Review of the Potential Effects of the Proposed Great Salt Lake Minerals Project on the Water and Salt Balance of Great Salt Lake, Utah

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As requested by FRIENDS of Great Salt Lake, I have reviewed the U.S. Army Corps Scoping Document (October, 2009). The review should be considered as a preliminary assessment. The calculations have not had rigorous technical scrutiny and are subject to revision. The review is based on data that can be interpreted differently using other technical approaches. Most of the data utilized in this review come from the State of Utah water-quality monitoring program, illustrations in the Scoping Document, and the U.S. Geological Survey data base and published reports.

The purpose of the requested review was to evaluate the potential effects of the proposed Great Salt Lake Minerals (GLSM) project on the water and salt balance of Great Salt Lake. Of particular concern is the effect of the proposed pond expansion on evaporation and associated lake elevations and the salinity balance between the north and south parts of the lake. According to the U.S. Army Corps of Engineers Scoping Document (October, 2009), GSLM proposes a 91,000 acre pond expansion to its operations to produce potassium sulfate, commonly known as SOP, a fertilizer. Associated with the pond expansion is an application for permit to withdraw an additional 353,000 acre-feet of brine for consumptive use.

Recent data (1999-2008) pertaining to Great Salt Lake water and salt balance were important for evaluating the proposed GSLM project because the effects of the project may be more pronounced at the lower lake elevations that have occurred since 1998 (fig.1). Also, the breach in the railroad causeway was deepened during November, 2000, which affects the flow exchange between the north and south parts of the lake. Historical trends in potassium were updated and compared to the estimated inflow of potassium. Suggestions for a thorough evaluation of the proposed GSLM project using a modification of the water and salt balance model presented in WRIR 00-4221 (Loving, Waddell, and Miller, 2000) and the methods and limitations of computations and assumptions used in this review are presented.

1. Recent trends in the water and salt balance between the north and south parts of the lake

Water-quality data collected as part of a monitoring program by the State of Utah were used to update trends in loads of dissolved and precipitated salt, potassium, and magnesium for 1999-2009. The trends of dissolved and precipitated loads of salt for 1963-98 and for loads of potassium and magnesium during 1966-1999 were illustrated and discussed by Loving, Waddell, and Miller (2000, figs.7 and 10).

During 1999–2008, the load of dissolved solids in the north part of Great Salt Lake decreased from about 3 to 1.9 billion tons, about 0.8 billion tons of sodium chloride precipitated in the north part of the lake (fig. 2), and the load of dissolved solids in the south part of the lake increased from about 1.4 to 1.7 billion tons. The large amount of precipitation of sodium chloride in the north part occurred primarily because the total dissolved solids was at or near saturation concentration with respect to sodium chloride (fig. 3) (about 355 grams per liter) as the lake altitude decreased about 10 feet (fig. 1).

During 2000-2009, the loads of potassium in the south part of the lake increased while the load in the north part (2000-2008) decreased by about the same amount of the increase in the south part (fig. 4). A similar pattern of increases and decreases in the south and north has occurred for magnesium (fig. 5). The time of occurrence of the increases of loads of potassium and magnesium as well as dissolved solids in the south part coincide with the November, 2000, lowering of the altitude of the breach bottom to 4193 ft. As intended, lowering of the altitude of the bottom of breach has enhanced the net movement of salt from the north to south part of lake.

The deeper breach during much of 2000-09 has allowed the altitude of the hydrostatic interface (INT, fig. 6) at the causeway to occur at a shallower depth (fig. 6). When the lake surface has sufficient depth above the breach bottom, the theoretical interface depth is often above the breach bottom and as the water surface approaches or drops below the bottom of breach, the interface drops to greater depth (fig. 6). A higher interface enhances more flow from north to south through the culverts and causeway fill and if above the breach bottom flow can also occur through the breach.

As shown in figure 7, intermittent measurements indicate there was no flow from north to south through the breach after 2003. Also, in 2009, when the lake altitudes ranged between about 4194 ft and 4196 ft at the Boat Harbor Gage, continuous monitoring of the breach flows by the USGS also indicated there was little or no flow from north to south through the breach.

Exchange of flows did occur through the east and west culverts during 2000-09 (fig. 8) and according to data presented in WRIR 00-4221 (2000, appendix C) exchange should have also occurred through the permeable rock-fill of the causeway. The total flow through both the breach and culverts (fig. 9) indicate a high variability in south to north flow, ranging from 0 to greater than 3,500 cubic feet per second (cfs). The north to south flows ranged mostly between 0 and 1,000 cfs, with one measurement of about 1,700 cfs.

Even though there has been little or no flow from north to south in the breach since 2003, the breach has probably allowed sufficient south to north flow to keep the head difference (HD in fig. 6) relatively small and the hydrostatic interface (INT) higher. According to Loving, Waddell, and Miller (2000, Appendix D), the culverts had ceilings of 4195 and 4198 ft and a bottom elevation of 4172 ft (for the deeper culvert) in 1998 (when free of debris). The culverts have a history of settling and may have settled to greater depths than reported in 1998.

2. Effects of brine extraction and additional evaporation on lake levels and salinity

The proposed GSLM project includes the development of 91,000 acres of additional evaporation ponds (U.S. Army CORPS Scoping Report, October, 2009). The State of Utah provided comments to the proposed project in the Scoping Report and included sections titled “Potential Effects on Great Salt Lake Elevation” and “Potential Effects on the Balance of Salt between the North and South Arms of the Great Salt Lake”. The State of Utah utilized calculations by the Utah Division of Water Resources (DWRe) to evaluate the potential elevation difference effect from the proposed project and a prior model by the USGS (WRIR 00-4221) of the water and salt balance to make the computations pertaining to the salt balance and salinity. These computations are quite pertinent to the concern for the lake elevation and associated effect on salinity of the lake for both the south and north parts.

Computations by the DWRe indicates that above the elevation 4201 ft there is little or no effect from the proposed project but below about 4195 ft there is a very large reduction in lake altitude reaching up to 2.5 ft at an altitude of 4193 ft (fig. 10). The potential reduction in lake altitude could have a profound impact on the salinity balance because the conveyance properties of the causeway (breach, culverts, and permeable rock-fill) are very sensitive to lake altitude, specifically in relation to the respective altitudes of the breach and culvert bottom altitudes of 4193 ft and 4172 ft (approximate depths when free of debris). Loving, Waddell, and Miller (2000, p. 25-27) made numerous model simulations for breach-bottom altitudes ranging from 4175 ft to 4198 ft that demonstrated the effects on the salinity of the north and south parts of the lake.

The effect of a 10 percent increase in evaporation was simulated by the USGS to determine the sensitivity of a water and salt balance model to evaporation (2000, fig. A10). The USGS simulated conditions for 1987-98 and the illustration was modified for this review (fig. 11) to illustrate the accumulative effect of increased evaporation on lake altitude from year-to-year. The actual water-surface altitudes ranged from about 4212 to 4197 ft, as compared to a range of about 4212 to 4190 ft with the simulated increase of evaporation. The decrease of water-surface altitude near the end of this simulated period does not imply that the proposed GSLM project would cause changes this great and is shown only to illustrate the accumulative effect of increased evaporation on lake altitude from year to year.

During much of 1987-98 observed salinities were below saturation (355 g/L) in the north part (fig. 3) and below 150 g/L in the south part. Also, the altitude of the breach bottom ranged from 4198 to 4200 ft or about 5-7 feet higher than during 2000-2009. The lower salinities at the higher water-surface altitudes increased the rate of evaporation from both parts of the lake.

DWRe performed some steady-state simulations with the USGS model to estimate how salinity in the south part would vary for a breach bottom altitude of 4193 ft for both open and closed culverts. For comparative purposes, salinities based on water-quality monitoring were added to the steady-state salinity trends presented by DWRe in the Scoping Document (October, 2009) and shown in figure 12.

When the breach-bottom altitude was lowered to 4193 ft in November, 2000, the percent salinity was about 10 percent at a water-surface altitude of 4201 ft. In November, 2008, the water surface altitude had decreased to 4194 ft and the percent salinity had increased to 17 percent (fig. 12). The simulations shown in figure 12 indicate that, at a water surface altitude of about 4194 ft, the south part salinity to be about 13 percent for fully open culverts and about 7 percent for fully closed culverts. Thus, even with fully open culverts the observed concentration is about 4 percent greater than predicted for steady-state conditions.

Based on the steady-state model simulations it was expected that the initial salinities in November, 2000 would increase after the altitude of the breach bottom was lowered but that it would begin to decrease as the water surface altitude approached 4193 ft. The trends of observed data do show an increase as expected, but are not in agreement with the model data for water-surface altitudes below about 4196 ft. The lack of agreement could mean that the lake is either not at or near a steady state, or that the model is not adequately simulating the conveyance properties of the causeway, or combination of both.

During 2000-2004 the water and salt balance was adjusting for the deepening of the breach in 2000, and for the rapid decline in water-surface altitude (fig. 1). During 2005-2009, however, the water surface fluctuated between about 4194 and 4198 feet, and although not at a steady-state, is probably as close to a steady-state condition as could be expected for Great Salt Lake.

Additional comparison was made between the model generated steady-state data and observed (or measured) loads of salt to see if the model generated data would have some credibility for lower lake levels that might occur with the proposed GSLM project. This comparison was only done for open culverts as the measurements show there has been consistent bi-directional flow during 1999-2008 (fig. 8). To make comparisons of model computed loads with loads computed from observed data required converting the percent salinities shown in figure 12 to loads (see section “Methods and Limitations of Computations”).

Similar to the comparison for percent salinities (fig. 12), the dissolved load observed in the south part began an upward trend and eventually went above the trend line of the model data (fig. 13). In the north part, however, the observed and model data for both the dissolved load and the precipitated load compare favorably with the modeled loads (fig. 14). In about 2005, or 5 years after the breach depth was lowered, the trends of observed loads merge with the model predicted trend.

The effect of the proposed GSLM project on the salt balance due to an increase of evaporation can be estimated from data shown in figures 10 and 14. If the lake altitude were at 4193.5 ft (2004 altitude) without the project, figure 10 indicates that the lake level would be lowered by 2.5 feet or to about 4191 ft with the project. Also, by assuming the observed trend of precipitated salt in the north part will continue to follow the model trend to a lake altitude of 4191 ft (fig. 14), the estimated load of precipitated salt in the north part of lake would be about 2.0 billion tons or about 45 percent of the total salt in the lake. In 2004, there was about 0.8 billion tons of salt precipitate in the north part when the lake altitude was at about 4193.5 feet.

Precipitation and re-solution of sodium chloride has been prevalent in the north part of the lake since the causeway was constructed. Although up to one billion tons has been deposited in the north part at times, there have been several periods when it has re-dissolved at the higher lake altitudes (fig. 2).

The principal concern is the potential for freshening of the south part at the lower lake altitudes, especially if the water surface of south part declines below the bottom of the breach (4193 ft). Even though the observed (or measured) salinity and load data shown in figures 12 and 13 are not trending lower at elevations below 4196 ft, past data have shown that, as more restriction occurs to flows through causeway, head difference increases, south part salinity decreases, and there is more net movement of salt to the north part.

To remediate such a condition might require enhancement of the north to south flows through deeper openings in the causeway or by pumpage of brine from the north to south part of lake, limit the proposed brine extraction below elevations of about 4194 ft, or combinations of each. Keeping the culverts relatively free of debris would be critical at the lower elevations.

The preceding calculations pertaining to the effects of evaporation on the lake level and salt balances are subject to error. Conclusions pertaining to the GSLM project should not be based on those assumptions and calculations without verification and or computations using appropriate modification of model(s) used for making the predictive estimates.

3. Historical trends in potassium

Since the causeway was completed in 1959 the records of water quality data have shown that the total load of potassium in Great Salt Lake has decreased from about 120 million tons to about 80 million tons in 2008 (fig. 4). About 12.5 million tons were lost from the lake presumably from mining during 1966-86, 16 million tons during the West Desert Pumping Project (1987-89) (Wold and Waddell, 1994), and about 9 million tons during 1990-2008 (fig. 4). Excluding the West Desert Pumping loss, about 21 million tons have been mined or sequestered from the lake.

The amount of inflow of potassium from inflowing streams, springs, drains and sewage canals around the lake was computed by Hahl and Langford (1964) for the 1960 and 1961 water years to be 31,200 and 23,100 tons, respectively (The water year is the 12-month period from October to September and is designated by the calendar year in which it ends and which includes 9 of the 12 months. For example, the year ending September 30, 1960 is called the "1960 water year".).

Although the Hahl and Langford study was a comprehensive assessment of all inflows around the lake, the inflows from streams were near all-time lows. The total inflow from all surficial sources during the 1960 and 1961 water years were 1,050,000 and 720,000 acre-feet, respectively. Average inflows to the lake during 1931-76 were reported by Waddell and Barton (1980) to be 2,900,000 acre-feet per year and Loving, Waddell, and Miller (2000) reported an average of 2,055,000 acre-feet per year during 1987-98.

The tonnage of potassium and other minerals entering the lake from inflowing streams generally increases with the volume of runoff even though the concentration would likely be less. Inflow of potassium from all sources was not analyzed during near average inflow but it is conceivable that the potassium inflow during average inflow years would be 2-3 times greater than during the study of Hahl and Langford (1984), or approximately 62,000 to 94,000 tons per year.

During 1990-2008, potassium decreased by an average of about 400,000 tons per year in the Great Salt Lake (fig. 4). This compares to inflows of about 31,200 tons in 1960 or in the case of an average inflow years, estimated to be about 62,000 to 94,000 tons per year.

These computations suggest that, irrespective of the historically recorded inflow and associated quantity of potassium, the losses from mining, whether from product sold and or that sequestered in the evaporation ponds, far exceeds the amount of inflowing minerals when inflow is near average.

4. Need for modifying, updating, and verifying USGS water and salt balance model to evaluate the effects of GSLM proposed project

Because of the dynamic equilibrium between the interconnected north and south parts of lake, it is necessary to account for all the interrelated dynamics in order to predict the results of making changes to the hydraulic properties of the causeway and or modifying the amount of inflow or evaporation on the water and salt balance of the lake. This was recognized by previous investigators concerned with the migration of the salt to the north part of the lake (Waddell and Bolke, 1973).

The USGS or similarly designed model would be a useful tool for evaluating the effects of the proposed GSLM project. The USGS model integrates all the components of water and salt balance and conveyance properties of the causeway. The model was updated by Wold, Thomas and Waddell (1997) and by Loving, Waddell, and Miller (2000).

The original purpose of the model was to evaluate changes to the conveyance properties on the water and salt balance of the lake. However, it can be used to change any of the components of the water balance, including evaporation, to evaluate its effect on the overall water and salt balance. It would require verification with data collected since 1998 and some modification to evaluate the effects of additional pond expansion and associated withdrawals and evaporation. The DWRe made some computations with the existing model for steady-state conditions as presented in the U.S. Army Corps Scoping Report (October, 2009) but verification is needed with recent data and modification for pond expansion.

Steady-state simulations provide some insight to trends, but conditions for the Great Salt Lake are seldom in a steady-state. A more realistic approach is to develop a base period in which the actual hydrologic conditions are known. Using a base period in which the simulated hydrology can be compared with actual conditions, the degree of accuracy of the calibrated model can be evaluated. The GSLM proposed pond expansion can then be simulated for this base period to determine the effects that it would have as if the project was carried out for the duration of the selected base period. This was the approach used to evaluate the effects of changing breach depth on the salt balance of the lake (WRIR-4221, 2000, pgs 25-28).

1. A base period of 1987-2009 would include altitudes ranging from 4211 ft to 4194 ft and would closely approximate the range of historically recorded lake levels. Since the hydrologic data used as input to the latest USGS model (WRIR-4221, 2000) is available for 1987-1998, it would only be necessary to update the input data for 1999-2009.
2. Additional data is available to test and validate the breach flow equations. Intermittent measurements were made at the breach and the culverts during 2000-08, and in October 2008, the USGS began continuous monitoring of the breach flows. Since the breach was deepened during 2000, this monitoring data could be used to verify and or modify the breach flow equations. The water quality data that has been routinely collected by the State of Utah also provides data that can used to update the trends in salinity. Pan evaporation and precipitation records used in prior studies can be updated with recent data at the same sites.

3. The proposed plans for the GSLM project would be incorporated into the model to assess the effects of additional evaporation and withdrawals that would occur during the base period 1987-2009. The model would then be used to make simulations for the 1987-2009 as if the proposed project began in 1987.

Summary of concerns

1. Potential decrease of salinity in the south part at water surface altitudes below about 4194 ft.

2. Large amounts of precipitation of sodium chloride in the north part of the lake at lake elevations below 4194 ft.

3. Possible need to remediate salinity of south part for lake altitudes below about 4194 ft.

4. Debris from construction that may affect the conveyance properties of causeway [1]

5. Need for modified USGS model to make estimates of effects of the proposed GSLM project on lake elevation and salinity.

Methods and Limitations of Computations

Most computations were made using procedures discussed in Loving, Waddell, and Miller (2000). Computations of loads of dissolved solids, potassium, and magnesium were made using the altitude-area-volume relationships shown in WRIR 00-4221. More recent bathymetric data was collected by the U.S. Geological Survey (Baskin, 2005, and Baskin, 2006) but was not used for this report so that 1999-2009 computations of loads could be compared to historical trends computed for 1965-1998. Also, the south part of the lake in this report includes Bear River and Farmington Bays which were not included in the recent bathymetric surveys of the main south part and did not include altitudes above 4200 ft.

The recent U.S. Geological Survey bathymetric data was compared to that of the data used in this report for both the north and south parts. In the south part a comparison of lake volumes for altitudes above 4180 ft indicated errors were less than 1.5 percent. However at lower elevations the errors were larger. At 4175 ft the error was about 5 percent. In the north part the comparison of new and old lake volume data indicated errors less than about 2 percent for altitudes at or above 4185 ft but larger at lower altitudes.

The bay areas have a lower salinity than the main body of south part but sufficient data were not available to make separate computations. The error involved by computing loads in the south part and assuming the concentrations are the same in the bay areas as in main body of south part was discussed by Loving, Waddell, and Miller (2000, p. B-7).

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[1] Debris in the culverts has been a problem for the exchange of flows between the north and south parts of lake since the causeway was constructed and flows are obstructed some of the time. It is of particular concern for the proposed GSLM project because of the debris that may result from construction involved with the Behrens Trench and possibly with construction of evaporation ponds on the western shore. Debris also could possibly affect the permeability of the causeway rock fill. Considerable exchange of flow thru the fill has been noted in several prior studies including that of Loving, Waddell, and Miller (2000, p. 28).

Lake volume was large enough in 1986 that the concentration of dissolved solids was far below the saturation concentration of sodium chloride (355 g/l) in both the south and north parts. This allowed most if not all precipitated salt in the north part to dissolve. The total dissolved load in the lake was computed using water-quality data to be 4.9 billion tons by Wold, Thomas, and Waddell (1986, appendix B).

The West Desert Pumping Project (WDPP) caused a net loss of dissolved solids to the West Pond during 1987-92. Loving, Waddell, and Miller (2000, p. 14) computed the net loss to the West Pond to be about 0.5 billion tons after return flow from West Pond to Great Salt Lake had ceased in about 1992. This loss left 4.4 billion tons remaining in the Great Salt Lake, and was used for 1999-2009 computations in this review (fig. 2).

The total dissolved solids in brines were computed from an empirical relationship between specific gravity and dissolved solids of samples instead of the sum of the individual ions. Loving, Waddell, and Miller (2000, pgs 15-17, and appendices B1-B3) found it to be a more reliable means of computing total dissolved solids for the Great Salt Lake analytical data.

The loads of ions were computed by developing vertical profiles of dissolved solids at each site and then weighting the concentration of each layer in the profile by the appropriate volume using the procedures explained in Appendices B, of WRIR 00-4221.

The computation of steady state loads in south and north parts using percent salinities in figure 12, the estimated total salt load in lake, and solubility of sodium chloride were made as follows:

The percent salinities shown in figure 12 were converted to concentration in tons per acre foot (CS). The tons of salt in the south part (LS) were then computed from the product of concentrations (CS) and volumes (VS).

$LS = CS*VS$

The total estimated load of salt (dissolved plus precipitated) in the lake after the West Pond pumping project was about 4.4 billion tons. Knowing the total load of salt in the entire lake (dissolved plus precipitated) and the dissolved load (LS) in the south part, the total dissolved plus precipitated load in the north part (TLN) was computed as follows:

TLN = 4.4 – LS

where

TLN = DLN (dissolved load north) + LNPPT (precipitated load north)

The maximum concentration that can be dissolved is a function of the solubility of sodium chloride and the volume of water in the north (VN). The solubility of sodium chloride is about 355 grams per liter, or 483 tons per acre-foot (355*1.36 = 483).

If VN*483 is less than or equal to total load north (TLN)

Then LNPPT = 0 and the dissolved load in north, DLN = TLN

If VN*483 is greater than TLN, then DLN = 483*VN

and

LNPPT = TLN – 483*VN

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