GREAT SALT LAKE BRINE CHEMISTRY DATABASES AND REPORTS – 1966-2006

by
J. Wallace Gwynn

OPEN-FILE REPORT 485
UTAH GEOLOGICAL SURVEY
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Walter Katzenberger (left), Utah Geological Survey, and Jay Christianson (right) State Parks and Recreation, taking brine samples on Great Salt Lake in about 1977. Photo from Utah Geological Survey photo archives.

Cover photo: Reddish-brown brine shrimp eggs floating on Great Salt Lake. Photo by Bill Case.

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ABSTRACT

Prior to the construction of the solid rock-fill railroad causeway across the central part of Great Salt Lake in 1959, the water was able to mix throughout the lake. Through this mixing, the salinity and chemistry were relatively constant both vertically and laterally. After the causeway's completion in 1959, the main body of the lake was physically divided into a north arm and a south arm. As a result of this division, the north arm of the lake became much more saline than the south arm, and the south arm became density stratified. This report presents the post-1966 brine density and chemistry data that have been collected by the Utah Geological Survey (UGS) through its Great Salt Lake brine collection and analysis program. Chemical and density analyses have been run on Great Salt Lake brine since the early-to-mid 1800s. These data, gleaned from the literature, are also presented. The UGS brine-sampling program began in 1966, and has run continuously to the present time. The databases resulting from this work contain several thousand chemical analyses and density values. Since 1963, over a dozen scientific interpretive reports about the lake have been published by UGS. Copies of these reports, in PDF format, and a file containing U.S. Geological Survey (USGS) provisional lake-level data, are included as part of this CD. Lake-brine analyses done by the USGS and the Utah Division of Water Quality are noted, but not included in this report.

INTRODUCTION AND BACKGROUND

Chemical and density analyses have been run on Great Salt Lake brine since the early- to mid-1800s. Until 1959, these analyses were made on brines that were taken periodically at various places around the lake. These analyses are considered fairly representative of the entire lake because the brine was free to mix throughout the entire lake. This was true, even after the Southern Pacific Railroad's Lucin Cutoff was constructed across Great Salt Lake in 1904, because the central 13-mile portion of the cutoff was built as an open, wooden trestle which permitted mixing to take place (see figure 1).

In the mid-1950s, the Southern Pacific Railroad determined that the wooden Lucin Cutoff trestle needed replacement. In 1955, work began to replace the trestle with a rock-fill causeway located parallel to, and 1500 feet north of the trestle, and by 1959, the work was completed. When the UGS began to sample lake brines on a regular and systematic basis in 1966, two major changes were noted between the north and south arms of the lake. First, the north arm became much saltier than the south arm, and second, the water column in the south arm became stratified, developing a dense, brown-colored, fetid brine layer (6 to 10 feet thick) on the bottom of the lake, overlain by a layer of clear, less-dense brine (20 to 25 feet thick). A transitional zone or interface separated the upper and lower brine layers. The stratification of the brine in the south arm makes it difficult to collect samples representative of the upper and lower brine types if the depth of the interface is unknown.

This report presents and discusses Great Salt Lake brine chemistry and density for two time periods: first, that collected prior to the completion of the rock-fill causeway, and second, that collected after the causeway's completion. First, the data given in appendix A give pre-causeway chemical and density data though some chemistry for the period 1959 to 1966 is included. Appendix A is followed by appendix B that gives annotated references for the citations in appendix A. These references are separate from the main body of the report. Second, the remainder of the report addresses the UGS sampling program and the databases that have been created, other sources of lake-brine chemistry, interpretative reports, the USGS south- and north-arm provisional lake-level records from 1847 to 2006. Appendix C gives the location of the UGS's sampling sites, appendix D gives details of the Great Salt Lake brine databases, and appendix E gives the USGS's Great Salt Lake datum correction.

LAKE-BRINE SAMPLING AND CHEMICAL ANALYSIS

Sampling Sites

Initially, brine sampling by the UGS was done at relatively frequent intervals and at numerous sites throughout the lake. This was done to ensure that the samples were representative of the lake, both in space and time. Eventually, both the frequency of sampling and the number of sampling sites decreased due to time and monetary constraints, and recognition of the lack of significant chemical variability from site to site. Figure 1 shows the location and designation of the sites that have been sampled during the life of the program. These designations, such as AS2 and LVG4, are the same as those used in appendices. Appendix C gives the latitude and longitude of each of the sampling sites and other points of interest.

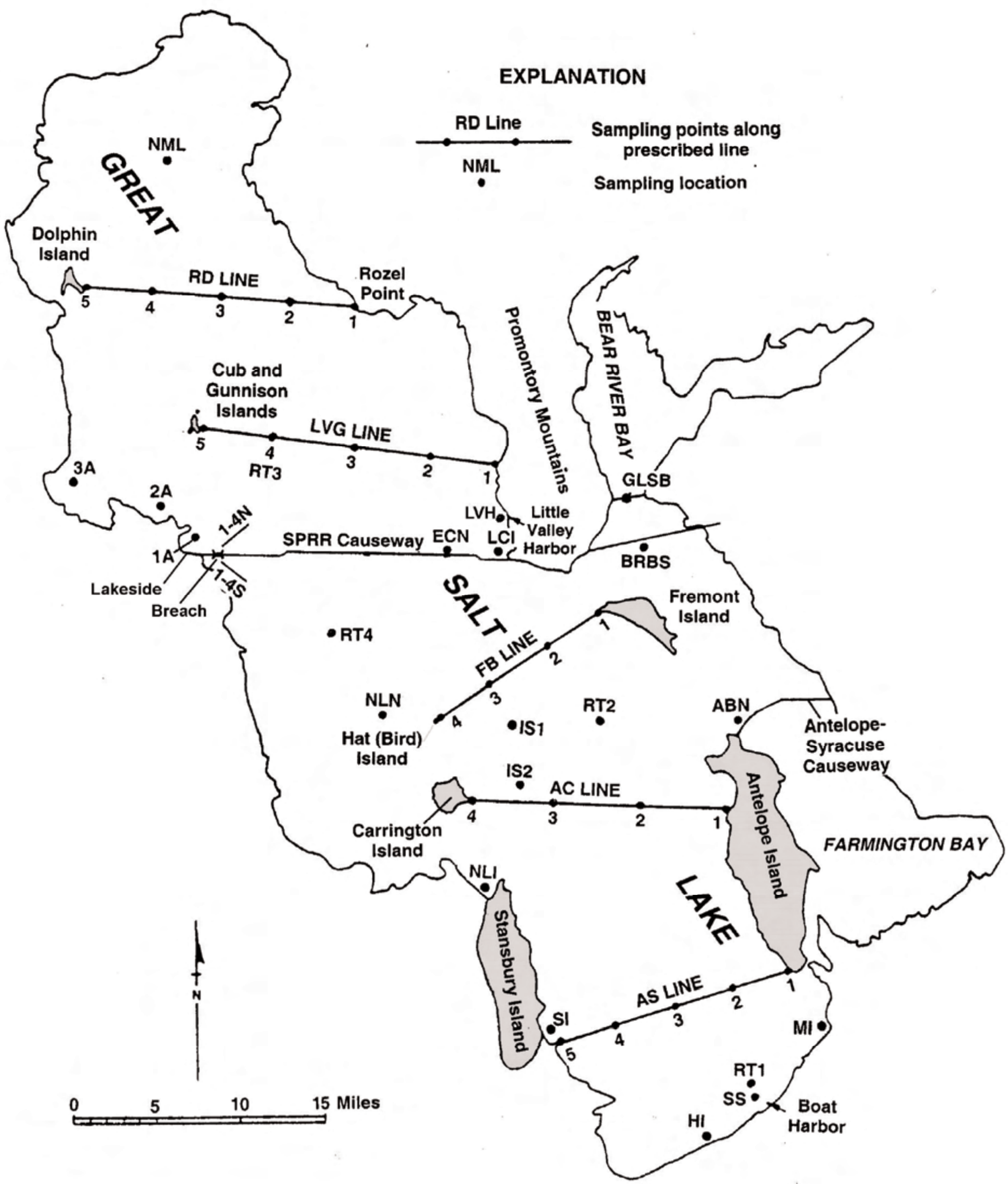

Figure 1. UGS brine-sampling locations and their designations on both the north and south arms of Great Salt Lake, from 1966 to 2005. Sampling sites are keyed to sites listed in appendices C and D.

Sampling Procedure

At each site, samples are taken vertically from the surface to the bottom of the lake at regular depth intervals, typically five feet. To collect the samples, a weighted plastic tube or hose, marked in feet and attached to a pump at the surface (normally positioned in a boat), is lowered incrementally to each sampling depth. When the end of the hose reaches a new sampling depth, sufficient brine is pumped through the hose to purge the old brine before a sample of new brine is pumped into a bottle. Sufficient brine (typically 8 oz) is collected for chemical analysis. Initially, brine temperature and density were determined at the time of sampling, but these measurements are not made now due to time constraints.

Brine Analyses

After collection, the samples are submitted to an outside laboratory for brine density determination and chemical analysis. The usual analytical suite includes the major cations (sodium, potassium, magnesium, and calcium) and the major anions (chloride and sulfate). The minor elements (lithium, bromine, and boron) were also determined, though these were dropped from the analytical schedule in recent years due to monetary constraints and laboratory capabilities. Bicarbonate is not part of the UGS's analytical suite because of its very low concentration in the lake brine.

Sturm (1986) lists the analytical laboratories that have analyzed the lake brines for UGS, and their years of service:

1966-1974	Utah Geological and Mineral Service Laboratory (old University of Utah Engineering Experiment Station Laboratory)
1975-1978	Chemical and Mineralogical Services
1979-1981	American Chemical and Research
1981-Present	Chemical and Mineralogical Services

Sturm (1986) also lists the analytical procedures used by the above laboratories to determine the individual ions or elements. Unfortunately, the quality of the lake-brine analyses has not been uniform. The analyses performed after 1974 are better than those done earlier, due to better equipment, improved laboratory techniques, and more qualified laboratory personnel.

LAKE-BRINE CHEMISTRY FILES

The following lake-brine chemistry database Excel® files are found on the accompanying CD: SOUTH OLD, NORTH OLD, MISC, BRBS, GSLB, AS2 & FB2, and LVG4, ECN & RD2.

The SOUTH OLD, NORTH OLD, BRBS, GSLB, and MISC files are compilations of brine analyses from numerous sampling sites in the south and north arms of the lake. Most of these sites are no longer sampled. Files AS2 & FB2 and LVG4, ECN & RD2 contain analyses from the AS2 and FB2 sites in the south arm, and from LVG4, RD2, and ECN sites in the north arm, respectively (figure 1). These sites have been sampled at least once each year from 1966 to 2006. One exception to the LVG4, ECN & RD2 file is that the ECN site sampling is not continuous, but was substituted for the RD2 site when the RD2 site could not be reached for a short period of time due to bad weather. Appendix D gives more detailed information on the above databases.

LAKE-BREACH AND LAKE-BRINE DENSITY FILES

On August 1, 1984, the State of Utah breached (created an opening in) the Southern Pacific Railroad causeway near the west shore of the lake, approximately 0.25 miles east of Lakeside (figure 1). The purpose of the breach was to reduce the head differential that had developed across the causeway; the south arm was about 3.5 feet higher than the north arm. Just before the breach was opened, the UGS instituted an incremental sampling program designed to monitor the changes in lake-brine densities that would take place as a result of the breach. The monitoring program consisted of taking samples from the top to the bottom of the lake at one-foot increments. On the south arm, samples were collected at sites RT2, RT4, and 1S through 4S. On the north arm, samples were collected at sites RT3 (LVG4), 1A to 3A, and 1N to 4N (figure 1).

The incremental sampling program was successful in monitoring the changes in density that occurred in both the south and north arms of the lake due to the breach. The measured densities showed that after the breach enormous volumes of south-arm brine rushed into the north arm as surface flow. Density data also showed that equally large volumes of dense, north-arm brine flowed into the south arm as return flow through the bottom of the breach opening, where it greatly increased both the density and volume of the deep, south-arm brine layer (Gwynn and Sturm, 1987). Incremental sampling continues at sites RT2, RT3, and RT4.

OTHER SOURCES OF LAKE-BRINE CHEMISTRY

In addition to the lake-brine chemical analyses discussed and presented in this report, the USGS and the Utah Division of Water Quality (DWQ) have also analyzed the lake brines. Chemical analyses performed by the USGS have been done periodically at various locations throughout the lake, and mainly for nutrients, temperature, and salinity. The chemical analyses done by DWQ have been done on brine samples collected at various locations throughout the lake, to include some of the sites sampled by the UGS. DWQ collects samples from the top, middle, and bottom of the water column only, and analyzes these samples for the major ions, metals, and nutrients. These analyses are not presented as part of this report, but are online at the following Web sites. For USGS brine analyses, go to http://nwis.waterdata.usgs.gov/nwis/wq. The brine analyses compiled by the DWQ (analyzed by the Utah Department of Health) are on the Environmental Protection Agency's Storet Web site at http://www.epa.gov/storet.

LAKE-BRINE CHEMISTRY INTERPRETIVE REPORTS PUBLISHED BY UGS

Great Salt Lake has been the focus of numerous studies related to its chemistry, lake-level fluctuations, and history. Since 1963, over a dozen scientific interpretive reports about the lake have been published by the UGS: Hahl and Mitchell (1963), Dickson and McCullom (1965), Peck and Dickson (1965), Hahl (1968), Hahl and Handy (1969), Dickson and Rickers (1970), Madison (1970), Waddell and Bolke (1973), Whelan (1973), Whelan and Petersen (1975), Waddell and Fields (1977), Whelan and Petersen (1977), Sturm (1986), and Gwynn and Sturm (1987). Digital scanned copies of these reports are included in this CD as PDF files, in the folder "Lake-Brine Interpretive Reports" by the UGS.

SOUTH AND NORTH ARM WATER ELEVATIONS

The increase in lake volume (rise) and decrease in lake volume (fall) of Great Salt Lake influence the salinity of its brines. As the lake rises, its volume increases, and the salinity of the water decreases. This is enhanced for the south arm of the lake because this arm receives the majority of the tributary inflow. The north arm of the lake receives only inflow of water from the south arm. Most of the time, evaporation is greater than the dilution effects of the south-arm inflow into the north arm. As a result, the salinity of the north-arm brine remains relatively high, despite the volumetric fluctuations of the lake. The north-arm brine salinity decreased during the heavy flooding of the 1980s because evaporation was less than the high influx of lower-salinity south-arm brine. The relationship between brine salinity (Wt.% total-dissolved-solids) and lake elevation is shown in figure 2.

This report contains the USGS's provisional water elevations for both the south and north arms of the lake. These records are in the CD file folder titled "South and North Arm Water Elevations" as file GSLSL1. Water-elevation data are presented for the south arm from 1847 to 2005 and from 1966 to 2005 for the north arm. During the period from April 16, 1984 through April 30, 2001, discrepancies in lake elevations led to revisions of the base datum and the water-level records. The subsequent corrections to the lake-level records and a detailed explanation of these corrections are given in appendix E.

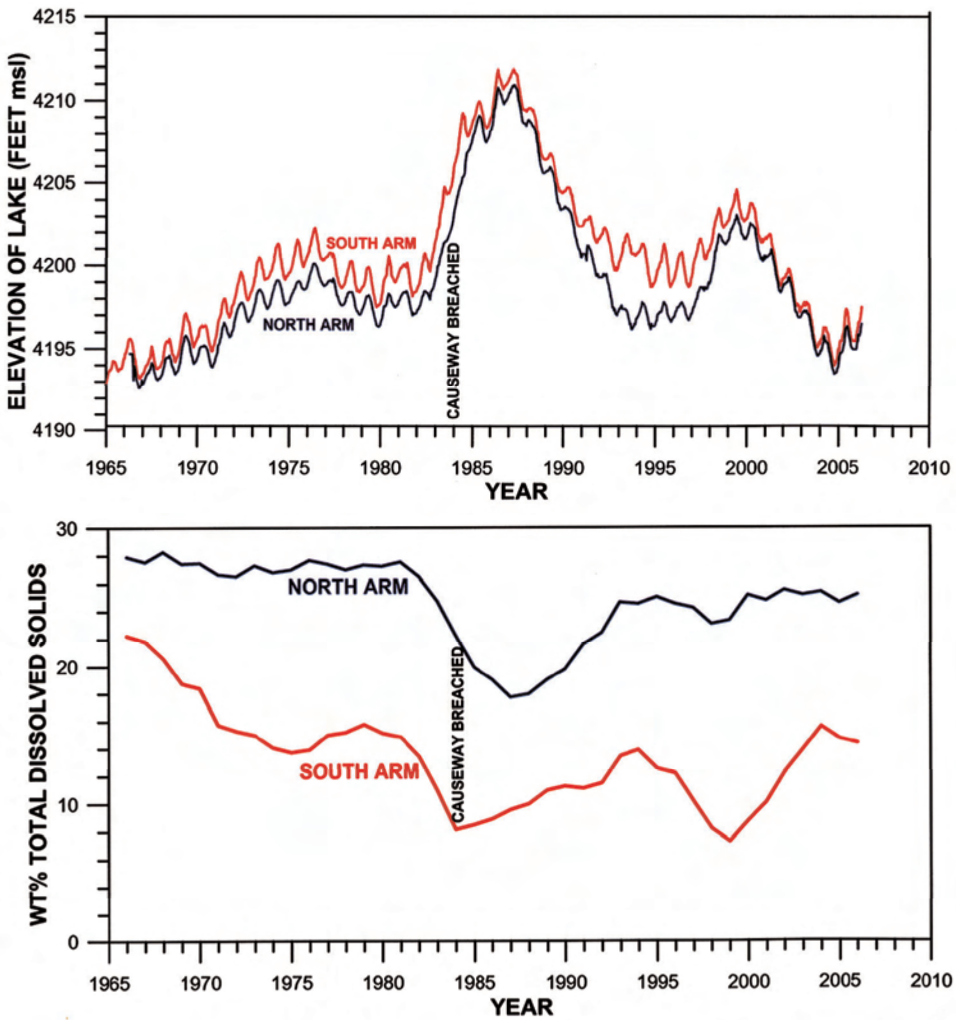

Figure 2. *Yearly average brine density versus lake elevation for the south and north arms of Great Salt Lake, 1966 to 2006.*

FUTURE OF THE UGS LAKE-BRINE SAMPLING PROGRAM

The UGS intends to continue to collect and analyze brine samples from Great Salt Lake. Currently, samples from the south arm are collected at sites AS2 and FB2 for chemistry, and at sites AC2, RT2, and RT4 for density only (figure 1). In the north arm of the lake, samples are collected from site LVG4 (RT3) for chemistry and density, site RD2 for chemistry, and site ECN for chemistry if site RD2 samples cannot be collected due to bad weather. If possible, samples from site NML at the northern end of the lake will be collected. Presently, the Utah Division of Wildlife Resources provides boat transportation to the north and south arm sites, and the Utah Division of Water Quality collects the samples. We anticipate that the lake-brine samples will continue to be analyzed by Chemical and Mineralogical Services, Salt Lake City, Utah, into the foreseeable future.

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APPENDIX A

PRE-1966 CHEMISTRY AND DENSITY DATA, GREAT SALT LAKE, UTAH

Date	Reference[1]	Density[2]	Wt%[3]	Na	K	Mg	Cl	SO_4	Ca	CO_3/HCO_3	Units	TDS[4]
1815	Frederick, E (1924)	1.123										
1850	Ebaugh, W.C. (1910)	1.170	22.28								g/l	261
1850	Ebaugh, W.C. (1910)	1.170	22.45								g/l	262
1850	Eckel, E.C. (1904)	1.170	22.28									
1850	Eckel, E.C. (1904)	1.170	22.48									
1850	Frederick, E (1924)	1.170										
1850	Garrett, V.B. (1960)	1.175	22.40									
1850	Miller, D.E. (1960)		22.40									
1869	Clarke, F.W. (1916)		14.99	33.15	1.60	2.52	55.99	6.57	0.17		DWt%	
1869	Ebaugh, W.C. (1910)	1.111	14.99								g/l	167
1869	Eckel, E.C. (1904)	1.111	14.99									
1869	Garrett, V.B. (1960)	1.108	14.80									
1869	Hague, A. (1877)			4.97	0.24	0.38	8.39	0.99	0.03		Wt%	
1869	Milne, D.B. (1934)			46.92	2.90	3.81	79.68	9.39	0.23		Moles/1000	
1873	Ebaugh, W.C. (1910)	1.102	13.42								g/l	148
1873	Eckel, E.C. (1904)	1.102	13.42									
1873	Frederick, E (1924)	1.110										
1873	Frederick, E (1924)		13.42									
1873	Kirkpatrick, R. (1934)		14.00									
1873	Miller, D.E. (1960)		13.70									
1877	Clarke, F.W. (1916)		13.79	33.45	?	3.18	56.21	6.89	0.20	0.07	DWt%	
1879	Clarke, F.W. (1916)		15.67	33.17	1.59	2.60	55.57	6.86	0.21		DWt%	
1883	Milne, D.B. (1934)			39.64	9.91	3.04	73.53	8.84	0.53		Moles/1000	
1885	Ebaugh, W.C. (1910)	1.123	16.72								g/l	188
1885	Eckel, E.C. (1904)	1.223	16.72									
1888	Ebaugh, W.C. (1910)	1.126									g/l	
1888	Eckel, E.C. (1904)	1.126										
1888	Frederick, E (1924)	1.261										
1889	Clarke, F.W. (1916)		19.56	33.39	1.08	2.60	56.54	5.97	0.24		DWt%	
1889	Ebaugh, W.C. (1910)	1.148									g/l	
1889	Ebaugh, W.C. (1910)	1.157	19.56								g/l	226
1889	Eckel, E.C. (1904)	1.148										
1889	Eckel, E.C. (1904)	1.157	19.56									
1889	Jones, D.K. (1933)		19.56	33.39	1.00	2.60	56.54	5.97	0.42		DWt%	
1892	Ebaugh, W.C. (1910)	1.156	20.51								g/l	238
1892	Ebaugh, W.C. (1910)	1.168	21.47								g/l	251
1892	Eckel, E.C. (1904)	1.156	20.51									
1892	Eckel, E.C. (1904)	1.168	21.47									
1892	Frederick, E (1924)	1.168										
1892	Stokes, W.L. (1966) [a]		14.99	33.15	1.60	2.52	55.99	6.57	0.17		DWt%	
1892	Clarke, F.W. (1916)		23.04	32.92	1.70	2.10	55.69	6.52	1.05		DWt%	230
1893	Ebaugh, W.C. (1910)		20.05								g/l	
1893	Eckel, E.C. (1904)		20.05									

Date	Reference[1]	Density[2]	Wt%[3]	Na	K	Mg	Cl	SO_4	Ca	CO_3/HCO_3	Units	TDS[4]
1894	Ebaugh, W.C. (1910)	1.154	21.16								g/l	244
1894	Eckel, E.C. (1904)	1.154	21.16									
1894	Frederick, E (1924)	1.154										
1895	Ebaugh, W.C. (1910)	1.158	21.39								g/l	248
1895	Eckel, E.C. (1904)	1.158	21.39									
1895	Frederice, E (1924)	1.158										
1896	Stokes, W.L. (1966) [b]		22.83	33.22	1.71	1.23	56.22	6.57	1.05		DWt%	
1900	Ebaugh, W.C. (1910)	1.158	20.90								g/l	242
1900	Ebaugh, W.C. (1910)	1.171	22.89								g/l	268
1900	Ebaugh, W.C. (1910)	1.181	23.36								g/l	276
1900	Ebaugh, W.C. (1910)	1.186	24.03								g/l	285
1900	Eckel, E.C. (1904)	1.158	20.90									
1900	Frederick, E (1924)	1.158										
1901	Ebaugh, W.C. (1910)	1.198	25.22								g/l	302
1903	Ebaugh, W.C. (1910)	1.221	27.72	9.58	0.73	0.16	15.27	1.86	0.05		Wt%	338
1903	Frederice, E (1924)		27.72									
1904	Clarke, F.W. (1916)		27.72	34.65	2.64	0.57	55.25	6.73	0.16		DWt%	
1904	Ebaugh, W.C. (1910)	1.191	25.20								Wt%	300
1904	Ebaugh, W.C. (1910)	1.212	26.71	8.77	0.89	0.43	14.54	1.82	0.06		Wt%	324
1904	Jones, D.K. (1933)		27.72	35.65	2.64	0.57	55.25	6.73	0.16		DWt%	
1905	Kirkpatrick, R. (1934)		26.00									
1907	Clarke, F.W. (1916)		22.99	32.97	3.13	1.96	55.11	6.66	0.17		DWt%	
1907	Ebaugh, W.C. (1910)	1.181	22.92	7.58	0.72	0.45	12.67	1.53	0.04		Wt%	271
1907	Jones, D.K. (1933)		22.99	32.97	3.13	1.96	55.11	6.66	0.17		DWt%	
1909	Ebaugh, W.C. (1910)	1.156	20.89	7.25	0.76	0.45	10.91	1.39	0.08		Wt%	242
1910	Clarke, F.W. (1911)		17.68	32.81	4.99	2.22	53.72	5.95	0.31		DWt%	
1910	Daines, L.L. (1920)			85.10	8.82	5.18	126.35	16.00	0.98		g/l	242
1910	Ebaugh, W.C. (1910)	1.133	17.68	5.79	0.88	0.39	9.48	1.05	0.06		Wt%	200
1913	Clarke, F.W. (1916)		20.35	33.17	1.66	2.67	55.48	6.68	0.16	0.09	DWt%	
1913	Stokes, W.L. (1966) [b]		20.35	33.17	1.66	2.76	55.48	6.68	0.16	0.09	DWt%	
1914	Frederick, E (1924)		19.71									
1914	Thomas, M.D. (1914)	1.152	19.71	74.18	4.34	6.06	127.81	14.57	0.46		g/l	228
1914	Thomas, M.D. (1914)	1.147	19.19	72.63	4.12	5.89	122.70	14.38	0.37		g/l	220
1914	Thomas, M.D. (1914)	1.149	19.45	73.49	4.56	5.97	125.00	14.42	0.40		g/l	224
1930	Conner, J.G. (1958)			69200	3380	5780	199500	11490	361	221	ppm	209800
1930	Stokes, W.L. (1966) [c]		21.00	32.90	1.61	2.75	57.05	5.47	0.17	0.05	DWt%	
1932	Harbeck, G.F. (1955)										ppm	251000
1935	Smith, W.W. (1933)	1.210	26.00									
1935	Smith, W.W. (1933)	1.220	27.00									
1935	Smith, W.W. (1933)			120.06		8.32	186.29	19.44	0.40	0.06	g/l	
1935	Smith, W.W. (1933)	1.220	27.00									
1935	Smith, W.W. (1933)	1.218	26.80									

Date	Reference[1]	Density[2]	Wt%[3]	Na	K	Mg	Cl	SO_4	Ca	CO_3/HCO_3	Units	TDS[4]
1936	Adams, T.C. (1938)		27.60			2.47	55.40	5.78	0.12	0.01	Moles/1000	
1936	Smith, W.W. (1933)											
1936	Smith, W.W. (1933)	1.217	26.75									
1936	Smith, W.W. (1933)	1.218	26.80									
1938	Done, R.S. (1838)			10.00	0.50	0.80	15.00	2.00	0.06		pph	
1939	State Chemist (1939)	1.223	27.85	111.60	7.50	8.83	185.23	27.15		0.07	g/l	341
1946	Nylander, A.F. (1964)			15.66	1.84	4.10	31.16	9.02	0.07		?	
1946	Perschon, A.R. (1947)	1.183	25.25									
1954	Conner, J.G. (1958)			86500	4070	6940	143000	17700	407	263	ppm	268000
1954	Conner, J.G. (1958)			88200	3980	7000	143000	17800	388	288	ppm	268000
1959	Glassett, J.M. (1964)	1.170	24.00	8.16	0.42	0.60	13.29	1.15			Wt%	
1959	Glassett, J.M. (1964)	1.170	24.00	34.00	1.75	2.50	55.44	6.31			DWt%	
1959	Hahl, D.C. (1965)	1.221	23.34	92200	5570	9440	158000	22600	463	398	ppm	286000
1960	Diaz, A.M. (1963)		27.00								Wt%	
1960	Glassett, J.M. (1964)	1.216	29.80	9.65	0.59	0.81	16.85	1.89			Wt%	
1960	Glassett, J.M. (1964)	1.208	26.10	8.22	0.59	0.85	14.56	1.88			Wt%	
1960	Glassett, J.M. (1964)	1.216	29.80	32.40	1.98	2.72	56.56	6.34			DWt%	
1960	Glassett, J.M. (1964)	1.208	26.10	31.50	2.25	3.25	55.80	7.20			DWt%	
1960	Hahl, D.C. (1965)	1.208	21.77	85700	4550	8050	147000	17400	319	327	ppm	263000
1960	Stokes, W.L. (1966) [c]		24.70	32.71	1.71	2.91	55.88	6.60	0.12	0.06	DWt%	
1961	Glassett, J.M. (1964)	1.098	14.40	1.63	0.32	0.45	7.90	1.08			Wt%	
1961	Glassett, J.M. (1964)	1.098	14.40	32.18	2.19	3.15	54.93	7.55			DWt%	
1961	Hahl, D.C. (1965)	1.186	20.23	77800	3810	6920	133000	12100	265	266	ppm	240000
1961	Stokes, W.L. (1966) [c]		26.90	31.55	1.95	3.49	54.63	8.21	0.10	0.07	DWt%	
1962	D'Arcy, R.G. (1967)			93.00	6.00	11.00	177.00	23.90	0.20		g/l	
1962	D'Arcy, R.G. (1967)			96.00	8.00	15.00	181.00	26.20	0.20		g/l	
1962	D'Arcy, R.G. (1967)			91.00	5.50	12.47	166.00	23.40	0.20		g/l	
1963	Eardley, A.J. (1964)	1.216	27.30	33.19	2.10	1.09	56.25	9.28			DWt%	
1963	Miller, D.E. (1960)		26.00									
1964	Stokes, W.L. (1966) [d]		22.10	32.25	2.12	3.22	54.81	7.29	0.10	0.08	DWt%	
1965	Stokes, W.L. (1966) [d]		22.20	32.58	2.06	3.31	54.14	7.67	0.12	0.09	DWt%	

EXPLANATION

[1] Reference listed in Appendix B
[2] Density is given in grams per cubic centimeter (g/cc)
[3] WT% is weight percent salt in the brine
[4] Units: g/l = grams per liter
DWt% = dry weight percent or percent of ion in the salt only
ppm = parts per million
Moles/1000 = Moles of ion per 1000 moles of water
Blank cells indicate analysis not made

APPENDIX B

ANNOTATED REFERENCES FOR PRE-1966 GREAT SALT LAKE BRINE CHEMISTRY LISTED IN APPENDIX A

Adams, T.C., 1938, Recent deposition of salt from Great Salt Lake: Journal of Geology, v. XLVI (Jan-Dec), p. 637-646.

Six of seven analyses given are already recorded from other sources. Analysis given from Zobell (written communication, 1936).

Arnow, Ted, 1984, Water-level and water-quality changes in Great Salt Lake, Utah, 1847-1983: U.S. Geological Survey Circular 913, 22 p.

Data have been reported elsewhere.

Clarke, F.W., 1911, Data of geochemistry: U.S. Geological Survey Bulletin 491, p. 143-146.

One sample not listed in 1926 issue as follows: W. Mac Farlane, Science v. 32, 1910. Collected Feb. 1910.

Clarke, F.W., 1916, Data of geochemistry: U.S. Geological Survey. Bulletin 616, p. 154-156.

Samples collected as follows:

(a) O.D. Allen, USGS Expl 40th parallel, Coll. 1869.
(b) C. Smart, Res. and attractions of Terr. UT., Anal. 1877.
(c) E. von Cochenhausen, Coll by Ochsenius April 16, 1879.
(d) J.E. Talmage, Sci. V. 14, 1892 – Sample collected 1889.
(e) E. Waller, Sch. Mines Quart. v. 14, 1892. Sample not dated.
(f) W. Blum, Rep. By Talmage, collected 1904.
(g) W.C. Ebaugh, collected October, 1907.
(h) R.K. Bailey, collected by Gale, Oct. 24, 1913. Also gives Br, Li, Fe_2O_3, Al_2O_3, and SiO_2.

Connor, J.G., and Mitchell, G., 1958, A compilation of chemical quality data for ground and surface water in Utah: Utah State Engineer Technical Publication no. 10. p. 276.

Three Analyses on Great Salt Lake as follows:

(a) Lucien Cutoff – main body, surface (1930)
(b) W. of Antelope Island, main body, Surface (1954)
(c) Main body, bottom – 24′ depth (1954)

Daines, L.L., 1910, Physiological experiments on some algae of Great Salt Lake: Salt Lake City, University of Utah, M.S. thesis, 12 p.

Total solids = 242.25, Salinity = 213.32

D'Arcy, R.G., Riley, J.M., and Crocker, L., 1967, Preliminary process development studies of desulfating Great Salt Lake brines and sea water: U.S. Bureau of Mines Report of Investigation 6928, 34 p.

Also gives following:	**Li**	**Normality**
(a) South Shore	.06	5.3
(b) N side SPRR causeway	.07	5.6
(c) S side SPRR causeway	.05	5.2

Diaz, A.M., 1963, Dissolved salt contribution to Great Salt Lake, Utah: U.S. Geological Survey Professional Paper 450-E, p. 163-165.

During 1960, 20 brine samples indicated lake was nearly saturated and TDS of lake was about 27 percent. Estimated lake load was 4.5 x 109 tons at end of 1960 Water Year.

Done, R.S., 1938, Low temperature equilibria between salts and solution in Great Salt Lake: Salt Lake City, University of Utah, M.A. thesis, 29 p.

Analysis from about 1938 – parts per hundred H_20 – 72, CO_3 = .02.

Eardley, A.J., 1938, Sediments of Great Salt Lake, Utah: Bulletin of the American Association of Petroleum Geologists, v. 22, no. 10, October, p. 1305-1411.

Gives eight analyses from Clarke, 1924, these analyses are similar to those given by Clarke (1922 or 1916).

Eardley, A.J., and Cohenour, R.E., 1964, Great Salt Lake *in* Crawford, A.L., editor, Geology of Salt Lake County: Utah Geological and Mineralogical Survey Bulletin 69, p. 79-87.

Analysis for sample taken 4-15-63; chemical analyses given in terms of assumed chemical combinations.

Ebaugh, W.C., and MacFarlane, W., 1910, Comparative analysis of water from Great Salt Lake: U [University of Utah] Pamphlet 34 (Reprinted from the Journal of Industrial and Engineering Chemistry, v. 2, no. 11, November 1910).

The following is a tabulation of Great Salt Lake brine data, and the source of that data, made by Ebaugh, W.C., and MacFarlane (1910).

Date	**Specific Gravity**	**TDS Wt. %**	**Grams/Liter**	**Authority**
1850	1.170	22.282	260.69	L.D. Gale
Summer 1869	1.111	14.9934	166.57	O.D. Allen
August 1873	1.102	13.42	147.88	H. Bassett
December 1885	1.1225	16.7162	187.65	J.E. Talmage
February 1888	1.1261	—	—	J.E. Talmage
June 1889	1.148	—	—	J.E. Talmage
August 1889	1.1569	19.5576	226.263	J.E. Talmage
August 1892	1.156	20.51	238.12	E. Waller
September 1892	1.1679	21.47	250.75	J.E. Talmage
1893	—	20.05	—	J.T. Kingsbury
December 1894	1.1538	21.16	244.144	J.E. Talmage
May 1895	1.1583	21.39	247.760	J.E. Talmage
June 1900	1.1576	20.90	241.98	H.N. McCoy & Thomas Hadley
July 1900	1.1711	22.89	268.09	H.W. Sheley
August 1900	1.1805	23.36	275.765	H.W. Sheley
October 1900	1.1860	24.03	285.020	H.W. Sheley
September 1901	1.1979	25.221	302.122	I.J. Seckles
October 1903	1.2206	27.72	338.36	Wm. Blum
June 1904	1.1905	25.196	299.96	J.E. Talmage
November 1904	1.2120	26.71	323.71	Wm. Blum
October 1907	1.1810	22.92	270.685	W.C. Ebaugh & Kenneth Williams
October 1909	1.1561	20.887	242.25	Wallace MacFarlane
February 1910	1.1331	17.681	200.32	Wallace MacFarlane

Eckel, E.C., 1904, The salt industry in Utah and California: U.S. Geological Survey Bulletin 225, p. 488-495.

Densities, weight percent salt, and total dissolved solids are as given in Ebaugh, W.C., and Mac Farlane, W. (1910) above. Chemical analyses are also given as salts.

Flint, Gerhard, 1971, Great Salt Lake Chemicals: Reprinted from Kirk-Othmer Encyclopedia of Chemical Technology, Supplemental Volumes, 2nd Edition, p. 438-467.

Data are not date specific (1963-65) other than sample taken between Promontory Point and Fremont Island which may show dilution from the Bear River.

Frederick, Elfriede, 1924, On the bacterial flora of Great Salt Lake and the viability of other microorganisms in Great Salt Lake water: Salt Lake City, University of Utah, M.S. thesis, 65 p.

Includes one analysis from Prof. O.D. Allen (1873) and three from M.D. Thomas thesis (1914, 1873, and 1903).

Glassett, J.M., and Anderson, B.J., 1964, The recovery of salts from the waters of Great Salt Lake: Salt Lake City, Utah Engineering Experiment Station Bulletin 128, v. 55, no. 21, 80 p.

Samples are as follows:

(a) Sunset Beach, Aug. 29, 1959
(b) Black Rock, July 2, 1960
(c) Boat Harbor, Nov. 20, 1960
(d) Boat Harbor, Sept. 4, 1961

Garrett, V.B., 1960, A study of hatching *Artemia salina* of Great Salt Lake: Salt Lake City, University of Utah, M.S. thesis, 49 p.

1850-52 reference from Howard Stansbury and the 1869-70 reference from Clarence King.

Hague, A., and Emmons, S.F., 1877, Report of the geological exploration of the 40th Parallel, *in* Descriptive Geology, Clarence King in Charge: Professional Papers of the Engineering Department, U.S. Army, no. 18, p. 436.

Includes water analysis as follows: Great Salt Lake (1869), Sevier Lake, Oroomcah Sea, Dead Sea, Atlantic Ocean and the Mediterranean Sea. Analyses are given as assumed salts.

Hahl, D.C., and Mitchell, C.G., 1963, Dissolved-mineral inflow to the Great Salt Lake and chemical characteristics of the Salt Lake brine – part 1- Selected hydrological Data: Utah Geological and Mineralogical Survey Water Resources Bulletin 3 – Part 1, 40 p.

Contains many good analyses, mainly between 1959 and 1961.

Hahl, D.C., Wilson, M.T., and Langford, R.H., 1965, Physical and chemical hydrology of Great Salt Lake, Utah: U.S. Geological Survey Professional Paper 525-C, p. C183.

Several trace elements are also reported, all data reported in ppm.

(a) June 1959
(b) November 1961
(c) Average of analyses collected in southern arm of lake in April, July, and October, 1960, and January to February, 1961.

Handy, A.H., and Hahl, D.C., 1966, Great Salt Lake – chemistry of the water, *in* Stokes, W.L., editor, Great Salt Lake - Guidebook to the Geology of Utah: Utah Geological Society Guidebook 20, p. 135-151.

Computed from data reported by Richardson (1906, p. 34). (a) – 1850 (b) Aug., 1892

Reported by Clarke (1924) (a) 1896, (b) 1913.

Hahl and Mitchell (1963, p. 38) 2 mi W. Prom. Pt. so. of causeway. (a) March 1930, (b) April 1960, (c) Nov. 1961.

Sample collected 1 mile south of causeway in 25 feet of water at 5-foot depths. (a) July, 1964, (b) July, 1965. Analyses also given for SiO_2, Fe, Li, and B.

Harbeck, G.F., Jr., 1955, The effect of salinity on evaporation: U.S. Geological Survey Professional Paper 272-A, 6 p.

Pan brine (experiment) was 251,000 ppm. Work done by Adams, July-Oct., 1932.

Jones, D.K., 1933, A study of the evaporation of the water of Great Salt Lake: Salt Lake City, University of Utah, M.S. thesis, 33 p.

Analyses: (a) J.E. Talage (1889); (b) W. Blum (1904); and (c) W.C. Ebough [sic] (1907). Also shows Trace for Br and Li respectively.

Kirkpatrick, Ruth, 1934, The life of Great Salt Lake with special reference to algae: Salt Lake City, University of Utah, M.S. thesis, 30 p.

Highest level was 1873 (14% salt). Lowest level was 1905 and 1906 (greater than 26% salt), at time of investigation, lake level low (almost 26%).

Madison, R.J., 1970, Effects of a causeway on the chemistry of the brine in Great Salt Lake, Utah: Utah Geological and Mineralogical Survey Water-Resources Bulletin 14, 52 p.

Contains many good analyses, mainly during 1967-68.

Miller, D.E., 1969, Great Salt Lake – past and present: (Distributed by Dr. David E. Miller, University of Utah) Salt Lake City. 2nd Edition.

The following is reported, (a) Stansbury, 1850, (b) extreme high water mark, 1873 and (c) 1962.

Milne, D.B., 1934, Economic possibilities of brines found in Great Salt Lake: Salt Lake City, University of Utah M.S. thesis, 120 p.

Ref. (a) 1850 by L.O. Gale; (b) Summer 1869 by A.D. Allen and (c) August 1883-4? by Bassett. Data are converted back from proposed compounds, originally given as % in 1000 moles ? water.

Nylander, A.F., and Jensen, J.H., 1964, Magnesium chloride from naturally occurring brines and evaporites: Journal of Metals, September, p. 718-20.

Gives four analyses for typical sea water, Dead Sea, Bonneville, and Boccana de Viorita Sechura samples. Analyses are pre-1946.

Perschon, A.R., 1947, The recovery of magnesia from the Great Salt Lake brine utilizing oolitic sand from the lake shorelines: Salt Lake City, University of Utah, M.S. thesis, 29 p.

Sample taken on June 1, 1946, near Black Rock.

Smith, W.W., 1933, Evidence of bacterial flora indigenous to the Great Salt Lake in Utah: Salt Lake City, University of Utah, M.S. thesis, 101 p.

1935 sample from Adams (hydrometer), and 1935-36 samples taken by Twleves (pychmometer). Actual chemical analysis for Dec. 29, 1935 given, includes 6.2 ml N2, 0.57 ml O_2, and 129.2 ml CO_2. Other analyses include densities (a) 1.220 (9-11-35), (b) 1.218 (11-30-35), (c) 1.217 (1-23-36), and (d) 1.218 (1-23-36).

State Chemist, 1939, Analysis of Great Salt Lake water made August 1939: Department of Agriculture (no other information available).

Several elements other than these reported.

Thomas, M.D., 1914, A study of the water of Great Salt Lake: Salt Lake City, University of Utah, B.A. thesis, 14 leaves.

(a) Sample collected on February 14, 1914. Height of water (Saltair gauge) 5.5 feet. Wt. Percent and percent of solids also given.
(b) Sample collected April 20, 1914, gauge = 6.0 feet.
(c) Sample collected March 14, 1914, gauge = 5.8 feet.

APPENDIX C

LOCATIONS OF GREAT SALT LAKE BRINE-SAMPLING SITES

SOUTH ARM SAMPLING SITES

SITE	LATITUDE	LONGITUDE	UTM-NORTH	UTM EAST	SITE-LOCATION DESCRIPTION
1S	41.2317	-112.8408	4565895.5730	345718.9954	SE FROM BREACH OPENING
2S	41.2267	-112.8373	4565334.2660	346000.6099	SE FROM BREACH OPENING
3S	41.2167	-112.8353	4564220.5270	346144.8086	SE FROM BREACH OPENING
4S	41.2058	-112.8252	4562996.9050	346972.0831	SE FROM BREACH OPENING
ABN	41.0683	-112.2317	4546857.7950	396518.6135	N OF ANTELOPE ISLAND CAUSEWAY BRIDGE
AC1	40.9933	-112.2502	4538554.0600	394841.6087	LINE FROM ANTELOPE & CARRINGTON ISLANDS
AC2	40.9960	-112.3483	4538976.5570	386594.5185	LINE FROM ANTELOPE & CARRINGTON ISLANDS
AC3	40.0000	-112.4458	4428548.2270	376581.4006	LINE FROM ANTELOPE & CARRINGTON ISLANDS
AC4	40.0024	-112.5443	4428955.6830	368177.3622	LINE FROM ANTELOPE & CARRINGTON ISLANDS
AS1	40.8483	-112.1841	4522380.1770	400183.6846	LINE FROM ANTELOPE & STANSBURY ISLANDS
AS2	40.8350	-112.2550	4520986.9840	394185.7247	LINE FROM ANTELOPE & STANSBURY ISLANDS
AS3	40.8166	-112.3241	4519030.1830	388328.6023	LINE FROM ANTELOPE & STANSBURY ISLANDS
AS4	40.8108	-112.3933	4518476.8130	382482.0403	LINE FROM ANTELOPE & STANSBURY ISLANDS
AS5	40.7958	-112.4608	4516904.3730	376760.8230	LINE FROM ANTELOPE & STANSBURY ISLANDS
BRBS	41.2333	-112.3366	4565305.0780	387982.8102	S OF OPENING IN SPRR EAST OF PROM. POINT
BREACH	41.2216	-112.8475	4564790.5770	345136.2109	W END OF SPRR CAUSEWAY NEAR LAKESIDE
FB1	41.1675	-112.3950	4558077.1380	382971.1477	LINE BETWEEN FREMONT AND BIRD ISLANDS
FB2	41.1350	-112.4600	4554558.5830	377457.5210	LINE BETWEEN FREMONT AND BIRD ISLANDS
FB3	41.1033	-112.5200	4551125.5690	372359.9596	LINE BETWEEN FREMONT AND BIRD ISLANDS
FB4	41.0716	-112.5816	4547698.4550	367123.1414	LINE BETWEEN FREMONT AND BIRD ISLANDS
GSLB	41.2717	-112.3675	4569603.9730	385460.1250	OPENING IN GSLM BRIDGE OVER BEAR RIVER
HI	41.7120	-112.3500	4507663.5000	385968.7200	HARDY SALT INLET ON SOUTH END OF LAKE
IS1	41.0696	-112.6601	4547599.0380	360523.5491	INDUSTRY SITE NO. 1
IS2	41.0106	-112.4863	4540785.7450	375014.5826	INDUSTRY SITE NO. 2
MI	40.7958	-112.4608	4516904.3730	376760.8230	MORTON INLET AT SOUTH END OF LAKE
NLI	40.9360	-112.5250	4532772.0000	371618.8800	NL INLET AT NORTH END STANSBURY ISLAND
NLN	41.0656	-112.5972	4547056.2580	365800.2712	WEST OF BIRD-HAT ISLAND
RT1	40.7525	-112.2441	4511815.7500	394974.8295	RES. TWR 1- 2 MI OFF SOUTH SHORE
RT2	41.0342	-112.2412	4543083.6380	395663.2016	RES TWR 2 - NEAR COUNTY(S) INTERSECTION
RT4	41.0966	-112.4324	4550257.1420	379704.0476	RESEARCH TOWER NORTHWEST OF BIRD-HAT ISL.
SI	40.8000	-112.4320	4517542.0000	379201.5000	MORTON INLET SOUTH END OF STANSBURY ISL.
SS	40.4758	-112.2200	4481072.3540	396583.5633	SOUTH END OF GSL NEAR BOAT HARBOR

NORTH ARM SAMPLING SITES

SITE	LATITUDE	LONGITUDE	UTM-NORTH	UTM EAST	SITE-LOCATION DESCRIPTION
1A	41.2270	-112.8705	4565431.3230	343221.0837	OUT AND WESWARD FROM BREACH OPENING
2A	41.2257	-112.9000	4565336.1960	340745.1224	OUT AND WESWARD FROM BREACH OPENING
3A	41.2832	-112.9323	4571779.6020	338179.6714	OUT AND WESWARD FROM BREACH OPENING
1N	41.2217	-112.8413	4564786.2100	345656.0812	SOUTHEAST FROM BREACH OPENING
2N	41.2237	-112.8398	4565005.5870	345786.5221	SOUTHEAST FROM BREACH OPENING
3N	41.2257	-112.8373	4565223.1930	346000.7775	SOUTHEAST FROM BREACH OPENING
4N	41.2266	-112.8358	4565324.8950	346128.7149	SOUTHEAST FROM BREACH OPENING
ECN	41.2198	-112.5652	4564126.1930	368796.8237	N OF EAST CULVERY IN SPRR CAUSEWAY
LCI	41.2150	-112.5100	4563723.5000	373418.1200	GSLM INLET SOUTH END PROMONTORY POINT
LVG1	41.2966	-112.5116	4572572.8500	373438.3679	LINE FROM LVH TO GUNNISON ISL.
LVG2	41.3075	-112.5916	4573902.7030	366762.1862	LINE FROM LVH TO GUNNISON ISL.
LVG3	41.3146	-112.6766	4574824.9470	359661.5432	LINE FROM LVH TO GUNNISON ISL.
LVG4	41.3241	-112.7608	4576019.2670	352634.7752	LINE FROM LVH TO GUNNISON ISL.
LVG5	41.3330	-112.8466	4577156.6840	345474.7064	LINE FROM LVH TO GUNNISON ISL.
LVH	41.2475	-112.5140	4567338.0000	373145.8000	ENTRANCE TO LITTLE VALLEY HARBOR
NML	41.5510	-112.8865	4601431.7700	342663.3141	FAR NORTH END OF LAKE
RD1	41.4366	-112.6675	4588354.8410	360683.9118	LINE FROM ROZEL POINT TO DOLPHIN ISLAND
RD2	41.4416	-112.7475	4589041.8210	354011.0351	LINE FROM ROZEL POINT TO DOLPHIN ISLAND
RD3	41.4483	-112.8250	4589919.3220	347551.9788	LINE FROM ROZEL POINT TO DOLPHIN ISLAND
RD4	41.4533	-112.9041	4590616.8340	340956.4235	LINE FROM ROZEL POINT TO DOLPHIN ISLAND
RD5	41.4583	-112.9766	4591307.7820	334913.1111	LINE FROM ROZEL POINT TO DOLPHIN ISLAND
RT3	41.3241	-112.7608	4576019.2670	352634.7752	RESEARCH TOWER 3 - AT LVG4 SITE

Note: Locations of sampling sites are shown on Figure 1.

APPENDIX D

DETAILS OF GREAT SALT LAKE BRINE DATABASES

The following Excel® files are included in the Utah Geological Survey's Great Salt Lake brine database: **AS2 & FB2.xls; LVG4, ECN & RD2.xls; SOUTH OLD.xls; NORTH OLD.xls; BRBS.xls; GSLB.xls; MISC.xls; DEN1-4S.xls; DEN 1-3A.xls; DEN 1-4N.xls; DENRT2.xls; DENRT3.xls;** and **DENRT4.xls**. The following paragraphs give details of the contents of the individual files.

File **AS2 & FB2.xls** contains 1778 south-arm chemical analyses from the AS2 and FB2 sites (see figure 1) for the period 1966 to 2006, and file **LVG4, ECN and RD2.xls** contains 1243 north-arm chemical analyses from the LVG4, ECN and RD2 sites (see figure 1) for the period 1966 to 2006. Both of these files contain location (latitude, longitude, UTM-north, and UTM-east); date of sampling; depth of the sample from the surface in feet; laboratory density; concentration values for Na, Mg, K, Ca, Cl, SO4, and TDS all in terms of grams per liter; and Br, Li, and B in terms of parts per million. The above values are followed by WT%-TDS (weight percent of dissolved solids), LK-ELEV (lake elevation), SAMP-ELEV (sample elevation), and DWP_NA (dry-weight percent of the various major ions).

Files **SOUTH OLD.xls** and **NORTH OLD.xls** represent south- and north-arm data, respectively. The **SOUTH OLD.xls** file contains data from the following sampling sites: AC1-4, AS1-AS5, FB1-FB4, IS1, IS2, NLN, RT1 and RT2, and SS, and contains 5478 records. The **NORTH OLD.xls** file contains data from the following sampling sites: ECN, LVG1-LVG5, NML, RD1-RD4, and contains 2419 records. Both files contain location (latitude and longitude); date sampled; depth of sample from the surface; lake elevation and sample depth; F.Den (field density); L.Den (lab density); concentration values for Na, Mg, K, Ca, Cl, SO_4, and TDS in terms of grams per liter; and Br, Li, and B in terms of parts per million. The above values are followed by WT%-TDS (weight percent of dissolved solids).

Files **BRBS.xls**, **GSLB.xls**, and **MISC.xls** present chemistry data from the Bear River Bridge (south), Great Salt Lake bridge, and miscellaneous sites (ABN, HI, LCI, LVH, MI, NLI, and SE locations). These files contain location (latitude, longitude, UTM-north, and UTM-east); date of sampling; depth of sample from the surface; field and lab density; brine temperature; the ions Na, K, Mg, Ca, Cl, SO4, and TDS in terms of grams per liter; Li, Br, and B in terms of parts per million; and weight percent total dissolved solids.

Files **DEN 1S-4S.xls, DEN 1A-3A.xls, DEN 1N-4N.xls, DEN RT2.xls, DEN RT3.xls** and **DEN RT4.xls** contain the following information: site, location (latitude, longitude, UTM-north, and UTM-east), date of sample, depth from surface, and laboratory density, lake elevation, and sample elevation. These files contain no chemical data.

APPENDIX E

USGS GREAT SALT LAKE DATUM CORRECTION

The following description of the adjustment of the elevation records is taken from the USGS Web site: http://ut.water.usgs.gov/gsl%20corr/gslcorrection.htm, accessed June 1, 2005.

ADJUSTMENTS TO 1966-2001 GREAT SALT LAKE WATER-SURFACE ELEVATION RECORDS AS A RESULT OF CORRECTED BENCHMARK ELEVATIONS

Introduction

Great Salt Lake is divided into a north and a south part by a rock-fill causeway. The U.S. Geological Survey (USGS) operates gages that collect water-surface elevation data on the south part of the lake at the Boat Harbor gage (USGS station 10010000), and on the north of the lake at the Saline gage (10010100). It has been known since the mid-1980s that the difference in water-surface elevation between the two parts of the lake as measured at the Boat Harbor and Saline gages was greater than the difference measured directly at the causeway. Because the lake surface is considered to be relatively flat on calm days and the gages were periodically checked against permanent benchmarks with surveying levels; the difference was assumed to be an error in the given elevations of the benchmarks to which the gages are referenced. During 1969-82 and 1997-99, a gage was operated on the south part of the lake at Promontory Point (USGS station 10010050), referenced to the same line of benchmarks as the Saline gage. The difference in water-surface elevation between the two parts of the lake as measured at the Promontory Point and Saline gages generally agreed with the difference measured directly at the causeway. Until this time (April 2001), there was no economically feasible way to verify the given elevations of the reference benchmarks of the Great Salt Lake elevation gages.

In 1999, a high-resolution Global Positioning System (GPS) survey was conducted by the National Geodetic Survey (NGS) in Utah. The U.S. Geological Survey and Utah Department of Natural Resources, Water Resources Division, participated in this survey to determine the elevation of five benchmarks around Great Salt Lake that are used for the determination of water-surface elevations of the lake. The final calculations from this survey were provided to the USGS by the NGS in March 2001. This survey provided the first direct check and comparison of the elevations of all of these benchmarks. When the Boat Harbor and Saline gages are adjusted to the new benchmark elevations, the difference in water-surface elevation between the two parts of the lake measured at the gages generally agrees with the difference measured directly at the causeway. The records of water-surface elevation will be adjusted at the Boat Harbor, Saline, and Promontory Point gages according to the 1999 NGS GPS benchmark elevations.

Findings

Water-surface elevations reported at the USGS Great Salt Lake gages are considered to be accurate to within +/- 0.10 foot of the datum in use. Of the five benchmarks surveyed by the USGS as part of the larger 1999 NGS GPS survey, only three were considered by the NGS to be accurate to within 0.10 foot (FMK 77 1966, Saltair, and WES DES UMPS). The elevation of the FMK 77 1966 benchmark, located near the Saline gage, was found by the GPS survey to be 4,231.155 feet National Geodetic Vertical Datum of 1929 (NGVD 29). Data from the establishment of the Saline gage in 1966 to the present are currently adjusted to the FMK 77 1966 benchmark with a given elevation of 4,230.888 feet. All Saline gage elevations from 1966 to 2001 need to be increased by 0.267 foot (0.27 foot, rounded) to account for the change in the given elevation of FMK 77 to 231.155 feet. The Promontory Point gage was referenced to the FMK 73 1966 benchmark, which is on the same line as the FMK 77 1966 benchmark. Because the GPS survey adjusted the FMK 77 benchmark 0.27 foot higher, and the datums of FMK 73 and 77 have historically agreed, it is assumed that the given elevation of FMK 73 should also be raised 0.27 foot. This will be verified with surveying levels in the near future. The Boat Harbor gage has been tied to two different permanent benchmarks since the 1960s. The first, BM H-39 1922, was used from sometime before the 1960s until 1985. Sometime between 1985 and 1989 it was destroyed by the construction of Interstate Highway 80. After 1985, the primary reference benchmark for the Boat Harbor gage was C-174 (1970). By using the new GPS survey elevation for the Saltair benchmark (located at the Boat Harbor gage) and the surveyed height differences between Saltair, C-174, and BM H-39 from previous levels, elevations for C-174 and BM H-39 corrected to the GPS survey were computed. From this it was found that the previously given elevation for the BM H-39 was 0.14 foot too high, and for the C-174 benchmark was 0.42 foot too high.

In addition to the changes in given elevations for the Boat Harbor gage reference benchmarks, all three gages used during 1980-2001 settled. Here is a synopsis of the findings on the settling of Boat Harbor gages from 1980 to 2001. During 1981-83, the gage settled 0.25 foot. This problem was discovered and corrected for in 1983. In 1985, the gage became inundated by the rising lake and had to be moved to a temporary location, attached to a large concrete sign nearby. This sign, and therefore the gage, settled about 0.44 foot during the period it was operated from 1985 to 1989. This problem was not discovered until 2001 because the gage was established with BM H-39 (1922), which had a given elevation 0.14 foot too high, and had its datum checked when it was discontinued against benchmark C-174 (1970), which had a given elevation that was 0.42 foot too high. Although the gage settled about 0.44 foot, it appeared to the surveyors at the time to be off by only about 0.12 foot, and no changes were made. A prorated correction for this settling will need to be applied to the Boat Harbor water-surface elevation data from July 1985 to August 1989. Because the current gage was established off of the settled temporary gage, a constant -0.44-foot correction will need to be applied to the data from August 1989 to September 1994, when the 0.44-foot error was removed.

The (current) gage installed in August of 1989 also settled during the first 6 or so years it was used. Levels indicate that the gage settled about 0.55 foot from September 1989 to July 1993, and about 0.11 foot from July 1993 to June 1995. The record was adjusted for part of this settling in 1995. In 1995, the 0.25-foot settling correction applied in 1983 was mistakenly applied to the 1984-1995 records. No evidence could be found in 2001 that this 0.25-foot correction was needed during 1984-1995. There is no indication that the gage has moved since 1995.

Changes to the Great Salt Lake Elevation Records on May 1, 2001

Saline Gage:

To adjust for the change in given elevation for benchmark FMK 77 (1966) (described above), 0.25 foot will be added to all Saline gage water-surface elevation data from April 1966 to April 30, 2001. From May 1, 2001, forward, reported water-surface elevation data will reflect the datum correction discovered by the 1999 GPS survey.

Promontory Point Gage:

To adjust for the change in given elevation for benchmark FMK 73 (1966) (described above), 0.25 foot will be added to the Promontory Point gage water-surface elevation data from 1969 to 1999.

Boat Harbor Gage:

It should be noted (as described above) that although GPS levels indicate that the benchmark BM H-39 had a given elevation that was 0.14 foot too high, the record will not be adjusted prior to 1984 for this apparent error at this time. This 0.14-foot error likely entered the record in the 1950s (or earlier), and not enough information is available to justify an adjustment back that far of such a small amount. Below is a tabular summary of the corrections that will be applied to the Boat Harbor gage water-surface elevation data on May 1, 2001. These corrections are actually the sum of a combination of corrections to the problems described above in the "Findings" section. From May 1, 2001 forward, reported water-surface elevation data will reflect the datum correction discovered by the 1999 GPS survey.

Period of time	**Correction applied to Boat Harbor gage record May 1, 2001 (in feet)**
4/16/1984 - 6/30/1985	+0.10
7/1/1985 - 6/30/1986	0.00
7/1/1986 - 6/30/1987	-0.10
7/1/1987 - 6/30/1988	-0.20
7/1/1988 - 8/21/1989	-0.35
8/22/1989 - 9/30/1990	-0.40
10/1/1990 - 9/30/1991	-0.40
10/1/1991 - 9/30/1992	-0.50
10/1/1992 - 9/30/1993	-0.50
10/1/1993 - 9/30/1994	-0.50
10/1/1994 - 9/30/1995	-0.40
10/1/1995 - 4/30/2001	-0.40

For information on these changes, please contact the U.S. Geological Survey at (801) 908-5000.