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Utah Lake Water Level Fluctuation Study

CENTRAL UTAH WATER CONSERVANCY DISTRICT

HDR

Final Report

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Water Level Fluctuation
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Introduction

This report summarizes an analysis of Utah Lake water level fluctuations conducted as part of the June Sucker Recovery Implementation Program (JSRIP). Excessive fluctuations in Utah Lake water surface levels are believed to be one of the factors adversely impacting aquatic vegetation in the Lake and thereby hampering the recovery of the endangered June sucker. This study makes use of available data and assumptions about Utah Lake water rights and water operations, and computer simulation models to estimate Utah Lake water levels and salinity under natural, current, and potential future conditions.

Purpose

The purpose of the study is to understand the fluctuation patterns of Utah Lake water level in its pre-water development state as well as under current and potential future conditions. This purpose includes quantifying the effects of water development on lake level fluctuation and investigating scenarios for managing Utah Lake water surface elevation to mimic more natural conditions. The ultimate goal for increasing our understanding is enhancement and restoration of rooted aquatic vegetation as an aid in June sucker recruitment. The information gained from this study may also be helpful in managing water levels of existing and future refuge locations. To this end, four conditions are examined:

- Historic (both prior to pumping from the Lake and for the 1950-1999 period)
- Pre-Water Development (representing near natural conditions, prior to large-scale human use of water in the area)
- Future, or Current and Planned (representing existing and planned water use)
- Stabilized (representing five scenarios developed to reduce level fluctuation)

Results

The results show that water development activities, including upstream depletion of inflow, use of the Lake as a storage reservoir, and enlargement of the Lake's outlet capacity by dredging, have tended to increase the average annual change in water level and to lower the maximum Lake drawdown level. Under historical conditions over the past 50 years (which included these water development activities), Utah Lake levels have fluctuated by an average of 3.5 feet. Much of this variation is caused by drafting the Lake to supply downstream water users. For pre-water development conditions the average fluctuation is only 2.1 feet, and minimum water levels are higher than under historical conditions of drawdown. Water development has also significantly affected Utah Lake salinity. Pre-water development TDS levels are estimated to average more than 350 mg/L less than under historical or Current and Planned conditions.

Much of the effect of water operations on Utah Lake levels is expected to be corrected under Current and Planned (i.e., future) conditions where the simulated average annual fluctuation is 2.5 feet. This is mainly from reduced demands for Utah Lake water as water rights are exchanged upstream to municipal water users and held in the Lake to improve Central Utah Project operations. Salinity levels under current and planned conditions are similar to recent historical levels.

Existing and predicted operations of Utah Lake will reduce historical water level fluctuations. Annual fluctuation under current and planned conditions is 2.5 feet. Three of the level fluctuation reduction scenarios evaluated in this study are simulated to further reduce the average annual change in water level, bringing average fluctuation even closer to the pre-water development estimate of 2.1 feet. One scenario, Provo Bay diking, would reduce water level fluctuations in Provo Bay to an average of less than one-half foot per year. Two of the level fluctuation reduction scenarios also produce an improvement in salinity levels, although only one, the reduced area-capacity scenario, would improve salinity in the entire Lake.

Recommendations

This report recommends specific, additional studies to further refine the hydrologic and environmental feasibility of the Provo Bay diking scenario and the analysis of other measures to improve the growth of aquatic vegetation under the effects of water level fluctuation.

Limitations and Assumptions

We have not considered whether the modeled scenarios are feasible from an engineering, economic, legal or management perspective. Additionally, we have not considered the potential secondary environmental and water supply impacts that could occur. The evaluation and approval process for changes of the magnitude represented by these scenarios could be difficult. In particular, it would be difficult to gain approval for changes in Lake operations that might affect water availability or change the Utah Lake Compromise level (which has been an issue of contention for 120 years).

In addition to detailed water rights evaluations, thorough environmental studies would need to be conducted to understand the potential environmental effects associated with such large potential changes in Utah Lake operations. Prior to embarking on these studies, additional review should be conducted to estimate to what extent these or related scenarios might significantly assist in the restoration of Utah Lake aquatic vegetation and habitat for the June sucker.

Assumptions regarding how the Lake will be operated in the future are critical to the model-simulated results. Appendix A presents an extended list of the assumptions incorporated in this study, and should be consulted in order to understand study results.

1.0 Introduction

This report documents an analysis of Utah Lake water level fluctuations conducted as part of the June Sucker Recovery Implementation Program. Excessive historical fluctuations in Utah Lake water levels are believed to be one of the reasons for the lack of deep-rooted aquatic vegetation in Utah Lake. Aquatic vegetation provides protection from predation for young June suckers. June sucker grow to maturity in Utah Lake and are a listed endangered species. The limiting effect of excessive water level fluctuations on the amount of lake vegetation is therefore one factor affecting the degradation of June sucker habitat and restricting the species' recovery.

In this study, water level fluctuations are estimated for historic and Pre-Water Development conditions, under Current and Planned future conditions, and for five level fluctuation reduction scenarios. Results (based primarily upon numerical simulation model analysis) are presented for a 50-year simulation period in terms of monthly levels, average annual fluctuations, and elevation versus frequency of occurrence. Results of a parallel analysis of Utah Lake salinity under the various level fluctuation scenarios are also presented.

1.1 Project Purpose

The objective of this project is to understand, to the extent possible, the fluctuation patterns of Utah Lake in its pre-water development state as well as under current and potential future conditions. This objective includes quantifying the effects of development (particularly water use and water operations) on lake level fluctuation and investigating scenarios for managing Utah Lake water surface elevation to mimic more natural conditions, with the ultimate goal of enhancement/restoration of rooted aquatic vegetation for June sucker recruitment. Understanding the natural fluctuation patterns of Utah Lake will provide information to determine if mimicking those patterns for recovery purposes is feasible. Whether or not it is determined that management of lake levels is feasible, the information gained from this study will be valuable for managing water levels of existing and future refuge locations.

1.2 Background – June Sucker Recovery

Utah Lake is a 150-square mile, shallow (average depth is less than 10 feet) remnant of ancient Lake Bonneville (see Figures 1and 2). The large water level fluctuations in Utah Lake are partly due to shallow depth and high summer evaporation losses and also due to large withdrawals from the Lake by downstream water users. The June Sucker Recovery Plan (USFWS 1999) recognizes that development and use of Utah Lake as a storage reservoir, which began in about 1872, have resulted in the management of water levels with a primary concern for water supply rather than for the ecological integrity of the lake community. Three primary factors have led to the degradation of June sucker habitat in Utah Lake and the elimination of historically-abundant aquatic plants:

1. Water level changes resulting from upstream depletions and water operations
2. Foraging-produced effects of common carp
3. Elevated nutrient loading

According to the Recovery Plan, these factors have resulted in a "recruitment bottleneck" for June sucker. There is an interactive effect of predation and aquatic vegetation. Predation becomes more efficient, and prey species are more vulnerable, when there are fewer aquatic plants to provide refuge. In 2006 the JSRIP (June Sucker Recovery Implementation Program) provided funds to investigate the role of predators and target fish communities that are compatible with the recovery of June sucker. To better understand how these three factors have contributed to the elimination of aquatic plants in Utah Lake, the JSRIP has funded and is in the process of finalizing an investigation of the feasibility of reducing and controlling the lake's carp population, while the Utah Department of Environmental Quality, Division of Water Quality is investigating the lake's nutrient loading. This pre-water development water levels project investigates the effect of water management on lake level fluctuations and alternative scenarios to minimize the level variation.

Shallow lakes typically are either eutrophic and turbid or oligotrophic to mesotrophic with low turbidity. The highest trophic level for shallow lakes is a clear-water oligotrophic to mesotrophic state with a rich array of rooted aquatic macrophytes. Nutrient loading, lake level fluctuation, and fish foraging can cause a lake to shift to a turbid, eutrophic state. Nutrient loading, water development, and the establishment of nonnative fish species have collectively altered the natural ecological state of Utah Lake.

Turbidity compounds the effect of water level fluctuation on rooted aquatic plants because it limits light penetration in the water column and decreases photosynthetic growth. In clear water, sunlight penetrates deeper and marcophytes can grow at greater depths. Even if turbidity and nutrient loading is reduced, macrophyte growth in Utah Lake is limited by level fluctuations, because macrophytes can only grow at depths below the low water line or temporarily in shallow areas in advance of rising water levels. In addition to aiding in June sucker recovery, the restoration of rooted aquatic vegetation could result in a cascade of ecological effects and could benefit a number of other species that use the lake.

1.3 Background – Level Fluctuations

Under natural conditions, Utah Lake's level fluctuated due to variations in hydrologic conditions. Historic information suggests that the lake had substantial annual and longer term fluctuations prior to the additional stresses induced through water development and management. Information from early records indicates that evaporation losses in Utah Lake decreased the level by about 8 or 9 inches below the natural outlet (at elevation 4485.7[1]) in the period 1857 to 1860. Maximum levels of 10 feet above the outlet are reported to have occurred in 1862. No historical reports are available that would indicate that there were efforts to control lake levels during this period, although a water level of 4495 (10 feet above the outlet sill) would have flooded many hundreds of acres of farmland around the lake and might have been a significant factor in the call for control over lake levels (discussed below). Direct human induced changes to Utah Lake level fluctuations began in 1872, when a low dam was placed across the Jordan River near the Jordan Narrows. This and subsequent dams at the Lake's outlet to the Jordan River transformed the lake into the state of Utah's first major storage reservoir. Although it is not clear how much this and other early dams affected maximum lake levels, it is generally believed that there was some effect at certain stages. A map of the Jordan River, from the lake to the Jordan Narrows, is presented in Figure 5.

[1] More than one vertical data reference may be applicable to Utah Lake water level measurements. In this document, levels are cited with respect to the USGS survey datum used in 1985 to establish the Compromise Elevation of 4,489.045, and subsequently used as the Utah State Engineer's office datum for reporting Utah Lake levels, based on a benchmark established near the Utah Lake outlet works.

In 1885 and earlier, landowners around Utah Lake became concerned that their land was being made unusable by flooding due to control of Utah Lake by the dam at the Jordan Narrows. A lawsuit between Utah County landowners and Salt Lake County water users eventually resulted in a “compromise agreement” that established the maximum level at which water could be impounded in Utah Lake. Above this “compromise elevation”, which was subsequently set at an elevation of 4,489.045 feet, the gates in the dam at the Narrows, and subsequently the gates on the dam at the outlet) had to be operated in accordance with the terms of the agreement. As a result of a subsequent lawsuit filed in 1986 the Utah Lake Jordan River Flood Management Program was developed, a new outlet structure was constructed at Utah Lake, and the Jordan River channel was dredged to allow more outflow. According to current operation of the Lake under the Utah Lake Distribution Plan by the Utah Lake and Jordan River commissioner (under the direction of the State Engineer), the outlet must be fully opened when the Lake is at or above compromise (subject to certain flood control limitations). The Lake may still rise above compromise if inflow is greater than the uncontrolled outflow possible through the outlet works, but water is not intentionally impounded above this level.

In 1902, the first dam and pumping plant were built at the outlet works to allow the lake level to be lowered below the outlet elevation and to permit storage of water in the lake during non-irrigation seasons. The pumping plant has since been modified several times. The channel of the Jordan River downstream of Utah Lake, and the channel to the lake outlet have been modified to allow more flow to be passed at a given Utah Lake water level. At its present capacity of 1,050 cubic feet per second, the pumping plant and channel (and evaporation losses) provide the capability to lower the lake level 8 to 10 feet below the compromise elevation of 4,489.045 feet (State Water Plan, Utah Lake Basin 1997). An aerial view of the Utah Lake outlet works is shown in Figure 6.

The compromise elevation represents the elevation at which Utah Lake is at its total (or full, managed, or conservation pool) storage capacity of 870,000 acre-feet[2]. At Compromise, the active storage of Utah Lake is 710,000 acre-feet. This is defined as the volume of water contained between the compromise elevation and 8.7 feet below compromise (the approximate lowest level at which water reaches the outlet works and can be pumped out of Utah Lake). The inactive storage, or that portion of water that is inaccessible to pumps and therefore cannot be diverted, is estimated to be 160,000 acre-feet. The average annual inflow (1950-1999) to Utah Lake from all sources (including precipitation) is about 726,000 acre-feet. Of this, 346,000 acre-feet is discharged to the Jordan River and about 380,000 acre-feet is lost to evaporation.

Under the direction of the State Engineer, Utah Lake is operated for water supply purposes according to the Utah Lake Interim Distribution Plan (Distribution Plan) by the Utah Lake and Jordan River Commissioner to meet the water needs of the downstream water right holders. Under the terms of the Distribution Plan, water may be held in Utah Lake, or in one of the upstream reservoirs (Jordanelle or Deer Creek). Water levels in the lake are maintained as close to compromise as possible, except when water is required by downstream users, or when runoff forecasts indicate that snowmelt runoff may produce significant flooding. As described above, whenever the level of Utah Lake is above the compromise level, the control gates at the outlet are required to be fully opened. Because of high snowmelt inflows to the lake, even with the control gates fully opened, the maximum level of Utah Lake may rise to as much as four feet above compromise and the maximum storage volume can exceed 1.4 million acre-feet. Average annual variation in

[2] Under high inflow conditions, Utah Lake can and does rise significantly above the compromise elevation, so this is not truly the “full” storage.

level is approximately 3.5 feet, and annual variations of up to 4 feet have been observed. Over the course of a four or five year long dry cycle, levels may fall close to the inactive storage level. The Distribution Plan was first implemented in water year 1993.

Additional background information on historic and pre-historic fluctuations in Utah Lake water levels is presented in the next section.

2.0 History and Pre-History of Utah Lake Levels

To properly understand the current and future fluctuations in Utah Lake levels, it is important to consider a certain amount of historic and pre-historic background. Indeed, some of the challenges associated with studying the natural, or pre-water development level of Utah Lake include deciding how far back in time to start, what Lake changes to include, and how to incorporate geologic and/or non-human caused changes in the Lake. When considering the evolution of a lake (or a species) changes occurring over tens of thousands of years may be significant. The following sub-sections briefly describe some of the history and pre-history of Utah Lake, as it relates to level fluctuations. The final sub-section summarizes available early data on historical lake level fluctuations.

2.1 Geologic Impacts on Lake Levels

Beginning as much as 750,000 years ago, Utah Lake was a portion of the much larger Lake Bonneville. Maximum water surface level (at about 5,090 feet) was reached about 15,500 years ago. This maximum elevation is 600 feet higher than today's compromise elevation. Lake Bonneville outflow erosion lowered the larger lake by 300 feet, prior to re-stabilization at around 4,800 feet. Subsequent erosion and periods of drier climate lowered the lake by another 300 feet, separating the Great Salt Lake/Lake Bonneville from Utah Lake. Indications are that this separation occurred about 12,000 years ago.

Other prehistoric water level fluctuations have occurred. A Native American burial site near Mosida, occupied 5,300 years ago, was uncovered in 1991, after levels dropped below elevation 4483. Ancient Lake Bonneville levels and extent are shown on Figure 2.

The geology and geochemistry of the Lake are interesting and are relevant with respect to a study of natural lake levels. The Utah Lake basin is a faulted graben, subsiding over time as the mountains on either side rise. This has an effect on levels in the lake, as well as on the survey datum used to measure water levels. The last major earthquake was about 10,000 years ago. The quake produced an approximate 25 foot vertical slip along the west shore, and a displacement of about 10 feet along the east shore. This is particularly interesting given that the rate of sediment accumulation (largely from deposition of calcium carbonate) is estimated to be about 3 feet per 1,000 years, just about the same as the rate of subsidence associated with the earthquake 10,000 years ago. These slow changes doubtless have some impact on the volume and level of the lake, even over a time span of just 100 or 150 years (the approximate "historical" record of the lake).

Because of lack of detailed data on hydrological conditions or water level variations associated with these past and potential future geological changes, this study will confine its evaluation of natural levels to lake conditions immediately prior to large-scale water development. Additionally, impacts associated with land subsidence, calcium carbonate sedimentation, and other non-human effects will, for the purposes of this analysis, be ignored. Thus the "natural" levels estimated herein are confined to those changes in lake inflow, outflow and surface variation that can reasonably be assigned to documented human causes, and most specifically to water resources development.

2.2 Water Development Impacts on Lake Levels

Three types of water development impacts affect Utah Lake level fluctuations:

1. Upstream water use, which depletes inflows to the Lake,

2. Changes in the Lake outlet, which controls how much water flows out, and
3. Use of the Lake as a storage reservoir, which affects storage and withdrawals.

Each of these impacts is discussed in the following sections.

2.2.1 Effects of Upstream Water Use on Lake Levels and Water Balance

This section describes the effects of upstream water development and use on Utah Lake. Because less water flows into Utah Lake than during pre-development conditions, the Lake is drawn down farther and is less able to refill rapidly following a dry period.

Significant water development upstream of Utah Lake started about the time that Mormon pioneers began arriving in large numbers in the vicinity of Utah Lake during the 1840s and 1850s. Water development for large irrigation projects began almost simultaneously. Irrigation canals were constructed upstream of the Lake on the American Fork, Provo, and Spanish Fork rivers, and on smaller Utah Lake tributaries. Unfortunately, no significant water records exist to document lake levels, diversion amounts, or even streamflows into or out of the Lake during or prior to this early period.

The State Water Plan estimates that current diversions from the watershed upstream of Utah Lake total more than 300,000 acre-feet per year. This agrees with the Provo River Simulation Model (PROSIM2000) analysis of virgin or natural flows on the Utah Lake system (CUWCD, 2001). According to the detailed hydrological analysis conducted during development of the PROSIM2000 and LKSIM2000 models, the pre-water development inflows and the baseline (or current condition) inflows to Utah Lake are as shown in Table 1 for the 1950-1999 hydrologic period. The baseline or “Current and Planned” Utah Lake condition was adjusted from a scenario developed as part of the Utah Lake Drainage Basin Water Delivery System, and is representative of future demands and operational conditions, with historically observed meteorological conditions.

The pre-development condition values shown in Table 1 are an estimate of how much surface and groundwater would have flowed into and out of Utah Lake if agricultural and urban development and water use had never occurred. These pre-development flows include the effects of leaving the historical and projected future diversions in the stream (i.e., not diverting water out), removing the return flows associated with the diversions from the stream and lake, removing the effects of reservoir storage and reservoir-produced evaporation loss, and removing all transbasin diversions (and their secondary effects) from the streamflows. This is a typical technique used to estimate streamflows in their natural, or virgin, state. That portion of the inflow into Utah Lake that occurs as subsurface and near-shore drainage (and is thus ungaged, or very poorly gaged) is included in the water balance, but has not been completely adjusted to natural conditions. This is because of the absence of usable historical information on changes in the timing and, to some extent, the volume of groundwater and drainage water inflowing to the lake. To the extent possible, the changes associated with agricultural and M&I supply depletion have been included. The changes associated with natural (non-irrigated) vegetation changes and other indirect water balance impacts from increased (or decreased) groundwater levels and increased impervious area have not been included. It is likely that, if these changes in timing were included, the simulated Pre-Water Development operation would show a somewhat later and more prolonged high water period, but the annual and long-term water levels would probably not change significantly.

The extent of the impact of upstream water development on total Utah Lake inflow is displayed graphically in Figure 4. The reduction in annual volume is almost 400,000 acre-feet per year, or 41 percent of the Pre-Water Development inflow. On a monthly basis, the reduction in inflow ranges from 12,000 acre-feet in the winter, to 75,000 acre-feet in May and June.

As seen in Table 1, evaporation from the water surface is a very large component of the Utah Lake water balance. The Utah Lake evaporation under these estimated pre-development conditions was calculated using a spreadsheet model that simulates the storage and outflow from the Lake assuming no calls on Lake storage and a natural lake stage versus discharge relationship. This stage versus discharge curve was developed using assumed channel geometry information and confirmed with early historical water level data. The hydraulic model HEC-RAS was used to estimate the effects of the undredged Indian Ford hydraulic control on Utah Lake water levels and outflow from the Lake. The development of the natural lake outlet relationship is described further in a subsequent section of this report.

Table 1 Average Annual Water Balance Elements for Utah Lake (acre-feet)

	Pre-Water Development	Current & Planned	Net Change
Provo River	364,386	113,705	-250,681
Spanish Fork River	110,540	93,012	-17,528
Local Inflow	478,125	350,036	-128,090
Precipitation	116,284	111,320	-4,964
Other Minor Elements	0	31,096	31,096
Total Inflow	**1,069,335**	**699,168**	**-370,167**
Evaporation	368,771	351,183	-17,588
Jordan River Outflow	693,996	343,528	-350,467
Total Outflow	**1,062,767**	**694,712**	**-368,056**

* Simulated results - 1950-1999

2.2.2 Effects of Jordan River Changes and Utah Lake Outlet Works on Lake Levels

In addition to changes in Utah Lake inflows, the most important historical change affecting Utah Lake levels has been the damming of the Lake and other changes to the Jordan River to manage outflow for water supply purposes. Over time, Utah Lake has been transformed from a naturally varying lake, to a reservoir whose level is controlled by regulating the outflow. This section briefly describes the changes to the Utah Lake outlet and the downstream channel and their effects on Lake levels.

The first diversion dam on the lower Jordan River was constructed in about 1850. The first dam with significant effect on Utah Lake was constructed at Jordan Narrows in 1872 ("Utah Lake and the Jordan River," LW Hooten, 1989).There have been many years of controversy concerning the impact of this and subsequent dams at Jordan Narrows on maximum Utah Lake water levels. Detailed hydraulic analyses have been conducted associated with the lawsuits filed regarding flooding of lands around Utah Lake. These studies have generally concluded that the natural hydraulic control (caused by the high spot in the channel) located near Indian Ford regulates (or did regulate, prior to dredging) outflow from the Lake and associated Lake levels, more than the presence of the diversion dam at Jordan Narrows. Similarly, the dam at the Utah Lake outlet works is operated more to prevent water pumped out of the Lake from flowing back in, than to keep water from flowing out (although it can, and does do both). It is apparent from examination of Jordan River hydraulics, that each of these features (i.e., the dam at the Narrows, the Jordan River channel, and the dam at the lake outlet) has an effect on the outflow from the lake, and thus on the level in the lake.

The other significant change to the stage versus discharge relationship controlling the outflow from Utah Lake has been caused by dredging and associated channel modifications. Again, precise historical records of changes constructed in the early years of the 20th Century are not readily available. What is apparent from old photographs and other accounts is that considerable efforts were expended to allow more water to be released from the Lake at lower water surface elevations. A major channel blasting project was reportedly undertaken in about 1906. General consensus is that most of these efforts were aimed at getting water from the middle of the drawn-down Lake to the pumps, rather than down the Jordan River. Details concerning these early projects are not available. It is likely that the earliest available records of channel profile (shown in Figure 7) are not the natural conditions. Nevertheless, this is the only information currently available, and therefore it will be used in this study to estimate the pre-water development stage versus discharge relationship for the Lake.

The Jordan River channel downstream of Utah Lake was surveyed prior to a major dredging project in about 1986. The channel was surveyed again in 1998, some time after the dredging. A map of the Jordan River, from the lake to the Jordan Narrows, is presented in Figure 5. The channel profile prior to dredging and the post-dredging profile are each shown on Figure 7. As can be seen, the most significant change is the removal of more than six feet of bed material at or near Indian Ford, approximately 7 miles downstream of Utah Lake. This dredging had a major effect on the stage versus discharge relationship for the combined Lake outlet and Jordan River, allowing much more water to be released at a given stage level. A HEC-RAS model of the channel hydraulic properties was used to develop generalized stage versus discharge curves for the Lake and channel before and after the 1980s dredging. These relationships are shown on Figure 8. The curves show that, with the dredged channel and with the lake at the compromise elevation, the outflow is more than doubled (1,050 cfs versus 480 cfs) compared with pre-dredging conditions. Although the pre-dredging curve does not necessarily represent the Lake outlet’s natural or pre-development conditions, it is the best information currently available on natural conditions. Until additional historic information is found with which to develop a better stage versus discharge curve for pre-development conditions, the curve representing the pre-dredging conditions must be used.

A brief sensitivity analysis was conducted to provide a better understanding of the effect of assumptions concerning the outlet stage versus discharge curve on the variation in Utah Lake levels. The natural lake outlet relationship described above and shown in Figure 8 was adjusted so that more or less water was discharged at a given elevation. The minimum level at which outflow occurs was held constant at the assumed undredged Indian Ford elevation. The outflow variations were essentially based on widening or narrowing the outflow channel. The sensitivity analysis showed that the capacity of the natural Utah Lake outlet does not affect the average annual lake level variation as much as do the operational changes associated with using the lake as a water supply reservoir.

2.2.3 Effects of the Use of Utah Lake as a Water Supply Reservoir on Lake Levels

This section describes the effects of the third major factor (operation of the Lake as a water supply reservoir) on Utah Lake levels. It presents information on the Lake's role in meeting downstream water demands and as a point of exchange to improve the reliability of upstream storage reservoirs with lower priority water rights.

Utah Lake is operated by the Utah State Engineer's Office to meet the water needs of the downstream water rights holders. It is also operated to facilitate the storage and exchange of water in upstream, federally operated storage reservoirs. The natural lake has been transformed into a partially controlled storage reservoir through structural modifications of its outlet to the Jordan River. These modifications allow more water to be held in storage than would naturally occur, and allow more water to be released from storage by pumping than would flow by gravity. These reservoir storage operations modify the pre-water development lake levels.

Operations to Meet Downstream Water Supply Demands

As early as 1850, water development projects in Salt Lake County began drawing water from the flow of the Jordan River. Fields were cleared, canals were dug, and diversion dams were constructed to bring water from the Jordan River to large areas of the Salt Lake Valley. By 1900, more than 50,000 acres were being irrigated by water from Utah Lake and the Jordan (Hooten, 1989). As the summertime flow of the Jordan River began to be used up, a need arose to be able to increase the reliability of the supply. This was achieved by the construction of dams at the Jordan Narrows and later at the Utah Lake outlet to the Jordan River. With these facilities (and subsequently with the pumping plant at the outlet works) releases from Utah Lake could be controlled for water supply purposes. Water could be held back during the winter and early spring, and released to meet downstream water needs during the summer and fall.

The total downstream demand for Utah Lake water eventually grew to more than 300,000 acre-feet, primarily for irrigated agriculture. The Utah State Engineer currently records 305,645 acre-feet of water rights derived from water flowing from or stored in Utah Lake. Based on the Utah Lake water balance summarized in Table 1, this represents 44 percent of the pre-water development condition outflow from the Lake and 89 percent of the Current and Planned condition outflow. The bulk of this water is used during the months of May though September. Operating Utah Lake to reliably supply this volume of water causes the Lake to be held at a higher level in the winter and spring, and to be quickly drawn down in the summer and fall.

Utah Lake Water Exchange Operations

Utah Lake water levels are also affected by the use of the Lake's storage as a point of exchange for upstream water supply projects. Because it receives the discharge of the Provo and Spanish Fork rivers, as well as various smaller streams, Utah Lake is well-positioned to serve as a common operational interface between the Strawberry Collection, Diamond Fork, M&I, and ULS systems of the Central Utah Project Bonneville Unit. The lake level is also affected by operation of the Provo River Project, which stores water in Deer Creek Reservoir and sometimes in Utah Lake, and diverts water into the Utah Lake basin from the Weber River and Duchesne River watersheds.

Under the Bonneville Unit, the lake receives water from Strawberry Reservoir in exchange for Provo River storage held in and delivered from Jordanelle Reservoir and in exchange for ground water pumped for M&I use in Utah County. Fed by these sources, Utah Lake provides water to irrigators adjacent to the lake and along the Jordan River downstream from the lake. Although essentially equal in volume, depending on the timing of these exchanges, they too can affect Utah Lake levels.

The unique position of Utah Lake enables it to serve as a link for water exchanges within the Bonneville Unit of the Central Utah Project (shown on Figure 3) and with other water projects. Diversion rights from Utah Lake, purchased by the Central Utah Water Conservancy District (CUWCD) can benefit the Bonneville Unit as a whole, reducing the volume of water that must be released from Strawberry Reservoir to offset diversions from the Provo River. Holding these rights in Utah Lake raises the lake level, allowing surplus (system storage) water stored in Jordanelle and Deer Creek to be converted to priority storage. Water from Strawberry Reservoir can, through releases to Utah Lake, be exchanged for storage in Jordanelle Reservoir, thereby augmenting storage in Jordanelle Reservoir, and allowing high quality Provo River water to be delivered by gravity along the Wasatch Front.

All of the Bonneville Unit systems benefit by this interconnected operation, especially when water availability can be adjusted during periods of unequal runoff conditions in the Uinta and Bonneville basins. Jordanelle Reservoir was constructed to provide holdover storage for the Bonneville Unit M&I System. This is accomplished by storing surplus Provo River water and water belonging to holders of diversion rights from Utah Lake. The storage of water belonging to Utah Lake water right holders is made possible through an exchange whereby the Utah Lake water rights holders receive water released from Strawberry Reservoir instead of water flowing down the Provo River. Thus, for water accounting purposes Jordanelle Reservoir can be used to store water released from Strawberry Reservoir. Releases from Jordanelle Reservoir then provide M&I water to contracting agencies in Salt Lake, northern Utah, and Wasatch counties, and provide irrigation water in Wasatch County.

The other major change to Utah Lake operations that is associated with Bonneville Unit and the ULS, is associated with the purchase of water rights in Utah Lake, and the use of those rights to facilitate the ULS water supply. In the 1980s, the CUWCD purchased 82,073 acre-feet of the total 305,645 acre-feet of rights in Utah Lake (302,045 acre-feet of deliveries, plus 3,600 acre-feet of carriage, or conveyance water, which must be released to offset channel losses). These rights have historically been for the water stored and released from the lake and used for agricultural and mining operations downstream in Salt Lake County. Most of these rights have subsequently been acquired by the Department of the Interior (DOI) and/or committed to upstream water supply needs. Thus these rights will be held in the lake or exchanged upstream, rather than being released from the Lake. By holding this water in storage, the amount of water required to be released from upstream storage to refill the lake has been reduced. This upstream storage water can therefore be used for other purposes. The holding of water rights in the lake tends to stabilize lake levels somewhat, depending upon the replacement releases of water from Strawberry Reservoir.

In effect, much of the water for storage in and supply from Jordanelle Reservoir comes from either the previously described Strawberry Jordanelle exchange or from Utah Lake water rights purchases. A related benefit of this reservoir water management is that these water exchanges provide a more reliable Bonneville Unit M&I water supply for Wasatch, northern Utah, and Salt Lake counties. The Provo River is regulated by Jordanelle and Deer Creek reservoir releases; therefore, the Provo River is managed more efficiently.

The combination of the depletions caused by upstream water development, the changes to the outlet and downstream Jordan River channel, the operation of the Lake as a reservoir to meet downstream irrigation demands, and the use of the Lake to facilitate Bonneville Unit water supply exchange operations is diagrammed on Figure 3. The use of the Lake for storage of surplus Provo River Project water, prior to exchange to Deer Creek Reservoir, also affects natural lake levels.

The extent of the impact of water development on total Utah Lake outflow is displayed in Figure 9. The reduction in annual volume averages 350,000 acre-feet per year, or 50 percent of the Pre-Water Development outflow. On a monthly basis, the reduction in outflow ranges from 16,000 acre-feet in September, to 30,000 to 40,000 acre-feet throughout most of the rest of the year.

2.3 Summary of Historical Utah Lake Levels

Early USGS records report that between 1857 and 1860, Utah Lake had a lowest level of 8.5 inches below the minimum outflow level, or about 4485.0 feet above sea level ("Outflow Records of Utah Lake," S.T. Harding, 1940). They report a maximum range of lake levels of 10 to 12 feet, and an inferred high water elevation of 4495.5 in 1862. The early historical measurements of Utah Lake levels may contain a high degree of inaccuracy for several reasons, including: use of different elevation datums, changes in benchmarks, and the effects of wind and waves on measured water levels, which may exceed one foot.

The earliest known continuous records of Utah Lake level start in 1883, well after significant upstream diversions had occurred, and after the development of dams on the Jordan River at the Narrows. A plot of historical Utah Lake levels from 1884 through 2006 is shown in Figure 10. The variations show the annual cycle between spring snow melt and summer and fall drawdown, as well as multiple-year dry and wet periods. In particular, the 1930s, 1960s, and early 1990s show the impacts of reduced inflows from three or more years of dry weather, exacerbated by withdrawals to meet downstream water needs.

The early records do provide some indication that water development and Lake operations have caused the extent of variation in Utah Lake levels to increase. Figure 11 is a plot of the annual variation between maximum and minimum level, for the historical period 1884 through 2006. For clarity, a line has been added to display the 5-year running average of these annual differences. Examination of this figure suggests that, prior to the start of major pumping from the Lake (in about 1906), annual variation in level was typically in the range of two to two and a half feet. During the remainder of the historical record, typical level variations were often three to four and a half or even five feet. A shift towards somewhat lower level variation is seen in the graph of data after about 1964. This may be due to decreases in demand for Utah Lake water or to more consistent operation of the lake under a number of water right institutional arrangements. Level variations are also affected by long- and short-term weather patterns, measurement changes and accuracy, and changes in water operations.

The increase in annual variation in lake level that occurred in the early part of the 20th century is primarily the result of pumping water out of the lake. The use of the pumps allows water to be released from the lake more rapidly, and allows the lake to be drawn down farther. The natural hydraulics of the Jordan River channel could only pass about 500 cfs, or less at lower lake levels. Using the large capacity pumps, up to 700 cfs could be withdrawn at much lower lake levels. This finding is substantiated by the results of analyses conducted by routing natural and operated flows through the computer model of the lake to simulate natural and baseline levels. This is further discussed below. These early historic level measurements indicate that, prior to the construction of the large pumping plant in 1906, the lake rarely fell below the level of the natural outlet sill, which was estimated to be about 3.3 feet below compromise, or elevation 4485.7.

The main difference between the early historical or pre-water development operation and the baseline or current operation is that, under natural conditions, when the lake fell to the level of the outlet control, evaporation would be the only source of additional outflow from the lake. Natural, undepleted inflows to the lake were significantly higher, allowing more rapid refill. Review of the earliest historical information concerning minimum lake levels suggests that the lowest observed lake level prior to the installation of pumps was approximately 4 feet below compromise between 1857 and 1860. (Harding, 1940) This corresponds with a level about 8 inches below the natural lake outlet, at about 4485.7 feet. Under current operations, water is held in the Lake until the Compromise elevation is reached, and pumped out of the Lake as necessary to provide water supply. This, combined with the effects of upstream depletion and other operational changes, now causes the Lake to draw down well below the level of the outlet. In multiple dry year periods, the Lake continues to draw down until a wet period provides sufficient inflow to return it to near the compromise elevation.

3.0 Data, Methods, and Assumptions

For the past 130 years, Utah Lake levels have been affected by a range of operational and water rights procedures and evolving water supply demands. Future demands and water operations are expected to be much different from historic conditions. This changing situation means that available historic information on water level fluctuations is not reflective of natural or pre-water development conditions nor of future conditions. This dictates that a simulation study be completed to estimate how Lake levels would have varied in the absence of human impacts and how Lake levels are likely to vary under future conditions.

This study of the variation in Utah Lake water levels was completed to improve understanding of the fluctuation patterns of Utah Lake in its pre-water development state as well as under current and potential future conditions. As described below, it uses data, methods, and assumptions derived from a wide range of sources. Hydrologic data were collected from historic measurements and from a number of previous studies. Analytical methods include computer models of the Utah Lake water balance, hydraulic models of the Jordan River, and calculations of model inputs. Study assumptions about historic, current, and future Lake operations are extensive and critically important, and come from measurements and studies, as well as historical documents and discussions with natural resource managers. A complete list of the methods and assumptions used in this study is included in Appendix A. The most significant data, methods, and assumptions are summarized below.

3.1 Hydrologic Data

Most of the hydrologic data describing Utah Lake inflows, outflows, levels and water rights comes from previous studies of Utah Lake or data records collected and maintained by the Utah State Engineer's Office (Water Use and Stream Flow Records, Utah Division of Water Rights, November 2003). Extensive information concerning Utah Lake inflows and water balance during the 1950 through 1999 hydrologic simulation period comes from the hydrologic studies conducted during the development of the LKSIM and PROSIM2000 simulation models (CUWCD, 2001). Early historical Utah Lake levels data come from microfiche records maintained by the Utah State Historical Library and by S.T. Harding, (Fluctuations of Utah Lake, September 1940).

3.2 Analytical Methods

To evaluate Utah Lake levels over an extended period under pre-water development, current, and future conditions, a numerical model, which simulates the operation of the Lake, was developed. The model incorporates current and planned future policies (including the Distribution Plan) and 50-years of historically based hydrology. The model simulates the inflows to, storage in, and outflows from the Lake based on historic hydrology, current operating rules, and predicted demands for water. The model was used to develop a simulated Pre-Water Development Scenario that predicts what Utah Lake levels would have been over the 1950 through 1999 study period if the previously mentioned impacts (i.e., depletion of inflows, changes to the outlet works, and operation of the Lake as a water supply reservoir) had not occurred. A Current and Planned Scenario simulation of Utah Lake was developed. This scenario reflects how the Lake would be expected to be operated in the future. Many of the assumptions used in this scenario (and listed in Appendix A) concerning operation of the lake and the major water projects that affect the Lake are based on the Proposed Action from the 2004 Utah Lake

Drainage Basin Water Delivery System Final Environmental Impact Statement (CUWCD, 2004). Additional assumptions have been developed to represent the hydrologic and operational effects of all known planned water rights changes affecting the Lake. These Current and Planned assumptions and the simulation model that incorporates them represent the best available information on how Utah Lake levels will fluctuate in the future.

3.3 Study Assumptions

Critically important, general analysis assumptions included in this study of Utah Lake levels include the following:

- Historically observed and estimated hydrological conditions data may be used and adjusted to represent future conditions.
- The hydrologic behavior of Utah Lake can be represented by a set of mathematical formulae relating these hydrological conditions to specific, simulated water balance parameters (Lake stage, storage, surface area, outflow, and evaporation).
- Adjusting hydrologic data or one or more formulae allows prediction of the effect of the particular adjustment on the simulated Lake water balance.
- Secondary impacts or unforeseen changes in water use or water rights administration are not considered in the analysis[3].

The scenario specific assumptions included in the analysis of Pre-Water Development conditions and the Current and Planned scenario, as well as assumptions included in the level fluctuation reduction scenarios are documented in Appendix A.

[3] Utah Lake is a complex and dynamic system. As such, a change in one parameter or condition is likely to affect other conditions that are not included in the analysis. This means that simulated results must be used with caution, particularly when they vary significantly from historical results.

4.0 Water Level Fluctuation Results under Pre-Water Development Conditions

The Pre-Water Development scenario was developed to estimate how Utah Lake levels would have fluctuated over the 1950-1999 period if the three, previously described impacts on the Lake (upstream depletion, changes to the outlet, and use as a storage reservoir) had not occurred. The scenario was simulated with the spreadsheet model of Lake operations under assumptions summarized in Appendix A. Inflows to the Lake were set to their pre-water development level, the outflow from the Lake was based solely on the pre-dredged stage versus discharge relationship, and water demands on the Lake were set to zero.

The resulting water levels are shown in Figure 12, which also presents the recorded historical water levels. Under Pre-Water Development conditions, the average anuual fluctuation in water levels is 2.13 feet. This compares with an average fluctuation under historical conditions of 3.51 feet. Without the drawdown effects of withdrawals from the Lake, minimum simulated levels under Pre-Water Development conditions are limited by the outlet sill elevation at just under 4486. Lake levels tend to be quite stable, hovering between 4487 and 4490. During extremely wet years maximum levels approach or exceed historical levels because there is no water being withdrawn for water supply purposes and the outlet stage versus discharge curve has not been increased by the dredging that occurred in the 1980s. Average monthly water levels under the Pre-Water Development scenario are summarized and compared against historical average monthly levels on Figure 13. Figure 14 presents Pre-Water Development, historical, and pre-1902 historical data in terms of the frequency of water level exceedance. The similarity between the pre-1902 levels and the simulated Pre-Water Development levels is evidence of the accuracy of the prediction of pre-development conditions. Simulation results for the Pre-Water Development scenario are tabulated on Tables 3 and 4.

5.0 Water Level Fluctuation Results under Current and Planned Utah Lake Operations

The Current and Planned Operations scenario was developed to estimate how Utah Lake will be operated in the future under the constraints of current and planned water rights, water uses, projects, and programs. As summarized in Appendix A, a number of elements are incorporated into the assumptions used in the Current and Planned Operations Scenario. Water demands on the Lake were adjusted from their historical values to expected future levels. These levels represent the exchanges of water rights out of Utah Lake to M&I supplies, and the existing and planned urbanization of lands that previously utilized Utah Lake water.

The approved Utah Lake water right changes have not all included the same conditions. Recent approvals provide an example of anticipated requirements for the exchange of Utah Lake rights and how past and future changes may be implemented. When exchanging a downstream right to an area upstream of Utah Lake, recent approvals allow the water right holder to deplete or consume 42.4 percent of the right. Recent State Engineer memorandum decisions require that return flows from exchanged Utah Lake rights be held in Utah Lake for release to lower Jordan water users when their supplies are impacted. Additionally, exchanged water right holders need to release 10% of their prior right to meet carriage water requirements in the canals that formerly delivered their rights. The Current and Planned scenario includes the effects of these State Engineer decisions: inflows are depleted by 42.4 percent of the right exchanged, 10 percent of the right continues to be called from Utah Lake, and the remaining amount (47.6 percent) is held in Utah Lake.

The simulated effects of these assumptions on the Utah Lake water balance are shown in Table 1. Simulated water levels for the Current and Planned scenario over the 1950-1999 study period are shown and compared against the simulated Pre-Water Development levels on Figures 15 through 17.

Figure 16 compares the water surface elevation versus frequency relationship for Utah Lake based on pre-1902 historical data, 1950-1999 historical data, 1950-1999 simulated data for the current and planned operation of the lake, and 1950-1999 simulated data for the pre-water development operation of the lake. The similarity between the Pre-Water Development curve and the pre-1902 historical curve is an indication that the estimated natural Utah Lake stage versus outflow relationship is relatively accurate, in that it duplicates the pre-pumping stage versus frequency curve. This is further confirmed by the plots in Figure 17, which display the average monthly lake levels for pre-1902 historical data, 1950-1999 historical data, 1950-1999 simulated data for the Current and Planned operation of the lake, and 1950-1999 simulated data for the pre-water development operation of the lake. The pre-1902 levels average somewhat lower than the Pre-Water Development levels. This is reasonable, since long-term water level measurements on Great Salt Lake indicate that the 1884-1902 period was considerably drier than normal.

In addition to the one to two foot (or more) decrease in level, the lake is shown to draw down much more rapidly under recent historical and simulated Current and Planned operations than under its Pre-Water Development or pre-1902 historical operation. The 1950-1999 historical and Current and Planned curves shown in both Figure 15 and 16 indicate how much water development has modified the water surface levels of Utah Lake.

6.0 Lake Level Fluctuation Reduction Scenarios

One goal of this study was to evaluate alternative scenarios for Utah Lake operation that might help to make Utah Lake levels respond more closely to the way that they would naturally. Based upon input and guidance received from the CUWCD and other June Sucker Recovery Plan partners, five scenarios, intended to help restore Utah Lake level variations to a more natural or more environmentally advantageous pattern, were developed:

- Lower the Lake's conservation pool or normal maximum operating level from 4489.045 to 4487.
- Reduce lake evaporation by changing the lake's volume versus surface area by diking off a portion of the area
- Increase volume of Lake rights that are exchanged upstream
- Increase the volume of Lake rights that are held in the Lake
- Stabilize levels in Provo Bay by cutting it off from the remainder of the Lake

Each of these scenarios was simulated as described below. No analysis was performed on the environmental, political, or economic feasibility of these scenarios. It is likely that the effects of implementing water use changes of this size could be significant. In particular, it should be noted that there is no assurance that the necessary permits and approvals for these activities could be obtained nor that the amounts of water needed could be obtained in Utah Lake, since several municipalities and water agencies have an interest in obtaining and using Utah Lake rights under future water supply projects. Then too, the cost associated with any of these scenarios would likely be extremely high. At a an assumed price of $2,000 per share, the purchase of 50,000 acre-feet of Utah Lake water rights would cost $100 Million.

More detailed level fluctuation reduction scenarios could be developed and analyzed in more detail if the effects on water levels, and the benefits to June sucker habitat, associated with any of these scenarios are judged to be sufficiently positive. Similarly, the scenarios could be refined if there is additional interest on the part of JSRIP participants.

The effects of each of these scenarios were simulated using the previously described spreadsheet model of Utah Lake operations and the scenario-specific assumptions listed in Appendix 1. The Current and Planned operation model was modified by changing the surface area versus elevation, storage volume versus elevation and/or outlow versus elevation relationships; downstream demands associated with primary water rights; and inflows associated with rights assumed to be exchanged upstream. No other changes were made, so that the specific effects of just the level fluctuation reduction scenarios would be quantified.

6.1 Lower Conservation Pool

Because the volume of water demands calling on Utah Lake storage has decreased, the volume of water being held in storage to assure water availability during drought conditions may be larger than necessary. This higher than needed maximum conservation pool level (associated with the Compromise Elevation of 4489.045) may tend to waste water through excessive evaporation and thereby increase the fluctuation in Utah Lake water levels. A series of simulation runs were performed to test whether fluctuations might be reduced by lowering the conservation pool level.

Initial simulations included no change to the Current and Planned Scenario assumptions other than a reduction in the spillway elevation (at which all inflow is released, up to the capacity of the outlet). Various maximum levels were tried, from 4489, down to 4485. Examination of results rapidly led to the conclusion that decreasing the pool level was only effective if the capacity of the outlet was increased to permit water above the conservation level to be released. At a water surface elevation of 4487, the existing outlet and Jordan River hydraulics only permits release of 285 cfs. At this rate, even with the lowered target pool level, the Lake surcharges by up to two feet in normal and wet years, thereby approaching it's Current and Planned level and not reducing level fluctuation. In fact, average level variation increased, from 2.50 feet under Current and Planned conditions, to 2.67 feet with a top of conservation pool set at 4487.

To eliminate this tendency for the Lake to approach its current Compromise elevation, the simulation run was adjusted to allow additional outflow at lower stage by doubling the stage versus discharge curve. This would require dredging of the Jordan River channel and/or use of the pumping station at the outlet works to release water at a higher rate when the Lake rises above elevation 4487.

The results for this scenario are summarized on Tables 3 and 4 and in Figures 18 and 19. During a typical year the Lake level varies from a high just above 4487, to a low between 4485 and 4485.5. The average change in water surface elevation for all 50 years simulated is 2.44 feet. More than half of the years simulated have a 2.50 foot or less change in water level.

6.2 Reduce Area-Capacity Relationship

Similar to the previous scenario, this scenario makes use of the fact that the present, smaller demands on Utah Lake storage might be satisfied with a smaller storage volume. The previous scenario assumed a lowering of the Lake by two feet; this scenario assumes that a large portion of the Lake might be separated from the main body of the lake by diking. This would reduce the surface area of the Lake and thus reduce the volume of evaporation losses and some of the resulting evaporative effects on Lake level.

This scenario assumed that approximately 28 percent of the Lake area was diked off from the remainder of the Lake. An area in the southern portion of the Lake was chosen for analysis purposes. LKSIM2000 inflow datasets were used to develop the reduced inflow to the remaining Lake. Modified elevation versus area and elevation versus capacity tables were developed using available bathymetric data on the Lake's subsurface contours. The remaining lake had a capacity of 650,000 acre-feet and a surface area of 67,900 acres at Compromise elevation. This is a reduction of 25 percent in capacity and 28 percent in area.

The results for this scenario show that the reduction in area and capacity actually tends to increase the level fluctuation slightly. This is because to release a given volume of water from a smaller lake, requires a larger drawdown. Both the average and the median annual fluctuation are 2.75 feet. The monthly results are displayed graphically on Figures 20 and 21.

6.3 Increase Upstream Exchange of Lake Rights

One way in which the variation in Utah Lake levels might be stabilized is by further reducing the downstream demands on the Lake, thus leaving more water in storage, and reducing lake draw down, particularly over multiple-year dry periods. As stated previously, there are 305,645 acre-feet of primary and secondary water rights in Utah

Lake, including 3,600 acre-feet of carriage water. Some of these rights (including 64,973 acre-feet acquired by the DOI as part of the Bonneville Unit M&I System and ULS projects) are already left in the lake and the Current and Planned operation reflects this fact. Additional rights (estimated at 40,044 acre-feet) have been or are being moved by municipalities and others to groundwater wells or other sources upstream of the lake in Utah County. These exchanges have been included in the Current and Planned scenario simulation.

For the purposes of this study, the lake level fluctuation reduction scenario evaluated exchanging an additional 50,000 acre-feet of Utah Lake rights to groundwater wells upstream of Utah Lake. To a certain extent, the exchange of rights to wells upstream of Utah Lake is already occurring. However, for the purpose of this study the effects of this scenario were directly imposed on top of the Current and Planned scenario operation.

The simulation results from this scenario show that additional upstream exchanges will tend to stabilize lake levels, since reducing the demand on the outflow will help to keep the lake from drawing down as far. Upstream exchanges will reduce the inflow to the lake, which may have some offsetting effect. A summary of Utah Lake water rights, taken from the Bonneville Unit Definite Plan Report Water Supply Appendix and updated by searching current water rights files on the State Engineer's on-line database, is shown in Table 2. A more complete table of Utah Lake rights is included in Appendix A.

Table 2 Summary of Utah Lake Water Rights

	Original Utah Lake Water Rights	Amount of Right Held in Utah Lake	Amount Exchanged Upstream of Utah Lake	Amount Exchanged Downstream of Utah Lake	Amount of Remaining Right	Remaining Amount Called from Lake*
	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft
Primary Rights	192,906	21,787	49,511	31,149	90,459	128,737
Secondary Rights	112,739	57,531	12,537	6,218	36,453	49,678
Total	305,645	79,318	62,048	37,367	126,912	178,415

* Remaining Call includes Remaining rights and Downstream Exchange rights plus 10 percent of Held and Upstream Exchange rights

The simulated results of exchanging an additional 50,000 acre-feet upstream of Utah Lake are summarized and displayed in Figures 22 and 23. The average annual fluctuation in Lake level was reduced to 2.27 feet. The median level fluctuation was reduced to 2.35 feet. The maximum drawdown level is 4482.9, a foot and a half higher than under Current and Planned operations, and three feet higher than historical.

6.4 Increase Rights Held in Lake

To improve its ability to convert and exchange system storage in Jordanelle Reservoir to priority storage, the DOI has acquired 57,000 acre-feet of Utah Lake water rights. These rights are currently being held in Utah Lake, allowing the Central Utah Project to convert its system storage in Jordanelle when Utah Lake is at a lower total level. In this scenario, the acquisition of an additional 50,000 acre-feet of Utah Lake rights is assumed. It is further assumed that these rights are not delivered out of the Lake or exchanged upstream, but simply left in the Lake to improve levels. No change in CUP operations is simulated as part of this scenario.

The simulation results for this scenario are summarized in Tables 3 and 4 and displayed on Figures 24 and 25. The average annual fluctuation in lake levels is reduced to 2.18 feet. Fifty percent of the years simulated have level fluctuation of less than 2.35 feet. The maximum drawdown level is 4483.95, two and a half feet higher than under Current and Planned operations, and four feet higher than historical.

6.5 Dike Provo Bay

This scenario involves diking off and reducing water level fluctuations in Provo Bay, creating a separate body of water. Aspects of this scenario have been under consideration for some time by the June Sucker Recovery Program, Diking of Provo Bay could facilitate the establishment of an additional refugia for June sucker and a second spawning area on Hobble Creek, as well as allowing for the removal/control of non-native fish in a smaller, more easily managed volume of water.

Although a number of different Provo Bay diking sub-scenarios are possible, in this analysis a 2.5 mile long levee was assumed to be created across the mouth of Provo Bay, from the southeastern edge of the Provo Airport, due south to the vicinity of River Lane, near the Spanish Fork River. Assuming a top width of 24 feet and height of 14 feet, with one-to-one side slopes, this dike would have a volume of approximately 250,000 cubic yards. LKSIM model area-capacity information estimates the Provo Bay area at 6,700 acres and 24,200 acre-feet in volume.

In addition to a number of drains and springs, inflow to Provo Bay currently includes Spring Creek, Dry Creek, and Hobble Creek; and could (with channel modifications) include a portion of the flow of the Provo and Spanish Fork rivers. Detailed 1950 to 1999 datasets of Utah Lake inflow are available from the LKSIM model for Provo Bay. For this alternative, Provo Bay area was assumed to receive an average annual inflow of 115,800 acre-feet. The dike along the western edge of Provo Bay was assumed to have a crest elevation of 4494, above the maximum Utah Lake water level (to restrict main Lake water from flowing into Provo Bay), with a spillway at elevation 4,489 and tide gates situated to release all excess inflow when Provo Bay levels exceed elevation 4489 and the level of Utah Lake. The only outflow from the diked off Provo Bay area would include spills when the level exceeds 4489, and evaporation losses.

Simulation of the 6,700 acre Provo Bay as a separate body of water shows that inflows are sufficiently large to counteract evaporation losses throughout most months in most years. This restricts evaporative drawdown to only a few inches. Similarly, the tide gate spillway is large enough to release all inflows above the capacity of the Bay[4].   These two factors combine to produce very stable simulated water levels. The only times when Provo Bay rises above 4489, occur when Utah Lake rises above Compromise (and above the level of Provo Bay), restricting outflow through the tide gate.

The results of the Provo Bay diking simulation run are summarized in Tables 3 and 4 and on the graphs shown in Figures 26 and 27. The average annual fluctuation in water surface level is 0.35 feet. The median level fluctuation is 0.10 feet. The maximum drawdown level is 4488.95, less than a foot below the full pool level.

Simulated average monthly water levels for each of the previously described level fluctuation reduction scenarios are presented in Figure 28.

[4] The simulation assumed a tide gate with a large capacity, operated to release all surcharging storage. The tide gate could be operated to allow additional surcharging (similar to the Pre-Water Development conditions) if this was desirable in terms of improving riparian habitat.

7.0 Simulation of Utah Lake Salinity

This chapter presents results from analyses of the salinity of Utah Lake under current and Planned and Pre-Water Development conditions and under each of the previously described Utah Lake water level fluctuation reduction scenarios. The salinity, expressed in terms of total dissolved solids (TDS) measured in milligrams per liter (mg/L) is a factor in the use of Utah Lake water for water supply and recreation. Lake salinity also serves as an indicator of the amount of flushing that is occurring in Utah Lake, since salinity levels will tend to rise (due to evaporation) as less water is released from the Lake and the salt flushing drops. Changes in Utah Lake water level fluctuation (the subject of this report) will directly affect Utah Lake salinity since changes in evaporation are directly correlated with changes in Lake elevation and area.

As modeled in LKSIM, Utah Lake receives water from about 80 separate sources, representing both point-specific inflows (rivers, creeks, waste water treatment plant discharges, and drains) and generalized flows (geographically-dispersed groundwater and surface water inflows). Evaporation from the Lake has a concentrating effect on the dissolved minerals in the lake and those carried in by inflows. Non-evaporative outflows from the lake consist of releases to the Jordan River and one or more minor, direct irrigation diversions. Jordan River outflow is the only significant means of discharging dissolved minerals from the lake.

Over time, the Lake continuously moves towards a "salinity balance". This means the Lake's salinity increases to the concentration at which the TDS of the water in the Lake and released to the Jordan River is in balance with the weighted average TDS of the inflows (as concentrated by evaporation). If conditions were constant the Lake's salinity would stabilize at the TDS at which the out flowing mass of salt carried by the Jordan River is equal to the mass of salt in all the inflows to the Lake. Evaporation changes the concentration of salt, but not the mass. However, hydrological conditions are constantly changing with resulting variations in the numerous sources of inflow to Utah Lake. The result is a highly complex system where cycles in water amounts and water quality result in large variations in TDS levels as well as Lake level. Of course, over historical times, TDS in the tributaries and in the Lake have varied markedly.

Water quality in Utah Lake is strongly affected by the Lake's large net evaporation loss, which concentrates the total dissolved solids in the Lake. The high levels of TDS are further compounded by mineral springs that occur around and in the Lake. In recent times a typical TDS concentration is about 900 parts per million (mg/L), but rather large variations occur with the ongoing wet and dry cycles of differing intensity and duration (Fuhriman et al., 1981).

Because of its size, Utah Lake receives, contains, and releases a large amount of salt. For perspective, one acre-foot of Utah Lake water at a relatively low TDS of approximately 735 milligrams per liter (mg/L) contains one ton of salt. Thus at the Compromise level, and at a more typical TDS concentration of 900 mg/L, Utah Lake would contain approximately 1 million tons of salt. Under Current and Planned conditions and over the 50-year simulation period, Jordan River outflow carries an average load of 440,000 tons of salt per year, which is also the average mass of salt entering the Lake.

7.1 Method of Analysis

Utah Lake was modeled as a storage reservoir that has inflows with various salinities and outflows reflecting the Lake's salinity. A computer model (LKSIM2000) was used as the basis for estimating Utah Lake TDS under conditions associated with the Pre-Water Development and Current and Planned scenarios, as well as each of the lake level fluctuation reduction scenarios. Relationships between monthly inflow and TDS were established for each of the 80 different sources of inflow. The LKSIM model was developed and calibrated for historical conditions and was used to simulate the ULS Proposed Action conditions prior to modeling the pre-water development and predicted future condition scenarios evaluated in this study.

7.1.1 LKSIM2000 TDS Model

TDS modeling was performed using the LKSIM model. This model is essentially a mass balance model that calculates water and salt balances for Utah Lake on a monthly time step. Early versions of the model were developed in the 1970's by Drs. LaVere Merritt and Dean Fuhriman. Since about 1985, Dr. Merritt has teamed with Dr. Wood Miller in continuing refinements to the LKSIM model. All are professors of civil and environmental engineering at Brigham Young University. This model includes input for 57 surface sources, 19 fresh and mineral groundwater sources, and precipitation. Salinity levels for each inflow dataset were established based on monitoring and regression analyses conducted in the 1980s and 1990s. Water quality conditions and tributary flow conditions in the future may change as the result of landuse changes and development.

The current version of the model, LKSIM2000, is used routinely by the CUWCD and their consultants to evaluate Utah Lake salt concentrations associated with various water management scenarios for Utah Lake. Simulation runs documented herein were performed by Dr. LaVere Merritt using input data developed by HDR Engineering for each modeled scenario. Specific aspects of certain input data sets were developed using water rights operations studies conducted using PROSIM2000 (CUWCD, 1998) and various spreadsheet models.

7.2 Modeling Results

7.2.1 Current and Planned Conditions

Figure 29 and Table 5 show the TDS concentrations in Utah Lake for the 1950 to 1999 simulation period under the simulated Current and Planned operating conditions. The results for each of the 600 months in the 50-year simulation period were averaged to calculate average results. The 50-year modeled average for the Current and Planned scenario was 942 mg/L. This corresponds very closely with the simulated average TDS for the ULS Proposed Action, which was 932 mg/L. The highest modeled TDS concentration, 1,700 mg/L[5], occurred in 1963, the year of lowest simulated water level. During the high Utah Lake level in 1984, the modeled TDS reached a low of about 455 mg/L. The simulated TDS was above 1,200 mg/L during 73 of the 600 months. Appendix B contains a print-out of the detailed results of the analysis. These TDS concentrations also apply to the Jordan River outflow to the Jordan Narrows. The TDS concentrations for each month of the 50-year period of analysis are presented in Appendix B, Utah Lake Salinity Analysis (LKSIM2000) – Current and Planned Conditions.

7.2.2 Pre-Water Development Conditions

Figure 29 and Table 5 show the TDS concentrations in Utah Lake for the 1950 to 1999 simulation period under the simulated Pre-Water Development operating conditions. As

[5] The 1,700 mg/L is an engineering judgment cap placed on the TDS. When the Lake contents and tributary flows get extremely low the model and data may be unreliable.

described in section 4.0, the Pre-Water Development scenario simulates the Lake's behavior with the quantifiable effects of upstream depletions, operations as a storage reservoir, and changes to the outlet removed. The Lake's operation under this scenario approaches natural conditions, and thus the salinity results would be expected to approximate natural salinity levels. The results for each of the 600 months in the 50-year simulation period were averaged to calculate average results. The 50-year modeled average for the Pre-Water Development scenario was 578 mg/L, more than 350 mg/L lower than under Current and Planned conditions. The highest modeled TDS concentration, 829 mg/L, occurred in 1992, a year of low simulated water level. During the high Utah Lake level in 1984, the modeled TDS reached a low of about 364 mg/L. The simulated TDS was never above 1,200 mg/L during the 600 months. Appendix B contains a print-out of the detailed results of the analysis. These TDS concentrations also apply to the Jordan River outflow to the Jordan Narrows. The TDS concentrations for each month of the 50-year period of analysis are presented in Appendix B, Utah Lake Salinity Analysis (LKSIM2000) – Pre-Water Development Scenario.

7.2.3 Lower Conservation Pool Scenario Conditions

Figure 30 and Table 5 show the TDS concentrations in Utah Lake for the 1950 to 1999 simulation period under the simulated Lower Conservation Pool scenario operating conditions. As described in section 6.0, the Lower Conservation Pool scenario assumes that the maximum level at which water is held in the lake is lowered from 4489.045 to 4487.045. The stage versus outflow curve is doubled to keep the Lake from surcharging. Inflows to the Lake remain unchanged. The results for each of the 600 months in the 50-year simulation period were averaged to calculate average results. The 50-year modeled average for the Lower Conservation Pool scenario was 923 mg/L, just 20 mg/L lower than under Current and Planned conditions. The highest modeled TDS concentration, 1,700 mg/L, occurred in 1961 and 1963, years of low simulated water level. During the high Utah Lake level in 1984, the modeled TDS reached a low of about 429 mg/L. The simulated TDS was above 1,200 mg/L during 66 of the 600 months. Appendix B contains a print-out of the detailed results of the analysis. These TDS concentrations also apply to the Jordan River outflow to the Jordan Narrows. The TDS concentrations for each month of the 50-year period of analysis are presented in Appendix B, Utah Lake Salinity Analysis (LKSIM2000) – Lower Conservation Pool Conditions.

7.2.4 Reduce Area-Capacity Relationship Scenario Conditions

Figure 31 and Table 5 show the TDS concentrations in Utah Lake for the 1950 to 1999 simulation period under the simulated Reduced Area-Capacity Relationship scenario operating conditions. As described in section 6.0, the Reduced Area-Capacity Relationship scenario assumes that lake evaporation losses are reduced by reducing the Lake's surface area and volume. This would presumably be accomplished by cutting off a portion of the shallow, saline areas of the Lake with a major dike. The results for each of the 600 months in the 50-year simulation period were averaged to calculate average results. The 50-year modeled average for the Reduced Area-Capacity Relationship scenario was 792 mg/L, 150 mg/L lower than under Current and Planned conditions. The highest modeled TDS concentration, 1,231 mg/L, occurred in 1963, a year of low simulated water level. During the high Utah Lake level in 1984, the modeled TDS reached a low of about 407 mg/L. The simulated TDS was above 1,200 mg/L during just 6 of the 600 months. Appendix B contains a print-out of the detailed results of the analysis. These TDS concentrations also apply to the Jordan River outflow to the Jordan Narrows. The TDS concentrations for each month of the 50-year period of analysis are presented in

Appendix B, Utah Lake Salinity Analysis (LKSIM2000) – Reduced Area-Capacity Relationship Conditions.

7.2.5 Increase Upstream Exchange Scenario Conditions

Figure 32 and Table 5 show the TDS concentrations in Utah Lake for the 1950 to 1999 simulation period under the simulated Increased Upstream Exchange scenario operating conditions. As described in section 6.0, the Increased Upstream Exchange scenario assumes that 50,000 acre-feet of water rights that are currently delivered downstream of the Lake are exchanged to wells and surface flows upstream of the Lake. The results for each of the 600 months in the 50-year simulation period were averaged to calculate average results. The 50-year modeled average for the Increased Upstream Exchange scenario was 947 mg/L, essentially the same as under Current and Planned conditions. The highest modeled TDS concentration, 1,641 mg/L, occurred in 1963, a year of low simulated water level. During the high Utah Lake level in 1984, the modeled TDS reached a low of about 453 mg/L. The simulated TDS was above 1,200 mg/L during 77 of the 600 months. Appendix B contains a print-out of the detailed results of the analysis. These TDS concentrations also apply to the Jordan River outflow to the Jordan Narrows. The TDS concentrations for each month of the 50-year period of analysis are presented in Appendix B, Utah Lake Salinity Analysis (LKSIM2000) – Increased Upstream Exchange Conditions.

7.2.6 Increase Rights Held in Lake Scenario Conditions

Figure 33 and Table 5 show the TDS concentrations in Utah Lake for the 1950 to 1999 simulation period under the simulated Increased Rights Held in Lake scenario operating conditions. As described in section 6.0, the Increased Rights Held in Utah Lake scenario assumes that 50,000 acre-feet of water rights that are currently delivered downstream of the Lake are instead held in the Lake, similar to the way CUWCD uses some of its rights to keep Lake levels higher. The results for each of the 600 months in the 50-year simulation period were averaged to calculate average results. The 50-year modeled average for the Increased Rights Held in Lake scenario was 964 mg/L, essentially the same as under Current and Planned conditions. The highest modeled TDS concentration, 1,652 mg/L, occurred in 1963, a year of low simulated water level. During the high Utah Lake level in 1984, the modeled TDS reached a low of about 455 mg/L. The simulated TDS was above 1,200 mg/L during 103 of the 600 months. Appendix B contains a print-out of the detailed results of the analysis. These TDS concentrations also apply to the Jordan River outflow to the Jordan Narrows. The TDS concentrations for each month of the 50-year period of analysis are presented in Appendix B, Utah Lake Salinity Analysis (LKSIM2000) – Increased Rights Held in Lake.

7.2.7 Provo Bay Diking Scenario Conditions

Figure 34, Figure 35, and Table 5 show the TDS concentrations in both Provo Bay and Utah Lake for the 1950 to 1999 simulation period under the simulated Provo Bay Diking scenario operating conditions. As described in section 6.0, the Provo Bay Diking scenario assumes that a 2.5 mile long dike was constructed across the mouth of Provo Bay and main Utah Lake salinity and level fluctuations were excluded from Provo Bay. The diked-off Provo Bay would receive a very high volume of runoff, and as a result, water levels would be kept high and salinity low.

The results for each of the 600 months in the 50-year simulation period were averaged to calculate average results. The 50-year modeled average in Utah Lake for the scenario was 948 mg/L, essentially the same as under Current and Planned conditions. This is reasonable, given that Lake inflows and outflows are largely unaffected by the scenario. The 50-year modeled average TDS in Provo Bay for the scenario was 566 mg/L, almost 400 mg/L less than in Utah Lake under Current and Planned conditions. This is because the Provo Bay area receives relatively low TDS inflow, and inflow volumes are very high compared to the storage volume in the Bay, thus preventing the build-up of evaporation effects. The highest modeled TDS concentration in the Lake, 1,700 mg/L, occurred in 1962, 1963, and 1964, years of low simulated water level. The highest modeled TDS concentration in Provo Bay reached only 829 mg/L. During the high Utah Lake level in 1984, the modeled TDS in Utah Lake reached a low of about 458 mg/L, and the simulated TDS in Provo Bay reached 163 mg/L. The simulated TDS was above 1,200 mg/L in Utah Lake during 80 of the 600 months. Appendix B contains a print-out of the detailed results of the analysis. These Utah Lake TDS concentrations also apply to the Jordan River outflow to the Jordan Narrows. The TDS concentrations for each month of the 50-year period of analysis are presented in Appendix B, Utah Lake Salinity Analysis (LKSIM2000) – Provo Bay Diking Scenario.

7.3 Salinity Modeling Conclusions

Simulation results from all of the modeling scenarios are compared graphically on Figures 36 and 37. Figure 36 shows the simulated monthly TDS levels for the entire 50-year period, and Figure 37 shows the monthly average TDS values. Examination of these figures shows that salinity levels under Current and Planned conditions and under all but two of the lake level fluctuation reduction scenarios are fairly close. The only scenarios that affect salinity enough to allow it to approach the simulated pre-water development conditions are the Reduced Area-Capacity scenario and the Provo Bay Diking scenario. If salinity reduction, in addition to level fluctuation reduction, is a significant goal of the June sucker Recovery Program, additional study should be focused on these two scenarios.

8.0 Conclusions and Recommendations

A number of conclusions and recommendations result from the completion of this study of Utah Lake water level fluctuations. The following sections summarize these conclusions and present recommendations for further progress designed to reduce the impacts of level fluctuations on June sucker recruitment.

8.1 Study Conclusions

This study shows that water development activities, including upstream depletion of inflow, use of the Lake as a storage reservoir, and enlargement of the Lake's outlet capacity by dredging, have tended to increase the average annual change in water level and to lower the maximum drawdown level. Salinity simulations show that the water development activities have increased the average TDS level in the Lake by over 350 mg/L. Level simulation results show that in its Pre-Water Development state, the average annual fluctuation of Utah Lake level would be slightly over 2.1 feet, and the minimum level of the Lake would rarely fall below elevation 4485.7. The average area that would dry up each year was about 6,000 acres. Over the 1950 through 1999 historical period, Utah Lake's average annual fluctuation was 3.51 feet, and its minimum level fell below 4480. The average annual area of dried up lake surface area was over 10,000 acres. Additionally, because of the use of the lake as a storage reservoir and the use of pumps to withdraw water, the lake was historically drawn down more rapidly in the early summer and by up to 8 feet during prolonged dry periods. These seasonal, annual, and long-term level variations may tend to hinder the establishment and survival of deep rooted aquatic vegetation.

Water right changes currently in place and planned for implementation will change how the level of Utah Lake varies in the future. Upstream and downstream water right exchanges and holding additional water rights in Utah Lake will tend to reduce level and TDS fluctuations. Simulation results from the Current and Planned scenario indicate that the average annual variation in Utah Lake level will be 2.50 feet and the minimum level during the 1950 to 1999 simulation period will be 4481.25. The Current and Planned operation decreases the average annual variation in water level from 3.51 feet to 2.50 feet and the area of lake surface that dries up from 10,000 acres to 6,600 acres. Increased outlet capacity resulting from the dredging of the Jordan River channel tends to reduce maximum water levels during extremely wet years as well. Simulations using the LKSIM model show that the Current and Planned operation will result in an average TDS of 942 mg/L, just slightly higher than the simulated average historical TDS of 907 mg/L.

The results of the simulations of Lake level fluctuation reduction scenarios indicate that lowering the Lake's conservation pool level and/or reducing the downstream demands on Utah Lake by exchanging water upstream or holding more water in the Lake would tend to return the lake levels to a more natural pattern. The only scenarios that significantly improve TDS concentrations are the reduced area-capacity and Provo Bay diking concepts. The lowering of the conservation pool is ineffective at reducing fluctuation, unless combined with additional upstream exchange. Increasing the volume of water being held in the Lake is somewhat more effective at reducing level fluctuation than exchanging water upstream. Simulation results indicate that the diking of Provo Bay would reduce fluctuations and TDS (in the diked off area) most effectively. Modifying the Lake's area-capacity relationship by diking off a large portion of the Lake was not shown to be effective at reducing level fluctuation, although it did decrease the average simulated TDS by 150 mg/L.

Tables 3, 4, and 5 present a summary of results for each of the level fluctuation reduction scenarios evaluated. It is important to note that the Current and Planned scenario has already reduced Utah Lake level fluctuations to a significant extent (compared to historical operations). This is largely due to the acquisition and use of Utah Lake rights under the Bonneville Unit of the Central Utah Project, and exchange of water rights to areas upstream of the Lake, as well as operation of the Lake under the Utah Lake Distribution Plan.

Further study would be necessary to determine whether these or other potential lake level fluctuation reduction scenarios could be feasible and effective in improving June sucker habitat. Evaluation of scenario feasibility was outside of the scope of this initial study. The acquisition and stabilization of 50,000 acre-feet of Utah Lake water rights would be expected to be a very expensive undertaking and to have significant impacts on other resources. Similarly, diking off Provo Bay, or another portion of the Lake, or lowering the Lake's conservation pool level or area-capacity relationship would be difficult and complex projects requiring significant environmental analysis, administrative approvals, and political consensus.

Given the significant demand for Utah Lake water rights, large amounts of water in Utah Lake for upstream exchange, to hold in storage, or for use to mitigate possible impacts on water supplies are unlikely to be available except at a very high price. Similarly, it would be difficult to gain approval for changes in Lake operations that might affect water availability for other water users. In particular it would be very difficult to gain approval for changing the Compromise level (which has been an issue of contention for 120 years), or for significantly altering the Lake in any way that might affect the reliability of water supplies during drought. These are likely to be some of the most difficult issues to overcome, and would require careful additional analysis. In addition to detailed water rights evaluations, thorough environmental studies would need to be conducted to understand the potential environmental effects associated with such large changes in Utah Lake operations.

Finally, from the standpoint of the June sucker Recovery Implementation Program, it is critically important to understand the extent to which these or related level fluctuation reduction scenarios, applied in conjunction with efforts to control nutrient loads and non-native species, might assist in the restoration of aquatic vegetation, increase June sucker recruitment, and improve the overall Utah Lake ecosystem.

8.2 Recommendations for Further Study

Further study would be necessary to determine whether the scenarios investigated herein or other potential lake level fluctuation reduction scenarios could be feasible and effective in improving June sucker habitat. Evaluation of scenario feasibility was outside of the scope of this initial study. However, based on the results of this study, the following additional investigations are recommended to provide information for additional evaluation of the effect of Utah Lake water level fluctuations on aquatic habitat and for the development and/or refinement of level fluctuation reduction scenarios and concepts.

1) Analyze hydraulic and hydrologic connection between Hobble Creek and Utah Lake and/or Provo Bay. The stream channel connecting Hobble Creek to Utah Lake should receive additional study pertaining to the ability of June sucker to move upstream into Hobble Creek under lower Utah Lake levels and under Provo Bay diking conditions.

2) Develop and/or test potential physical measures to minimize the effects of water level fluctuation on aquatic vegetation. Aquatic mitigation measures that might be effective in reducing the effects of level fluctuations include floating habitat beds and vegetated offshore islands or berms. The goal of these studies would be to increase Utah Lake habitat complexity, without additional control of water level fluctuation.

3) Develop additional detailed hydrologic information regarding inflows, design, and operation of Provo Bay diking scenario. Inflow data are quite old and may not still be pertinent. Various diking designs are possible and should be compared in terms of their ability to increase habitat complexity and reduce habitat limitations on June sucker recruitment.

4) Develop additional project feasibility information on Provo Bay diking and potential other scenarios. Information could include review of water quality, wetlands, costs, permitting, land ownership, and other issues and studies required to move forward with the project.

Table 3 Water Level Results of Pre-Water Development, Historical, Current and Planned, and Level Fluctuation Reduction Simulations for the 1950-1999 Period*

		Pre-Water Development	Historical	Current & Planned	Scenario 1 - Lower Conservation Pool Level	Scenario 2 - Modify Stage-Area Relationship	Scenario 3 - Increase Upstream Exchanges	Scenario 4 - Increase Rights Held in Lake	Scenario 5 - Stabilize Provo Bay (Lake Results)	Scenario 5 - Stabilize Provo Bay (Bay Results)
Average Water Surface Elevation	(feet)	4489.16	4487.10	4487.57	4485.87	4487.96	4487.97	4488.24	4487.33	4489.13
Average Annual Change in Water Surface Elevation	(feet)	2.13	3.51	2.50	2.44	2.57	2.27	2.18	2.67	0.35
Minimum Water Surface Elevation	(feet)	4485.80	4479.94	4481.25	4480.25	4482.40	4482.90	4483.95	4480.20	4488.95
Average Water Surface Area	(acres)	94,665	88,709	90,297	85,563	66,184	91,457	92,202	84,300	6,797
Average Annual Change in Water Surface Area	(acres)	5,345	10,320	6,637	6,906	4,318	5,873	5,618	5,152	170
Minimum Water Surface Area	(acres)	85,771	62,174	70,330	65,066	55,550	76,356	79,924	64,635	6,705
Average Storage Volume	(acre-ft)	884,851	700,520	741,336	589,724	584,309	775,718	799,635	705,136	25,017
Average Annual Change in Storage Volume	(acre-ft)	187,877	307,475	213,103	196,139	159,208	195,716	190,089	212,292	1,879
Minimum Storage Volume	(acre-ft)	563,928	132,139	225,422	158,444	249,552	344,191	426,589	154,301	24,131

* All results are based on simulating lake operations using 1950-1999 hydrology, except Historical, which are based on measured levels for the same period

Table 4 Level Fluctuation Reduction Water Balance Simulations for the 1950-1999 Period* (acre-feet)

	Pre-Water Development	Current & Planned	Scenario 1 - Lower Conservation Pool Level	Scenario 2 - Modify Stage-Area Relationship	Scenario 3 - Increase Upstream Exchanges	Scenario 4 - Increase Rights Held in Lake	Scenario 5 - Stabilize Provo Bay (Lake Results)	Scenario 5 - Stabilize Provo Bay (Bay Results)
Provo River	364,386	113,705	113,705	113,705	113,705	113,705	113,705	0
Spanish Fork River	110,540	93,012	93,012	93,012	93,012	93,012	93,012	0
Local Inflow	478,125	350,036	350,036	310,073	328,836	350,036	350,036	82,406
Precipitation	116,284	111,320	105,350	81,401	112,578	113,427	103,844	8,375
Other Minor Elements	0	31,096	31,096	31,096	31,096	31,096	13,082	33,405
Total Inflow	**1,069,335**	**699,168**	**693,199**	**629,287**	**679,227**	**701,276**	**673,679**	**124,186**
Evaporation	368,771	351,183	332,725	257,106	355,418	358,123	327,579	26,384
Outflow	693,996	343,528	359,469	371,552	319,179	338,349	342,173	97,797
Total Outflow	**1,062,767**	**694,712**	**692,195**	**628,658**	**674,597**	**696,473**	**669,752**	**124,181**

[1] All results are based on simulating lake operations using 1950-1999 hydrology

Table 5 Average, Maximum, and Minimum Simulated TDS Results for All Scenarios

	Pre-Water Development	Current & Planned	Scenario 1 - Lower Conservation Pool Level	Scenario 2 - Reduced Area-Capacity Relationship	Scenario 3 - Increased Upstream Exchange	Scenario 4 - Increase Rights Held in Lake	Scenario 5 - Dike Provo Bay (Lake Results)	Scenario 5 - Dike Provo Bay (Bay Results)
Average TDS (mg/L)	579	942	923	792	947	964	948	566
Change from Current and Planned (mg/L)	-364	0	-19	-150	5	21	6	-376
Maximum TDS (mg/L)	829	1,700	1,700	1,231	1,641	1,652	1,700	829
Minimum TDS (mg/L)	364	455	429	407	453	455	458	285
Number of Months TDS >1200	0	73	66	6	77	103	80	0

[1] All results are based on simulating lake operations using 1950-1999 hydrology

Figure 1 Utah Lake Location

Figure 2 Prehistoric Lake Bonneville Levels

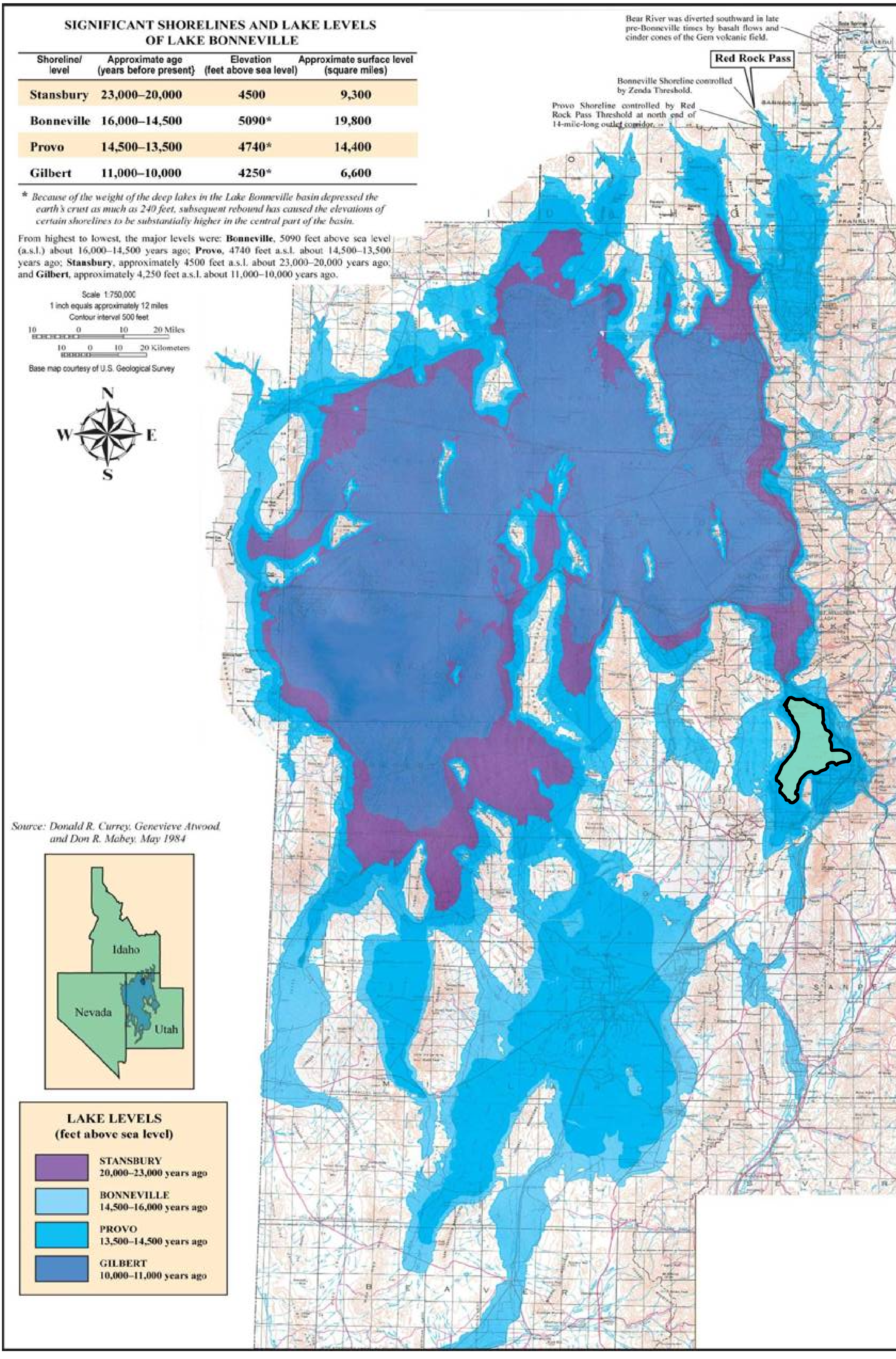
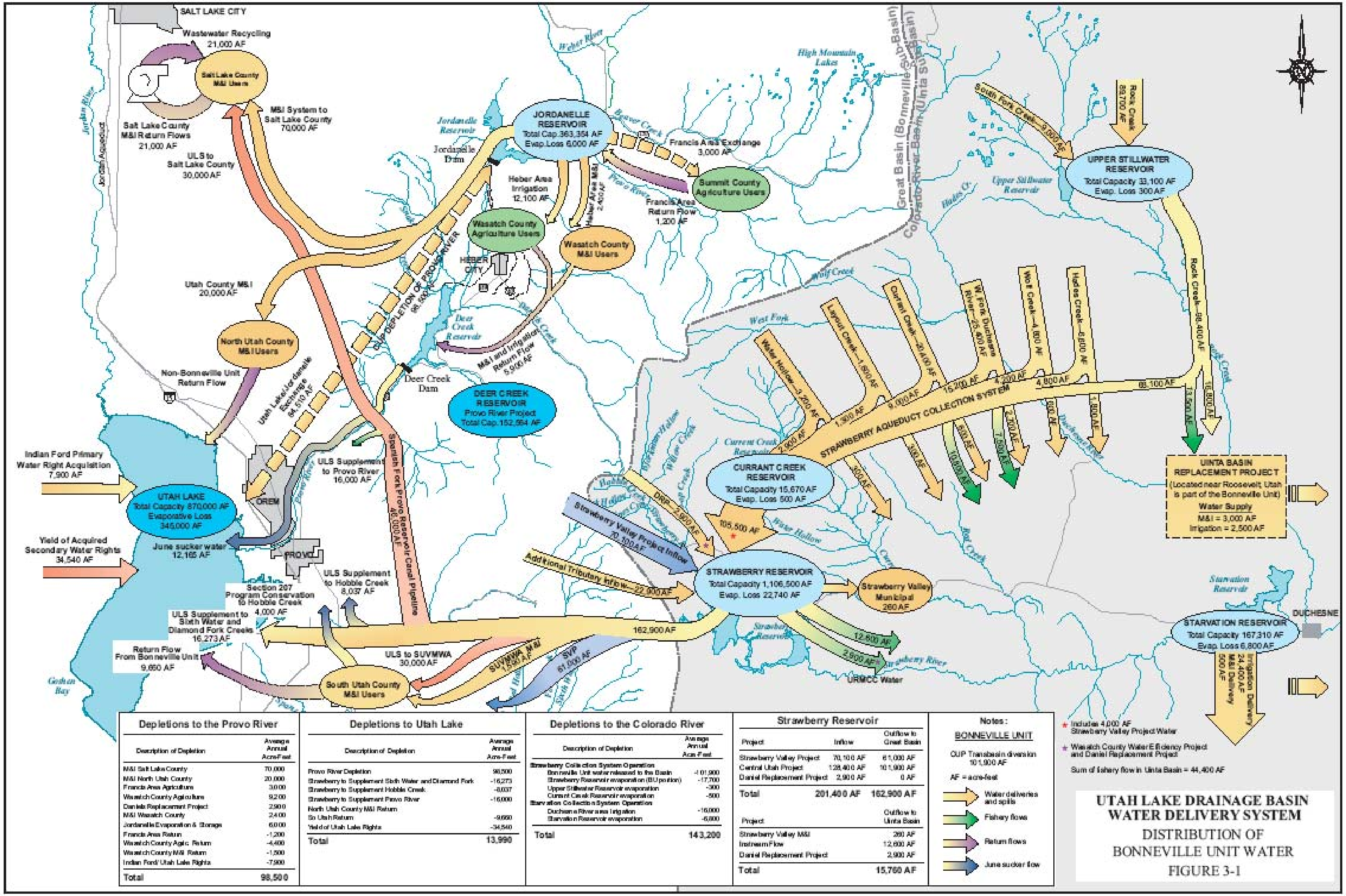


Figure 3 Utah Lake's Role in the Operation of the CUP Bonneville Unit



Depletions to the Provo River

Description of Depletion	Average Annual Acre-Feet
M&I Salt Lake County	70,000
M&I North Utah County	20,000
Francis Area Agriculture	3,000
Wasatch County Agriculture	9,200
Daniels Replacement Project	2,900
M&I Wasatch County	2,400
Jordanelle Evaporation & Storage	6,000
Francis Area Return	-1,200
Wasatch County Agric. Return	-4,400
Wasatch County M&I Return	-1,500
Indian Ford/ Utah Lake Rights	-7,900
Total	98,500

Depletions to Utah Lake

Description of Depletion	Average Annual Acre-Feet
Provo River Depletion	98,500
Strawberry to Supplement Sixth Water and Diamond Fork	-16,273
Strawberry to Supplement Hobble Creek	-8,037
Strawberry to Supplement Provo River	-16,000
North Utah County M&I Return	
So Utah Return	-9,650
Yield of Utah Lake Rights	-34,540
Total	13,990

Depletions to the Colorado River

Description of Depletion	Average Annual Acre-Feet
Strawberry Collection System Operation	
Bonneville Unit water released to the Basin	-101,900
Strawberry Reservoir evaporation (BU portion)	-17,700
Upper Stillwater Reservoir evaporation	-300
Currant Creek Reservoir evaporation	-500
Starvation Collection System Operation	
Duchesne River area Irrigation	-16,000
Starvation Reservoir evaporation	-6,800
Total	143,200

Strawberry Reservoir

Project	Inflow	Outflow to Great Basin
Strawberry Valley Project	70,100 AF	61,000 AF
Central Utah Project	128,400 AF	101,900 AF
Daniel Replacement Project	2,900 AF	0 AF
Total	201,400 AF	162,900 AF

Project	Outflow to Uinta Basin
Strawberry Valley M&I	260 AF
Instream Flow	12,600 AF
Daniel Replacement Project	2,900 AF
Total	15,760 AF

Figure 4 Average Monthly Utah Lake Inflow Pre-Water Development and Current and Planned

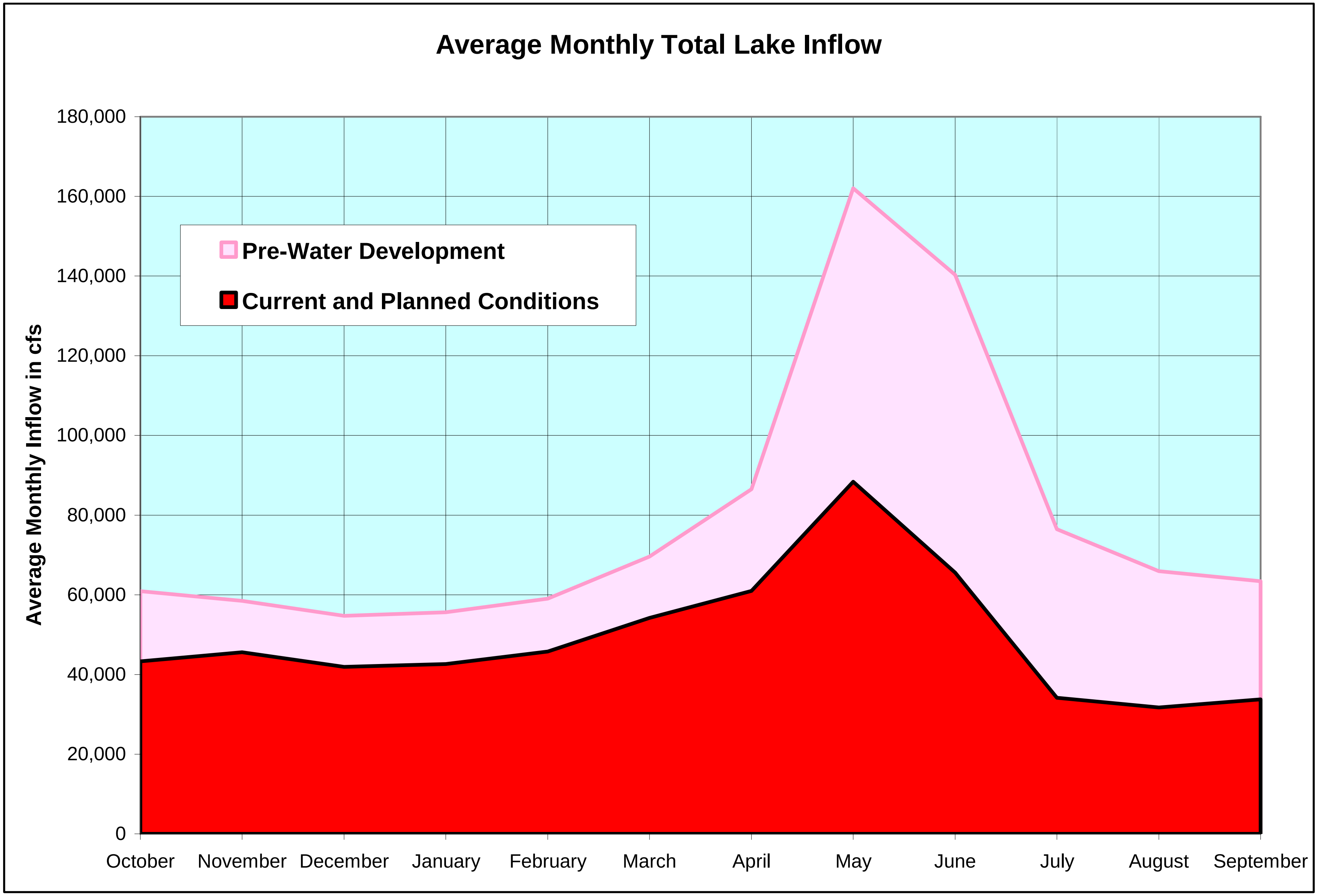


Figure 5 Jordan River from Utah Lake to Jordan Narrows

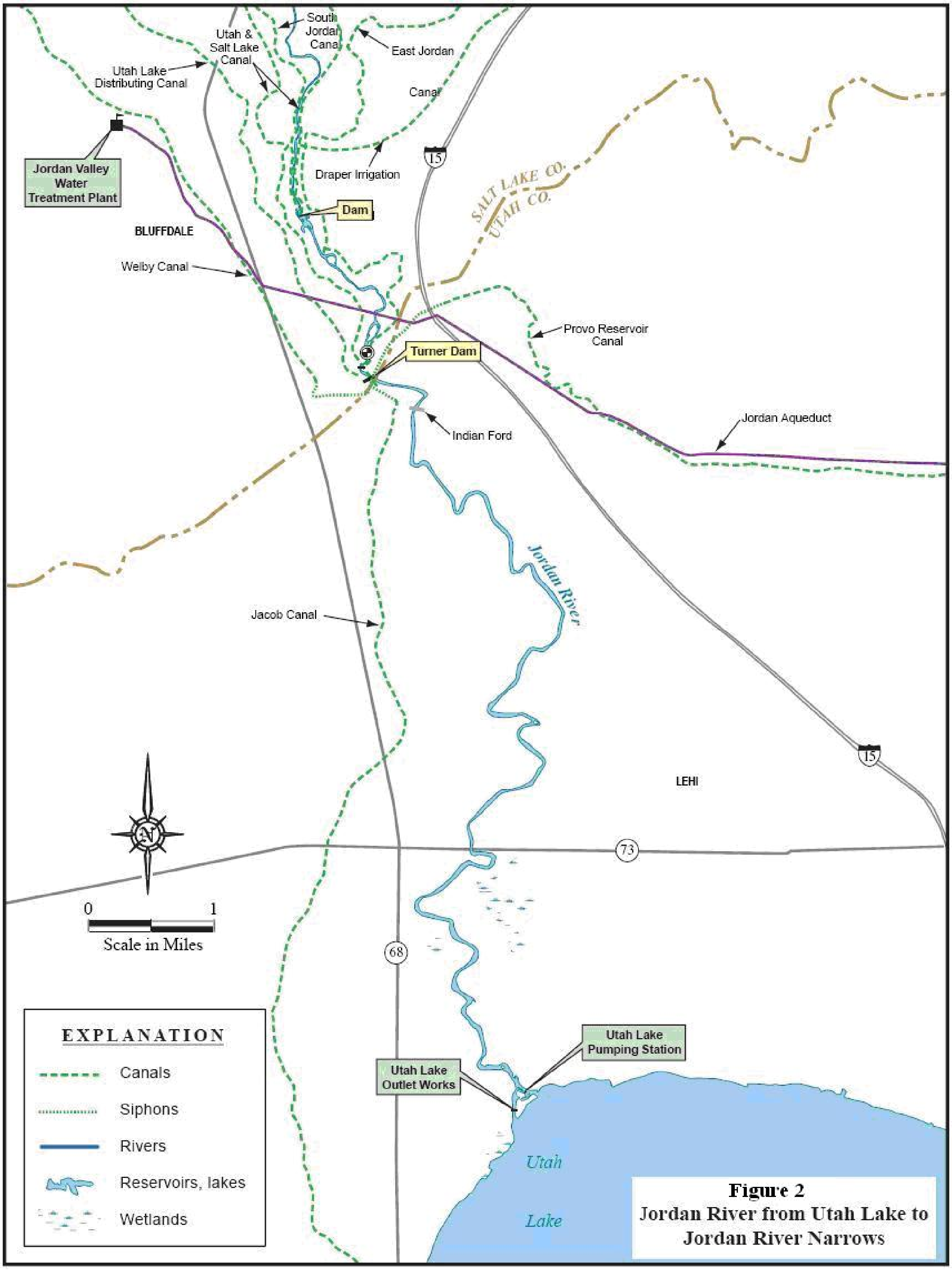


Figure 6 Utah Lake Outlet Works

Figure 7 Pre- and Post-Dredging Jordan River Channel Profile

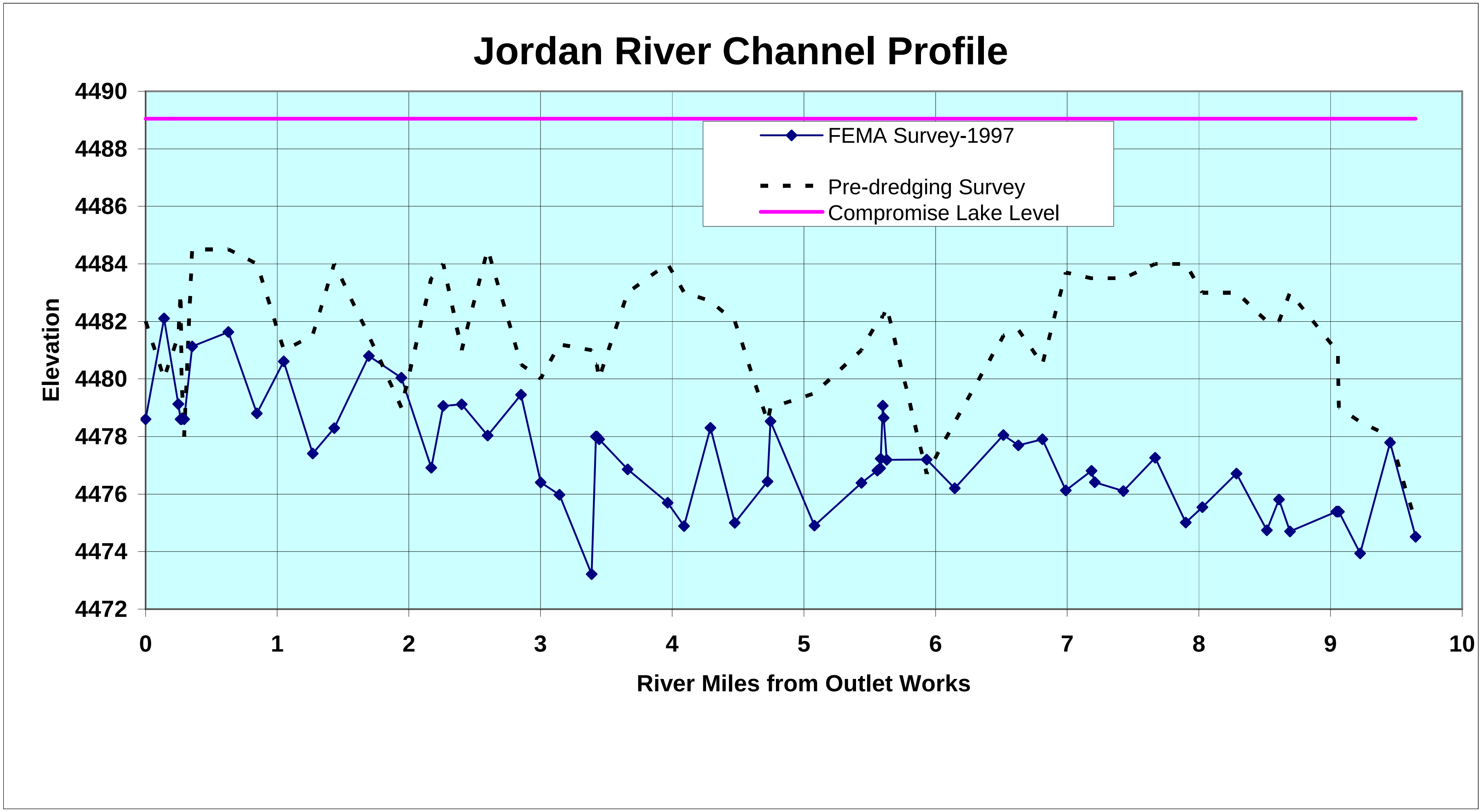


Figure 8 Pre- and Post-dredging Utah Lake Outlet Stage versus Discharge Curves

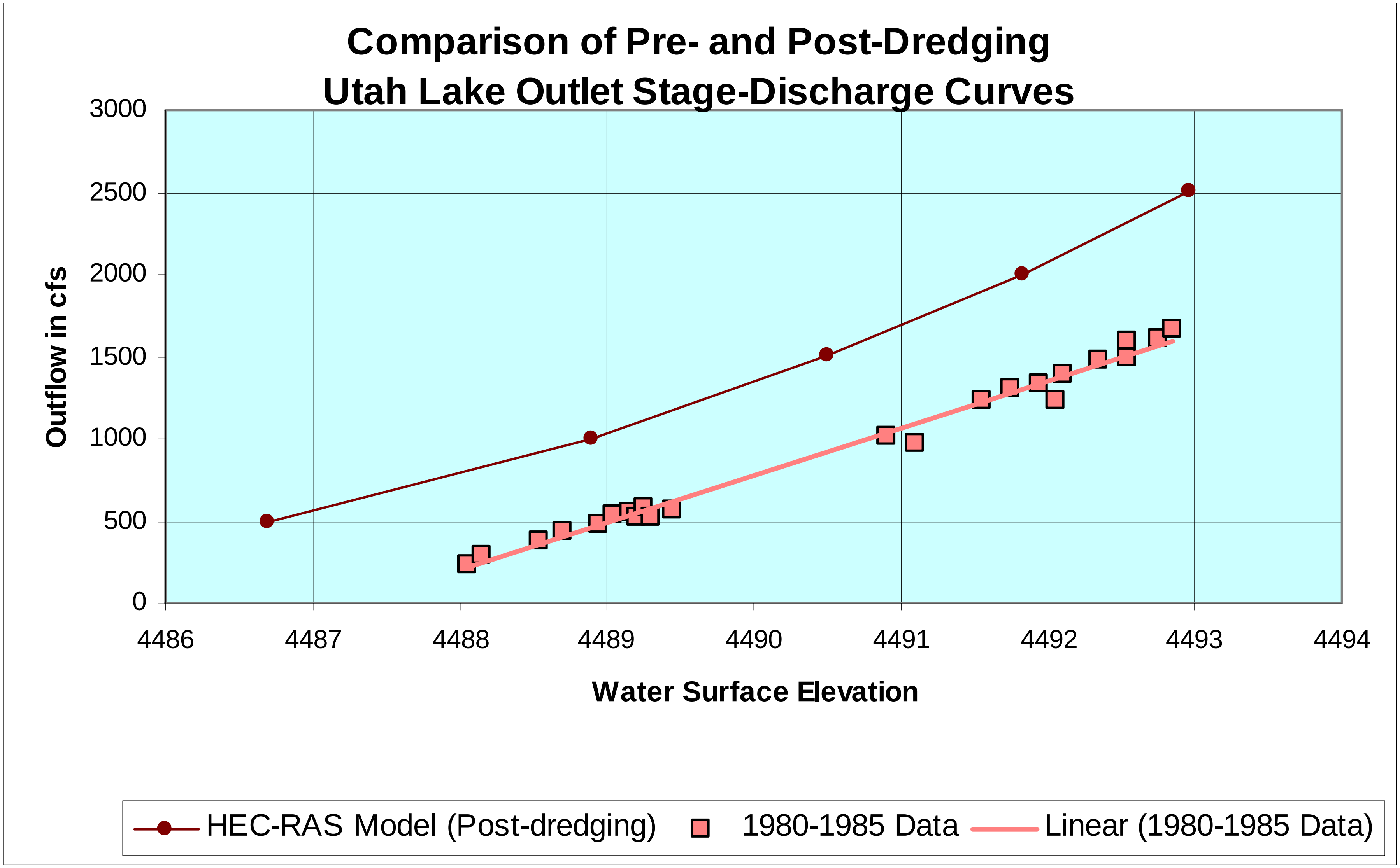


Figure 9 Average Monthly Utah Lake Outflow Pre-Water Development and Current and Planned

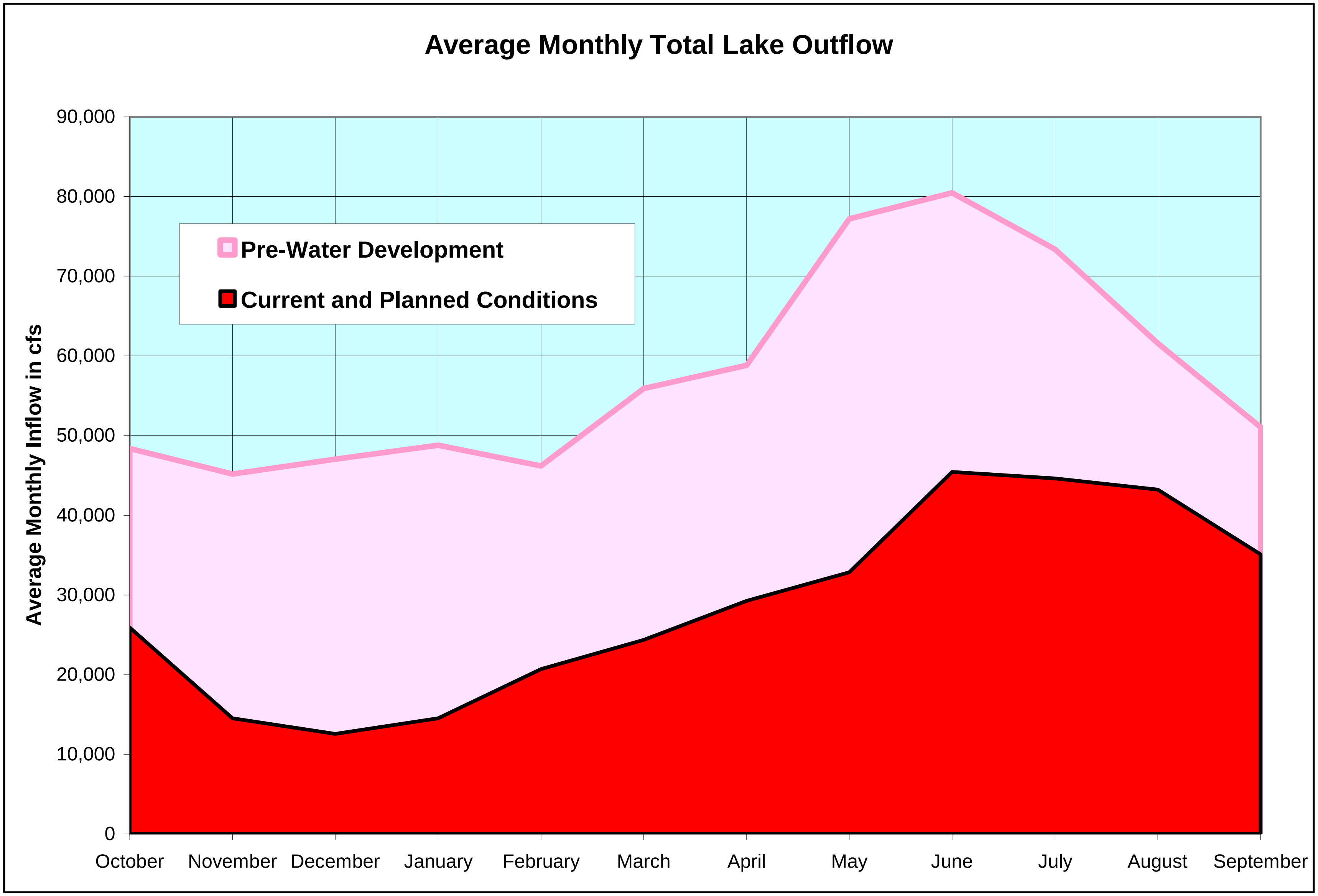


Figure 10 Historical Utah Lake Level – 1884- 2006

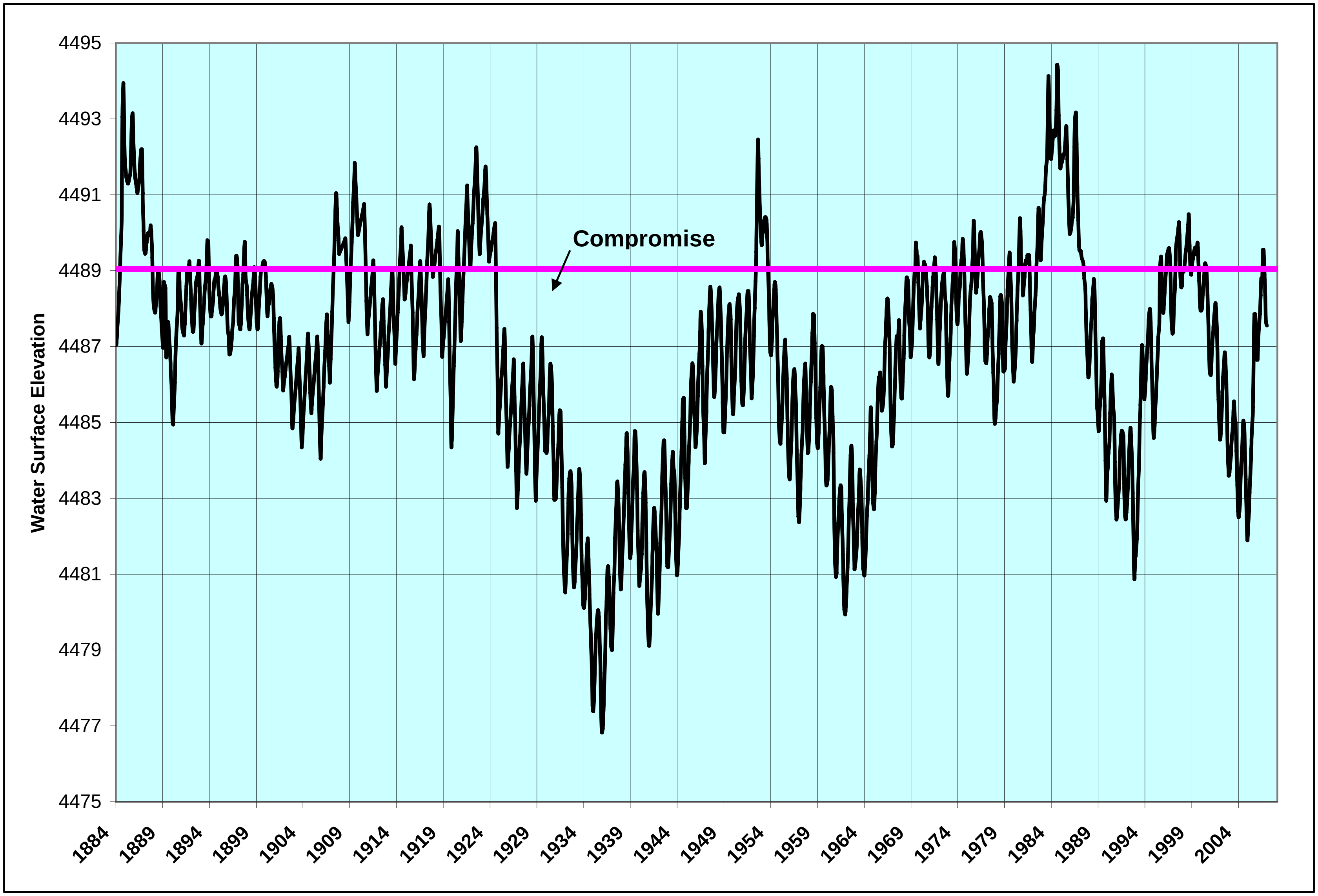


Figure 11 Annual and Five-Year Variation in Utah Lake Level – 1884-2006

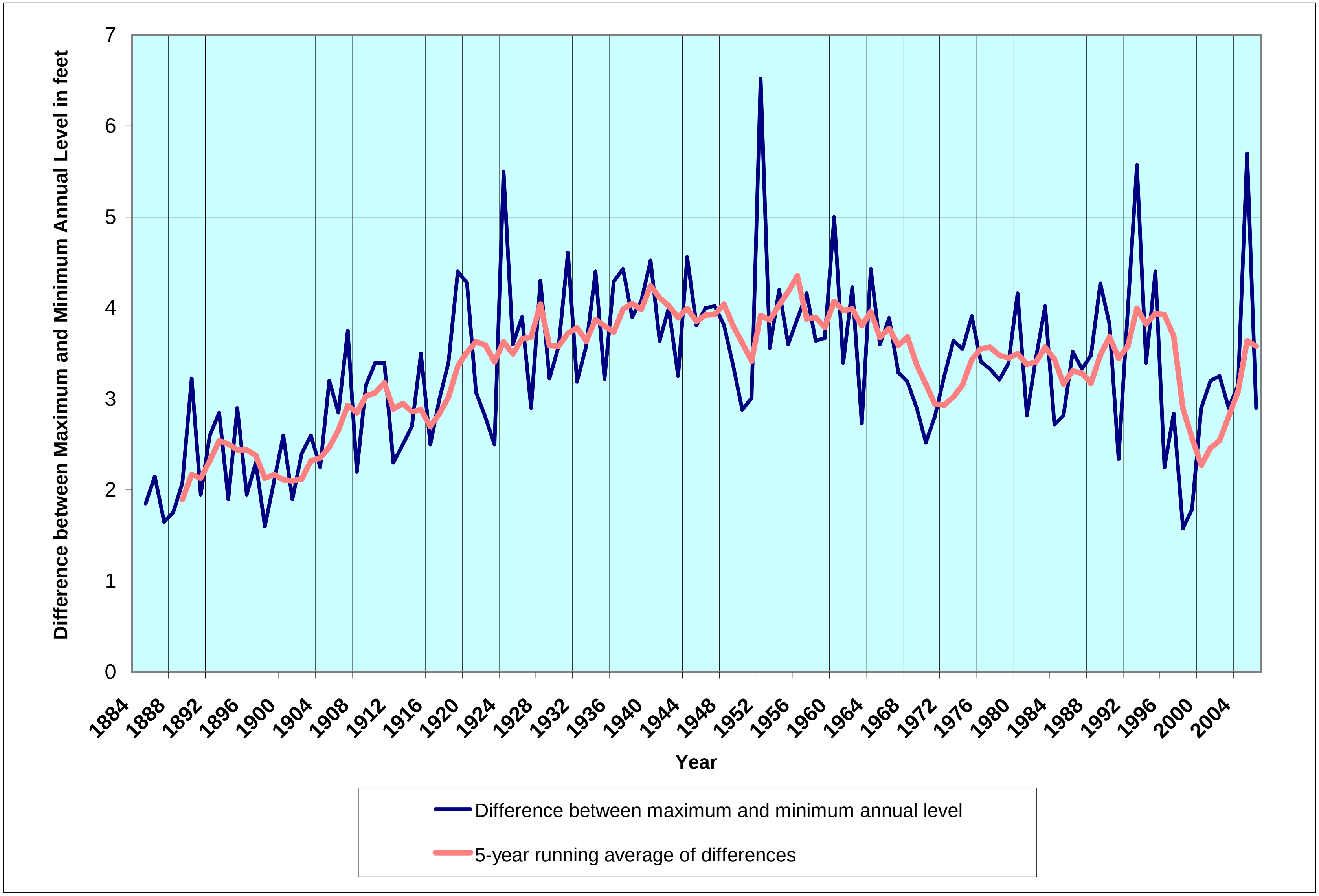


Figure 12 Historical and Simulated Pre-Water Development Utah Lake Water Levels

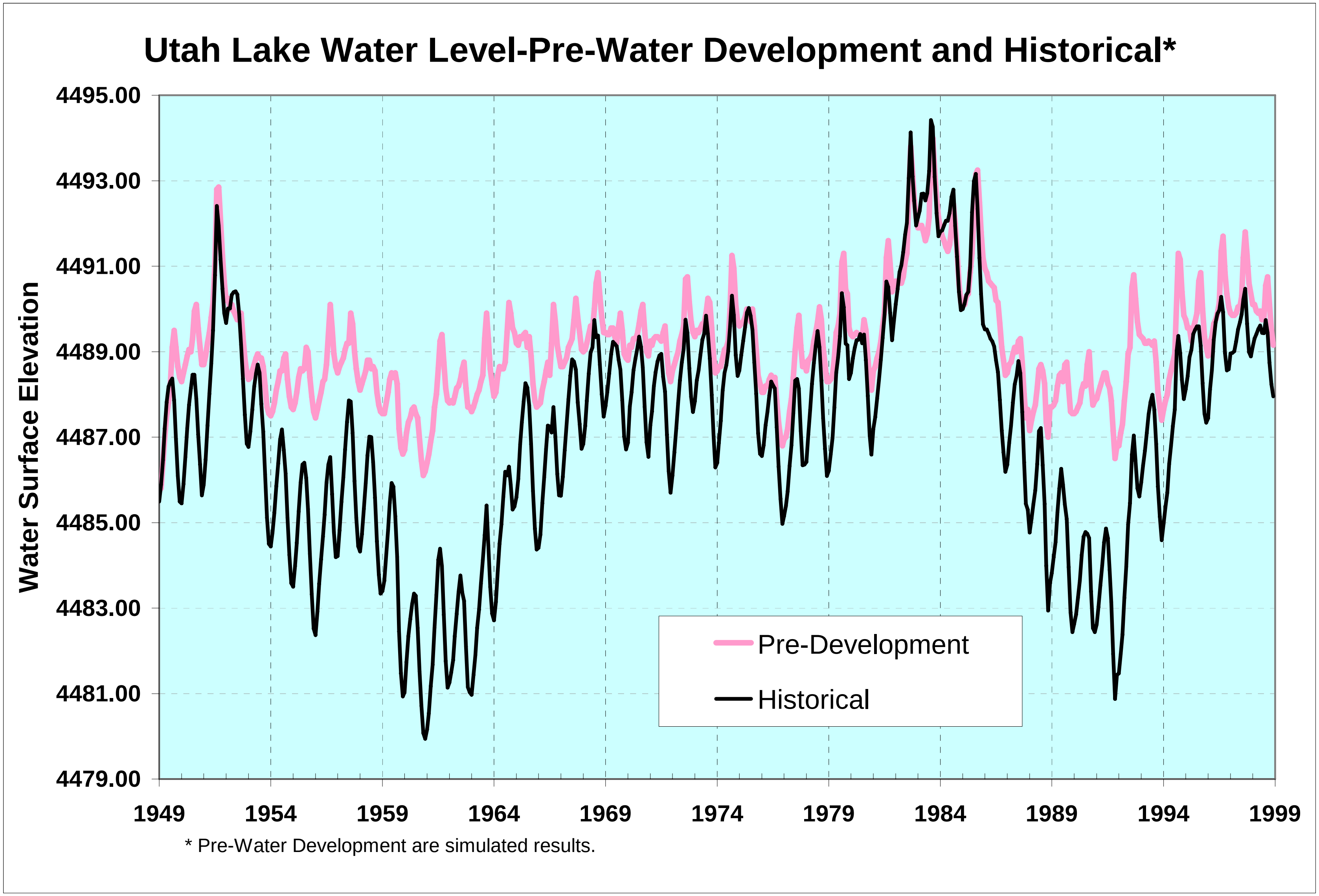


Figure 13 Simulated Pre-Water Development Average Monthly Water Levels

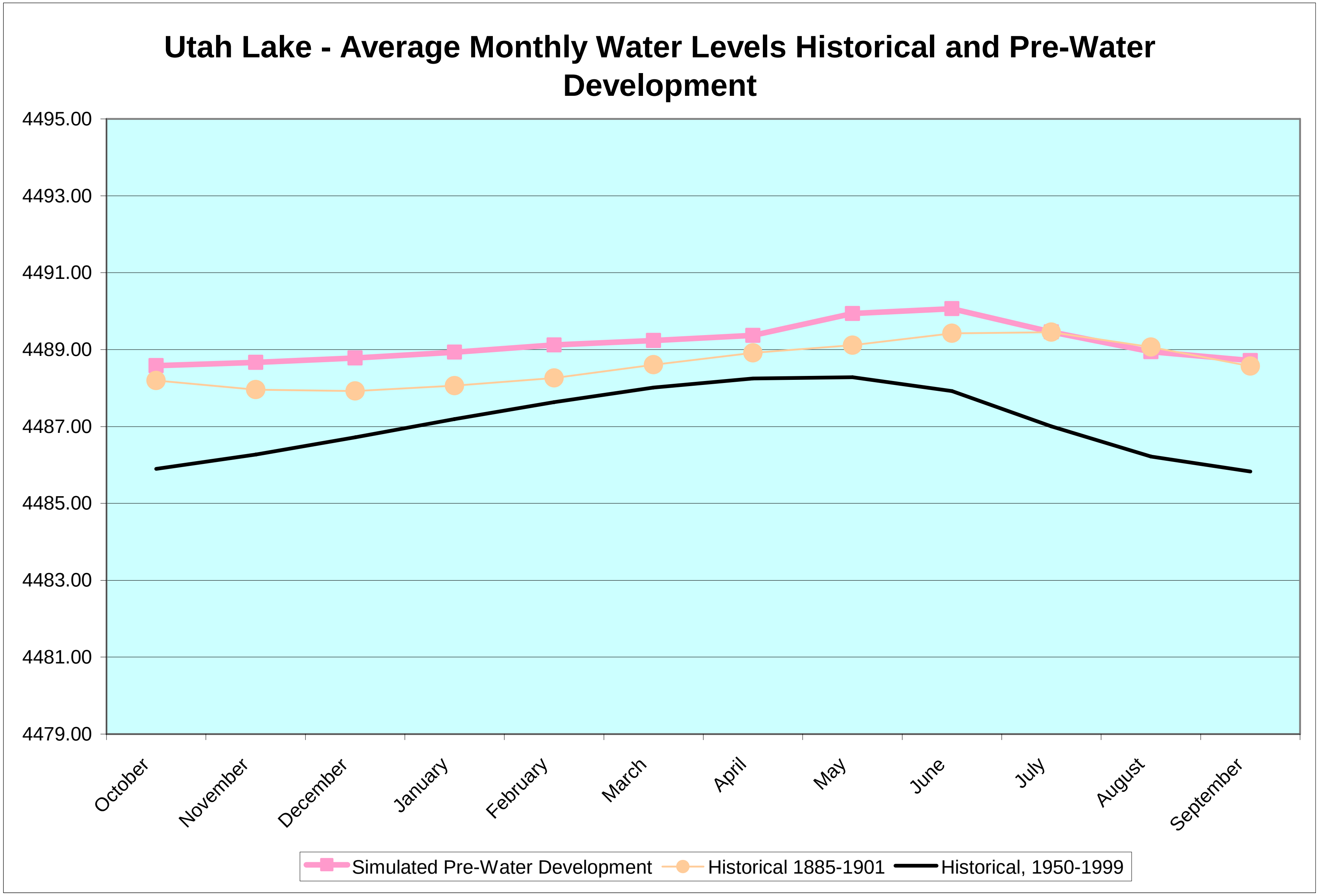


Figure 14 Simulated Pre-Water Development Water Level versus Frequency Curves

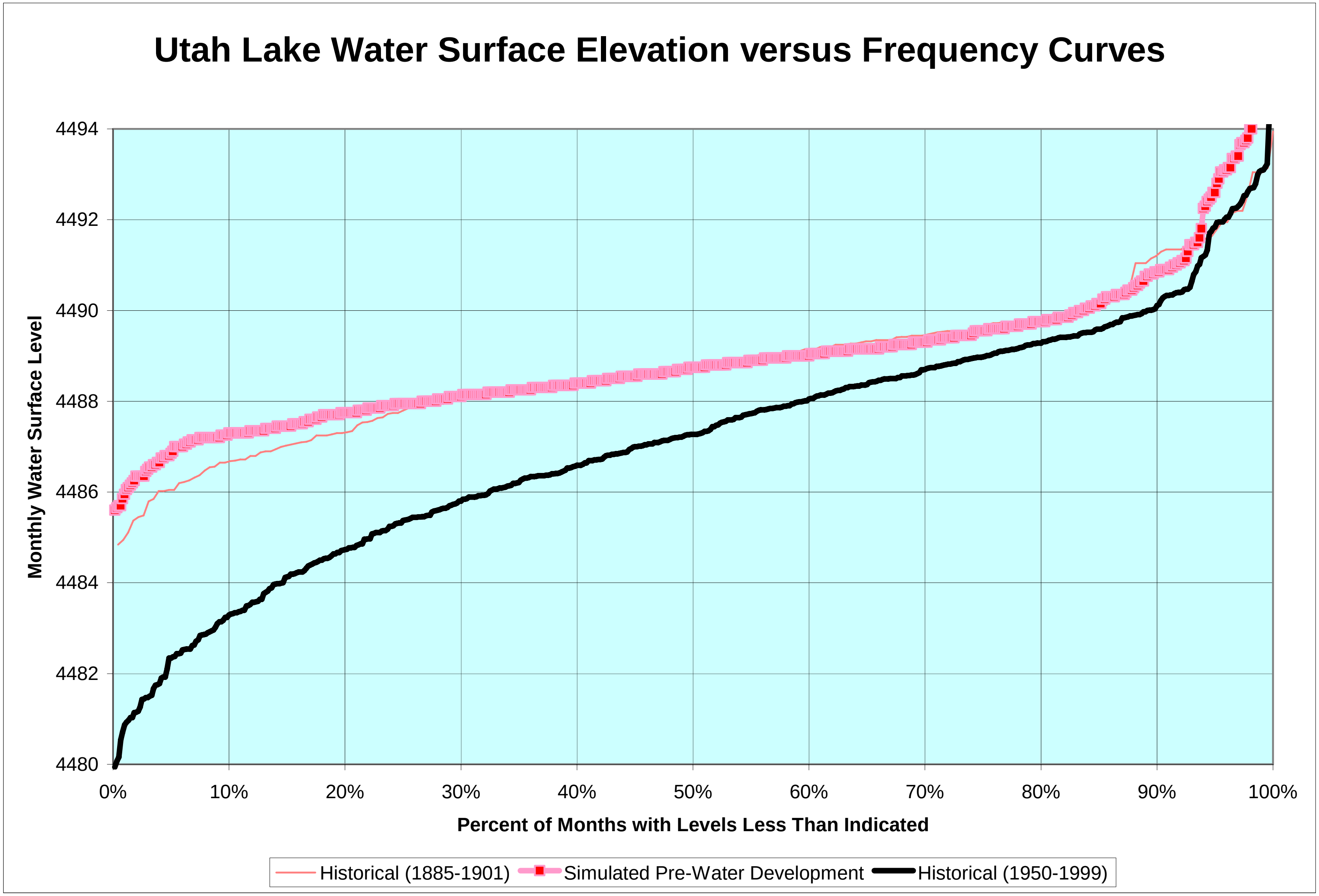


Figure 15 Simulated Current and Planned Utah Lake Water Levels

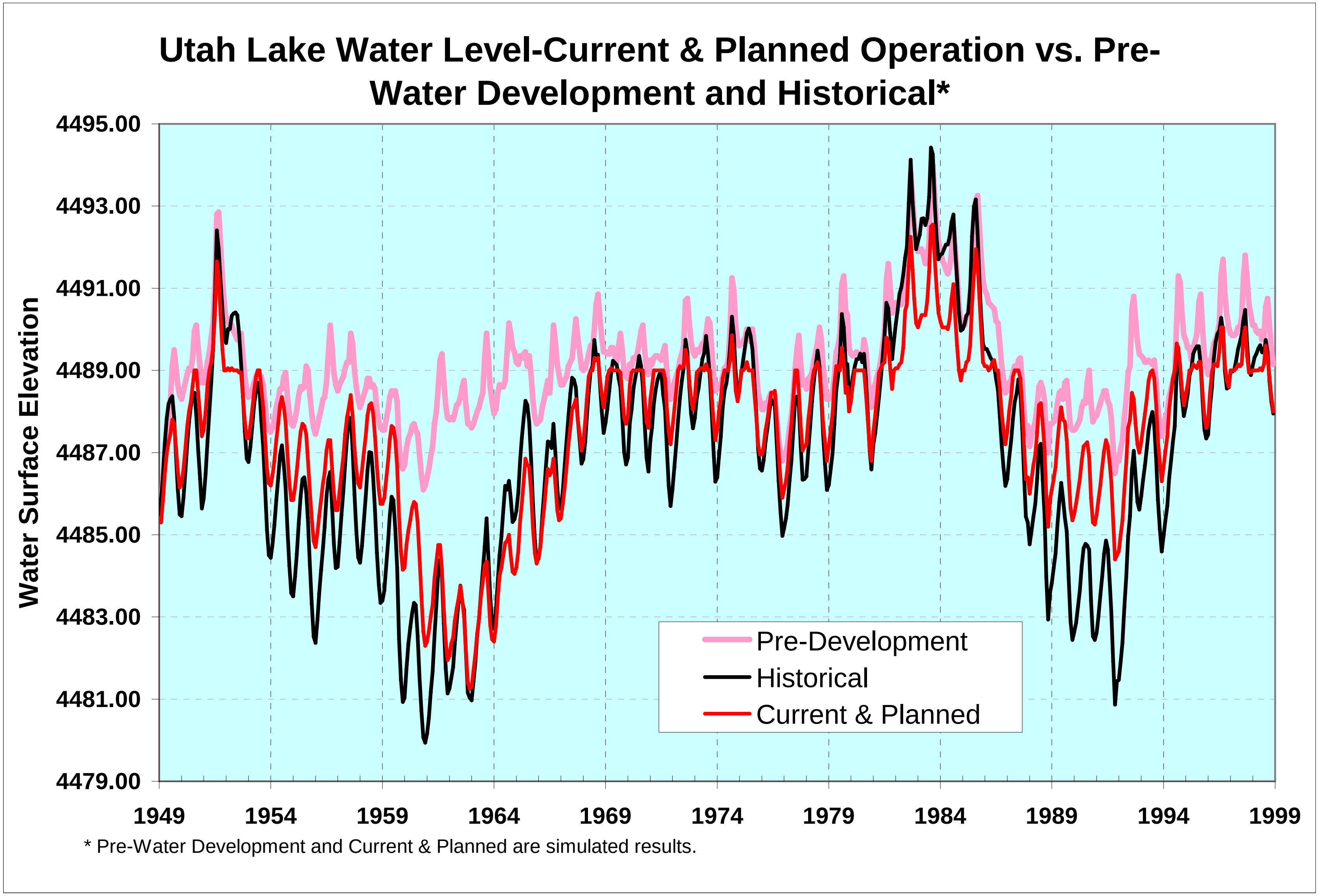


Figure 16 Simulated Current and Planned Water Level versus Frequency Curves

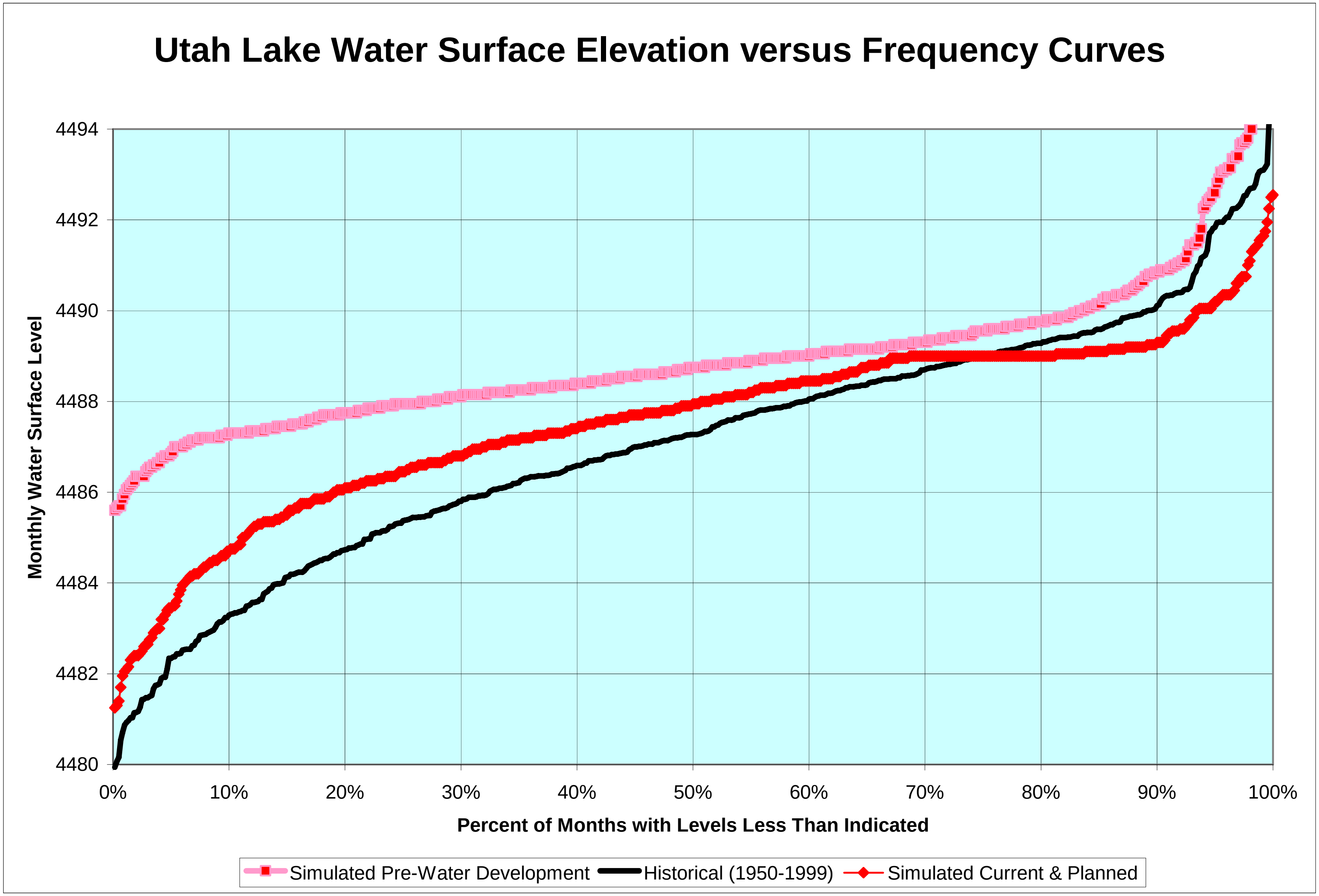


Figure 17 Simulated Current and Planned Average Monthly Water Levels

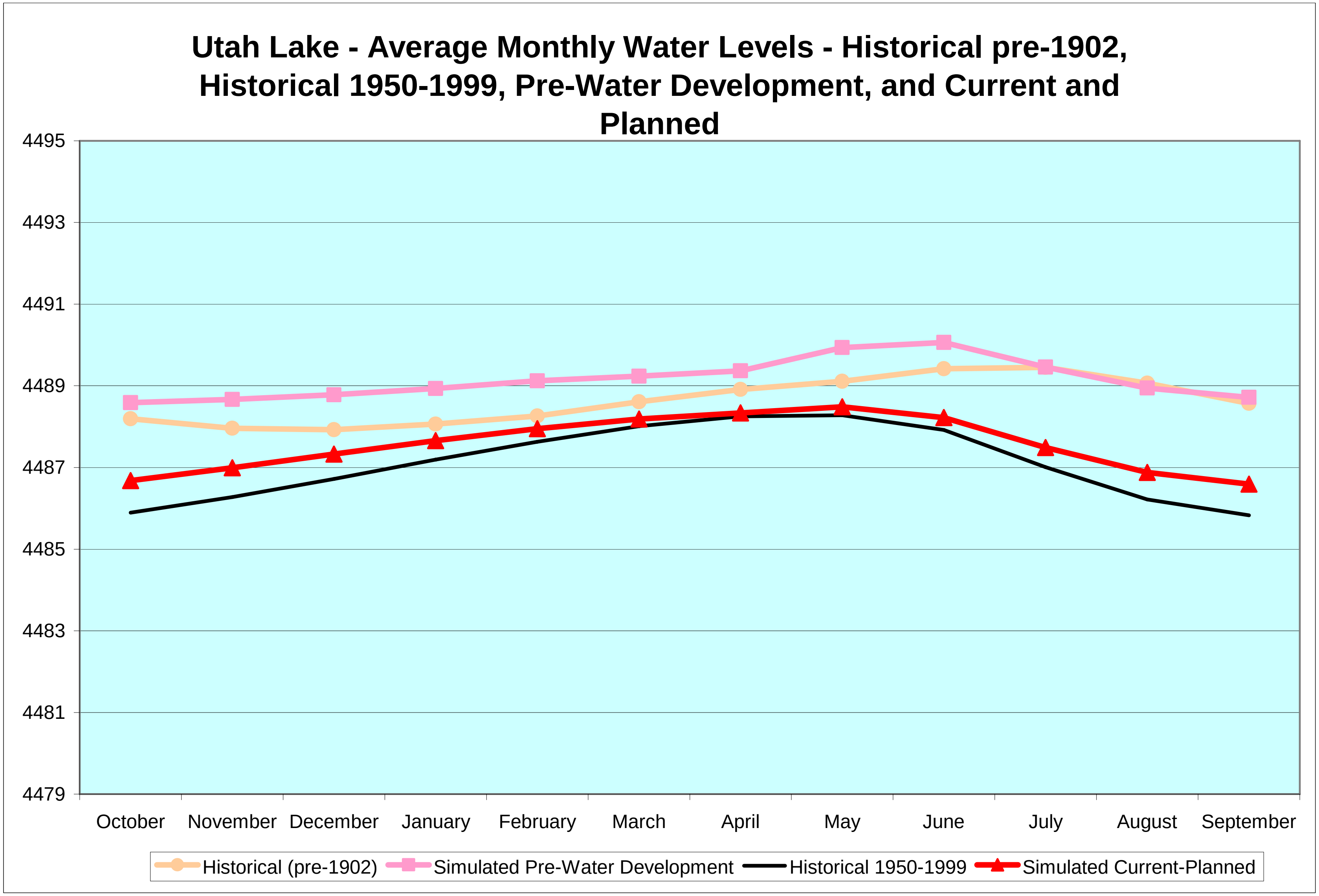


Figure 18 Simulated Utah Lake Water Levels with Lowered Conservation Pool

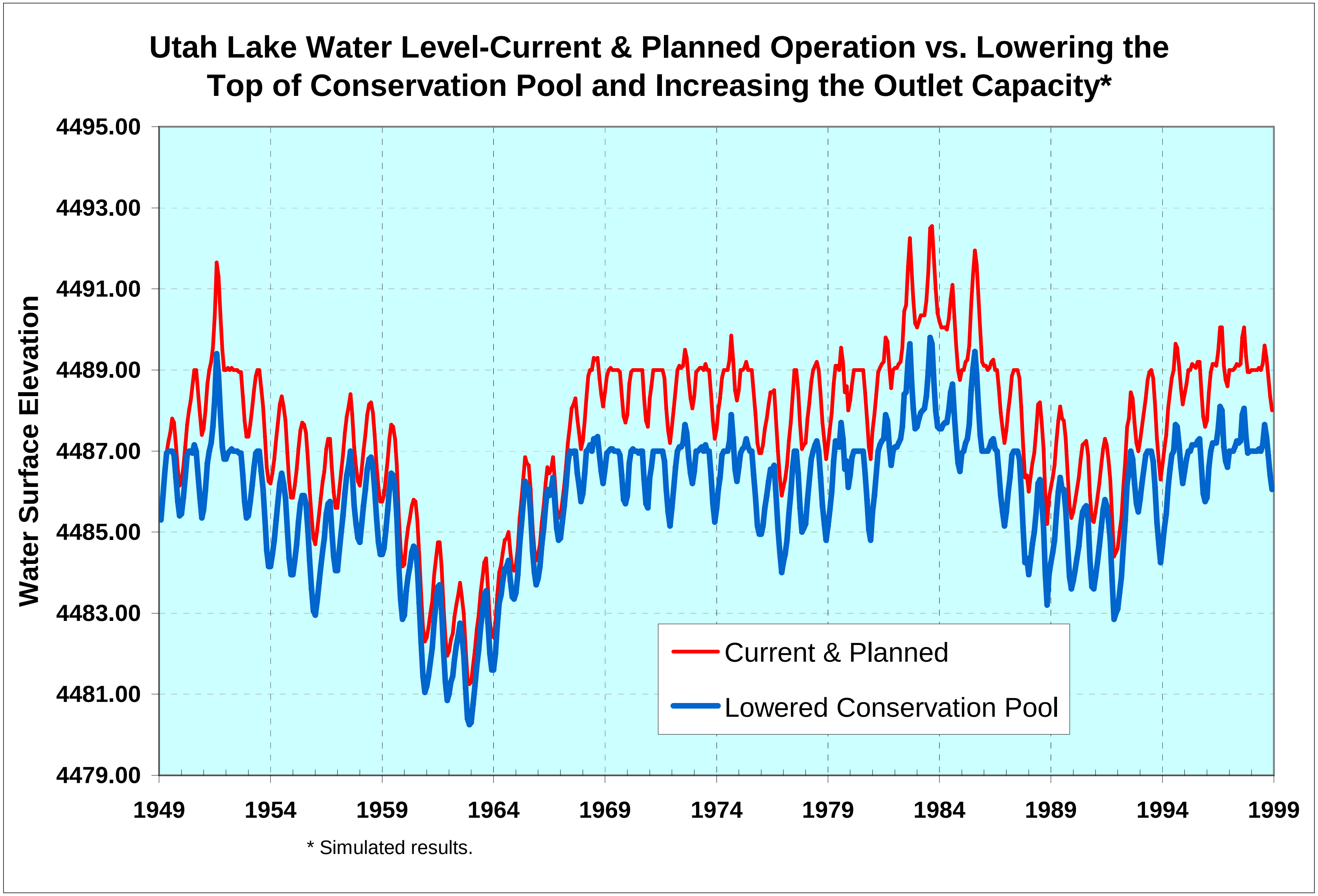


Figure 19 Simulated Water Level versus Frequency with Lowered Conservation Pool

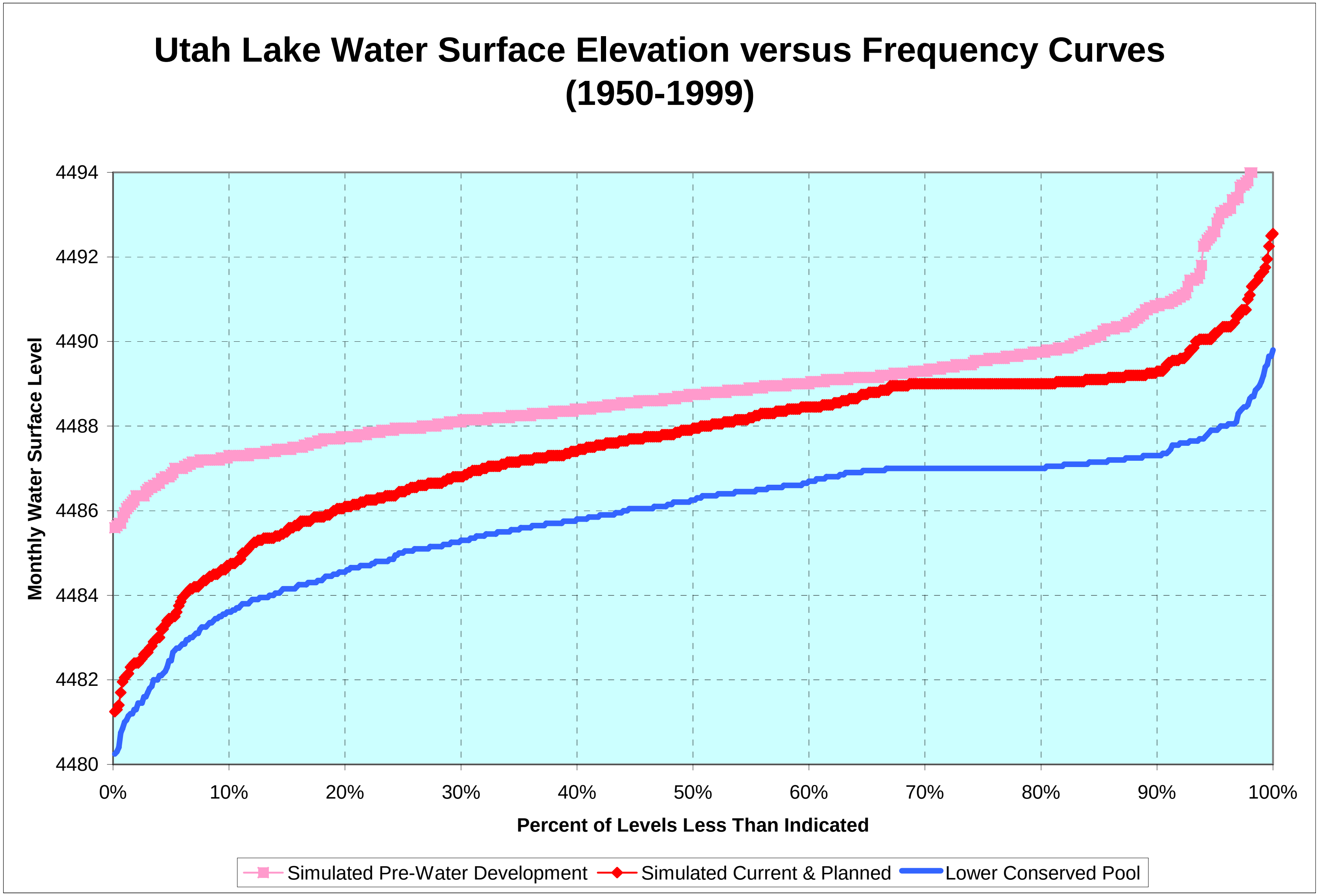


Figure 20 Simulated Utah Lake Water Levels with Reduced Area-Capacity Curve

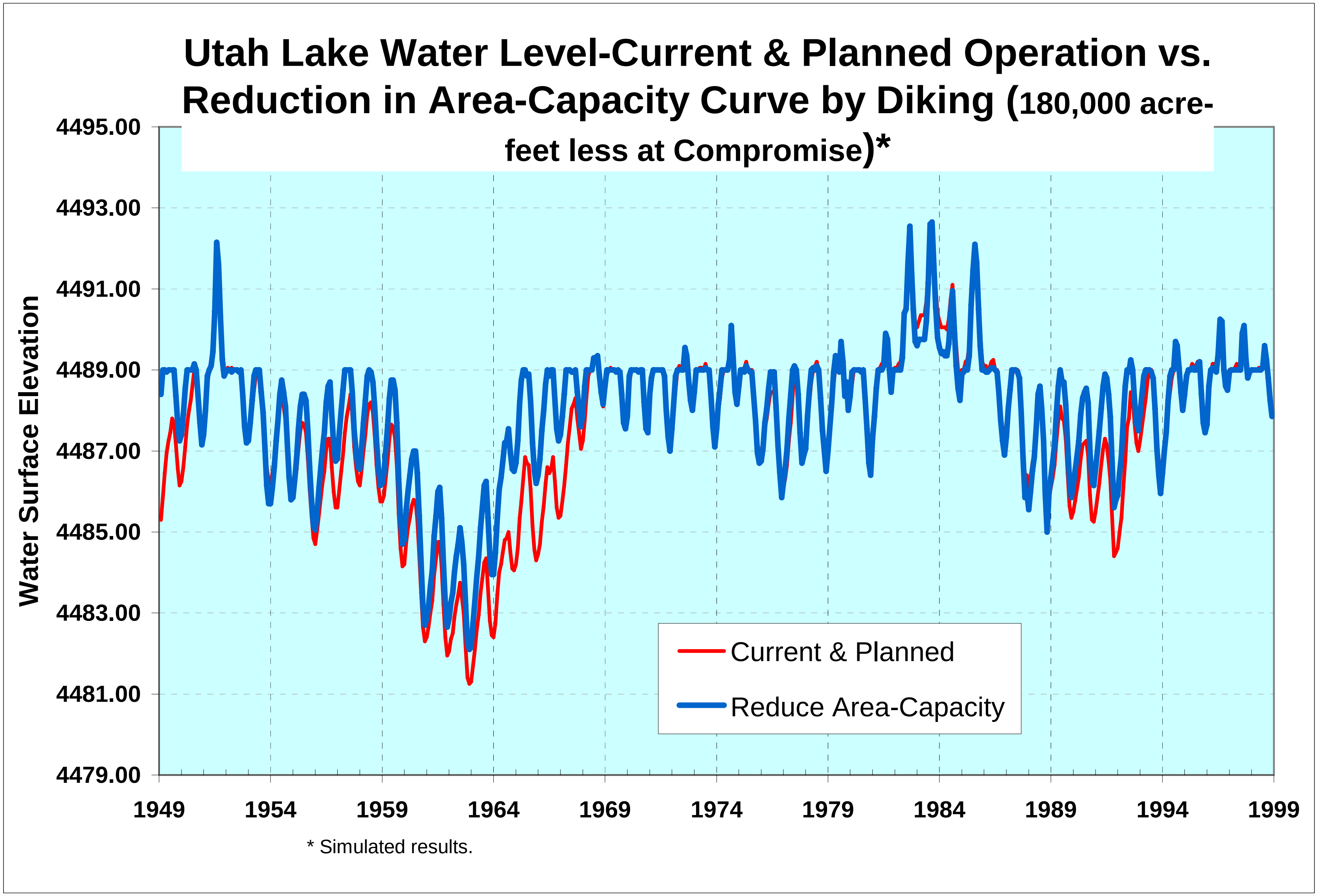


Figure 21 Simulated Water Level versus Frequency Curves with Reduced Area Capacity Curve

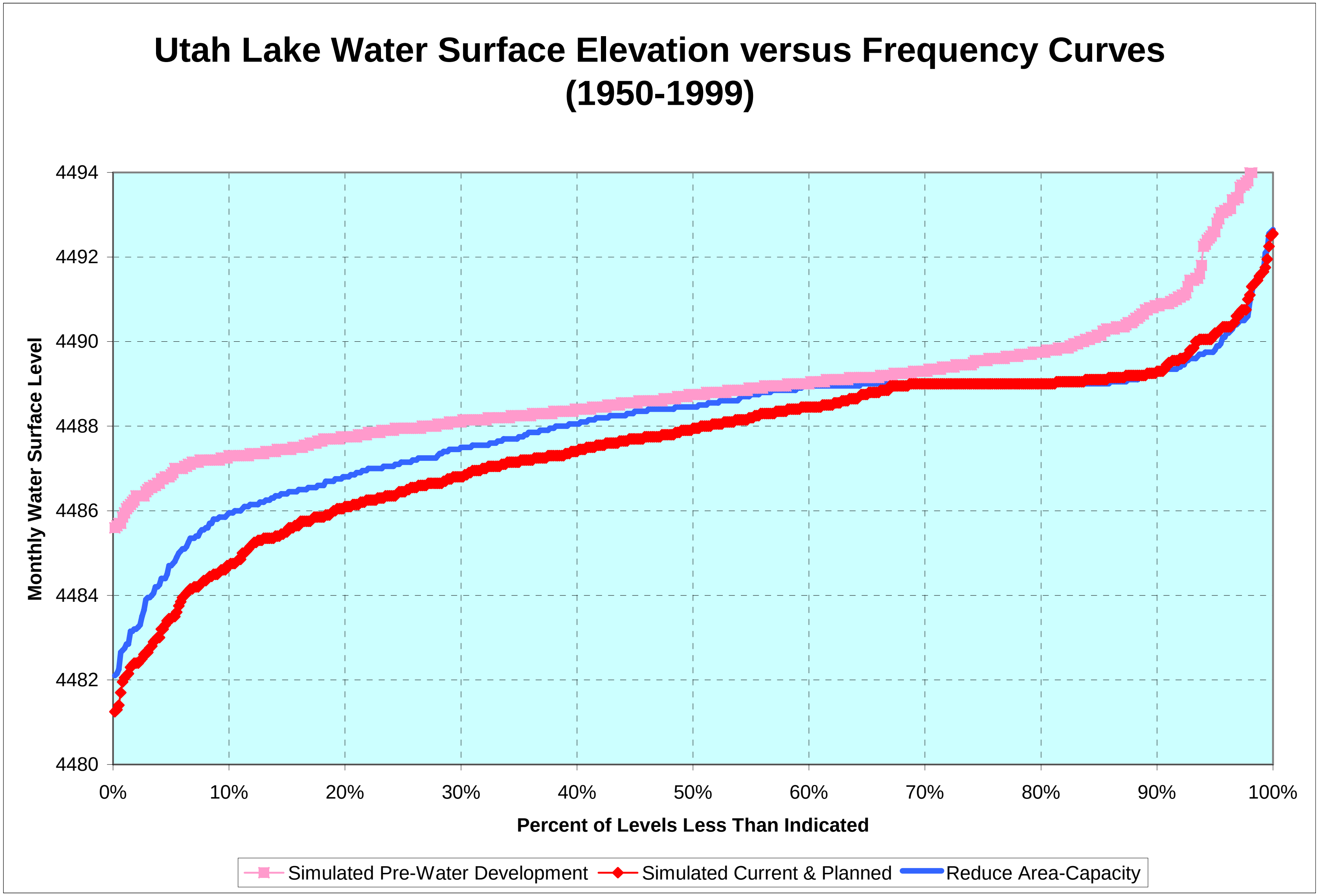


Figure 22 Simulated Utah Lake Water Levels with 50,000 Acre-feet Additional Upstream Exchange

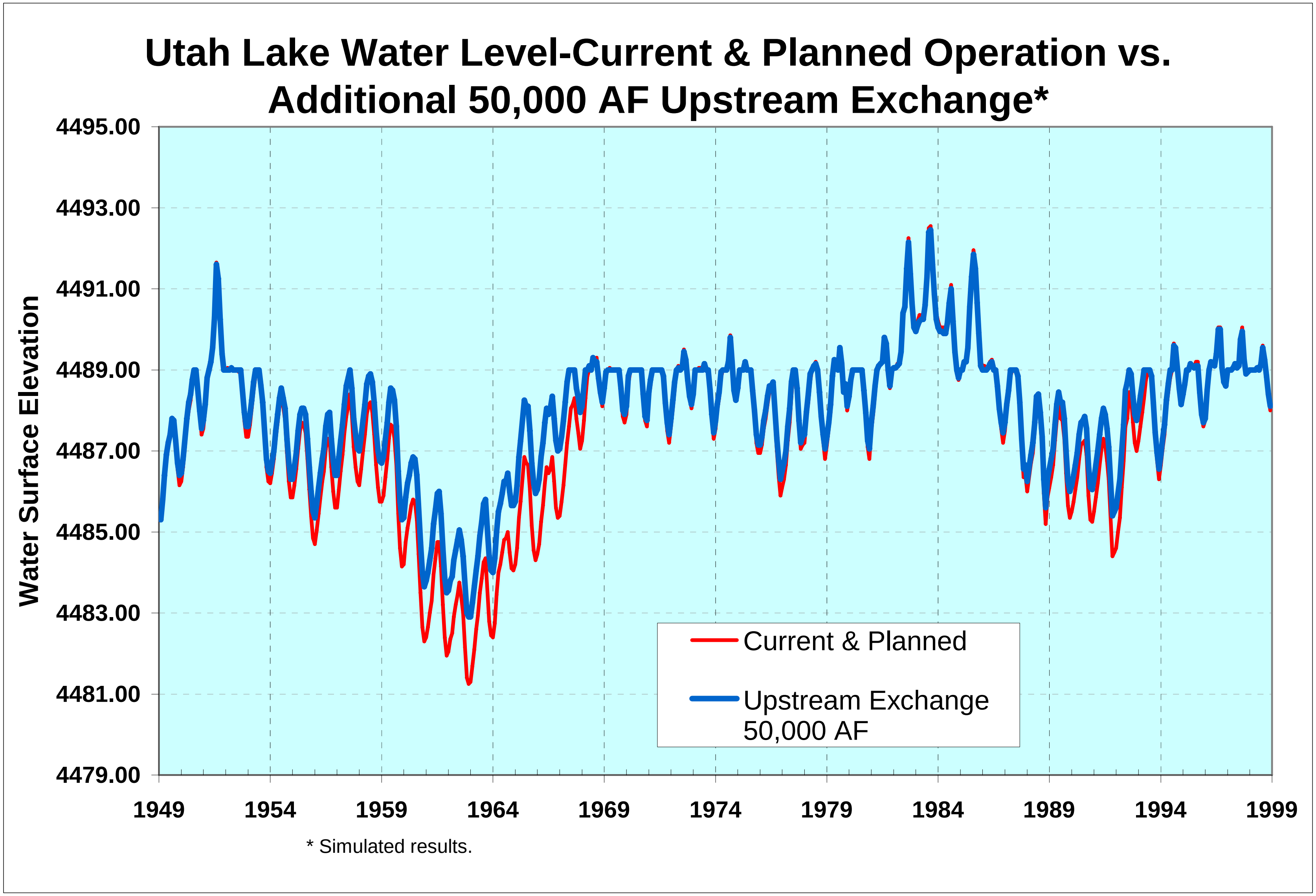


Figure 23 Simulated Water Level versus Frequency Curves with 50,000 Acre-feet Upstream Exchange

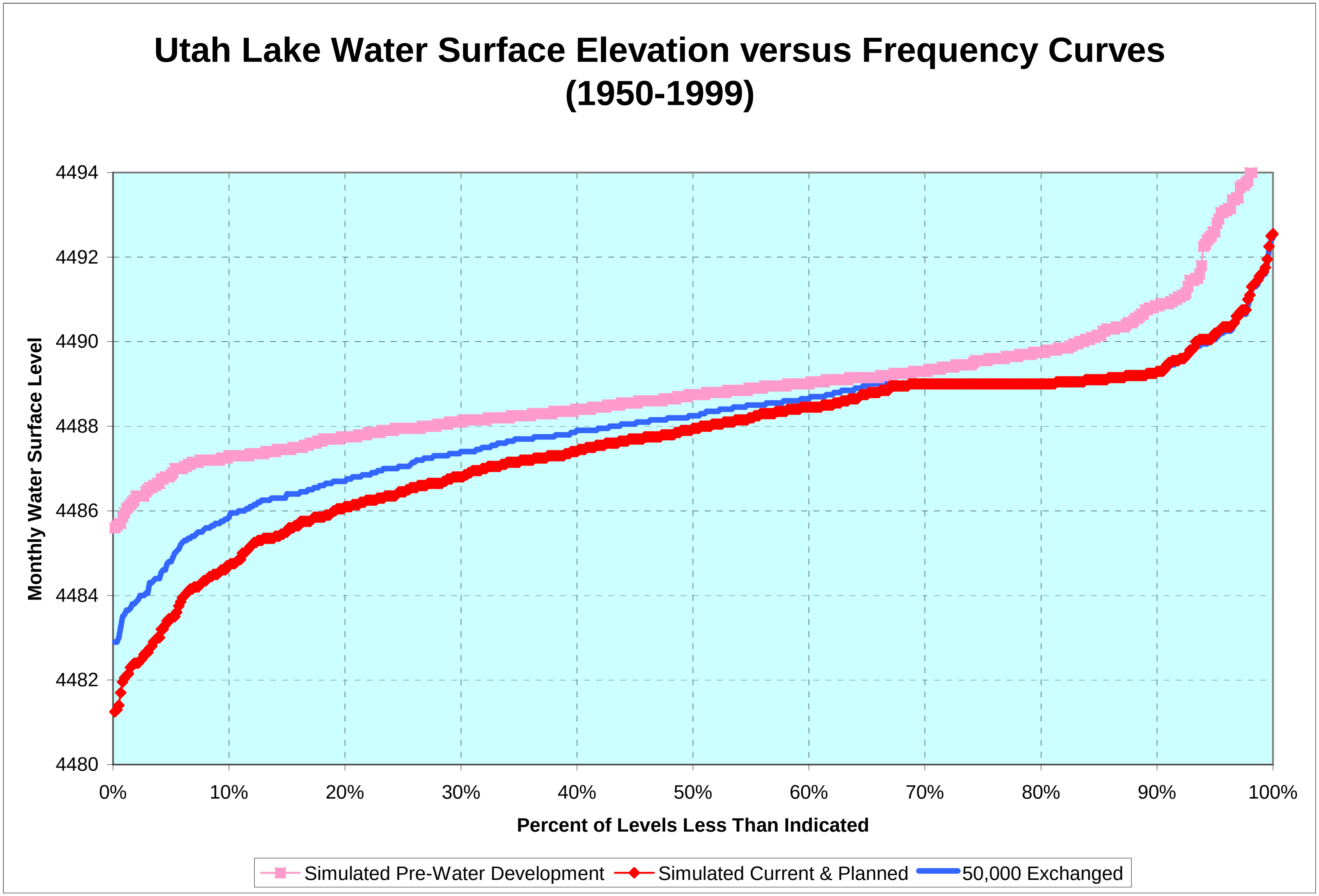


Figure 24 Simulated Utah Lake Water Levels with 50,000 Acre-feet Held in Lake

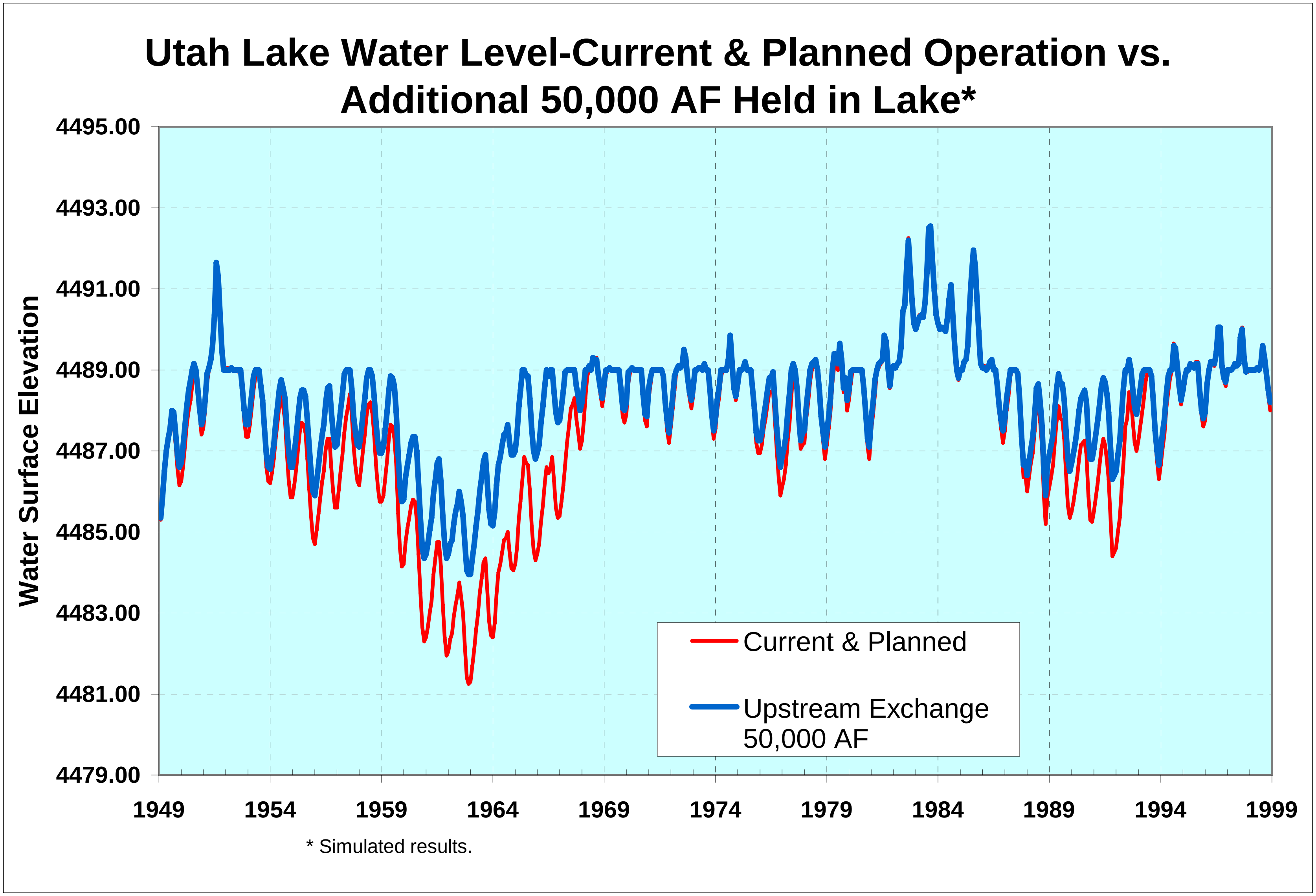


Figure 25 Simulated Water Level versus Frequency Curves with 50,000 Acre-feet Held in Lake

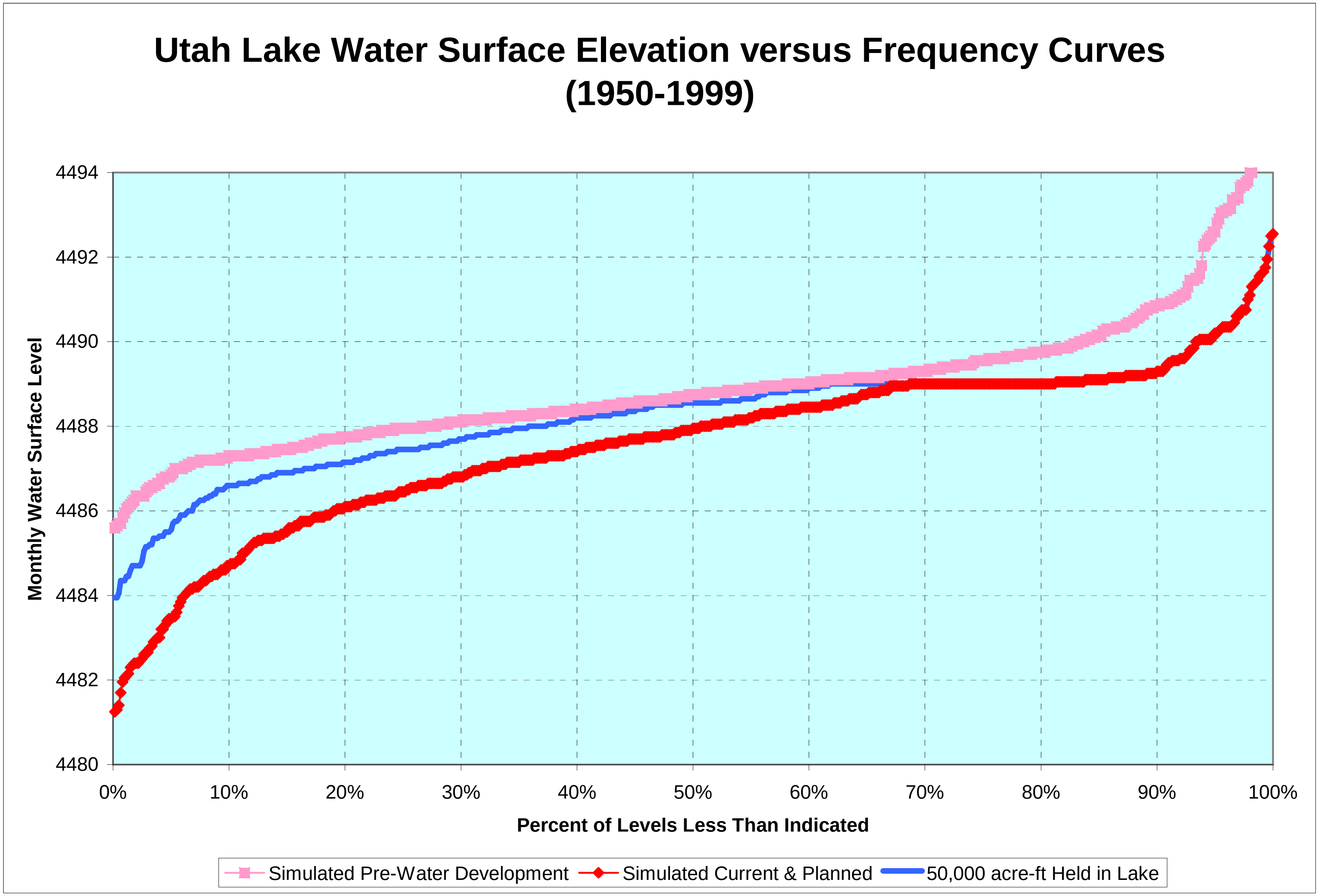


Figure 26 Simulated Utah Lake Water Levels and Diked Provo Bay Water Levels

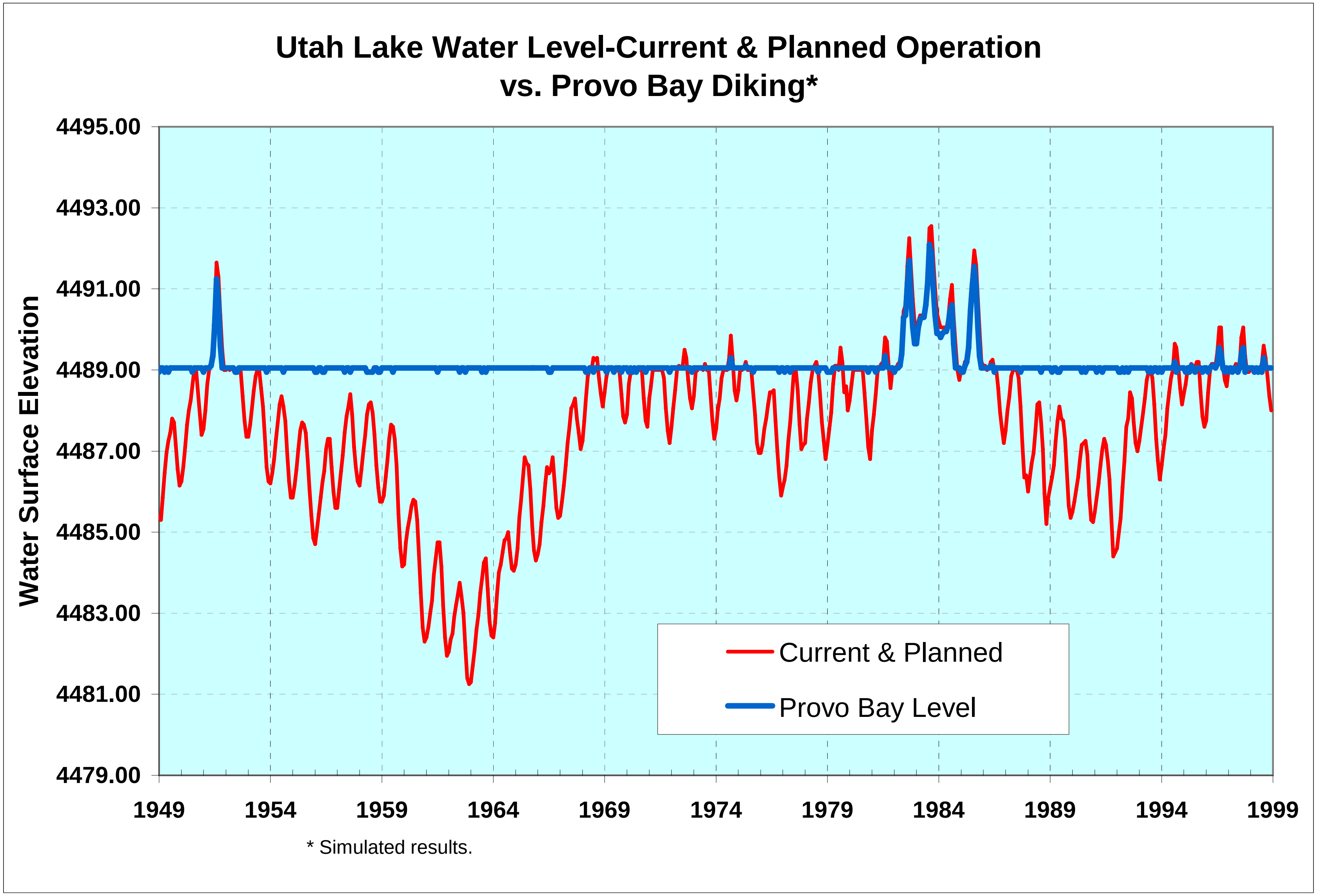


Figure 27 Simulated Utah Lake Water Level and Diked Provo Bay Water Level versus Frequency Curves

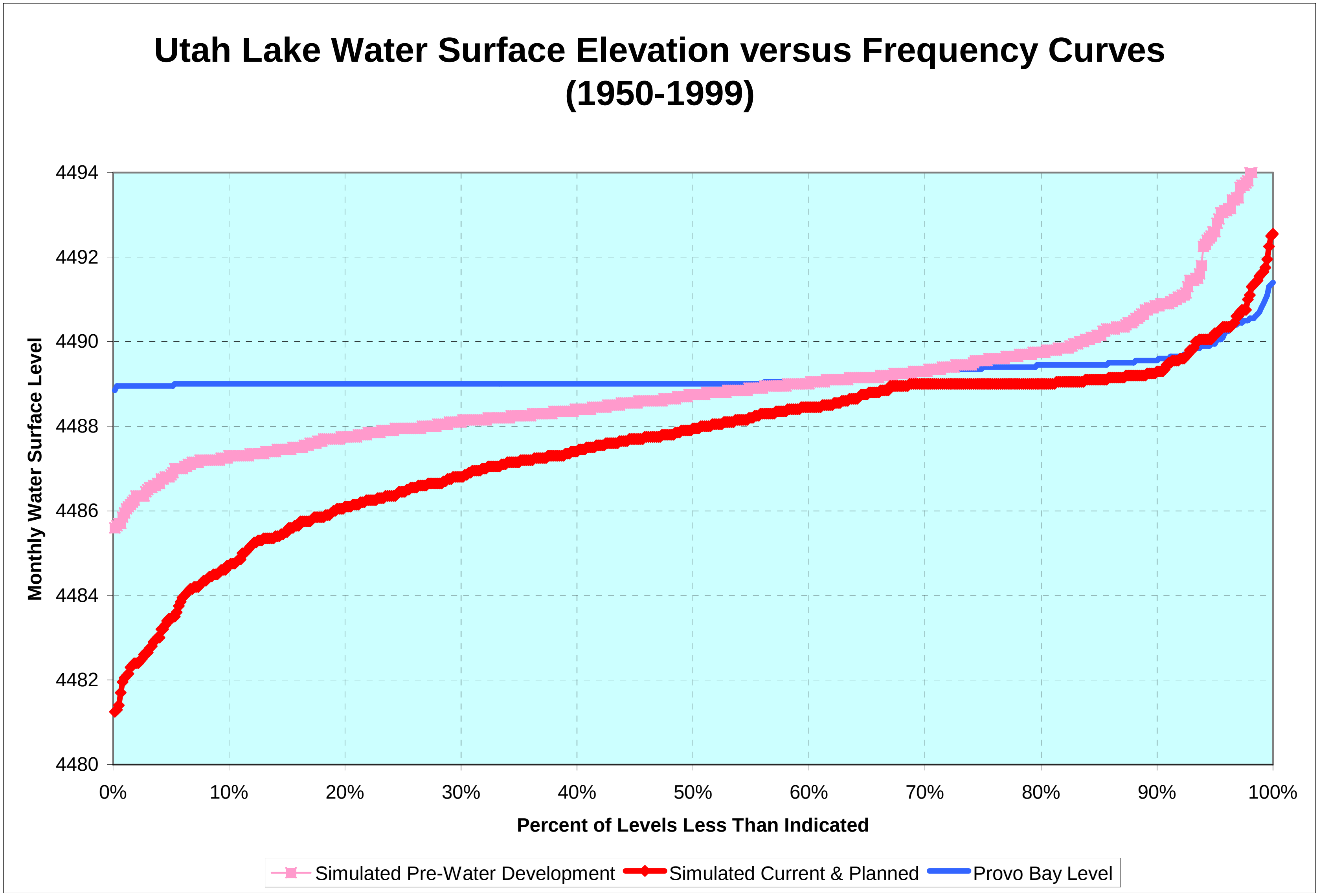


Figure 28 Simulated Average Monthly Water Levels with Level Fluctuation Reduction Scenarios

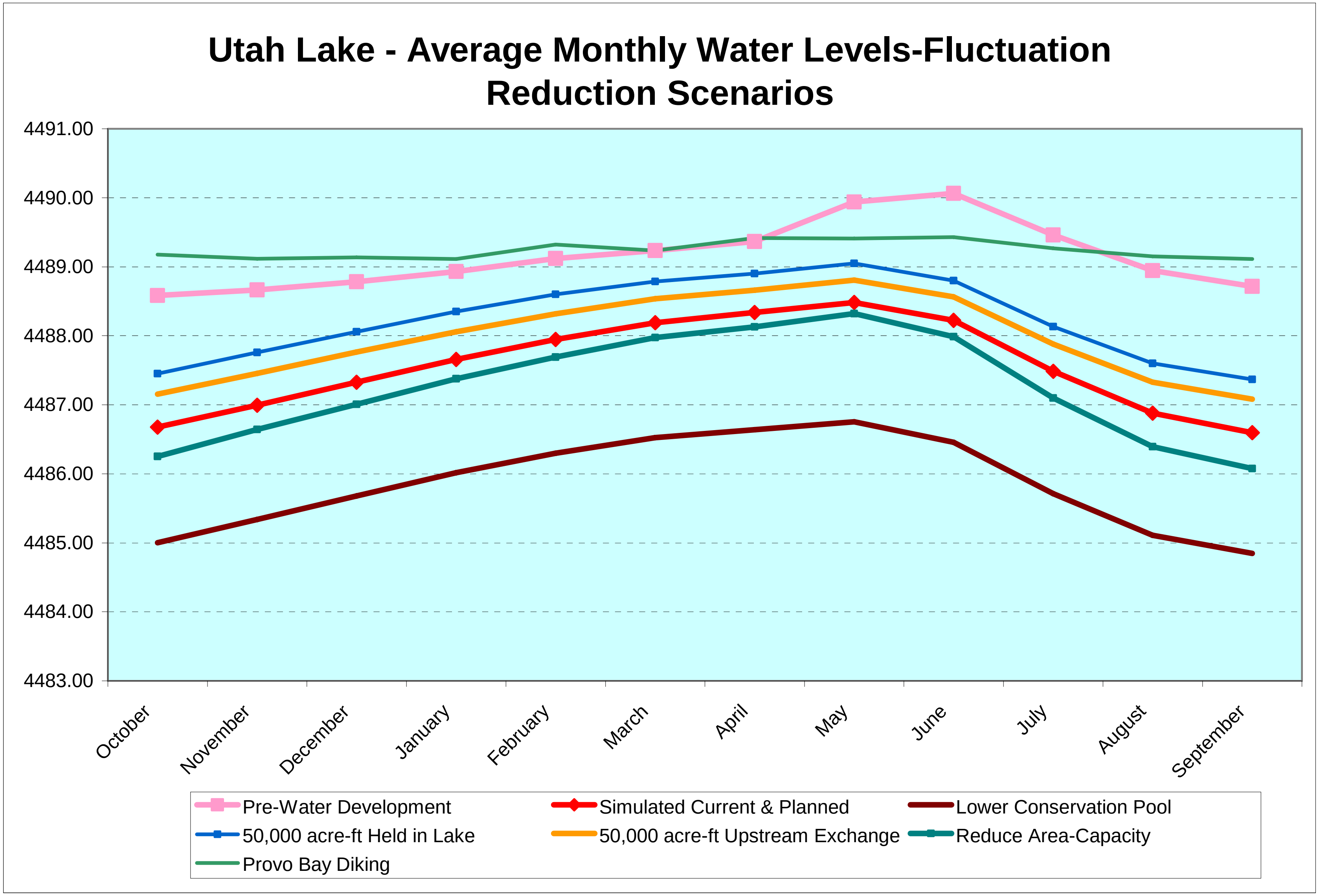


Figure 29 Pre-Water Development and Current and Planned Utah Lake TDS Concentrations

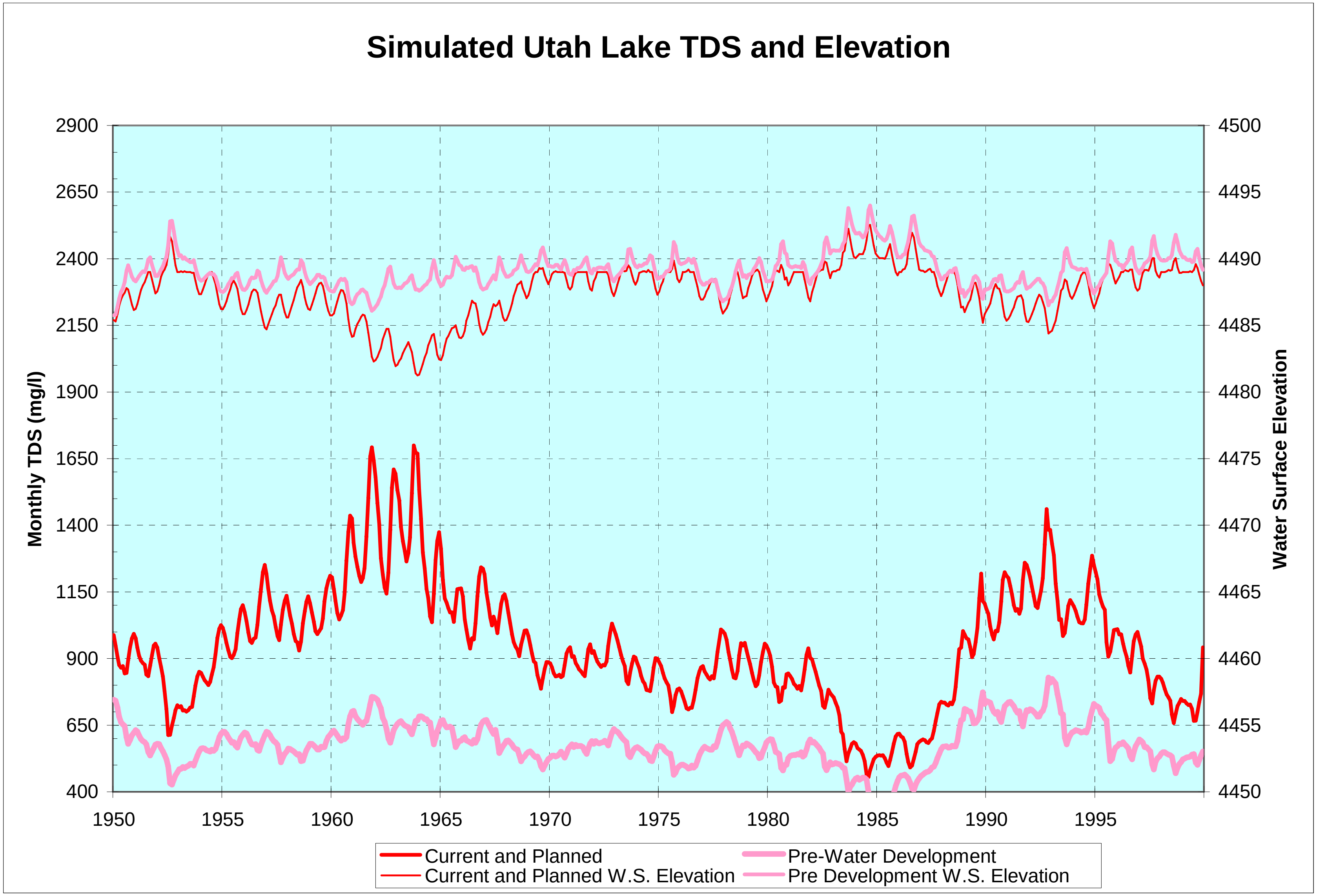


Figure 30 Lower Conservation Pool and Current and Planned Utah Lake TDS Concentrations

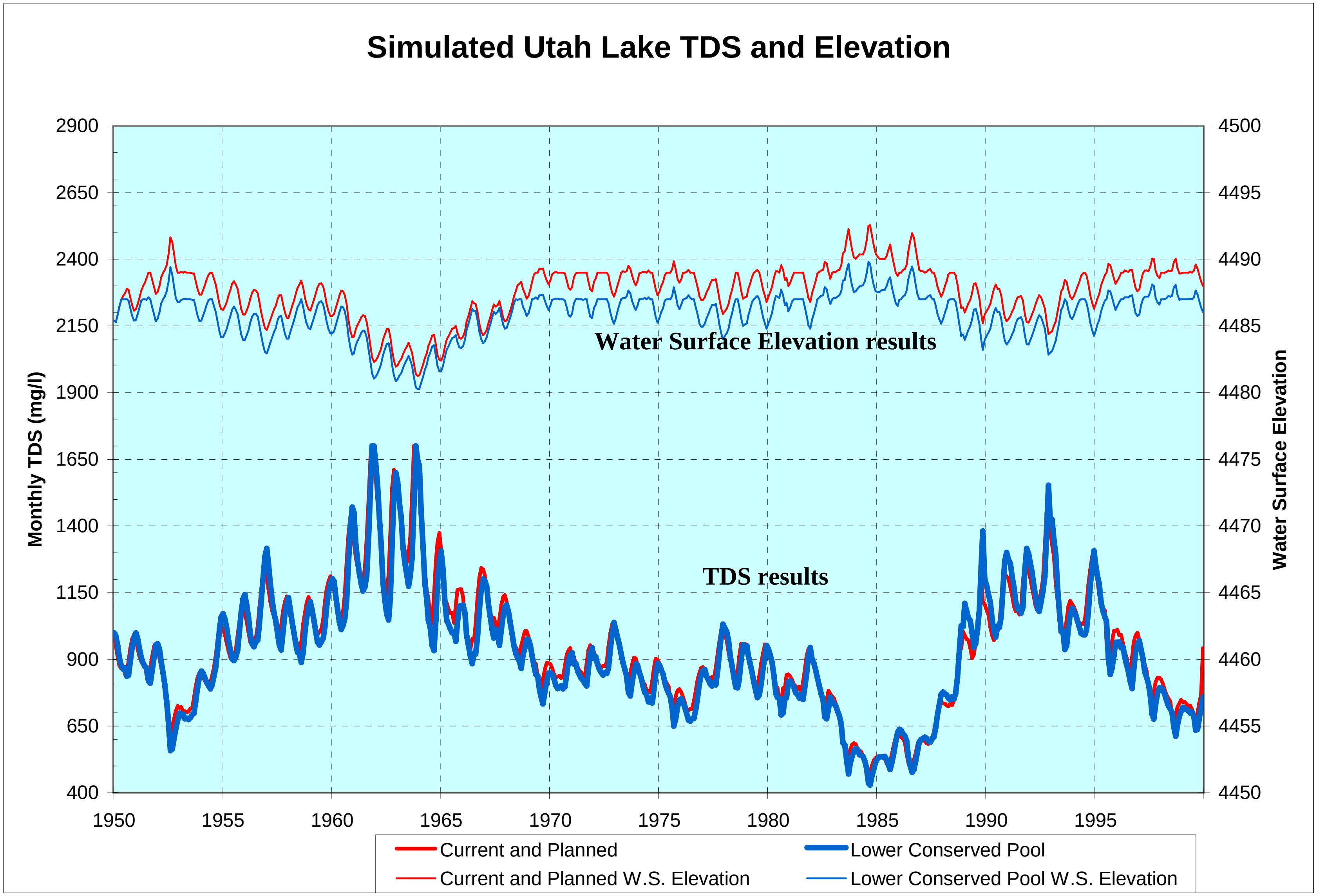


Figure 31 Reduced Area Capacity and Current and Planned Utah Lake TDS Concentrations

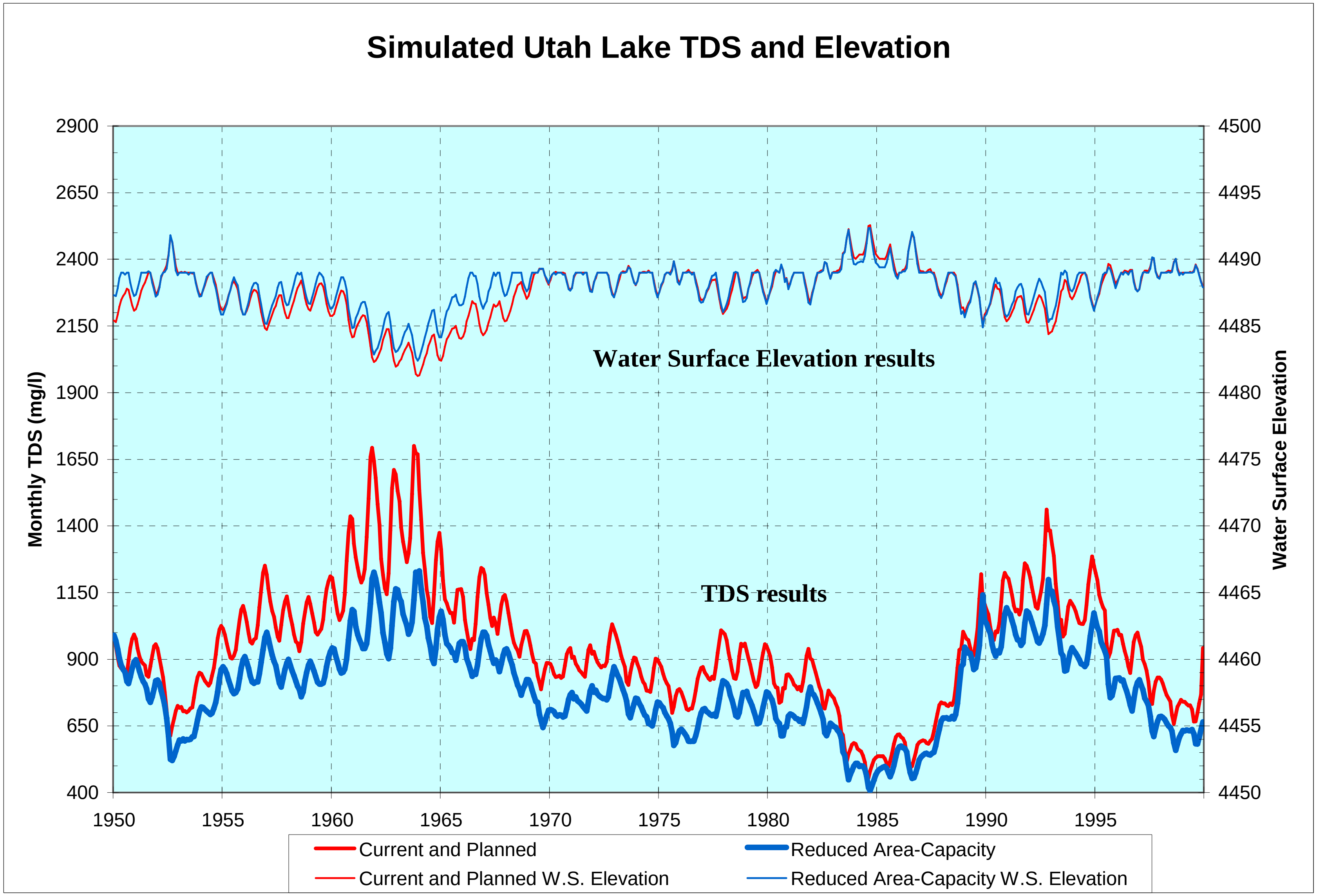


Figure 32 Increased Upstream Exchange and Current and Planned Utah Lake TDS Concentrations

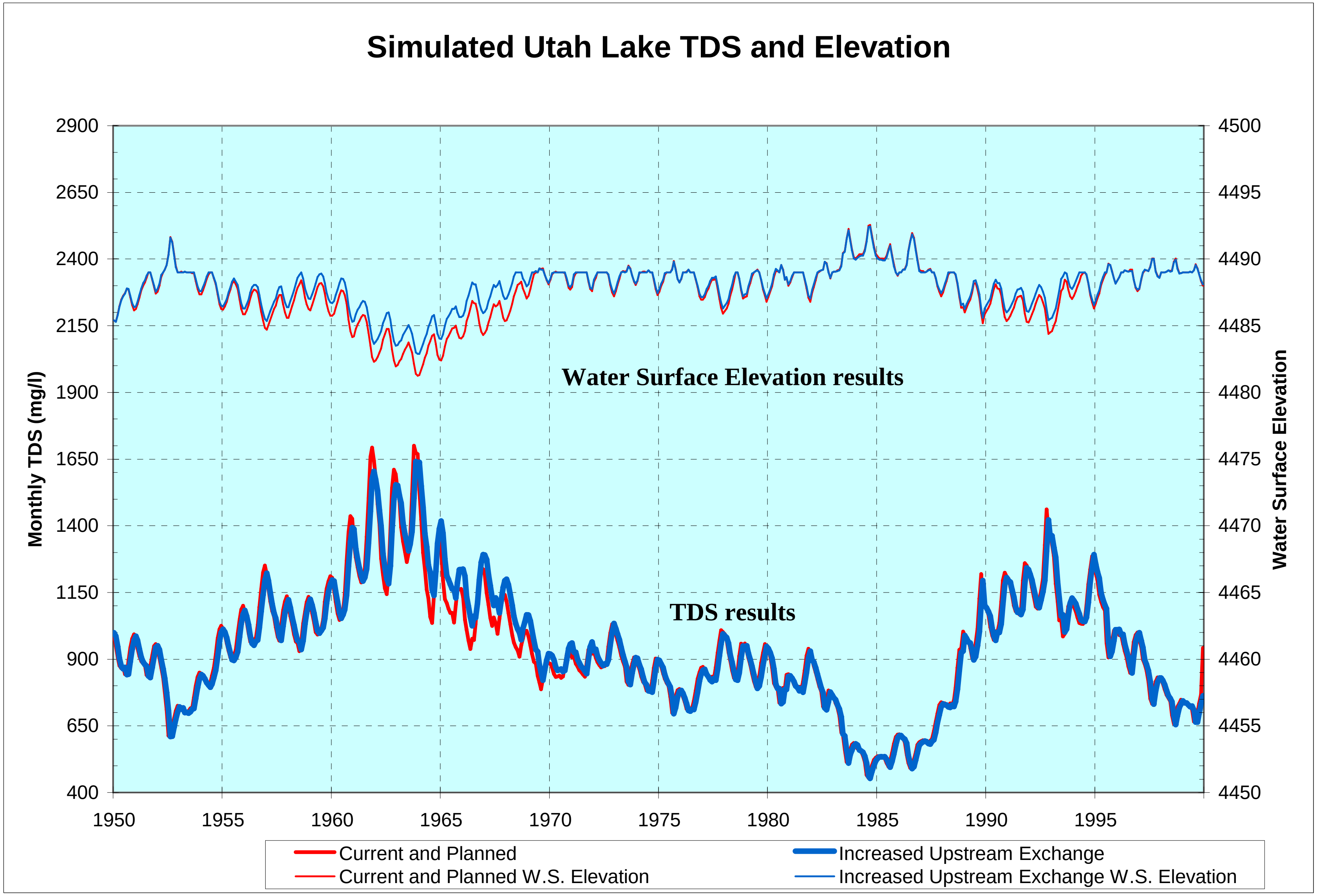


Figure 33 Increase Rights Held in Lake and Current and Planned Utah Lake TDS Concentrations

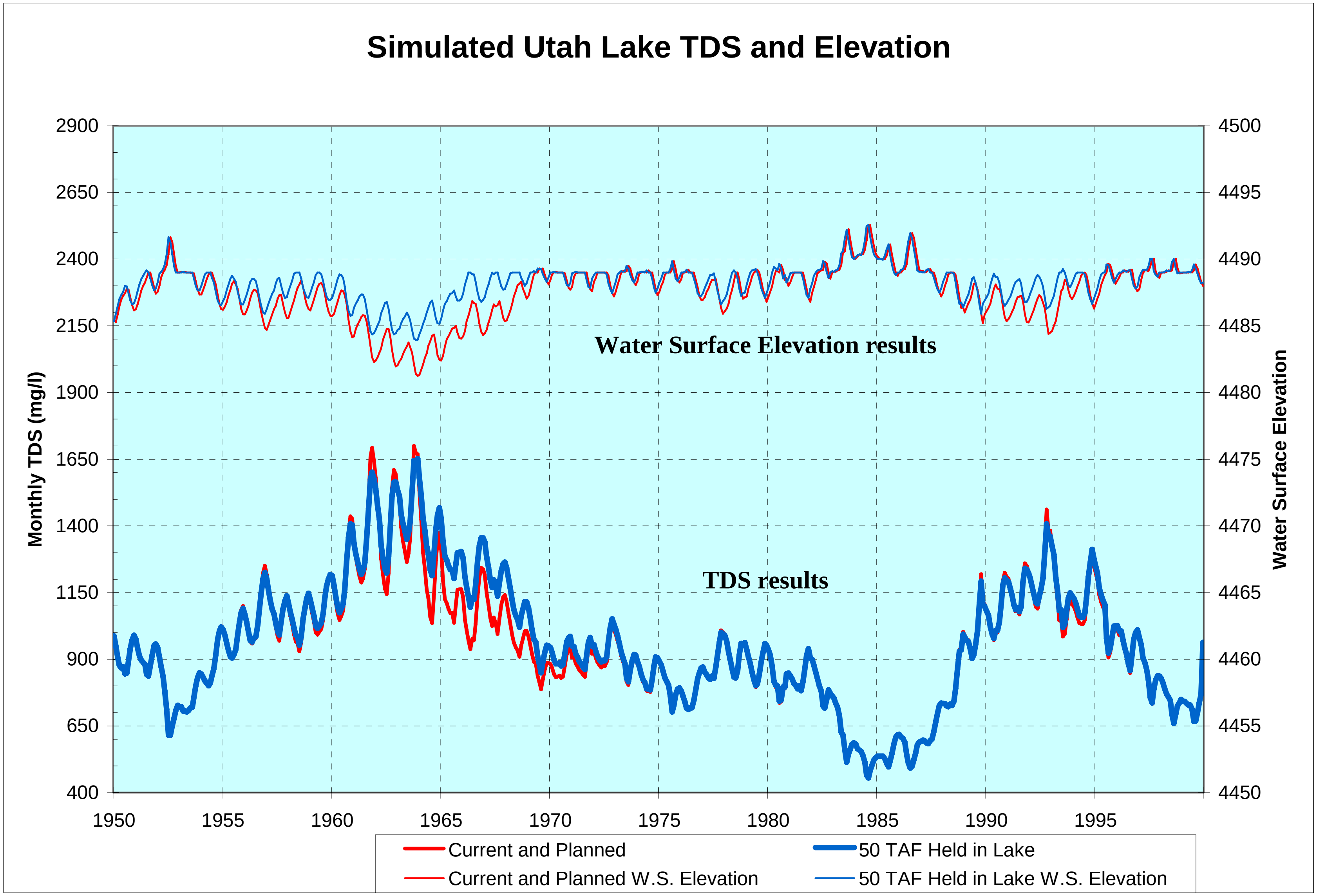


Figure 34 Dike Provo Bay and Current and Planned Utah Lake TDS Concentrations

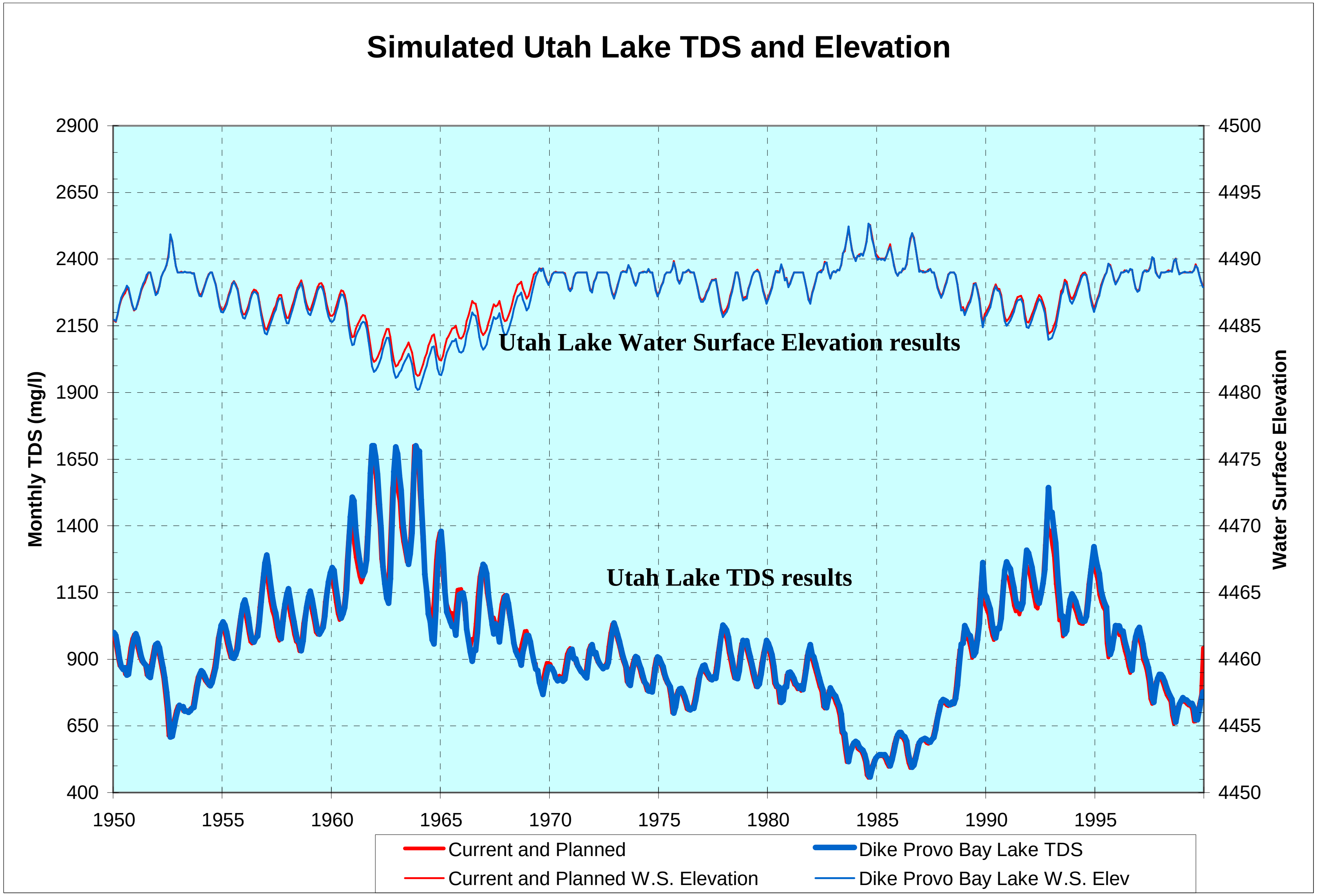


Figure 35 Dike Provo Bay and Current and Planned Bay and Lake TDS Concentrations

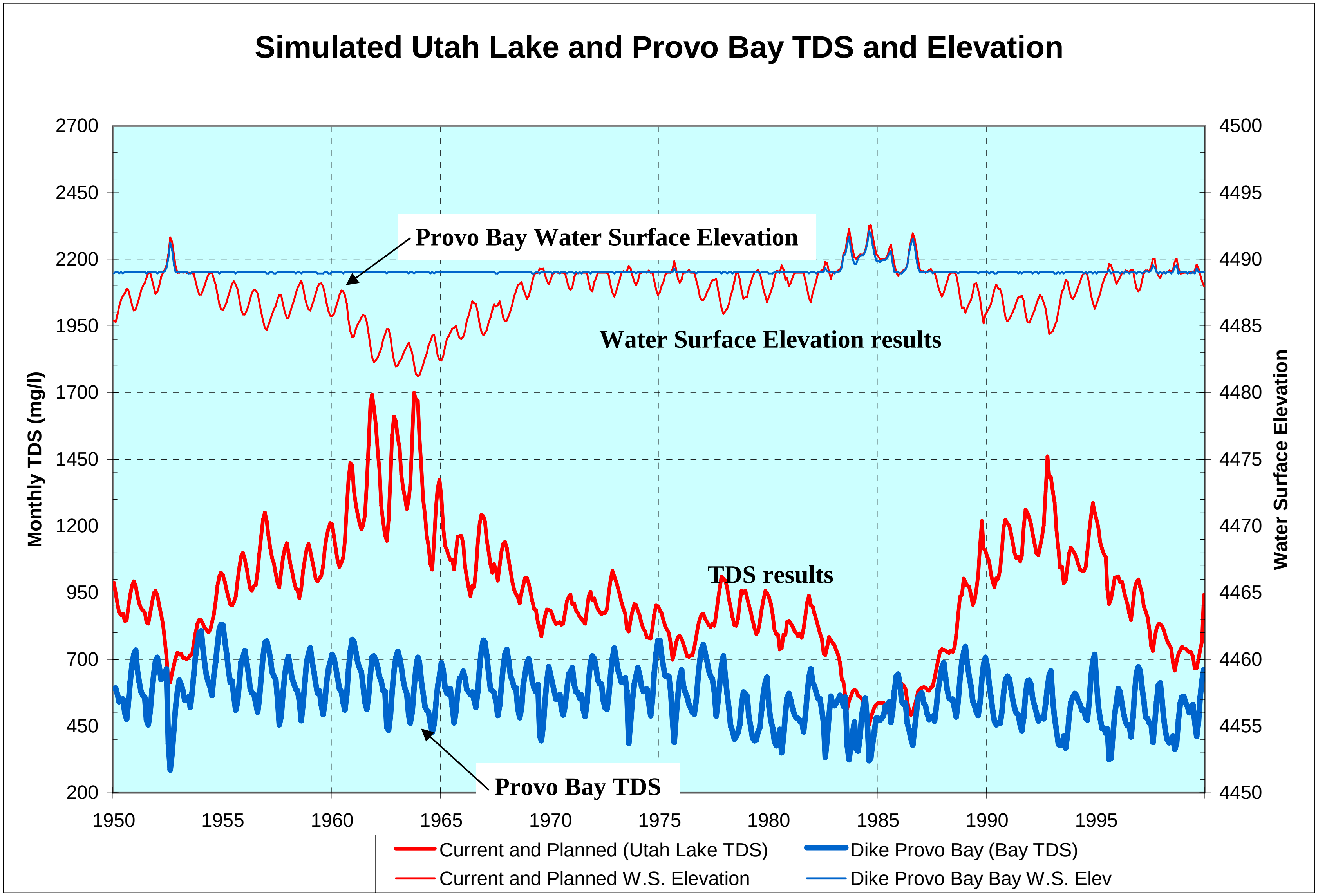


Figure 36 Simulated Utah Lake TDS Concentrations – 1950-1999

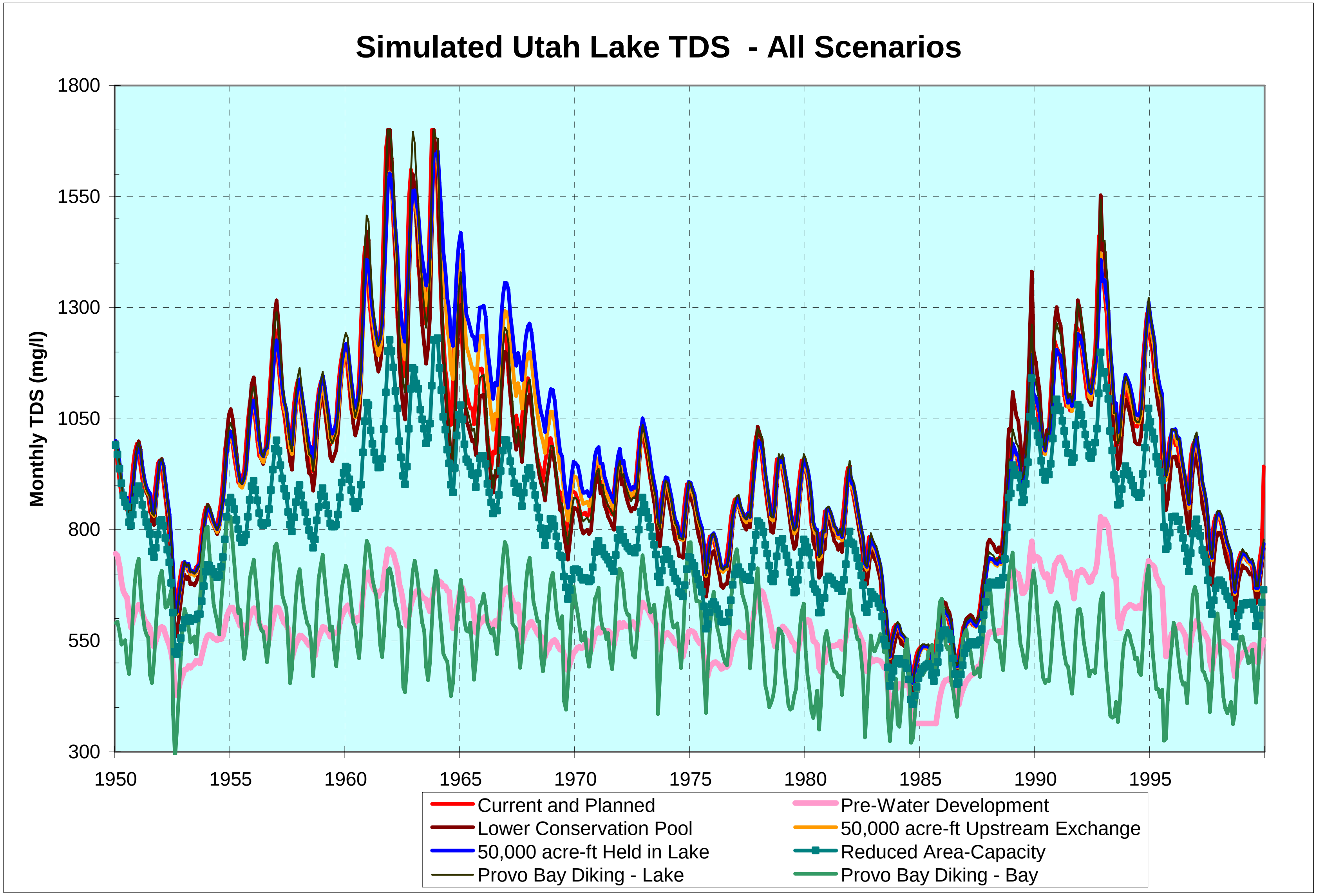
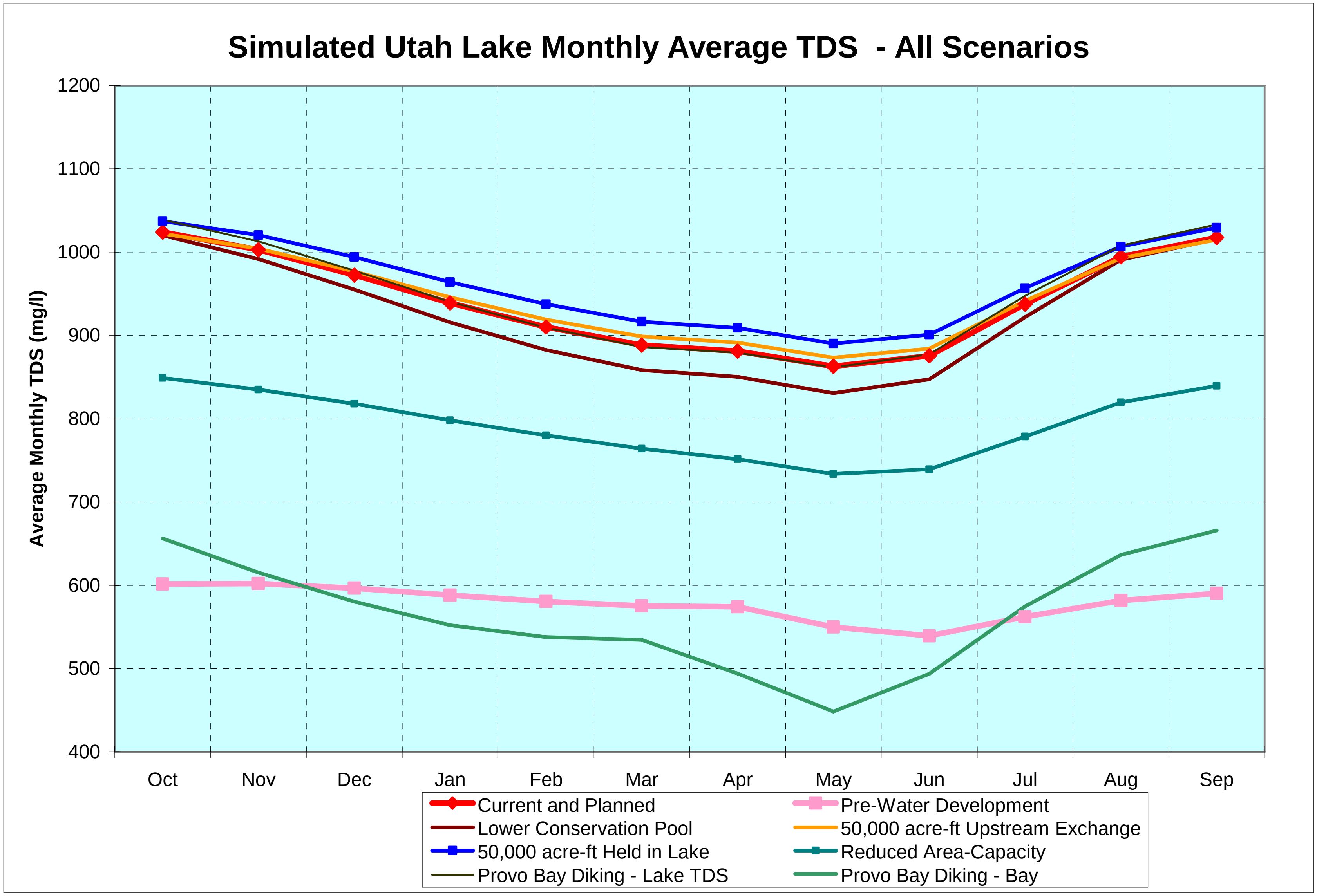


Figure 37 Simulated Monthly Average Utah Lake TDS Concentrations



Appendix A –

Utah Lake Pre-Water Development Levels Study - Study Assumptions

The following assumptions are made for the purpose of analyzing Utah Lake levels, both past and future. These assumptions and the results of the computer model simulations in which they are incorporated are an approximation for the purposes of comparative analysis. This is typical of simulation studies of extremely complex systems. The number of variables that may influence the prototype, and the many incompletely understood interactions between these variables, make completely accurate predictions impossible, or excessively expensive. Thus the results are a simplified analysis of the factors considered; and the factors not considered must be understood to properly interpret the results.

Many conflicting factors influence the level at which Utah Lake is operated that are not strictly incorporated in this lake levels analysis. Rather, the study relies on the assumption that the future will be the same as the past, except for certain, limited changes that are incorporated into the analysis. The future hydrology (including climatic conditions and sequence of wet and dry years) is assumed to be exactly like the past, except for the specifically incorporated changes associated with water use and operations. In addition to not incorporating hydrologic variations different from those experienced during the 1950-1999 study period, some other factors that are not included in the analysis are:

1. The manner and extent to which the lake is operated according to water rights. Currently, releases are made in response to calls by downstream users, without necessarily incorporating the effects of all prior water rights exchanges and without full consideration for water being held in storage for subsequent exchange to upstream reservoirs.
2. The possibility that, were the Lake to be held at more stable level, the State Engineer could decide to lower the system storage conversion line[6], allow other right holders to divert more water, and/or even approve new water right applications in the basin, resulting in the Lake being drawn down again and to fluctuate more widely.
3. Operation of the Lake at a different level could affect the amount of transbasin water brought into the basin by the Central Utah Project and/or Provo River Project. These secondary effects were not evaluated.
4. There is a recent tendency of the Lake to experience higher inflows and lower deliveries while water user's demands and operational procedures are changing and while M&I water users' demands are building up toward full utilization. In particular, recent historical data are from a time when utilization of CUP water has been much less than it will be in the future, Utah Lake water rights have been being rapidly exchanged and under-utilized, and instream flows have not been fully implemented. These factors have probably tended to keep Utah Lake at a higher level during the last decade or more. Simulated results should not be affected by these historical

[6] The system storage conversion line is a variable volume of water that must be stored in Utah Lake and Jordanelle and Deer Creek reservoirs for storage right holders in the upper to reservoirs to be able to convert the water that they have stored under their lower priority water rights into usable/deliverable storage.

demand trends because the model runs use projected, constant-level future demands, rather than varying historical demands.

5. The delay between the start of pumping from a well and the reduced groundwater inflows to Utah Lake. Where a right has been moved the impact on Lake inflows could take decades. Similarly, historical changes in water use and inflows may not be fully reflected in the observed flows, model data, and assumptions.

For these and other reasons, it is important to realize that the study results are reported for the *relative* impact of certain changes on Lake levels[7].

With this in mind, the assumptions used in developing the historical results are summarized below, as are the assumptions for three categories of simulation results: Pre-Water Development, Current and Planned Operations, and Level Fluctuation-Reduction Operations.

General Assumptions

1. Utah Lake levels and operations (other than historical) are simulated using a monthly-time-step water balance model.
2. Simulation results use hydrological and meteorological data associated with the October 1950 through September 1999 (water years 1950-1999) study period.
3. As described below, historical water levels are based primarily on recorded data.

Historical Assumptions

1. The historical (1950-1999) Utah Lake water levels and water balance are derived from Utah Lake water level, outflow, and diversion records recorded and documented by the Utah State Engineer's office.
2. Historical lake contents and surface area were derived from stage versus volume and stage versus area curves (shown in Figure A-1) that was developed as part of the LKSIM model.
3. Historical Utah Lake diversion data form the initial basis for downstream calls on Utah Lake storage utilized in the modeling of future Utah Lake operational scenarios. Diversions have varied over the 1950-1999 study period. For simulations of future conditions, the historically-based average monthly pattern of diversions is used.

Pre-Water Development Assumptions

1. Study results include an estimate of pre-water development Utah Lake levels. Pre-water development results represent 1950-1999 hydrologic conditions, with as many as possible of the effects of water use and water resources development removed. In the simulated pre-water development lake levels, water use impacts are removed from Lake inflows and outflows so that the lake responds nearly the way it would have without human impacts.

[7] Comparative modeling examines differences between multiple model runs to evaluate the effects that varying a condition, facility, or operating policy will have on the system, while absolute (or predictive) modeling directly estimates what is likely to happen to the system given a single set of inputs.

2. Pre-water development results remove the quantifiable effects of the following in estimating pre-development inflows to Utah Lake:
    a. M&I and agricultural depletions upstream of Utah Lake
    b. Transbasin diversions into the drainage basin from Weber, Duchesne, and Strawberry basins
    c. Diversion to storage and release from storage in Jordanelle and Deer Creek reservoirs
3. Pre-water development results remove the effects of the following in estimating pre-development outflows from Utah Lake:
    a. Calls on the Lake by downstream water right holders
    b. Dredging of Jordan River channel to allow more outflow at a given stage
    c. Damming of the Jordan River at the Narrows
    d. Damming at the outlet works
    e. Pumping from the outlet works and other (historical) pumping stations
4. Pre-water development results remove the secondary effects of higher or lower stage on lake surface evaporation and precipitation into the Lake, and simulate evaporation losses and precipitation gains based on pre-development modeled surface area.
5. Pre-water development results make use of natural inflows to Utah Lake from the Provo and Spanish Fork rivers that were prepared as part of the hydrological analysis conducted in developing the PROSIM2000 and LKSIM models. These natural inflows remove the depletions, transbasin inflows, and timing changes associated with the Bonneville Unit of the Central Utah Project, the Provo River Project, the Strawberry Valley Project, and local, recorded non-project agricultural and M&I diversions from the Provo and Spanish Fork rivers. Combined Spanish Fork and Provo river depletions to Utah Lake are estimated at 220,000 acre-feet per year.
6. In addition to the Provo and Spanish Fork river inflow changes, pre-water development results incorporate other lake inflow changes based on the water balance calculations documented in Chapter 5 of the 1997 State Water Plan for the Utah Lake Basin. These changes include the effects of groundwater pumping, springflow diversions, and smaller tributary stream diversions of water that would otherwise have flowed into Utah Lake. The State Water Plan estimates these diversions at 190,000 acre-feet per year. These diversions lump together all of the surface and subsurface diversions from throughout northern and southern Utah County, as well as the portion of Juab County within the Utah Lake drainage area. Consumptive use (excluding return flow losses) from this 190,000 acre-feet of combined diversions is estimated at 40%, resulting in a depletion to the Lake of 76,000 acre-feet. Of the return flow portion, based on a 2001 MODFLOW analysis, 25% will be consumed prior to getting to the Lake. This results in a net depletion of 55% or 104,500 acre-feet. This is added back into historic lake inflow to produce the pre-development lake inflow.
7. Changes to Utah Lake inflows resulting from depletions due to increased groundwater levels, reductions in phreatophyte consumptive use, and other landuse associated changes are assumed to be incorporated in the depletions summarized in 6).

8. In its pre-development condition, Utah Lake outflow is assumed to be controlled solely by the pre-dredging stage vs. discharge relationship of the Jordan River channel. The pre-development stage vs. discharge (outflow) relationship is estimated using a HEC-RAS model of the Jordan River channel with channel geometry data measured prior to dredging in the 1980s. The pre-dredging stage versus discharge curve is compared against the post-dredging curve in Figure 6.
9. The pre-development "sill" or minimum elevation at which water would essentially stop flowing out of Utah Lake was 4485.7.

Current and Planned Operational Assumptions

1. The "Current and Planned" scenario is an estimate of how Utah Lake would operate under the effects of existing and planned water supply projects and water right changes. It is a prediction of the future (based on 1950-1999 hydrology), against which historical and potential future level-fluctuation reduction scenarios can be compared.
2. CUP operations under the Current and Planned scenario duplicate the ULS Proposed Action operations, as documented in the ULS Final EIS and Surface Water Technical Report. The Current and Planned scenario inflows to the Lake reflect all of the Bonneville Unit (and other) operations and institutional arrangements incorporated in the ULS Proposed Action.
3. Historical diversions (calls) from the Lake are modified (reduced) in the Current and Planned scenario to represent only the remaining volume of water rights being supplied downstream of Utah Lake. These reductions include the volume of CUWCD/DOI rights currently being held in the Lake, as well as those rights currently approved for exchange upstream. The call reductions include the effects of JVWCD and other municipal water suppliers' approved and proposed downstream water right changes.
4. Water rights inventories (summarized in Table 2) estimate that 79,318 acre-feet of water rights will be held in Utah Lake, 62,048 acre-feet will be exchanged upstream, and 37,367 acre-feet will be exchanged downstream. (It is assumed that these downstream exchanges will still be called out of the Lake.) This leaves 164,279 acre-feet of remaining (downstream) calls on Utah Lake storage, plus 14,137 acre-feet of calls associated with the 10 percent carrier water requirement on the rights exchanged upstream and held in the Lake.
5. Water rights exchanged upstream are assumed to deplete the local inflow to the Lake by 42.4 percent of their original volume. Additionally, 10 percent of the volume of rights exchanged upstream is assumed to be left in the canal from which it was exchanged and is called out of Utah Lake. The remaining 47.6 percent is assumed to be held in the Lake pending any calls by lower Jordan River water users[8].
6. The results of the Jordan River Return Flow Study show increasing flows on the lower Jordan River, in spite of exchanges and conversion of supplies from agricultural to M&I, and increased utilization of water recycling. This conclusion indicates that the

[8] During water right hearings associated with exchange of Utah Lake water rights, the State Engineer's office has assured other Utah Lake water users that the exchanges would result in no net effect on Utah Lake. The assumptions used in this study do not validate this, the primary reason being the absence of any historical basis for predicting calls by lower Jordan River water users on the remainder of the water right which is left in Utah Lake.

remainder of exchanged water rights, which are held in Utah Lake, may not regularly be called to meet downstream uses.

7. Water rights exchanged to wells downstream are assumed to be released from Utah Lake, exactly as if the water was still being delivered to downstream users.

Level Fluctuation Reduction Scenario Assumptions

1. Lake level fluctuation reduction scenarios assume operation of the Lake inflows and outflows exactly the same as under Current and Planned conditions, except for the specific variable (or variables) being evaluated in the scenario.
2. Under scenarios involving additional water rights being held in Utah Lake, the Current and Planned demands on the Lake are reduced in proportion to the volume of rights assumed to be stabilized.
3. Under scenarios involving water rights being exchanged upstream, the Current and Planned demands on the Lake are reduced in proportion to 90 percent of the volume of rights exchanged upstream (10 % of the right is left in the canal and called from the Lake as carrier water). Additionally, 42.4 percent of the volume of rights exchanged upstream is assumed to be depleted from the inflow to the Lake, and 47.6 percent is held in Utah Lake on-call by Lower Jordan River water users.
4. Level fluctuation reduction scenarios to be evaluated are summarized in the table below:

Table A - 1 Level Fluctuation Reduction Scenarios

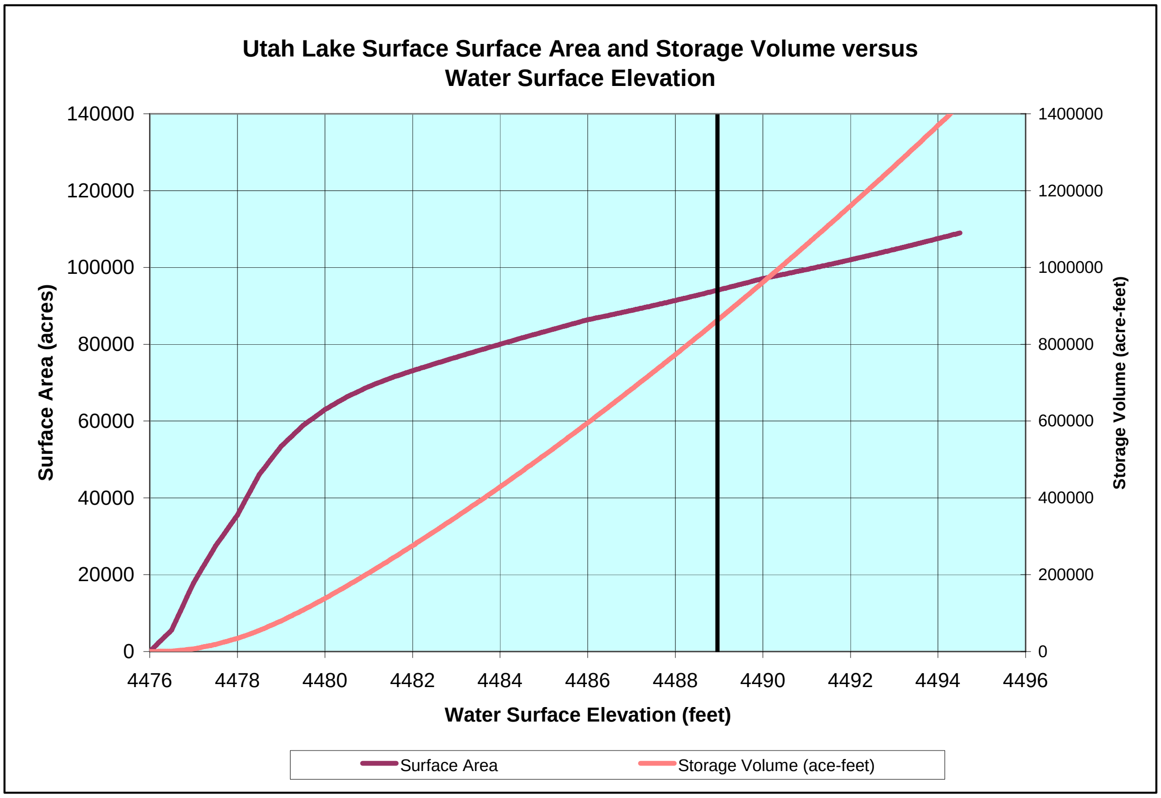
#	Scenario	Primary Change	Goal	Expected Result
1	Lower maximum conservation pool level	Lower the maximum level at which water is held in the lake from 4489.045 by two feet. Double the stage versus outflow curve to keep the Lake from surcharging.	Reduce salinity and improve level stability	Reduce level variation by forcing the lake to operate in a narrower range
2	Modify stage versus surface area and volume relationship by diking off a portion of the Lake	Lower lake evaporation losses by reducing the surface area by effectively cutting off a portion of the shallow, saline areas	Reduce salinity	Reduce evaporation-caused level fluctuation; reduced salinity
3	Increase upstream exchange by 50,000 acre-feet (trend already occurring)	Assume a significant portion of the remaining rights downstream of Utah Lake are exchanged to Utah County	Improve level stability	Reduce calls on the Lake and reduce resulting level fluctuation. 126,912 acre-feet of water rights have not been affected by prior exchanges and might be used.
4	Increase rights held in Utah Lake by 50,000 acre-feet	Assume a significant portion of the remaining rights downstream of Utah Lake are acquired and held in the Lake	Improve level stability	Reduce calls on the Lake and reduce resulting level fluctuation
5	Dike Provo Bay	Reduce volume of Lake allowed to rise and fall by cutting Provo Bay off from the remainder of the Lake and holding its volume essentially constant	Reduce salinity and improve level stability	Main Lake levels vary approx. as in Current and Planned, but Provo Bay is held stable with lower salinity, and non-native fish control

Table A - 2 Summary of Utah Lake Water Rights

Water Right Number	Owner of Record	Amount of Original Right	Amount of Right Held in Utah Lake[9]	Amount Exchanged Upstream of Utah Lake[10]	Amount Exchanged Downstream of Utah Lake	Amount of Remaining Right
		ac-ft	**ac-ft**	**ac-ft**	**ac-ft**	**ac-ft**
59-3500	South Jordan Canal Co.	29,634.9	1,205.4	6,691.3	7,308.7	14,429.5
59-3499	Utah and Salt Lake Canal Co	45,673.3	2,882.5	3,823.5	14,743.1	24,224.2
59-3496	North Jordan Irrigation Co	15,848.0	0.0	10,498.6	0.0	5,349.4
59-3517	Kennecott Utah Copper Corp	13,750.0	5,000.0	0.0	0.0	8,750.0
57-7637	East Jordan Irrigation Co.	48,400.0	4,799.4	11,397.9	9,096.8	23,105.9
57-7624	Salt Lake City	14,600.0	0.0	0.0	0.0	14,600.0
E3101	Central Utah Water Cons. District	16,862.4	0.0	16,862.4[11]	0.0	0.0
55-9695	U.S. DOI	7,900.0	7,900.0	0.0	0.0	0.0
51-7755	Elk Ridge City	237.6	0.0	237.6	0.0	0.0
57-23	Sandy & Draper Irrigation Co	12,500.0	0.0	6,004.4	2,779.4	3,716.2
59-13	Utah Lake Distributing Co	43,165.9	457.9	6,532.5	3,439.0	32,736.5
59-14,15,20	U.S. DOI	57,073.0	57,073.0		0.0	0.0
	Subtotal	**305,645.1**	**79,318.2**	**62,048.2**	**37,367.0**	**126,911.7**

[9] A portion (estimated at 10 percent) of these upstream exchanges must continue to be released from Utah Lake as carriage water to protect the remaining canal users.
[10] A portion (estimated at 10 percent) of these upstream exchanges must continue to be released from Utah Lake as carriage water to protect the remaining canal users.
[11] This water right was purchased by the District from Salt Lake City. Long range planning calls for it to be exchanged upstream.

Figure A - 1 Utah Lake Stage versus Area and Stage versus Volume Curves



Appendix B –
Utah Lake Salinity Analysis (LKSIM2000)

B-3. Pre-Water Development Lake Salinity Results
B-4. Current and Planned Scenario Lake Salinity Results
B-5. Lower Conservation Pool Lake Salinity Results
B-6. Reduce Area-Capacity Lake Salinity Results
B-7. Increase Upstream Exchange Scenario Lake Salinity Results
B-8. Increase Rights Held in Lake Salinity Results
B-9. Dike Provo Bay Lake Salinity Results
B-10. Dike Provo Bay Provo Bay Salinity Results

Simulated Utah Lake TDS - Pre-Water Development Scenario (mg/L)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1950	746	742	716	682	661	653	647	605	580	595	612	622	655
1951	631	626	611	598	590	586	578	549	536	551	564	577	583
1952	581	579	564	552	539	522	495	432	427	446	462	473	506
1953	485	486	493	489	494	498	505	505	499	517	535	552	505
1954	562	564	562	556	554	551	558	554	561	582	605	617	569
1955	625	625	617	604	594	584	587	573	566	588	604	614	598
1956	623	619	605	589	578	576	579	557	554	576	595	612	589
1957	625	623	613	600	590	585	576	546	511	528	542	551	574
1958	562	561	556	552	545	540	541	515	517	540	556	568	546
1959	581	580	574	568	559	559	569	568	568	590	606	614	578
1960	624	630	621	611	600	592	601	597	605	654	684	701	627
1961	704	684	673	665	658	651	662	666	694	728	756	755	691
1962	751	745	727	713	678	663	636	600	584	606	631	644	665
1963	655	662	665	656	649	645	643	627	616	641	666	668	649
1964	683	684	680	672	672	663	660	616	578	602	628	646	649
1965	667	669	651	642	643	644	640	606	568	579	590	592	624
1966	601	605	593	589	585	581	595	584	597	628	652	664	606
1967	668	670	654	641	628	617	632	595	546	559	572	580	614
1968	591	593	585	577	567	561	559	539	514	527	533	543	557
1969	549	552	546	536	530	533	518	496	484	499	512	523	523
1970	528	535	536	533	535	542	551	540	528	544	563	570	542
1971	578	568	576	571	572	572	568	553	542	562	582	590	570
1972	580	590	584	582	584	586	592	583	574	600	622	636	593
1973	629	625	618	608	599	592	587	539	530	546	559	565	583
1974	568	563	558	549	544	542	534	518	515	533	554	570	546
1975	572	571	567	556	549	544	543	512	464	472	489	496	528
1976	501	502	499	494	487	489	499	491	498	517	538	550	505
1977	562	569	564	561	558	558	571	568	586	612	633	650	583
1978	656	662	656	638	625	603	580	557	537	558	575	571	602
1979	582	578	573	567	558	548	543	527	529	551	567	585	559
1980	593	597	596	577	549	547	541	490	480	501	501	526	542
1981	534	537	538	538	541	540	548	532	537	558	583	596	549
1982	585	588	581	573	565	553	543	495	481	496	511	503	540
1983	505	508	506	504	499	490	488	446	399	419	427	440	469
1984	450	453	445	449	453	452	446	400	364	364	364	364	417
1985	364	364	364	364	364	364	364	364	364	395	422	441	378
1986	454	461	462	465	458	451	434	412	407	427	440	451	444
1987	459	465	471	474	476	481	492	494	509	527	543	560	496
1988	569	570	571	566	567	573	570	570	592	634	669	672	594
1989	711	708	702	701	684	657	658	668	682	740	774	730	701
1990	740	738	734	713	700	692	700	675	662	691	721	728	708
1991	736	738	730	721	707	697	703	669	645	682	706	703	703
1992	710	707	700	692	682	683	698	704	724	774	829	809	726
1993	823	815	806	766	738	695	691	603	578	597	613	623	696
1994	626	631	630	628	623	624	629	623	642	678	705	730	647
1995	723	720	715	695	687	675	670	587	515	523	551	566	636
1996	571	581	579	586	578	571	563	534	522	548	571	583	566
1997	596	591	585	568	568	560	552	504	484	513	526	533	548
1998	543	548	548	543	540	537	532	499	470	491	505	512	522
1999	522	525	529	530	532	540	541	510	501	519	536	552	528
Average	**601.7**	**602.1**	**596.6**	**588.1**	**580.7**	**575.2**	**574.2**	**549.9**	**539.3**	**562.2**	**581.7**	**590.4**	**578.5**
Wet Years[1]	513.3	516.0	510.7	507.0	498.7	487.7	472.3	430.0	411.0	430.7	443.0	454.7	472.9
Dry Years[2]	658.7	653.3	645.7	639.3	632.7	630.7	643.7	646.0	668.0	704.7	739.3	738.0	666.7

[1] Wet years are 1952, 1983, and 1986
[2] Dry years are 1961, 1977, and 1992

Simulated Utah Lake TDS - Current and Planned Scenario (mg/L)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1950	1000	988	949	907	876	866	871	844	846	894	942	976	913
1951	993	976	941	911	892	883	877	840	834	873	913	949	907
1952	956	941	903	869	832	778	710	613	614	649	678	706	771
1953	725	718	721	705	706	701	706	716	719	757	799	833	734
1954	850	846	833	819	810	801	812	839	867	917	978	1012	865
1955	1025	1015	992	959	931	906	902	914	935	995	1047	1085	976
1956	1100	1075	1040	997	966	959	974	979	1028	1095	1160	1224	1050
1957	1251	1217	1165	1117	1081	1059	1019	984	969	1028	1083	1117	1091
1958	1136	1101	1061	1030	993	966	961	930	964	1033	1077	1113	1030
1959	1133	1107	1072	1038	1002	992	1003	1014	1050	1115	1163	1192	1073
1960	1211	1205	1159	1115	1071	1047	1062	1082	1143	1268	1375	1436	1181
1961	1426	1334	1282	1244	1211	1187	1201	1239	1358	1502	1658	1693	1361
1962	1644	1580	1482	1405	1277	1217	1166	1144	1222	1383	1541	1610	1389
1963	1593	1531	1493	1394	1342	1304	1264	1296	1355	1520	1700	1673	1455
1964	1669	1534	1423	1299	1239	1160	1128	1058	1036	1143	1270	1341	1275
1965	1374	1311	1195	1125	1110	1090	1073	1073	1037	1104	1160	1162	1151
1966	1163	1133	1048	1010	970	938	976	972	1033	1133	1208	1242	1069
1967	1237	1216	1148	1104	1055	1024	1057	1035	995	1052	1105	1134	1097
1968	1141	1117	1073	1032	990	962	945	933	909	952	976	1005	1003
1969	1006	985	951	920	890	884	838	813	787	826	862	887	887
1970	886	882	868	845	833	835	839	830	835	876	919	935	865
1971	942	907	909	883	872	859	852	842	834	888	935	953	890
1972	921	928	905	889	878	869	876	874	890	947	997	1031	917
1973	1011	991	969	943	914	891	871	816	804	849	882	907	904
1974	904	882	864	835	815	806	782	781	778	820	867	902	836
1975	899	885	872	846	826	811	799	759	699	722	762	784	805
1976	788	777	759	738	713	709	715	715	744	783	826	851	760
1977	867	871	851	840	828	822	834	826	870	924	969	1009	876
1978	1002	994	970	925	895	858	829	826	853	912	958	949	914
1979	959	930	905	879	847	818	796	803	838	886	924	956	878
1980	949	933	911	869	810	795	793	737	742	792	791	841	830
1981	844	835	823	805	799	787	797	781	816	858	913	939	833
1982	903	897	874	850	825	798	779	722	715	746	783	770	805
1983	761	754	735	718	688	625	616	561	514	545	562	580	638
1984	586	582	564	559	554	539	514	465	455	481	502	522	527
1985	531	536	537	536	537	527	510	497	519	548	582	608	539
1986	617	618	608	603	588	542	512	492	499	525	550	579	561
1987	588	593	596	594	586	583	594	601	630	666	696	728	621
1988	738	735	734	727	724	734	728	746	793	868	935	941	784
1989	1003	990	976	972	942	905	917	960	1015	1127	1219	1116	1012
1990	1106	1085	1068	1020	989	972	1004	1002	1036	1114	1195	1224	1068
1991	1210	1202	1171	1141	1100	1079	1086	1068	1088	1195	1260	1251	1154
1992	1230	1207	1169	1134	1097	1090	1121	1156	1202	1328	1461	1383	1215
1993	1383	1331	1287	1182	1117	1045	1048	985	996	1050	1098	1119	1137
1994	1108	1096	1078	1057	1036	1033	1032	1047	1103	1181	1236	1286	1108
1995	1250	1222	1197	1141	1115	1095	1083	961	907	926	966	1007	1073
1996	1008	1010	990	991	957	931	907	873	848	909	965	990	948
1997	1000	971	946	899	881	858	817	751	732	781	816	832	857
1998	832	824	809	786	766	754	742	690	658	692	722	735	751
1999	748	741	740	732	726	727	712	666	667	700	735	768	722
Average	**1024.1**	**1002.8**	**972.3**	**938.8**	**910.0**	**888.4**	**881.0**	**863.0**	**875.6**	**937.6**	**994.4**	**1017.7**	**942.2**
Wet Years[1]	778.0	771.0	748.7	730.0	702.7	648.3	612.7	555.3	542.3	573.0	596.7	621.7	656.7
Dry Years[2]	1174.3	1137.3	1100.7	1072.7	1045.3	1033.0	1052.0	1073.7	1143.3	1251.3	1362.7	1361.7	1150.7

Simulated Utah Lake TDS - 50,000 acre-feet Upstream Water Rights Exchange Scenario (mg/L)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1950	999	986	947	904	874	864	869	842	844	891	937	970	911
1951	986	970	937	907	889	880	874	837	831	869	908	944	903
1952	950	935	899	864	828	775	707	610	611	646	675	702	767
1953	721	713	717	700	701	697	703	713	715	753	793	826	729
1954	842	838	826	812	803	795	806	832	859	908	967	1000	857
1955	1012	1002	980	949	922	898	895	907	928	984	1033	1069	965
1956	1083	1060	1028	988	959	952	967	972	1018	1079	1140	1197	1037
1957	1222	1194	1149	1106	1072	1053	1016	984	970	1024	1074	1105	1081
1958	1123	1093	1057	1028	994	970	965	936	969	1033	1073	1105	1029
1959	1125	1102	1071	1039	1006	997	1007	1018	1052	1111	1153	1180	1072
1960	1197	1193	1153	1114	1075	1053	1067	1086	1141	1250	1341	1393	1172
1961	1388	1315	1273	1241	1213	1193	1206	1239	1338	1456	1575	1604	1337
1962	1573	1530	1457	1398	1295	1244	1202	1183	1250	1379	1500	1554	1380
1963	1551	1512	1485	1410	1369	1338	1306	1331	1379	1505	1641	1631	1455
1964	1638	1549	1469	1371	1321	1253	1225	1161	1139	1230	1333	1389	1340
1965	1418	1371	1275	1213	1199	1180	1163	1163	1130	1187	1235	1236	1231
1966	1237	1211	1134	1097	1058	1025	1061	1055	1110	1198	1263	1292	1145
1967	1290	1274	1216	1175	1130	1101	1130	1110	1073	1123	1169	1194	1165
1968	1200	1179	1140	1101	1062	1033	1013	999	973	1015	1038	1066	1068
1969	1065	1043	1007	969	936	928	878	850	821	861	896	921	931
1970	919	914	897	871	858	860	863	853	858	898	941	956	891
1971	961	926	926	899	887	873	865	854	846	900	946	964	904
1972	931	937	912	896	885	876	882	881	897	953	1001	1034	924
1973	1014	994	973	944	915	892	872	817	805	849	882	906	905
1974	903	880	862	833	813	804	781	780	777	817	864	898	834
1975	895	881	868	842	822	808	796	756	696	719	758	779	802
1976	783	772	754	733	708	705	711	711	739	777	819	843	755
1977	859	862	843	833	822	816	828	821	863	914	957	995	868
1978	988	981	959	917	888	853	824	821	848	905	949	940	906
1979	950	922	898	873	841	813	791	799	833	879	916	948	872
1980	940	925	903	863	806	791	790	733	739	787	786	835	825
1981	838	828	816	799	793	781	791	776	810	852	905	930	827
1982	895	889	867	843	818	792	774	717	710	741	777	765	799
1983	755	748	729	713	683	620	612	558	511	543	559	576	634
1984	582	578	560	556	551	536	511	463	453	479	500	519	524
1985	528	533	534	533	534	525	508	495	517	546	579	605	536
1986	614	614	605	600	585	539	510	490	497	523	548	577	559
1987	585	590	593	591	584	581	592	598	627	662	692	722	618
1988	732	729	728	721	719	728	723	741	787	859	925	930	777
1989	989	978	964	961	933	897	909	951	1003	1109	1194	1101	999
1990	1092	1078	1061	1015	987	970	1001	1000	1032	1104	1178	1206	1060
1991	1194	1189	1161	1133	1096	1076	1083	1067	1086	1183	1242	1235	1145
1992	1218	1197	1164	1133	1099	1093	1122	1153	1195	1307	1422	1361	1205
1993	1363	1319	1282	1188	1129	1062	1066	1002	1013	1064	1110	1129	1144
1994	1119	1108	1089	1070	1047	1042	1041	1057	1112	1190	1244	1292	1118
1995	1256	1228	1204	1148	1123	1103	1089	966	911	929	969	1010	1078
1996	1010	1011	992	993	959	932	908	874	848	909	965	989	949
1997	999	969	944	897	880	857	816	750	731	780	814	829	856
1998	829	820	805	783	763	752	740	688	655	689	719	731	748
1999	744	737	736	728	722	724	709	664	664	697	731	763	718
Average	**1022.1**	**1004.1**	**977.0**	**945.9**	**919.1**	**898.6**	**891.4**	**873.3**	**884.3**	**941.3**	**992.7**	**1014.9**	**947.1**
Wet Years[1]	773.0	765.7	744.3	725.7	698.7	644.7	609.7	552.7	539.7	570.7	594.0	618.3	653.1
Dry Years[2]	1155.0	1124.7	1093.3	1069.0	1044.7	1034.0	1052.0	1071.0	1132.0	1225.7	1318.0	1320.0	1136.6

[1] Wet years are 1952, 1983, and 1986
[2] Dry years are 1961, 1977, and 1992

Simulated Utah Lake TDS - Lower Conservation Pool Scenario (mg/L)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1950	1000	988	949	907	876	864	869	837	840	892	945	982	912
1951	999	980	941	907	885	874	865	819	811	859	908	954	900
1952	959	938	891	848	806	744	666	558	564	605	640	674	741
1953	698	689	695	677	679	675	682	694	697	743	794	836	713
1954	856	848	832	813	801	790	803	836	870	935	1014	1058	871
1955	1071	1051	1016	970	933	901	895	909	935	1011	1077	1127	991
1956	1143	1103	1054	998	958	948	966	972	1033	1116	1200	1285	1065
1957	1316	1260	1185	1121	1072	1045	994	954	935	1005	1071	1111	1089
1958	1132	1085	1037	999	956	927	922	888	925	1005	1055	1095	1002
1959	1117	1084	1044	1005	964	954	966	979	1021	1095	1150	1184	1047
1960	1203	1193	1138	1087	1038	1012	1029	1051	1120	1267	1397	1471	1167
1961	1452	1332	1267	1221	1182	1156	1171	1214	1356	1538	1700	1700	1357
1962	1635	1551	1427	1334	1187	1122	1069	1048	1135	1322	1518	1600	1329
1963	1567	1482	1435	1317	1259	1217	1174	1211	1281	1480	1700	1646	1397
1964	1627	1450	1320	1186	1125	1047	1019	952	933	1047	1188	1269	1180
1965	1306	1236	1116	1045	1033	1015	999	1002	968	1038	1099	1102	1080
1966	1104	1073	989	952	914	884	923	920	983	1086	1164	1201	1016
1967	1195	1174	1104	1059	1010	980	1013	992	953	1011	1066	1097	1055
1968	1104	1079	1035	994	952	924	905	892	866	914	942	975	965
1969	975	952	914	877	844	839	787	760	733	777	818	848	844
1970	848	844	828	803	791	795	800	790	797	845	898	918	830
1971	925	882	885	855	844	829	821	809	800	865	922	944	865
1972	902	909	881	863	851	841	849	847	865	935	996	1038	898
1973	1009	982	955	921	887	861	839	776	763	815	854	883	879
1974	879	852	831	799	777	767	741	740	737	785	842	885	803
1975	879	860	844	814	790	774	760	716	649	676	722	748	769
1976	752	740	720	698	672	669	677	678	711	758	811	841	727
1977	859	862	836	822	808	800	815	805	859	925	982	1032	867
1978	1017	1003	969	912	875	832	796	793	825	897	955	941	901
1979	951	914	882	851	814	781	757	766	808	866	912	952	855
1980	939	917	888	839	772	757	755	692	699	756	756	815	799
1981	819	808	794	775	768	755	767	750	792	844	913	944	811
1982	896	887	859	830	800	770	749	684	677	715	758	744	781
1983	734	727	706	689	657	587	580	520	471	512	534	557	606
1984	566	562	543	540	536	519	492	436	429	464	491	516	508
1985	528	535	535	535	536	524	503	487	515	551	594	627	539
1986	637	635	621	614	594	536	501	477	488	520	552	590	564
1987	600	604	608	604	593	589	602	609	645	692	730	769	637
1988	778	771	767	755	749	760	751	771	833	934	1026	1023	827
1989	1110	1083	1055	1045	999	945	959	1014	1087	1248	1381	1202	1094
1990	1178	1143	1114	1047	1006	983	1024	1020	1061	1161	1269	1301	1109
1991	1274	1259	1214	1172	1116	1088	1096	1073	1096	1233	1316	1297	1186
1992	1263	1229	1178	1133	1088	1080	1116	1157	1211	1372	1553	1430	1234
1993	1425	1350	1293	1164	1088	1004	1008	937	951	1012	1069	1092	1116
1994	1079	1065	1044	1022	997	993	992	1010	1078	1176	1244	1307	1084
1995	1253	1214	1182	1112	1081	1058	1043	902	844	867	914	963	1036
1996	964	965	943	946	909	880	855	818	791	862	927	957	901
1997	969	934	904	853	834	810	765	694	676	732	773	793	811
1998	793	785	769	745	725	714	702	646	612	653	688	704	711
1999	720	713	713	706	699	703	685	635	637	676	718	758	697
Average	**1020.1**	**991.6**	**955.0**	**915.6**	**882.6**	**858.4**	**850.3**	**830.8**	**847.3**	**921.9**	**990.9**	**1015.7**	**923.4**
Wet Years[1]	776.7	766.7	739.3	717.0	685.7	622.3	582.3	518.3	507.7	545.7	575.3	607.0	637.0
Dry Years[2]	1191.3	1141.0	1093.7	1058.7	1026.0	1012.0	1034.0	1058.7	1142.0	1278.3	1411.7	1387.3	1152.9

[1] Wet years are 1952, 1983, and 1986

[2] Dry years are 1961, 1977, and 1992

Simulated Utah Lake TDS - Additional 50,000 acre-feet Held in Lake Scenario (mg/L)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1950	1000	988	949	907	877	867	872	846	848	894	940	973	913
1951	990	975	942	913	896	888	881	843	837	876	915	951	909
1952	957	944	907	871	835	781	713	615	615	651	680	708	773
1953	727	719	723	706	707	703	708	718	720	758	799	832	735
1954	849	845	833	819	810	801	812	839	866	916	975	1008	864
1955	1021	1012	990	959	932	909	905	917	937	993	1041	1076	974
1956	1091	1069	1038	1000	971	965	980	985	1029	1088	1146	1202	1047
1957	1226	1201	1160	1120	1088	1070	1034	1004	991	1043	1090	1119	1096
1958	1138	1110	1077	1050	1017	990	985	953	986	1053	1094	1127	1048
1959	1147	1124	1092	1061	1026	1016	1026	1037	1072	1131	1174	1201	1092
1960	1218	1214	1175	1136	1097	1075	1089	1108	1162	1268	1357	1408	1192
1961	1404	1336	1295	1265	1238	1218	1231	1262	1356	1465	1575	1602	1354
1962	1577	1540	1475	1423	1328	1280	1240	1223	1285	1403	1513	1563	1404
1963	1564	1533	1511	1444	1408	1380	1350	1373	1417	1528	1645	1642	1483
1964	1652	1581	1514	1428	1383	1322	1295	1235	1214	1297	1389	1441	1396
1965	1468	1428	1342	1285	1271	1252	1236	1234	1203	1255	1300	1301	1298
1966	1304	1280	1208	1172	1133	1095	1131	1125	1179	1265	1327	1356	1215
1967	1355	1340	1283	1243	1199	1169	1198	1177	1137	1187	1233	1258	1232
1968	1264	1244	1204	1165	1120	1086	1064	1049	1020	1064	1088	1116	1124
1969	1115	1092	1051	1010	974	965	911	880	849	891	927	953	968
1970	950	944	926	898	883	884	887	875	880	921	966	981	916
1971	986	949	948	920	907	892	883	871	862	917	964	982	923
1972	949	955	929	912	900	890	896	894	910	967	1017	1051	939
1973	1031	1010	989	958	928	905	884	828	816	860	894	918	918
1974	916	892	873	844	823	814	790	788	785	826	873	908	844
1975	906	892	879	853	832	817	804	764	703	726	767	788	811
1976	792	781	762	741	716	712	718	718	746	785	827	851	762
1977	867	871	852	842	830	825	837	829	871	921	964	1001	876
1978	996	989	968	927	899	864	833	830	857	915	960	952	916
1979	962	935	910	884	852	823	801	808	843	890	927	959	883
1980	952	937	916	875	817	802	800	743	748	797	796	846	836
1981	848	839	826	809	802	790	800	783	818	860	914	940	836
1982	905	900	878	852	827	800	781	724	717	748	785	772	807
1983	762	755	736	720	689	626	617	562	514	546	563	581	639
1984	587	582	564	560	555	539	514	465	455	482	503	522	527
1985	531	537	537	537	537	527	510	497	519	548	582	608	539
1986	617	618	608	603	588	542	512	492	499	525	550	580	561
1987	589	593	597	594	587	584	595	601	630	666	696	726	622
1988	736	734	733	725	723	732	727	744	791	863	929	935	781
1989	994	983	970	967	939	904	916	956	1008	1111	1193	1106	1004
1990	1098	1081	1065	1022	994	978	1008	1008	1039	1108	1179	1205	1065
1991	1196	1191	1165	1140	1105	1086	1093	1078	1096	1187	1241	1237	1151
1992	1223	1205	1174	1145	1113	1108	1135	1165	1204	1305	1408	1359	1212
1993	1362	1325	1293	1207	1153	1083	1085	1020	1031	1083	1129	1149	1160
1994	1139	1128	1110	1088	1064	1058	1057	1073	1129	1208	1262	1312	1136
1995	1276	1248	1224	1167	1142	1120	1105	979	923	942	983	1024	1094
1996	1025	1026	1005	1006	971	943	919	884	858	919	975	1000	961
1997	1010	981	954	907	888	865	823	757	737	787	822	838	864
1998	837	828	813	790	770	758	745	693	660	695	725	737	754
1999	750	744	742	734	728	729	713	668	669	701	736	768	724
Average	**1037.2**	**1020.6**	**994.3**	**964.1**	**937.4**	**916.6**	**909.0**	**890.4**	**900.8**	**956.7**	**1006.8**	**1029.5**	**963.6**
Wet Years[1]	778.7	772.3	750.3	731.3	704.0	649.7	614.0	556.3	542.7	574.0	597.7	623.0	657.8
Dry Years[2]	1164.7	1137.3	1107.0	1084.0	1060.3	1050.3	1067.7	1085.3	1143.7	1230.3	1315.7	1320.7	1147.3

[1] Wet years are 1952, 1983, and 1986

[2] Dry years are 1961, 1977, and 1992

Simulated Utah Lake TDS - Reduce Area-Capacity Scenario (mg/L)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1950	990	969	937	904	877	862	852	817	809	834	866	890	884
1951	898	882	856	834	817	807	790	751	738	759	789	819	812
1952	822	809	781	755	726	680	613	525	520	536	556	579	659
1953	597	594	601	594	599	598	600	609	610	639	673	705	618
1954	721	719	712	705	699	693	697	716	738	778	829	861	739
1955	872	862	846	822	801	781	771	775	789	829	867	898	826
1956	910	889	866	837	815	810	815	815	846	889	935	982	867
1957	1001	977	945	915	892	876	840	811	796	828	862	887	886
1958	900	877	855	839	818	799	786	759	778	821	851	878	830
1959	893	875	855	836	814	807	807	811	834	873	906	928	853
1960	942	939	913	889	863	848	852	863	901	974	1044	1086	926
1961	1080	1023	993	974	957	940	941	959	1026	1109	1202	1227	1036
1962	1202	1165	1112	1073	999	963	921	902	942	1027	1117	1164	1049
1963	1160	1129	1117	1070	1048	1027	994	1007	1039	1124	1227	1226	1097
1964	1231	1164	1114	1054	1025	980	949	901	884	939	1012	1058	1026
1965	1080	1048	992	958	952	942	925	922	896	927	960	966	964
1966	966	948	903	884	861	836	851	843	878	932	978	1002	907
1967	1001	989	954	931	904	885	897	882	853	883	915	935	919
1968	939	923	899	878	849	827	803	789	765	787	802	824	840
1969	823	808	785	763	742	738	694	670	644	664	689	709	727
1970	711	709	704	692	687	691	690	683	687	715	750	767	707
1971	775	751	758	744	739	732	723	714	706	743	781	800	747
1972	777	784	770	762	757	752	752	748	759	800	840	872	781
1973	856	840	826	806	785	766	744	695	681	708	733	754	766
1974	751	734	722	704	690	684	659	656	650	675	711	739	698
1975	737	725	718	701	688	676	660	627	577	587	614	632	662
1976	637	630	621	610	593	592	593	593	613	641	676	699	625
1977	712	715	704	699	693	689	694	686	716	753	788	819	722
1978	815	809	795	766	746	719	689	683	700	740	775	771	751
1979	779	757	742	726	704	682	658	662	687	720	750	778	720
1980	773	760	748	720	677	666	659	613	614	646	646	687	684
1981	695	691	686	678	676	668	673	661	687	722	769	796	700
1982	771	767	753	736	718	697	675	624	614	632	660	654	692
1983	648	645	634	625	604	553	539	490	448	468	482	499	553
1984	509	509	498	500	499	488	463	418	407	426	446	466	469
1985	479	487	491	495	498	491	473	459	478	502	534	561	496
1986	572	574	568	566	553	510	475	453	456	474	495	522	518
1987	533	540	546	547	543	541	547	551	576	608	637	669	570
1988	680	680	681	676	676	685	676	692	734	805	872	881	728
1989	945	935	923	922	895	861	867	903	952	1054	1141	1045	954
1990	1034	1012	997	955	929	912	931	924	948	1005	1069	1093	984
1991	1077	1068	1045	1022	992	973	971	952	962	1035	1081	1075	1021
1992	1058	1038	1014	991	966	961	975	996	1027	1107	1199	1153	1040
1993	1155	1119	1094	1022	978	923	914	856	859	891	925	943	973
1994	932	922	912	899	883	880	873	882	925	985	1030	1073	933
1995	1043	1019	1004	964	948	930	911	806	756	763	793	828	897
1996	829	830	819	822	800	781	758	729	706	747	791	813	785
1997	823	802	786	754	743	727	686	630	610	641	668	684	713
1998	686	682	675	662	650	643	630	587	559	582	607	620	632
1999	633	631	635	633	632	636	621	583	582	607	636	665	625
Average	**849.1**	**835.1**	**818.1**	**798.3**	**780.0**	**764.2**	**751.5**	**733.7**	**739.2**	**778.7**	**819.6**	**839.6**	**792.3**
Wet Years[1]	680.7	676.0	661.0	648.7	627.7	581.0	542.3	489.3	474.7	492.7	511.0	533.3	576.5
Dry Years[2]	950.0	925.3	903.7	888.0	872.0	863.3	870.0	880.3	923.0	989.7	1063.0	1066.3	932.9

[1] Wet years are 1952, 1983, and 1986
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	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1950	1000	989	948	905	873	862	868	840	844	893	943	979	912
1951	996	979	942	909	890	881	874	837	832	874	916	955	907
1952	960	943	904	868	831	777	708	608	611	647	678	707	770
1953	727	719	722	705	706	701	707	717	719	760	804	840	736
1954	857	851	836	820	809	800	812	840	870	925	990	1027	870
1955	1040	1028	1001	965	935	907	903	917	941	1007	1063	1106	984
1956	1122	1093	1054	1007	973	964	980	987	1041	1115	1189	1260	1065
1957	1290	1250	1191	1138	1096	1072	1028	992	977	1044	1106	1144	1111
1958	1164	1123	1077	1041	1000	970	965	932	969	1046	1095	1133	1043
1959	1155	1125	1084	1046	1006	994	1006	1020	1062	1135	1189	1223	1087
1960	1243	1233	1179	1129	1081	1054	1071	1094	1163	1308	1433	1507	1208
1961	1494	1385	1321	1276	1237	1213	1228	1273	1416	1597	1700	1700	1403
1962	1659	1591	1478	1389	1246	1182	1129	1110	1202	1398	1603	1696	1390
1963	1670	1585	1534	1409	1345	1300	1255	1295	1375	1597	1700	1681	1479
1964	1680	1499	1362	1218	1153	1070	1042	974	957	1083	1242	1336	1218
1965	1379	1295	1156	1077	1061	1041	1023	1027	990	1071	1142	1146	1117
1966	1148	1111	1014	971	927	893	935	933	1002	1120	1212	1255	1043
1967	1248	1221	1139	1088	1030	995	1032	1009	965	1032	1096	1131	1082
1968	1138	1108	1057	1008	961	930	914	902	878	926	955	989	981
1969	989	965	927	892	863	858	814	792	768	809	845	871	866
1970	871	866	852	830	819	823	827	818	825	868	914	931	854
1971	937	901	901	876	866	853	847	837	830	887	936	955	886
1972	921	925	901	885	874	865	872	871	888	948	1000	1036	916
1973	1015	993	968	939	910	888	869	812	802	849	884	910	903
1974	906	881	863	835	814	805	781	780	778	821	871	908	837
1975	904	887	872	844	823	808	797	757	698	722	765	788	805
1976	791	779	761	739	715	710	717	716	747	788	834	859	763
1977	875	878	856	843	829	823	835	828	876	935	985	1028	883
1978	1019	1009	981	932	900	861	830	827	856	920	970	960	922
1979	969	938	910	881	849	819	798	806	844	895	935	970	885
1980	960	941	916	872	812	798	795	738	745	797	796	849	835
1981	852	841	827	809	802	791	801	786	824	869	928	955	840
1982	917	908	882	856	830	804	784	725	718	753	792	779	812
1983	769	762	742	725	694	629	620	565	516	551	567	586	644
1984	592	587	570	564	559	542	516	466	458	487	507	528	531
1985	537	542	542	541	542	531	514	500	523	554	589	616	544
1986	625	625	614	609	593	546	516	495	503	529	556	587	567
1987	596	600	603	600	593	589	600	607	637	676	708	740	629
1988	749	745	742	733	730	739	734	752	803	883	956	960	794
1989	1026	1011	994	988	955	914	926	973	1034	1159	1262	1147	1032
1990	1133	1110	1088	1034	1000	980	1016	1015	1054	1142	1233	1265	1089
1991	1249	1239	1203	1169	1122	1097	1106	1088	1111	1233	1309	1298	1185
1992	1273	1246	1201	1160	1119	1110	1144	1184	1236	1383	1543	1451	1254
1993	1451	1388	1336	1218	1144	1062	1062	995	1008	1068	1123	1145	1167
1994	1132	1117	1095	1071	1047	1042	1043	1060	1120	1207	1267	1322	1127
1995	1281	1249	1221	1158	1129	1108	1095	970	918	938	982	1026	1090
1996	1025	1024	1003	1005	971	944	921	885	859	925	983	1009	963
1997	1019	985	957	910	892	868	825	757	738	791	827	843	868
1998	842	833	817	795	776	762	750	695	664	699	731	743	759
1999	756	749	747	739	732	734	718	673	673	708	745	778	729
Average	**1039.0**	**1013.0**	**977.8**	**940.4**	**909.3**	**886.2**	**879.1**	**861.6**	**877.4**	**947.4**	**1008.0**	**1033.2**	**947.7**
Wet Years[1]	784.7	776.7	753.3	734.0	706.0	650.7	614.7	556.0	543.3	575.7	600.3	626.7	660.2
Dry Years[2]	1214.0	1169.7	1126.0	1093.0	1061.7	1048.7	1069.0	1095.0	1176.0	1305.0	1409.3	1393.0	1180.0

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	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1950	590	593	568	541	544	551	500	476	532	613	682	718	576
1951	735	662	617	578	564	557	473	455	506	586	646	693	589
1952	707	672	625	628	645	664	483	188	278	354	452	514	518
1953	574	572	559	533	542	553	517	562	635	712	757	799	610
1954	804	742	683	634	612	593	564	635	689	757	816	829	697
1955	829	771	720	659	613	619	562	509	539	617	690	709	653
1956	733	689	643	590	574	570	536	502	548	632	708	762	624
1957	769	742	707	654	637	623	545	454	487	576	647	692	628
1958	711	672	629	608	589	583	545	470	535	621	691	721	614
1959	743	692	651	610	573	582	529	493	536	616	668	691	615
1960	719	703	670	632	590	580	537	511	566	661	732	775	640
1961	766	730	690	668	652	601	540	513	560	642	708	713	649
1962	697	671	633	619	583	581	445	434	490	577	656	707	591
1963	730	706	674	623	590	572	491	461	502	592	667	707	610
1964	689	620	572	521	510	503	462	426	456	535	598	638	544
1965	687	660	592	573	571	591	524	462	507	578	629	634	584
1966	655	630	589	579	567	577	548	520	577	671	736	772	618
1967	763	716	648	588	582	577	541	489	526	605	674	720	619
1968	737	694	638	620	595	593	515	481	518	602	643	687	610
1969	702	665	618	593	578	605	414	403	464	541	625	675	574
1970	642	613	582	551	552	571	516	492	517	595	646	655	578
1971	670	606	578	575	560	573	534	504	552	634	699	720	601
1972	708	670	625	611	610	566	534	523	569	648	711	747	627
1973	704	664	639	615	618	631	597	391	454	546	607	636	592
1974	667	637	598	580	581	587	538	505	580	670	741	788	623
1975	784	726	678	643	642	639	579	468	416	523	589	656	612
1976	677	614	592	569	546	525	507	498	547	633	697	739	595
1977	757	725	694	656	638	625	579	488	542	613	675	713	642
1978	637	572	514	450	431	401	411	425	454	531	577	572	498
1979	562	487	448	405	396	398	418	444	511	577	616	634	491
1980	526	471	443	392	376	394	437	349	392	490	552	569	449
1981	544	513	491	480	479	468	470	428	483	564	635	665	518
1982	613	601	576	554	552	525	470	392	452	518	590	549	532
1983	536	540	548	560	543	523	574	425	277	343	382	450	475
1984	396	354	398	515	546	570	491	163	245	298	410	456	403
1985	461	463	472	486	522	530	537	487	544	592	653	655	534
1986	615	568	542	543	445	433	382	364	410	507	548	558	493
1987	574	548	534	501	484	483	488	474	517	586	625	668	540
1988	687	632	586	554	548	550	514	484	542	628	694	727	596
1989	748	683	636	599	544	528	503	490	538	627	682	708	607
1990	673	606	559	504	467	455	462	459	505	575	623	636	544
1991	629	590	550	518	497	492	456	431	482	568	620	621	538
1992	604	553	526	499	470	482	483	477	535	598	642	657	544
1993	547	478	433	381	377	379	412	367	418	489	539	559	448
1994	572	564	545	531	508	511	489	486	551	645	703	725	569
1995	612	528	481	442	442	423	440	318	324	425	488	536	455
1996	589	576	532	492	472	454	456	416	472	573	649	671	529
1997	657	591	548	481	478	464	458	386	442	503	588	600	516
1998	534	474	423	398	391	400	408	361	378	477	526	556	444
1999	557	536	524	499	502	533	466	430	484	557	627	667	532
Average	**656.5**	**615.7**	**580.4**	**552.8**	**538.6**	**535.8**	**497.6**	**447.4**	**491.7**	**572.3**	**635.1**	**665.0**	**565.7**
Wet Years[1]	619.4	593.4	571.7	576.9	544.7	540.1	479.3	326.0	321.7	401.0	460.6	507.7	495.2
Dry Years[2]	709.0	669.3	636.5	607.9	586.8	569.3	534.1	492.8	545.6	617.7	675.1	694.4	611.5

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