assure wise and diligent development of mineral resources within GSL's boundaries

To provide for the orderly leasing of mineral resources to existing and potential mineral lessees

To receive fair compensation for development and extraction of GSL's various mineral resources

Assert the role of DFFSL as a manager of state-owned lands.

To clearly define sovereign lands for resource users, the public and other resource management agencies

The MLP identifies and evaluates the mineral resources of GSL, impacts of diking and causeways, evaporative pond impacts and constraints, issues and conflicts and the relationships of mineral operations to the other trust resources present on GSL. The plan identifies areas of potential resource conflicts and addresses them by establishing leasing "zones" in the lake and creating mitigation strategies. The plan is the result of a multi-interest, public process conducted over many months.

Recreation, Tourism and Cultural Resources

Perceptions of GSL vary among local residents. Some find that the lake offers great beauty, quality recreation and significantly enhances the quality of their lives. Others view the lake negatively and find little value in GSL. Out-of-state tourists often view GSL as one of the most well-known of Utah's natural resources, and aspire to visit the lake while visiting northern Utah. The tourism industry and local residents alike desire greater access to GSL provided in a manner that does not impair lake resources (DPR, 1994).

The demand for recreational uses of GSL's resources is expected to grow in the future. The lake's extraordinary numbers of birds, magnificent sunsets and vistas, no-sink swimming, trails, wildlife, cultural and range resources, development of Antelope Island and open space next to a growing metropolitan area all indicate growing interest in visiting and recreating at GSL.

Based on internal and external scoping, the planning team identified a number of interests and concerns with regard to management of GSL's recreation resources, including:

- **Capacities and uses of existing recreational sites, marinas and other facilities are issues.**
- **Management of AISP needs to be considered.**
- **Recreational boat navigation through existing causeways is a concern.**
- **Camping, hiking, biking, trails, automobile touring and picnicking opportunities and access are issues to be considered.**
- **Hunting, birdwatching and wildlife management area access and opportunities need to be considered.**
- **Hunting and AISP user conflicts are issues to be addressed.**
- **Resource education and interpretation opportunities are issues to consider.**
- **Cultural resource protection needs to be addressed.**
- **Recreational off-highway vehicle (OHV) use on sovereign lands is an area of concern.**
- **A centralized south shore visitors/activities area needs to be considered.**

Although a large number of specific recreation-related concerns and issues were raised, the general themes related to the numbers and types of recreational opportunities available on GSL, user conflicts, the environmental impacts of recreational uses and educational and interpretive opportunities. Rather than devote discrete sections to discussion of each issue, this section provides a description of the kinds, locations and uses of recreational facilities and opportunities on GSL, existing interpretive and educational opportunities and programs and cultural resource protection and interpretation.

Recreation Sites and Opportunities on and around Great Salt Lake

Antelope Island
(DPR)

The largest island in GSL is Utah's largest state park. Reopened in July 1993, Antelope Island's annual visitation (currently at 350,000) has grown steadily, and the island has been identified by the Utah Travel Council as one of Utah's fastest growing tourist attractions. DFFSL has signed an MOU with DPR to allow AISP to manage sovereign lands surrounding the island as a buffer zone.

Antelope Island has been called the best place to see and experience GSL, given the island's sandy beaches, lofty overlooks and amenities. Antelope Island has a unique array of wildlife—abundant large mammals adjacent to concentrations of water birds of hemispheric importance. Ungulate species on Antelope Island include the third largest publicly owned bison herd in the nation, pronghorn, big horn sheep and mule deer. The island's east shore is dominated by freshwater seeps and wetlands and is connected to the mainland marshes by playas off the south end of the island. This array of wildlife, accompanied by limited access provides outstanding wildlife viewing opportunities.

Antelope Island has important cultural sites, most significant of which is the Fielding Garr Ranch. The Fielding Garr Ranch contains some of the oldest anglo-constructed buildings in Utah and was the home ranch for some of Utah's largest ranching operations from 1848-1981. The site's interpretive focus is on the length of occupation and the evolution of large- scale western ranching from pre-mechanization to mechanization. Recreational opportunities and development include, scenic drives with bicycle lanes, a back country trail system, campgrounds and picnic areas, interpretive information and programs, a swimming beach and a marina. A private concession business, food and souvenirs, a small tour boat and guided horseback rides are located on the island.

Significant educational opportunities are available on Antelope Island. DPR, in partnership with Davis County, developed a 5,200 sq. ft. visitor center overlooking the lake. Interpretive exhibits and programs focus on GSL including Antelope Island and the other surrounding resources. The Fielding Garr Ranch is open daily and is another important historical interpretive venue. Opportunities for self-directed interpretation are available with nature trails, wayside exhibits and publications. An outdoor amphitheater, located at the visitor center enhances the park's ability to provide personal programs. The park provides educational talks to thousands of school children per year and the proximity to universities and significance of resources allows for a number of outside research projects.

Challenging issues confront AISP. Foremost is to provide greater access while still protecting the park's resources. Park staff have identified critical habitat which is inappropriate for access and development. Managing the back country non-motorized trail system is a particular challenge and management has instituted a program of area and time of use limitations. The park has an independent, outside Wildlife Committee to advise management on resource-based issues. The park is initiating social carrying capacity and wildlife protection studies in an attempt to quantify and safeguard the quality of visitor experience. Other significant issues facing the park include the potential development of a southern road access to the island, separation of waterfowl hunters from traditional park visitors, overflights from aircraft and increasing visitation and use.

Great Salt Lake Marina
(DPR)

The GSL Marina is the most popular launching and mooring site on the lake. The marina is a highly developed, attractive and safe mooring site for approximately 300 sailboats. Given the marina's proximity to Salt Lake City and level of development it is generally filled to capacity. The marina also provides access to the lake for boaters who do not moor their vessels at the site. Two tour boats operate occasionally on the lake—one based at Antelope Island and the other at the GSL Marina. The park staff offers educational talks by reservation. Visitation to GSL Marina in 1999 is estimated at 136,496.

Willard Bay State Park
(DPR)

Willard Bay Reservoir is a U.S. Bureau of Reclamation project which provides water for irrigation, M&I use, flood control, recreation, fish and wildlife purposes. The dike that separates Willard Bay from GSL is 36 feet high and 14.5 miles long. When the reservoir is full, it exceeds the elevation of GSL. When reservoir water levels are low, GSL's old shoreline is exposed on the south and southeast side of the reservoir. DPR manages the recreation resources and facilities, and DWR manages the fish and wildlife.

Visitation to Willard Bay State Park in 1997 was 461,000. This level of use is causing some user conflicts and degradation of the park facilities. The first phase of a Bureau of Reclamation-sponsored Resource Management Plan (RMP) has been completed. Major renovation of facilities will begin in the spring of 2000. The RMP effort will identify management goals and objectives for the reservoir. Some important issues which have emerged include improving coordination with other entities, resolving user conflicts and expanding educational and interpretive opportunities. Water quality, management of concession services, visitor needs for additional recreational facilities to reduce congestion, improved safety and resource protection are other issues to be addressed in the RMP.

Saltair/South Shore
(DFFSL)

This recreational complex consists of south shore beach areas and the Saltair Resort. It offers access to the lake and has an attractive visual impact, with its open expanse, islands and beautiful sunsets. Birding opportunities are also significant. Saltair Resort provides interpretive information, food, souvenirs, an historic site and special events ranging from concerts to beach festivals. This site provides the quickest and easiest access to the lake from downtown Salt Lake

City. The entire south shore beach area and the marina were managed by DPR as GSL State Park. Management of the South Shore Beach Area was returned to DFFSL in 1997. At that time, over 600,000 people visited GSL State Park.

There are a number of challenges inherent to the site including fluctuating water levels, odors and proximity to the Kennecott Copper Smelter.

Rozel Point
(DFFSL)

The Spiral Jetty is a famous international work of art. It is an “earthwork sculpture” on sovereign land off Rozel Point in the north arm of GSL. The jetty was constructed in 1970 by Robert Smithson. In the years following its creation it received a wealth of publicity in the national press, photographs in every major art periodical, in surveys of 20th century art and magazines of more general circulation. The Spiral Jetty is among the classics of modern sculpture and has been viewed by many international visitors (Appendix B, SULA 889).

Rozel Point is also one of the few access points to the north arm of the lake. Access is through the Golden Spike National Historic Site and visitors can obtain a map at the visitor center. There are no facilities at Rozel Point and the site has suffered from unauthorized dumping and construction which detracts from the beauty of the location. DFFSL is working to clean up the site.

Farmington Bay Waterfowl Management Area
(DWR)

This 17,916-acre management area is one of the most popular waterfowl hunting areas in Utah and also is an outstanding birding area. Farmington Bay WMA is unique in that it provides important wetland habitat and wildlife-based recreation close to an urban area. The management area is also one of the best places to observe the freshwater interface with GSL. DWR manages their WMAs to provide habitat for water-dependent birds.

Currently the Farmington Bay WMA receives 48,644 visitors annually. Of this, 20,644 are waterfowl hunters and the rest are birding or other recreationists. Staff has identified March 1 through August 1 as a critical wildlife production period. During the critical production period, a 1.5-mile road is opened, with an overlook and interpretive signing and an additional 2.5 miles is opened for non-motorized use. During the non-critical production period another 26 miles of dikes are opened to non-motorized use. An air boat ramp is opened from two weeks prior to hunting season through the hunting season. DWR is pursuing funding for enhanced visitor use development, possibly including a visitor center on the north end of the management area to enhance lake-wide interpretive and education efforts.

A number of critical issues confront the Farmington Bay WMA. These include potential impacts from the proposed Legacy Parkway, maintaining adequate water supply and water quality from the Jordan River, flooding from GSL and urban development on the boundary of the management area.

Ogden Bay Waterfowl Management Area
(DWR)

Ogden Bay WMA is over 21,000 acres and is the largest WMA in the state. Besides being a tremendous waterfowl production and habitat area, it also contributes significantly to recreation around GSL. The area hosts 70,000 visitor days per year, with 28,000 of those days representing hunters during the fall waterfowl season. A portion of the area is open year round for hosted organized group tours, appointments must be made with the Area Superintendent. From April 1 until September 1, the area is closed to general public use to protect wildlife habitat values. During the balance of the year, some portions of the area are open for wildlife viewing and hunting is allowed during prescribed seasons. There are approximately 45 miles of dikes that control water, one air boat launch that allows access to the Ogden Bay portion of GSL and several small boat ramps that allow access to interior ponds of the management area.

Water control is a critical issue at Ogden Bay WMA. The area is vulnerable to flooding, both from the Weber River and GSL. Ogden Bay is one of the oldest WMAs in Utah and has senior water rights.

Howard Slough Waterfowl Management Area
(DWR)

Howard Slough WMA is located along the GSL shoreline between the south boundary of Ogden Bay WMA and the Davis County Causeway. The area was created in 1958 to utilize irrigation water return flow to create an impounded marsh and wetlands of more than 3,500 acres. This relatively small area hosts up to 11 percent of all waterfowl hunter days in Utah. There are approximately 11,000 visitor days annually, which includes both wildlife watchers and hunters. Exact figures are difficult to establish because the manager of this area resides at Ogden Bay. The area is closed for general public use from April 1 until September 1 to protect wildlife habitat values. Different portions of the area are open during the balance of the year for wildlife watching and hunting during the prescribed seasons. There are approximately 7.5 miles of dikes and roadways that provide pathways for access. There are several small boat ramps that provide access to interior ponds.

Most of the ponds have dikes that front the GSL shoreline. At current lake elevations of 4203.5, these dikes are being destroyed by wave action and over-topped by salt water from the lake. This saline intrusion kills the aquatic vegetation within the interior ponds sometimes resulting in diminished wildlife habitat values.

Locomotive Springs Waterfowl Management Area
(DWR)

Locomotive Springs WMA is an isolated wetland at the north end of GSL. This 17,317 acre WMA is an oasis for wildlife in the middle of the west desert. Currently, the staff is able to flood approximately 1,200 acres and the rest of the area is comprised of playas and upland habitat. Locomotive Springs provides year round fishing and primitive camping. Public access is limited to three miles of roads. During hunting season the entire WMA is accessible. Locomotive Springs receives approximately 6,000 visitors a year, of which 5,000 are hunters and fisherman. Future plans include expanding the WMA by 2,600 acres to include protection of playas which are Snowy plover habitat. The critical issue at Locomotive Springs WMA is the diminishing flows from the springs.

Timpie Springs Waterfowl Management Area

(DWR)

Timpie Springs WMA is a 1,440 wetland located near the southwest corner of the lake. Timpie Springs WMA contains two water impoundments, 3.5 miles of dikes, a half-mile road, parking lot and some information signs. Timpie Springs has around 400 annual visitors of which approximately 300 are waterfowl hunters. Critical issues at Timpie Springs WMA include adjacent land use, water allocation and management.

Stansbury Island

(BLM/Private)

Only a small area on the south end of Stansbury Island is opened to the public and readily accessible. Development consists of an access road and a nine-mile trail on the west side that is open for non-motorized use. Stansbury Island is comprised of some of the most striking rock formations surrounding GSL. The island's vistas of the lake, mountain ranges and islands are dramatic. Currently the south end of Stansbury Island is utilized for dispersed recreation including the non-motorized trail, camping, some OHV use and chukar hunting.

There has been a great deal of local interest in securing greater public access to Stansbury Island, for both motorized and non-motorized recreation. Given the island's size, location and resources, greater public access would significantly expand recreational opportunities surrounding GSL. The legality of the west side road closure is uncertain. BLM is willing to work with private landowners to secure better public access to the northern portion of the island and then coordinate management with the state if the northern portion is made accessible. The greatest challenge will be to secure greater public access from private land owners and then appropriately manage that visitation if made accessible.

Monument Point

(BLM/DFFSL)

The 700 acres which make up Monument Point and the immediate section to the north are lands owned and managed by SITLA and private landowners. These lands have been used in trespass by OHV users. The Monument Point area offers pedestrian access to Spring Bay and the north arm of the lake, a stunning vista of one of the lake's most remote reaches, and nearby historical sites. BLM manages the old Central Pacific Railroad Grade as a Back Country Byway, complete with kiosk and interpretive signs at each siding, or what once were siding locations. BLM encourages driving or riding on the grade only, and discourages motorized use on surrounding, unroaded, BLM lands. BLM marshlands or wetlands at Salt Wells Flats, and between Locomotive

Springs and the Crocodile Mountains, have been posted closed to all vehicles. The Salt Wells Flats has been identified as an Area of Critical Environmental Concern (ACEC) to protect this unique wetlands resource. The key challenge at, or surrounding the Monument Point area, is managing a growing, illegal use of motorized vehicles on state, private, and BLM lands. "No Motorized Vehicle" signs have been posted on BLM lands, but they are torn down or vandalized within weeks, resulting in abuse of the resources. BLM may be interested in securing a land exchange in the Salt Wells area to complement the ACEC.

Davis County Causeway

(Davis County)

In return for maintaining the causeway from Syracuse to Antelope Island, the State of Utah deeded the roadway to Davis County. Davis County now manages this causeway in cooperation with DPR. The Davis County Causeway is one of the most scenic drives around GSL, and is an outstanding birding area. The bike lanes provide one of the most popular cycling tours in northern Utah. Davis County has developed a trail head parking lot for cyclists and other areas with interpretive information on GSL.

The primary issue facing the causeway is maintaining the roadway at high lake levels. The causeway was constructed at an elevation of 4208.75. The causeway is essentially a toll road, and $7.00 per vehicle collected is by AISP. Of this, $2.00 is returned to Davis County. Davis County utilizes these funds to maintain the causeway. There has also been some concern that the causeway restricts water flow from Farmington Bay to the south arm of the lake and inhibits brine exchange between the bay and the main body of the lake. This results in freshening of Farmington Bay relative to the rest of the lake. This issue is discussed more completely in the "Water-Hydrology" section.

Southern Causeway

(KUC/Private)

This unpaved causeway fill was constructed to provide a transportation route for material to complete I-80 reconstruction and to stabilize the island access road. The southern causeway provides administrative access to the south end of AISP. Occasionally, a few private landowners allow recreational activities.

At the present time, DPR does not have plans for major improvements of the existing corridor. The division would support minimal development for management access for emergency ingress and egress as well as access for non-motorized (hiking, biking) use. The division would support "low-impact" use of the corridor because of the various recreational and wildlife viewing opportunities in the area.

While the development of an access road is feasible in terms of engineering and function, development of an enhanced causeway for general access to Antelope Island would entail expenditures that are beyond the division's current budgetary scope and priorities. Similarly, the current operations, maintenance and law enforcement resources necessary to effectively manage a developed causeway would be pressed beyond reasonable limits.

The division has used the corridor for emergency purposes such as fire control and search and rescue activities during low lake level years. The division is also responsible for ensuring access to various structures owned by the FAA on the island. In lieu of any development activities, the division will continue to maintain an easement for access along the corridor.

Private Duck Clubs
(Private)

There are over 25 duck clubs with combined area over 50,000 acres around GSL. Duck club properties have been formed by private groups that acquired waterfowl habitat or lands that were developed into habitat. Many of these areas are intensively managed with extensive diking systems and water control structures that allow for optimum wetlands and foraging areas for birds. Many species of birds and other wildlife occupy these areas besides waterfowl. Some duck clubs have existed for over 100 years and they cumulatively have made a significant contribution to protecting and developing wetlands on and around the lake. Many duck clubs are adjacent to state and federal marshes and form a continuum of similar developments and habitat. There are 13 clubs on the south shore of GSL that total more than 16,791 acres of managed wetlands for waterfowl habitat (Dunstan and Martinson, 1995). All of the clubs are used for hunting by members only and use is regulated with bylaws. Members also utilize the areas for wildlife observation and nature study. Other opportunities include fishing, birdwatching, walking, bicycling, ice skating and photography. The primary goal of the clubs is to create high quality wetland habitat that is used by wildlife. These areas play a significant role for waterfowl during all parts of the year including hunting seasons. Hunter activity on duck club property is relatively less than on most publicly owned and used marshes. Therefore these areas become a daytime sanctuary for waterfowl feeding and resting. Many clubs only allow hunting on selected days during the week. The net effect provides for a mosaic of habitats available to waterfowl with varying degrees of security over the course of the hunting season.

Bear River Migratory Bird Refuge
(USFWS)

At 74,000 acres, BRMBR is considered one of the premier birding sites in the nation. Given the refuge's beautiful scenic background, isolated nature and sheer abundance of water birds, its complex of freshwater impoundments has long attracted birders from around the country and is one of the best places to experience the freshwater marshes of GSL. The refuge is recognized internationally and was integral to GSL's designation as a Western Hemispheric Shorebird Reserve. The refuge is also one of the finest waterfowl hunting areas in Utah. Currently the refuge is visited by 36,000 people annually, with 11,660 being waterfowl hunters. In addition, annual visitation includes 21,000 auto tour route visits, 1,155 fishermen and 2,185 others (Bull, 1998).

The refuge was damaged extensively during the 1980s flooding, and is being rebuilt ever since. Currently the refuge offers a 12-mile scenic drive that is popular for birding and bicycling, interpretive information, an air boat ramp that is open during hunting season and expanded access during hunting season. Fishing is allowed in the Bear River channel. USFWS is developing plans for a visitor center to be constructed near

Brigham City. This visitor center will dramatically expand interpretation opportunities of GSL's concentration of water birds. The visitor center is scheduled for completion by 2002. Currently the refuge offers educational tours by reservation. Management is working on a plan that will allow expanded fishing access, foot trails and a short canoe trip.

Given USFWS's dual mandate of protecting migrating birds and providing opportunities for hunting, the refuge follows a management mandate practiced throughout the agency. That is, 60 percent of the refuge is closed, 20 percent is open throughout the year and an additional 20 percent is opened only during hunting season.

Issues facing BRMBR include; safeguarding a dependable freshwater flow throughout the year, balancing hunting with watchable wildlife activities (consumptive and non-consumptive uses), protection from industrial encroachment along the southern boundary and utilizing sovereign lands for refuge purposes.

Layton Wetlands Preserve

(TNC)

The Layton Wetlands Preserve protects approximately 3,500 acres of wetland and upland habitats. TNC's stewardship goals are based on improving the long-term viability of specific conservation targets identified within a conservation planning framework. Conservation targets include plants, animals, natural communities and ecological systems. The preserve is an excellent teaching environment and TNC facilitates research, educational and interpretative tours, and volunteer work projects.

Waterfowl hunting is allowed on a portion of the preserve for which DWR holds a hunting easement. Certain activities and areas of the preserve are restricted.

Critical issues facing the preserve include inappropriate infrastructure and development in the flood plain, fragmentation and loss of buffer habitat, water quality and water quantity reaching the preserve and disturbance of wildlife during production periods (Peterson, 2000).

Inland Sea Shorebird Reserve

(KUC)

This 4,500 acre reserve was developed by KUC to mitigate for the tailings modernization and expansion project. The reserve features a relatively large contiguous acreage to provide nesting and resting habitat for migratory shorebirds and waterfowl. The reserve utilizes brackish water with mudflats and marshes to maximize invertebrate populations as food sources for birds.

Currently there is no public access to the reserve, though staff provides educational tours by appointment. Once mitigation has proven successful and COE accepts the mitigation results (scheduled for 2002), Kennecott could potentially open the reserve for greater public access. The most significant issues to the Inland Sea Shorebird Reserve would be trespass by hunters and encroachment from a potential southern road access to Antelope Island.

Gillmor Wildlife Sanctuary
(National Audubon Society)

This 1,425 acre sanctuary was donated to the National Audubon Society to preserve the natural ecosystem of GSL. The Audubon Society places value on all components, both biotic and abiotic, of the ecosystem. The sanctuary is comprised of a variety of habitats, from open water to playas and upland areas. It is situated on the former Jordan River delta, which is considered to be the best preserved river delta on GSL.

The Audubon Society is working with URMCC to develop a hydrological engineering plan to restore water to the natural waterways of the Jordan River Delta. The plan will encompass the South Shore Wetland Ecological Reserve, which is comprised of the Gillmor Wildlife Sanctuary and parcels of land owned by several other private land owners. Currently, public access is not available to the sanctuary as it is surrounded by private land. The National Audubon Society is working on a management plan that will address the public access issue. The most significant issues facing the Gillmor Wildlife Sanctuary are a potential southern road access to Antelope Island and trespass by hunters.

Promontory Point
(Private)

Promontory Point offers a striking vista and is the only location that could provide access to both the south and north arms of GSL. The site is currently accessible via a public road, but the surrounding lands are almost exclusively in private ownership. There has been interest in acquiring greater public access to this interesting location. Multiple private land owners surrounding this site will make any expansion of public access difficult.

Recreational Activities on Great Salt Lake

Most of the recreation that occurs on GSL is dispersed in nature and visitor counts are not well quantified.

Navigation

The navigability of GSL, which is a key component of establishing state ownership under the Equal Footing Doctrine, was challenged by the Justice Department early in the contest over ownership. This challenge was based on the theory that the shore lands were remote, and in most places along the shore the water was so shallow that it would be impracticable to construct facilities for meaningful navigation on the lake. Utah was successful in proving that, both before and after statehood, the lake had been used for a variety of navigational purposes (UGS, 1980). Historical navigation includes watercraft use during construction of the Lucin Cutoff (the original northern railroad trestle and earth-fill), and tour boating during the heyday of resort development on GSL. Present navigation includes recreational sailboating, most of which occurs within six miles of the two marinas operated by DPR, a small tour boat which occasionally operates out of the Antelope Island Marina, a commercial tour boat that operates out of GSLM, commercial brine shrimp harvesting, salvage of the old railroad trestle, air boating, some power boating and law enforcement. Brine shrimp sampling, water quality monitoring and lake bottom measurements collected by the state and extraction industries along with search and rescue activities require boat access.

Two box culverts in the northern railroad causeway between Little Mountain, Promontory Point and Lakeside initially allowed small watercraft to pass between the north and south arms of the lake through the causeway under certain lake levels. The culverts are no longer useful for this purpose. The breach near the west end of the causeway is not generally deep enough for navigation by deep bottomed craft. However, during 1997-98 numerous large brine shrimp harvesting boats navigated through the breach. Some crafts as long as 44 feet, 14 feet wide and less than 2.5 feet draft successfully navigated through this opening. As lake level changes, the height of the boat becomes the limiting factor in clearing the bridge.

In addition to the constraints associated with the causeway, navigation on the north arm is limited by the lack of launch and harbor facilities. Islands in the north arm provide critical bird nesting sites and are somewhat better protected by the causeway's restriction on navigation.. Development of facilities to accommodate north arm navigation would have to be planned carefully to minimize encroachment or visitation to the very sensitive nesting colonies.

Boating

There are two public boat ramps open year-around on the south arm; GSL Marina and Antelope Island. Both of these marinas offer safe mooring sites and are developed. These marinas are utilized almost exclusively by sailboats. GSL Marina sponsors a large number of sailing races and festivals in conjunction with the Great Salt Lake Yacht Club. Motor boating is feasible but not popular. The corrosive nature of high salinity in the lake demands extra care and rinsing of engines and equipment. Navigation in the lake demands a high level of expertise; there is no fishing, and water skiing is not popular. These factors have prevented GSL from becoming very popular for motor boating. Approximately 300 sailboats are moored at the GSL Marina and an additional 25 at the Antelope Island Marina.

Farmington Bay WMA has the only public boat ramp in Farmington Bay. This ramp is suitable for air boats and small vessels only. The ramp is open from two weeks prior to hunting season through hunting season. Ogden Bay WMA, BRMBR, Bear River Bay and Willard Spur all have boat ramps suitable for small vessels and air boats. The north arm does not have a public boat ramp.

Non-Motorized Recreation

AISP has an extensive back country trail system (35 miles). Currently, well over 10,000 people a year utilize the Antelope Island back country trail system. Stansbury Island has a nine-mile trail. DWR WMAs have extensive dike systems open for cycling. BRMBR has a 12-mile graveled auto tour open for cycling. The Davis County Causeway is seven miles long with bike lanes in both directions.

Camping

The developed campgrounds of Antelope Island are used by approximately 25,000 campers per year. There are 26 individual and five group camping sites at AISP. There is dispersed camping on BLM lands on Stansbury Island and in the area of Monument Point. Locomotive Springs WMA also allows camping.

Off-Highway Vehicles

Many of the public roads along the north and west sides of GSL in Box Elder County are open to OHV use. Sovereign lands surrounding GSL are not open to recreational use by OHVs. Through participation on the West Box Elder Access Management Team, DFFSL is anticipating the opening of limited sovereign lands to OHV use in the vicinity of Kelton.

Birdwatching

GSL is one the most renowned birding areas in the U.S. Avifauna associated with GSL and its periphery are abundant and diverse including migratory waterfowl, shore and wading birds, and marsh-associated songbirds. Over 250 different species have been identified. Several million individual birds use GSL throughout spring, summer and fall migration. GSL also has one of the largest concentrations of bald eagles in the 48 contiguous states during winter (DWR and Great Salt Lake Site Assessment Team, 1997). Nearly all the recreation areas identified above have outstanding opportunities for birding.

Hunting

GSL is the most important waterfowl hunting area in Utah. It is estimated that 63 percent of Utah's total waterfowl hunting occurs at GSL, with 80-85 percent of all waterfowl harvested in Utah coming from the GSL area. The state WMAs and parts of the BRMBR were purchased and are maintained by revenues and taxes from hunting. The state WMAs, BRMBR, sovereign lands and many private lands are open for hunting. The estimated number of waterfowl hunters utilizing GSL and environs in 1996 was 22,700 and 1998 was 22,593. The estimated number of hunter days on state-managed areas around the lake in 1996 was 53,700 and 1998 was 43,119. These numbers are impacted by lake level fluctuations, bag limits and hunting regulations (Aldrich, 1998 and 2000).

Sightseeing (auto tours)

AISP and the Davis County Causeway combined offer a 42-mile round trip auto tour. BRMBR has a 12-mile auto tour. The Monument Point area and surrounding lands have many miles of remote dirt roads for auto touring. The lack of a public thoroughfare between Lakeside and Hogup Ridge on the lake's western shore precludes circumnavigation of the lake by automobile.

The impacts to the existing transportation facilities at GSL are discussed in other sections of this statement, including "Water-Chemistry." Access to and on sovereign lands is discussed in the sections which addresses the uses for which access is provided.

Interpretive and Educational Opportunities at Great Salt Lake

Interpretive and educational programs have been significantly enhanced in recent years. AISP has developed a

5,200 sq. ft. visitor center on Lady Finger Point to provide interpretative and educational opportunities. The Fielding Garr Ranch is open and provides self-guided historical interpretive opportunities. Picnic and parking facilities are available. The park has wayside exhibits, nature trails, educational tours, and interpretive talks. The Salt Lake Convention and Visitors Bureau has opened a visitor center with information about GSL, Salt Lake City, and the rest of the state. The visitor center is located at the 7200 West exit on I-80.

BRMBR breaks ground on a new visitor center in 2001. Completion is scheduled for 2002. Farmington Bay WMA is initiating an effort to significantly expand interpretive development and visitor services for their north end.

URMCC completed a *Needs Assessment and Conceptual Plan for Interpretive Recreation and Education for the Greater Great Salt Lake Wetlands Ecosystem* (1995). One of the commission's key objectives of the plan is to: "Create an umbrella concept under which all local projects play a role; the entire scheme should be a nonrepetitive delivery of messages, each site carrying appropriate messages for that site and complementing efforts at other sites, thereby encouraging people to visit another location." To begin implementing this objective, the URMCC, in cooperation with DWR, is developing a "Wetlands Ecosystem Education Plan," which should be completed in 2000. A master plan should also be completed by 2000. The plan will specify a comprehensive educational program and, when implemented, will enhance diverse audiences' understanding of the functions, values and importance of the greater GSL ecosystem wetlands, threats to these wetlands, and means to protect and restore them.

Layton Wetlands Preserve is working on a plan to implement an interpretive program at the preserve. Most of the GSL attractions offer educational tours by reservation or appointment. Friends of Great Salt Lake has an hour long interpretive slide show, called *The Lake Effect, Living Together Along the Shores of Something Great*, and outreach programs designed to educate people about lake resources and issues.

The MLP for GSL specifies DFFSL will work with mineral lessees to provide interpretive displays of mineral development sites with particular emphasis on contributions to Utah's economy and recognizing effective mitigation efforts on the lake.

Cultural Resources on Great Salt Lake

Human activity in the region has been drawn to the lake shore for thousands of years. Prehistoric archaeological sites have been documented in and adjacent to lake wetlands. Several of the oldest documented cultural sites in the mainland U.S., Danger and Hogup Caves, are located in the lake environment.

Jim Bridger is credited with the Anglo discovery of the lake. The lake was the focus of early mountain man expeditions, government expeditions and wagon trains which crossed close to the shore, sometimes with ill-fated results. With the arrival of the Mormon pioneers, resorts and other economic enterprises sprang up along the lake shore.

Cultural resources of GSL have been the subject of much research, primarily by agencies and institutions external to DNR. State agencies are required to consult with the Division of State History prior to the initiation of any project which may disturb cultural resources.

Prehistoric Resources

Use of GSL wetlands started with Paleoindian cultures as long as 10,000 years ago. Cultures primarily utilized areas immediately adjacent to wetlands. Paleoindian and later Archaic cultures utilized areas adjacent to wetlands for thousands of years. The Fremont Culture which flourished in the GSL valley from 500-2,000 years ago built permanent villages along the wetland margins. The Fremont, Paleoindian and Archaic groups hunted and gathered in the wetland ecosystem. The Fremont added farming corn, beans and squash to their subsistence base. Fremont remains are found connected to nearly every wetland around the lake. Subsequent cultures, the late prehistoric and historical tribes, also made extensive use of GSL wetlands. Today, there are nearly 400,000 acres of wetlands on GSL. Several hundred Native American archaeological sites have been identified in GSL wetlands.

Well known sites such as Danger Cave and Hogup Cave are situated near wetlands of former Lake Bonneville. Cultural deposits along GSL have supplied valuable information about prehistoric cultures. Currently, most protection of cultural resources is done through state and federal agencies, to ensure development complies with state and federal law. Cultural deposits in GSL wetlands can be difficult to locate as they are usually buried under the surface or obscured by vegetation. Often erosional events, such as wave action associated with high lake levels, expose previously buried archaeological sites and, in the past, Native American human burials have been exposed..

The most immediate threat to prehistoric cultural resources is construction activity adjacent to the east side of the lake, such as the proposed Legacy Parkway. The Division of State History is confident that when surveying and construction is undertaken in these areas, numerous Fremont camp sites and human burials will be discovered in affected wetlands. This will necessitate archaeological surveys and compliance with the Native American Graves Protection and Repatriation Act (NAGPRA). If these human remains are treated in the same manner as those which were exposed after the 1980s floods, they will be deposited in the Native American Remains vault at This Is The Place State Park.

Unique prehistoric and historical cultural resources of significance have been identified on Fremont Island. Prehistoric sites including rock art have been discovered on Stansbury Island and elsewhere around GSL. Antelope Island contains prehistoric sites, and active cultural surveying will continue. Cultural resource management on state lands along the east shore is conducted on a case-by-case basis as projects are undertaken or discoveries made. It has been suggested by some archeologists that the state conduct regular monitoring of sensitive areas.