GREAT SALT LAKE

An Overview of Change

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EFFECTS OF THE WEST DESERT PUMPING PROJECT ON THE NEAR-SURFACE BRINES IN A PORTION OF THE GREAT SALT LAKE DESERT, TOOELE AND BOX ELDER COUNTIES, UTAH

by

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Introduction

In the early 1980s, the elevation of the Great Salt Lake increased significantly, which resulted in property damage due to flooding of lands adjacent to the lake. The State of Utah investigated various solutions to mitigate the damages caused by the rise in the lake, and in 1986 began construction of the West Desert Pumping Project (WDPP). The project was designed to pump Great Salt Lake waters into an area of the Great Salt Lake Desert and allow the volume of the pumped waters to be reduced through evaporation. Figure 1 shows the area of the Great Salt Lake Desert that was inundated by the WDPP, often referred to as the West Pond. West Pond was confined on the south and southwest by a dike constructed to keep the pond from impinging upon Interstate 80 and the Bonneville Salt Flats. West Pond is bounded on the east by the Newfoundland Mountains and on the west by Floating Island, Silver Island Mountains, and Crater Island. At the south end of the Newfoundland Mountains, an additional dike, the Newfoundland Weir, was constructed with outlet structures to control the level of the water in West Pond and allow the overflow to drain back to the Great Salt Lake. To avoid filling shallow basins in the Great Salt Lake Desert with salt and depleting the mineral resources of the Great Salt Lake, provisions were made in the original design of the project to use less saline brine from the south arm of the Great Salt Lake and convey the brine concentrated in West Pond back to Great Salt Lake by maintaining a return flow averaging 500 cubic feet per second (cfs) (EWP, 1983).

In May, 1986, the Utah State Legislature authorized construction of a "bare-bones" project which departed from the original design by withdrawing water from the more saline north arm of the Great Salt Lake and eliminating some of the features east of the Newfoundland Weir designed to facilitate the flow of the concentrated brines back into the Great Salt Lake (Bureau of Land Management, 1986). The pumping project started operation on April 10, 1987 and continued through June, 30, 1989. During this period, the United States Geological Survey (USGS) estimated that Great Salt Lake brines containing 695 million tons of salt were pumped into the West Desert (Wold and Waddell, 1993). At the end of pumping, on June 30, 1989, they estimated that 315 million tons remained in the evaporation pond in the West Desert, 71 million tons were contained in a salt crust on the floor of the pond, 10 million tons infiltrated the subsurface of the inun-

dated area, 88 million tons were withdrawn as part of a mineral extraction operation, and 123 million tons were discharged from the evaporation pond back towards the Great Salt Lake. In this study, the USGS was unable to account for about 88 million tons of the 695 million tons they estimated had been removed from the Great Salt Lake.

The area of the Great Salt Lake Desert inundated by the WDPP was known to contain a shallow subsurface brine prior to being flooded. This near-surface brine resource in the Great Salt Lake Desert was also known to differ chemically from Great Salt Lake. The purpose of this investigation is to document what was known about these shallow brine resources before the area was flooded by the WDPP and to assess any impacts the introduction of Great Salt Lake brine to the West Pond may have had on these resources.

GEOLOGIC SETTING

The Great Salt Lake Desert is a broad valley in the Great Basin portion of the Basin and Range physiographic province. The Great Salt Lake Desert is a closed basin with all drainage towards the center of the basin. This broad basin consists of a number of smaller subbasins that are separated by very low topographic divides. The principle subbasins within the Great Salt Lake Desert include the Bonneville Salt Flats and Pilot Valley. Two other basins, which have not been formally named, include the areas to the east and west of the Newfoundland Mountains, which will be referred to in this report as the East Pond and Newfoundland Basin. These subbasins are designated on a satellite image of the West Desert shown on figure 2. In this report, the term Great Salt Lake Desert will be used in a restricted sense to include the areas of mud flats or salt flats within the basin.

The sediments comprising the mudflats consist primarily of carbonate muds, clay, gypsum and salt. Minor occurrences of oolitic sand and thin carbonate layers of probable algal origin are also present in the surface sediments within the Great Salt Lake Desert. Salt crusts cover the playa surfaces of Pilot Valley and Bonneville Salt Flats. Since cessation of the WDPP in 1989, a salt crust has also been deposited on the playa in the deeper part of the Newfoundland Basin.

The area of the mud flats exhibits very low relief with elevations generally ranging from about 4,210 to 4,225 feet
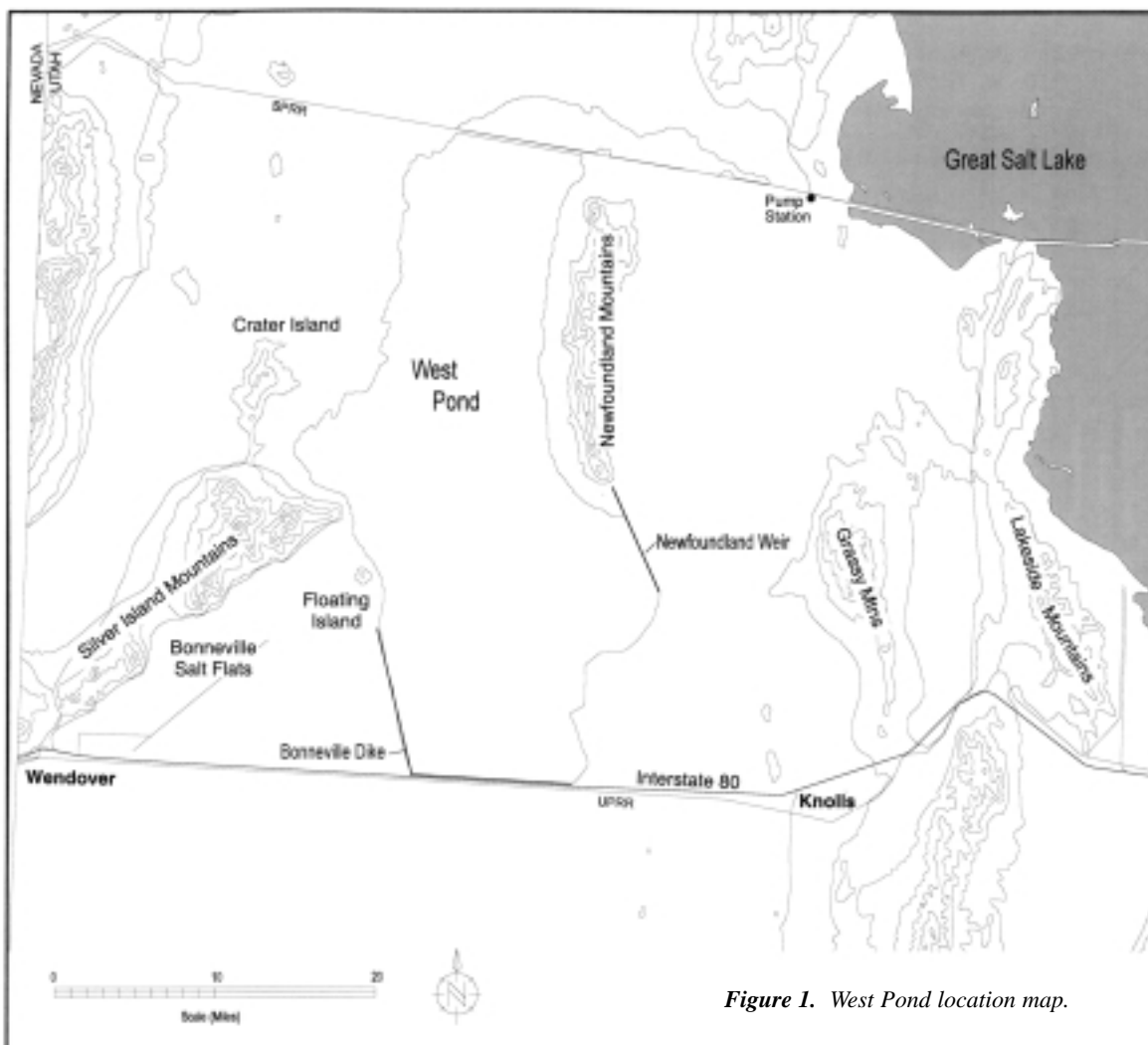
Figure 1. *West Pond location map.*

Figure 2. *Great Salt Lake Desert showing sub-basins.*

above sea level. Locally, small dunes of wind-blown gypsum sand provide a slight amount of relief to the otherwise flat surface. Extensive dunes of gypsum sand are present along the eastern edge of the Newfoundland Basin playa.

The hydrologic system within West Pond generally consists of three types of aquifers: an alluvial fan aquifer adjacent to the mountain ranges around the perimeter of a playa, a shallow brine aquifer that occurs in the upper 20 feet of a playa, and a deep basin-fill aquifer. The shallow brine aquifer is the only part of the ground-water system that was affected by the WDPP.

PREVIOUS WORK

The shallow brine resources of the West Pond were investigated at various times in the past. The sampling points from these investigations are shown on figure 3. Thomas Nolan of the USGS conducted an initial assessment of the area in the 1920's (Nolan, 1927). Nolan completed 405 shallow test holes distributed over the entire Great Salt Lake Desert. Brine samples were collected and analyzed from these drill holes, but complete analyses were not included in Nolan's published report. However, the report does include a composite analysis of 126 samples taken during his field
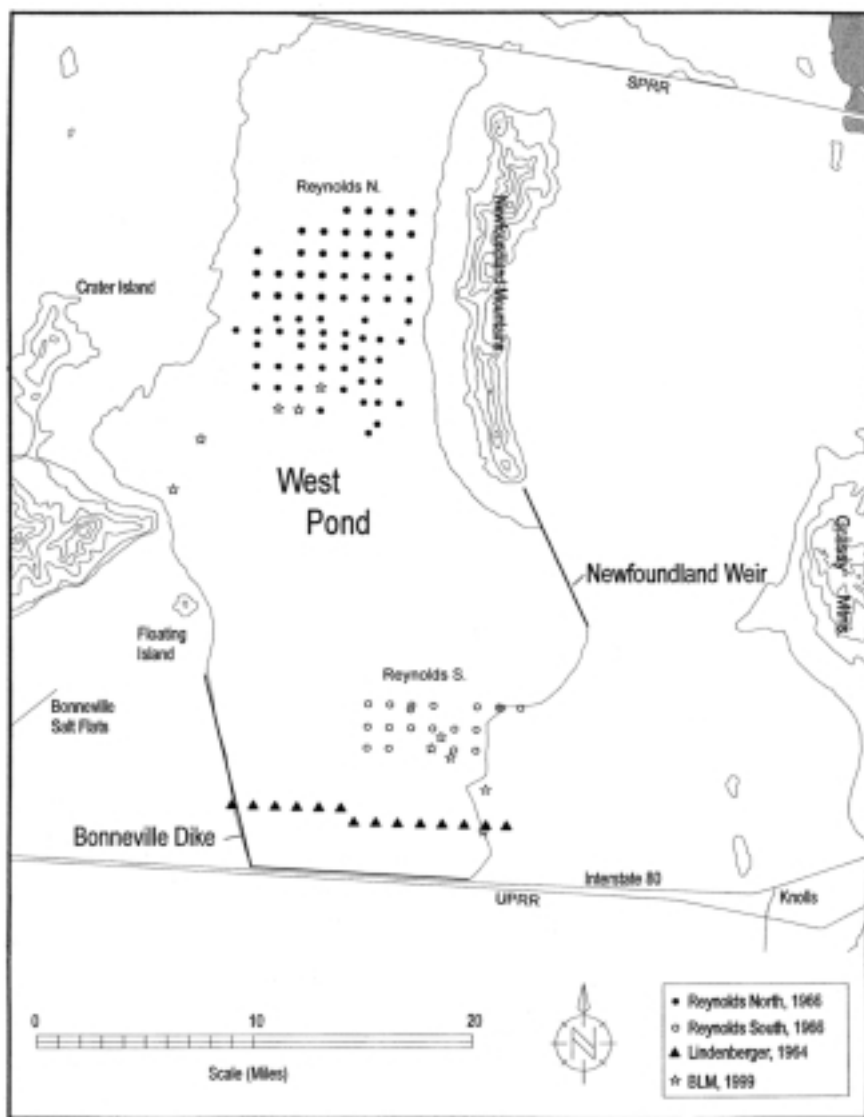
Figure 3. *Shallow-brine aquifer drill holes in the Great Salt Lake Desert.*

In the mid-1960s, much of the area of the West Pond was explored for potassium by Reynolds Metals Company under a prospecting permit from the federal government (unpublished BLM data files). During this exploration program, 92 shallow drill holes were completed within the area of West Pond and analyzed for potassium, magnesium, chloride and sulfate. Two areas were sampled on one-mile centers. Twenty samples were taken within a small topographic depression south of the Utah Test and Training Range (Reynolds S), and 72 samples were taken from the deeper part of the West Pond basin to the west of the Newfoundland Mountains (Reynolds N).

As part of the feasibility study for the WDPP, Dames & Moore completed a report that addressed the shallow brine aquifer within West Pond (Dames & Moore, 1983). As part of their field investigation, Dames & Moore drilled a number of wells along the alignment of the dike along the south and southwest boundary of the proposed West Pond. The Utah Geological Survey (UGS) analyzed water samples taken from these wells, and major ions were reported on a weight-percent basis. The sum of the weight-percent values for the individual ions was reported as percent total dissolved solids (TDS).

DATA COMPILATION

In order to be able to compare the Reynolds (1966) data with other analyses from the area, it was necessary to estimate values for the missing sodium and calcium concentrations. Available data from the shallow brine aquifer in the Great Salt Lake Desert show a strong linear relationship when sodium is plotted against chloride. The mole balance of the samples was checked by comparing the sum of the anions and cations. Data from all samples collected within the West Pond area with a mole balance of +/- 5 percent were used to show this relationship (figure 4).

A linear regression curve fit to these data was used to estimate the sodium values for the Reynolds (1966) data using the following relationship developed from this regression:

$$Na_{(mmoles)} = (.9349 \times Cl_{(mmoles)}) - 42.19$$

The calcium values for the samples were then estimated by determining the amount of Ca^{++} necessary to achieve a charge balance for the solution. The chemical analyses of the Reynolds data along with the estimates for sodium and calcium are given in appendix 1.

The brine chemistry reported by Dames & Moore (1983) as part of their investigation in support of the design of the WDPP was reported on a weight-percent basis. To convert these values to a grams per liter basis, a linear regression was run on the plot of percent TDS versus density for the Lindenburg data from 1974 (figure 5).

investigation. Nolan does not identify which of his 405 test holes were included in the composite sample, so his hole locations are not shown on figure 3. The results of Nolan's investigation were used by the USGS to designate much of the Great Salt Lake Desert as an area known to contain valuable deposits of potassium for land classification purposes.

In 1974, George J. Lindenburg, a graduate student at the University of Utah, conducted an investigation of the shallow brines in part of the Great Salt Lake Desert and compared them with brines of the Great Salt Lake. As part of this investigation, brine samples were collected from the shallow brine aquifer at 65 different locations. Fourteen of these sites were within the boundary of the West Pond. Lindenburg (1974) concluded that the shallow brines from the Great Salt Lake have a higher sulfate content than the shallow subsurface brines of the Great Salt Lake Desert. He attributed this difference to the addition of sulfate to the waters of the Great Salt Lake from the Jordan River and other tributaries that feed the lake. Higher sulfate values are not found in the shallow subsurface brines of the Great Salt Lake Desert because they are essentially a closed system and do not receive similar recharge.
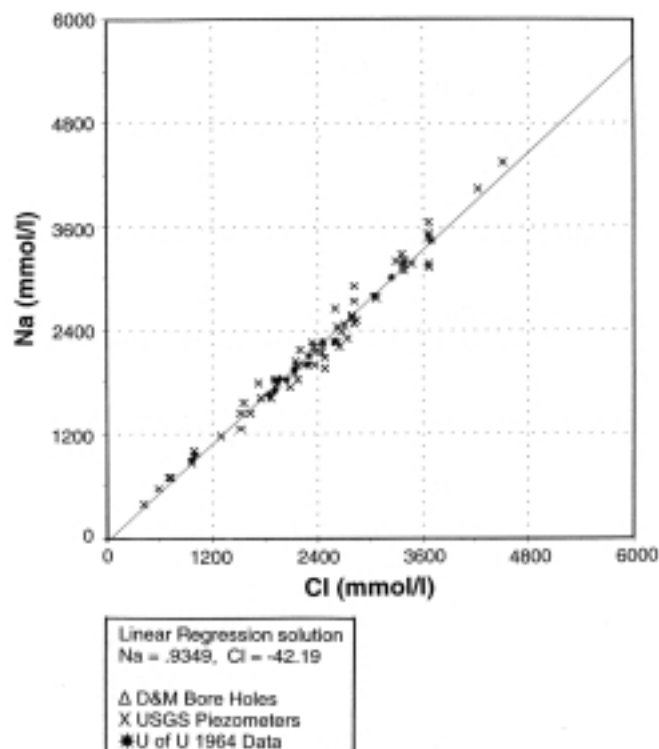
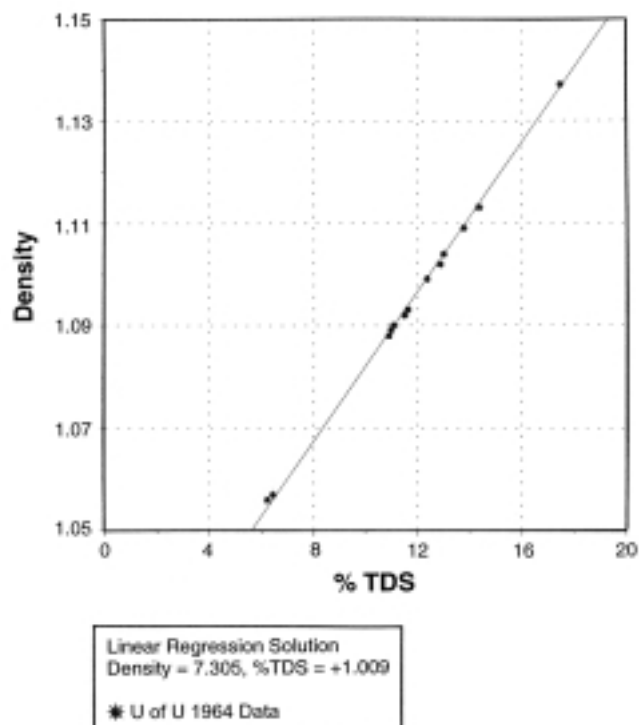*Figure 4. Cl vs Na for West Pond pre-WDPP brine samples (n=81).*

Figure 5. TDS vs density for West Pond pre-WDPP in brine samples (n=81).

This relationship was used to derive a density for each sample. This density was then used to convert the reported weight-percent values for each ion to grams per liter.

After adjusting the brine analyses to show the major ion content in terms of grams per liter, the samples were converted to moles per liter by dividing their composition in grams per liter by their gram-molecular weights. The average pre-WDPP brine chemistry for the adjusted data from the various sources is listed in table 1.

None of these studies developed any quantitative information on the hydrologic characteristics of the shallow brine aquifer in the West Pond, but some qualitative observations were made. Nolan noted that the brine was found in thin horizontal zones in the sediments rather than being uniformly distributed throughout them. He also observed that in the areas away from the edge of the flat, the brine flow, if plentiful, was under a small hydrostatic pressure and would raise a few inches in the borehole (Nolan, 1927, p. 37). Nolan also noted that in some areas, brine flow was scanty, but did not identify exactly where those areas were located. With regard to the characteristics of the shallow brine aquifer, Reynolds Metals offered the following: "A few holes filled very quickly, others very slowly. In many we could see liquid trickling down the walls from just below the collar, but we could not often distinguish successive lower points of influx that certainly contributed to the flow. In a few cases it seemed as if the liquid welled up from the bottom faster than it oozed in from the sides" (Reynolds Metals, 1966).

GREAT SALT LAKE BRINE PUMPED INTO THE WEST POND

From April 10, 1987, to June 30, 1989, brine from the Great Salt Lake was moved to the West Pond by the WDPP. During this period, an estimated 2.7 million acre-feet of water was pumped into the West Pond (Wold and Waddell, 1993). The USGS collected periodic samples at the outlet of the pump and analyzed them for the major ions (Kidd Waddell, USGS, personal communication, 1999). Of the 13 brine samples analyzed by the USGS at the pump while it was in operation, only one sample had a mole balance of +/- 5 percent and was brought forward in this study. However, the UGS also collected samples from the Great Salt Lake during the period that the pumping project was operating, which would also be considered representative of the brine that was pumped into the West Pond. Analyses from these samples were obtained from the UGS (J.W. Gwynn, UGS, personal communication, 1999). In addition to sampling the brine at the pump, the USGS collected 24 samples from points scattered throughout the West Pond in June 1989, to estimate the amount of salt contained in solution in the pond at the end of pumping on June 30, 1989 (Wold and Waddell, 1993). The major ion content of the brine from these sources that are considered to represent the brine introduced to the Great Salt Lake Desert by the WDPP is summarized in table 2.

Compared to brine in the shallow brine aquifer underlying the West Pond area prior to pumping, Great Salt Lake brines differ in that they generally contain a higher concentration of magnesium and sulfate. This difference is evident when a comparison is made of the ratios of potassium to magnesium and calcium to sulfate for the two different brines. The pre-WDPP shallow ground-water brine represented by the Reynolds N data (table 1) has a K/Mg value of 0.77 and a Ca/SO$_4$ value of 0.74. In contrast, analyses of the Great Salt Lake brine using the average values from April 1987, to June 1989, (table 2) show a K/Mg value of 0.34 and a Ca/SO$_4$ value of 0.059.

Table 1. Summary of pre-WDPP shallow brine samples from the West Pond area. Ion concentrations reported in moles per liter.

Data Source	Number of Samples	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}
Nolan	12	2.492	0.075	0.038	0.079	2.712	0.042
Lindenburg	13	1.875	0.072	0.045	0.060	2.057	0.071
Reynolds N	72	3.128	0.099	0.045	0.129	3.354	0.061
Reynolds S	20	2.537	0.148	0.048	0.107	2.728	0.060
Dames and Moore	7	2.187	0.084	0.036	0.077	2.401	0.024

Table 2. Summary of brine samples representative of Great Salt Lake brine pumped into the West Pond. Ion concentrations reported in moles per liter.

Data Source	Number of Samples	Na^{++}	K^{++}	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}
West Desert Pump	1	2.175	0.066	0.005	0.160	2.454	0.115
Great Salt Lake Average, April 1987 to June 1989	13	2.301	0.075	0.006	0.217	2.591	0.101
West Pond June, 1989	24	4.789	0.153	0.010	0.342	5.308	0.188

When pumping stopped in June 1989, water remaining in the West Pond continued to evaporate and the pond decreased in size and retreated to the deepest part of the basin where it eventually dried up. Satellite imagery of the West Pond suggests that it disappeared by July 22, 1991, leaving behind an extensive salt crust. Since 1991, a surface pond has formed in the deeper part of the West Pond during periods of low evaporation in the winter and following heavy precipitation events.

PRESENT SHALLOW BRINE AQUIFER IN THE WEST POND

In order to make a preliminary assessment of the brine presently in the shallow brine aquifer in the West Pond, a field investigation was undertaken by the BLM during the summer of 1999. As part of this investigation, brine samples were recovered from shallow (6 to 8 feet) boreholes drilled in various locations throughout the West Pond area. These boreholes were drilled with a standard 4-inch bucket soil auger and the sedimentary sequence and the depth to brine was recorded. The brine was then pumped from the borehole with a portable centrifugal pump at a rate of 1 to 2 gallons per minute until approximately 50 gallons of brine had been removed from the hole before samples were collected for analysis. In a typical borehole, the pumping rate of 1 to 2 gallons per minute lowered the water level a few inches, where a sustainable level was maintained. When pumping stopped, the water level in the borehole returned to the original static level. In the boreholes away from the center of the basin, the brine was typically under confined conditions and the water level would rise a few inches above the level where it was first encountered. In the deepest part of the basin, no

such confined conditions were observed. Three of the samples collected during this investigation, obtained in the deepest portion of the basin on or near locations sampled by Reynolds Metals in the 1960s, are of particular interest. They provide a basis for identifying changes to the shallow brine aquifer chemistry in the area last occupied by the waters from the WDPP. The analyses from these three samples are summarized in table 3.

Not surprisingly, the marked increases in concentrations of potassium and magnesium reflect brine that has been concentrated through evaporation.

COMPARISON OF THE BRINES USING IONIC RATIOS

Because brines from the West Desert and the Great Salt Lake are dominated by sodium chloride, subtle differences in the brines are not always evident from comparison of chemical analyses of the brines. In addition, the shallow brine aquifer receives recharge from direct precipitation that may dilute the brine during wet years. A similar situation occurs with the Great Salt Lake in that, during wet weather cycles, the level of the lake rises and the lake brine becomes diluted. The variable composition of the brines resulting from this dilution further masks subtle difference in the brine chemistry.

Initially, comparisons of Great Salt Lake and West Desert brines were made with ratios of major ions. Previous work had indicated that brine from the Great Salt Lake had a higher magnesium and sulfate content than Great Salt Lake Desert shallow brine aquifer brine. Nolan (1927) noted that ground-water brine in the Great Salt Lake Desert had a potassium to magnesium ratio approaching one and a molar com-

Table 3. Brine samples from the shallow brine aquifer collected in the deep part of the West Pond, 1999. Ion concentrations reported in moles per liter

Well Designation	Na^{++}	K^{++}	Ca^{++}	Mg^{++}	Cl^{--}	SO_4^{--}
NB-8	3.454	0.425	0.004	0.823	4.727	0.365
NB-9	3.341	0.527	0.008	0.848	5.012	0.373
NB-10	3.310	0.486	0.008	0.859	5.012	0.318
Average	3.367	0.479	0.007	0.843	4.917	0.352

Table 4. Comparison of K/Mg and Ca/SO$_4$ for brine samples from the Great Salt Lake, pre-WDPP shallow brine aquifer in the Newfoundland Basin, and present (1999) shallow brine aquifer in the Newfoundland Basin. Ratios are calculated on a molar basis.

Source of Brine	K/Mg	Ca/SO$_4$
Average of Great Salt Lake (1987 to 1989)	0.34	0.059
Average brine in West Pond (June 1989)	0.45	0.053
Average Reynolds N brine samples (1960)	0.77	0.738
Average of NB-8, NB-9, and NB-10 (1999)	0.57	0.020

position of calcium and sulfate close to being in balance with precipitation of gypsum. Based on these observations, a comparison was made of the potassium to magnesium and calcium to sulfate ratios for ground water from the Great Salt Lake Desert prior to being inundated by the West Desert Pumping Project, brine from the Great Salt Lake during the period that the pumping project was being operated, brine in the West Pond at the end of pumping in June, 1989, and shallow ground-water brine presently in the area formerly covered by the West Pond. The results of this comparison are shown in table 4.

The K/Mg ratio for the pre-WDPP brine in the Newfoundland Basin (i.e., Reynolds N) is more than twice the value for the Great Salt Lake during the period of the pumping project. The K/Mg ratio for the brine presently in the shallow brine aquifer in the basin lies between the values for the Great Salt Lake and the pre-WDPP ground water. However, comparison of the Ca/SO$_4$ ratio does not yield the same results. Rather than a Ca/SO$_4$ ratio that lies between the Great Salt Lake and the pre-WDPP shallow brine aquifer, the ratio for the present shallow brine aquifer is actually lower. This could be the result of the excess sulfate from the Great Salt Lake brine combining with the calcium in the shallow brine aquifer brine resulting in the precipitation of gypsum. The removal of the calcium in this manner results in a lower Ca/SO$_4$ ratio.

This comparison of the ionic ratios suggests that the chemistry of the present shallow brine in the Newfoundland Basin could result from mixing Great Salt Lake brine with the pre-WDPP ground water. To better understand this relationship, a model was used to simulate evaporation of the brines and then make a comparison based on the various precipitated minerals.

Geochemical Modeling of West Pond Brines

The TEQUIL program was developed by the University of California at San Diego for the geothermal industry to predict the chemical behavior of the natural brines from which the thermal energy is extracted. Although the program was developed initially for the geothermal industry, is has been found to have wide applications in other industries including solar pond engineering (Moller and others, 1997). The program is based on a model which uses semi-empirical equations of Pitzer (1973) that were used by Harvie and Weare (1980) to show that the free energy calculations on electrolyte solutions could be used to accurately predict complex solubility relationship in the Na-K-Ca-Mg-SO$_4$ system (Moller and others, 1997). Various versions of this program are available, but for the purposes of this investigation, the 25°C model for the Na-K-Ca-Mg-H-Cl-OH-SO$_4$-HCO$_3$-CO$_3$-CO$_2$-H$_2$O system (Harvie and others, 1984) was used.

TEQUIL provides a user interface to input the composition of the initial solution in moles. The model then simulates removal of 10 percent of the water through an iterative process to simulate evaporation. For each iteration, the program calculates the solubility for the various minerals that could be expected to precipitate from the brine. When the solution becomes saturated with a given mineral, the mineral is allowed to precipitate. The precipitated salt remains in contact with and is allowed to react with the brine. The results of the evaporation simulation are saved by the program in a text file that lists the molar composition of the concentrated brine and any minerals that precipitate from the brine.

In order to better understand how the brines introduced to the West Pond from the Great Salt Lake may have inter-

acted with the subsurface brines contained within the shallow brine aquifer, the TEQUIL program was used to identify the minerals that would precipitate from the brine and the sequence of precipitation. The model shows that evaporation of samples of brine from the Great Salt Lake produced a very consistent sequence of minerals even though the brine chemistries appear to be different. The mineral sequence projected by the model for the Great Salt Lake is consistent with actual results reported from the evaporation of Great Salt Lake brine (Butts, 1993; Jones and others, 1997).

The model also shows that when brines from the shallow brine aquifer from the Great Salt Lake Desert before the WDPP are evaporated, an equally consistent sequence of minerals results which is significantly different than the minerals which precipitate from the Great Salt Lake. The mineral sequence projected by the model for brine from the shallow brine aquifer in the Great Salt Lake Desert is consistent with the sequence reported for Reilly-Wendover's potash extraction operation near the Bonneville Salt Flats (Bingham, 1980).

The model was applied to the following brines: (1) subsurface brine from the deepest part of the West Pond before the area was inundated by the WDPP, (2) brine from Great Salt Lake during the WDPP pumping period, (3) brine contained within the West Pond when pumping ceased in 1989, and (4) subsurface brine presently found in the deepest part of the basin. The program was run for 45 iterations to simulate the removal of over 99 percent of the water through evaporation. The model results were then graphed to show the sequence of minerals that precipitated from the brine. The primary minerals expected to precipitate from the brines used in this exercise are as shown in table 5. The model projected precipitation of all of the minerals in table 5 except for mirabilite that is known to precipitate from Great Salt Lake brine during the winter. Because the model was run at a constant 25°C, the temperature-dependent precipitation of mirabilite was not reflected in the model.

The results of using the TEQUIL 25°C model to simulate evaporation of a brine with a composition of the average of the Great Salt Lake during the period the WDPP was in operation (1987 through 1989) are shown on figure 6. The y-axis values on the left side of the graph show the percent of the original water in the brine. The y-axis values on the right side of the graph show the amount of the various salts precipitated in moles.

On the graphical outputs from the model, halite is excluded because its greater abundance would mask the other minerals. For Great Salt Lake brine, the model indicates that the non-halite minerals precipitate out in the following sequence: anhydrite - glauberite - bloedite - polyhalite - epsomite - hexahydrite - kainite - kieserite - carnallite.

The model's projection of minerals that would precipitate from the average subsurface brines from the deep part of the West Pond basin before the area was flooded by the

Table 5. Evaporite minerals derived from West Desert brines (adapted from Braitsch, 1971).

Mineral	Formula	Molecular Weight
Anhydrite	$CaSO_4$	136.15
Bischofite	$MgCl_2 . 6\ H_2O$	203.33
Bloedite	$Na_2Mg(SO_4)_2 . 4\ H_2O$	334.51
Carnallite	$KMgCl_3 . 6\ H_2O$	277.88
Epsomite	$MgSO_4 . 7\ H_2O$	246.50
Gypsum	$CaSO_4 . 2\ H_2O$	172.18
Glauberite	$Na_2Ca(SO_4)_2$	278.21
Halite (common salt)	$NaCl$	58.454
Hexahydrite	$MgSO_4 . 6\ H_2O$	228.49
Kainite	$KMgClSO_4 . 3\ x\ H_2O$	244.48
Kieserite	$MgSO_4 . H_2O$	138.41
Leonite	$K_2Mg(SO_4)_2 . 2\ H_2O$	366.71
Mirabilite	$Na_2SO_4 . 10\ H_2O$	322.22
Polyhalite	$Ca_2K_2Mg(SO_4)_4 . 2\ H_2O$	602.98
Sylvite	KCl	74.553
Syngenite	$K_2Ca(SO_4)_2 . H_2O$	328.43

WDPP is shown on figure 7.

The minerals precipitated from the subsurface West Desert brine as projected by the model are quite different than minerals derived from Great Salt Lake brine. The non-halite minerals precipitate in the following order: anhydrite - polyhalite - sylvite - carnallite - kieserite.

The model's projection of minerals precipitating from the final brine in the West Pond in June 1989 is shown on figure 8.

When figure 8 is compared with the original Great Salt Lake brine on figure 6, the results appear fairly similar except for the greater amount of precipitated salts. This is most likely due to the fact that the brine in the West Pond represents brine that had already been concentrated by evap-

oration. The modeled output differs slightly from the Great Salt Lake brine in the relative abundance of the sodium sulfate minerals bloedite, epsomite, and hexahydrite. Instead, a different mineral, leonite ($K_2Mg(SO_4)_2 \cdot 4 H_2O$), precipitates. The non-halite minerals precipitate as follows: glauberite - polyhalite - bloedite - leonite - epsomite - kainite - hexahydrite - kieserite - carnallite.

The TEQUIL model was then applied to the average shallow brine aquifer in the deepest part of the West Pond basin during the summer of 1999. The results, as shown on figure 9, appear to be significantly different than the three previous brines. First of all, the brine has been significantly concentrated by evaporation. Because of this, the maximum value on the y-axis for the precipitated salts had to be in-
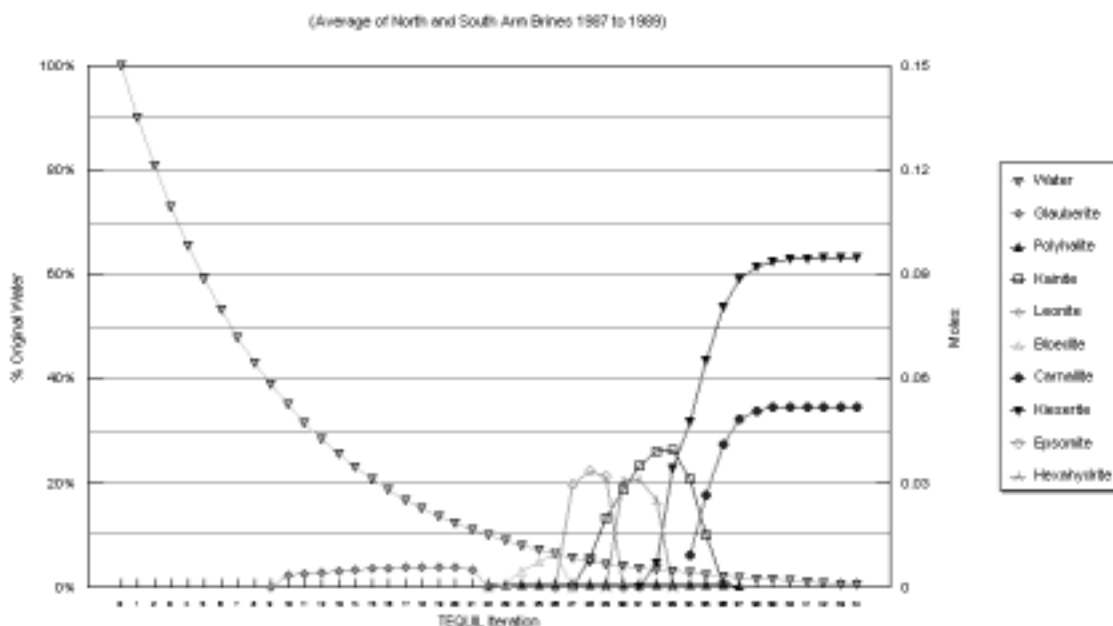

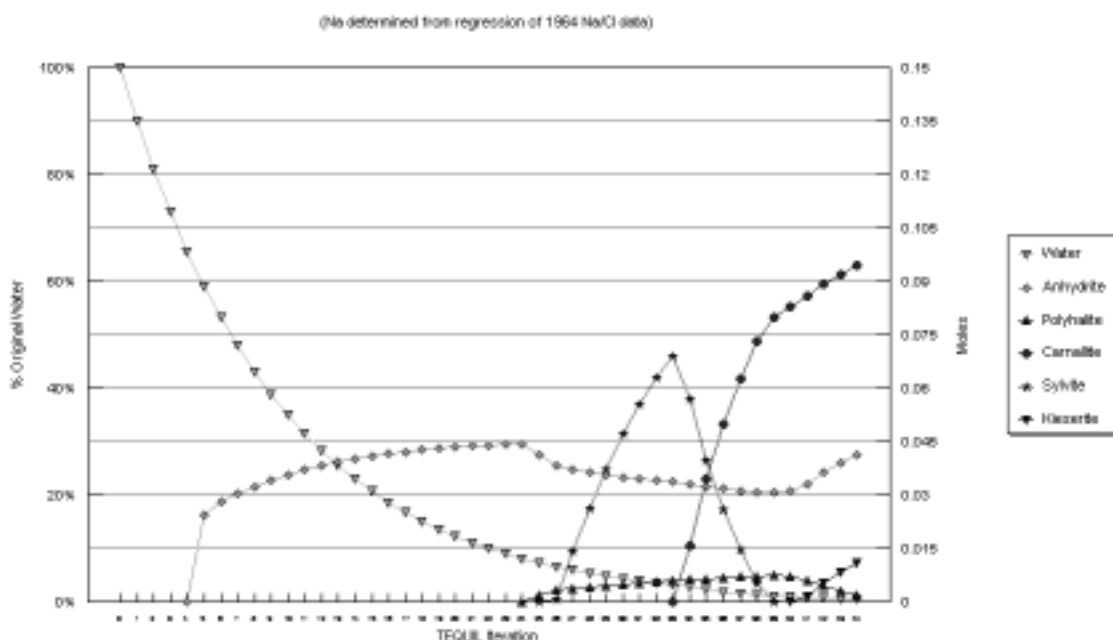*Figure 6.* *TEQUIL model - salts precipitated from Great Salt Lake brine.*

Figure 7. *TEQUIL model - salts precipitated from Reynolds north data.*

creased to 0.5 moles from the 0.15 moles used on the other graphs to adequately show the distribution of the precipitated minerals. For the present ground water brine in the deepest part of the basin, the non-halite minerals precipitated out as follows: glauberite - polyhalite - leonite - sylvite - kainite - carnallite - kieserite.

The mineral suite projected by the model for the shallow ground water brine in the deepest part of the West Pond is different than that projected for the Great Salt Lake and the original ground water. However, it contains components of both which, suggests that the brine presently contained in the shallow brine aquifer in the deepest part of the basin represents a mixture of the original ground water brine and brine from the Great Salt Lake.

SUMMARY AND CONCLUSION

Subtle differences in brine chemistry are not always readily apparent in brine from the Great Salt Lake and the Great Salt Lake Desert when these brines are compared using analyses of the major ions contained within the brine. This may be due to dilution of the brine by meteoric water, or simply due to the fact that the brines are dominated by sodium and chloride, which tend to mask differences in the other ions. By evaporating the brines and identifying the minerals that precipitate out of the solution, these subtle differences become more evident. The TEQUIL model at 25°C seems to produce a reasonable projection of the simple Na-K-Ca-Mg-Cl-SO$_4$-H$_2$O system to which these brines belong. Application of the model shows that the mineral suite precipitating
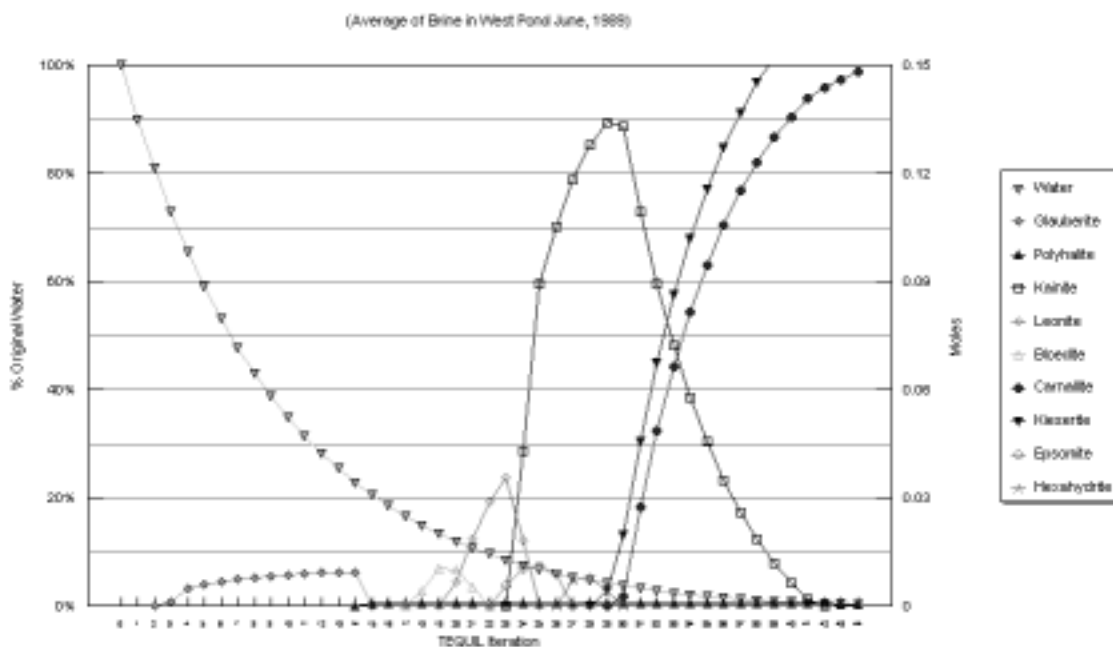

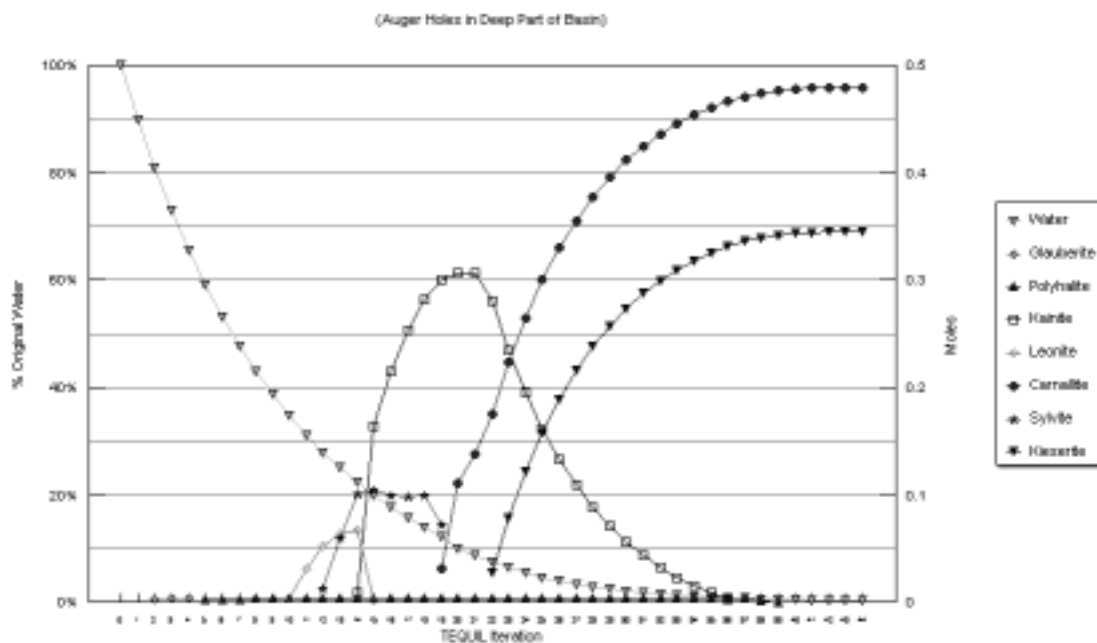**Figure 8.** *TEQUIL model-salts precipitated from West Pond brine.*

Figure 9. *TEQUIL model-salts precipitated from shallow brine aquifer.*

from Great Salt Lake brine is very different than the minerals precipitating from ground-water brines in the Great Salt Lake Desert. The model also shows that the brines presently in the shallow brine aquifer in the portion of the Great Salt Lake Desert inundated by Great Salt Lake brine by the WDPP contain components of both brines and could be considered a mixed brine. These conclusions are based on a limited field investigation, and more sampling should be undertaken to confirm and refine the interpretations. However, these data suggest that the subsurface brine resource that existed in the West Pond has been impacted by the WDPP in two significant ways. First, the brine from the Great Salt Lake mixed with the existing ground-water brine, which changed the chemical character of the brine. Instead of a simple halite - sylvite - carnallite system, the higher levels of sulfate from the Great Salt Lake have resulted in a system with a more complex mineralogy. Secondly, the brine left in the basin was concentrated through evaporation, which significantly increased the amount of potassium and magnesium in the brine in the deepest part of the basin.

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APPENDIX 1. Brine analyses from the shallow brine aquifer in the Great Salt Lake Desert, 1966 (data from Reynolds Metals Co., 1966).

Sample ID	UTM Northing	UTM Easting	Na * mg/l	K mg/l	Mg mg/l	Ca ** mg/l	SO4 mg/l	TDS mg/l	Density
60135	4521304	292806	45593	3100	2100	1742	4900	133336	1.083
60136	4521349	291198	48042	3000	2000	1992	4800	139734	1.087
60137	4522823	294451	52693	5900	2200	2112	5300	155706	1.096
60138	4524486	296111	58447	5700	2500	2250	6100	171896	1.106
60139	4524531	294501	74544	7200	3800	1359	7100	217202	1.134
60140	4524219	294404	75010	8000	3700	1402	6700	218812	1.135
60141	4522868	292842	55325	5400	2400	2044	5600	162569	1.101
60142	4522913	291234	51102	3800	2200	1779	4700	148481	1.092
60143	4524575	292892	78216	7600	3200	2371	6700	227287	1.141
60144	4524620	291282	56121	6100	2300	2292	5700	165613	1.102
60145	4521215	296021	44308	4000	2000	2216	5800	132124	1.082
60146	4521171	297628	64751	7600	3100	1087	4900	188638	1.116
60147	4521126	299236	58263	5900	2700	1619	5400	170481	1.105
60148	4522733	297664	54346	4800	2300	2158	5600	159404	1.099
60150	4522688	299273	56978	5900	2400	2005	5300	167082	1.103
60151	4524397	299330	56672	5600	2400	2072	5500	166244	1.103
60152	4524326	301142	62241	6600	2900	1996	6600	183437	1.113
60153	4524352	300938	62792	8900	3000	1859	6600	187152	1.115
60154	4524307	302547	56243	4600	2500	2261	6400	165304	1.103
60155	4522778	296056	54958	6000	2500	1860	5600	162118	1.100
60201	4556536	294254	73564	4000	3000	2293	6300	210757	1.132
60202	4551854	293643	80174	5100	3700	1440	6200	229014	1.143
60203	4551964	292058	68117	4000	3000	1802	5800	195419	1.122
60204	4552064	290798	62853	3800	2700	1982	5700	181135	1.113
60205	4550422	292015	75829	4000	3600	1421	6300	216450	1.135
60206	4550454	290752	68117	3800	3100	1804	6200	195721	1.122
60207	4548824	290730	80664	5100	4100	681	5900	229645	1.143
60208	4548809	291969	76074	3000	2800	2544	5800	215918	1.135
60209	4547199	291924	80848	5100	3600	1473	5800	230321	1.143
60210	4547225	290867	80419	5300	3700	827	4700	227746	1.142
60211	4545591	291878	79256	4700	3300	1968	6000	226125	1.141
60212	4544923	291233	76013	4700	3700	473	4400	214886	1.134
60213	4547153	293509	79746	4400	3600	1833	6800	228079	1.142
60214	4558193	292692	79746	4400	4500	0	5200	224986	1.140
60215	4558239	291086	66954	3500	4100	1013	8400	194767	1.122
60216	4556630	291039	58997	3000	2700	1239	4400	168137	1.105
60217	4556584	292645	74482	3700	3900	606	5700	211489	1.132
60218	4554974	292598	71055	4000	3300	1126	5000	201981	1.126
60219	4554926	294207	79318	4200	3100	1884	5000	224502	1.140
60220	4553317	294160	75156	4200	3000	2334	6200	215089	1.134
60221	4559754	294346	85683	4400	3800	1185	5300	241768	1.151
60222	4561363	294394	77910	4200	2800	2139	4600	220349	1.138
60223	4561410	292786	79269	4200	3700	1852	7300	227241	1.142
60224	4559802	292739	80174	4500	4000	1237	6900	229212	1.143
60225	4551452	287883	75400	4500	3800	1319	6900	216520	1.135
60226	4551499	286273	78155	4000	3200	1867	5500	221822	1.138
60227	4552570	284692	39534	1600	1400	1622	2600	112756	1.071
60228	4551594	283052	72401	2600	2800	2270	5600	205372	1.129
60229	4552665	281471	82255	2700	3600	544	3400	228300	1.143
60230	4552618	283082	70626	2800	2600	1548	3300	197675	1.124
60231	4552427	289523	64445	3200	2800	1816	5500	184461	1.115
60232	4552475	287913	68545	3100	2500	3191	7100	197836	1.124
60233	4552523	286302	92538	4500	3700	2081	6200	261619	1.163
60234	4549938	284617	71055	4500	2800	2409	6100	204364	1.127
60235	4549986	283006	67383	3200	3000	2181	6800	194064	1.121
60236	4548377	282961	68974	3600	2800	2426	6400	198300	1.124
60237	4548330	284571	70626	3800	3400	1481	6300	202408	1.126
60238	4546720	284520	65118	3800	3600	1200	7100	188617	1.118
60239	4546673	286130	71483	4100	4500	964	9300	208547	1.130
60240	4546625	287741	80664	5000	4300	601	6500	230265	1.143
60241	4551404	289494	66097	3700	3400	1747	7500	191844	1.120
60242	4549796	289448	67627	4000	3100	1904	6500	195031	1.122
60243	4549843	287838	68790	4000	2800	2584	6800	198774	1.124

(Appendix 1 continued)

Sample ID	UTM Northing	UTM Easting	Na * mg/l	K mg/l	Mg mg/l	Ca ** mg/l	SO$_4$ mg/l	TDS mg/l	Density
60244	4549891	286227	77420	4200	3100	1493	4300	218414	1.136
60245	4548282	286182	62853	3700	3000	2196	7400	183250	1.114
60246	4548235	287792	70810	3800	3100	2236	6900	203946	1.127
60247	4548187	289403	81337	5300	4300	594	6400	232232	1.144
60248	4553412	290946	63282	3500	3000	1801	6400	182783	1.114
60249	4555020	290993	63282	3500	2700	2296	6400	182978	1.114
60250	4555066	289388	77910	4600	3700	1740	7200	223850	1.140
60251	4556675	289434	75400	4800	4100	950	7200	217051	1.135
60253	4559893	289529	69096	4000	4100	1166	8500	201162	1.125
60254	4559848	291133	69953	4000	4600	1387	10900	206540	1.129
60255	4561457	291179	71055	3700	4500	1609	10900	209264	1.131
60256	4561501	289574	78889	4400	4000	1797	8400	227786	1.142
60257	4553494	286121	80174	4000	2900	2467	5500	227441	1.142
60258	4555155	286169	77787	3700	2500	2585	4500	219573	1.137
60259	4556766	286216	74299	3700	2300	2734	4500	210333	1.131
60260	4558376	286263	71300	3500	2100	2783	4200	201783	1.126
60261	4559985	286310	62792	3200	1600	2832	3400	177825	1.111
60262	4559939	287920	59303	2500	2100	2453	4900	169557	1.106
60263	4558330	287873	61935	2700	2200	1674	3100	174209	1.109
60264	4556720	287826	68913	3500	2500	2000	4200	195113	1.122
60265	4555110	287779	83235	4800	3400	1676	5200	235711	1.147
60266	4553500	287733	66036	4200	2700	1855	5000	189091	1.118
60268	4558468	283044	56733	3100	1200	3470	4100	162703	1.102
60269	4556857	282997	55631	2600	1500	2084	2100	156215	1.098
60270	4556813	284606	69341	3200	1800	2675	3000	194717	1.122
60271	4555245	282950	52571	3000	1300	2755	3300	150226	1.094
60272	4555201	284559	63037	3000	1800	2474	3300	178011	1.111
60273	4553537	284511	79318	3600	2600	3042	5800	225360	1.141

*   Na determined from linear regression of Na/Cl for 80 brine samples
** Ca estimated from value needed to achieve mole balance for the sample