1.0 Introduction

Great Salt Lake is of vital importance to resident and migratory birds, local recreation, and the brine shrimp and mineral industries. In recognition of this importance, and in response to increasing development pressures within the lake's watershed, the State of Utah initiated a program to complete research supporting the development of a site-specific selenium numeric water quality standard for the open waters of Great Salt Lake. This document summarizes this program and its recommendations.

This section of this document describes the physical setting of Great Salt Lake, the study area, lake conditions during the study period, and this document's organization.

1.1 Physical Setting

Great Salt Lake is a uniquely dynamic terminal lake located adjacent to a rapidly growing metropolitan area in northern Utah (refer to Figure 1-1). Its approximate watershed area is 21,540 square miles, extending over three states, with an estimated population exceeding 1.9 million people in 2003. Population in the watershed is expected to increase by almost 75 percent by the year 2030 (Governor's Office of Planning and Budget, 2005). Changes in land use, hydrology, and water quality as a result of this population growth will add further dimensions of complexity to the lake's dynamics.

Great Salt Lake is the largest remnant of the ancient Lake Bonneville, which existed from about 32,000 to 14,000 years ago and once covered about 20,000 square miles of western Utah, eastern Nevada, and southern Idaho. A natural dam gave way about 16,000 years ago, resulting in a large flood that drained much of Lake Bonneville. Increased evaporation over the following millennia has led to the present-day Great Salt Lake, occupying the lowest depression in the Great Basin. As is characteristic of terminal lakes, Great Salt Lake has no outlet; water that flows in can only evaporate or percolate into the substrate.

Great Salt Lake is the sixth-largest lake in the United States and the world's fourth-largest terminal lake. It varies significantly in size and depth as a result of changes in inflow from precipitation, tributaries, and groundwater, as well as from losses through evaporation. At a lake elevation of 4,200 feet, the lake is about 75 miles long and 30 miles wide, and has about 335 miles of shoreline. It occupies more than 1,700 square miles and contains more than 15 million acre-feet (or almost 5 trillion gallons) of water. Great Salt Lake's shallow depths (its maximum depth is about 35 feet) and its gradually sloping shoreline result in dramatic surface area variations with any increase or decrease in lake level. Lake levels fluctuated more than 20 feet between 1873 and 1963, which had elevations of 4,211.5 and 4,191.35 feet, respectively. The lake's surface area fluctuated between 938 and 2,500 square miles in that same period (Hahl and Handy, 1969). The lake level rose 20.5 feet after 1963 to reach its record high level of 4,211.85 feet on June 3, 1986. The net rise between 1982 and 1986 was 12.2 feet (Arnow and Stephens, 1987).

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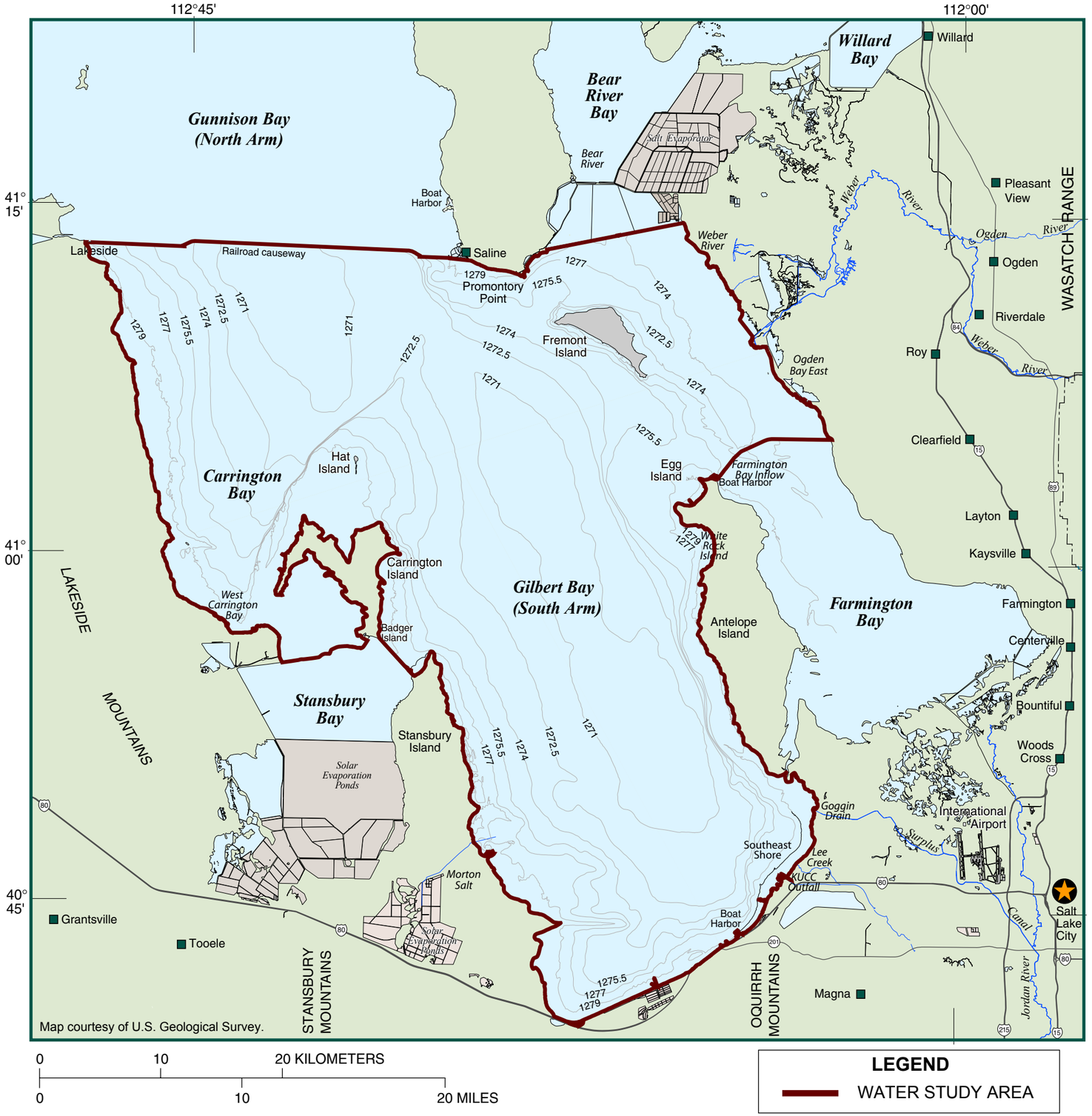

LEGEND

WATER STUDY AREA

FIGURE 1-1
Study Area
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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On average, 2.9 million acre-feet of water and 2.2 million tons of salt enter Great Salt Lake each year. The vast majority of lake inflow typically comes from three drainages: the Jordan River (9 percent), Weber River (13 percent), and Bear River (39 percent). Additional inflow comes from groundwater (3 percent), direct precipitation (31 percent), and other minor east-side streams (5 percent) (Arnow and Stephens, 1987). Because the lake's only substantial water loss mechanism is evaporation, minerals, salts, and sediments from the watershed accumulate in Great Salt Lake. This results in lake water that is typically three to five times more salty than sea water and creates a unique habitat for biota that have adapted to and rely on the Great Salt Lake ecosystem.

1.2 Resources Dependent on Great Salt Lake

Great Salt Lake's unique yet harsh conditions are significant to the ecology and economy of the region and Western Hemisphere. Each of the lake's resources—including bird habitat, people, the mineral industry, and brine shrimp harvesters—maintains a fragile balance with the ecology of Great Salt Lake, often dependent on the annual conditions of the lake for its scale, diversity, and economic value.

Millions of birds use the lake as they migrate from breeding grounds as far away as the arctic to wintering areas as far away as Argentina. For example, up to 1 million Wilson's phalaropes (*Phalaropus tricolor*), or more than two-thirds of the world's population, annually migrate through Great Salt Lake as they travel from the near arctic to the high Andes (Jehl, 1988; Colwell and Jehl, 1994). The magnitude of the Wilson's phalarope population was a primary factor in the designation of Great Salt Lake as one of six sites within the Western Hemisphere's Shorebird Reserve Network in the United States (Aldrich and Paul, 2002). Over half of the world's population of eared grebes (*Podiceps nigricollis*) use Great Salt Lake for up to 4 months during fall migration (Jehl, 1988), and in 2007 their population on Great Salt Lake exceeded 2.5 million birds (N. Darnall, personal communication, October 15, 2007). Great Salt Lake hosts the largest nesting colony of American white pelicans (*Pelecanus erythrorhynchos*) west of the continental divide (King and Anderson, 2005) and the largest breeding population of California gulls (*Larus californicus*) in the world (Aldrich and Paul, 2002).

Opportunities for recreation abound on and around Great Salt Lake. Thousands of people visit the lake annually to enjoy sailing, hiking, hunting, and watching the diverse bird life. Along the lake are two state parks, numerous state wildlife refuges, and one federal wildlife refuge. Waterfowl hunting alone was estimated to be almost an $8-million industry in 1998 (Isaacson et al., 2002).

As a result of the minerals left behind by evaporation, Great Salt Lake is home to a burgeoning mineral industry that is perhaps the Great Salt Lake industry with the greatest impact on Utah's economy (Isaacson et al., 2002). Several mineral extraction companies currently operating on Great Salt Lake generated a total of about 2.8 million tons of sodium chloride, potassium sulfate, magnesium chloride, magnesium metal, chlorine gas, and other products—all estimated to be worth about $300 million in 1995 (Gwynn, 1997). This represents about 16 percent of the annual value of all minerals produced in 1995 in Utah (U.S. Geological Survey [USGS], 1995).

Great Salt Lake produces a significant portion of the world's supply of brine shrimp cysts. Commercial harvest on the lake began in 1952, and the lake has become an internationally renowned source of cysts for their quality as feed for the aquaculture and ornamental fish industry. The market value is estimated to average $8 to 11 million annually with an estimated peak value of $58 million in 1995. The annual harvest from Great Salt Lake is often limited by biological factors rather than market forces (Isaacson et al., 2002).

1.3 Study Area

Figure 1-1 shows the study area referred to as the "open waters of Great Salt Lake" for this project. This area is commonly referred to in the literature as Gilbert Bay or the South Arm, and includes Ogden Bay and Carrington Bay within its area (Gwynn, 1987). Farmington Bay, Gunnison Bay (also known as the North Arm), Bear River Bay, Willard Bay, and Stansbury Bay are not included in the study area.

The study area is generally bounded by the shoreline as defined by the current lake water level but an area no greater than as represented by the lake's bed elevation of 4,202 feet (Moellmer, 2007, personal communication). The Union Pacific Railroad Causeway separates Gilbert Bay from Gunnison Bay and Bear River Bay. The Antelope Island Causeway and Island Dike Road at the southern end of Antelope Island separate Gilbert Bay from Farmington Bay. A series of evaporation pond dikes separate Gilbert Bay from what was historically known as Stansbury Bay.

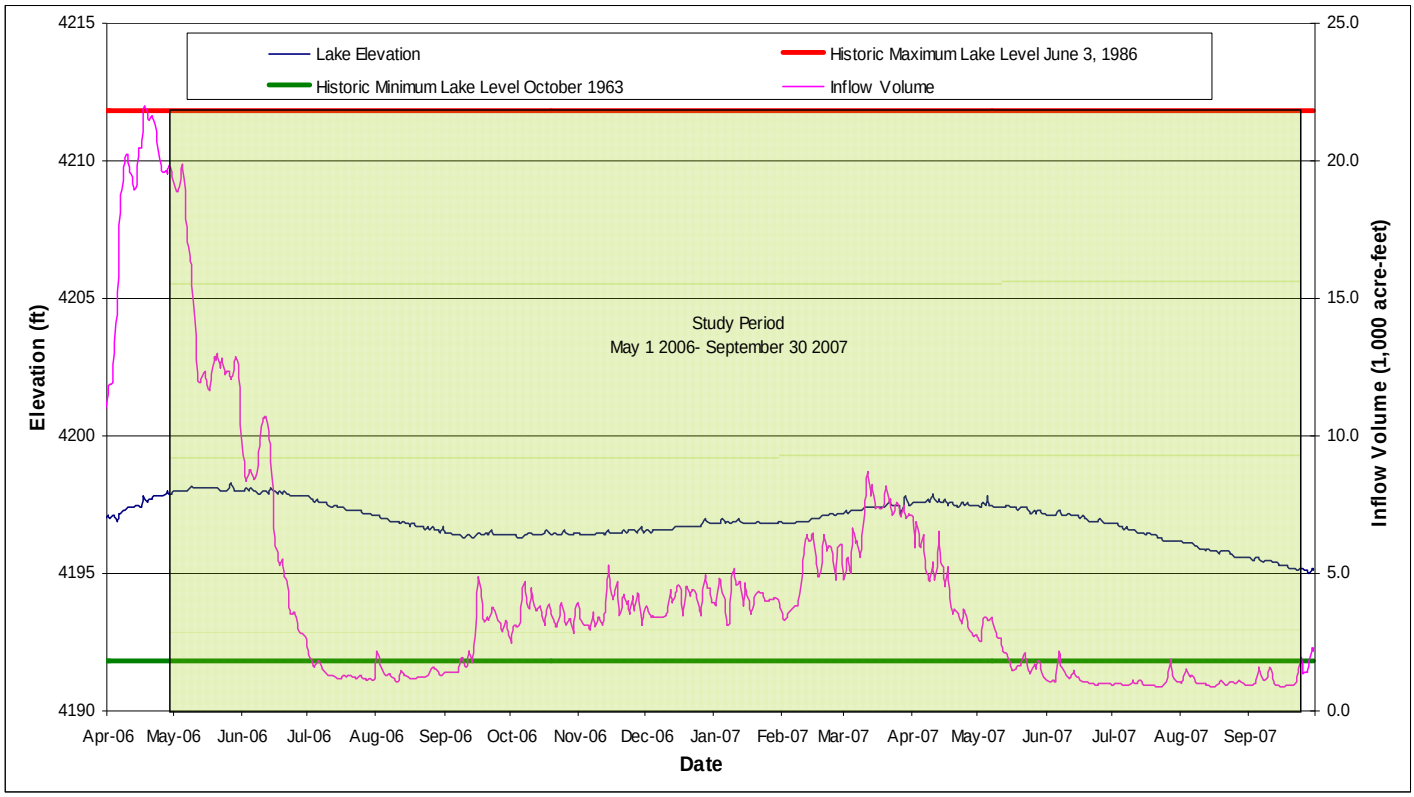
1.4 Lake Conditions during the Study Period

As previously described, Great Salt Lake is a uniquely dynamic water body dependent on a wide variety of variables that affect its physical characteristics. While an objective of this selenium program is to characterize the cycling of selenium in Great Salt Lake, it is important to understand the context of the research in terms of the historic variability of the lake and its watershed. Field studies for this program began in May 2006 and generally ended in September 2007.

1.4.1 Lake Level

The lake elevation for the study period, as measured at the USGS station at Saltair (USGS 10010000 Great Salt Lake at Saltair Boat Harbor, Utah), varied from 4,198.0 feet on May 1, 2006 to 4,195.1 feet on September 30, 2007 (see Figure 1-2). The maximum lake elevation in the study period was 4,198.3 feet (May 27, 2006) and the minimum elevation was 4,195.0 feet (September 28, 2007). As noted earlier in Section 1.1, the lake elevation has historically fluctuated more than 20 feet with a maximum elevation of 4,211.85 feet in 1986 and a minimum elevation of 4,191.85 feet in 1963.

FIGURE 1-2
Lake Elevation and Inflow Volume throughout Study Period



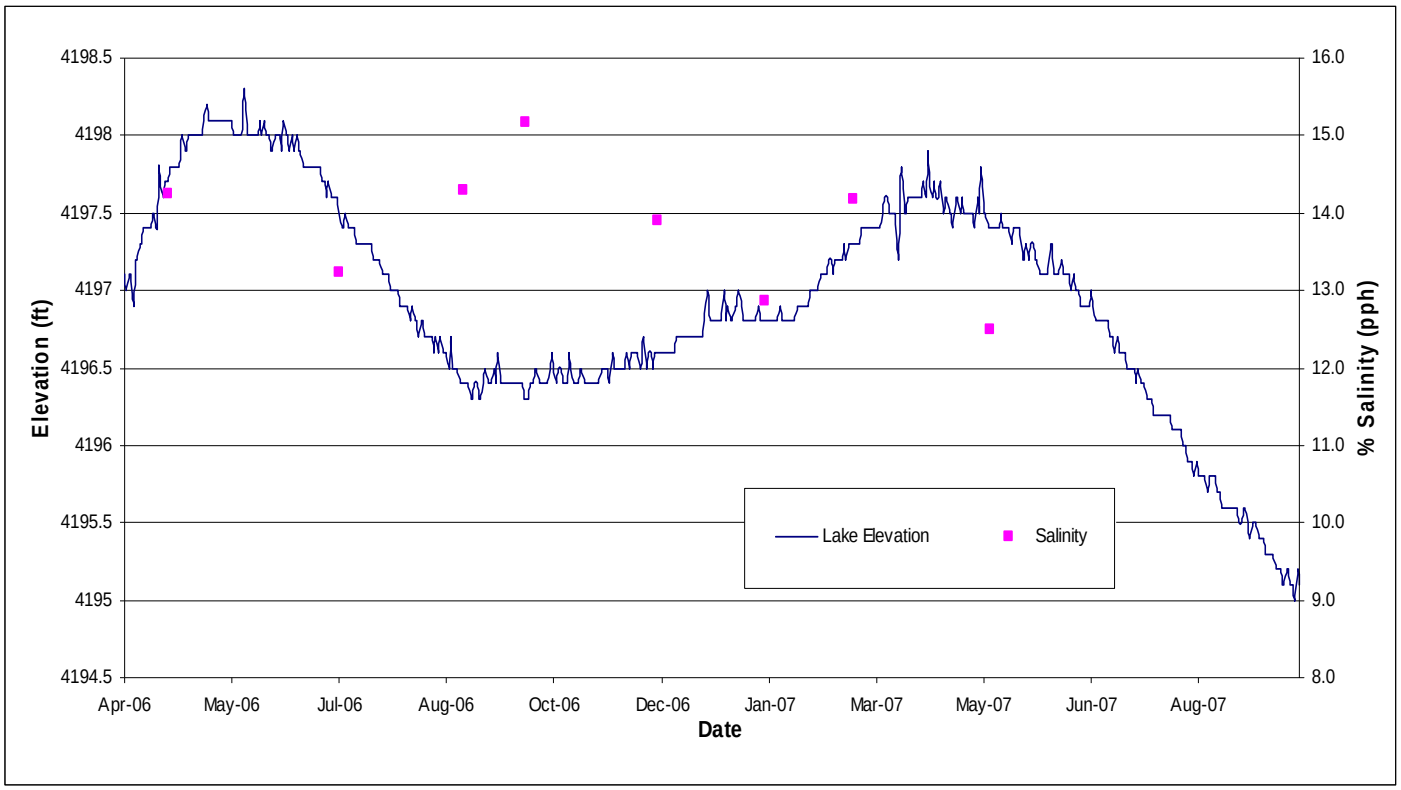
1.4.2 Surface Area and Volume

The surface area and water volume of the study area for the study period varied from an area of 743 square miles and volume of 8,273,227 acre-feet on May 1, 2006 to an area of 659 square miles and volume of 6,908,632 acre-feet on September 30, 2007 (as estimated from the elevation/volume relationship of Baskin [2005]). This represents a reduction in surface area of about 11 percent and a reduction in volume of about 16 percent over the study period. The lake's surface area varied between 2,500 and 938 square miles between 1873 (similar elevation as in 1986) and 1963, respectively (Hahl and Handy, 1969).

1.4.3 Salinity

The USGS monitors the salinity of Great Salt Lake at 16 locations on a monthly basis. The salinity for the study period, as measured by the USGS, varied from 14.2 percent in April 2006 to 12.5 percent in May 2007. The maximum measured salinity in the study period was 15.2 percent and the minimum measured salinity was 12.5 percent. See Figure 1-3 for salinity values plotted along with lake elevations for the study period. The lake's salinity generally varies inversely with lake level and has historically varied between 5.6 percent in 1986 to 28 percent in 1963 (Arnow and Stephens, 1987).

FIGURE 1-3
Lake Elevation and Salinity

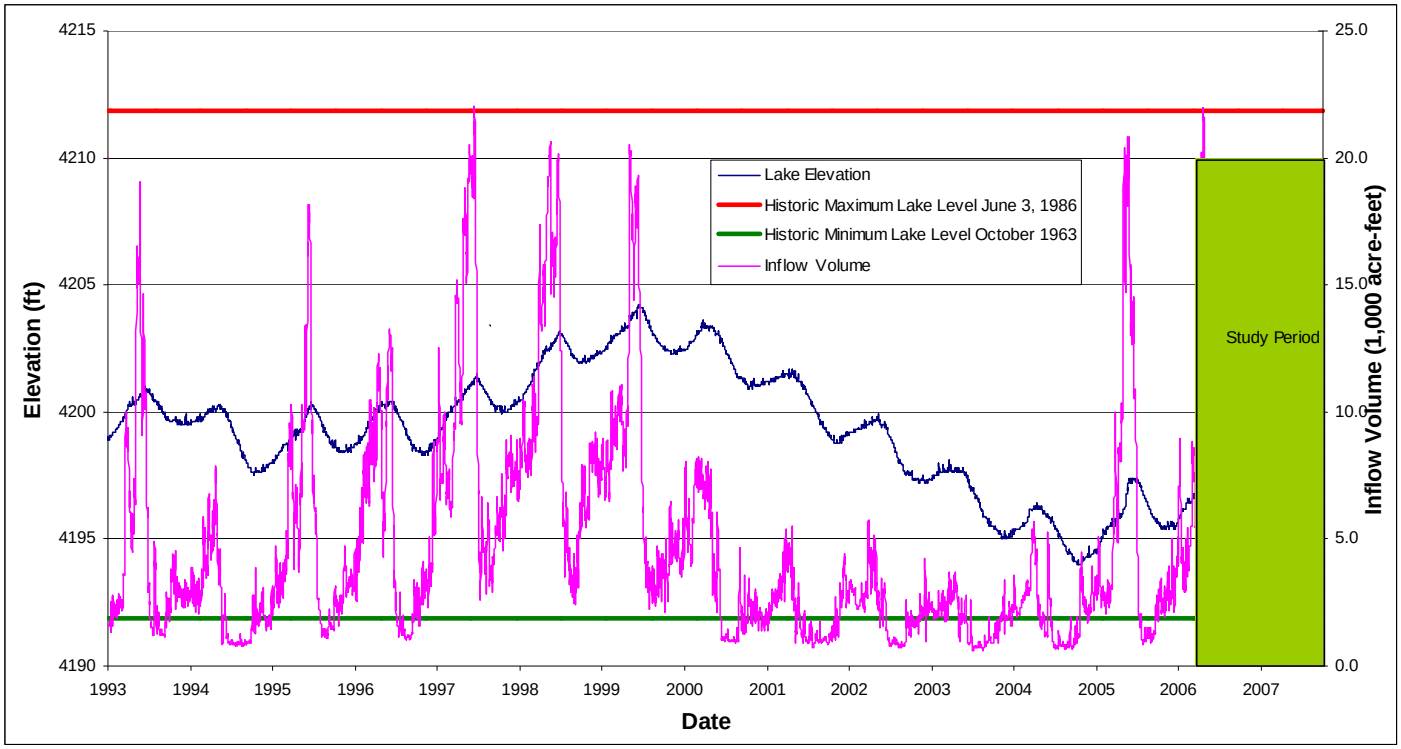


1.4.4 Hydrology

The elevation, size, and salinity of Great Salt Lake vary largely as a result of changes in inflow from precipitation, tributaries, and groundwater, as well as from losses through evaporation. Understanding the watershed's recent hydrologic regime helps to place the lake's response during the study period in context.

The study period (May 2006 through September 2007) provided a unique opportunity to understand the dynamics of Great Salt Lake during a dry period of the hydrologic cycle. The two indices used by the State of Utah to define and compare cumulative drought events, the Palmer Drought Severity Index (PDSI) and the Palmer Hydrologic Drought Index (PHDI), indicate that the watershed moved into a drought condition during the study period (Utah Division of Water Resources, 2007). Great Salt Lake's watershed had a PDSI and PHDI in May 2006 that indicated "moderately moist" to "very moist" conditions in the watershed. This is consistent with the generally "wet" water years of 2005 and 2006. Throughout the study period, however, conditions consistently became drier within the watershed and the PDSI and PHDI at the end of the study period in September 2007 indicated "severe drought" to "extreme drought" condition in the watershed (National Oceanic and Atmospheric Administration, 2007). These effects of the dry cycle can also be observed in Figure 1-4; lake levels generally decreased during the study period as inflow volumes decreased. While the effects of a drought period upon the cycling of selenium in Great Salt Lake are not understood, it is certainly a variable that affects the dynamics of the lake.

FIGURE 1-4
Lake Elevation and Inflow Volume 1993 to 2007



1.5 Document Organization

The remainder of this document is divided in the following sections:

- Section 2.0 provides the historical background of the project, regulatory framework, and need for a numeric site-specific water quality standard.
- Section 3.0 describes the development of the Utah Division of Water Quality's (UDWQ's) public involvement, consultation, and coordination program and the development of the overall selenium program.
- Section 4.0 defines the objectives for the overall selenium program and for each of the individual projects.
- Section 5.0 provides a summary of the program's quality assurance protocol and the results and conclusions for each of the seven projects.
- Section 6.0 provides a summary of the considerations, assumptions, and methodology used to develop a quantitative model of selenium cycling in the open waters of Great Salt Lake.
- Section 7.0 provides a summary of the results of the conceptual model for each of the alternatives selected by the Science Panel.
- Section 8.0 identifies considerations and recommendations for implementation of a new selenium water quality standard for the open waters of Great Salt Lake.

- Section 9.0 provides a summary of this report and offers conclusions based on the presented information.
- Section 10.0 provides references cited in this document.

Final reports and other pertinent technical memoranda prepared as part of this program are included in the appendices of this document.

- Appendix A, Conceptual Model for Selenium Cycling in the Great Salt Lake
- Appendix B, Recommended Guidelines Fact Sheet and Threshold Values Memoranda
- Appendix C, Project 1A - Shorebirds
- Appendix D, Project 1B – Gulls, Grebes, Ducks
- Appendix E, Project 2A - Benthic Zone and Brine Flies
- Appendix F, Project 2B - Pelagic Zone and Brine Shrimp
- Appendix G, Project 3 - Selenium Loads to the Lake
- Appendix H, Project 4 - Selenium Flux within and from the Lake
- Appendix I, Project 5 - Brine Shrimp Kinetics Study
- Appendix J, Data Validation Report
- Appendix K, Avian Blood Memo
- Appendix L, Evaluation of Mercury Concentrations in Birds Collected from Great Salt Lake, 2006 and 2007
- Appendix M, Science Panel White Papers