Utah Lake: A Few Considerations

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These observations and insights have evolved during my 50 years in Utah Valley as a professor, researcher, environmental engineer, consultant and interested local citizen— Over the years I have been asked many questions about Utah Lake—this white paper addresses some of the more pertinent physical, hydrological and water quality issues. At the end, I have included a review of some relevant water quality and pollution issues, a tabulation of Utah Lake water and salt balances, and a graph showing salt and lake water levels since 1930. This white paper has evolved over many years with updated versions—information from additional studies has supported year by year refinement of earlier observations, findings and understanding of the lake.

Special Note: *Recent important nutrient information is found on page 7.*

Utah Lake overview. Utah Lake is a major physical feature and unusually complex lake eco-system covering about half of Utah Valley's floor area. When "full", it averages only 9 ft. deep and covers about 150 square miles. Attitudes towards the lake range over an interesting spectrum—from "priceless beautiful lake" to "worthless swampy pond." Intense competition to use and benefit from the lake for many different purposes is confronted by its rich ecological communities that contest many use and development ideas. Beneficial use of this lake's resources will always feature complexity and controversy due to the eco-richness, importance and value of these resources. Overall, public consensus favors persistent pollution-control efforts and continuing reasonable steps to protect the lake and its tributaries. Recently however, one feels increased concern that public funds used for environmental and pollution-control programs be used where real benefits gained are in line with costs.

What is Utah Lake's natural condition? Utah Lake is a shallow, eutrophic, basin-bottom lake in a semi-arid region. For millions of years, lake sediments have accumulated and are thousands of feet deep beneath the main lake. The lake is naturally turbid, slightly saline and very biologically productive (eutrophic). As to most of its water quality aspects, it seems that the lake has not dramatically changed since its hydrology and ecosystem "stabilized" after Lake Bonneville last receded about 10,000 years ago—as the last ice age ended and the climate slowly warmed in early stages of the current, natural, cyclic, global-warming period. It's sobering to realize that over past hundreds of thousands of years, this huge lake has cyclically filled Utah's Great Basin (about 20% of the State), often accompanied by massive glaciers creeping down from the mountaintops—with dry valley land and habitable conditions, similar to those found today, occurring occasionally between inhospitable climatic periods.

The Utah Lake sub-basin was formed by massive, geologic block movements that define the local topographic geology of this area. Field evidence indicates that in this immediate area, the last major earthquake and faulting episodes occurred some 8,000 years ago. This geologic faulting deepened the main lake—making it as much as 20 feet deeper in some areas but generally some 3 to 10 feet deeper. In the intervening 8000 years, some 15 to 20 feet of sediments have accumulated in the main lake—less in the bays and shallows. Hence the lake is likely slightly shallower now than it was before that major faulting episode. If that basin-deepening fault movement had not occurred, the lake would have largely filled in by now, with its surviving remnant just a meandering channel through swampy lowlands—an upward extension of the Jordan River.

Since pioneer settlement beginning nearly 170 years ago, indications are that water quality in Utah Lake has not experienced large changes. However, land use changes, water diversions and introduced plants and animals have caused significant changes in ecosystems in and around the perimeter of the lake, as well as along its tributaries.

Naturally, lake outflow rate was controlled by its water level relative to a natural rock sill that crosses beneath the Jordan River about 7 miles downstream from the lake at Indian Ford Park. Had larger fault-movement occurred during the big earthquake(s) some 8000 years ago, the lake might not exist at all or might be deeper, depending on the relative vertical movement of the lakebed as compared to this bedrock sill. The top few feet of this rock sill were removed in the late 1980s as engineers dredged the Jordan River channel to increase lake-outflow capacity, after several years of very high lake levels and serious shoreline flooding. The lake reached its highest recorded level over 5 ft above “full” during this very wet period in the mid-1980s.

Nowadays, when lake-outlet gates are fully open, discharge rate down the Jordan River is determined by lake water level relative to the elevation of irrigation diversion works about a mile downstream from Indian Ford. The channel dredging and sill removal of the 1980s increased the unimpeded outflow rate about 100% at full elevation (Compromise elev.)—from about 500 to 1050 cubic feet per second (cfs); 400% greater at one foot below “Compromise”—from about 200 to 800 cfs, etc. Compromise elevation of 4489.04 ft is the lakes “legal” full elevation—the water elevation at which outlet gates must be opened fully to minimize additional rise in lake elevation and thus reduce flood damage to farmland and facilities around the lake.

Why does Lake level fluctuate so much? Unfortunately, the combination of physical, hydrological and water rights factors, makes it essentially impossible to keep the lake within a couple of feet of a desired elevation, especially during the summer months when, in addition to large natural differences in yearly and seasonal inflows, evaporation causes much of the natural depth fluctuation. Most of the annual evaporation of about 4 ft. occurs June through September, largely after the spring runoff. Note that 4 feet of evaporation represents about 300,000 acre feet of water which is about one-third of lake-full volume and about one-half of the annual average water inflow. During droughts, even if most upstream stored waters could somehow be commandeered from the “owners” the amount would still fall short of that needed to keep the lake full. Normally during spring runoff, the lake’s limited outflow capacity can’t keep up with inflows and the lake rises as excess inflowing water is stored in increased depth. Over time, this stored water is discharged as outflows finally exceed decreasing inflows.

For about 150 years, outflow rate has also been managed to accommodate downstream water rights. Under natural conditions, lake level varied 2 to 4 feet within a given year due to the natural cycle of large spring-runoff followed by much smaller inflows and high evaporation during summer and fall. About 150 years ago, only a few years after initial pioneer settlement, efforts began to control discharges and operate the lake as a shallow storage reservoir from which stored water was released on demand for downstream uses. Natural periodic flooding of land around the lake was worsened when water was stored and land owners strongly protested this practice that sometimes flooded thousands of acres of agricultural land around the lake. These conflicts led to the establishment of “Compromise” lake elevation (4489.04 ft.)—the water elevation where lake outlet gates must legally be fully open and allow unimpeded outflow. Also, several other upstream water storage reservoirs and/or diversions exist. These three factors, outlet control works, upstream storage and water diversions, typically add annual lake level fluctuations of 2 or 3 feet—thus increasing annual lake level fluctuations to a range of some 3 to 6 feet. Since the lake averages only 9 ft. deep when full with the deepest areas about 14 ft., a 6 ft. variation within a single year causes major changes in water-edge location and lake characteristics.

Over several-year-long wet to dry cycles, lake level drops as much as 15 feet from its highest to lowest levels. When at its lowest point, the lake is very small, receding to the middle of the lakebed where it becomes a pond only 3 or 4 feet deep with no natural spill-over outflow. Wet-dry cycles vary in magnitude and length; recently they seem to be bottoming about every 20 to 30 years. As the lake goes into a dry cycle, it drops lower and lower with annual fluctuations continuing in the 3 to 6 feet range. During major droughts, annual evaporation may exceed annual inflow and the lake continues to shrink even though there is no natural Jordan River outflow. In the extreme drought of the 1930s, pumps were put out into the lake and used to pump the lake almost dry—this has not been repeated since it was found that under such conditions the water was too salty to be used for irrigation.

Why is Utah Lake slightly salty (brackish) at times? Over many years TDS in the lake averages about 900 mg/l. Evaporation concentrates natural dissolved salts in the lake—during an average year, about half of inflowing water evaporates. This evaporation averages 4 feet annually and precipitation averages 1 ft, so net evaporation is about 3 ft.—a net loss of about 230,000 acre feet a year. This large volume of water would supply a city of about 1 million people or irrigate about 70,000 acres of farmland. During average years this evaporation approximately doubles the lake's total dissolved salt (TDS) concentrations. During the peak of wet cycles, outflowing water averages less than one year of in-lake residence time; while at the bottom of dry cycles, residence time increases to several years.

A major source of TDS is numerous small mineral springs that flow into the lake. These mildly thermal, slightly salty springs—with TDS concentrations typically 1500 mg/l to 7000 mg/l[1]—are associated with numerous geological faults that encircle, as well as pass under, the lake. These mineral springs only make up about 5 percent of the inflowing water but contribute about 27 percent of the salts. Most of these mineral springs are small, scattered, often diffuse, and most are submerged. These factors make it infeasible to undertake large-scale collection and export of these brackish waters to reduce TDS levels in the lake.

Note that for traditional irrigation practice in Utah, many crops begin to experience significant salt damage when irrigated with water having TDS levels above about 1,500 mg/l. The State's 1,200 mg/l irrigation water quality standard is occasionally exceeded in Utah Lake during prolonged droughts. During the worst part of drought cycles—usually 1 or 2 months in late summer—TDS levels have occasionally reached 2000 mg/l or higher, making the water essentially unusable for irrigation. As indicated in Figure 1, TDS levels have been above 1500 mg/l about 3.5% of the time (40 of 996 months.) Most of these occurred during the Sept-Dec period, after the main irrigation season. Although salinity damage to crops irrigated with this water is a threat, it appears to be a modest one if reasonable field-drainage practices are followed.

Importantly, about 30% of inflowing dissolved salts precipitate as sediments and comprise some 60 to 80 percent of the lake-bottom sediments (mostly Ca and HCO3). The net result of these

[1] Utah Lake averages about 900 mg/l over the last 85 years; for reference, sea water is about 35,000 mg/l.

factors is that average TDS in the lake is about two times higher than average inflowing waters, but even then lake waters are only moderately high in TDS if viewed from a water quality and beneficial use point of view. Over the years, through major wet and dry cycles, TDS in the lake averages about 900 mg/l but varies fourfold, from about 500 mg/l to 2000 mg/l. Lake plant and animal communities seem well adapted to this salt range and these TDS variations do not seem to cause them any significant problems.

Modeling simulations of the lake, based on simulated conditions in pre-settlement times, indicate that current TDS levels in the lake average some 35% to 45% higher than existed in pre-settlement times before about 1850. The TDS increase is mainly due to (1) diversions of some tributary waters that reduce the inflow of low-salt waters and also reduces lake flushing, and (2) increased TDS in tributary waters due to upstream water use.

TDS limitation is usually not included in primary drinking water standards but secondary guidelines often limit it for aesthetic and palatability reasons. Most agencies prefer to have less than 500 mg/l in drinking water, but some areas allow up to about 1000 mg/l, or so, when better waters are not available. Therefore, over time, given the fluctuations in TDS levels, Utah Lake water is poor to unacceptable for drinking water without TDS reduction. Unfortunately, the highest lake TDS concentrations occur during dry cycles when additional sources of drinking water are most needed. Since natural biological residues make Utah Lake waters rather difficult and expensive to treat, the necessary advanced treatment would cost some 2 to 3 times more than for conventionally-treated drinking water. The Jordan Valley Water Conservancy District estimates that costs for the most promising advanced treatment for salt removal (reverse osmosis) would be about the same as costs for both developing and treating other low TDS water sources using conventional treatment plants. Someday, if a dramatic need for additional drinking water arises; large-scale treatment of Utah Lake water might become economically competitive. But for the time being, the cost of advanced treatment is too high for lake water to be used as a significant source of drinking water. In the future, it is likely that we will see additional use for drinking water of inflowing higher quality water, particularly groundwater, both along the lake shoreline and along lands adjacent to the Jordan River. This approach could develop a large amount of groundwater that could be used directly for municipal use with relatively low treatment costs. The needed water rights purchases or swaps are sometimes difficult, but using the high quality water seems to be a rational and economical way to obtain additional culinary water.

Why is Utah Lake so dirty, muddy, and sometimes stinky? Utah Lake is naturally “dirty” primarily due to the formation of mineral particles (precipitates) from dissolved salts in the lake water itself; coupled with the re-suspension of flocculent bottom sediments by frequent, rather high waves on this shallow lake. The result is a milky gray-brown to a milky gray-brown-green color of the lake much of the time. The natural precipitates include a variety of mineral complexes, comprised mainly of calcium and carbonate (carbonate converts from bi-carbonate in the lakes high pH water) mingled with lesser amounts of other minerals including considerable silica and phosphorus. Although eroded upland soils carried by larger tributaries are often the dominant sediments at their mouths, overall these tributary sediments contribute only a small percentage of the total lake sediments. Thus, bottom sediments are largely precipitated minerals combined with relatively small amounts of eroded soil sediments and even smaller amounts of aquatic plant and animal detritus.

The lake salt balance (see Table 1) shows that about 65% of inflowing calcium and 55% of inflowing bicarbonate precipitate. On average this is nearly 100,000 tons of precipitates per year—spread over the total lake area, this is about 2 inches of bottom sediment buildup every 100 years. The remaining dissolved salts are carried down the Jordan River. The deeper lake areas actually fill in with sediments more rapidly than do shallow areas. This due to both more total precipitates from the larger volume of overlaying water and migration of sediments from near-shore shallows where wave agitation re-suspends the flocculent sediments almost continuously—over time re-suspended sediments migrate to deeper waters, resulting in accretion rates in the main lake of some 3 to 4 inches per 100 years.

Based largely on incidental mention of clear lake water in early writings, some people maintain that the lake must have been clear and sparkling when modern settlers arrived in the 1850s. This is very likely not the case. Sediment sonar imaging and sediment cores indicate that the mineral formation and precipitation has always been present. Even today, when viewed from vantage points a few miles away, the lake often appears to be blue and clear due to the reflected blue light from the lake surface, but, in fact, the main lake is almost continuously rather turbid. In pioneer days, most human contact with the lake was with the clear, sparkling rivers, streams, springs, ponds and seepage water along the south, east and north boundaries of the lake. Emergent vegetation was also much more prevalent—the shallow clear water in extensive cattail and rush areas was protected from mixing with the turbid open-lake waters. In addition, no Carp were present to root through the shallows and stir up mud; but the main lake turbidity was very likely just as “muddy” as it is today.

As to noxious odors, Utah Lake is eutrophic—meaning overall biological growth and biomass is very high—growth and decay of the abundant plant and animal life sometimes result in “swampy” conditions. In spite of its very high biological productivity, such conditions are relatively moderate in the lake due to its well-mixed, well-aerated nature. But at times and in some locations anoxic zones develop, bad odors are generated and aesthetics suffer. This natural problem was/is sometimes intensified by human-caused pollution—particularly more than 50 years ago when untreated sewage and industrial wastewaters discharged into the lake.

How polluted Is Utah Lake? Considering the lake’s basin-bottom location and eutrophic nature, its overall water quality is good. However, it is likely that the lake was not, is not, nor can it be, a “clear” lake, largely because of its natural mineral precipitation and its wave-stirred nature, in addition to its high biological turbidity component. Fortunately, the lake has excellent natural capacity for degrading and stabilizing both natural and human-caused pollutants. Its high oxygen levels, along with its naturally high pH, are favorable for removing and stabilizing many pollutants, such as organic debris, and binding and precipitating phosphorus and heavy metals, e.g., mercury and lead. Even during the 45 years or so that Geneva Steel discharged its treated process waters into the lake from the 1940s to 1990s significant water-quality deterioration was not found except occasionally in the immediate vicinity of Geneva’s larger discharges.

For the lake and most of its tributaries, there is a dearth of long-term water quality data. Most available water quality data have been collected rather sporadically over just the past 45 years. The lake is large and has numerous tributaries, most of which are rather small and many are fairly difficult to locate and access. This makes comprehensive tributary measuring and sampling efforts difficult, time-consuming and costly. The lake also has a large groundwater inflow—those waters are inherently difficult to identify, quantify or sample. Nevertheless, a few lake hydrological and water quality studies have been completed. These studies indicate that overall lake water quality has changed very little over the last 60 years and in some parameters it has significantly improved—remember that prior to about 1955 most sewage, storm runoff and industrial wastes received little, if any, retention or treatment before being dumped into the lake.

However, constant vigilance is required to avoid future serious pollution problems. Since the lake is downstream of many human activities in Utah Valley, too often tributaries are illegally used as "convenient" dumps for garbage and trash that sometimes contain rather nasty polluting materials, some of which are carried into the lake Although many polluting discharges have been cleaned up via better treatment and management, we shouldn't erroneously believe that we have solved all of the lake's pollution problems—from time-to-time illegal dumping or emerging pollution issues arise. For example, in 2007 State agencies conducted surveillance testing of Utah Lake fish and found violations of allowable Polychlorinated Biphenyl (PCB) levels in some fish species—notably bottom-feeding species, carp and channel catfish. Subsequently they issued a health advisory containing recommended consumption limits on these species.

In 2008, an intensive survey by the State of water and bottom sediments at the mouth of main tributaries and below wastewater effluent discharges failed to locate any current or recent PCB sources—the PCBs initially detected are probably a long-term carryover in bottom sediments from spillage or illegal dumping many years ago when the long life and polluting impacts of PCBs were not generally recognized. Given the extremely low levels of PCBs that triggered the health advisory, it might be argued that risk of injury or death is far greater in driving to the lake than in eating fish caught there. However, the important point is not this particular pollutant or advisory, but rather the point that prevention and elimination of pollution whenever feasible is a wise policy, particularly the control of pollutants at their "throw-away" point of origin. For most exotic pollutants of concern around the world today, cleanup and restoration are often monumentally more costly than initial costs for proper waste disposal and pollution prevention.

Are algae in Utah Lake harmful? Algae are natural plants and a vital part (base) of aquatic food chains; they might be thought of as analogous to grass in aquatic ecosystems but sometimes excessive algal growth occurs. These algal "blooms" sometimes cause water quality and habitat quality problems similar to problems caused by tangles of plants and weeds on land. When blooms die away and decompose there is a threat of dissolved oxygen depletion. Utah Lake is naturally very productive—algae grow abundantly in the lake. Some algae found naturally in the lake, particularly during late summer or early fall, are cyanobacteria (blue-greens) that sometimes become temporarily dominate and are particularly troublesome and even poisonous at times. The toxins from decaying blue-green algae sometimes reach levels that harm, or even kill, other organisms. In rare cases, these toxins even kill large animals if they drink enough water containing elevated toxin concentrations. These toxins degrade naturally and are usually largely dissipated within a few days.

A good indicator of historic water quality in a lake comes from identifying types and numbers of tiny diatom algae (their shells) deposited in the layered bottom sediments laid down over the years. Studies of sediment cores from Utah Lake indicate that types and relative amounts of diatom algae have not changed significantly over the last few thousand years. Since algae types and relative numbers are rather sensitive to changes in water quality and other aquatic conditions, consistency in types and amounts of diatom algae is strong evidence that environmental and water quality factors have been relatively constant in Utah Lake for at least a few thousand years.

Should phosphorus (and nitrogen) removal be a high priority for Utah Lake? **No**!

Note: Atmospheric P & N deposition studies were started in late 2016. We thought this source was significant but we were startled to find how large it is—much larger than expected with atmospheric phosphorus being about 600% larger than all other sources combined. And atmospheric nitrogen about 50% as large as all other sources —thus atmospheric phosphorus completely dominates lake loading sources. Final results will not be available until late Spring, 2018, but the preliminary results are so important they are incorporated here.

In a dramatic way, the huge phosphorus loading coming from the atmospheric "dust" reinforces and adds to earlier findings—I.e., Utah Lake receives extreme amounts of phosphorus as compared to amounts used by the algae that grow in the lake. Earlier the amount was thought to be about 20 times more than algae need; with the addition of the atmospheric P it increases to about 100 times.

Here are the phosphorus loading quantities:

		% of total	
Atmospheric deposition:	~1600 ton/yr	85.5	(Estimate. based on May-Sept 2017 data)
Wastewater Treat. Plants:	215 ton/yr	11.5	(from 2009-2013 study)
All other sources:	55 ton/yr	2.9	(from 2009-2013 study)
Total:	1870		
Amt. for eutrophic loading:	17 ton/yr	0.9	(less than 1/100 of the loading)
Amt. out in the Jordan R.	~27 ton/yr	1.4	(meaning ~98.6 % precipitates as sediment)

The EPA Larsen-Mercier model indicates that only about 17 ton/yr is needed to give a 40 µg/l eutrophic loading to the Lake (the combined 1870 ton/yr loading gives about 4400 µg/l which is over 100 times more than needed by the algae growing in the lake). Since only about 27 ton/yr (50 µg/l) flows out the Jordan River, the lake retains a remarkable 98.6% of its phosphorus loading. As to the phosphorus, solubility equilibria reactions are at work and precipitate phosphorus concentrations down to moderate levels (typically 40–60 µg/l), regardless of the amounts entering the lake. This mineral co-precipitation of phosphorus with calcium, carbonate, silicate and other trace minerals precipitates most of the phosphorus to the bottom where it is a harmless residue that is largely unavailable to algae. Relative to algae needs, phosphorus precipitated each year would be sufficient to provide enough for about 110 years of algae growth. Thus the lake sediments are essentially an infinite sink**—removing any amount of phosphorus put into the lake above about 30 ton/yr!**

However, closer scrutiny of the lake's chemical characteristics and algae-growth dynamics indicates that even this huge phosphorus loading is a **moot poin**t since Utah Lake algal growth appears to be largely controlled not by nutrients but by light limitation resulting from the lake's natural turbidity. The loading to the lake would need to be reduced to less than 17 ton.yr (40 µg/l) to begin to make phosphorus limiting to algae growth. Obviously, this amount of reduction is an impossibility for Utah Lake—the corollary: any money spent on nutrient removal for Utah Lake is a complete waste!

Utah Lake is thus much different than clear lakes, where such high phosphorus loadings would usually cause persistent massive algal blooms with resulting serious water quality problems and ecosystem deterioration. Occasionally in Utah Lake, usually in the late summer and fall, calm weather conditions result in clearer water lasting more than a few days. Algae growth quickens with the increased light availability and sufficient nitrogen and phosphorus are initially available to support heavy algal blooms. If a series of blooms occur, nutrients are temporarily depleted in the water column, usually nitrogen first. This condition favors less desirable blue-green algae (these cyanobacteria can use dissolved nitrogen gas as their nitrogen source). Such blooms have long occurred naturally in Utah Lake and will continue in the future. Fortunately, in Utah Lake conditions are such that heavy blue-green blooms are rather rare, typically short-lived and limited in extent. Also, cyanobacteria species most common in Utah Lake tend to generate relatively small amounts of toxins.

With respect to nutrient levels in the Jordan River, even extreme reductions in phosphorus loadings to Utah Lake would not result in significant reductions in levels in the Jordan River since, again, residual concentrations are largely a function of lake chemical equilibria reactions between the precipitated minerals and concentrations in the water, and are not determined by the amount of phosphorus coming into the lake. As a result of this lake chemistry, phosphorus levels tend to average 50–60 µg/l in lake water year after year as it flows out in the Jordan River—concentrations would have to be reduced to 10–20 µg/l to begin to become significantly limiting to algae growth in the river. The natural lake chemistry makes it impossible to achieve phosphorus concentrations that low in the river.. However, in the Jordan River as in the lake, it is highly probable that water turbidity, not nutrients, is limiting algae growth in the River..

Another interesting point regarding nutrients is that many lakes in Utah experience nutrient loading ratios less than N/P of about 10—Utah Lake is extremely low at less than 2, but this is due to the fact that the huge atmospheric component has about equal amounts of N & P, whereas the ratio in most surface waters is near 10. This implies that if nutrients are limiting then nitrogen is likely more so than phosphorus. Some 70 years ago, early scientific research on nutrient loadings and lake productivity was largely done in areas of the world where phosphorus was the more limiting nutrient to overall algal growth. Thus phosphorus concerns dominated early scientific studies, the literature, and subsequent nutrient-control efforts. Later it became evident that many lakes, particularly in many alpine and arid areas, are nitrogen-limited. In nutrient-control programs, even when nitrogen seems more limiting, phosphorus reduction is often the only viable option.

One major factor in this regard is that “nasty” blue-green algae tend to be a larger problem in nitrogen-limited lakes when nutrients are limiting, since they can use gaseous nitrogen dissolved in the water. Reduction of nitrogen loadings may exacerbate this blue-green problem by stimulating even more growth of the blue-green algae as low ionic nitrogen more quickly becomes limiting to the growth of other algae.

In summary, in Utah Lake algae blooms are natural in the lake’s ecosystem. The current huge nutrient loading to the lake is a moot issue as to its overall water quality, since natural turbidity appears to cause light limitation that moderates the amount of algae that grows. The concentrations of phosphorus available in the water column are determined largely from chemical solubility reactions with precipitated particulates/bottom sediments and not on the amount of phosphorus coming into the lake, but even then ambient concentrations would probably trigger much more algae growth if the growth were not light-limited. The occurrence of more troublesome, sometimes toxic, blue-green algae is associated with a temporary shortage of ionic nitrogen—since blue-green algae can get needed nitrogen from dissolved air, they out-grow other algae, sometimes resulting in a blue-green bloom that, upon die-away, may cause poisonous/toxic conditions for a short time. In Utah Lake, these toxins rarely build up to serious levels In the open lake water

Would Utah Lake be clearer if it were dredged deeper? Very likely not! If deeper, the lake would experience less wave-stirred sediment turbidity and thus be clearer during early spring and late fall. However increased biological turbidity from more algae growth during spring into the fall would likely counter the decrease in sediment turbidity. This situation could often result in a "pea soup" of algal growth during much of summer and early fall. This would likely cause a major deterioration in lake quality and habitat—the most damaging effect would be increased episodes of oxygen loss during the decay phase of algal blooms. Stresses on aquatic life, high turbidity, and bad odors are some of the common problems accompanying the growth die away and decay of algae blooms.

Incidentally, beneath the lake's winter ice, clear water is often found since the flocculent sediments have settled to the bottom. Light limitation, caused by the ice-snow cover, and low water temperatures combine to limit winter algae growth to low levels. However, in early spring, after the ice breaks up, algae growth accelerates from warmer temperatures and more sunlight, waves stir up bottom sediments and turbid conditions return.

What Lake depth would likely trigger the problems mentioned above? Water depths of about 15 feet or deeper would likely result in considerable summer thermal stratification where a warmer surface layer overlies deeper, colder water. This condition inhibits vertical mixing in the water column and thus limits oxygen transfer from the atmosphere to the bottom layers. Often aesthetics, water quality and habitat seriously deteriorate when persistent stratification occurs, particularly in eutrophic lakes. In Utah Lake, significant stratification is rare and short-lived. However, significant summer stratification would likely occur if the water were deeper than about 15 feet. Currently, the lake does not experience persistent summer stratification—i.e., it is shallower than 15 feet and wave action keeps it well mixed; thus it largely avoids the oxygen-depletion problems that plague many deeper lakes.

More on stratification. *(skip to next section if not interested)* In this climatic region, when clear, ponded water is deeper than about 20 feet, summer thermal stratification is common and often persistent from late spring through summer —the top 10 to 15 feet of surface water does not mix with bottom waters for weeks or even months. During such stratification, ongoing natural decay of accumulated organic debris at the bottom often results in loss of oxygen—First at the bottom and then upward in the overlying water. Under these conditions the anoxic water at the bottom is stagnant and septic. Septic conditions stress or kill normal aquatic organisms and will also kill fish if they can't locate refuge areas still containing oxygen; such refuge areas are the shallows or near the surface or in areas of inflowing streams or springs.

In turbid lakes, thermal stratification can occur in a little shallower water; since turbid waters absorb more sunlight energy (heat) nearer the surface—so persistent summer thermal stratification can occur in turbid lakes in areas as shallow as 15 feet or so. Therefore in Utah Lake if any large area were dredged to depths of about 15 feet or deeper, persistent summer stratification would likely occur at times and trigger water quality and habitat problems that were previously rare in the lake. Note that waves 2 or 3 feet high impart significant stirring energy down to a depth of about 12 to 13 feet. So when such waves occur, as they normally do at least each week or two on Utah Lake, stratification breaks up as waves mix the water.

Under ice cover, water stratification can occur even in very shallow areas. Again, low oxygen occurs when microbes that decompose organic debris deplete the oxygen. Typically, the worst winter oxygen loss occurs in ice-covered shallow areas that are heavily loaded with organic debris and that have little water circulation or local inflows. Under these conditions winterkill of fish and other aquatic organisms often occurs. This problem may sometimes occur to a limited extent in some of the more stagnant bays and inlets of Utah Lake. It is generally not a problem in the main lake, since (1) organic debris from summer growth largely degrades during fall months before ice cover develops, and (2) in addition to numerous surface inflows, many small springs issuing from the lake's bed contain oxygen and also foster local circulation.

What maximum dredged depth might be acceptable in Utah Lake? About 16 feet. To avoid summer lake stratification and its attendant problems, most of the lake needs to be shallower than about 13 feet from early summer into the fall. Initial depths of about 16 feet in deeper parts in the late spring would, after normal early summer drawdown, result in depths shallower than 13 feet into the summer and fall. When full, the deepest parts of Utah Lake are currently 13 to 14 feet deep; the lake averages about 9 feet deep. Its average depth (and water volume) could be increased some 50 percent if most of the lake were dredged 16 to 17 feet deep. If only a relatively small area were dredged deeper than surrounding areas, the dredged area would still be turbid since its water would continue to experience mineral precipitation. Even, more importantly, water circulating from other areas would carry suspended particles to the dredged area and dredged areas would tend to fill back in rapidly since its relatively quiescent bottom water would foster a more stable bottom accumulation of settled sediments. In addition, large scale dredging is likely not feasible for a variety of ecological, engineering, and economic reasons. For example, dredged bottom sediments are clayey—when exposed to the air to dry, they shrink, crack, and become very hard, but when wet they swell and become mucky.

The massive amount of dredged muck would be major disposal challenge. If the entire lake were dredged an average of just two feet deeper, the dredged material could cover an area 5 x 5 miles if 10 feet deep. But proactively, this material could be used to construct islands with total area of perhaps 7 square miles—built with about 35 ft of initial fill that would likely settle to about 25 ft above the lake bottom, giving about 10 feet above water level when the lake is full.

In summary on dredging, if areas of the lake were deeper than about 16 feet, lake water would be clearer in the spring; followed by increased algal growth during the late spring and summer—because of more light availability due to decreased turbidity. These algae blooms would likely cause some oxygen depletion problems and bad odor events during die-off. Some of these areas would hover back and forth as latent biologically-dead zones along the bottom.

How about constructing islands in Utah Lake? Construction of wildlife-reserve, residential and recreational islands in the lake, perhaps with some of them linked together by causeways or bridges, is appealing to some people. Sale of some of the constructed islands for residential and commercial use could provide hundreds of millions of dollars to fund the island-building projects and perhaps other lake development, recreational, and environmental-enhancement projects. One or more islands reserved as wildlife refuges with no, or limited, recreation use would be great wildlife (and ecological) assets—rubble and rock shoreline banks could be used to enhance fisheries; the open land could host numerous plants and animals. Lake-bottom sediments could be used for most of the needed fill material; top soils would need to be added for vigorous growth of grass, trees and other vegetation. Initial fill would need to be some 25 to 30 ft above the lake bottom, to order to give adequately-settled bottom sediments and fill materials with resulting ground levels at least 10 ft. above full-lake elevation.

How about road causeway(s) or bridge(s) across Utah Lake? Crossings could be built, but numerous, difficult environmental, engineering and financial problems exist. They would be major engineering and construction challenges and very expensive!—likely costing several hundreds of millions of dollars for a single major crossing near the middle of the lake.

Long anticipated suburban growth is continuing on the west side of the lake. Many feel that this growth would accelerate considerably if more direct accesses were available to economic hubs on the east side. Build a road across the lake? Can it be done? Technically, yes. Practically and economically, it would be difficult, since the bed of Utah Lake is a very poor foundation. If a fill causeway were used for a highway, it would need a very wide base (several hundred feet wide) or would need to be placed on driven piles. Both methods would be very expensive; bridges would cost even more. The roadway surface would need to be some 10 feet above the highest lake level to protect it from wave action, and to also protect it from major ice-sheet movement. (Occasionally, in early spring as the ice breaks up, wind-driven ice sheets can stack up 10 to 20 feet high along the shoreline or even move inland for several hundred feet. However, this condition is rare and short-lived—perhaps a few hours every few years).

When loaded with the weight of a fill causeway, the lake bed under the causeway would settle several inches a year for many years. Of course, the settlement rate would decrease over the years as underlying sediments compacted. Uneven settlement would occur in places and result in an undulating road surface; problems of pavement cracking and breakup might be persistent. In addition to these problems, two or three shorter bridges or many very large culverts would be needed along a fill causeway to allow for good water and aquatic biota circulation through the causeway to minimize adverse impacts on the lake's ecosystem and recreational use. Likely the best solution both structurally and environmentally would be a bridge roadway, supported on pilings driven into the lake bottom, perhaps used together with structural floats if the sediments are not sufficiently strong for piles alone to support the bridge. Engineering studies would determine how deep piles would have to be driven into the bottom—perhaps 50 to 100 ft. Also, at perhaps two locations, higher spans would be needed for passage of up to medium-size sail boats—the keels of large sail boats are too deep to operate in this shallow lake.

A generally north-south causeway/bridge across Provo Bay would have less-challenging foundation problems than across the main lake, since bottom layers there contain more stable soils, particularly more sand and gravel layers, than under the main lake. However, if a dike causeway were also used to control water levels in Provo Bay at levels much different than the main lake, the project would need a large hydraulic and pumping station(s) component—flood bypass channels would have to be built for Hobble Creek and perhaps other tributaries. Pumping stations large enough to pump flood-year water over the dike would be very costly.

Why are trout no longer abundant in Utah Lake? Bonneville Cutthroat trout were abundant in pioneer times and fairly common in Utah Lake until about 1900. This Cutthroat was a large fish, with many weighing more than 10 lbs. Over-fishing, competition from introduced fish species, and interferences with stream spawning and migration cycles caused by dams and water diversions for irrigation, resulted in low trout numbers after about 1900. Intensified stresses hit the greatly reduced trout population during the 1930s drought when fish struggled to survive in extremely low levels of warmer and warmer water in both the lake and its tributaries. These combined stress factors eliminated the Bonneville Cutthroat from the lake by the 1940s.

Similar factors continue to challenge other remaining native species in the lake, notably the endangered June Sucker.

Re-establishment of large numbers of trout in Utah Lake is unlikely—it would require major changes in other fish species now there and probably a major hatchery-based stocking program to maintain good populations. Remember, however, that the lake has very large populations of other fish in this prolific warm-water fishery. Overall, Utah Lake's fishery is greatly underused. Two of its species, Carp and Catfish, are under a limited-consumption advisory due to possible PCB accumulation in some fish, but most knowledgeable people have no concerns in eating these fish unless they are a very frequent and substantial part of one's diet.

June Suckers are currently listed as an endangered species under the Federal Endangered Species Act, therefore continuing efforts to protect and restore them are major driving factors in lake management. As part of restoration plans, projects have been underway for several years to greatly reduce the lake's Carp population. The huge Carp population is felt to be a major stressor and disruptor in the lake's ecosystem. They have devastated much of the natural, rooted aquatic vegetation and in several ways contributed to significant degradation of the aquatic ecosystem, particularly in the lake's shallows, inlets, and bays. In 2012, the lake contained an estimated 6 to 8 million adult Carp. Even after the removal of several million Carp over the last several years, they are still by far the dominant fish in the lake. The most feasible carp-control plan appears to be a continuing, targeted net harvesting for several years to greatly reduce carp numbers that will hopefully bring them into better balance with the rest of the ecosystem. The long term effectiveness of this harvesting is debatable but it currently seems to be making favorable headway. A large reduction in Carp will likely not result in discernable changes in water quality but should result in other improvements in the lake's ecosystem, particularly in shallow bay and near-shore areas, resulting mainly from re-establishment of native aquatic vegetation—many otherwise favorable habitat areas have been largely devoid of native aquatic vegetation for many years due to the Carp's feeding habits that destroy vegetation.

Some experts and many other observers question the long term wisdom and economic feasibility of efforts to re-balance species and altered ecosystems. Questions as to our ability to actually accomplish the hoped-for results, the value of these results, and large costs often associated with trying to achieve restoration-preservation goals, give rise to serious value and cost/benefit issues. This is the case for Utah Lake where many people feel these issues should be more openly and critically debated and considered before additional tens of millions of dollars are spend on attempts to restore this endangered species. Sometimes ongoing external funding and local vesting in the effort combine to push detractors into a "politically incorrect" corner from where they find it difficult to raise feasibility and cost issues, or to generate balanced, serious discussion on them. Hopefully all sides will strive for opportunities to discuss and debate these and similar issues without extraneous intimidation.

The invasive plant—Phragmites. A non-native, invasive water plant, Phragmites, has become a huge problem in Utah Lake. Over the last 20 years, or so, since it was first introduced into the lake by an unknown carrier, it has spread throughout most of the lake's shallows. Phragmites is a tall reed plant that chokes out other aquatic plant life and its debris fills in shallows rather rapidly, thus damaging and reducing aquatic habitat. This exotic plant grows prolifically in shallows along the shoreline and even on adjacent wet flats. When uncontrolled, it crowds out nearly all other aquatic plants and forms an almost impenetrable mass of growth and does great damage to a lake ecosystem. Initially, it grew mainly in the Saratoga area (NW corner) of the lake but it is now found essentially around the entire lake. Trial efforts have been underway for several years to develop control techniques and plans; elimination is very difficult and unlikely. Utah County Weed Control personnel have energetically attacked Phragmites the past several years and are adapting control methodologies that promise success, but they need adequate resources to continue control programs in a rigorous and persistent manner year after year or else Phragmites will become entrenched as a major disaster to the lake's natural ecosystem.

Why not fill in or dike off much of Utah Lake and use reclaimed lands for agriculture, land developments and additional wildlife habitat? At this point in our national experience, most lake and marshland areas are considered too valuable to allow further significant encroachment or destruction; therefore, current environmental laws and requirements make it very difficult to dike or fill shoreline and wetland areas. Though very unlikely, if at some point diking and dewatering were to be done to reclaim land, only the Provo Bay area has bottom sediments (soils) somewhat suitable for farming, but Provo Bay is also one of the most important wildlife areas and mitigation would be very difficult. The rest of the lake has clayey, Marl sediments that are not suitable for farming or most other developments.

Major environmental issues would arise with dewatering projects of this type. Given current environmental requirements, stabilized water levels would be needed to support the large replacement marsh and wetland areas. Therefore, the net outcome would likely be little, if any, additional lands for farming or development, as well as little, if any, water savings from reduced evaporation. Also, diked areas might suffer up to several feet of flooding for a few months about every 30 years or so during the peak of wet cycles since the cost of dikes high enough to isolate diked areas from high lake levels, along with the cost of standby pumping or bypass channels for tributaries to keep the diked area water levels low, would likely prove to be prohibitive.

Why aren't there more boat launch and recreation areas at Utah Lake? Lake levels over the years are rather variable and unpredictable. Around much of the lake, particularly along north, east and south boundaries, the lakebed slope is rather flat—only about 1 to 3 ft per 1000 ft out into the lake. Consequently, along much of the shoreline, continual boat access to open water is a major problem without dredged access channels and harbors since the water's edge moves large distances with relatively small depth changes.

Therefore, facilities positioned at normal high-water, lake-edge locations must dredge channels some distance out into the lake for boat access during dry cycles. Conversely, during wet cycles, they are confronted with water several feet higher than desired. These depth fluctuations are a major obstacle to boat use on the lake; particularly for larger motorboats and sailboats. The main lake provides only about 10 ft of reliable depth when the lake is "full" but during drought periods depths are often much shallower. E.g., during the last 50 years about 20 summers experienced depths less than 8 ft in the middle of the lake, and for 10 summers depths were less than 6 ft. In the future, environmental and ecological needs, water storage rights, and ongoing wet and dry meteorological cycles will likely result in depth fluctuations about the same as in the historic past. These fluctuations will continue to pose serious lake access and flooding challenges to most shoreline facilities.

Are major ecosystem improvements feasible in Utah Lake? This issue is extremely complex and controversial! Major ecosystem restorations and significant improvements are difficult to formulate, rare and expensive—both in direct project costs and lost opportunity costs for competing uses. Many of the pressures on disrupted bird and animal populations come from factors other than water quality and in-lake habitat. For example, restoration of the endangered June Sucker depends more on additional favorable spawning and brood areas in the streams and rivers and reduced competition from other fish, than on pollution reduction or improved water quality.

Shoreline vegetation and habitat may benefit from current projects of the Central Utah Project, which significantly reduce the frequency and magnitude of extreme high and low lake levels. These reductions in depth extremes are important in re-establishing shallow water vegetation, such as cattails and bull-rushes; hopefully future scientific studies will help clarify this important aspect of habitat improvement. Control of the pest plant Phragmites is also a crucial factor in this recovery.

With reasonable attention to ecosystem preservation and enhancement, Utah Lake can continue to support very rich and diverse plant and animal communities. Some enhancing habitat and water quality changes are possible. Some people hope that by making as many unidentified "improvements" as possible the lake might morph into a clear water state (low mineral precipitation). This is very unlikely for many reasons, especially the alkaline, calcium-rich water in its major tributaries. It is difficult to imagine a large-enough water chemistry change to significantly reduce the large mineral precipitation that gives the lake its turbid nature. Appropriate emphasis on preserving and enhancing its ecology does not preclude additional development. True environmental sensitivity, not just popular, politically-correct actions of the day, will always be crucial in any development projects affecting the lake
.

What will Utah Lake water quality be like in the future? Utah Lake water quality is not likely to change significantly in the foreseeable future assuming that wastewater treatment, agricultural pollution control, and other pollution control efforts are continued near current levels. A Total Maximum Daily Load (TMDL) water quality study, begun by the State of Utah in 2005 is still open. This study's purpose is determining whether additional pollution control is needed to protect lake beneficial uses, including recreation and wildlife. The TMDL study was initiated because of occasional violations of phosphorus and TDS guidelines in the water quality classifications assigned to the lake. It is unlikely that significant new pollution control restrictions or requirements will result from the TMDL study since the first phase of the study did not identify any significant problems associated with occasional exceedances of current TDS and phosphorus "limits". As discussed earlier, hopefully there will be an awakening as to the futility of trying to improve the lake's water quality and ecosystem via nutrient reductions since the probability is extremely high that it would not result in significant improvements.

Regardless, Utah Lake will neither be clear, nor deep, nor bordered by expansive clean, sandy beaches—although some sandy beaches exist and might be expanded. Utah Lake will continue to be a shallow, eutrophic, turbid, slightly-saline lake that is largely bordered by marshy, and muddy, wetland areas. Hopefully we all recognize that in addition to economic uses, it is an extremely valuable ecological and recreational resource. Lake level fluctuations, wetland protection laws, threatened native species and possible environmental impacts will combine to limit shoreline developments. Causeways, bridges, and additional dikes will likely be built in the lake sometime; perhaps even some islands will be constructed. Near-shore development conditions are less restrictive on the west side than on the east side, since on the west side the shoreline is steeper, more stable and fewer wetlands exist there. Some east side zones also exist where development conditions are somewhat favorable, including manageable wetland issues.

Do we need more research on Utah Lake? Yes! We stand to benefit greatly from more data, information and understanding than is currently available. However, good, productive research is an ongoing process; hopefully one without repeated major starts and stops, and especially one without scattered short-term efforts with long inactive periods in between—it requires extended and dedicated effort to become knowledgeable on Utah Lake's unique nature and characteristics. Realistically, resources are simply not available to fund ongoing, long-term, intensive research activities on large numbers of lakes and rivers. But Utah Lake is indeed a special case, where developments, projects and decisions will address actions involving hundreds of millions, or even billions, of dollars in coming decades as population growth continues.

I passionately believe that information and knowledge gained from a significant, ongoing Utah Lake research program would result in savings far in excess of their costs! Establishment of a permanent lake research station is a wise, much-needed, course of action.

Lake Management Planning and Lake-use oversight. The Utah Lake Commission, established in 2007, is the recognized, authorized, representative body that was organized to give long term uniformity and continuity in addressing Utah Lake planning and use issues. The Commission is pivotal in generating wise consensus on lake use and management issues and in seeking funds for important studies. The Commission's initial lake master plan was formally signed on June 26, 2009. This Plan, with periodic updates, is extremely valuable in setting priorities and giving direction on lake issues. Although the Commission is only a coordinating body, it has broad support and representation from most cities and agencies in the area, including local, County, State and Federal management and regulatory entities.

Background Notes:

Perspectives on water quality. Various perspectives exist as to the meaning of "water quality." As a result, confusion often results from differing perceptions as to what constitutes good or bad water quality. An understanding of the way government views water quality is important in any discussion on water quality:

Briefly: water quality and pollution as used in water quality management and enforcement are based on a waters designated **classification and associated beneficial uses**—these are established by states via professional staff evaluation and analysis, and adopted after review publication and public hearings. Officially then, water quality and pollution are defined relative to whether quality parameters for a particular classification are being violated, and if so, how often, how persistent, etc.

This approach means that water quality it not measured as compared to an absolute good or bad reference level but rather quality is judged relative the assigned classification and quality levels established for its associated beneficial uses. E.g., suppose a water source is designated as drinking water, but pollution-indicator bacteria persistently show up in samples. The water would then be considered polluted and of poor quality as a drinking water even though it may be of excellent quality for most other beneficial uses. Likewise, a water might be of good quality for a warm water fishery but unacceptable for most other uses.

In addition to this beneficial-use orientation in defining water quality, there are also non-degradation clauses in water quality laws to help prevent significant additional pollution—these clauses are aimed at preventing water quality deterioration when the existing quality is currently better than required by designated beneficial uses.

Official designated beneficial uses for Utah Lake:

Beneficial Use Designation	Use Description
2B	Protected for secondary contact recreation such as boating, wading, or similar uses.
3B	Protected for warm water species of game fish, including the necessary aquatic organisms in their food chain.
3D	Protected for other aquatic wildlife.
4	Protected for agricultural uses including irrigation of crops and stock watering.

See the state code for more details, water classifications, and associated water quality and pollution parameters.

Total Dissolved Solids (TDS). TDS is a general classifying parameter giving the weight of the total dissolved ions (salts)—in addition to having specific limits for some beneficial uses. Typically, TDS levels increase as one considers alpine lakes (typically 50-100 mg/l) to mountain streams, rivers, and lakes (100-400 mg/l) to lowland rivers and lakes (400-2000 mg/l) to oceans (30,000-40,000 mg/l) to salt lakes (200,000-400,000 mg/l). TDS limits or guidelines are typically 1000 mg/l for drinking water, 1200-1500 mg/l for irrigation, and 2000-2500 mg/l for livestock watering. A healthy person could survive on water containing as much as 10,000-15,000 mg/l TDS although it might taste rather nasty—At about these levels that the human body needs more water to flush out the consumed salts than is being drunk and dehydration ensues—drinking only water more salty than 15,000 mg/l leads to serious health problems or death.

The current Utah TDS standard for irrigation water is 1200 mg/l. The types of crops and irrigation practices determine TDS levels in irrigation water at which crop damage becomes a significant problem. For the crops and irrigation practices commonly used in Utah, TDS begins to cause noticeable crop damage when TDS is above about 1500 mg/l.

Phosphorus. Phosphorus is a necessary nutrient for plant growth and a major part of most fertilizers. In aquatic systems, excessive phosphorus becomes a problem when it over-stimulates algae and other plants to such heavy growth (blooms) that significant water quality and habitat problems result. In the Utah Water Quality Code, "pollution-indicator" threshold values for phosphorus are 0.050 mg/l (50 µg/l) in flowing waters and 0.025 mg/l in ponded water. However, concentrations higher than these are found naturally in many of Utah's waters; particularly in valley-basin areas when upstream drainage-basin geology is rich in phosphorus, as is the case for some of the Utah Lake drainage basin. Nutrients are not significantly removed by most conventional wastewater treatments. Modified or advanced treatments for high percentages of phosphorus removal are 1 to 3+ times the cost of conventional treatment.

Nitrogen. Nitrogen is another necessary nutrient for plant growth and the major ingredient in most fertilizers. The N/P weight ratio in most plants is about 10 to 1. Nitrogen standards as related to possible excessive algal or other plant growth are generally not included in water quality standards since the bioavailability of various nitrogen species in water and interaction with atmospheric nitrogen raise difficult issues on sources, controllability, and reasonable levels that elude structuring it into standards form. Often in lakes when nitrogen or phosphorus availability is actually limiting to algal growth, control of phosphorus is preferred since relatively low nitrogen often encourages growth of nitrogen-fixing cyanobacteria (often referred to as blue-green algae). Cyanobacteria are more troublesome than most other algae, in that they often occur as heavy blooms and sometimes produce enough poisonous toxins to be of serious concern. It is important to note that if nitrogen and phosphorus are not at growth-limiting levels, it means that some other growth factor(s) is controlling the amount grown. Other possible limiting factors are: low light, other trace nutrients, temperature, grazing by zooplankton, toxics, crowding, and rapidity of change in various factors. etc

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His research and public service activities have included many multidisciplinary studies and evaluations concerning Utah Lake. He is the developer of the LKSIM model; this computer-based model simulates the water and salt balances for the Lake. He served as member and then chair of the Provo Metropolitan Water Board for many years. He is a consultant to both public and private entities on Utah Lake matters.

The table and figure on the following two pages are summary results from the LKSIM model that simulates water balances and salt concentrations in Utah Lake.

Table 1: Utah Lake-Avg. water & salt quantities-**1930-2013 Hist. simulation** (83 yr.)

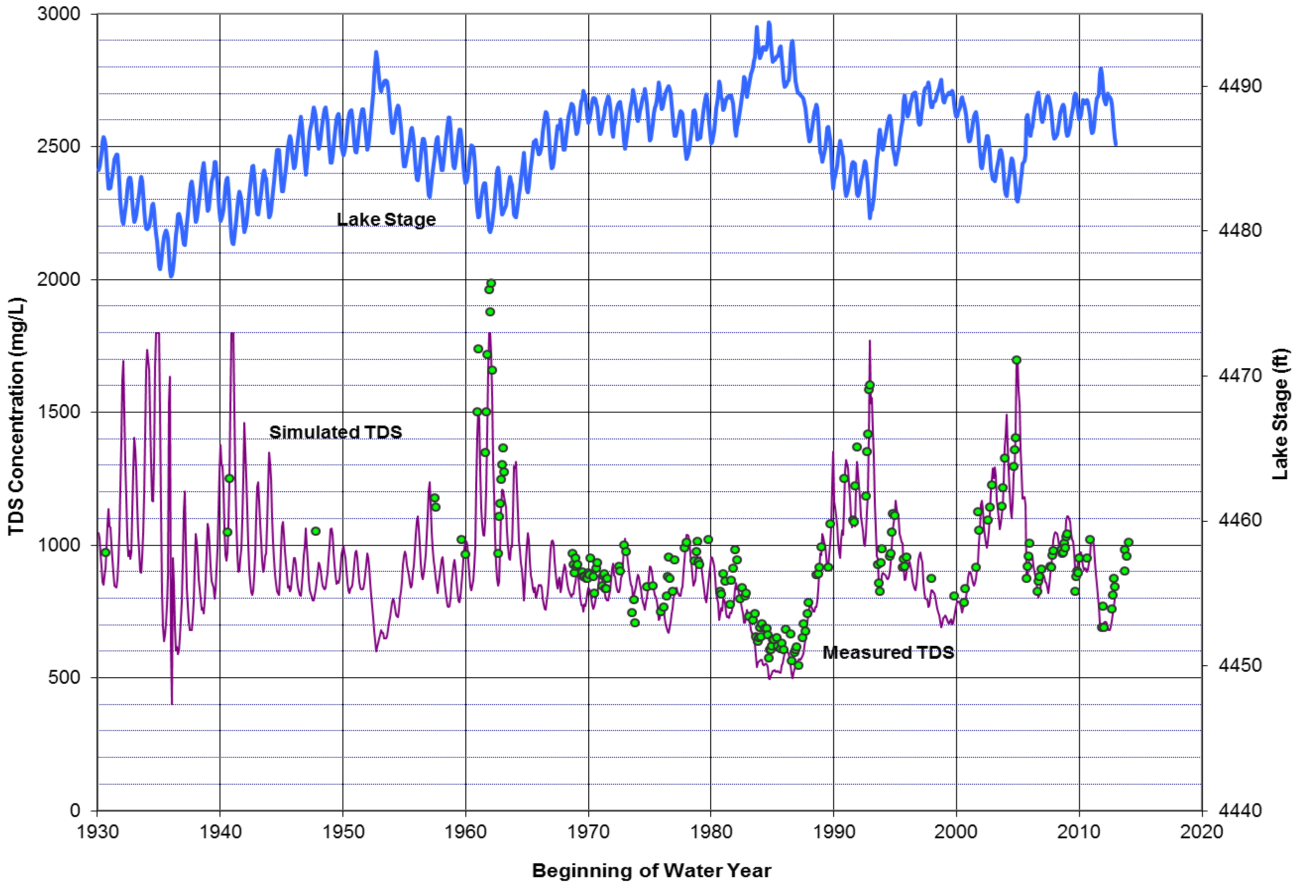
I. **INFLOW**	Flow	Inflow		Salts---Percent of the Total Input							
	af/yr	%[1]	%[2]	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4
1. **Surface Inflow**											
a. Mountain Strms	228385.	42.7	36.3	23.0	10.9	32.9	27.4	12.7	9.8	35.1	20.5
b. Wastewater Trt	27346.	5.1	4.3	4.1	3.6	4.6	3.8	5.5	3.4	5.7	2.9
c. Other—Main Lake	116231.	21.7	18.5	20.8	15.8	20.8	28.2	22.0	11.9	25.6	22.6
d. Other—Provo Bay	62519.	11.7	9.9	10.3	6.3	13.5	12.0	8.4	4.6	12.8	13.2
e. Other—Goshen Bay	6134.	1.1	1.0	5.7	10.6	1.1	3.9	6.6	9.9	1.5	6.0
1. Sub-Total	**440615.**	**82.4**	**70.1**	**63.8**	**47.1**	**73.0**	**75.3**	**55.0**	**39.5**	**80.7**	**65.2**
2. **Fresh Groundwater**											
a. Main Lake	34396.	6.4	5.4								
b. Goshen Bay	33915.	6.3	5.4								
2. Sub-Total	68311.	**12.8**	**10.8**	**9.5**	**8.1**	**10.4**	**12.9**	**11.1**	**7.9**	**11.8**	**9.6**
3. **Thermal/Mineral GW**											
a. Main Lake	24233.	4.5	3.9	26.1	43.8	16.4	11.6	33.2	51.6	7.3	24.6
b. Goshen Bay	1365.	0.3	0.2	0.5	1.0	0.3	0.2	0.6	0.9	0.2	0.7
3. Sub-Total	**25598.**	**4.8**	**4.1**	**26.6**	**44.8**	**16.6**	**11.8**	**33.8**	**52.5**	**7.5**`	**25.3**
1 + 2 + 3 Sub-Total	**534523.**	100.0	84.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
4. **Precipitation**											
a. Main Lake	65358.										
b. Provo Bay	5675.										
c. Goshen Bay	26740.										
4. Sub-Total	**97774.**		**15.5**								
Inflow Total:	**628895.**		100.0								

II. **Outflow**	Flow	%
1. **Jordan River**	**304290.**	**48.0**
2. **Evaporation**		
a. Main Lake	221320.	35.2
b. Provo Bay	16043.	2.5
c. Goshen Bay	88916.	14.1
2. Sub-Total	**326279.**	**52.0**
Outflow Total:	**630579.**	100.0
Lake storage:	-1684.	
Net:	628895.	

	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4
Ratio: Total Salts Out/Salts In (%)	**71.8**	**98.0**	**35.7**	**97.7**	**98.3**	**98.3**	**45.3**	**98.0**

[1]Based on Total w/o precipitation. [2]Based on Total Including precipitation

Table data from LKSIM model simulation of historical conditions in Utah Lake.



Historical Total Dissolved Solids and Water Levels in Utah Lake

Figure 1.