SALT BUDGET FOR WEST POND, UTAH,

APRIL 1987 TO JUNE 1989

By Steven R. Wold and Kidd M. Waddell

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Multiply	By	To obtain
acre	0.4047	hectare
	4,047	square meter
acre-foot	0.001233	cubic hectometer
	1,233	cubic meter
foot	0.3048	meter
inch	2.54	centimeter
mile	1.609	kilometer
ton (short)	0.9072	metric ton or megagram
ton per acre-foot	0.735467	gram per liter

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{o}F = 1.8\ (^{o}C) + 32.$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Concentration is given in grams per liter (g/L) or milligrams per liter (mg/L). Grams or milligrams per liter are units expressing the solute per unit volume (liter) of water.

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ABSTRACT

During operation of the West Desert pumping project, April 10, 1987, to June 30, 1989, data were collected as part of a monitoring program to evaluate the effects of pumping brine from Great Salt Lake into West Pond in northern Utah. The removal of brine from Great Salt Lake was part of an effort to lower the level of Great Salt Lake when the water level was at a high in 1986. These data were used to prepare a salt budget that indicates about 695 million tons of salt or about 14.2 percent of salt contained in Great Salt Lake was pumped into West Pond. Of the 695 million tons of salt pumped into West Pond, 315 million tons (45 percent) were dissolved in the pond, 71 million tons (10.2 percent) formed a salt crust at the bottom of the pond, 10 million tons (1.4 percent) infiltrated the subsurface areas inundated by storage in the pond, 88 million tons (12.7 percent) were withdrawn by American Magnesium Corporation, and 123 million tons (17.7 percent) discharged from the pond through the Newfoundland weir. About 88 million tons (13 percent) of the salt pumped from the lake could not be accounted for in the salt budget. About 94 million tons of salt (1.9 percent of the total salt in Great Salt Lake) flowed back to Great Salt Lake.

INTRODUCTION

West Pond is in a basin west of Great Salt Lake in northern Utah (fig. 1). West Pond is bordered to the east by the Newfoundland Mountains, to the north by the Southern Pacific Transportation Company railroad, to the west by the Bonneville Salt Flats (not shown in fig. 1), and to the south by Interstate 80. Because of the recent history of Great Salt Lake, the West Pond pumping project was designed, and a monitoring program was established to evaluate the movement and storage of brine from Great Salt Lake to West Pond. The monitoring program resulted in a salt budget for West Pond as presented in the following synopsis adapted from Waddell and others (1992):

Great Salt Lake in northern Utah is divided into north and south parts by the Southern Pacific Transportation Company railroad causeway. West Pond is west of Great Salt Lake in the West Desert. Prior to 1983, the level of Great Salt Lake was at an elevation of about 4,200 feet above sea level. In 1983, the level of Great Salt Lake began a rapid rise, and by 1986 had reached its recent historic high of 4,211.85 feet above sea level, causing flooding around the lake. To combat the rising waters, the State of Utah implemented two lake-level-control measures: (1) breaching the Southern Pacific Transportation Company causeway, and (2) beginning the West Desert pumping project.

In 1984, the Southern Pacific Transportation Company causeway was breached by a 270-foot opening at a site near Lakeside (not shown in fig. 1) on the western edge of the lake. The breach was designed to equalize the hydraulic-head differential that had developed between the parts of the lake to the south and north of the causeway, the water to the south being the highest. Although the project was successful in lowering the level of the south part by about 9 inches, the level of the entire lake continued to rise in response to greater-than-average precipitation over the basin.

The West Desert pumping project was implemented after breaching the causeway. The pumping project was designed to remove water from Great Salt Lake and store it in West Pond where additional storage area was available, and where additional surface area would provide for a net increase in evaporation. On April 10, 1987, the first of three pumps was started at the new pumping plant at Hogup Ridge (fig. 1) on the western shore of Great Salt Lake. The brine was lifted from the north part of the lake and discharged westward through a 4-mile-long canal. At the end of the canal, brine spread out on the floor of the Great Salt Lake Desert north of the Southern Pacific Transportation

Company causeway and then flowed southward through a trestle into West Pond.

West Pond occupies a natural basin in the Great Salt Lake Desert. The two Bonneville Dike segments (south of Floating Island) (fig. 1) were built to protect the Bonneville Salt Flats to the west and the interstate freeway to the south, especially from wind tides driven by the north wind. The Newfoundland Dike (south of the Newfoundland Mountains)(fig. 1) was built to keep the water from flowing from West Pond to the northeast and back into the lake. The dike also was designed to provide control to the elevation of the surface of West Pond through a series of adjustable sections of the weir. The elevation of the brine during the 2-year (1987-89) pumping period in West Pond is shown in figure 2. When filled to capacity of 690,000 acre-feet at 4,216.5 feet above sea level, West Pond covers an area of about 320,000 acres, with a maximum depth of about 7 feet.

The quantity of inflow and outflow of brine for West Pond is controlled by the rate of pumpage, by evaporation, and by the elevation of the weir at the Newfoundland Dike. American Magnesium Corporation (AMAX) constructed a solar ponding complex at the southern end of West Pond in which a magnesium-chloride-rich brine is produced. Brine from West Pond was pumped into the solar ponds and concentrated to form high-magnesium chloride feedstock for the AMAX magnesium-production plant. The study was done in cooperation with the Utah Geological Survey and the Utah Department of Natural Resources, Division of Water Resources, to evaluate the movement and storage of brine from Great Salt Lake to West Pond.

Purpose and Scope

The purpose of this report is to present the results of a study by the U.S. Geological Survey (USGS) to evaluate the quantity and distribution of dissolved salts that were pumped into West Pond from April 1987 to June 1989 from Great Salt Lake. The salt load and distribution of brine in West Pond is a concern of the Utah State legislature, officials of salt companies in the area, and the general public, who are interested in the quantity of salt that was deposited in West Pond from Great Salt Lake and in the feasibility of reusing the deposited salt.

Waddell and others (1992) determined the salt budget of West Pond from April 10, 1987, to April 6, 1988, and this report updates the salt budget through June 11, 1989. Data used for the evaluation, such as specific gravity, water levels, and chemical constituents of brine, were collected as part of a study that began April 10, 1987, when pumping into West Pond began.

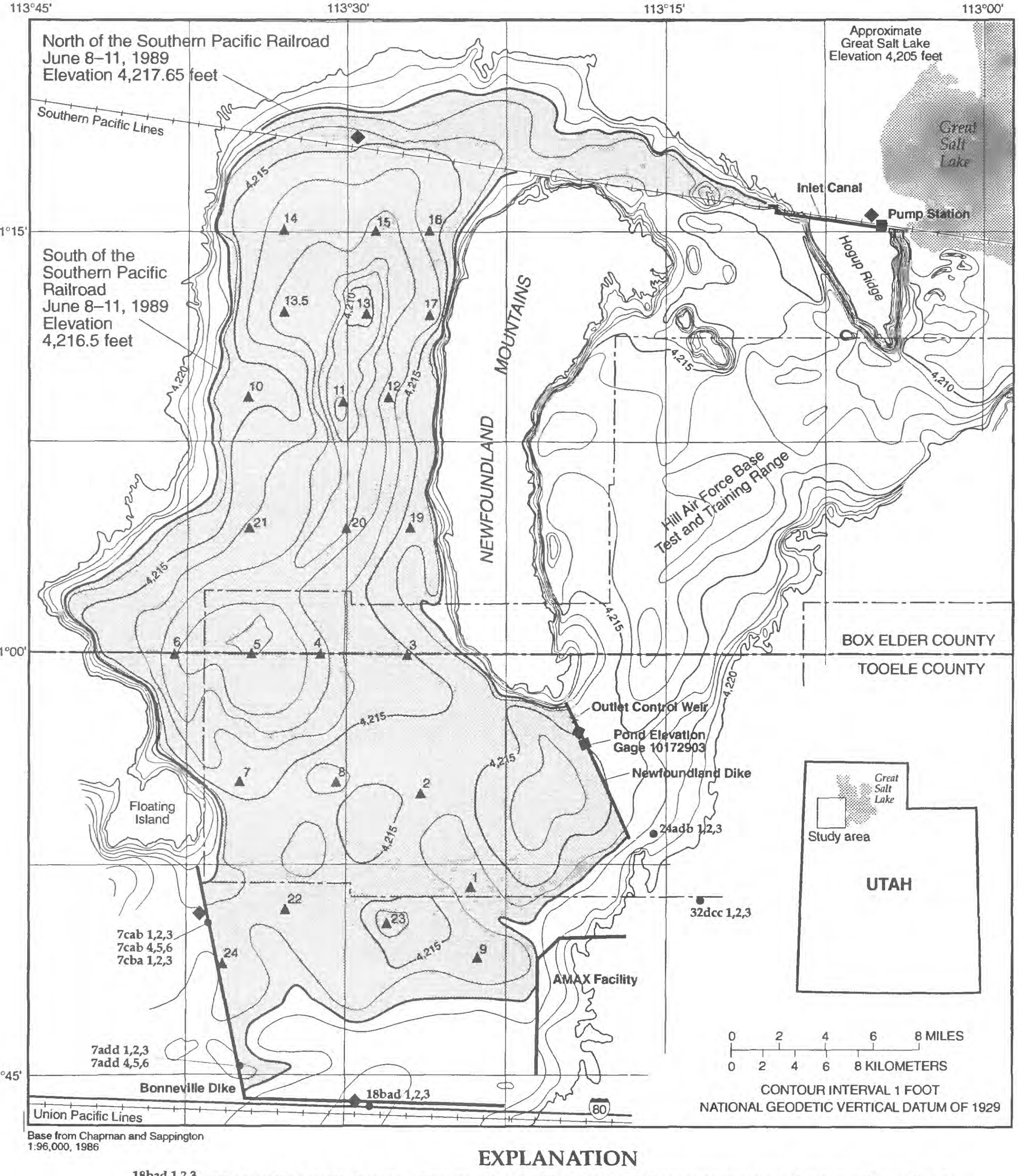
Well- and Spring-Numbering System

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake Base Line and the Salt Lake Meridian. These quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and it is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres[1] for regular sections; the lowercase letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well within the 10-acre tract. If a well cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus, (B-1-15)7cab-3 designates the third well constructed or visited in the NW¹/4NE¹/4SW¹/4 sec. 7, T. 1 N., R. 15 W. The numbering system is illustrated in figure 3.

Data Sources

To evaluate the effects of the movement and storage of brine from Great Salt Lake to West Pond and evaporation on the salt budget, the following were monitored: (1) the quantity and quality of brine pumped from Great Salt Lake into West Pond, (2) the quantity and quality of brine stored in West Pond and east of the Newfoundland Mountains, (3) the quantity and quality of brine pumped from the pond by AMAX,

[1] Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.



EXPLANATION

● 18bad 1,2,3 **Observation well cluster**—First number and letters are reference to location. Last number refers to each of three wells in cluster: one shallow, one intermediate, and one deep well in each cluster

▲23 **Site in West Pond where samples were collected for chemical analysis (table 3)**—Number is sampling site

◆ **Site at which climatic data were collected**

Figure 1. Location of study area and data-collection sites.

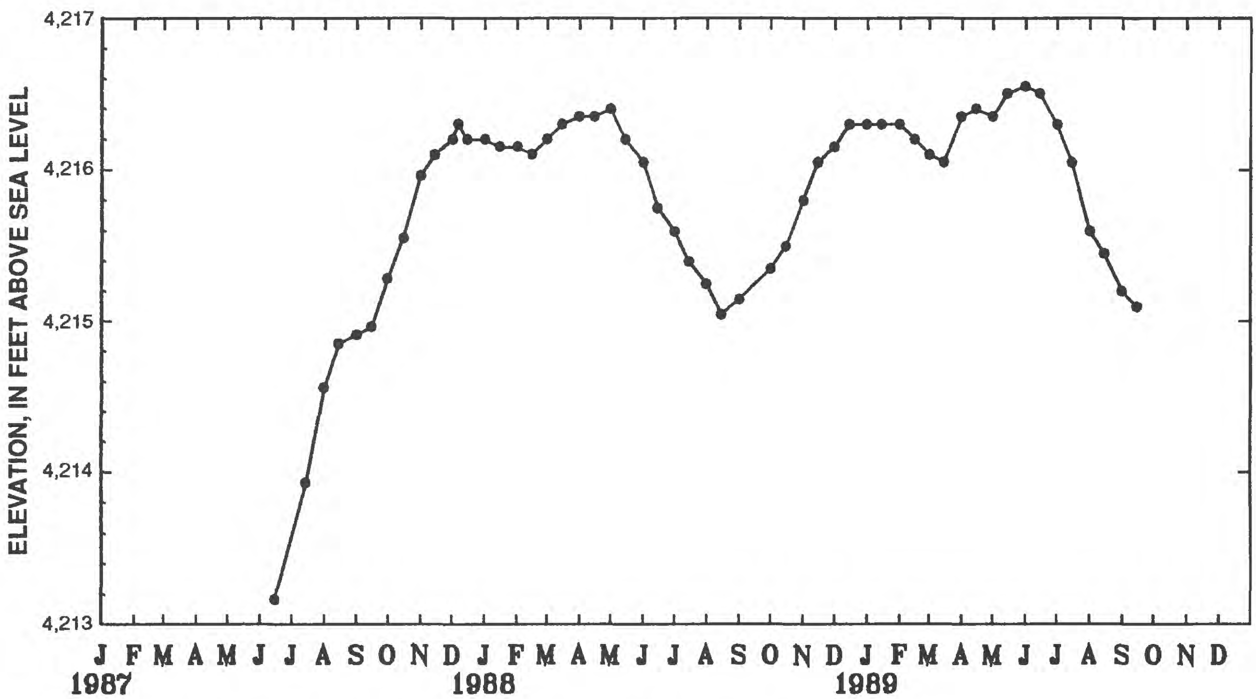


Figure 2. Elevation of the brine in West Pond during the 1987-89 pumping period.

(4) the quantity and quality of brine outflow through the Newfoundland weir, (5) precipitation, and (6) evaporation.

Several agencies and companies were involved with data collection necessary for the monitoring program. This information is summarized in table 1 (adapted from Waddell and others, 1992).

West Pond has been sampled three times for the purpose of computing the quantity of salts stored in the pond. The results of the first two sampling periods are discussed by Waddell and others (1992). The third sampling was from an air boat by the USGS during June 8-11, 1989.

SALT BUDGET FOR WEST POND

The quantity of salt pumped into West Pond from Great Salt Lake during April 7, 1988, to June 11, 1989, should approximate the change in quantity of salt stored in the pond during the same period plus that which left the pond through the Newfoundland weir, was withdrawn by AMAX, or entered into the shallow groundwater storage in West Pond, also during the same period. This can be written in terms of the mass of salt as

Inflow Salt = Outflow Salt ± Salt from Storage Change ± Unaccounted Salt

An accounting of the tonnages of salt using minimum, average, and maximum estimates is shown in table 2.

About 695 million tons or 14.2 percent of salt contained in Great Salt Lake was pumped into West Pond. Of the quantity of salt pumped into West Pond, 396 million tons (57 percent) was stored in West Pond during April 10, 1987, to June 11, 1989, as dissolved salt, salt crust, and salt that infiltrated subsurface areas inundated by storage in West Pond. The remaining quantity, 211 million tons (30 percent), comprised discharge from West Pond through the Newfoundland weir and withdrawal by AMAX.

The average estimate for period 2 in table 2 indicates that about 13 percent of the salt that was pumped into West Pond during April 10, 1987, to June 11, 1989, is not accounted for by the budget calculations. Most of the inaccuracy in the budget is believed to be associated with the elevation-volume relations, which affect the computed loads of salt stored in West Pond. (See section "Dissolved Salt".)

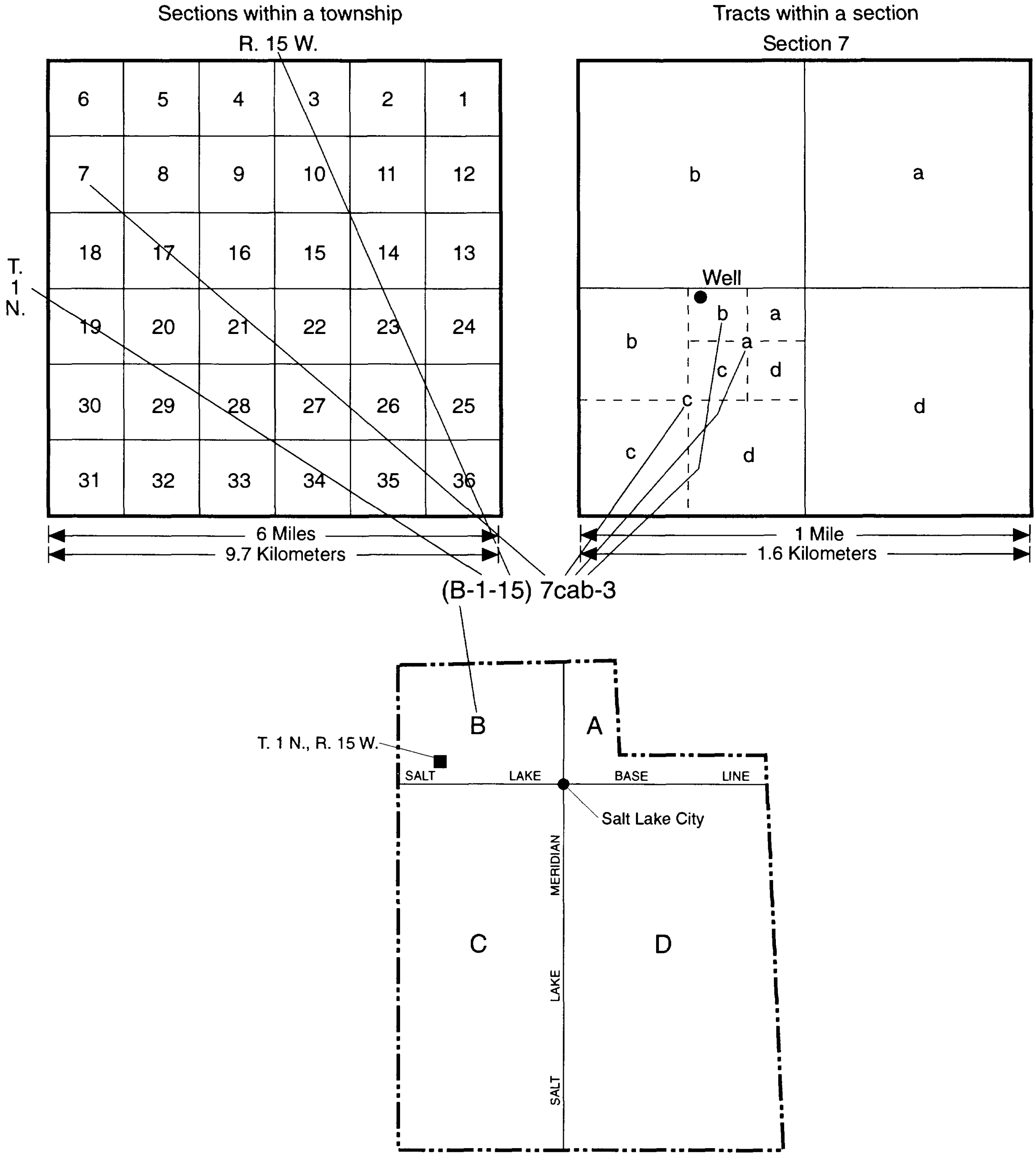


Figure 3. Well- and spring-numbering system used in Utah.

Inflow

Inflow to West Pond as a result of pumpage from Great Salt Lake began April 10, 1987, and ended June 30, 1989. The quantity of salt dissolved in Great Salt Lake prior to the pumping period was estimated to be about 4.9 billion tons. The quantity of salt pumped from Great Salt Lake into West Pond during April 10, 1987, to June 11, 1989, was about 695 million tons or about 14.2 percent of the salt contained in the lake.

Concentration of dissolved solids and monthly and cumulative salt loads of the brine that were pumped from April 1988 to June 1989 are shown in figure 4. The load of dissolved salts entering West Pond each month was computed from the product of the monthly volume in acre-feet and the average concentration of dissolved solids for a given month was computed in tons per acre-foot. Approximately 361 million tons of salt were pumped from the lake during April 7, 1988, to June 11, 1989 (fig. 4). The accuracy of the pumpage estimates was not evaluated; however, if the pumpage was underestimated or overestimated by 5 percent, then the total salt pumped into the pond during this period would range from about 343 million to 379 million tons.

Storage

Salt stored during April 7, 1988, to June 11, 1989, consisted of dissolved salt, a salt crust covering the floor of the south part of the pond, and brine that infiltrated the subsurface areas inundated by West Pond. Previously, from April 10, 1987, to April 6, 1988, as described by Waddell and others (1992), salt was stored in West Pond as brine and in the subsurface sediments, but no salt crust was present.

Of the quantity of salt pumped into West Pond from April 10, 1987, to June 11, 1989, 315 million tons (45 percent) was dissolved in West Pond, 71 million tons (10.2 percent) formed a salt crust at the bottom of West Pond, and 10 million tons (1.4 percent) infiltrated the subsurface areas inundated by storage in West Pond. Thus, 396 million tons (57 percent) of salt pumped from Great Salt Lake was stored in West Pond.

Dissolved Salt

Once the brine enters West Pond, the salinity increases as water is evaporated. Salinity is lower to the north where the brine pumped from the north part of Great Salt Lake through the canal enters West Pond, and is higher at the south end and at the weir in the Newfoundland Dike. During the hot summer months when the concentration of dissolved solids exceeds about 355 grams per liter, halite (sodium chloride) will precipitate onto the bottom sediments of the pond. The halite dissolves into the less concentrated water that is pumped into the pond during the cooler months. During the cold winter months, mirabilite, a hydrated sodium sulfate, precipitates when the brine temperature drops below about 3 degrees Celsius (the solubility temperature varies, depending upon the concentration of dissolved solids) and dissolves as the brine warms again in the spring.

In June 1989, halite had been deposited on the bottom in the south part of West Pond. During June 1989, the maximum observed concentration of dissolved solids was 363 g/L, which is greater than the saturation concentration of about 355 g/L at which halite begins to precipitate in Great Salt Lake.

During June 8-11, 1989, the USGS made field measurements of specific gravity and temperature and collected samples at 24 sites on West Pond (fig. 5). Of the 24 sampling sites, 23 were the same sites sampled during April 4-6, 1988. Site 13.5 was sampled only during June 8-11, 1989, and site 18 was sampled only during April 4-6, 1988. Locations were determined through use of a LORAN unit, an electronic sensing instrument for remote determination of latitude and longitude, and a USGS map, scale 1:100,000, showing the bathymetric contours of the bottom of the pond (Chapman and Sappington, 1986).

Sampling sites were selected along approximate east-west lines through the pond (fig. 5). Specific gravity and temperature measurements were made at the surface and bottom of the pond where depths were greater than 2 feet and at the surface only when depths were less than 2 feet. Measurements were made at intermediate depths at each site if there were substantial differences between the surface and bottom measurements. Samples for chemical analysis also were collected at each site, and 28 samples were selected and analyzed for major ions (table 3). For the purpose of calculating the salt load, the pond was divided into nine sections.

The salt load contained in West Pond was determined by computing the loads for each section of the pond and summing the values. Because there was vertical salt stratification at some of the deeper sites, it was necessary to compute incremental loads for 1-foot layers within each section. This required determining the volume and average concentration of dissolved solids

Table 1. Responsible agencies, performing agencies and companies, and data-collection schedule for West Pond monitoring program, 1987-89

Responsible agency: DWR, Utah Division of Water Resources; UGS, Utah Geological Survey.
Performing agency or company: EWP, Eckhoff, Watson, and Preator Engineering; UGS, Utah Geological Survey; USGS, U.S. Geological Survey; USU, Utah State University; AMAX, American Magnesium Corporation

Data collected	Responsible agency	Performing agency or company	Beginning date of collection	Frequency of collection
		West Pond pumpage		
Quantity	DWR	EWP	04-10-87	hourly
Quality				
Specific gravity	DWR	EWP/UGS	04-10-87	weekly
Major ions	DWR	USGS	04-10-87	monthly
		West Pond storage		
Quantity	DWR	USU	06-01-87	hourly
	DWR	USGS	12-01-87	continuous
Quality	UGS	UGS/USGS	04-06-88	annual
		Ground water		
Levels	DWR	USGS	06-01-87	monthly
Quality				
Specific gravity	DWR	USGS	06-01-87	monthly
Major ions	DWR	USGS	07-01-87	quarterly
		West Pond outflow		
Quantity	DWR	EWP	04-10-87	hourly
AMAX pumpage	DWR	AMAX	01-10-88	continuous
Quality	UGS	USGS	01-07-88	monthly
Precipitation	DWR	USU	04-10-87	continuous
Evaporation	DWR	USU	04-10-87	continuous

in each section. The average concentration of dissolved solids was determined from specific gravity or density (Waddell and others, 1992, fig. 5). No samples were taken in sections A and C-D during June 8-11, 1989, so the salt loads for these two sections were estimated from specific-gravity measurements from adjacent or surrounding sites.

The volume of each layer for each section was computed by digitizing the areas defined by the bathymetric contours on the 1:100,000-scale map and then preparing elevation-volume relations for each section (Waddell and others, 1992, fig. 6). The salt load for a layer was then computed from the product of the concentration of dissolved solids and the volume of a layer (table 7, at back of report).

Next, the total salt load for each section was calculated from the sum of the layer loads (table 4), and the loads for all sections were summed. Dissolved salt in West Pond on June 11, 1989, was estimated as 278 million tons (table 4).

Correction to the dissolved salt storage, made by subtracting the volume of salt crust (see fig. 6, “Salt Crust” section) in the two southern-most sections G-H and H (shown in fig. 5) from the uncorrected volume of dissolved salt storage, are included in table 4. These corrections resulted in less than a 1-percent change in dissolved salt storage and are considered insignificant

Table 2. Salt budget for West Pond, April 10, 1987, to June 11, 1989

[n/a, not available; —, not calculated]

	Estimates of salt load, in millions of tons								
	Salt load [1]April 10, 1987, to April 6, 1988 (period 1)			Salt load April 7, 1988, to June 11, 1989 (period 2)			Salt load April 10, 1987, to June 11, 1989 (period 1 plus period 2)		
	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
Inflow									
Pumped from Great Salt Lake[2]	317	334	351	343	361	379	660	695	730
Storage									
Dissolved[3]	189	215	240	89	100	112	278	315	352
Salt crust	0	0	0	n/a	71	n/a	n/a	71	n/a
Subsurface[4]	4.5	7.2	9.9	1.7	2.8	3.8	6.2	10.0	13.7
Outflow									
AMAX withdrawal[2]	12.2	12.8	13.4	71	75	79	84	88	92
Newfoundland weir[5]	36.5	40.6	44.7	74	82	90	111	123	135
Unaccounted salt									
Inflow - (storage + outflow)	—	58	—	n/a	30	n/a	n/a	88	n/a
(As percentage of inflow)		(17 percent)			(8 percent)			(13 percent)	

[1] Waddell and others, 1992, table 4.
[2] Minimum and maximum values were computed assuming ± 5 percent error in measurements of pumping.
[3]The maximum value was computed with Eckhoff, Watson, and Preator elevation-volume curves and the minimum value was computed with U.S. Geological Survey elevation-volume curves.
[4] Minimum and maximum values were based on an estimated range of thicknesses for the unsaturated zone and a range of specific yield, at West Pond and east of the Newfoundland Mountains.
[5] Minimum and maximum values were computed using ±10 percent error (Brent S. Bingham, Bingham Engineering, oral commun., 1990)

because of limitations of data used in computations of dissolved salt.

The engineering firm of Eckhoff, Watson, and Preator (EWP) prepared elevation-volume relations from map imagery that showed larger brine volumes than were prepared from the USGS map. The elevation-volume curve prepared by EWP shows that at an elevation of 4,216.5 feet above sea level, the volume is 770,000 acre-feet (Waddell and others, 1992). The curve prepared from the USGS map shows a volume of 608,000 acre-feet, or a difference of about 27 percent. The salt loads computed by the USGS elevation-volume curves were adjusted by the ratio of EWP to USGS volumes. The average of the EWP and USGS calculations shows that about 315 million tons of salt were dissolved in West Pond on June 11, 1989. The change in storage of the pond brine from April 7, 1988, to June 11, 1989, is about 100 million tons and ranges from 89 million to 112 million tons.

Salt Crust

Storage of salt in the form of a salt crust composed primarily of halite deposits on the bottom of the southern part of West Pond was measured in June 1989. Core samples of the salt crust were collected at selected sites and were analyzed so that the load of salt could be calculated (fig. 6 and table 5).

Core samples were taken with clear plastic tubes penetrating the salt crust into the mud below. The transition between salt crust and mud is gradual with large salt crystals found in mud just beneath the salt crust.

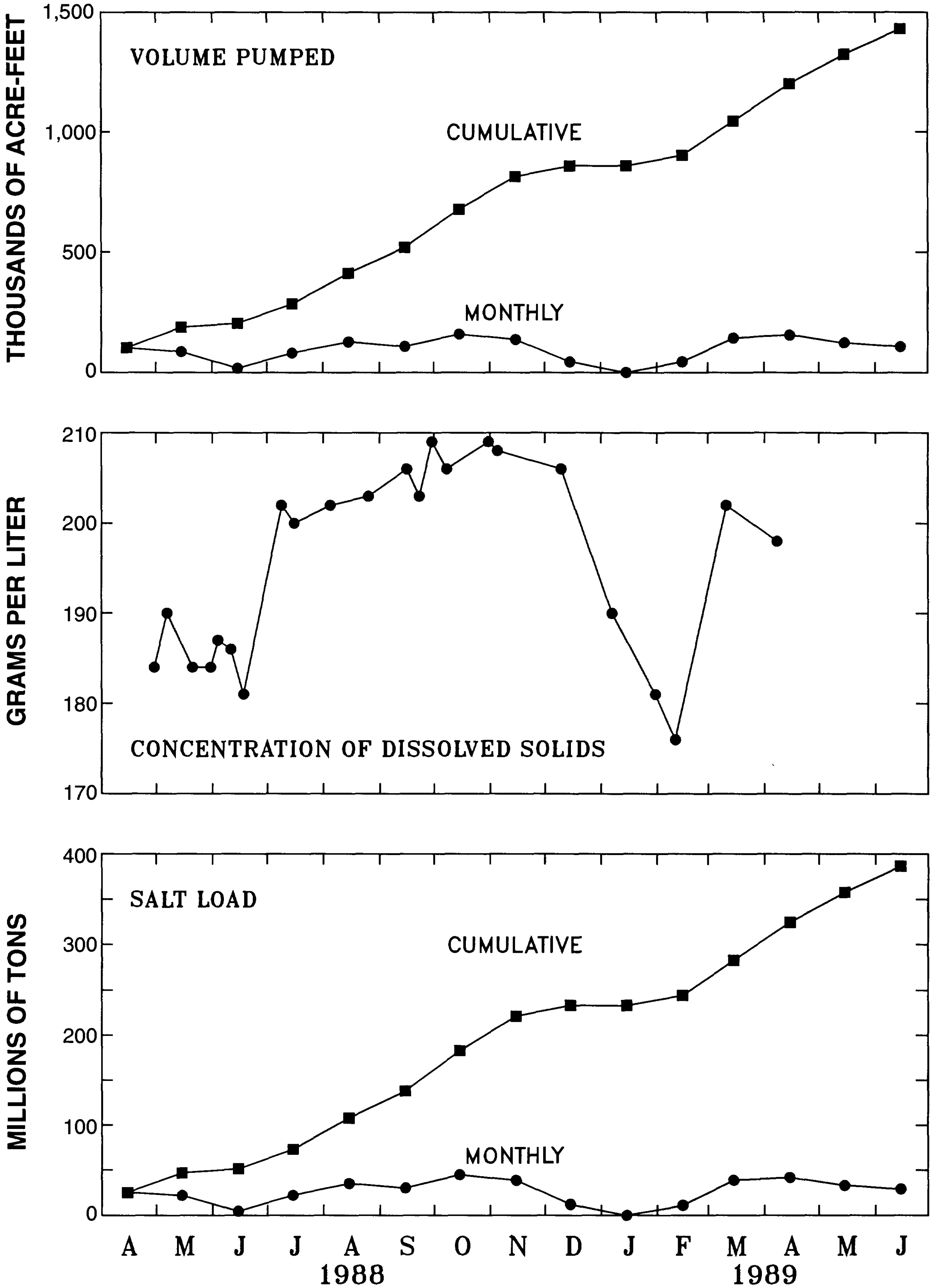


Figure 4. Volume pumped, concentration of dissolved solids, and salt load of brine pumped from Great Salt Lake into West Pond, April 1988 to June 1989.

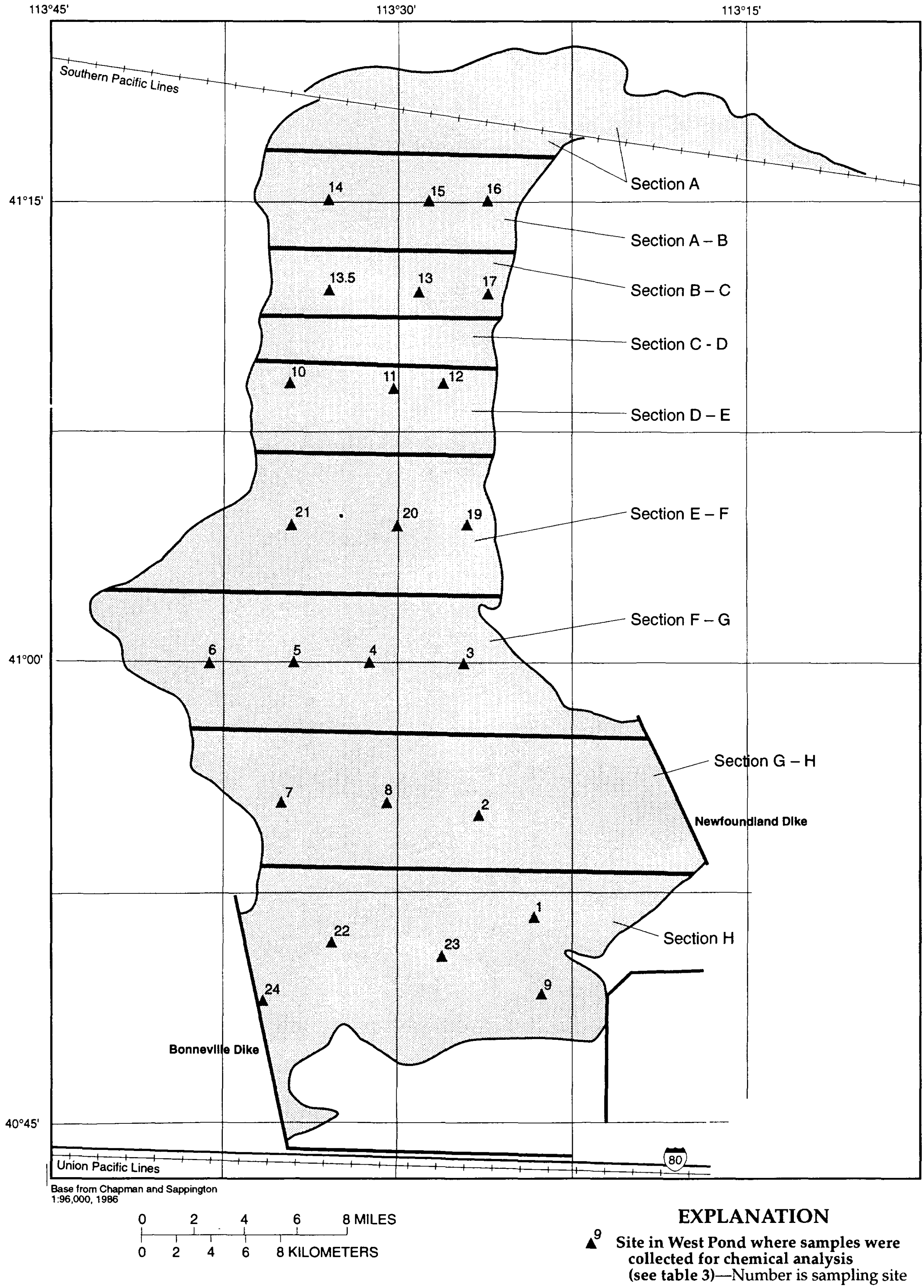


Figure 5. West Pond sampling sites and section divisions used for computing salt load, June 8–11, 1989.

Table 3. Chemical analyses and field measurements of temperature and specific gravity for West Pond, June 8-11, 1989

[°C, degrees Celsius; mg/L, milligrams per liter; g/ml, grams per milliliter; dashes (—) indicate no data]

Sampling site: See figure 1 for site location.

Sampling site	Date	Water temperature (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Density, laboratory (g/ml at 20 °C)	Specific gravity, field (at 20 °C)	Depth at sample location, total (feet)	Depth of lake, maximum (feet)
1	06-08-89	19.5	340	12,800	110,700	9,000	198,860	28,550	1.225	1.229	0.00	0.58
2	06-08-89	28.5	290	11,800	110,500	8,200	200,240	21,760	1.220	1.223	0.00	1.25
	06-08-89	29.0	—	—	—	—	—	—	—	1.223	1.25	1.25
3	06-08-89	27.5	—	—	—	—	—	—	—	1.213	0.00	2.25
	06-08-89	27.5	—	—	—	—	—	—	—	1.213	1.00	2.25
	06-08-89	27.5	400	8,600	113,000	6,100	196,100	16,080	1.212	1.213	2.25	2.25
4	06-09-89	23.0	—	—	—	—	—	—	—	1.216	0.00	4.25
	06-09-89	23.0	—	—	—	—	—	—	—	1.215	1.00	4.25
	06-09-89	23.0	—	—	—	—	—	—	—	1.215	2.00	4.25
	06-09-89	23.0	—	—	—	—	—	—	—	1.215	3.00	4.25
	06-09-89	23.0	410	8,600	114,800	6,000	198,170	15,960	1.213	1.216	4.00	4.25
5	06-08-89	23.0	—	—	—	—	—	—	—	1.215	0.50	5.00
	06-08-89	22.5	—	—	—	—	—	—	—	1.215	3.00	5.00
	06-08-89	23.0	430	8,800	115,200	6,000	199,550	16,380	1.213	1.216	5.00	5.00
6	06-08-89	24.5	—	—	—	—	—	—	—	1.209	0.00	2.75
	06-08-89	24.5	—	—	—	—	—	—	—	1.209	2.00	2.75
	06-08-89	24.0	430	8,100	111,000	6,200	191,960	16,380	1.207	1.209	2.75	2.75
7	06-08-89	25.5	—	—	—	—	—	—	—	1.218	0.00	2.50
	06-08-89	25.5	—	—	—	—	—	—	—	1.218	1.00	2.50
	06-08-89	25.5	420	9,000	113,800	6,500	198,170	17,350	1.215	1.218	2.50	2.50
8	06-08-89	22.0	390	9,900	114,000	7,100	200,240	18,450	1.216	1.220	0.00	1.63
	06-08-89	22.0	—	—	—	—	—	—	—	1.220	1.63	1.63
9	06-08-89	19.5	260	11,900	111,000	9,500	196,100	30,060	1.226	1.229	0.00	0.63
10	06-09-89	26.0	—	—	—	—	—	—	—	1.189	0.00	3.08
	06-09-89	26.0	—	—	—	—	—	—	—	1.189	1.00	3.08
	06-09-89	26.0	—	—	—	—	—	—	—	1.188	2.00	3.08
	06-09-89	26.0	390	7,100	98,900	5,400	171,260	13,850	1.186	1.189	2.50	3.08
11	06-09-89	25.5	—	—	—	—	—	—	—	1.204	0.00	5.17
	06-09-89	25.5	—	—	—	—	—	—	—	1.204	1.00	5.17
	06-09-89	25.5	—	—	—	—	—	—	—	1.204	2.00	5.17
	06-09-89	25.5	—	—	—	—	—	—	—	1.204	3.00	5.17
	06-09-89	25.5	—	—	—	—	—	—	—	1.204	4.00	5.17
	06-09-89	25.5	640	7,800	110,800	5,200	188,510	15,810	1.201	1.204	5.00	5.17
12	06-09-89	25.5	—	—	—	—	—	—	—	1.207	0.00	4.00
	06-09-89	25.0	—	—	—	—	—	—	—	1.206	1.00	4.00
	06-09-89	25.5	—	—	—	—	—	—	—	1.207	2.00	4.00
	06-09-89	25.5	470	7,500	113,600	5,300	193,340	16,290	1.205	1.208	3.50	4.00
13	06-10-89	24.5	460	7,200	107,300	5,000	180,920	15,720	1.192	1.194	0.00	7.00
	06-10-89	24.5	—	—	—	—	—	—	—	1.194	1.00	7.00
	06-10-89	24.0	460	7,100	107,300	5,000	182,300	15,560	1.193	1.196	2.00	7.00
	06-10-89	24.0	—	—	—	—	—	—	—	1.197	3.00	7.00
	06-10-89	24.0	—	—	—	—	—	—	—	1.197	4.00	7.00
	06-10-89	24.5	—	—	—	—	—	—	—	1.197	5.00	7.00
	06-10-89	23.5	470	7,000	108,600	5,000	182,990	15,900	1.196	1.198	7.00	7.00
13.5	06-10-89	23.5	—	—	—	—	—	—	—	1.188	0.00	3.33
	06-10-89	23.5	—	—	—	—	—	—	—	1.188	1.00	3.33
	06-10-89	23.5	—	—	—	—	—	—	—	1.188	2.00	3.33
	06-10-89	23.5	450	6,800	104,700	4,900	177,470	15,460	1.187	1.189	3.00	3.33

Table 3. Chemical analyses and field measurements of temperature and specific gravity for West Pond, June 8-11, 1989—Continued

Sampling site	Date	Water temperature (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Density, laboratory (g/ml at 20 °C)	Specific gravity, field (at 20 °C)	Depth at sample location, total (feet)	Depth of lake, maximum (feet)
14	06-10-89	23.5	—	—	—	—	—	—	—	1.180	0.00	3.00
	06-10-89	23.5	—	—	—	—	—	—	—	1.180	1.00	3.00
	06-10-89	23.5	—	—	—	—	—	—	—	1.180	2.00	3.00
	06-10-89	23.0	370	6,500	100,000	4,700	169,880	14,700	1.178	1.180	2.50	3.00
15	06-10-89	24.5	—	—	—	—	—	—	—	1.187	0.00	4.17
	06-10-89	25.0	—	—	—	—	—	—	—	1.187	1.00	4.17
	06-10-89	25.0	—	—	—	—	—	—	—	1.187	2.00	4.17
	06-10-89	24.5	—	—	—	—	—	—	—	1.187	3.00	4.17
	06-10-89	25.0	390	6,700	103,700	4,800	171,260	15,060	1.185	1.188	4.00	4.17
16	06-10-89	24.5	400	6,600	97,700	4,500	160,220	14,420	1.170	1.172	0.00	3.08
	06-10-89	25.0	—	—	—	—	—	—	—	1.172	1.00	3.08
	06-10-89	25.5	—	—	—	—	—	—	—	1.177	1.75	3.08
	06-10-89	25.5	—	—	—	—	—	—	—	1.184	2.00	3.08
	06-10-89	25.5	380	6,700	103,000	4,700	168,500	15,160	1.182	1.185	3.00	3.08
17	06-10-89	25.0	440	6,500	109,000	4,500	178,160	15,720	1.190	1.193	0.00	2.33
	06-10-89	25.0	—	—	—	—	—	—	—	1.192	1.00	2.33
	06-10-89	26.0	640	7,400	107,000	4,800	182,300	16,000	1.193	1.196	2.00	2.33
19	06-09-89	25.5	—	—	—	—	—	—	—	1.210	0.00	2.50
	06-09-89	25.5	—	—	—	—	—	—	—	1.209	1.00	2.50
	06-09-89	25.5	450	7,600	117,700	5,500	195,410	16,320	1.207	1.209	2.00	2.50
20	06-09-89	24.0	—	—	—	—	—	—	—	1.209	0.00	5.67
	06-09-89	24.0	—	—	—	—	—	—	—	1.210	1.00	5.67
	06-09-89	24.0	—	—	—	—	—	—	—	1.210	2.00	5.67
	06-09-89	24.0	—	—	—	—	—	—	—	1.210	3.00	5.67
	06-09-89	24.0	—	—	—	—	—	—	—	1.210	4.00	5.67
	06-09-89	23.5	480	7,700	117,100	5,500	195,410	16,440	1.207	1.210	5.00	5.67
21	06-09-89	26.0	—	—	—	—	—	—	—	1.204	0.00	3.83
	06-09-89	26.0	—	—	—	—	—	—	—	1.204	1.00	3.83
	06-09-89	26.0	—	—	—	—	—	—	—	1.204	2.00	3.83
	06-09-89	26.0	—	—	—	—	—	—	—	1.204	3.00	3.83
	06-09-89	26.5	470	7,000	113,400	5,000	191,960	16,060	1.203	1.205	3.50	3.83
22	06-08-89	27.5	380	8,900	117,200	6,600	199,550	19,720	1.218	1.220	0.63	0.63
23	06-08-89	26.5	—	—	—	—	—	—	—	1.226	0.33	1.13
	06-08-89	26.5	300	10,400	117,200	7,900	201,620	27,460	1.224	1.226	1.13	1.13
24	06-11-89	21.0	280	10,900	114,900	9,200	199,550	28,720	1.225	1.228	0.00	0.44

Table 4. Summary of volume of brine and salt load for sections of West Pond, June 8-11, 1989

Section	Volume (thousands of acre-feet)	Salt load (millions of tons)
A	23.78	9.48
A-B	63.52	25.45
B-C	57.38	24.32
C-D	29.93	12.91
D-E	67.20	29.44
E-F	78.69	35.60
F-G	145.77	67.77
G-H	95.04	45.36
H	56.12	27.31
TOTAL (rounded)	617	278

Preparation of the core sample for laboratory analysis was performed by first carefully pouring out all water just above the top of the salt crust. The entire core sample then was mixed with enough water to dissolve all of the salt crust. This mixture, which included salt from the salt crust and liquid brine in the salt crust, was then sent to the laboratory for analysis.

Salt mass per unit area was calculated from the volume of the salt crust core sample (including water added for dissolution of the salt) multiplied by the total dissolved solids (determined by laboratory analysis). The salt mass per unit area data were contoured and the results are shown in figure 6. The salt load for each zone (table 6) is the average salt mass per unit area multiplied by the area of the zone. The sum of the salt loads for each zone gives the total salt load, 71 million tons of salt stored as salt crust in West Pond on June 11, 1989.

A definite trend of increasing salt mass per unit area (which generally indicates salt-crust thickness) from the north to the south end of West Pond is shown in figure 6. The gradual transition from mud to salt upward toward the surface was seen at sites 4 and 10. Salt was stored at these two sites, but not enough to form a salt crust. No salt crust was detected at the sample sites in the north part (50 to 75 tons per acre interval) of West Pond. Up to 1 inch of salt crust was detected in the 75 to 150 tons per acre zone; from 1 to 3.2 inches of salt crust were detected in the 150 to 450 tons per acre zone; up to 4.4 inches of salt crust were detected in the 450 to 750 tons per acre zone; and the greatest salt-crust thickness for June 1989 was 4.7 inches in the 750 to 830 tons per acre zone. Because of the limited quantity of data collected, the statistical error of this salt-load computation cannot be calculated.

Subsurface Salt

Waddell and others (1992) indicated that the unsaturated sediments beneath the bottom of West Pond probably became saturated during the filling of West Pond. The quantity of salt stored in the subsurface sediments depends on the depth to the water table before pumping began, the inundated area, the specific yield of the sediments, and the salinity of the brine infiltrating the sediments.

Using water levels obtained during the drilling of test holes prior to construction of the dikes (Eckhoff, Watson, and Preator Engineering, 1985) and from monitoring wells near the dikes about 2 months after West Pond began filling, the depth to the water table from the pond bottom was estimated to range from about 0.5 to 1.1 feet. Data from Johnson (1967) indicate that specific yield of sediments similar to those in Great Salt Lake Desert could range from about 0.05 to 0.10.

The density of infiltrated brine changes with time and is similar to that of the brine above the pond bottom. The salinity of the brine that seeped into the subsurface beneath West Pond was assumed to be the average concentration computed from sampling on West Pond. During June 8-11, 1989, the average concentration was 331 g/L, and during April 4-6, 1988, it was 240 g/L. The area inundated by West Pond was estimated to be about 277,000 acres. The salt load that seeped into the sediments ranged from 6.2 million (using an unsaturated thickness of 0.5 foot) to 13.7 million tons (using an unsaturated thickness of 1.1 feet and specific yield of 0.10). The change in storage of the subsurface brine from April 7, 1988, to June 11, 1989, is about 2.8 million tons and is estimated to range from 1.7 million to 3.8 million tons.

Outflow

Salt removed from storage in West Pond comprised withdrawals by AMAX and outflow through the Newfoundland weir. The quantity of salt removed from West Pond during April 10, 1987, to June 11, 1989, was calculated as a percentage of the quantity pumped into West Pond; 12.7 percent was withdrawn by AMAX, and 17.7 percent was discharged through the Newfoundland weir.

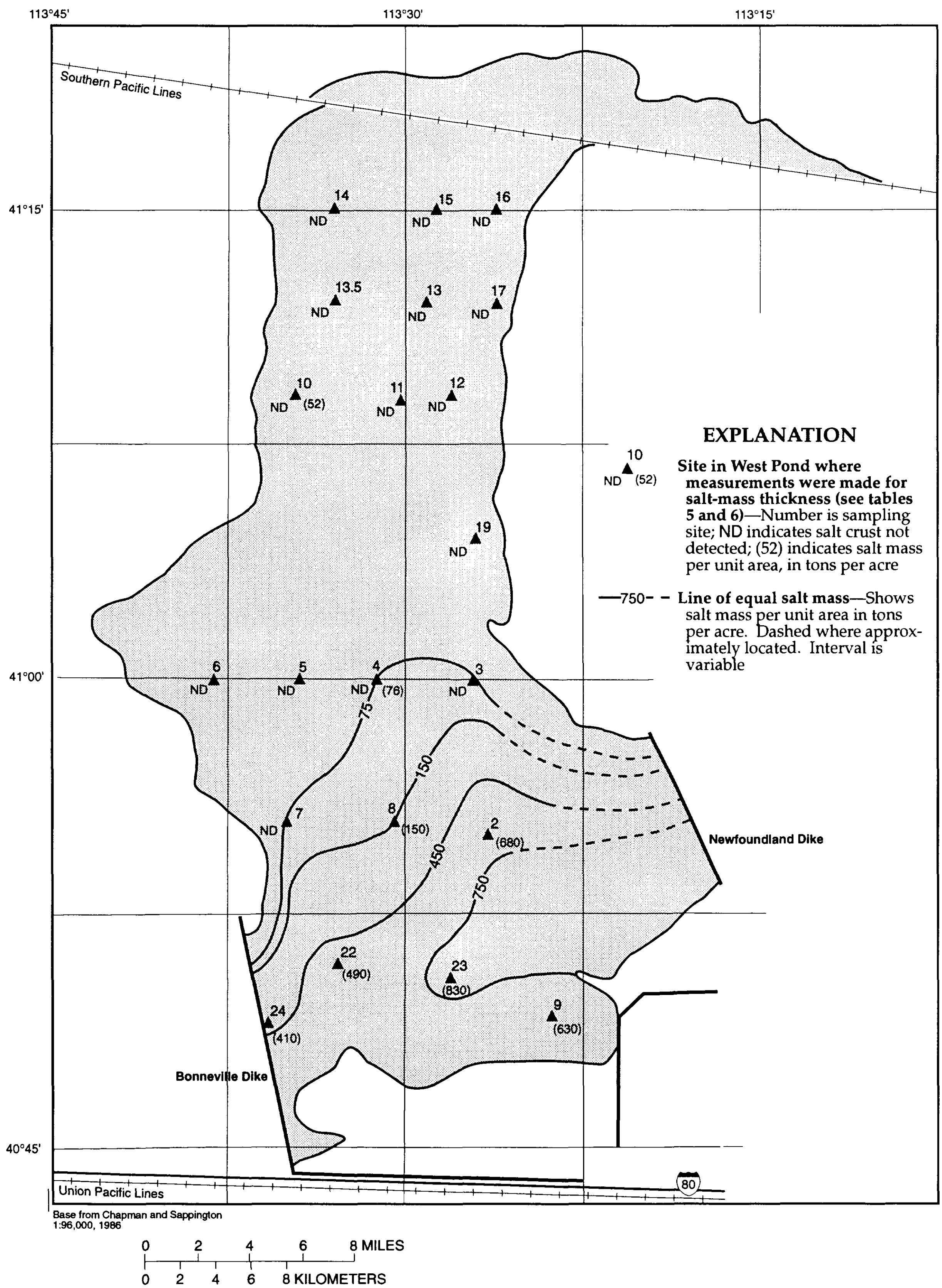


Figure 6. Distribution of salt mass in West Pond, June 8–11, 1989.

Table 5. Salt-mass data for West Pond, sampled June 8-11, 1989

[See fig. 6 for location of site]

Site	Thickness of salt crust (inches)	Volume of core and additional water (liters)	Total dissolved solids (grams per liter)	Salt mass per unit area (tons per acre)[1]
2	[2]4.4	1.90	209	680
4	0.0	1.65	26.7	76
8	1.0	—	—	[3]150
9	[2]4.2	2.10	174	630
10	0.0	1.51	20.1	52
22	3.6	1.48	191	490
23	4.7	2.45	196	830
24	[2]3.2	1.62	149	410

[1]Calculated using an inside core diameter of 2.26 inches (area = 4.02 square inches).
[2]Interpolated from values of salt mass per unit area and thickness for sites 4, 10, 22, and 23.
[3]Salt mass per unit area estimated from thickness of salt crust.

Table 6. Salt load stored as precipitated salt in West Pond, June 8-11, 1989

[Zone of salt mass per unit area: See fig. 6 for location]

Zone of salt mass per unit area (tons per acre)	Average salt mass per unit area in zone (tons per acre)	Area of zone (acres)	Salt load (millions of tons)
[1]50-75	67.5	186,000	13
75-150	112.5	15,900	1.8
150 - 450	300	29,300	8.8
450 - 750	600	43,500	26
750 - 830	790	26,600	21
		Total for entire area of West Pond:	71

[1] This zone has at least 50 tons per acre of salt because site 10 with no visible salt crust has 52 tons per acre of salt. Therefore, salt has precipitated in this zone but not enough to form a visible salt crust.

Withdrawals by American Magnesium Corporation

On January 21, 1988, the American Magnesium Corporation (AMAX) began pumping brine from West Pond into a 54,000-acre solar-evaporation complex. Pumping records supplied to EWP by AMAX indicate about 42,000 acre-feet of brine were pumped from West Pond into their system during January 21 to April 6, 1988 (Waddell and others, 1992), and 162,000 acre-feet pumped from April 7, 1988, to June 11, 1989 (fig. 7).

The concentration of dissolved solids (fig. 7) of the brine pumped by AMAX was calculated from density measurements. The load of dissolved salts withdrawn from West Pond each month was computed from the product of the monthly volume in acre-feet and the average concentration of dissolved solids for a given month. The graph of cumulative loads shown in figure 7 indicates that AMAX pumped about 75 million tons of salt into their facility during April 7, 1988, to June 11, 1989. The accuracy of the pumpage estimates was not evaluated; however, if the pumpage was underestimated or overestimated by 5 percent, then the total tons of salt pumped by AMAX from the pond would range from about 71 million to 79 million tons.

Outflow through the Newfoundland Weir

Outflow from West Pond is controlled by a 1,004-foot-long weir in the Newfoundland Dike. The weir consists of a series of 4-foot openings separated by segments of a solid wall. Within the openings, 4-foot stop logs can be placed horizontally, one on top of the other, to provide for variable crest elevations.

Outflow from West Pond through the Newfoundland weir did not take place on a regular basis. Measurements made by Bingham Engineering (written commun., 1990) show that 183,770 acre-feet of brine passed through the Newfoundland weir from April 7, 1988, to June 11, 1989. The monthly and cumulative volumes and salt loads of brine that passed through the Newfoundland weir are shown in figure 8.

The load of dissolved salts passing through the Newfoundland weir each month was computed from the product of the monthly volume passing through the weir in acre-feet and the average concentration of dissolved solids at the weir for a given month. The graph showing cumulative salt loads (fig. 8; Waddell and others, 1992, fig. 9) indicates that approximately 123 million tons of salt passed through the Newfoundland weir during April 10, 1987, to June 11, 1989. The Newfoundland weir outflow measurements have an accuracy of plus or minus 10-percent error (Brent S. Bingham, Bingham Engineering, oral commun., 1990). If the outflow was underestimated or overestimated by 10 percent, then the total tons of salt passing through the Newfoundland weir would range from about 111 million to 135 million tons.

RETURN FLOW TO GREAT SALT LAKE

Waddell and others (1992) indicated that part of the brine outflow from West Pond returned to Great Salt Lake by gravity flow over land. Part of this brine formed a small, shallow lake with an area of about 60,000 acres east of the Newfoundland Mountains, and the rest of the brine was stored beneath the small lake. During April 10, 1987, to June 11, 1989, of the salt pumped out of Great Salt Lake and into West Pond, 0.5 percent or 3.6 million tons of brine was stored beneath the small, shallow lake, and 13.5 percent or an estimated 94 million tons of brine flowed back into Great Salt Lake.

The storage of subsurface brine east of the Newfoundland Mountains was estimated for June 11, 1989 (see also "Subsurface Salt" section). As was assumed and described in the "Subsurface Salt" section, the density of infiltrated brine changes with time and is similar to the brine above the pond bottom. The salinity of the brine that infiltrated beneath the small, shallow lake east of the Newfoundland Mountains was assumed to be the same as the average concentration of the outflow from the weir during November 1987 to June 11, 1989, which was 300 g/L. The area inundated by the outflow from the small, shallow lake was estimated to be 60,000 acres. The salt load that seeped into the sediments ranged from 1.2 million (using an unsaturated thickness of 0.5 foot) to 2.7 million tons (using an unsaturated thickness of 1.1 feet and specific yield of 0.10). The change in storage of the subsurface brine of the small, shallow lake from April 7, 1988, to June 11, 1989, is about 0.3 million tons and is estimated to range from 0.2 million to 0.4 million tons.

Procedures similar to those of Waddell and others (1992) were used to estimate return flow to Great Salt Lake. Monthly outflow through the weir from April 1988 to June 1989 is minute compared to the outflow during February and March 1989; thus, only outflow during these two months (140.4 thousand acre-feet) was considered in this calculation. Because temperatures are relatively low in February and March, evaporation can be assumed to be negligible; therefore, the

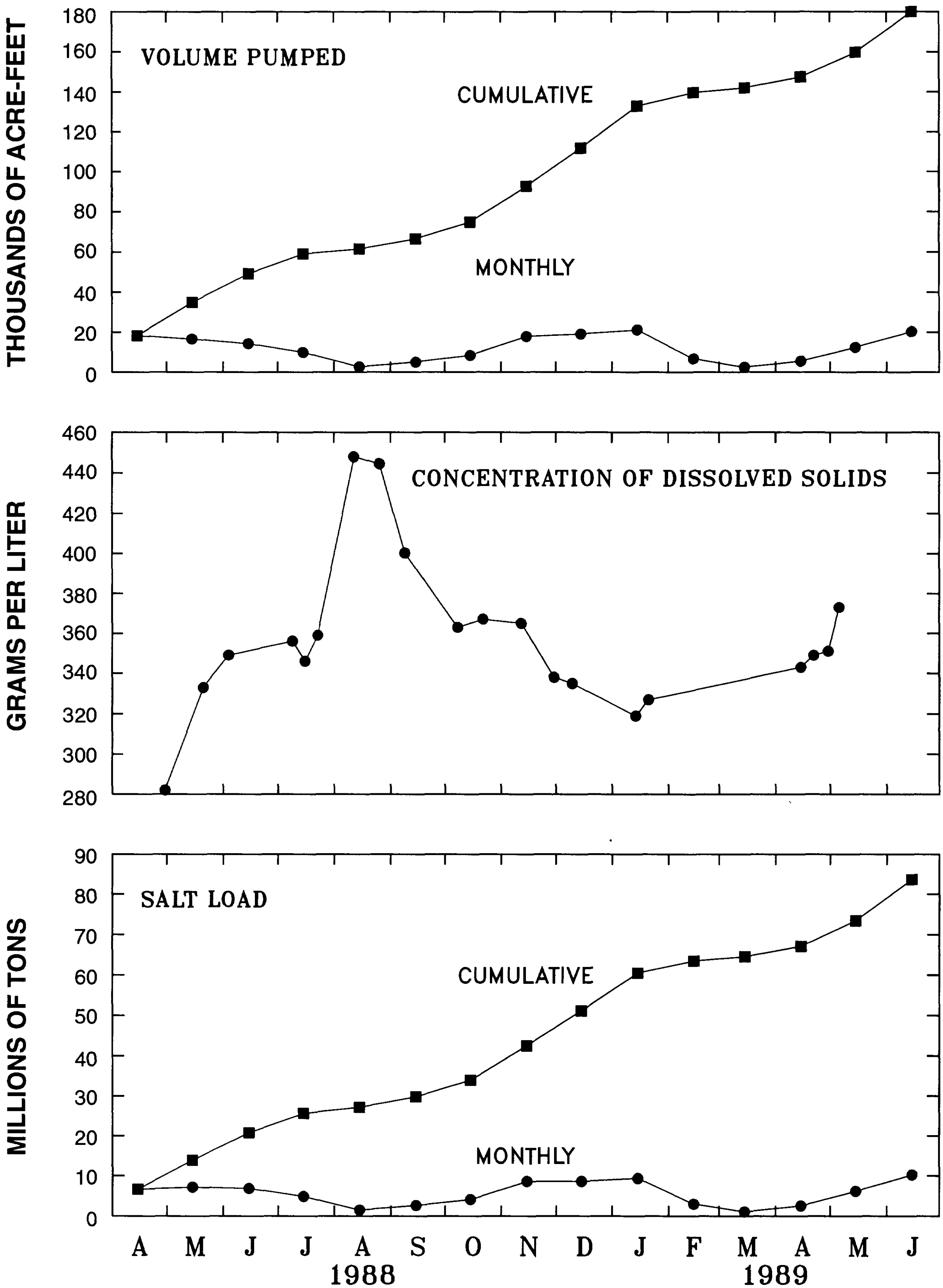


Figure 7. Volume pumped, concentration of dissolved solids, and salt load of brine pumped from West Pond into American Magnesium Corporation solar ponds, April 1988 to June 1989.

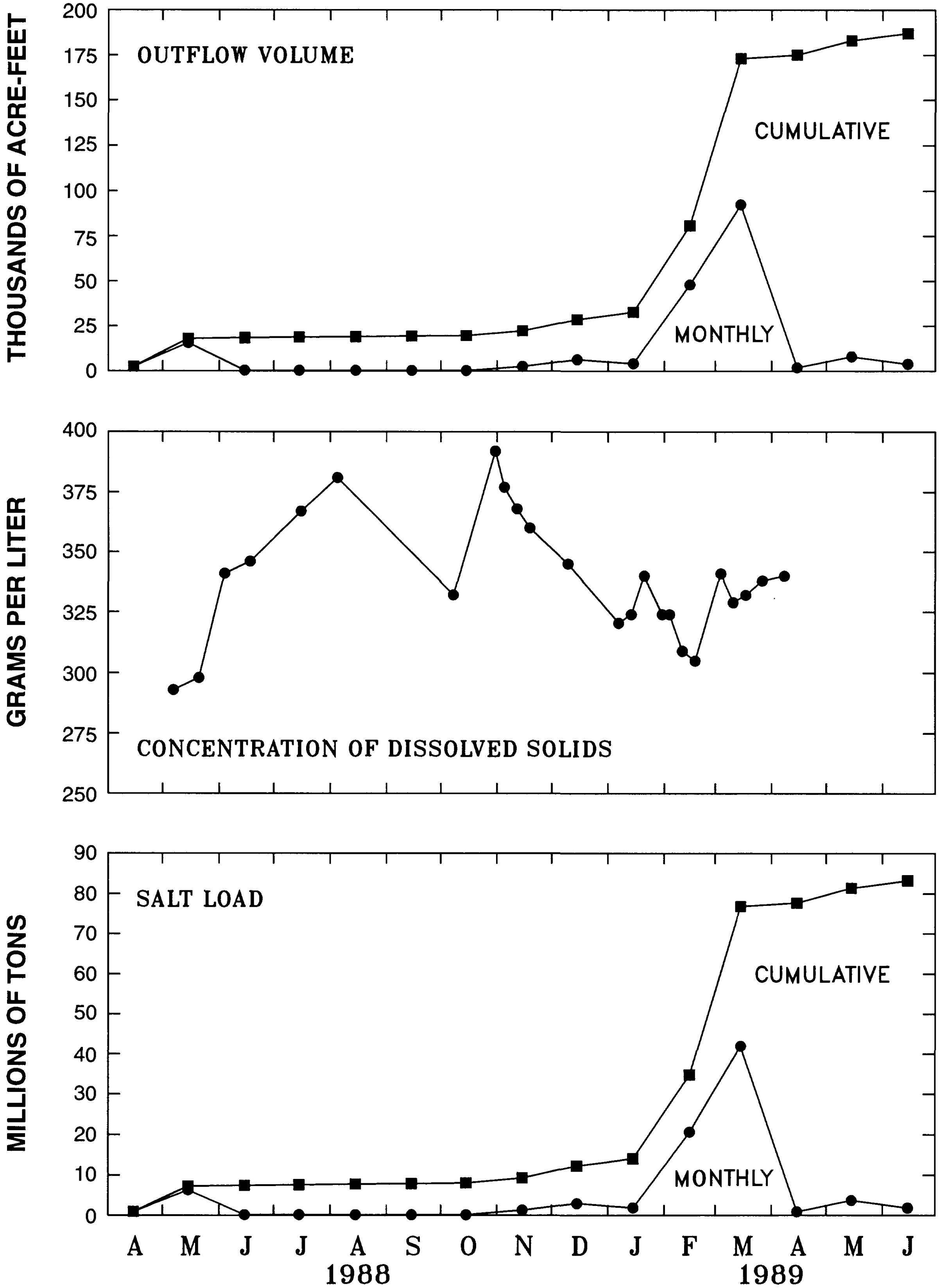


Figure 8. Outflow volume, concentration of dissolved solids, and salt load of brine outflow from West Pond through the Newfoundland weir, April 1988 to June 1989.

quantity of return flow to Great Salt Lake was assumed to be nearly the same as the weir outflow.

The quantity of brine that returned to Great Salt Lake from April 7, 1988, to June 11, 1989, was estimated to be the 63 million tons of outflow through the Newfoundland weir (with an average concentration of 327 grams per liter) during February and March 1989. This assumes that very little salt went into subsurface storage compared with the outflow through the weir from April 7, 1988, to June 11, 1989.

SUMMARY

The salt load and distribution of brine in West Pond in northern Utah is of concern to those interested in the quantity of salt that was deposited in West Pond from Great Salt Lake in 1987-89. The U.S. Geological Survey, in cooperation with the Utah Geological Survey and the Utah Department of Natural Resources, Division of Water Resources, completed a study evaluating the quantity and distribution of dissolved salts that were pumped into West Pond during this period.

A salt budget for April 10, 1987, to June 11, 1989, indicates that about 695 million tons of salt (or about 14.2 percent of salt contained in Great Salt Lake) was pumped into West Pond. About 94 million tons (1.9 percent of the total salt in Great Salt Lake) flowed from West Pond back to Great Salt Lake. Of the quantity of salt pumped into West Pond, approximately 396 million tons (57 percent) was stored as dissolved salt, salt crust, or in the subsurface of West Pond. Withdrawal by American Magnesium Corporation and discharge from West Pond through the Newfoundland weir comprised 211 million tons (30 percent) of salt pumped.

The remaining quantity, 88 million tons (about 13 percent of the salt pumped from Great Salt Lake) could not be accounted for in data collected in the monitoring program and calculations made for the salt budget. Most of the inaccuracy in the budget is believed to be associated with the elevation-volume relations that affect the computed salt loads stored in West Pond.

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Waddell, K.M, Gwynn, J.W., Burden, C.B., and Wold, S.R., 1992, Salt budget for West Pond, Utah, April 1987 to April 1988: U.S. Geological Survey Water-Resources Investigations Report 92-4117, 70 p.

Table 7. Compilation of volume and salt load for sections of West Pond, June 8-11, 1989

Elevation, in feet above sea level	Incremental volume (acre-feet)	Concentration of dissolved solids (grams per liter)	Salt load (tons)
SECTION A			
4,214	330	302	136,850
4,215	3,390	296	1,364,600
4,216	8,800	293	3,505,200
4,216.5	11,260	292	4,472,200
TOTAL (rounded)	23,780		9,479,000
SECTION A-B			
4,211	8	309	3,480
4,212	191	308	79,950
4,213	2,220	303	915,500
4,214	9,550	299	3,884,500
4,215	17,860	294	7,142,700
4,216	21,900	293	8,728,600
4,216.5	11,790	293	4,696,700
TOTAL (rounded)	63,520		25,451,000
SECTION B-C			
4,210	393	321	171,500
4,211	1,647	320	716,700
4,212	3,030	318	1,308,300
4,213	6,170	316	2,652,800
4,214	10,770	313	4,586,200
4,215	13,450	310	5,670,500
4,216	14,440	309	6,069,600
4,216.5	7,480	309	3,142,800
TOTAL (rounded)	57,380		24,318,000
SECTION C-D			
4,211	754	322	330,100
4,212	1,950	321	850,300
4,213	2,970	320	1,292,300
4,214	4,470	318	1,933,400
4,215	6,530	316	2,806,700
4,216	8,480	316	3,646,400
4,216.5	4,780	316	2,055,200
TOTAL (rounded)	29,930		12,914,000
SECTION D-E			
4,210	103	331	46,300
4,211	962	330	431,900
4,212	2,820	328	1,257,700
4,213	5,630	326	2,498,100
4,214	9,430	323	4,142,300
4,215	14,700	322	6,435,200
4,216	21,130	321	9,225,800
4,216.5	12,420	320	5,403,700
TOTAL (rounded)	67,200		29,441,000
SECTION E-F			
4,212	1,160	335	530,000
4,213	5,110	334	2,319,000
4,214	12,360	332	5,580,300
4,215	19,430	334	8,827,800
4,216	25,410	332	11,472,400
4,216.5	15,220	332	6,873,000
TOTAL (rounded)	78,690		35,602,000
SECTION F-G			
4,211	491	342	228,200
4,212	5,840	342	2,716,100
4,213	15,130	342	7,036,400
4,214	23,050	341	10,689,800
4,215	33,270	342	15,472,700
4,216	43,700	342	20,327,500
4,216.5	24,290	342	11,295,300
TOTAL (rounded)	145,770		67,766,000
SECTION G-H			
4,213	448	350	213,200
4,214	5,260	350	2,504,200
4,215	18,880	351	9,014,500
4,216	42,170	351	20,130,200
4,216.5	28,280	351	13,501,600
TOTAL (rounded)	95,040		45,364,000
SECTION H			
4,214	418	356	202,500
4,215	4,390	356	2,126,700
4,216	25,630	358	12,477,000
4,216.5	25,680	358	12,505,100
TOTAL (rounded)	56,120		27,311,000

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