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WATER BUDGET AND WATER-SURFACE FLUCTUATIONS, GREAT SALT LAKE, UTAH

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WATER BUDGET AND WATER-SURFACE FLUCTUATIONS,

GREAT SALT LAKE, UTAH

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ABSTRACT

The water-budget equation for Great Salt Lake, Utah, is:

Inflow (surface water, ground water, and precipitation) =

Outflow (evaporation) $\pm$ Storage change

The average annual inflow for the period 1931-76 was about 2.9 million acre-feet--1.9 million acre-feet from surface sources, about 900,000 acre-feet from direct precipitation, and about 75,000 acre-feet from ground water. The average annual outflow for the same period, all by evaporation, also was about 2.9 million acre-feet.

Storage changes are computed on the basis of changes in the surface level of the lake. During the period of historic record, 1847-1978, the lake surface has fluctuated within a range of about 20 feet but has shown little overall change. The lake surface would have been about 5 feet higher in 1978 than it was in 1847 had there been no consumptive use of water caused by man's activities in the lake basin.

Since 1959 the lake has been divided into two parts by a railroad causeway, which has restricted the natural circulation. This has resulted in a difference of salinity and of surface level across the causeway. The difference in surface level between the two parts of the lake varies seasonally and annually and has been as much as 2.35 feet.

INTRODUCTION

The surface level of Great Salt Lake, Utah, fluctuates continuously, primarily in response to climatic factors. The level reflects an equilibrium between the inflow to the lake from surface and ground water and precipitation directly on the lake and the outflow from the lake by evaporation. Man's activities have had a lesser effect on the lake level.

During dry years the surface level drops, causing a decrease in surface area, and consequently the volume of evaporation decreases. But less inflow is required to raise the lake level a given increment. In contrast, during wet years the surface level rises, causing an increase of surface area, and consequently the volume of evaporation increases. More inflow is required to raise the lake level a given increment. For example, at the historic low level of 4,191.35 ft, a net increase in inflow of about 600,000 acre-ft was necessary to raise the lake 1 ft; whereas at the historic high level of 4,211.5 ft, a net increase in inflow of about 1.5 million acre-ft would have been necessary to raise the lake level 1 ft. (See fig. 1.)

WATER BUDGET

The water-budget equation for a selected time increment for Great Salt Lake can be written as follows:

$$\text{Inflow} = \text{Outflow} \pm \text{Storage change}$$

The inflow comes from surface water that flows into the lake, from precipitation that falls directly on the lake surface, and from ground water that moves upward through the bottom of the lake. The outflow is entirely by evaporation. The storage change is the change in the volume of the lake during the selected time increment.

Values for the elements of the water-budget equation are discussed in the following pages for the 46-year period from 1931-76. Most of the discussion is based on the results of computer-model studies of Great Salt Lake made by Waddell and Fields (1977) and Waddell and Barton (1978).

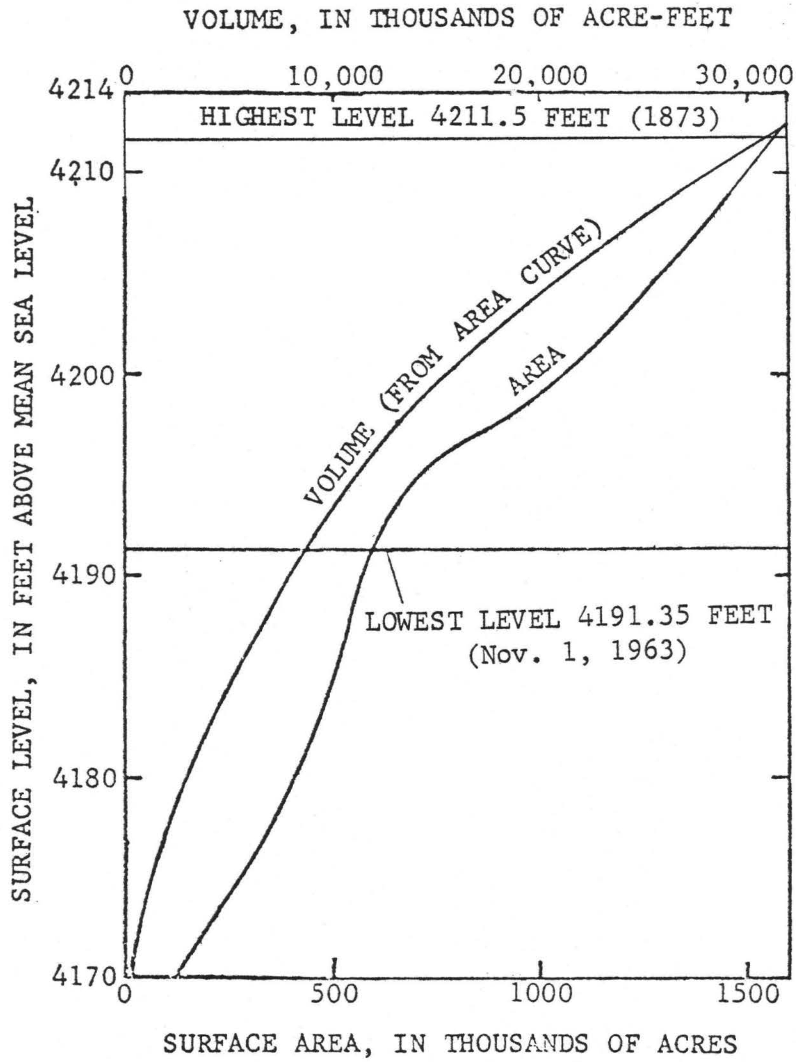


Figure 1.--Relations among the level, area, and volume of Great Salt Lake prior to 1957. (Adapted from Hahl and Handy, 1969, p. 10.)

Inflow

Surface water constitutes about 66 percent of the average annual inflow to Great Salt Lake, precipitation about 31 percent, and ground water about 3 percent. Figure 2 shows the distribution of inflow by source. The total annual inflow during 1931-76 ranged from about 1.3 (1961) to 5.0 (1971) million acre-ft and averaged about 2.9 million acre-ft.

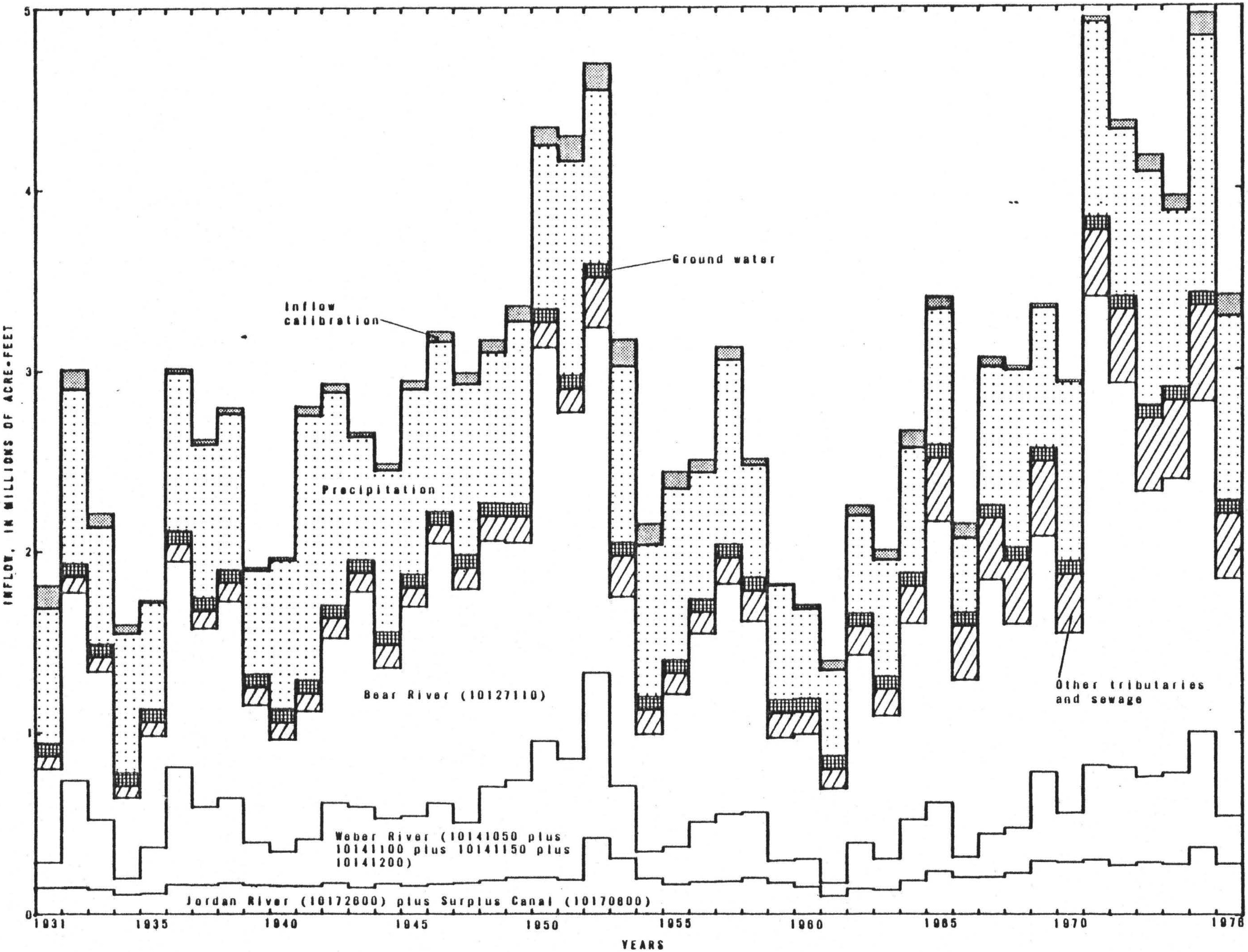


Figure 2.--Annual inflow to Great Salt Lake from all sources, 1931-76.
(From Waddell and Barton, 1978, fig. 7.) Numbers in parentheses are
gaging-station numbers listed in table 1.

Surface water

Approximately 92 percent of the average annual surface inflow to Great Salt Lake is from the Bear (59 percent), Weber (20 percent), and Jordan (13 percent) River drainage systems. The U.S. Geological Survey has operated gaging stations on the main stems of these streams upstream from the lake for many years. During 1971-76 records were obtained at numerous gaging stations near the lakeshore in the three drainage basins. Surface inflow to the lake during 1931-76 was estimated by correlation of the short-term records obtained near the lakeshore with the long-term records obtained farther upstream. The locations of all gaging stations are shown in figure 3, and the period of record at each site is shown in table 1.

An additional 5 percent of the surface inflow to the lake is from 10 tributaries on the east and south shores. Measurements made in these tributaries during varying periods from 1950-76 were used as a basis for estimating the inflow during 1931-76. These sites are also shown in figure 3 and are listed in table 1. Surface inflow from the remainder of the lakeshore is negligible.

Approximately 3 percent of the surface inflow to Great Salt Lake is from five sewage plants. These all discharge their effluent directly into Farmington Bay, east of Antelope Island.

The total annual surface inflow during 1931-76 ranged from about 700,000 (1934) to 3.8 million (1971) acre-ft and averaged about 1.9 million acre-ft.

Precipitation

Inflow to Great Salt Lake from precipitation directly on the lake surface was calculated by using the average annual precipitation during 1931-76 for 68 sites in a large area surrounding the lake. A multiple-regression equation was derived to describe the average annual precipitation as a

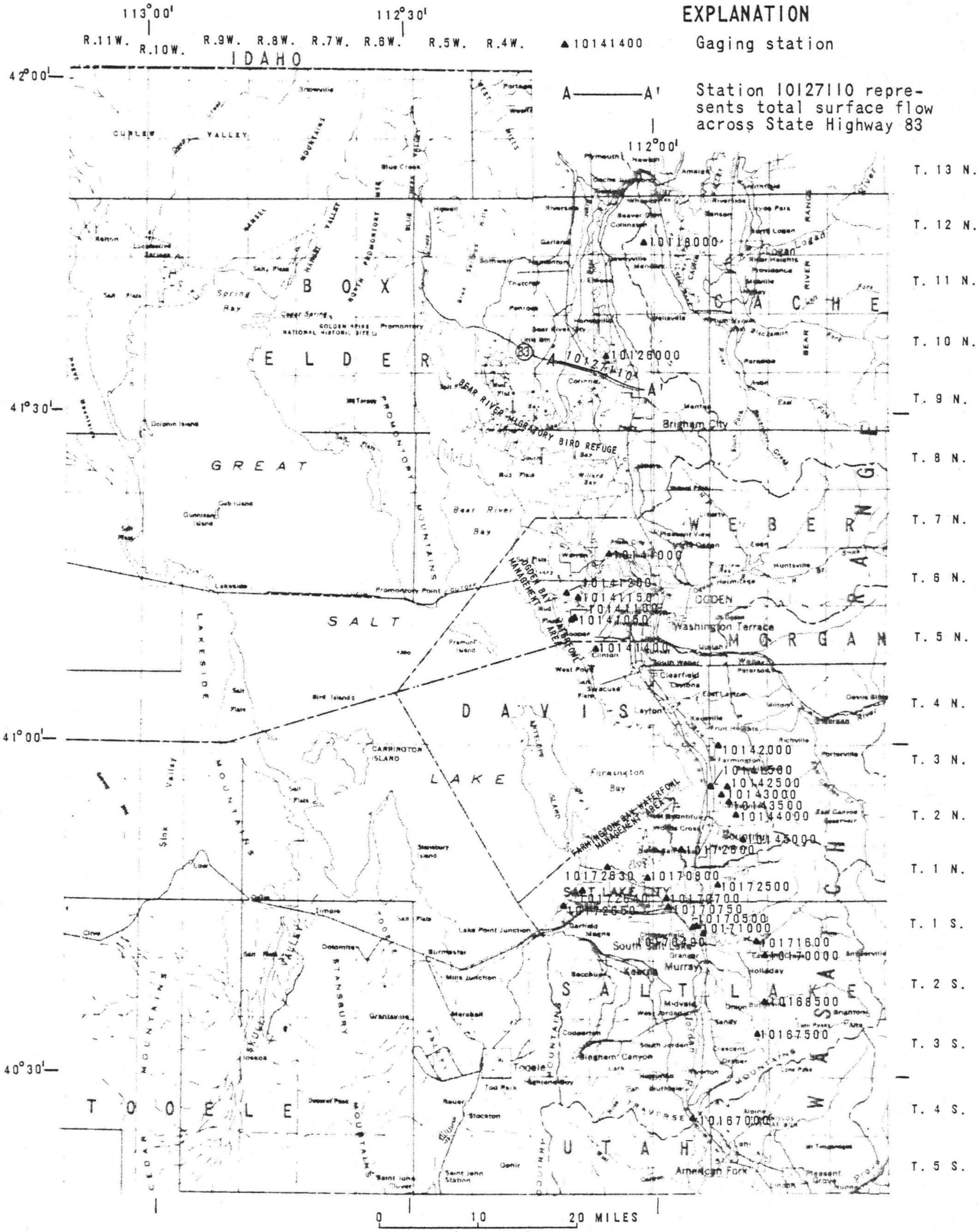
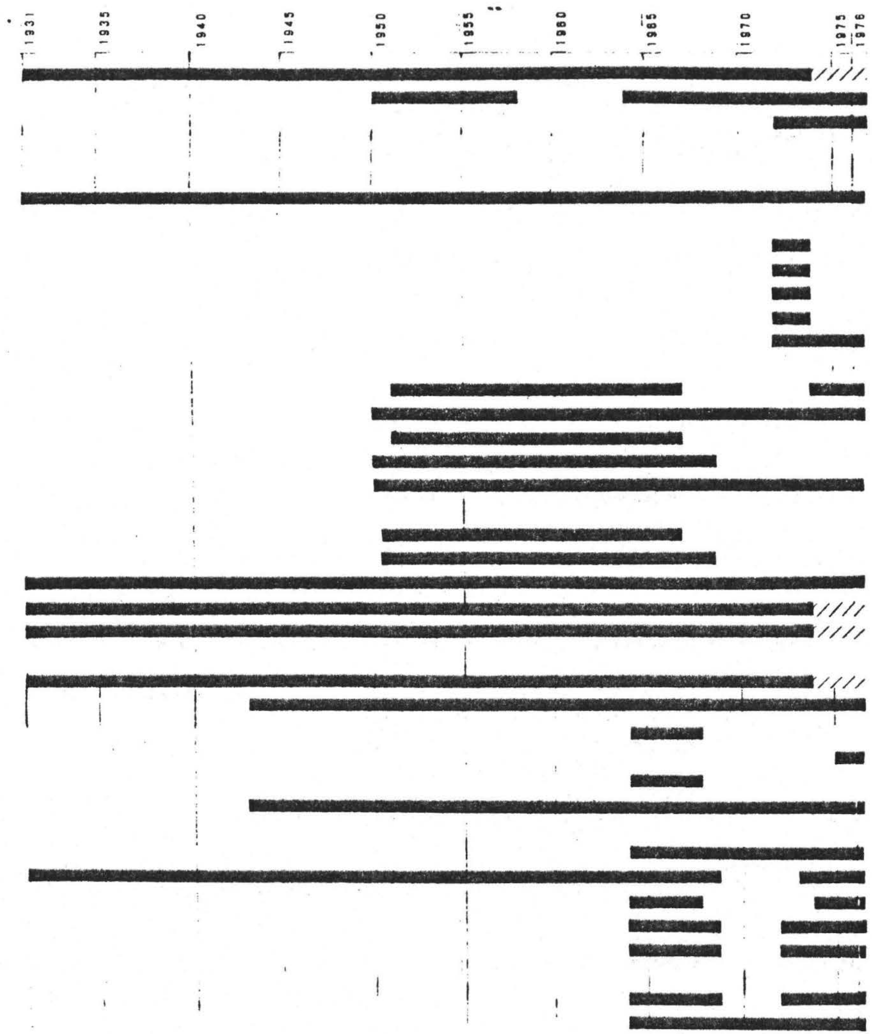


Figure 3.--Map showing location of gaging stations used for estimating surface inflow to Great Salt Lake. (Modified from Waddell and Barton, 1978, fig. 3.)

Table 1.--Bar chart of gaging-station records, 1931-76
(From Waddell and Barton, 1978, table 2)

Station No.	Name
10118000	Bear River near Collinston
10126000	Bear River near Corinne
10127110	Bear River basin outflow across State Highway 83 near Corinne
10141000	Weber River near Plain City
10141050	South Fork Weber Canal near Hooper
10141100	South Fork Weber River near Hooper
10141150	Middle Fork Weber River near Hooper
10141200	North Fork Weber River near Hooper
10141400	Howard Slough at Hooper
10141500	Holmes Creek near Kaysville
10142000	Farmington Creek above diversions, near Farmington
10142500	Ricks Creek above diversions, near Centerville
10143000	Parrish Creek above diversions, near Centerville
10143500	Centerville Creek above diversions, near Centerville
10144000	Stone Creek above diversions, near Bountiful
10145000	Mill Creek at Mueller Park, near Bountiful
10167000	Jordan River at narrows, near Lehi
10167500	Little Cottonwood Creek near Salt Lake City
10168500	Big Cottonwood Creek near Salt Lake City
10170000	Mill Creek near Salt Lake City
10170500	Surplus Canal at Salt Lake City
10170700	North Point Consolidated Canal below Goss flume, at Salt Lake City
10170750	Surplus Canal at North Temple Street, near Salt Lake City
10170800	Surplus Canal at Cohen flume, near Salt Lake City
10171000	Jordan River at Salt Lake City
10171600	Parley Creek at Suicide Rock, near Salt Lake City
10172500	City Creek near Salt Lake City
10172600	Jordan River below Cudahy Lane, near Salt Lake City
10172630	Goggin Drain near Magna
10172640	Lee Creek near Magna
10172650	Kennecott Drain near Magna
	Salt Lake City sewage canal

Period of record



//// Records available but not used.

function of altitude, latitude, and longitude. The equation was used as a means of drawing lines of equal average annual precipitation for the lake area. Then the annual precipitation directly on the lake was computed for the period 1931-76 on the basis of monthly lake-surface altitudes and areas during that period.

The estimated annual precipitation on the lake during 1931-76 ranged from about 500,000 (1966) to 1.5 million (1941) acre-ft and averaged about 900,000 acre-ft.

Precipitation that falls on the lakeshore runs into the lake and must be considered as part of the inflow. The amount is relatively small, however, and in figure 2 it is included in "inflow calibration," which is the factor used by Waddell and Barton (1978) to balance their water budget for the lake.

Ground water

The ground-water inflow to Great Salt Lake was estimated by adding inflow values for 13 segments of the lakeshore.

The values in acre-feet per year are: 0 for Curlew, Sink, and Skull Valleys, the lower Bear River basin, and the northern Great Salt Lake Desert (west of Great Salt Lake); 1,000 for Hansel Valley; 3,000 for Antelope Island and Park Valley (northwest of Great Salt Lake); 4,000 for Jordan Valley (Salt Lake County); 7,000 for Tooele Valley; 9,000 for the Promontory Mountains; and 48,000 for the area east of Great Salt Lake. (See Arnow and Stephens, 1975.)

The total ground-water inflow to the lake thus is estimated to be about 75,000 acre-ft per year. This is assumed to be an average annual inflow value for the period 1931-76.

Outflow

Outflow from Great Salt Lake by evaporation from the lake surface was calculated primarily on the basis of pan-evaporation data from 49 sites in Utah and bordering States. Short-term records were extended to the full period 1931-76 by correlation with a site near Lehi (about 30 mi southeast of Great Salt Lake), and seasonal records were extended to the entire year by use of ratios developed for a few sites where complete annual records were available. Pan coefficients were applied, and a multiple-regression equation based on latitude, longitude, and altitude was used to draw lines of annual freshwater evaporation for the lake. The freshwater evaporation was then corrected for the effect of salinity by applying the appropriate factors for each part of the lake.

The estimated annual evaporation from the lake for the period 1931-76 ranged from about 2.1 to 3.9 million acre-ft and averaged 2.9 million acre-ft. The latter is equivalent to about 45 in. per year for the average lake level during 1931-76.

A small amount of water has been withdrawn from Great Salt Lake during the entire period 1931-76 and evaporated for salt production, but in recent years the amount has increased because of withdrawals for production of other minerals. The total withdrawal for mineral production in 1976 was about 71,000 acre-ft.

Storage changes

The final element in the water budget--storage change--is the change in the volume of the lake. Changes in volume are computed on the basis of changes in the surface level of the lake, and figure 1 illustrates the relation between volume and surface level.

A discussion of the record of water-surface fluctuations and the effects of man's activities on the level of the lake is given in the following sections, which are taken largely from a report by Arnow and Jensen (1977).

WATER-SURFACE FLUCTUATIONS

Source of record

The historic record of lake-level fluctuations begins in 1847. The level was determined indirectly by Gilbert (1890, p. 240-241) for the period 1847-75 on the basis of reported observations of the depth of water over the sandbars between the mainland and Antelope and Stansbury Islands. This information was relayed to Gilbert by stockmen who rode horses across the bars to reach the islands. Gilbert related these oral reports to later measurements by determining the altitudes of the Antelope and Stansbury Island bars, making soundings on the Antelope Island bar, and relating the water level there to gage readings near Black Rock and Farmington.

From 1875 to 1938 the lake level was measured periodically at staff gages at six different sites. The level has been measured continuously at the Salt Lake County boat harbor since 1939 (fig. 4), at Saline since 1966, and at Promontory Point since 1968. The gaging sites and the chronology of the record are shown in figure 5.

Historic record

When the Mormon pioneers arrived in Utah in 1847, the surface of Great Salt Lake was at about 4,200 ft above mean sea level (fig. 6). It rose almost 5 ft by 1855 but then declined again to 4,200 ft by 1860. From 1862 until 1873 the lake level rose almost 12 ft to reach a historic high of about 4,211.5 ft. The rapid rise of the lake from 1862-73 was of considerable concern to the Mormon settlers. If the lake continued to rise, they feared that Salt Lake City and adjacent farmlands would be flooded. In the hope of being able to avert such a calamity, they sent out an exploration party to determine if the water could be spilled from the lake into the vast desert area to the west. But the lake peaked in 1873, ending the problem for the time being.

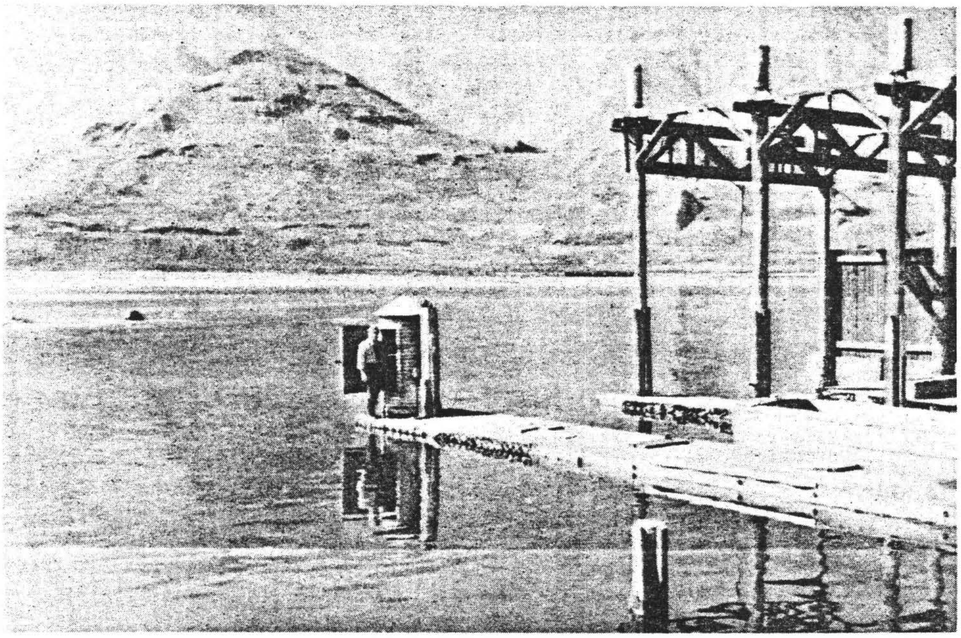


Figure 4.--Continuous lake-level recording gage at Salt Lake County Boat Harbor, 1972. (Photograph by Verda Jensen.)

EXPLANATION

Number	Gage	Period of record
1	Black Rock	1875-1876
2	Farmington	1876-1879
3	Lakeshore	1879-1881
4	Garfield	1881-1901
5	Midlake	1902-1903
6	Saltair	1903-1938
7	Salt Lake County Boat Harbor	1939-Present
8	Saline	1966-Present
9	Promontory Point	1968-Present

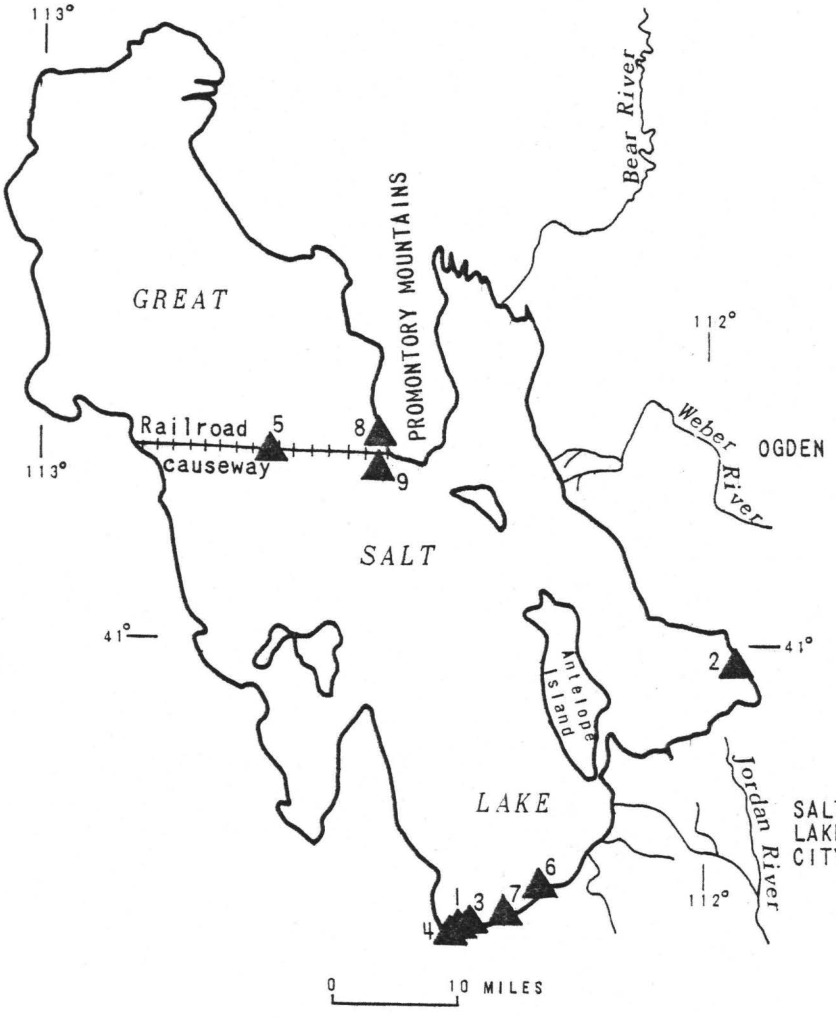


Figure 5.—Location of gages used to determine the level of Great Salt Lake, 1875-1978.

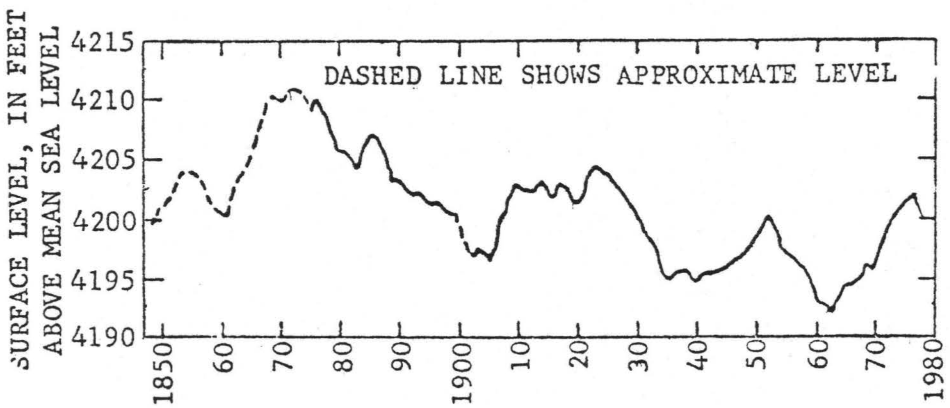


Figure 6.--Fluctuations of the surface level of Great Salt Lake, 1847-1978.

During the next 31 years the lake level declined almost 16 ft, and by 1905 it was at a then historic low of slightly less than 4,196 ft. A series of fluctuations followed, each time the lake declining to a lower level, and by 1963 it had dropped to an alltime historic low of 4,191.35 ft. The fluctuations of the lake surface generally reflected fluctuations of precipitation as represented by the record for Salt Lake City (fig. 7) where systematic recordkeeping of precipitation was started during 1874.

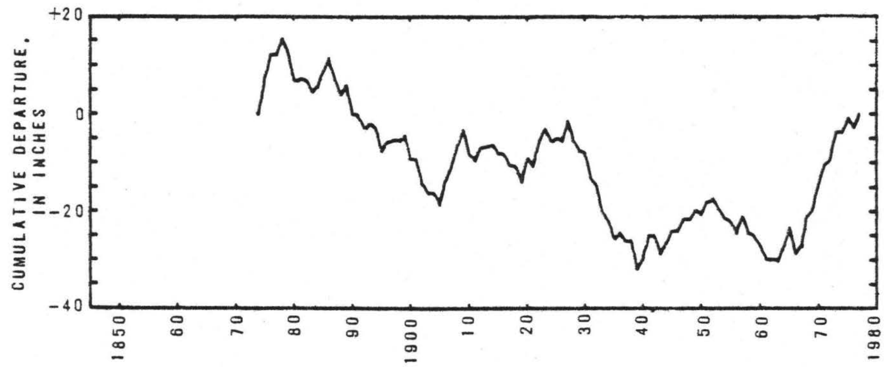


Figure 7.--Cumulative departure from average annual precipitation at Salt Lake City, 1875-1977. (Data from E. A. Richardson, Utah State Climatologist.)

Many people thought that the lake was going dry. Roads, railroads, wildfowl-management areas, and industrial installations encroached on the relicted shores. But then the lake began to rise again in response to above-average precipitation, and by 1976 it had risen almost 11 ft to slightly above

4,202 ft. Again fears of a calamity arose, and studies were made of the feasibility of pumping water out of the lake into the desert to the west. But the lake began to decline in 1977 in response to unusually low snowfall during the preceding winter, again ending the problem for the time being.

In the summer of 1978, the lake surface was at about 4,200 ft--the same level that it was 131 years prior when the pioneers arrived. Thus, the lake surface has fluctuated within a range of about 20 ft but has shown little overall change.

Effect of man's activities

Consumptive use

The lake surface would have been about 5 ft higher in 1978 than it was in 1847 had there been no consumptive use of water caused by man's activities in the lake basin. Figure 8 shows the effect of such consumptive use on the level of the lake for the period 1850-1965. The difference between the observed level and the level adjusted for consumptive use reached a maximum of about 5 ft around 1925 and has remained relatively constant since then. Thus, the lake surface is about 5 ft lower than it would have been if man had not caused evapotranspiration of water by impounding it in reservoirs and marshes upstream from the lake and diverting it for irrigation and other uses.

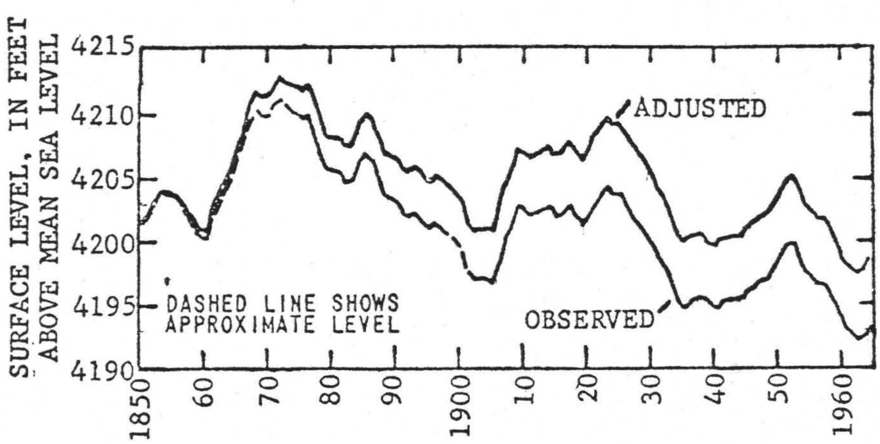


Figure 8.--Effects of consumptive use of water resulting from man's activities on recorded levels of Great Salt Lake, 1850-1965. (From Whitaker, 1971, fig. 3.)

Railroad causeway

The Southern Pacific Transportation Co. built a railroad causeway during 1957-59 between Promontory Point and Lakeside (fig. 3). The causeway, which replaces an open trestle, was constructed mostly of gravel and sandfill capped with boulder-sized riprap. It is breached by two box culverts, each 15 ft wide. The causeway separates the lake into two parts--about two-thirds of the lake is south of the causeway and about one-third is north of it. Because the causeway fill is permeable, however, brine can move both northward and southward through the causeway.

The southern part of the lake receives most of the freshwater inflow, whereas the northern part receives most of its water in the form of brine that moves through the causeway from the southern part. These factors, in conjunction with restriction of flow by the causeway, have caused differences of salinity and of surface level between the two parts of the lake. The differences increased steadily throughout the 1960's. Since 1966, when measurements of the surface level were started in the northern part, the southern surface has been consistently higher and the difference reached a maximum of 2.35 ft in June 1975 (fig. 9). The difference of surface level also varies seasonally, with the minimum generally occurring during the fall and the maximum generally occurring during the late spring.

CONCLUSIONS

The surface level of Great Salt Lake fluctuates in dynamic equilibrium between inflow and outflow. Although man's use of water has affected the level somewhat, the greatest effect is caused by natural variations of climate. Unless climatic conditions or man's use change significantly from that experienced since 1847, the lake will not dry up or rise above the historically recorded high level.

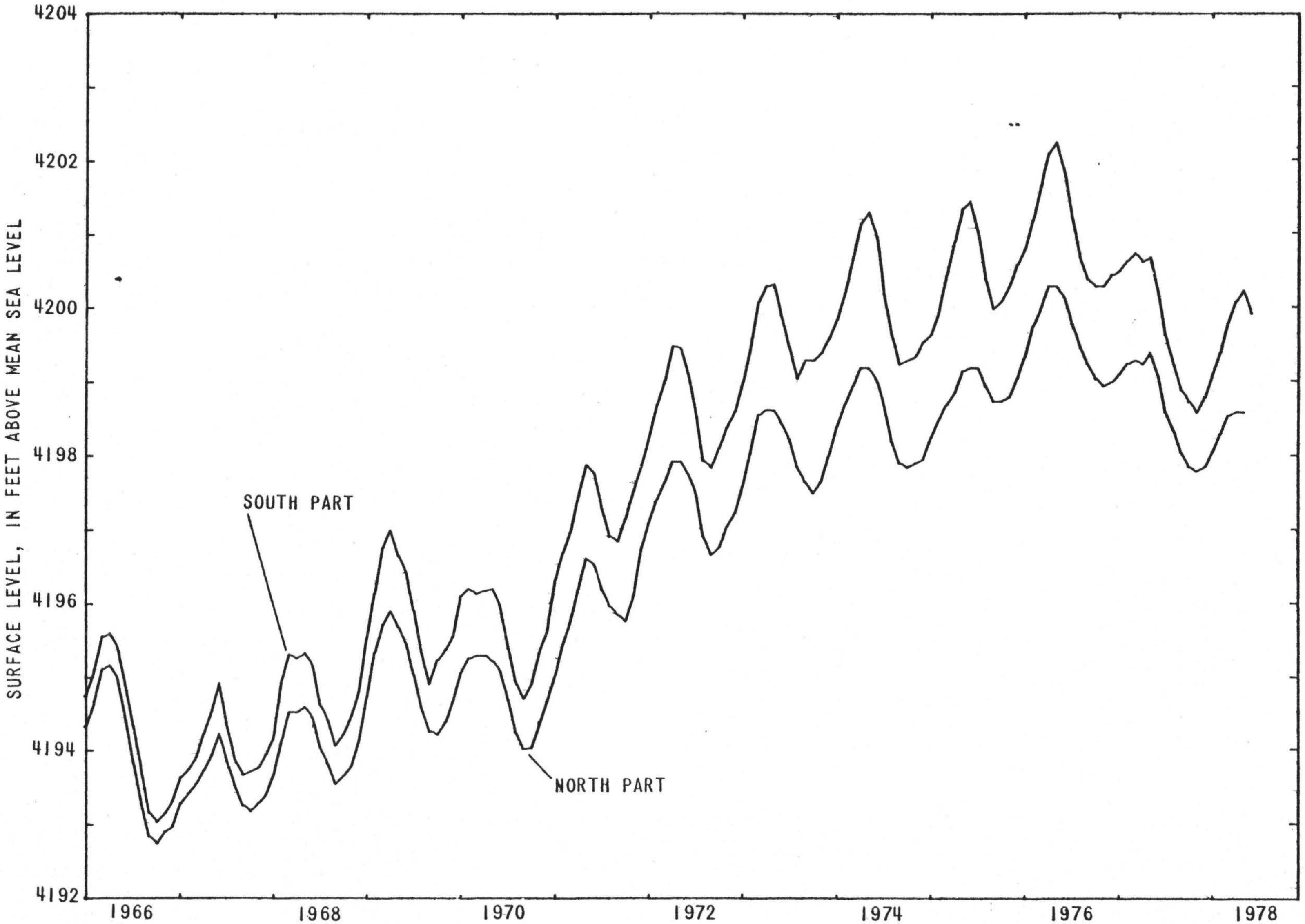


Figure 9.--Surface levels of the north and south parts of Great Salt Lake, 1966-78.

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