The Effects of Restricted Circulation on the Salt Balance of Great Salt Lake, Utah

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K. M. Waddell and E. L. Bolke

Prepared by
The United States Geological Survey
in cooperation with
The Utah Geological and Mineral Survey

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of the
UTAH DEPARTMENT OF NATURAL RESOURCES
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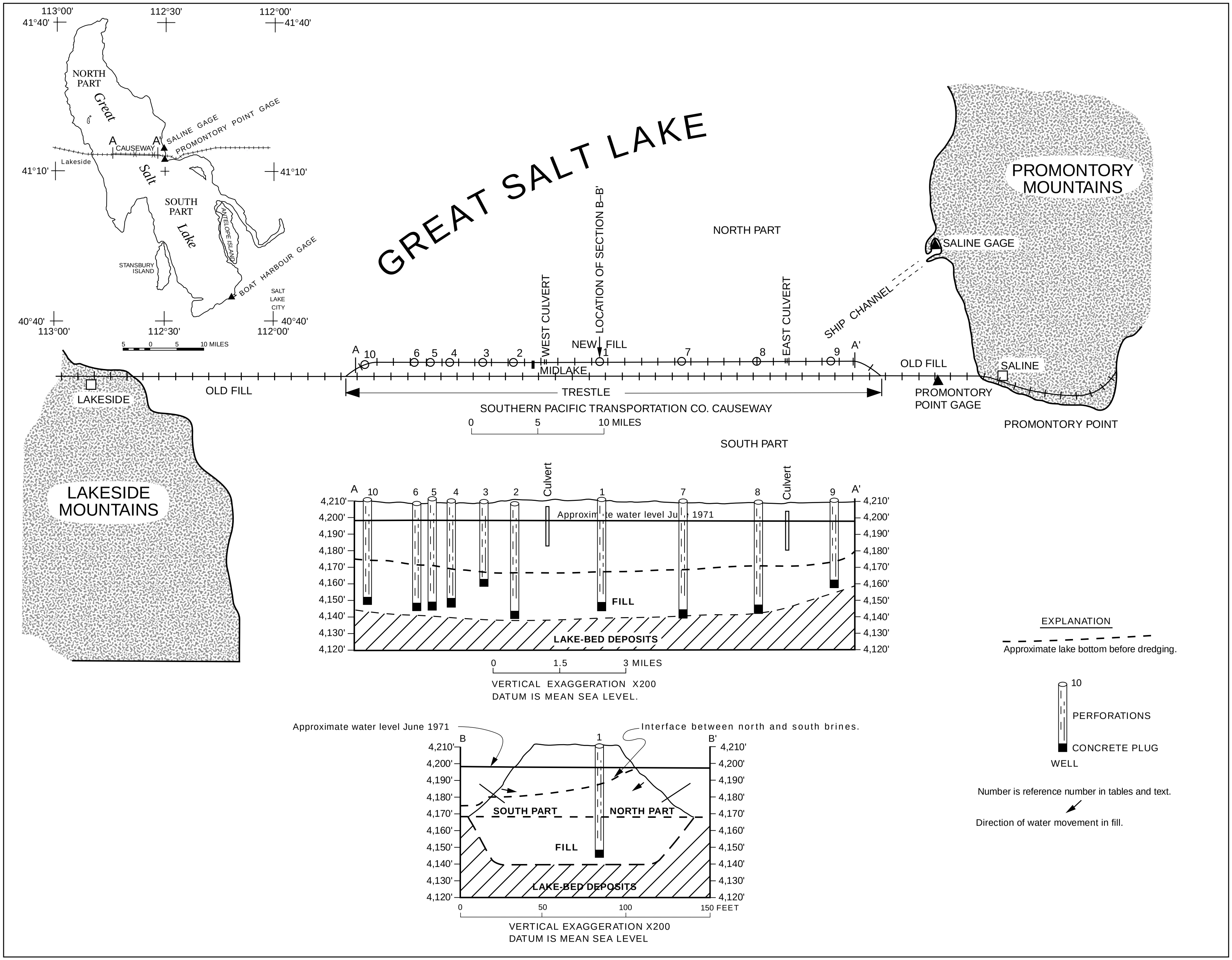


Figure 1. Map of Great Salt Lake showing location of causeway, test wells, culverts, and diagrammatic cross section of causeway fill.

THE EFFECTS OF RESTRICTED CIRCULATION ON THE SALT BALANCE OF GREAT SALT LAKE, UTAH

by K M. Waddell[1] and E. L. Bolke[1]

ABSTRACT

During the 1970-1972 water years a net load of dissolved solids of 0.26 billion tons moved from the south to north part of Great Salt Lake, Utah, through the causeway of the Southern Pacific Transportation Co. The load loss from the south part during the 1972 water year was only 0.01 billion tons, thus indicating that the salt balance between the two parts of the lake was near equilibrium for inflow conditions such as those of 1972.

The future balance of dissolved-solids load in the lake for the existing (1972) causeway conditions depends principally upon the quantity of fresh-water inflow to the lake. For simulated inflow rates resulting in rising stages, the net dissolved-solids load increased slightly in the south part during a 10-year period. If the rate of rise of lake stage is great enough (greater than rates simulated for a 10-year period in a digital computer model), however, net load movement could be to the north part. And if the lake stage drops at the simulated rate for a 10-year period, the net effect would be a loss of 0.27 billion tons of dissolved-solids load from the south to the north part and the deposit of 1.08 billion tons of sodium chloride in the north part.

The salt balance in Great Salt Lake can be changed by increasing the number of culverts or by widening the culverts in the causeway. The width of culvert opening necessary to bring the lake near chemical equilibrium depends upon the inflow conditions and desired salt balance. A culvert width of 500 ± 100 feet would be required to bring the dissolved-solids concentration in the south part to within about 85 percent of that in the north part and to limit precipitation of sodium chloride in the north part to less than 0.1 billion tons (for lake altitudes above 4,192 feet) for all the simulated inflow rates. A culvert width of 750 ± 150 feet would be required to bring the dissolved-solids concentration in the south part to within about 90 percent of that in the north part. Widening of culverts in excess of 500 feet would result in relatively little additional gain of net load of dissolved solids in the south part.

The model was based largely on data collected during the 1971-1972 water years. The predictive accuracy of the model will be improved if the equations used in the model are refined on the basis of data collected in the future on the causeway and in the lake.

INTRODUCTION

The causeway of the Southern Pacific Transportation Co. across Great Salt Lake, Utah (figure 1), has caused changes in the water and salt balance in the lake, and a reconnaissance by Madison (1970) indicated that a net load of about 0.30 billion tons of dissolved solids had moved from the south to north part of the lake from 1963 to 1969 due to the effects of the causeway. On the basis of his study, Madison recommended that a detailed study be made to enable predictions for long-term future effects of the causeway.

During 1970-1972, the U. S. Geological Survey in cooperation with the Utah Geological and Mineralogical Survey carried out an investigation based principally on Madison's recommendations. The purpose of this study was to determine the net movement of dissolved-solids load through the causeway during the 1971-1972 water years, to predict load movements for simulated rising and falling lake stages for the existing causeway, and to predict the possible effects of various culvert widths on load movement. Changing the culvert widths would effect changes in the salt balance of the lake, which in turn could cause economic and sociologic changes that are beyond the scope of this report.

The Southern Pacific Transportation Co. constructed the causeway during 1957-1959 for its railroad track across Great Salt Lake. According to Madison (1970, p. 7 and 9):

> The causeway traverses the lake in an east-west direction from Promontory Point to Lakeside (figure 1), where the lake is about 18 miles wide. Approximately 13 miles of this distance is covered by the causeway fill emplaced in 1957-59; and an older fill, constructed in the early 1900's, abuts each end of the newer fill. The older fill, which has a total length of about 5 miles, formed the approaches to a trestle which crossed the lake before the new fill was emplaced.
>
> The causeway was constructed by dredging a channel 25-40 feet deep and 150-500 feet wide to remove bottom muds. The channel was then back-filled with sand and gravel. The causeway was raised above the lake surface with quarry-run rock and finished with riprap varying in size from 1-ton capstone 15 feet below the surface to 3-ton capstone at the

[1]Hydrologist, U. S. Geological Survey.

top . . . The causeway is permeable and is also breached by two open culverts, each 15 feet wide, which allow brine to flow through the causeway . . . The culverts were placed where the lake is deepest. The bottoms of the culverts are about 10 feet above the lake bottom, but the bottom of the east culvert is [a few] feet lower than that of the west culvert.

. . . the causeway acts as a partial dike dividing the lake into north and south parts. A little more than one-third of the lake lies north of the causeway. The causeway interrupts the formerly free movement of brine within the lake. This, along with the fact that more than 95 percent of the fresh-water surface inflow enters the lake south of the causeway, has resulted in substantial changes in the hydrology and chemistry of the lake.

During the fall of 1970, bubbler-gage manometers were installed on either side of the east culvert to monitor continuously the difference of water-surface altitude[1] across the causeway (table 9). In addition, continuous records of the water-surface altitudes were collected at Promontory Point and Saline (figure 1 and table 9). Measurements of discharge and specific gravity were made monthly and at additional intermittent intervals (table 7) at both the east and west culverts.

During the summer of 1971, five test wells were constructed in the causeway and five abandoned wells were cleaned, perforated, and relined (figure 1). Tracer studies were conducted at the 10 test wells to determine the hydraulic properties of the fill, and chemical-quality data were collected to determine the extent of the exchange of dissolved-solids load through the fill (table 8).

The Utah Geological and Mineralogical Survey obtained water-quality data about four times per year during 1970-1972 from a sampling network in both parts of the lake. They also cored the bottom of the north part of the lake during the fall of 1970 and 1972 to determine the quantity of deposited salt, rate of deposition, and type of minerals deposited.

A digital computer model describing the brine movement through the causeway was developed to predict the future trend of the salt balance between the two parts of the lake for the existing causeway and for modified culvert openings and various rates of inflow.

The personnel of the Southern Pacific Transportation Co. were most cooperative throughout the project, and in particular J. E. Newby, L. E. Lutz, L. S. Schaub, and Jack Edwards aided and facilitated various phases of the work. The Great Salt Lake Minerals and Chemical Corp. allowed access to their road, which saved considerable travel time to and from the causeway. Many personnel of the U. S. Geological Survey provided technical support without which the project would not have been possible.

The main body of this report contains the results of the investigation. Most of the details concerning the development of the digital model and the collection of data are discussed in the Appendix.

HYDROLOGY OF THE LAKE SINCE 1969

Madison (1970, p. 9-19) described the hydrology of the lake through the 1969 water year[2], and most trends in lake parameters that he reported for the period 1964-1969 have continued since 1969. The lake stage has continued to rise (figure 2), stage difference across the causeway has continued to increase (figure 2), and the load and concentration of dissolved solids in the south part of the lake have continued to decrease (figures 2 and 3). In addition, a layer of more concentrated brine has persisted in the deeper part of the south part of the lake (figure 14).

Two major changes occurred during the 1971-1972 water years. The concentration of dissolved solids in the north part, which since construction of the causeway has been saturated with respect to sodium and chloride, began dropping below the saturation point—355 g/l (grams per liter)—during the 1971 water year. During the 1971-1972 water years, the concentration dropped below saturation level in the north part because as the lake volume increased, water in the south part became more dilute, stage difference across the causeway increased, and relatively larger quantities of water moved north through the causeway. Although the load of dissolved solids moving north was large, it was small in relation to the increase of water volume (net discharge to the north minus evaporation); and as a result, the north part became diluted below the saturation concentration of 355 g/l. Because of this dilution, about 0.18 billion tons of salt which had precipitated during 1969-1970 was redissolved during 1971-1972 (see page 6).

The other major change was that the load loss of dissolved solids from the south part during the 1972 water year was almost nil. The net load movement of dissolved solids to the north part was only 0.01 billion tons for the year, and this net loss from the south part was only about one-tenth of the lowest load loss that had occurred during the previous three water years.

[1]In this report, altitude difference and stage difference have the same meaning and are used interchangeably.

[2]A water year is the 12-month period, October 1 through September 30, designated by the calendar year in which it ends.

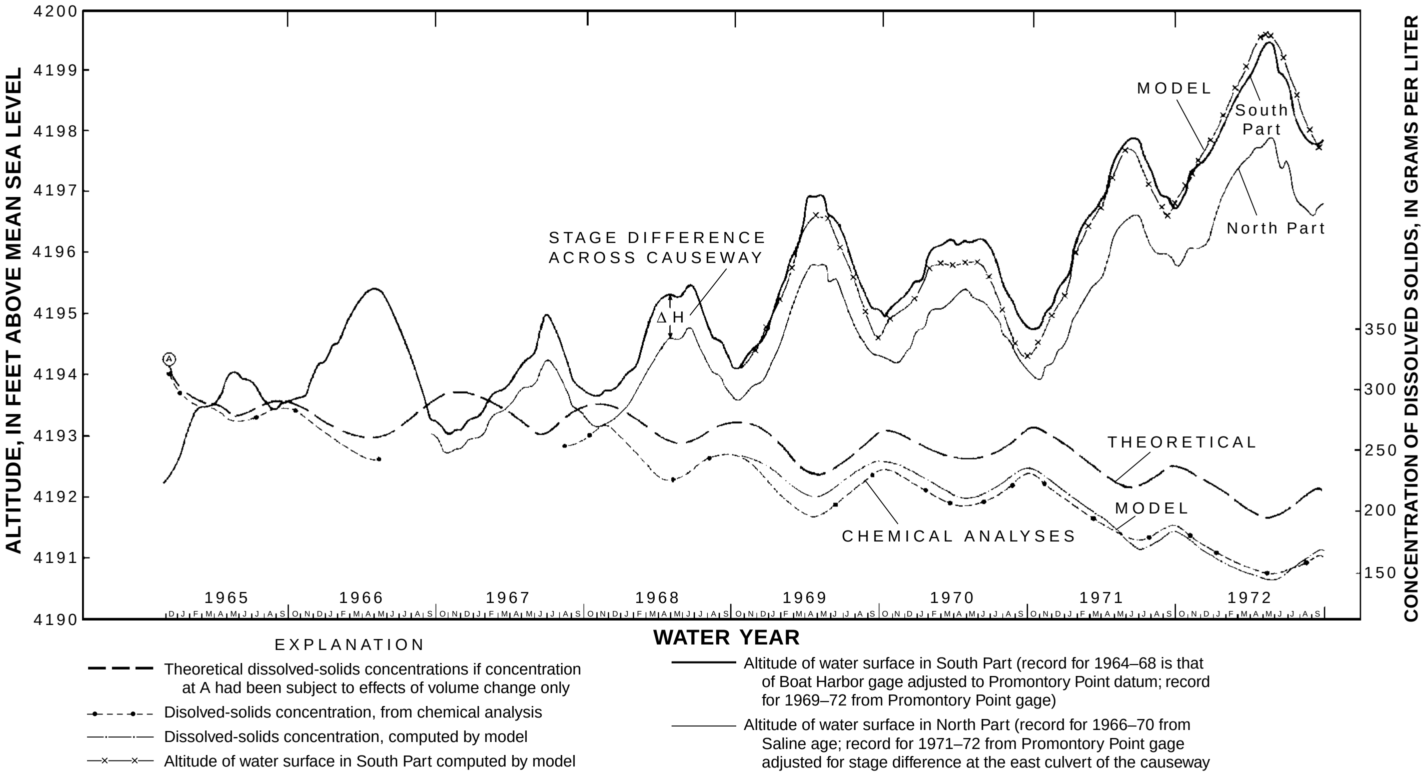


Figure 2. Altitude, stage difference, and actual and theoretical dissolved-solids concentration of water in the south part of Great Salt Lake.

MOVEMENT OF DISSOLVED-SOLIDS LOAD AND WATER DISCHARGE THROUGH THE CAUSEWAY DURING THE 1970-1972 WATER YEARS

Movement of Dissolved-solids Load

During the 1970-1972 water years a net dissolved-solids load of 0.26 billion tons moved from the south to north part (figure 4), and the overall decrease in concentration of dissolved solids in the south part of the lake was 65 g/l. The drop in concentration resulted from a decrease of 17 g/l due to load movement from south to north and a decrease of 48 g/l due to an increase in volume. Most of the net movement of dissolved-solids load occurred during the 1971 water year, when 0.16 billion tons moved north. This large load loss from the south part was due to the unusually high rate of stage increase as the lake rose by about 2 feet during the year. The net movement of dissolved-solids load to the north was only 0.09 billion tons during the 1970 water year as the stage dropped about 0.3 foot; and during the 1972 water year, the lake rose about 1 foot and net load movement to the north was only 0.01 billion tons. The rate of loss of dissolved-solids load from the south part decreased during 1972 because the salinity and density difference between the north and south parts was increasing during the period 1970-1972. As the density difference becomes larger, relatively more inflow is required to effect movement of dissolved-solids load to the north.

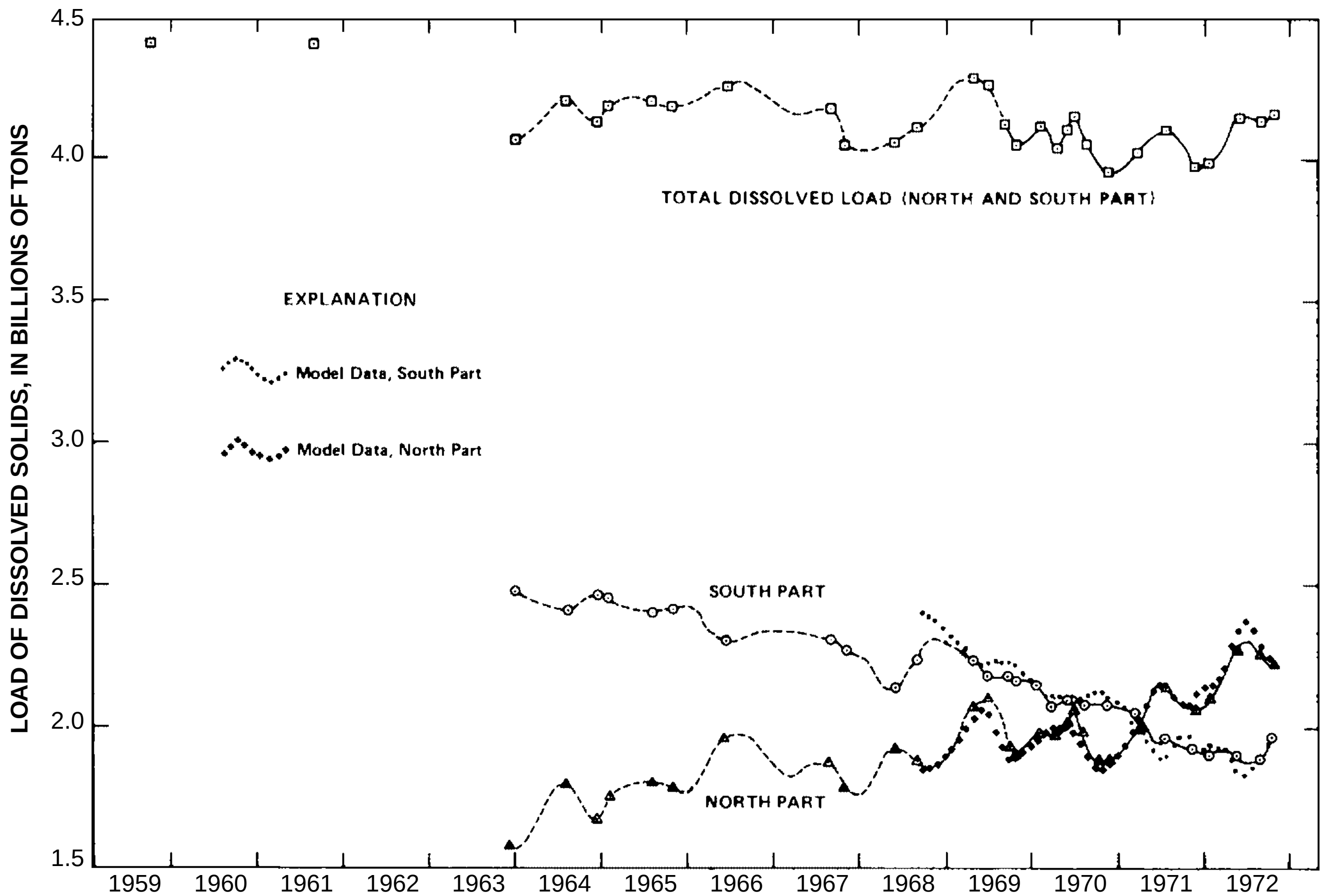
Discharge Through Fill and Culverts

The average discharges, in cubic feet per second, in the fill and culverts during the 1970-1972 water years were:

	1970		1971		1972	
Discharge	S-N	N-S	S-N	N-S	S-N	N-S
Culverts	840	60	1,000	30	1,100	40
Fill	1,900	1,200	3,100	1,500	3,800	1,900
Total	2,740	1,260	4,100	1,530	4,900	1,940

As indicated above, the discharge through the fill comprises more than 80 percent of the total flow through the causeway. The flow through the fill accounted for about 97 percent of the north-to-south discharge and about 75 percent of the south-to-north discharge during the 1970-1972 water years.

The flow through the fill and culverts is controlled primarily by the lake altitude and the stage and



EXPLANATION

Load figures for 1959-61 from Hahl and Langford (1964, p. 25)

Load figures for 1970-72 computed from data in table 8 and from data collected by Utah Geological and Mineralogical Survey

Load figures for 1963-69 revised from Madison (1970) using new altitude-volume relationship for the lake

All load figures (1963-72) based on water-surface altitudes at Promontory Point and Saline gages

Figure 3. Variation of load of dissolved solids in Great Salt Lake, 1963-1972.

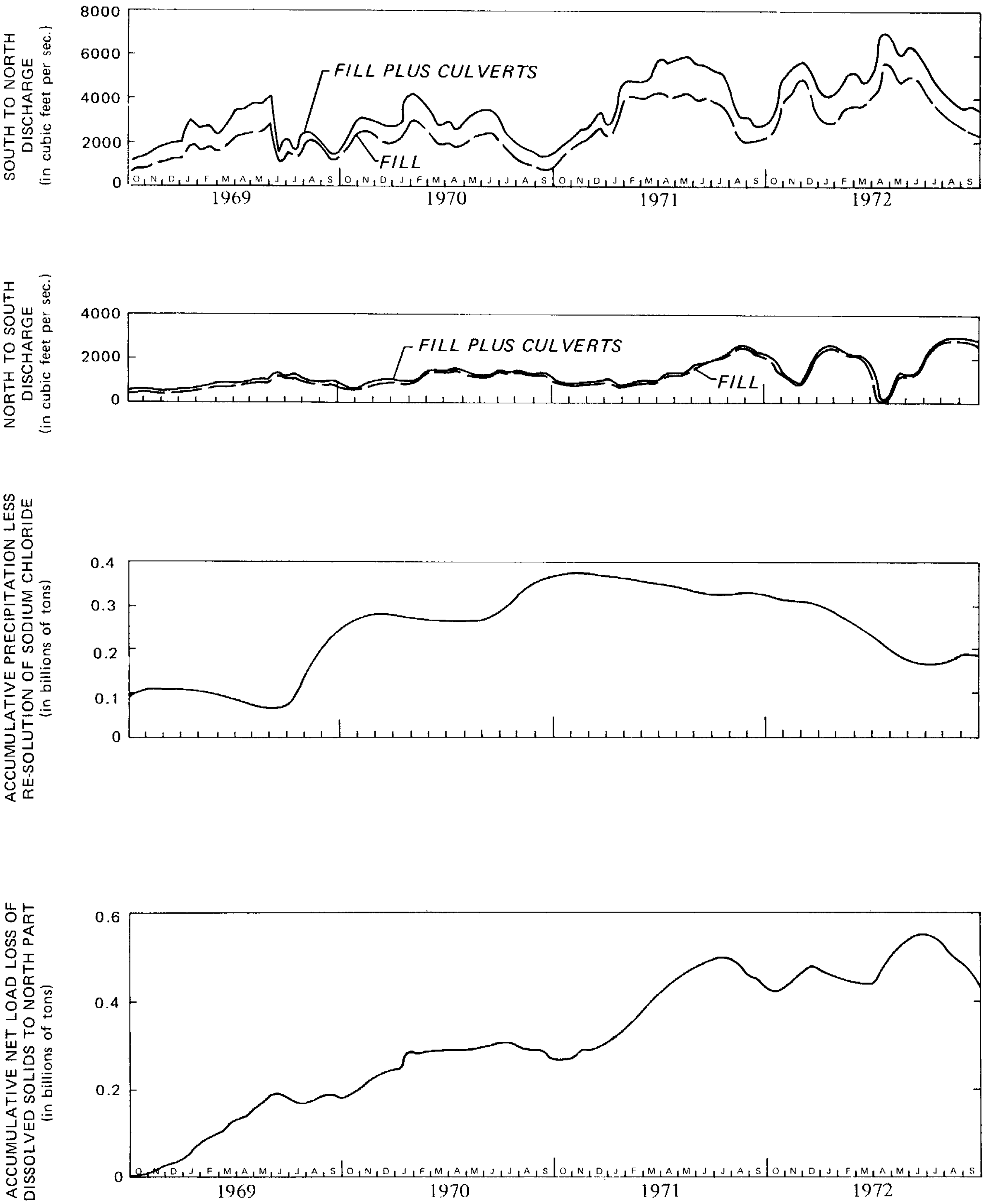


Figure 4. Culvert and fill discharge, accumulative precipitation of sodium chloride, and net movement of dissolved-solids load through the causeway, 1969-1972 water years.

density differences across the causeway. Increasing stage and decreasing density differences result in an increase of south-to-north discharges and a decrease of north-to-south discharges. Conversely, decreasing stage and increasing density differences result in a decrease of south-to-north discharges and an increase of north-to-south discharges.

SALT PRECIPITATION AND RE-SOLUTION

Study Period

During 1969-1972 precipitation and re-solution of sodium chloride in Great Salt Lake were studied by coring, salt-load computations based on water-quality sampling, and salt-balance computation by the digital model.

During the fall of 1970 and 1972, the Utah Geological and Mineralogical Survey cored the bottom of the north part of the lake. Hedberg (1970, p. 5) estimated the salt crust at 0.6 billion tons and reported it to be 98.7 percent halite (sodium chloride). J. H. Goodwin (written commun., 1973) later analyzed the 1970 as well as the 1972 cores and estimated the salt crust at 1.14 billion tons in 1970 and 1.33 billion tons in 1972. However, Goodwin also indicated that the 1970 and 1972 salt-crust tonnages were not directly comparable because a large shallow part sampled during 1972 was not accessible to sampling during 1970. Thus, the amount of re-solution or precipitation of sodium chloride during 1970-1972 cannot be computed on the basis of the coring data. Also, it is not known how much of this salt crust has been deposited since the causeway was completed in 1959.

The amount of salt deposition or re-solution in the north part of the lake can be computed indirectly if sufficient water-quality data are available to allow accurate computation of the dissolved load in each part of the lake during a given period of time. During the 1969-1972 water years, a considerable amount of water-quality data collected in both parts of the lake indicated that the load of dissolved solids ranged from about 3.9 to 4.3 billion tons (figure 3). Seasonal fluctuations are indicative of salt precipitation and resolution. Precipitation of salt is indicated in figure 3 during July-October 1970 when the total load of dissolved solids decreased, and re-solution of salt is indicated during November 1970-July 1971 when the total load of dissolved solids increased.

The salt-balance computation by the digital model indicates that the salt-precipitation patterns are in good agreement with those determined from water-quality data (figure 3). Re-solution patterns are also in agreement, but this is expected since the re-solution rates used in the model were computed from the observed water-quality data. Because of the uncertainty of the total precipitated load in the north part and the amount that might redissolve, it was assumed, for convenience in the digital model, that the precipitated load was 0.1 billion tons at the beginning of the 1969 water year. Although the coring data indicate that a larger amount was undoubtedly present, testing of the model with various amounts of initial salt precipitate indicated that increasing the precipitate beyond 0.05 billion tons had no effect on the relative load balance of dissolved solids between the north and south parts during the 1969-1972 water years.

The causeway model computed that 0.27 billion tons of salt precipitated during the 1969-1970 water years (in addition to the initial 0.1 billion tons) and that 0.18 billion tons redissolved during the 1971-1972 water years. Thus, the total precipitate at the end of the 1972 water year was computed by the model to be 0.19 billion tons—for a net gain of 0.09 billion tons during the 1969-1972 water years. The model also indicated that the precipitated load was at a maximum during the fall of 1970 when the Utah Geological and Mineralogical Survey cored the north part (see figure 4).

Most salt precipitation in the north part occurs during the summer and fall (figure 4) when the lake stage is falling, and re-solution generally occurs during the winter and spring when the stage is rising. When the stage is falling, water loss from evaporation in the north part exceeds the net gain of water to the north part. Consequently, the concentration of dissolved solids increases in the north part, and if saturation concentration is attained (355 g/l) sodium chloride may precipitate. When the stage is rising, the net gain of water in the north part exceeds the water loss from evaporation and the concentrations in the north part may be diluted below saturation concentration. If dilution occurs, then conditions are conducive to re-solution of salt precipitate. Whether there is a net increase of salt precipitation or re-solution in the north part depends upon the magnitude of salt gain relative to the net water gain (see Appendix, p. 34).

Simulated Period

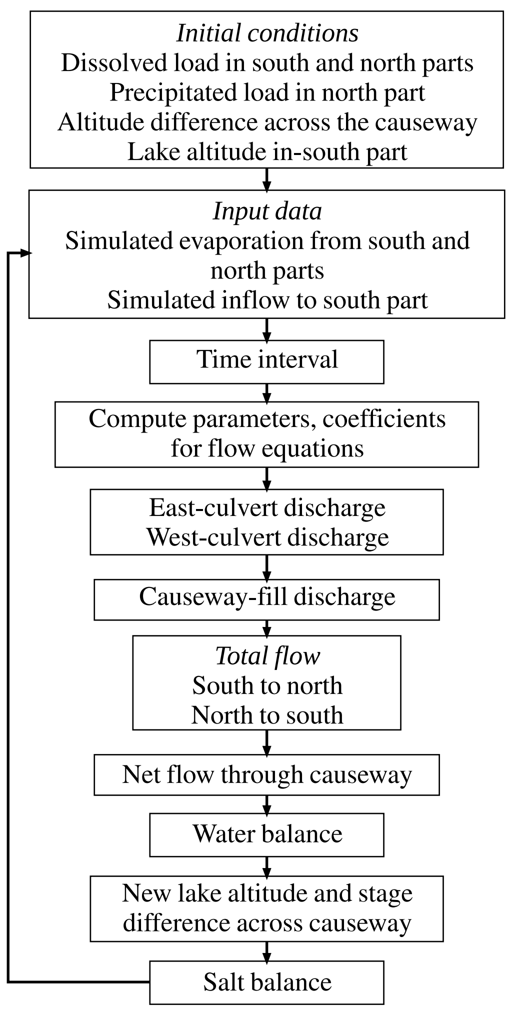
The 0.19 billion tons of salt precipitate remaining at the end of the 1972 water year, according to the model computations, were used for the simulated predictive period. Computations for the predictive period were also made using larger quantities of initial salt precipitate. The computations indicated that the effect of larger quantities of initial precipitate was to increase the dissolved-solids load and concentrations in both parts of the lake for the simulated rising lake stages, in addition to that shown in this report, due to additional re-solution. For the simulated falling lake stage, it had only a small effect on the computations of dissolved-solids load.

The amount of salt precipitation that may occur in the future is contingent upon inflow conditions and the hydraulic conductivity of the causeway. The simulated trends are discussed in later sections.

CAUSEWAY MODEL

In order to predict the effects of the causeway on the salt balance of the lake for simulated inflow and evaporation rates, a digital computer model was developed to handle the complex computations required by the equations governing the flows. The development of the principal equations and assemblage of the equations into the overall model are shown in the Appendix, and the following is a generalized flow chart describing the approach used in the model:

Flow chart



Verification of Model

Accuracy and Limitations of Model Predictions

Because of the many equations used in the model, the accuracy of the model predictions can best be evaluated by comparing these predictions with observed data or data computed by independent procedures.

The dissolved-solids loads as computed by the model and those computed from water-quality sampling during the 1969-1972 water years are shown in figure 3. The standard deviation between the dissolved-solids loads as computed by the model and those computed from water-quality data was 0.024 billion tons for the south and north parts. The maximum deviation for the north part was 0.08 billion tons, and for the south part it was 0.12 billion tons.

The only bias built into the model is that of re-solution rates, which were computed from the observed water-quality data (figure 3).

For the present causeway structure, the predicted dissolved-solids load figures for the simulated inflow conditions to the lake should be within the same accuracy as observed during the verification period of 1969-1972. If the assumption is made that the culverts are widened, however, the error of prediction is greater. When considering wider culverts, predicted altitude and density differences (ΔH and $\Delta\rho$)[1] drop below the limits of existing observed data, and thus confidence in the predictive accuracy decreases. The predicted discharge through the fill becomes almost negligible when wider culverts are considered, and the predicted north-to-south discharge (Q2C) through the culverts becomes almost equal to the south-to-north discharge (Q1C). By comparison, during the verification period, Q1C was generally at least 10 times higher than Q2C.

In order to determine the degree of accuracy that is involved when wider culverts are considered in the model, a statistical analysis of observed and computed culvert discharges was made for the existing culverts (table 1). The analysis shows that computed culvert discharges have an overall error of about 30 percent. Assuming that this same percentage error exists for the widened culverts, the model was run to determine how much effect a 30 percent error would have for a 500-foot wide culvert during the simulated predictive period. The results indicated that this error would have the equivalent effect of about a 100-foot wide culvert. That is, a 500-foot culvert has an uncertainty of ± 100 feet, or ± 20 percent. Assuming this

[1]See Glossary in Appendix.

same percentage error of 20 percent for a 750-foot culvert, the uncertainty would be ± 150 feet; and for a 350-foot culvert, ± 70 feet.

Constraints and Assumptions for the Simulated Predictive Period

1. The optimum operating range of the model is for lake altitudes ranging from 4,192 to 4,203 feet above mean sea level. The crown of the east culvert during the 1972 water year was at an altitude of 4,203 ± 0.5 foot. The equations are not valid for stratified flows in a submerged culvert.

2. The model is limited to positive stage difference (ΔH) from the south to north part and positive density differences (or specific gravity, ΔS) from the north to south part. The model is valid for stage differences ranging from about 0.10 to 2.00 feet and density differences ranging from approximately 0.015 to 0.180 grams per milliliter (g/ml) (see page 29).

3. It is assumed that for the simulated predictive period the deep layer of brine in the south part contains a constant dissolved-solids load, and the rate of north-to-south flow is about the same as the rate of diffusion and mixing of the deep and upper layers of brine in the south part.

4. It is assumed that possible increase of velocity of lake currents caused by culvert widening will have negligible effect on approach velocities to the culverts. If approach velocities were increased, however, it would have the effect of enhancing the culvert flows and decreasing the necessary culvert widths.

5. The dissolved-solids load trends were made with the assumptions that the altitude of the culvert bottoms remained constant and that the culvert flows would not be blocked by debris for a significant period of time.

Predicted Movement of Dissolved-solids Load For Variable Inflow Conditions

There is no known method for predicting future long-term inflow and evaporation trends for Great Salt Lake. The lake-stage hydrograph for 1850-1972 indicates that the lake generally rises or falls for a period of several years and seldom stays at a constant altitude for an extended period. The lake also has seasonal fluctuations, generally reaching a minimum stage during the fall when net inflow is low and a peak during the spring or early summer when net inflow is high. In order to predict the effects of the causeway on the future salt balance in the lake, therefore, it was necessary to simulate both long-term rising or falling stages as well as seasonal highs and lows.

To simulate a 10-year trend in lake stage for prediction purposes, the net inflow (QIN) to the south part and evaporation rates (EOS, EON) that were computed for the 1972 water year were used as input data to the model (see Appendix, pages 31-33). A constant factor (IR) times QIN was used to simulate a rising stage (IR = 1.15), falling stage (IR = 0.6), and near constant stage (IR= 1.0) (figure 5). Because the inflow rate is multiplied by a constant factor from the beginning to the end of the simulated period, most of the stage increase or decrease occurs during the first few years of the period.

The probability of such simulated stages actually occurring is small, but the range of simulated stages probably incorporates the range of stages that could occur.

The predicted dissolved-solids load in the south part of the lake for the existing culverts for simulated inflow rates is shown in figure 5. For inflow rates resulting in constant and rising stages (IR = 1.0 and 1.15), the net load of dissolved solids increased slightly in the south part during the 10-year simulated period. The concentrations of dissolved solids in both parts at the end of the simulated period were less than the initial concentrations because of the dilution effected by the increased lake stage and volume. In the north part, conditions were conducive to re-solution of previously deposited salt, and 0.19 billion tons were computed to have redissolved during the 10-year period. Potentially much more could have redissolved, but only 0.19 billion tons were actually available (see page 6). Any additional re-solution would have had the effect of increasing the dissolved-solids load and concentration of dissolved solids in both parts of the lake above that computed by the model.

The constant trend of falling stage (IR = 0.6) illustrates the delicate and complex nature of the water and salt balance between the two parts of the lake (figure 5). During the first year, when the net drop in stage was about 1.7 feet, net load movement was to the south part. During the next 9 years, when the net drop in stage per year was less then 1.7 feet, the net movement of dissolved-solids load reversed to the north part; and salt deposition was continuous in the north part. The net effect of the 10-year period was a loss of 0.27 billion tons from the south to north part and the deposit of 1.08 billion tons of salt in the north part. The concentration of dissolved solids increased in the south part, despite the load loss, due to the decreased lake stage and volume. The concentration of dissolved solids in the north part was at or near saturation (355 g/l) throughout the period.

For the conditions simulated (10-year rise, IR= 1.00 and 1.15), therefore, the model indicates

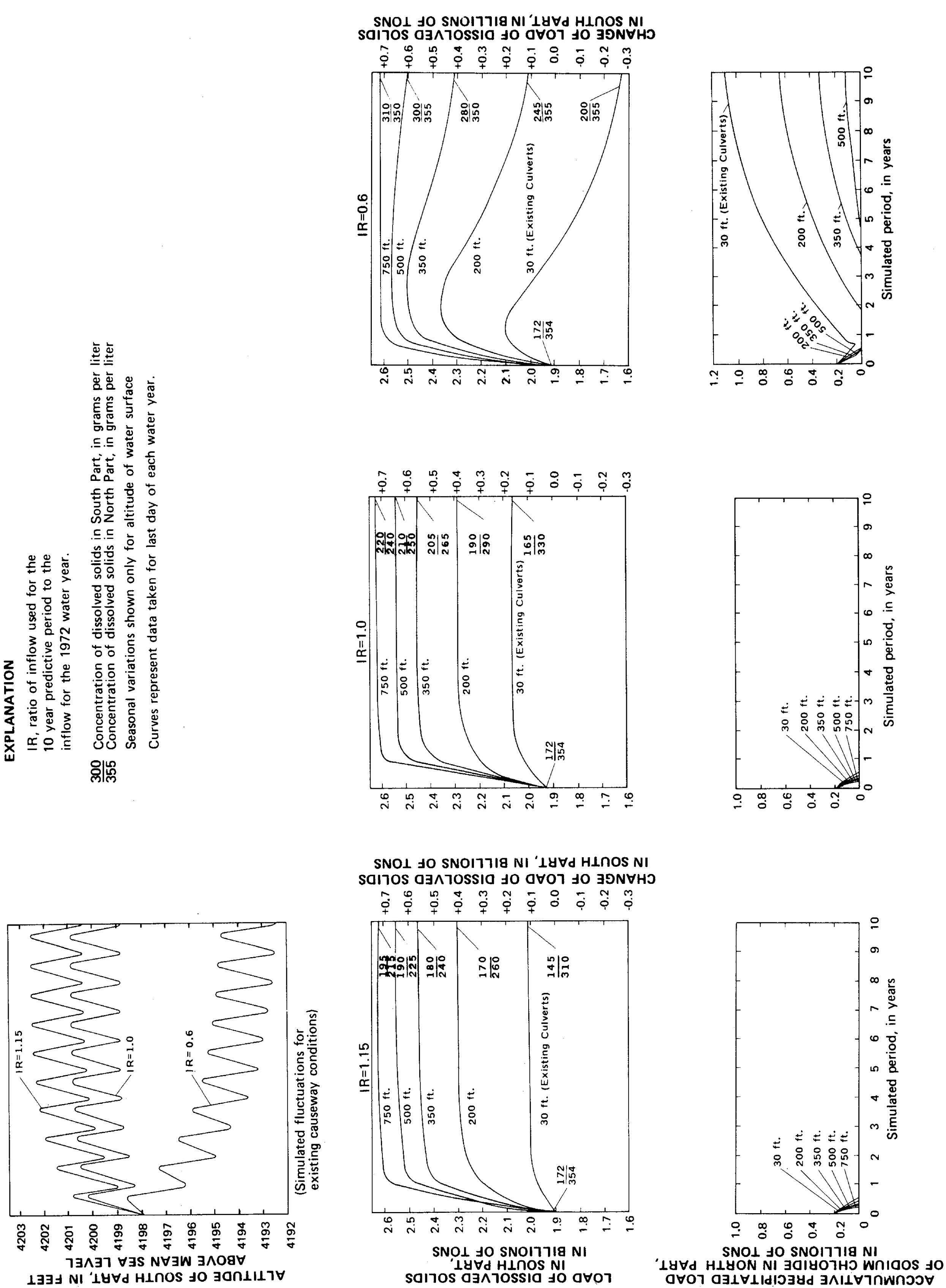


Figure 5. Predicted effect of various culvert widths on the net movement of dissolved-solids load and accumulative precipitation of sodium chloride for simulated inflow conditions.

that for existing culvert widths, the load loss of dissolved solids from the south part will decline or even cease in the future if the lake stage continues to rise. The model also indicates that if the lake stage declines, large quantities of sodium chloride will precipitate in the north part.

The net movement of dissolved-solids load through the causeway for either a rising or falling lake stage depends upon the rate of rise or fall. If the inflow rate were high enough (IR greater than 1.15) during a given year, net load movement could be to the north part; and if the rate of decline of the lake stage were great enough (IR less than 0.6), net load movement could be to the south part. As the density difference between the two parts increases, however, there is more potential to increase north-to-south flow and associated movement of salt load to the south part as it requires relatively more fresh-water inflow to continue net load movement northward.

It should be re-emphasized that none of the simulated trends in lake stage may actually occur in the future. In the past, long periods of rising stages included individual years in which the stage fell; and similarly long periods of falling stages included individual years in which the stage rose.

Predicted Movement of Dissolved-solids Load For Various Culvert Modifications

The salt balance in Great Salt Lake can be changed by increasing the causeway's ability to convey water. One means of doing this is by increasing the number of culverts or by widening the culverts.

Each particular culvert design has its own particular set of flow dynamics. In this report, therefore, modification of culverts is confined to evaluation of the effects of increasing the number of the existing 15-foot-wide culverts. Thus in order to simulate wider culverts in the model, only the width (B) in the discharge equation for the culverts was varied (see pages 18-20). Hence, a reference in this report to different culvert widths actually refers to a multiple of the existing 15-foot-wide culverts.

The culvert equations developed for the model (see pages 17-20) were based in part on empirical relationships developed from data observed in the existing culverts, and sidewall friction losses were included together with other losses associated with the flow dynamics. Hence, culverts with widths greater than 15 feet will have proportionately smaller sidewall losses, and these losses become proportionately still smaller as the culvert width increases.

Although wider culverts may have support structures that create friction loss, this loss would probably be smaller than the sidewall losses in an equivalent number of 15-foot-wide culverts. Thus, if a particular culvert design had less friction loss than that of an equivalent number of 15-foot-wide culverts, the necessary culvert width to bring about the same flow conditions would be less than that indicated in this report.

Various widths of culverts were simulated in the model for prediction of changes of dissolved-solids load in the south part of the lake and concentrations of dissolved solids in both parts for the three lake-stage trends shown in figure 5. The curves for the various widths of culverts indicate that most of the change in load occurs during the first year after opening of the culverts. The wider the culvert, the greater is the net load movement back to the south part. The net load gained in the south part because of increased culvert width, however, decreases with proportional increases of culvert width (figure 6), primarily because of the large decrease of stage difference that occurs with widening.

The optimum culvert width depends upon the conditions one wishes to establish in the lake. The culvert widths can be designed for various inflow conditions to (1) stop net loss of dissolved-solids load from the south to north part—this would require a culvert width of less than 200 ± 40 feet (assuming an uncertainty of ± 20 percent, see page 7); (2) prevent deposition of salt in the north part—for lake elevations above 4,192 feet, a culvert width of about 500 ± 100 feet would limit precipitation of sodium chloride to less than 0.1 billion tons; (3) establish approximately equal concentrations in both parts—to bring the south part concentration to within about 85 percent of the north part concentration would require a culvert width of about 500 ± 100 feet and to bring the south part concentration to about 90 percent of the north part concentration would require a culvert width of about 750 ± 150 feet; or (4) design for all conditions 1-3—this would require a culvert width of about 750 ± 150 feet. The concentrations in each part might be higher than predicted by the model depending upon the amount of salt crust (deposited prior to 1969) that redissolved.

The curves in figure 6 indicate how rapidly the proportional effect on dissolved-solids load decreases as the culvert widths become greater. A width of 350 feet results in an increase in the dissolved load in the south part of 0.41 to 0.56 billion tons [depending upon the inflow rate (IR)], whereas a 500-foot culvert results in an increase of only 0.60-0.65 billion tons. A 750-foot culvert increases the load to only 0.72 billion tons, and a culvert width of 1,500 feet would result in an

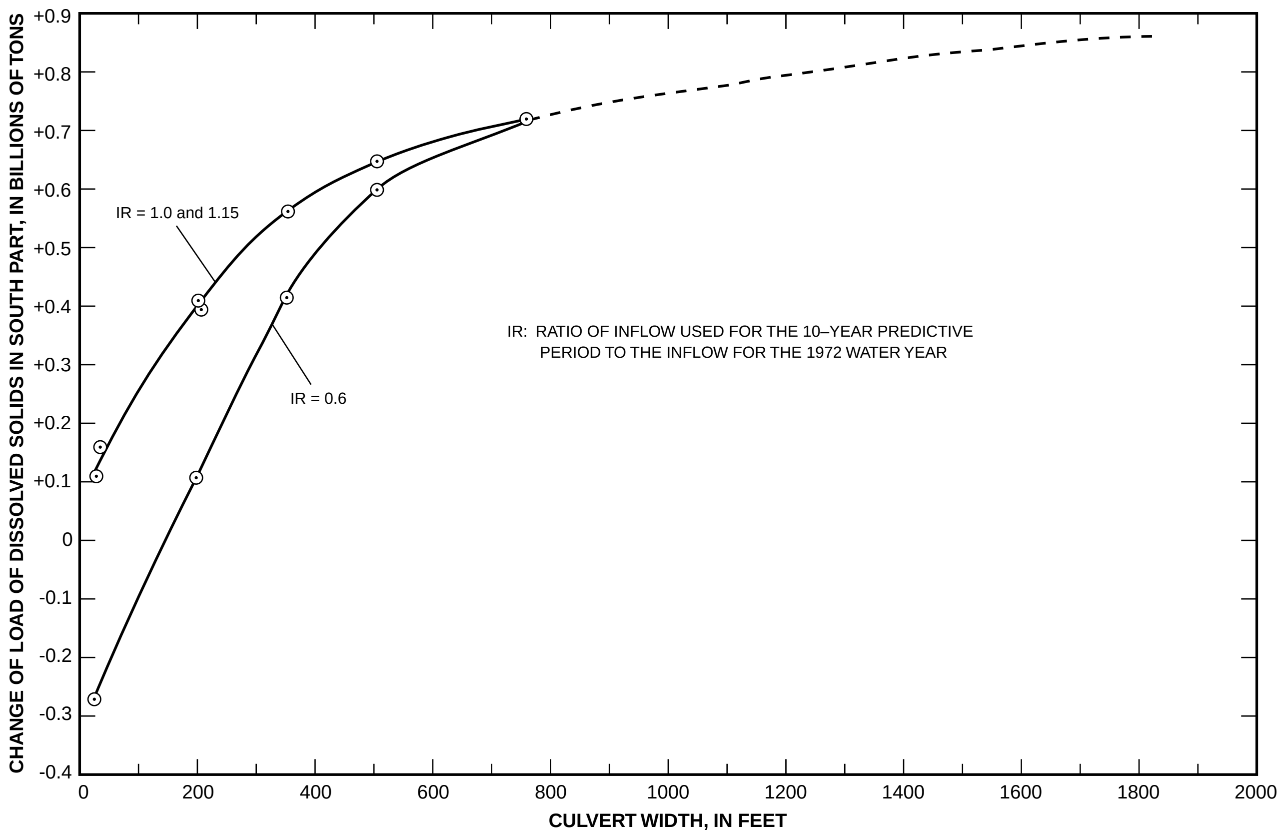


Figure 6. Effect of culvert width on dissolved-solids load in the south part of Great Salt Lake for simulated inflow conditions for the 10-year predictive period.

increase of dissolved load in the south part of only about 0.84 billion tons. Thus the widening of culverts beyond 500 feet results in relatively little additional gain of dissolved-solids load in the south part.

EFFECTS OF DEBRIS ON THE DISCHARGE IN THE WEST CULVERT

During May to August 1972 rock debris from the causeway washed into the north end of the west culvert and blocked the flow of brine from the north part of the lake. At the section where discharge measurements are made (same section as indicated for the east culvert in figure 7), the debris had filled the culvert to near the point where an interface between the north and south brines often occurs when the culvert is free of debris. During May to August, as indicated in the following tabulation, four discharge measurements in the east and west culverts indicated that the south-to-north discharge in the west culvert was 1.4 to 1.9 times greater than that in the east culvert.

Date	Discharge (cfs) East culvert	Discharge (cfs) West culvert	Discharge ratio west/east	Depth below water surface to top of fill (feet ± 0.5)	
1972					
Feb. 15	572	680	1.2	15.0	Interface in culvert
Mar. 16	784	889	1.1	15.3	
May 15	986	1,530	1.6	12.0	No interface in culvert
June 15	764	1,310	1.7	12.5	
July 21	594	830	1.4	8.5	
Aug. 15	473	899	1.9	9.0	

When free of debris (as in February and March), the south-to-north discharge in the west culvert is almost the same as that in the east culvert, with discharge ratios ranging from 1.1 to 1.2. More often than not during the period of the study, however, the debris filled the west culvert far above where the interface normally occurs; and the south-to-north discharge in the west culvert was less than in the east culvert, and sometimes it was shut off completely.

An important aspect of the observed effects of the debris in the west culvert is that there may be a more efficient design for transmitting water through the causeway than merely by widening of the existing culverts. Apparently, the debris restrains the gravity flow from north to south by acting as a stationary body held in place by its own gravity forces. Thus the energy losses are reduced due to the effects of the debris and the northward flow is increased. Of course, two-way flow must occur if there is to be circulation between the north and south parts. Perhaps a design that would separate the two flows, such as a combination skimmer wall for the northward flow and a submerged culvert for the southward flow, might be more efficient than the existing culverts. Such a design may not be practical, however, but this and possibly other designs might be investigated before modifications are made to the existing culverts.

RECOMMENDATIONS FOR FUTURE STUDY

The model developed during this study was based to a large extent on data collected during a relatively short span of time (1971-1972 water years). The model provides predictions for both existing and modified culvert openings that are valid within the stated limits of accuracy. These predictions can be used as an aid to industry in planning future activities as well as to parties concerned with modification of the causeway to effect net movement of dissolved-solids load.

If more refined limits of accuracy are needed for future predictions, then future data-collection programs should be oriented toward refinement of the parameters that control the causeway flow and should include:

1. Continued monitoring of the lake altitude and the stage differences across the causeway.

2. Monthly measurements of discharge and specific gravities in the east and west culverts.

3. Additional tracer studies in the causeway fill.

4. Monthly sampling of test wells to determine the chemical quality of water moving through the fill.

5. Sampling in both parts of the lake, with emphasis on better delineation of the deep layer of brine in the south part.

6. Improvement of lake altitude, volume, and area relationships by means of aerial photography and lake-bottom contouring.

7. Coring of salt crust to detect changes at a few selected sites.

8. Refinement of the model with the new data.

9. Construction of physical models of the culverts to determine more precisely the effects of culvert widening.

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APPENDIX

GLOSSARY

Symbol	Description	Units
AN	Area of north part	Acres
AS	Area of south part	Acres
ASOLN	Redissolved salt in north part	Tons
ASOLS	Redissolved salt in south part	Tons
B	Width of culvert	Feet
CFS	Coefficient of head loss for south-to-north culvert flows	—
CFS'	Coefficient of head loss for north to-south culvert flows	
CLNPPT	Cumulative precipitated salt load in north part at beginning of new time interval	Tons
CN	Dissolved-solids concentration in north part	Grams/milliliter
CS	Dissolved-solids concentration in south part	Grams/milliliter
dH	Difference between altitude of water in south part and altitude of water in well	Feet
dL	Distance between south edge of fill and well	Feet
E	Simulated evaporation rate for south part for time interval	Feet/day
EEC	Altitude of bottom of east culvert (datum is 4,000 feet above msl)	Feet
EN	Altitude of water surface in north part	Feet
EON	Evaporation from north part	Acre-feet/day
EOS	Evaporation from south part	Acre-feet/day
EOT	Total evaporation (EON + EOS)	Acre-feet/day
ES	Altitude of water surface in south part	Feet
EWC	Altitude of bottom of west culvert (datum is 4,000 feet above msl)	Feet
F	Simulated evaporation rate for north part for time interval	Feet/day

Symbol	Description	Units
fi	Coefficient of interfacial shear stress	—
g	Gravitational acceleration	Feet/second^2
$d(\Delta H)/dt$	Time rate of change of altitude (stage) difference across causeway	Feet/day
ΔH	Difference between altitude (stage) of south and north parts of lake at causeway	Feet
$\Delta H'$	Difference between altitude of water in the south part and altitude of water surface at measuring section in culvert	Feet
GIN	Ground-water inflow to north part day	Acre-feet/
GIS	Ground-water inflow to south part day	Acre-feet/
hl	Total head loss from south part to measuring section in culvert	Feet
hl'	Total head loss from north entrance to measuring section in culverts	Feet
I	Number of elapsed time intervals during simulated period	—
IR	Ratio of inflow used for the 10-year predictive period to the inflow for the 1972 water year	—
K	Field hydraulic conductivity of cross section in fill	Feet/second
L	Distance from south entrance of culvert to measuring section	Feet
LC	Integration constant for salt-load equation	—
LN	Dissolved-solids load in north part	Tons
LNMAX	Maximum load of dissolved solids that can remain in solution in north part for a given volume	Tons
LNPPT	Precipitated salt load in north part	Tons
LPPT	Total precipitated salt load in lake (LNPPT + LSPPT)	Tons

GLOSSARY, continued

Symbol	Description	Units
LS	Dissolved-solids load in south part	Tons
LSDL	Dissolved-solids load in deep brine layer in south part	Tons
LSMAX	Maximum load of dissolved solids that can remain in solution in south part for a given volume	Tons
LSPPT	Precipitated salt load in south part	Tons
M	Total discharge from south to north through causeway	Acre-feet/ day
MAXSOLN	Maximum amount of redissolved salt in north part	Tons
MAXSOLS	Maximum amount of redissolved salt in south part	Tons
N	Total discharge from north to south through causeway	Acre-feet/ day
NCLNPPT	Accumulative precipitated load in north part after new lime interval	Tons
NEWLN	Temporary load in north part prior to solution or precipitation	Tons
NEWTL	New total salt load in lake after time interval	Tons
NEWVN	Temporary volume in north part at end of time period	Acre-feet
NEWVS	Temporary volume in south part at end of time period	Acre-feet
q	Discharge per linear foot of fill (cfs/ft)	Cubic feet/ second/foot
QIN	Simulated surface plus ground-water inflow to south part	Acre-feet/ day
QINB	Surface plus ground-water inflow to south part for base period	Acre-feet/ day
QINPPT	Precipitation in north part	Acre-feet/ day
QIS	Surface inflow to south part	Acre-feet/ day
QISPPT	Precipitation in south part	Acre-feet/ day
QS	Net discharge through causeway to north part	Acre-feet/ day
Q1C	South-to-north discharge through culverts	Cubic feet/ second
Q2C	North-to-south discharge through culverts	Cubic feet/ second

Symbol	Description	Units
Q1F	South-to-north discharge through fill	Cubic feet/ second
Q2F	North-to-south discharge through fill	Cubic feet/ second
R	Total difference of evaporation rate between north and south parts	Feet/day
SCB	Initial difference of evaporation rate between north and south parts due to salinity	—
SCE	Effect of salinity on evaporation rate in south part	—
SCEN	Effect of salinity on evaporation rate in north part	—
S1	Specific gravity of brine in south part	—
S2	Specific gravity of brine in north part	—
ΔS	Difference in specific gravity between brine south and north of causeway	—
Δt	Time interval (1.901 days used in model)	Days
t	Total elapsed time (sum of all time intervals Δt)	Days
T	Temperature (°C)	Degrees Celsius
TDS	Total dissolved-solids load (LN + LS)	Tons
TL	Total salt load in Great Salt Lake at beginning of time interval	Tons
ΔVN	Total change of lake volume in north part	Acre-feet
ΔVS	Total change of lake volume in south part	Acre-feet
VN	Volume of north part	Acre-feet
VS	Volume of south part	Acre-feet
V1C	Mean velocity of south-to-north flow through culverts	Feet/ second
V2C	Mean velocity of north-to-south flow through culverts	Feet/ second
V1F	Average pore velocity of upper brine between south edge of fill and well	Feet/ second

GLOSSARY, continued

Symbol	Description	Units
V2F	Average pore velocity of lower brine between well and south edge of fill	Feet/ second
W	Effective length of causeway	Miles
Y1	Height of water surface in south part above culvert bottom	Feet
Y2	Height of water surface in north part above culvert bottom	Feet
y1	Depth of upper brine in culvert at measuring section	Feet
$\overline{y1}$	Mean hydraulic radius of the south-to-north flow	Feet
y2	Depth of lower brine in culvert at measuring section	Feet
Y1F	Average depth of upper brine in fill	Feet
$(Y1F)_S$	Computed depth to the exit point of the north brine at south edge of fill	Feet
y2F	Average depth of lower brine in fill	Feet
∇	Lake-level indicator (indicates free water surface)	—
α	Porosity	—
γ	Specific weight of water	Pounds/ feet^3
ρ	Mass density	Pounds-seconds^2/feet^4
ρF	Density of freshwater at any temperature	Grams/ milliliter
ρF_{20}	Density of fresh water at 20°C	Grams/ milliliter
ρN	Density of brine in north part at any temperature	Grams/ milliliter
ρN_{20}	Density of brine in north part at 20°C	Grams/ milliliter
ρS	Density of brine in south part at any temperature	Grams/ milliliter
ρS_{20}	Density of brine in south part at 20°C	Grams/ milliliter
$\Delta\rho$	Difference in density between brines in north and south parts	Grams/ milliliter
τi	Interfacial shear stress	Pounds/ feet^2

CULVERT FLOW

Culvert Equations

The energy equations for the two-directional flow in the culverts were developed for points between the measuring section in the culverts and points south and north of the culverts (1 to 2 and 3 to 2 in figure 7) assuming conditions of (1) steady flow and (2) a sharp interface within the culverts. Although these conditions do not occur at all times, observations during the study show that they exist during a sufficient length of time to make the computations valid. Discharge measurements made during storms or seiches were not included in the development of the empirical equations.

Following storms, various thicknesses of debris have been observed in the culverts, and flow through the west culvert was completely stopped much of the time. Flow through the east culvert was never stopped by the debris, but the debris had the effect of raising the altitude of the culvert bottom. The height of the brine above the culvert bottom (Y1 and Y2, figure 7) has been adjusted for the amount of debris in the culvert, assuming that the thickness of debris was the same throughout the culvert as at the measuring section. Discharges measured in the west culvert were not used in the development of the equations due to uncertainty of the thickness of debris. Because of the similarity in dimensions between the east and west culverts, the equations developed for the east culvert can be applied to the west culvert by changing the altitude of the culvert bottom.

South-to-north Flow

Writing the energy equation for the upper layer of fluid from section 1 to 2 (figure 7) while treating the interface as a boundary and assuming steady flow we have:

(1) $$(Y1 - y2) = y1 + (V1C)^2/2g + hl,$$

where hl is the total head loss in the flow. Now assuming that the total head losses (hl) in the culvert are generated by interfacial shear forces, and using a formula for determining the interfacial shear stress (Bata, 1957, p. 1265-3),

(2) $$\tau i = (fi\rho/8)\ |V1C - V2C|\ (V1C - V2C).$$

Since the direction of V1C is always opposite to that of V2C equation (2) becomes

3) $$\tau i = (fi\rho/8)\ (V1C + V2C)^2.$$

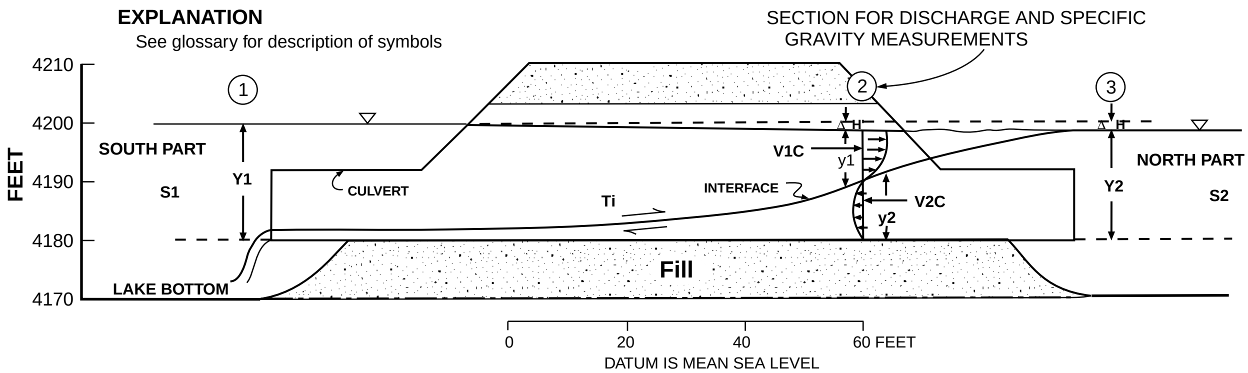


Figure 7. Schematic cross section of the east culvert showing typical velocity profile and related hydraulic properties.

Now rearranging and dividing both sides of equation (3) by ρg and substituting $\gamma = \rho g$, equation (3) becomes

(4) $$\tau i/\gamma = (fi/4)\,(V1C + V2C)^2/2g.$$

$\tau i/\gamma$ in equation (4) is the head loss (in feet) due to interfacial frictional losses where fi is a constant frictional coefficient for interfacial flows. The head loss due to interfacial frictional losses was also computed from consideration of momentum forces in the culvert as $\tau i \bullet L/(\gamma \bullet \overline{y1})$ where L is the distance from the south entrance of culvert to the measuring section and $\overline{y1}$ is the mean hydraulic radius of the south-to-north flow. The variation of factor $L/\overline{y1}$ was small, however, and regression analysis indicated that its effect on the head loss was not significant.

Now let CFS = fi/4, where CFS is a new coefficient representing all losses in the culvert for south-to-north flow. Then,

(5) $$hl = CFS\,(V1C + V2C)^2/2g.$$

Substituting the expression for hl given in equation (5) into equation (1),

(6) $$CFS = [Y1 - (y1 + y2) - (V1C)^2/2g] \bullet 2g/(V1C + V2C)^2.$$

The values for CFS were computed from data observed at the time of discharge measurements utilizing equation (6) (table 1). A regression analysis treating the observed values for CFS as the dependent variable and Y1 - Y2 and Y1 - (y1 + y2) as the independent variables yielded the following empirical relation for CFS:

(7) $$CFS = 3.55\,[Y1 - (yl - y2)]/(Y1 - Y2) - 1.02$$

The observed and computed values of CFS are shown in table 1.

Now solving equation (6) for V1C and substituting V1C = Q1C/(B • y1) where Q1C is the south-to-north discharge, y1 is the depth of the upper brine at the measuring section and B is the culvert width we have:

(8) $$Q1C = B \bullet y1\left[\sqrt{\left[Y1 - y1 - y2 - CFS\,\frac{(V2C)^2}{2g}\right] \bullet \frac{2g}{(1 + CFS)} + \left(\frac{CFS(V2C)}{1 + CFS}\right)^2} - \frac{CFS(V2C)}{(1 + CFS)}\right].$$

Equation (8) contains four unknowns–CFS, y1, y2, and V2C, which must be determined from given values of Y1, Y2, S1, and S2.

CFS may be determined from equation (7) once values of y1 and y2 are known. Empirical developments for y1 and y2 treating Y1, Y2, S1, and S2 as the independent variables yielded:

(9) $$y1 = -6.30 \bullet Y2 - 5.84(S2 - S1)Y1 + 7.09 \bullet Y1, \text{ and}$$

(10) $$y2 = 6.39 \bullet Y2 + 5.94(S2 - S1)Y1 - 6.23 \bullet Y1.$$

Equations (9) and (10) are valid for $S2 - S1 \geqslant 0$. The observed and computed values of y1 and y2 are shown in table 1.

Now given the altitudes of the water surface and specific gravities of both parts, CFS, y1, and y2 can be computed using equations (7), (9), and (10). Q1C and Q2C are then obtained by the simultaneous solution of equations (8) and (15) (equations for V2C and Q2C are developed in the following section). A trial and error technique was used in the causeway model for obtaining the simultaneous solution.

Table 1. Observed and computed culvert discharges and related parameters.

Observation No.	Y1	ΔH	Y2 (Y1 - ΔH)	S1	S2	ΔS (S2-S1)	y1		y2		CFS		CFS'		Q1C		Q2C	
							Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed
1																		
2																		
3																		
4[1]	14.18	.79 ± .08	13.39	1.157	1.226	.069	10.5	10.5	3.0	3.3	2.0	2.6	2.1	2.6	580	438	5	18
5	14.36	.78 ± .08	13.58	1.150	1.225	.075	10.0	10.5	3.7	3.3	2.0	1.7	2.1	1.8	530	521	20	28
6	15.14	.78 ± .05	14.36	1.150	1.221	.071	10.6	10.0	3.8	4.6	2.3	1.5	2.4	1.4	560	500	20	43
7	15.71	.80 ± .05	14.91	1.135	1.221	.086	9.6	10.5	5.4	4.5	2.1	1.9	2.2	2.4	470	556	70	42
8[2]	16.15	.45 ± .05	15.70	1.140	1.211	.071	8.9	7.0	6.5	8.2	4.9	3.8	5.2	3.9	180	213	170	226
9	16.71	1.08 ± .05	15.63	1.121	1.217	.096	10.7	11.5	5.3	4.5	1.5	1.4	1.5	1.6	640	684	50	43
10[2]	17.10	1.40 ± .20	15.70	1.116	1.215	.099	12.4	15.0	3.8	1.6	1.0	.3	1.0	.8	920	1,100	10	0
11	17.10	1.12 ± .08	15.98	1.127	1.221	.094	11.2	12.0	5.1	4.3	1.5	1.4	1.5	1.7	710	810	40	40
12	17.24	1.05 ± .01	16.19	1.127	1.222	.095	10.7	10.5	5.8	5.7	1.7	2.6	1.7	2.6	640	627	60	62
13	16.30	.88 ± .02	15.42	1.130	1.227	.097	9.2	9.5	6.4	6.3	1.8	.9	1.9	1.1	480	514	80	104
14	16.57	.95 ± .02	15.62	1.129	1.225	.096	9.8	10.0	6.0	5.7	1.8	1.6	1.9	1.9	540	614	70	71
15	16.07	.80 ± .02	15.27	1.139	1.226	.087	9.6	9.5	5.8	6.0	2.2	1.2	2.3	1.4	460	504	75	89
16	15.78	.86 ± .05	14.92	1.142	1.226	.084	10.1	9.5	5.0	5.6	2.0	1.5	2.1	1.5	530	508	50	79
17	15.64	.70 ± .03	14.94	1.145[3]	1.225[3]	.080	9.5	8.5	5.5	6.1	2.6	3.1	2.7	2.8	410	412	80	95
18	14.91	.75 ± .02	14.16	1.155	1.230	.075	10.0	9.0	4.2	5.4	2.3	1.2	2.4	1.1	490	471	40	56
19	15.47	.96 ± .02	14.51	1.140	1.232	.092	10.0	10.0	4.8	4.8	1.6	1.6	1.7	1.6	570	556	40	40
20	14.18	.92 ± .02	13.26	1.140	1.222	.082	10.2	9.5	3.3	4.0	1.6	1.9	1.6	1.6	600	507	12	28
21[2]	15.95	.66 ± .25	15.29	1.136	1.215	.079	9.4	6.7	5.8	8.6	3.0	3.1	3.2	2.6	370	292	100	46
22	16.35	.86 ± .04	15.49	1.136	1.221	.085	10.2	10.5	5.4	5.0	2.1	3.6	2.1	3.8	520	498	70	27
23	15.50	.95 ± .01	14.55	1.134	1.221	.087	10.4	10.0	4.4	4.7	1.6	1.9	1.6	1.9	590	594	35	29
24	15.02	1.06 ± .04	13.96	1.130	1.226	.096	10.1	10.5	4.2	3.7	1.4	1.8	1.4	1.8	630	643	25	26
25	14.57	.80 ± .10	13.77	1.133	1.225	.092	8.7	8.5	5.2	5.4	1.9	2.0	2.0	2.2	440	452	55	29
26	14.35	.80 ± .05	13.55	1.137	1.228	.091	8.8	9.0	4.9	4.6	1.9	2.4	1.9	2.6	440	476	50	24
27	11.94	.75 ± .05[3]	11.19	1.145	1.232	.087	8.1	8.7	3.3	2.9	1.5	.7	1.6	.9	420	439	20	20
28	12.35	.80 ± .05	11.55	1.146	1.229	.083	8.8	8.7	3.0	3.0	1.6	2.1	1.6	1.9	490	429	10	24
29	12.52	.94 ± .01	11.58	1.144	1.232	.088	9.4	10.0	2.5	2.0	1.3	1.2	1.3	1.0	580	522	0	24
30[2]		.93 ± .10						11.2		1.4						640		18
31[2]		.33 ± .20																289
32[2]		1.09 ± .05														619		—
33	13.75	1.08 ± .05	12.67	1.137	1.220[3]	.083	11.0	10.5	2.1	2.4	1.1	2.1	1.1	1.6	730	591	0	25
34	14.76	1.34 ± .05	13.42	1.128	1.220[3]	.092	12.2	13.0	1.9	1.1	.9	1.4	.9	.9	900	682	0	20
35	15.34	1.25 ± .05	14.09	1.132	1.220[3]	.088	12.1	14.2	2.5	.5	1.1	1.4	1.1	1.2	870	730	0	9
36	15.23	1.03 ± .03	14.20	1.124	1.220[3]	.096	10.0	10.4	4.5	4.2	1.5	1.2	1.5	1.3	610	618	30	38
37	15.34	1.31 ± .06	14.03	1.116	1.220[3]	.104	11.1	12.5	3.6	2.2	.9	.7	.9	.8	800	825	10	45
38	16.00	1.52 ± .10	14.48	1.108[3]	1.220[3]	.112	11.8	11.0	3.5	4.1	.6	1.0	.6	1.0	920	835	5	41
39	16.39	1.41 ± .05	14.98	1.101	1.220[3]	.119	10.4	9.8	5.2	6.0	1.0	.5	.9	.3	780	711	20	45
40	16.48	1.36 ± .05	15.12	1.106	1.220[3]	.114	10.6	10.5	5.1	5.3	1.0	.7	1.0	.7	770	767	20	44
41	14.55	1.32 ± .05	13.23	1.108	1.220[3]	.112	10.3	10.5	3.6	3.5	.7	.4	.7	.4	750	734	10	45
42	14.08	1.06 ± .05	13.02	1.110	1.214	.104	9.3	9.0	4.2	4.5	1.2	1.0	1.2	.9	580	549	25	38
43		1.10 ± .05		1.112	1.218[3]	.106		8.5		4.5		—		—		478		—
44	15.12	.98 ± .05	14.04	1.114	1.218	.104	9.6	8.0	4.8	6.5	1.3	1.1	1.3	1.0	600	498	35	42
45	15.80	1.29 ± .05	14.51	1.116	1.220[3]	.104	11.0	10.5	4.1	4.5	.9	1.1	.9	.9	780	703	15	59
46	15.40	1.28 ± .05	14.12	1.114	1.220[3]	.106	10.7	10.0	4.0	5.0	.9	.3	.9	.1	760	653	15	49
47	15.66	1.41 ± .02	14.25	1.108	1.220[3]	.112	11.0	10.0	3.9	5.0	.9	.7	.9	.4	820	696	10	51
48	15.21	1.15 ± .01	14.06	1.100	1.220[3]	.120	8.6	9.0	5.9	5.5	1.2	1.2	1.2	1.4	570	545	25	45
49	16.09	1.22 ± .02	14.87	1.100	1.212	.112	9.9	9.5	5.5	6.0	1.0	.7	1.0	.9	670	572	35	41
50	17.14	1.29 ± .01	15.85	1.091	1.192	.101	11.6	10.5	4.8	6.0	1.2	.8	1.2	.5	790	794	40	61
51	17.09	1.46 ± .02	15.63	1.088	1.214	.126	10.1	11.2	6.2	5.2	.9	.7	.9	.6	770	942	20	88
52	16.70	1.56 ± .01	15.14	1.084	1.200[3]	.116	11.7	11.3	4.2	4.6	.8	.8	.8	.4	910	986	25	73
53	16.50	1.50 ± .04	15.00	1.090	1.200[3]	.110	11.8	10.0	3.9	5.9	.9	.5	.9	.1	900	764	20	63
54	16.08	1.33 ± .05	14.75	1.094	1.201	.107	11.0	9.5	4.3	6.0	1.1	.6	1.1	.1	780	594	30	62
55	15.58	1.05 ± .10	14.53	1.097[3]	1.202[3]	.105	9.3	7.6	5.5	7.5	1.4	.7	1.4	.3	560	473	55	84
56	15.23	1.14 ± .02	14.09	1.104	1.208	.104	10.0	8.2	4.6	6.5	.9	.6	.9	.3	640	532	35	69

[1] Due to ice on sides of culvert B = 13 feet.
[2] Unsteady conditions in culvert due to wind and waves.
[3] Estimated.

North-to-south Flow

Writing the energy equation for lower layer of fluid from points three to two in figure 7:

$$Y2 \bullet S2 = y1 \bullet S1 + y2 \bullet S2 + S2(V2C)^2/2g + S2 \bullet h1'.$$

Rearranging,

$$(V2C)^2/2g + hl' = Y2 - y2 - y1 \bullet S1/S2. \tag{11}$$

Now similar to development of equation (5)

$$h1' = CFS'\ (V1C + V2C)^2/2g. \tag{12}$$

Substituting the expression for hl' in equation (12) into equation (11) and solving for CFS':

$$CFS' = [Y2 - y2 - y1 \bullet S1/S2 - (V2C)^2/2g] \bullet 2g/(V1C + V2C)^2. \tag{13}$$

The values for CFS' were computed from data observed at the time of discharge measurements (table 1). A regression analysis treating the observed values for CFS' as the dependent variable and the ratio of (Y1 - y1 - y2) to (Y1 - Y2) as the independent variable yielded the following empirical relation for CFS':

$$CFS' = 3.83\ [Y1 - (y1 + y2)]/(Y1 - Y2) - 1.19. \tag{14}$$

Now solving equation (13) for V2C and substituting V2C = Q2C/(B • y2) where Q2C is the north-to-south discharge and y2 is the depth of the lower brine in the culvert at the measuring section, we have

$$Q2C = B \bullet y2\left[\sqrt{[Y2 - y2 - y1 \bullet \frac{S1}{S2} - CFS'\ \frac{(V1C)^2}{2g}] \bullet \frac{2g}{(1 + CFS)} + \left(\frac{CFS'(V1C)}{1 + CFS'}\right)^2} - \frac{CFS'(V1C)}{1 + CFS'}\right]. \tag{15}$$

Now utilizing equations (7), (8), (9), (10), (14), and (15), Q1C and Q2C can be determined. The computed and observed values are shown in table 1.

CAUSEWAY-FILL FLOW

Test Wells

During the late spring and early summer of 1971, five new test wells were drilled in the causeway fill (wells 1, 7, 8, 9, and 10 in figure 1) and five abandoned wells previously drilled by the Southern Pacific Transportation Co. were cleaned, perforated, and relined with perforated plastic casing (wells 2, 3, 4, 5, and 6 in figure 1). All wells are along the north side of the causeway, about 10-15 feet from the brine surface of the north part of the take. The test wells were constructed in order to facilitate the measurement of brine exchange through the fill.

The new test wells completely penetrate the causeway, being finished either at the contact with the old lakebed deposits or at the Glauber's salt bed that underlies much of the causeway (Eardley, 1962). They were finished with 6-inch diameter plastic casing set into a 5-foot concrete plug at the bottom of the well. The plastic casing used in all wells was perforated with 12 vertical slots (2 inches in length and 1/8 inch in width) per foot, evenly spaced and staggered around the casing to allow free circulation of brines.

The new test wells have finished depths ranging from 54 to 68 feet below the causeway surface (see table 6), and the reconstructed wells have finished depths ranging from 47 to 64 feet below the causeway surface.

All wells were cleaned by pumping from 2 to 6 hours at a rate of about 60 to 100 gallons per minute.

Well Logs

Descriptions of both bailed and core samples obtained during the drilling of the new test wells are shown in table 6. Brine was encountered in all test wells 10 to 15 feet below the causeway surface. Some samples obtained from test wells 7, 8, 9, and 10 from below the brine level were flushed with fresh water immediately after collection. This was done to remove the brine before it could evaporate and precipitate salts which could not be distinguished from possible salt deposits formed during the past movement of brine through the fill. Field inspection of both the bailed and core samples did not reveal any evidence of significant salt precipitation in the fill. Most of the cement or salt deposits noted in table 6 were extremely thin and were formed by desiccation of the brine in the sample. Although some evaporites were found in the core samples, the quantity was extremely small and was usually confined to small clay zones. In addition, leaching tests run on core samples from test wells 8, 9, and 10 did not indicate any evidence of significant salt deposits. The maximum percentage of soluble materials found in the leachate was 2 percent (by weight) (table 2). This could have been contributed by residue from the brine encountered during drilling which was not completely flushed from the pore spaces of the sample.

Above the brine level in the test wells, the fill is cemented with salt deposits from brine that has blown onto the causeway during storms and seeped down through the fill. This cement is probably dissolved when the lake rises and brine flows through the fill.

Table 2. Results of leaching tests on core samples taken from the Southern Pacific Transportation Co. causeway.
[Core samples were doused with fresh water on exterior surface to remove excess brine encountered during drilling.]

Test well No.	Depth below causeway surface (feet)	Volume of leachate (millimeters)	Percent by weight soluble material in leachate	Milligrams per liter					Specific conductance (micromhos/cm at 25°C)
				Magnesium (Mg)	Sodium (Na)	Potassium (K)	Sulfate (SO_4)	Chloride (Cl)	
8	30-30.5	500	0.8	28	540	9.2	130	850	2,970
	43-43.5	500	.5	19	187	12	330	310	1,630
9	30-30.5	500	.3	130	1,300	140	560	2,400	7,940
	52-52.5	500	2.0	210	1,800	180	—	3,200	12,300
10	30-30.5	500	.7	110	1,100	110	440	2,000	6,850
	50-50.5	500	1.4	250	2,400	210	900	4,400	14,000

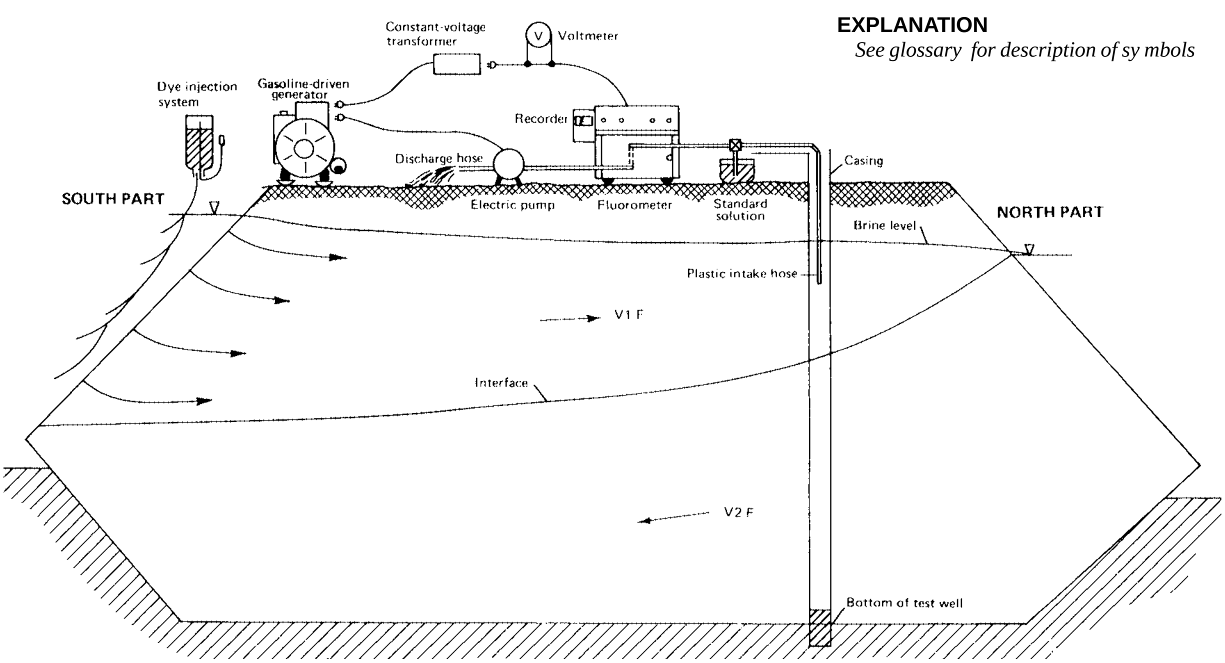
Below the brine surface in test wells 1, 7, 8, and 9, most of the material examined consisted of quartzite particles ranging in size from fine sand to fine gravel. Some rock fragments exceeded 2 inches in diameter. The material from test well 10 consisted mostly of limestone particles, ranging in size from fine sand to cobbles that were 3½ inches in diameter.

Examination of the samples from the five new test wells did not suggest any differences of permeability from the brine level down to within a few feet of the bottom of the wells. Larger amounts of clay were noted near the bottoms of wells 7 and 10, however; and this clay, which may have been squeezed up from below, would cause a lower permeability than that in the upper parts of the holes.

Tracer studies

Tracer studies at 10 test wells were conducted during August to October 1971 and during March, May, and June 1972 to determine the hydraulic properties of the fill and to obtain data about the two-way flow of brine through the fill.

For the south-to-north flow studies, Rhodamine WT fluorescent dye, adjusted to the density of the brine, was injected south of the fill directly across from a well. The dye was injected simultaneously at 3-foot intervals below the lake surface. A flow-through monitoring system (figure 8) was initiated after the injection and continued past the peak fluorescence. A stream of water was pumped from the desired depth in



the well at a rate of about 0.3 liter per minute. The fluorometer was equipped with a recorder, which permitted continuous monitoring at various depths by changing the depth of the intake hose in the well.

For the north-to-south flow studies, the dye was injected in a well from the interface of the north and south brines to the bottom of the well. Time of travel was determined from samples collected from the bottom of the lake south of the fill directly across from the well.

South-to-north Flow

Data obtained from tracer studies at eight of the wells (1, 3, 4, 5, 7, 8, 9, and 10) were adequate for computation of travel rates and hydraulic properties of the fill at the well sites (table 3). The tracer studies also indicate that wells 2 and 6 were not open to the south-to-north flows. Dye was not detected in these two wells, but it was detected in the north part of the lake directly across from the wells. It should be noted that wells 2, 3, 4, 5, and 6 are old wells that were reconditioned. Apparently wells 2 and 6 were not adequately cleaned and perforated to permit free brine circulation.

Velocity profiles for the eight wells (figure 9) and the unit discharge rates in table 4 indicate that estimates of discharge through the fill made on the basis of travel time alone would be misleading. Knowledge of interfacial depths in the wells is necessary in order to determine the discharge rates. For example, flows at wells 8 and 10 during August-September 1971 had about the same mean velocities, but the unit discharge rate (q) at well 8 was more than double that of well 10.

The velocities were generally at a maximum near the surface and zero near the interface of the upper and lower brines. A mean velocity was determined for each velocity profile. Knowing the mean velocity and the mean interfacial depth of the upper flow (south to north), the discharges per unit length were computed (table 4). The discharges per unit length west of Midlake during May-June 1972 ranged from .022 to 0.221 cfs/ft whereas those east of Midlake ranged from less than 0.009 to 0.174 cfs/ft. During August-September 1971 the discharges per unit length west of Midlake ranged from 0.013 to 0.031 cfs/ft and those east of Midlake ranged from less than 0.005 to 0.065 cfs/ft. The weighted mean discharge for the 12.21 miles of new fill during August-September 1971 was 1,600 cfs and during May-June 1972 was 4,500 cfs. The 1971 data were collected during a period of minimum inflow and stage difference across the causeway, whereas the 1972 data were collected when the inflow and stage difference were at a maximum for the year.

All the wells are near the north edge of the causeway, where the slope of the interface is steepest (see figure 1). Hence the interfacial depth and velocity profile characteristics that each well exhibits depends to a large extent on where the well is located in relation to the interface profile. Interfacial depths and velocity profiles are unique for the position of the well but do not necessarily indicate different hydraulic properties in the fill cross section.

The degree of “piping” in the fill is less than previously believed. Although visual observations would lead one to believe that “piping” is quite extensive in the fill, the tracer studies at the wells indicated that the flow was generally uniform. Even though there were exit points on the north side of the fill across from the wells where more south brine emerged from the fill than at points a short distance away, the tracer studies indicated that the peak travel time to the well was less than to the exit point. These exit points where brine appears to be “piping” through the fill may be related to the large nonuniform size of the riprap which protects the fill. The brine probably flows uniformly through most of the fill until it reaches the riprap, and then it exits through the easiest route around the riprap, resulting in a nonuniform exit pattern along the fill. At several of the wells, samples were taken at exit points where large quantities of brine were emerging on the north side as well as at points a few feet away where smaller quantities were emerging. In all cases the peak travel times checked with that observed in the well. There are some points along the fill, however, where “piping” does occur.

North-to-south Flow

During June 1972, dye was injected in wells 1, 3, 4, 5, 7, 8, and 9 below the interface of the brines. After injection, the dye was thoroughly mixed from the interface to the bottom of the well. Analysis of samples collected at various depths between the interface and the bottom of the well indicated that the dye concentrations decayed at approximately the same rate from a few feet below the interface down to an altitude of about 4,170 feet (approximately 40 feet below the causeway surface). Below 4,170 feet the dye concentrations decayed at a much reduced rate, indicating very little brine movement. From this information, the effective flow zone for the deeper brine was determined.

In addition to the samples obtained from the wells, samples were collected from various depths along the south edge of the fill across from the wells. The travel rates from the wells to the edge of fill were then approximated. Utilizing this information, more closely controlled tests were made at wells 1 and 7. The mean

Table 3. Hydraulic properties of the causeway fill computed from tracer studies.

dH, difference between altitude of water in south part and altitude of water in well; dL, distance between south edge of fill and well; Y1F, average depth of upper brine in fill; V1F, average pore velocity of brine between south edge of fill and well; K, field hydraulic conductivity of cross section in fill; q, discharge per linear foot of fill; α, porosity of cross section in fill.

Test well No.	Date	Depth to interface at well		Depth to interface at south edge of fill		Average depth. of upper brine, Y1F	dH	dL	V1F	α	K([2])	q
		Observed (A) (ft)	Computed[1] (B) (ft)	Observed (C) (ft)	Computed $(Y1F)_S$[1] (D) (ft)	$\frac{(A)+(D)}{2}$ (ft)	(ft)	(ft)	(ft/sec)		(ft/sec)	(cfs/ft)
						East of Midlake						
1	Sept. 9, 1971	12.0	—	—	11.9	12.0	0.00	50	0.007	0.3	2.10	0.025
1	Mar. 6, 1972	12.0	11.8	—	14.6	13.3	.26	50	.005	.3	.29	.026
1	June 2, 1972	11.0	13.0	—	14.1	12.6	.31	50	.008	.3	.39	.030
7	Sept. 2, 1971	17.0	18.3	—	18.7	17.8	.17	51	<.001	.3	<.09	<.005
7	June 1, 1972	—	—	—	—	15.0	—	—	—	—	—	.009[3]
8	Aug. 30, 1971	18.0	16.0	—	18.0	18.0	.12	55	.012	.3	1.65	.065
8	June 2, 1972	16.0	14.2	—	19.2	17.6	.30	55	.033	.3	1.81	.174
9	Aug. 30, 1971	—	—	—	—	—	—	—	—	—	—	.013[3]
9	Mar. 10, 1972	6.0	4.9	—	16.9	11.4	.91	45	.007	.3	.10	.024
9	June 1, 1972	5.0	4.8	—	18.0	11.5	1.19	45	.007	.3	.08	.024
						West of Midlake						
3	Sept. 10, 1971	—	—	—	—	—	—	—	—	—	—	0.013[3]
3	June 1, 1972	5.0	6.9	21.0	13.4	9.2	0.87	50	0.009	0.3	0.16	.025
4	Sept. 23, 1971	2.5	3.7	—	10.6	6.5	.69	48	.016	.3	.33	.031
4	May 31, 1972	3.5	5.7	21.0	14.6	9.0	1.12	48	.026	.3	.32	.070
5	Sept. 23, 1971	4.0	3.1	—	13.0	8.5	.76	50	.008	.3	.16	.020
5	May 30, 1972	3.5	4.5	17.0	17.1	10.3	1.25	50	.007	.3	.08	.022
10	Sept. 10, 1971	3.0	3.1	—	12.0	7.5	.73	50	.013	.3	.27	.029
10	May 30, 1972	6.5	6.7	—	16.9	11.7	.93	50	.063	.3	1.02	.221

[1] Computed values for Ghyben-Herzberg principle $(Y1F)_S$ $[Ps/(Pn - Ps)] \bullet \Delta H$. The values were used only to estimate the exit depth of the north brine on the south edge of the fill. This exit depth is difficult to measure because of the irregular size of the riprap near the emergent points of the brine.

[2] The hydraulic conductivity for the cross section of the fill at each well was calculated by means of the equation $K = \alpha(V1F)dL/dH$, an adaptation of Darcy's law. Although the law is not entirely valid for the steep gradients and high velocities observed in the fill, the first estimates of hydraulic conductivity were very close to the final values used, being reduced by a factor of only 0.95 for use in the model.

[3] Estimated, using ratio of August-September 1971 measurements to May-June 1972 measurements.

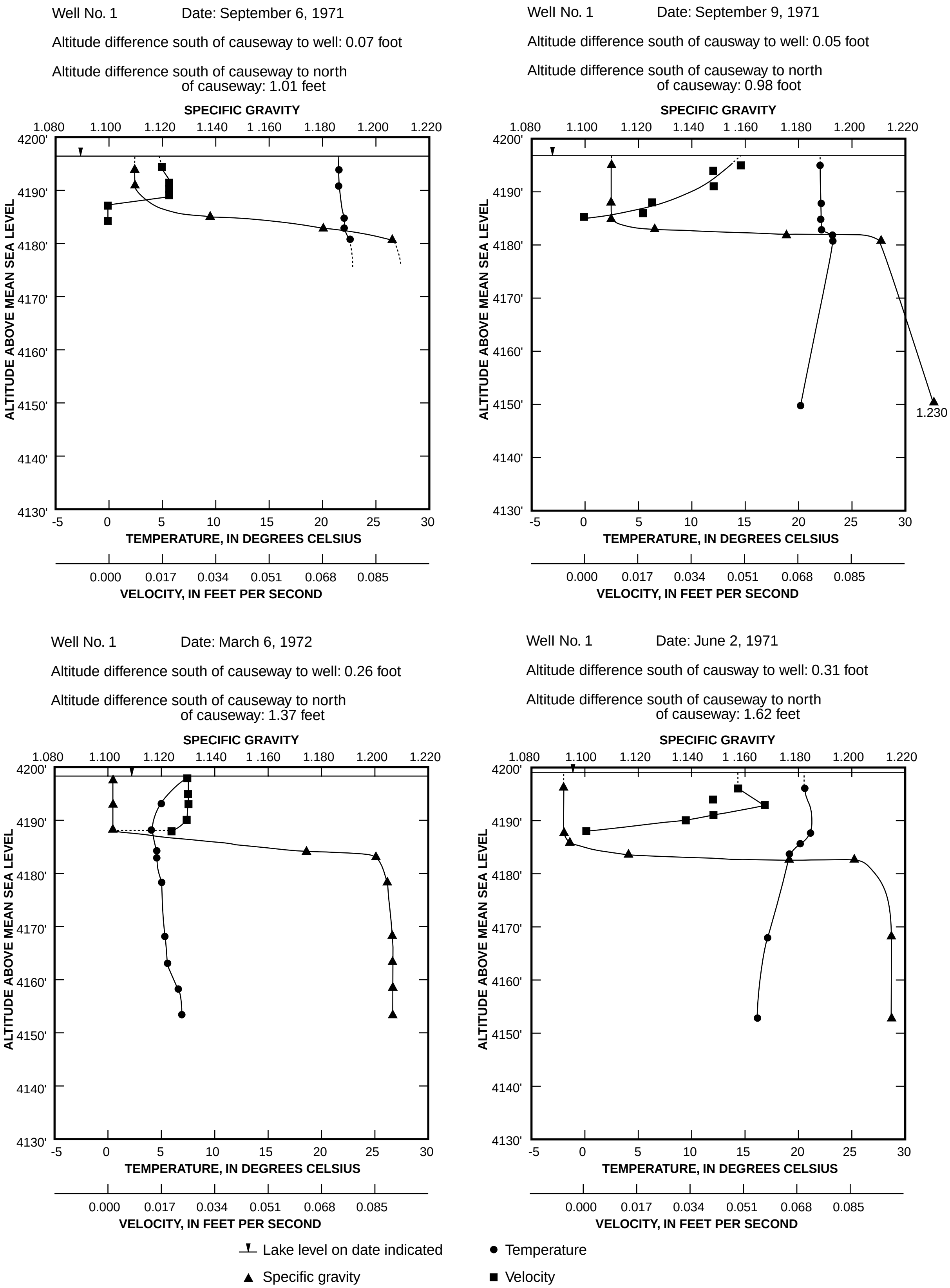


Figure 9. Profiles of specific gravity, temperature, and velocity of the brine in test wells.

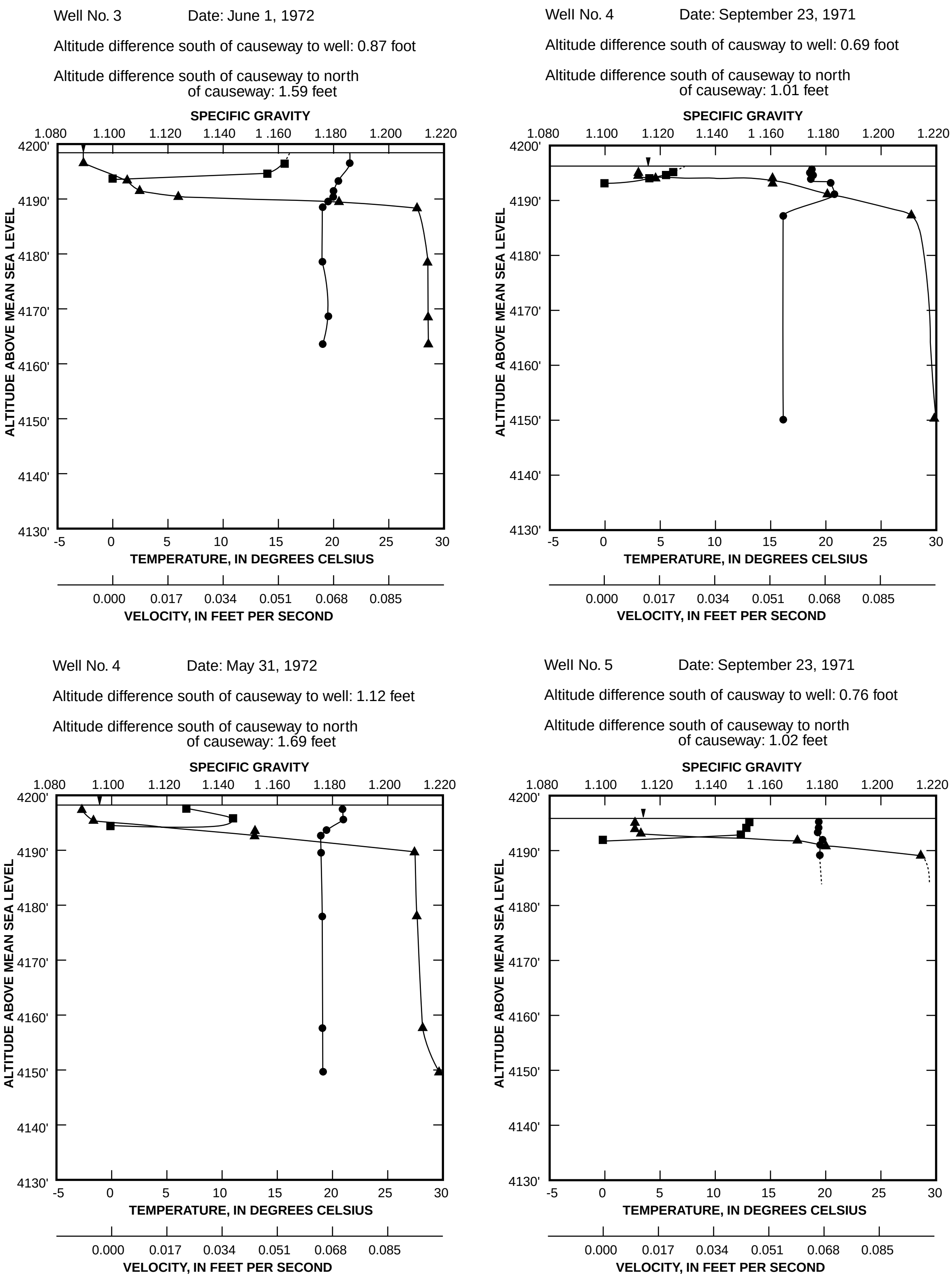


Figure 9. (continued)

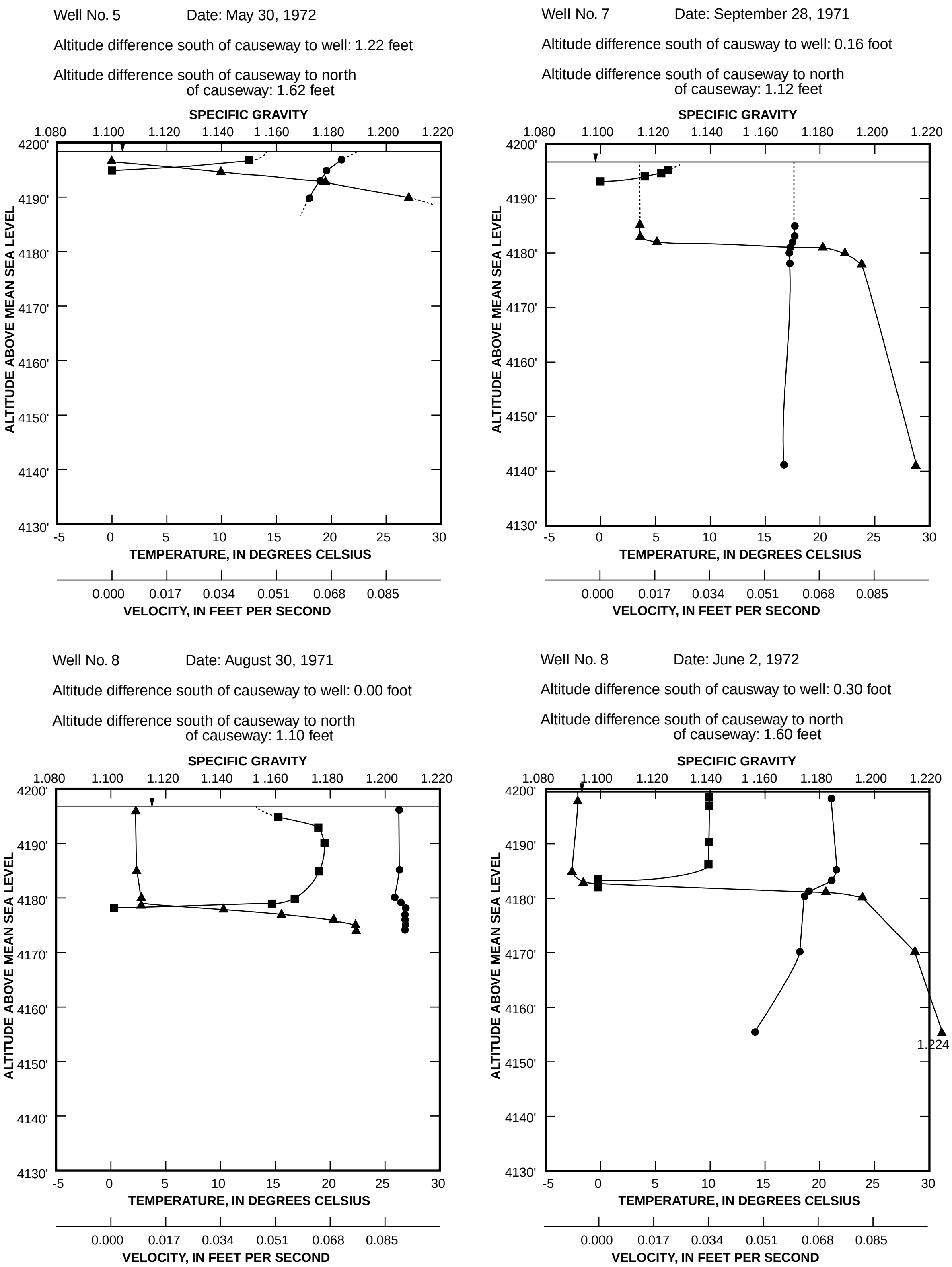


Figure 9. (continued)

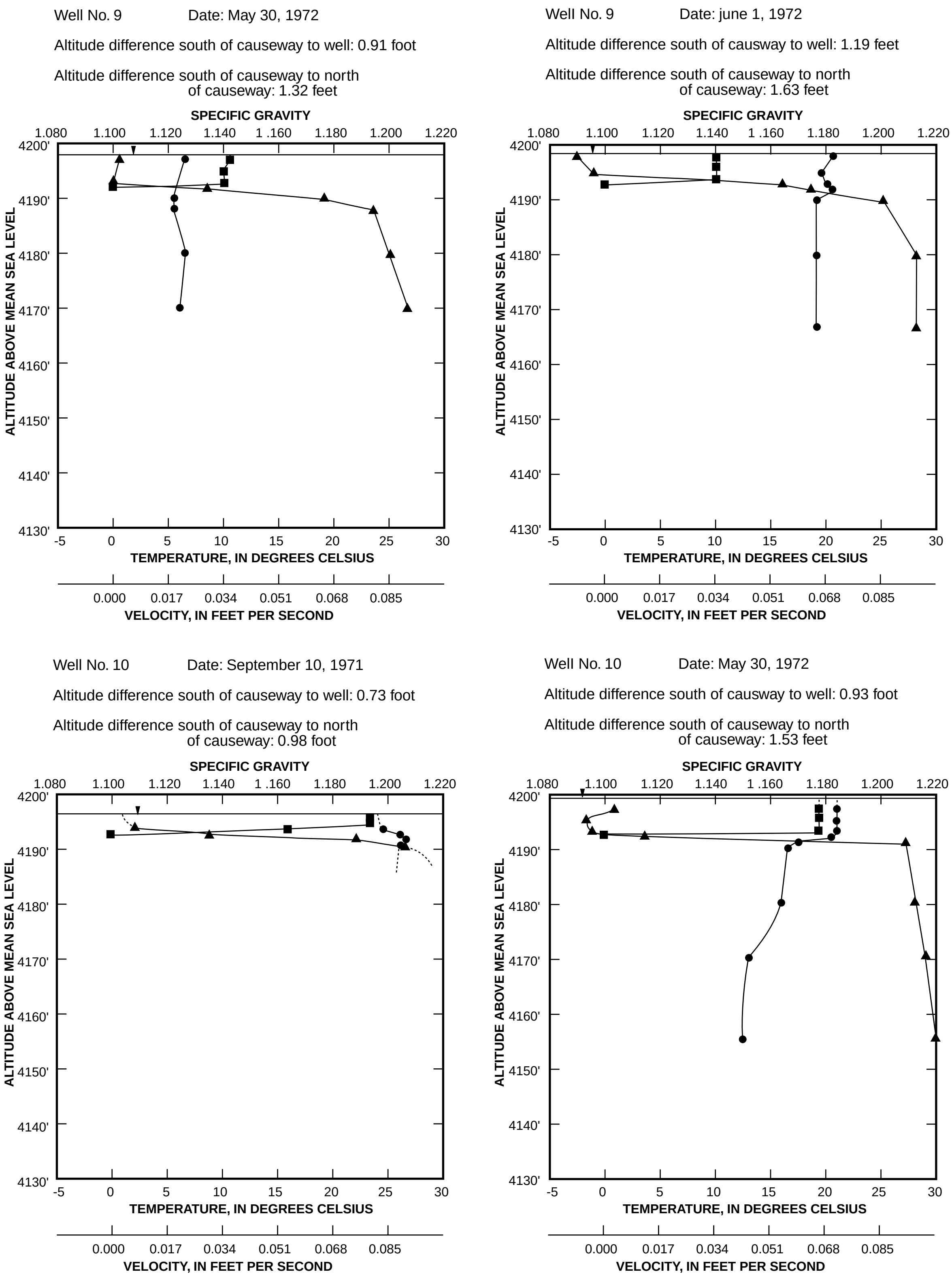


Figure 9. (continued)

Table 4. South-to-north discharge through the causeway fill as determined during tracer studies.

Discharge per unit length, q (cfs/ft)

East of Midlake			West of Midlake		
Well No.	Aug.-Sept. 1971 q	May-June 1972 q	Well No.	Aug.-Sept 1971 q	May-June 1972 q
1	0.025	0.030	3	0.013	0.025
7	.005	.009	4	.031	.070
8	.065	.174	5	.020	.022
9	.013	.024	10	.029	.221
Average q	.027	.059	Average q	.023	.085

Total discharge, Q1F (cfs)

Effective length of causeway (W)	12.21 miles
Length of causeway east of Midlake (60% x W)	7.33 miles
Length of causeway west of Midlake (40% x W)	4.88 miles

East West
Q1F = (q x 0.6W) + (q x 0.4W)

For August-September 1971
Q1F = (0.027 x 7.33 x 5,280) + (0.023 x 4.88 x 5,280) = 1,600 cfs (rounded)

For May-June 1972
Q1F = (0.059 x 7.33 x 5,280) + (0.085 x 4.88 x 5,280) = 4,500 cfs (rounded)

travel rates (V2F in table 5) between both wells and the south part of the lake were almost the same.

The shallowest observed emergence point of north-to-south flow along the south edge of the fill was 17 feet below the brine surface, across from well 5. The shallowest emergence point of the north-to-south flow across from well 1 was 21 feet below the water surface. The emergence point across from the other wells could not be determined because the large riprap, which protects the fill, made the emergence points of the north-to-south flow inaccessible with available sampling equipment. (A small battery-operated suction pump was used for sampling.)

Utilizing data from table 5, the north-to-south discharge per unit length computed for the causeway during June 1972 was 0.021 cfs/ft, or a total discharge of 1,400 cfs for the entire causeway.

Effect of Temperature on Flow Rates in the Fill

Hydraulic conductivity is a function of the fluid viscosity, which varies with temperature, as well as the medium through which the fluid passes. Since the temperature of the Great Salt Lake varies seasonally, the hydraulic conductivity should vary likewise. Theoretical corrections for the effect of the viscosity on the flows in the fill could be determined. However, tracer studies during March and May-June 1972 at wells 1 and 9 did not indicate any significant difference of hydraulic conductivity even though the brine temperatures in the wells during May-June 1972 were about 15°C higher than those observed during March 1972. Theoretically (Todd, 1959, p. 51), the hydraulic conductivity should have been about 60 percent less during the March measurements than during the May-June measurements. Either field data were not sufficient to detect the change or for unknown reasons the theoretical effect was overshadowed by other variables. Additional data are necessary in order to refine this aspect of the flow through the fill.

Modeling of Flows in the Fill

A numerical technique for determining the transient position of the salt-water front in coastal aquifers was developed by Pinder and Cooper (1970). They (written commun., 1971) also developed a digital model for handling the complex computations required by the numerical technique. The technique makes possible the solution of problems involving irregular boundaries and nonuniform permeabilities such as are encountered in the causeway fill. This digital model was adapted to simulate the two-directional flows through the fill.

In order to adapt the model to the fill it was necessary to compute the mean hydraulic properties and cross-sectional dimensions of the fill. The hydraulic properties were computed from data observed during tracer studies and then modified until the unit flow rates agreed with those determined by the tracer studies during August-September 1971. The model was then verified by entering the boundary conditions of stage difference and density difference observed during May-June 1972, when another tracer study was made. The unit-flow rates determined by the model were in

Table 5. North-to-south discharge parameters in the causeway fill as determined during tracer studies.

Test well No.	Date	Mean lake altitude in fill (A) (ft)	Altitude of lower limit of brine flow in fill[1] (B) (ft)	Total depth of brine flow in fill (C) (A-B) (ft)	Average depth of upper brine (from table 3, rounded) Y1F (D) (ft)	Total depth below Y1F (E) (C-D) (ft)	Diffusion zone (F) (ft)	Effective depth of lower brine (G) (E-F) (ft)	Average velocity V2F (ft/sec)
				East of Midlake					
1	June 2, 1972	4,199	4,170	29	13	16	4	12	0.0067
7[2]	June 1, 1972	4,199	4,170	29	15	14	4	10	.0063
8	June 2, l972	4 199	4,170	29	18	11	2	9	⩾.0063
9	June 1, 1972	4,199	4,174	25	12	13	6	7	⩾.0063
				West of Midlake					
3	June 1 1972	4,199	4,170	29	9	20	4	16	—
4	May 31, 1972	4,199	4,170	29	9	20	7	13	—
5	May 30, 1972	4,199	4,170	29	10	19	7[3]	12	([4])
10	May 30, 1972	4,199	4,175	24	12	12	2	10	
						Mean (rounded)		11	.0065

[1] Determined from dye dispersion in wells and lake-bottom profiles.
[2] Flow profile determined from data collected at earlier date.
[3] Estimated.
[4] Dye detected on south edge of fill, but travel time unknown.

good agreement with those determined during the tracer study. Additional verification was indicated by the agreement between the north-to-south unit flow rates determined by the tracer study during May-June 1972 and by the model for the same boundary conditions (figure 11).

After verification, the model was used to generate new discharge data in much the same way as a physical model. That is, discharges were determined for various boundary conditions of stage difference, density difference, and lake depth. After determining the discharges for a wide range of possible boundary conditions, multiple regression analysis involving Q1F and Q2F as functions of density difference ($\Delta\rho$) or specific gravity difference (ΔS) and stage difference (ΔH), yielded the following equations for the flows in the fill.

(1) $$Q1F = 6.9835 - 1{,}675.0\Delta S + 158.97\Delta H + 45{,}535.\Delta S^2 - 3{,}773.3\Delta S\Delta H + 14.010\Delta H^2\ 429{,}070.\Delta S^3 + 34{,}904.\Delta S^2\Delta H - 631.20\Delta S\Delta H^2 + 48.556\Delta H^3 + 1{,}302{,}000.\Delta S^4 - 105{,}270.\Delta S^3\Delta H - 176.07\Delta S\Delta H^3 - 5.4593\Delta H^4 + 3{,}352.1\Delta S^2\,\Delta H^2.$$

(2) $$Q2F = [2.1629 + 1{,}290.3\Delta S - 113.24\Delta H - 19{,}649.\Delta S^2 - 912.81\Delta S\Delta H + 186.17\Delta H^2 + 195{,}100.\Delta S^3 + 20{,}974.\Delta S^2\Delta H - 1{,}861.6\Delta S\Delta H^2 - 18.802.\Delta H^3 - 629{,}690.\Delta S^4 - 66{,}502.\Delta S^3\Delta H + 308.06.\Delta S\Delta H^3 - 15.187\Delta H^4 + 2{,}865.3\Delta S^2\Delta H^2] \bullet [1. -(4{,}199.5 - ES)/y2F].$$

The equation for Q2F was first developed for a lake altitude of 4,199.5 feet. Because the velocity profiles indicated that velocities were essentially constant with depth, the discharge (Q2F) can be adjusted for variable lake altitudes by knowing the average depth of the deep layer (y2F). The factor [1. -(4,199.5 - ES)/y2F] was used to correct Q2F for variable lake altitudes. The equation developed for y2F is shown on page 38.

Approximate limiting conditions: ΔS = 0.015 to 0.180, ES = 4,192' to 4,203', ΔH = 0.10' to 2.00'.

The curve-fitting technique (Esler, Smith, and Davis, 1968) yielded an excellent fit. The envelope of curves in figures 10 and 11 provide rating curves for determining the discharges for the causeway for various values of ΔH, and ΔS. The discharges determined from

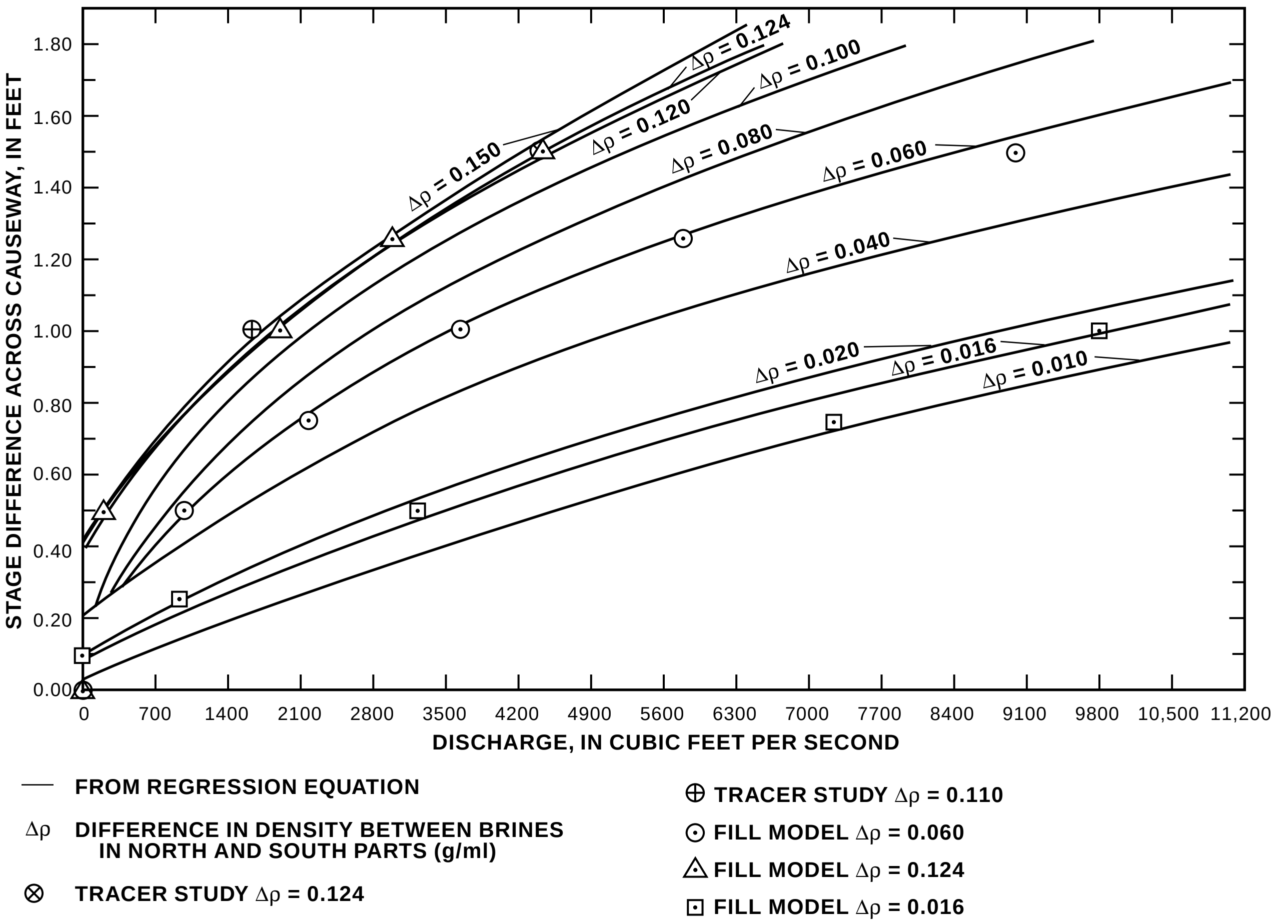


Figure 10. South-to-north discharge through the fill as a function of stage difference and density difference across the causeway.

the Pinder and Cooper model and from the tracer studies are shown in figures 10 and 11.

Equations (1) and (2) are reliable only for ranges of stage difference and discharge shown in figures 10 and 11. If these ranges are exceeded, the equations may provide erroneous answers. Negative values were handled in the overall model by letting all discharges computed as negative values equal zero.

LAKE ALTITUDE, VOLUME, AND AREA EQUATIONS

The equations developed for volume and area of both parts of the lake (VN, VS, AN, AS) as functions of lake altitude (ES and EN) (D. B. Adams and F. K. Fields, U. S. Geol. Survey, written commun., 1972) are:

$$(1) \quad VS = [876{,}369.500 - 9{,}349.313\,(ES - 4{,}000) + 25.07962\,(ES - 4{,}000)^2]\ 1{,}000.$$

$$(2) \quad VN = [368{,}644.750 - 4{,}010.910\,(EN - 4{,}000) + 10.98323\,(EN - 4{,}000)^2]\ 1{,}000.$$

$$(3) \quad AS = [509{,}380. - 7{,}262.5\,(ES - 4{,}000) + 34.1625\,(ES - 4{,}000)^2\ .052836\,(ES - 4{,}000)^3]\ 1{,}000.$$

$$(4) \quad AN = [960{,}910 - 14{,}644.8\,(EN - 4{,}000) + 74.3108\,(EN - 4{,}000)^2 - .12550\,(EN - 4{,}000)^3]\ 1{,}000.$$

The values computed from equations 1-4 and planimetered values (rounded) for various lake altitudes are contrasted (top of page 31).

WATER-BALANCE EQUATIONS

The causeway model was developed for stage differences and lake altitudes observed during 1965-1972. In order to predict brine exchange through the causeway for different conditions of inflow, specific gravity, lake altitude, culvert width, and related parameters it was necessary to develop an equation for predicting stage differences for variable conditions that could occur in the future.

ES (feet)	VS (acre-feet)		EN (feet)	VN (acre-feet)	
	Planimetered	Computed		Planimetered	Computed
4,193.00	6,078,000	6,143,000	4,193.00	3,639,000	3,653,000
4,194.00	6,487,000	6,500,000	4,194.00	3,886,000	3,893,000
4,195.00	6,914,000	6,907,000	4,195.00	4,151,000	4,155,000
4,196.00	7,367,000	7,364,000	4,196.00	4,437,000	4,438,000
4,197.00	7,867,000	7,871,000	4,197.00	4,745,000	4,744,000
4,198.00	8,429,000	8,428,000	4,198.00	5,073,000	5,071,000
4,199.00	9,045,000	9,035,000	4,199.00	5,423,000	5,421,000
4,200.00	4,706,000	9,692,000	4,200.00	5,794,000	5,792,000

ES (feet)	VS (acres)		EN (feet)	AN (acres)	
	Planimetered	Computed		Planimetered	Computed
4,193.00	401,000	394,900	4,193.00	239,000	239,500
4,194.00	417,000	418,300	4,194.00	255,000	255,900
4,195.00	437,200	448,500	4,195.00	274,800	274,900
4,196.00	469,000	485,300	4,196.00	297,000	295,700
4,197.00	532,000	528,200	4,197.00	318,000	317,500
4,198.00	591,000	577,100	4,198.00	339,000	339,600
4,199.00	642,000	631,400	4,199.00	360,000	361,200
4,200.00	679,700	691,000	4,200.00	382,300	381,600

Relation of Net Inflow, Stage Difference, and Brine Movement

The following equations for both parts of the lake (N. Yotsukura, U. S. Geol. Survey, written commun., 1972) were used to determine the relationship among net inflow, stage difference, and brine exchange through the causeway (see figure 12):

(1)[1] $[d(ES)/dt] \bullet AS = QIS + GIS - EOS - QS + QISPPT$

(2)[1] $[d(EN)/dt] \bullet AN = QS - EON + GIN + QINPPT.$

(3) $\Delta H = ES - EN.$

Now subtracting equation (2) from equation (1).

$$d(ES)/dt - d(EN)/dt = QIS/AS + GIS/AS - EOS/AS - QS/AS - QS/AN + EON/AN - GIN/AN + QISPPT/AS - QINPPT/AN.$$

Now after substituting equation (3) and simplifying,

(4) $d(/\Delta H)/dt = (QIS + GIS)/AS - EOS/AS - QS(AS + AN)/(AS \bullet AN) + EON/AN - GIN/AN.$

The precipitation rates for the north and south parts are approximately equal or $QISPPT/AS \cong QINPPT/AN$ and these terms cancel out of equation (4).

Now the evaporation terms EON/AN - EOS/AS represent the difference of evaporation rates between the north and south parts or EON/AN - EOS/AS= R. If the evaporation rates for each part were assumed equal, R would become zero. The assumption may not be correct, however, because of the many variables affecting evaporation; therefore, R will be retained in the following equations.

Ground-water inflow to the south part (GIS) is not known but can be combined with the surface inflow (QIS) as one term (QIN), or QIN = GIS + QIS.

Ground-water inflow (GIN) to the north part is estimated to be on the order of 10,000 acre-feet/year (J. W. Hood, U. S. Geol. Survey. oral commun., 1972).

[1][d(ES)/dt] • AS and [d(EN)/dt] • AN are first order approximations to dV/dt, where V is volume. Since the relation between V and E is non-linear, the approximation of d(ES)/dt or d(EN)/dt should not be used for values of d(ES) or d(EN) exceeding 1 foot.

The amount (GIN) is so small compared to QIN and QS that it could be ignored, but it will be included for consistency in equation (5). Now revising equation (4) according to the preceding considerations,

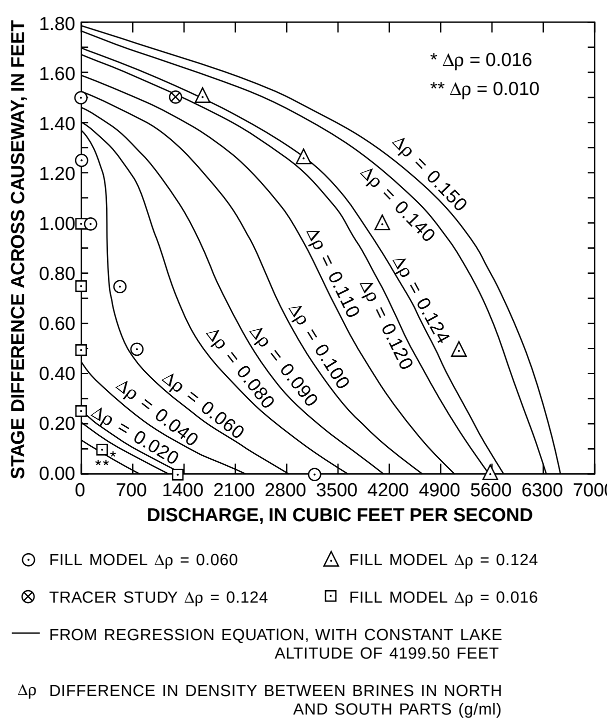


Figure 11. North-to-south discharge through the fill as a function of stage difference and density difference across the causeway.

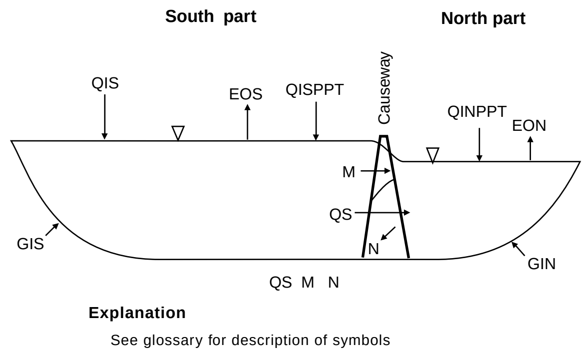


Figure 12. Schematic diagram of water balance for Great Salt Lake.

$$(5) \qquad d(\Delta H)/dt = QIN/AS - QS(AS + AN)/(AS \bullet AN) - 10{,}000/(AN \bullet 365) + R.$$

and rearranging,

$$(6) \qquad QIN + R(AS) = AS[d(\Delta H)/dt + QS(AS + AN)/(AS \bullet AN) + 10{,}000/(AN \bullet 365)].$$

For the period 1969-1972 (period during which most stage difference, culvert flow, and chemical-quality data were collected) d(ΔH)/dt, and QS, AS, and AN can be determined.

Hence QIN + R(AS) can be determined from equation (6) for any part of this period.

Now by knowing QIN + R(AS) for the existing culverts, the change in stage difference for different widths of culverts and inflow conditions can be determined.

The only variables that change in equation (6) when the culverts are widened are d(ΔH)/dt and QS, where

$$(7) \qquad QS = \underset{\text{fill}}{(Q1F \bullet Q2F)} + \underset{\text{culverts}}{(Q1C - Q2C)},$$

(Q1F - Q2F) can be determined from the equations governing the fill flows (see page 29) and (Q1C - Q2C) can be determined from the culvert equations (see pages 17-20).

Now by utilizing water-balance equations for the south and north parts of the lake, ΔH can be determined for unobserved inflow conditions and/or various widths of culverts for small time intervals, Δt.

$$(8) \qquad NEWVS = VS + QIN \bullet \Delta t - QS \bullet \Delta t - EOS \bullet \Delta t.$$

$$(9) \qquad NEWVN = VN + QS \bullet \Delta t - EON \bullet \Delta t.$$

$$(10) \qquad ES = \sqrt{NEWVS/25{,}079.62 - 201.277} + 4{,}186.393.$$

$$(11) \qquad EN = \sqrt{NEWVN/10{,}983.23 - 224.32} + 4{,}182.592.$$

$$(12) \qquad \Delta H = ES - EN.$$

Hence the new stage difference after a small increment of time (1.901 days used in model) for various inflow (QIN) and net causeway flows (QS) can be determined from equation (12) in conjunction with equations (7)-(11).

Relation of Evaporation and Brine Movement

Evaporation less precipitation from either part of the lake can be computed for the 1969-1972 water years through use of the data for net inflow [QIN + R(AS)] determined from equation (6) (column 1) in conjunction with the following water-budget equations (13) and (14) for each part of the lake.

$$(13) \qquad EOS - QISPPT = QIN - \Delta VS/\Delta t - QS.$$

$$(14) \qquad EON - QINPPT = QS - \Delta VN/\Delta t + GIN.$$

Since QIN is not known, QIN + R(AS) as determined from equation (6) (column 1), must be used in equation (13) in place of QIN. Therefore, EOS - QISPPT in equation (13) will also contain the error factor R(AS) or

$$(15) \qquad EOS - QISPPT = QIN - \Delta VS/\Delta t - QS + R(AS).$$

Now because both QIN and EOS data, as determined during the 1969-1972 water years, are input to the water budget for the south part, the error factor [R(AS)] due to possible differences of evaporation rate between the two parts cancels out [see equation (16)] and is not a source of error for the predictive years.

$$(16) \qquad \begin{aligned} NEWVS &= VS + [QIN + R(AS)]\,\Delta t - (QS)\Delta t - [EOS - QISPPT + R(AS)]\,\Delta t \\ &= VS + QIN(\Delta t) - QS(\Delta t) - (EOS - QISPPT)\Delta t + \cancel{R(AS)}\Delta t - \cancel{R(AS)}\Delta t. \end{aligned}$$

During the 1969-1972 water years, a considerable difference in salinity existed between the north and south parts of the lake. The effect of salinity on evaporation rate has been studied by several investigators, including Adams (1934), Jones (1933), and Harbeck (1955). The effects of the differences of salinity between the north and south parts that occurred during 1969-1972 were considered when the evaporation rates were computed for the period. In the future, however, the salinity differences between the two parts may differ from that of 1969-1972; consequently, the evaporation rate will change. To compensate for this possibility, it was necessary to develop equations to predict the effects of changes of salinity on evaporation rate.

Utilizing data from Adams (1934), an equation describing the effects of salinity on evaporation rate in each part was developed.

(17) $SCE = (1 - 0.778\ CS/\rho S)$

(18) $SCEN = (1 - 0.778\ CN/\rho N)$

where SCE and SCEN are the factors for correcting evaporation rate in the south and north parts for the effect of salinity difference. Note that this salinity correction does not imply that the south part has a higher rate of evaporation, as many other factors enter into it. The salinity correction (SCE, SCEN) is only being used as an index so that evaporation figures computed for 1969-1972 can be extrapolated into the predictive years. In the predictive period, the 1972 evaporation rates are used, modified only by the index of salinity difference.

Now for 1972, the average concentration of dissolved solids in the south part was 175 g/l. Hence for 1972, SCE = 0.88. The average concentration of dissolved solids in the north part for 1972 was 340 g/l, hence SCEN = 0.78. Now to correct the evaporation rate for either part (EOS, EON) as determined for 1972, in the predictive years the following equations were used.

(19) $EOS\ (\text{predictive years}) = [E(EOS/AS\ \text{for}\ 1972) \bullet (SCE)/(0.88)l\ AS$

(20) $EON\ (\text{predictive years}) = [F(EON/AN\ \text{for}\ 1972) \bullet (SCEN)/(0.78)]\ AN$

For example, suppose at some time (t) during the predictive years the salinity in either part was the same as during 1972. Then equations (19) and (20) would yield the same evaporation rate for the predictive period as during 1972 (correction factor would equal 1.0). If the salinity in each part were greater during the predictive years than during 1972, EOS and EON would be smaller than the 1972 rates.

The net inflow [QIN + R(AS)] and evaporation rates [EOS - QISPPT + R(AS) and EON - QINPPT] as determined in this section are not intended to be precise. These values were computed only to give simulated input data similar to that observed during recent years. Any inaccuracy of the simulated input data does not invalidate the causeway model. No means are available to predict long-term future inflow and evaporation rates. The simulated inflow and evaporation rates given, however, allow one to simulate a long-term rising or falling stage and to compute the effects of such on movement of dissolved-solids load through the causeway.

SALT-BALANCE EQUATIONS

The total salt load in the Great Salt Lake consists of dissolved-solids load and precipitated load. The annual inflow load (Hahl and Handy, 1969, p. 11) and net extract by salt companies (Madison, 1970, p. 28) is small compared to the total load in the lake. Hence the total salt load in the lake may be assumed to be constant.

Salt Balance

The salt balance in the lake at any given time is a function of the brine exchange through the causeway (figure 13). In turn, the net brine exchange through the causeway is controlled by the relation of discharges from south to north and north to south.

The equation used to express the total salt load in the lake is:

(1) $TL = LS + LN + LPPT$

where LPPT = LSPPT + LNPPT. The rate of change of dissolved load in either part of the lake is equal to the rate of entrance minus the rate of exit, or for the north part:

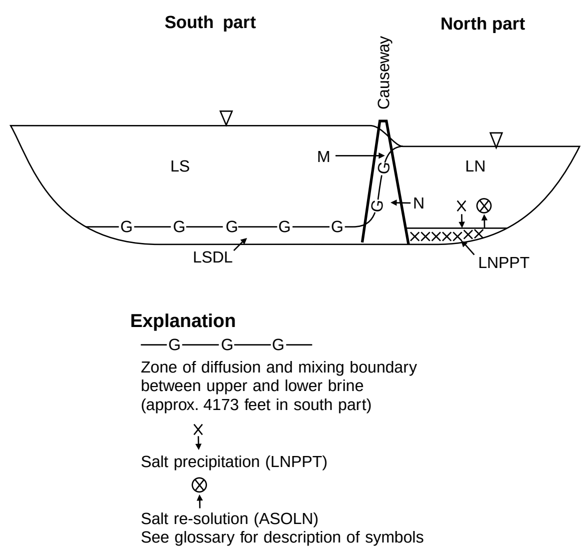


Figure 13. Schematic diagram of salt balance for Great Salt Lake.

(2) North part

Rate of change = Rate of entrance - Rate of exit

$d(LN)/dt = M(LS)/VS - N(LN)/VN.$

Now assuming that initially LPPT = 0 (or at t = 0) and substituting LS = TL - LN (from equation 1),

(3) $d(LN)/dt = (M/VS) \cdot (TL - LN) - N(LN)/VN.$

Treating VS, VN, M, N, and TL as constants, the general solution for the differential equation (3) is:

(4) $LN = (LC) \exp[-(M/VS + N/VN)\Delta t] + (M \cdot TL/VS)/(M/VS + N/VN)$

where (LC) is an integration constant that can be solved by setting $\Delta t = 0$ for the initial conditions of M, N, VS, VN, TL, LN, and LPPT in equations (1) and (4)

Equation (4) is now used to predict a new load (LN) in the north part after a selected time interval (Δt). It is then necessary to test the dissolved-salt load to determine if precipitation will occur. For a given load and volume, there is a maximum amount of salt that can remain dissolved. The limiting or maximum load that the north part can contain is developed in a subsequent section.

The concentration of dissolved solids in grams per milliliter (g/ml) can be determined from the salt load and volume of either part.

(5) $CN = (LN/VN)\ (7.353 \times 10^{-4})$ g/ml,

where 7.353×10^{-4} is a unit conversion factor from tons/acre-foot to g/ml. Likewise,

(6) $CS = (LS/VS)\ (7.353 \times 10^{-4})$g/ml.

Salt Precipitation and Re-solution

The maximum concentrations of dissolved solids that have been observed in the north part of Great Salt Lake and in the north-to-south flows in the causeway fill and culverts have ranged from about 0.350 g/ml to 0.360 g/ml. Since a salt crust containing a high percentage of sodium chloride has been observed in the north part, a limiting value of 0.355 g/ml was selected as the concentration at which salt precipitation could occur.

The limiting salt load (LNMAX and LSMAX) in either part for a given volume can be determined by letting CN = 0.355 g/ml and CS = 0.355 g/ml in equations (5) and (6), respectively (above).

(7) $LNMAX = 483 \cdot VN.$

(8) $LSMAX = 483 \cdot VS.$

If the dissolved salt load (LN or LS) in either part of the lake exceeds either LNMAX or LSMAX precipitation of sodium chloride will occur in that part of the lake. The amount of salt precipitation in either part of the lake for a given time interval can be determined by first computing LS and LN from equations (1) and (4) (pages 33 and 34). Then LN and LS are tested in equations (7) and (8). If either LN or LS exceed the limiting values (LNMAX and LSMAX) then precipitation occurs. The amount of precipitation is determined by means of equations (9) and (10) as follows:

(9) $LNPPT = LN - LNMAX.$

(10) $LSPPT = LS - LSMAX.$

If LN - LNMAX is less than or equal to zero, precipitation will not occur in the north part. If LS - LSMAX is less than or equal to zero, precipitation will not occur in the south part.

If either LN - LNMAX or LS - LSMAX in equations (9) and (10) are less than zero and a salt crust exists, re-solution of the salt crust may occur. The approximate re-solution rate of 0.01 was determined from data shown in figure 3. The maximum amount of salt that could redissolve in either part of the lake (MAXSOLS, MAXSOLN) can be determined from:

(11) $MAXSOLN = LNMAX - LN.$

(12) $MAXSOLS = LSMAX - LS.$

Assuming one-hundredth of this amount is actually redissolved, then

(13) $ASOLN = 0.01\ (LNMAX - LN).$

(14) $ASOLS = 0.01\ (LSMAX - LS).$

Although provisions were made in the model for precipitation and re-solution of sodium chloride in the south part, LSPPT and ASOLS could have been assumed equal to zero. In all salt-balance computations considered in the lake, the south part did not reach saturation with respect to sodium chloride. Thus after a new dissolved-solids load (LN) is calculated by equation (4) (column 1) for a given time interval, Δt, a new distribution of LN and LNPPT is computed by means of equations (7), (9), (11), and (13). Then LS is simply computed from equation (1) (page 33).

Effect of the Lower Layer of Brine in the South Part on the Computation of Dissolved-solids Load

Madison (1970, p. 12) observed that the lower layer of brine in the south part of the lake occurred everywhere the lake bottom is below 4,175 feet. He further surmised that the volume of the lower layer remains relatively constant and that the apparent stability of the lower layer of brine is due to equilibrium between the amount of brine moving south through the causeway and the amount of mixing taking place at the interface. Additional data collected in the south part during 1971-1972 (figure 14) indicated that this volume was about the same as during the study by Madison. The volume of this layer, therefore, was assumed to be constant for all computations of salt balance in the lake. The average load of dissolved solids in this layer was computed as 0.2 billion tons.

Density

The empirical relations between density at 20°C and concentration of dissolved solids in either part of the lake are:

(15) $\rho N_{20} = 1.000 + CN(0.63).$

(16) $\rho S_{20} = 1.000 + CS(0.63).$

Now substituting for CN and CS from equations (5) and (6) (page 34) into equations (15) and (16), we have:

(17) $\rho N_{20} = 1.000 + (LN/VN)\ (4.63 \times 10^{-4}).$

(18) $\rho N_{20} = 1.000 + (LS/VS)\ (4.63 \times 10^{-4}).$

Specific Gravity and Temperature

Determination of flows through the causeway fill and culverts require knowledge of the specific gravity of the brine in the south and north parts (Sl and S2) of the lake for various temperatures. In the metric system, specific gravity (dimensionless) and density (g/ml) are numerically equal for a given temperature. By correcting the densities as determined by equations (17) and (18) (above) to any lake temperature, therefore, the values determined can be used as specific gravities.

The density of fresh water, ρF, at any temperature, T(°C) was developed from data given in Hodgman (1963. p. 2198).

(19) $\rho F = (8T - T^2 + 132.416)/132,432.$

The density of fresh water at 20°C is $\rho F_{20} = 0.99823$.

The relationship developed for the average seasonal variation of temperature in Great Salt Lake (see figure 15) is:

(20) $T(°C) = 12.5 + 12.0 \sin (0.262I - 3.53).$

where I is the number of elapsed time intervals during the simulated period for Δt = 1.901 days. The densities (or specific gravity values) in equations (17) and (18) (column 1) can now be corrected to any temperature by the following relationships:

$$\rho S = \rho S_{20}\ \rho F/\rho F_{20} = \rho F/\rho F_{20}\ [1.000 + (LS/VS)\ (4.63 \times 10^{-4})],$$

The correction of density for temperature is not statistically significant as far as the overall accuracy of the model is concerned, but it may become more significant as future data improve the overall control of the many parameters involved.

ASSEMBLAGE OF MODEL EQUATIONS

The assemblage of the equations into the overall causeway model are given below. The computer language and manipulations are omitted, but the order given is generally the same as is used in the actual digital model.

Initial conditions (1969 water year)

LN	=	1,845,000,000
LS	=	2,199,000,000
CLNPPT	=	100,000,000
LNPPT	=	0
LSPPT	=	0
LSDL	=	200,000,000
ES	=	4,194.1
ΔH	=	0.50

START CYCLE

Time interval

Δt	=	1.901 days

Parameters and constants for flow equations

AS	=	$[509380. - 7262.5(ES - 4000) \bullet 34.162(ES - 4000)^2 - 0.052836(ES - 4000)^3]\ 1000$
AN	=	$[960910. - 14645.(ES - \Delta H - 4000) + 74.310(ES - \Delta H\ 4000)^2\ 0.12550(ES - \Delta H - 4000)^3]\ 1000$

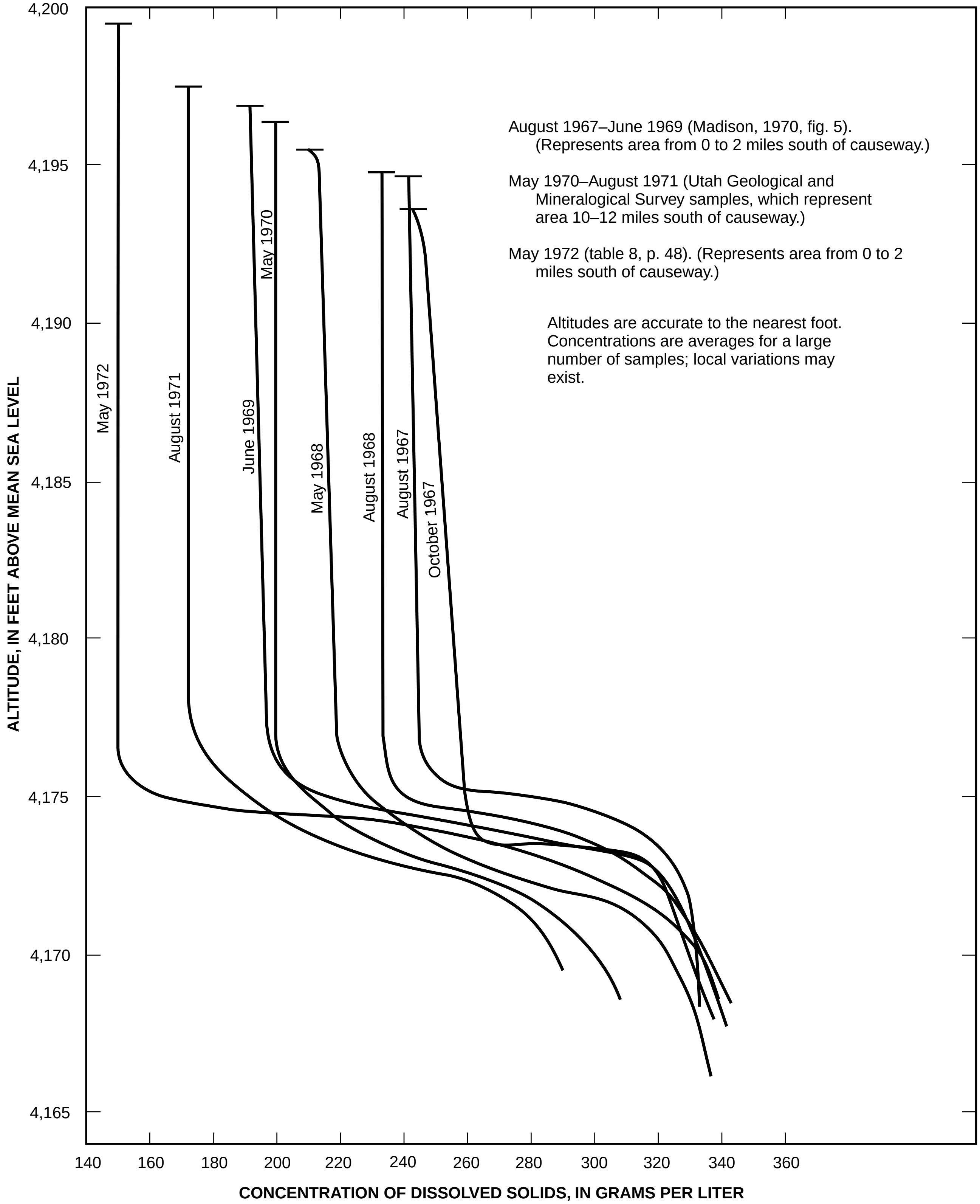


Figure 14. Approximate concentration gradients for south part of Great Salt Lake.

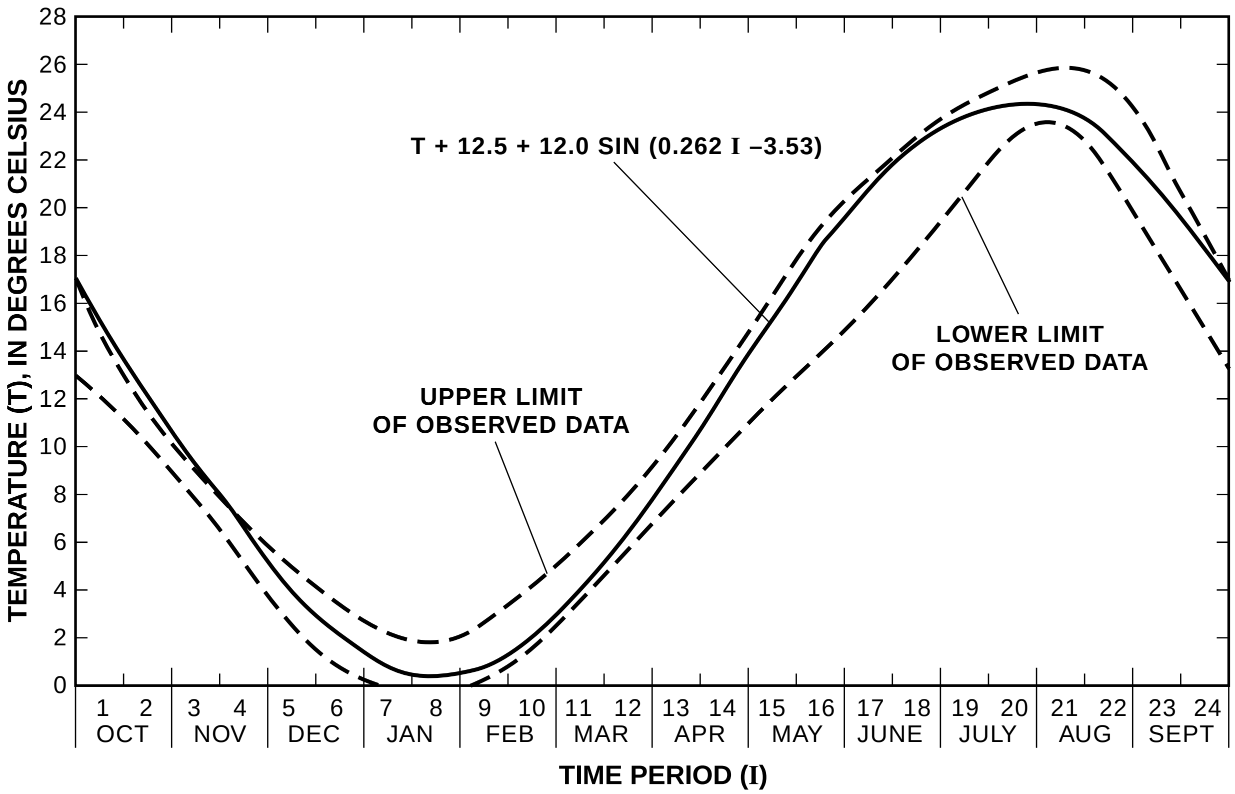


Figure 15. Annual variation of brine temperatures at the east culvert during water years 1969-1972.

Parameters and constants for flow equations (continued)

VN	=	[368644.750 - 4010.910(ES - ΔH - 4000) + 10.98323 • (EN - ΔH - 4000)^2] 1000
VS	=	[876369.500 - 9349.313(ES - 4000) + 25.07962 • (ES - 4000)^2] 1000
CN	=	LN(0.0007353)/VN
CS	=	LS(0.0007353)/VS
ρN^{20}	=	1.000 + 0.63CN
ρS^{20}	=	1.000 + 0.63CS
T	=	12.5 + 12.0 sin (0.262I - 3.53)
TDS	=	LN + LS
ρF^{20}	=	0.99823
ρF	=	(8T - T^2 + 132416)/132432
ρS	=	$(\rho S_{20})(\rho F)/(\rho F_{20})$
ρN	=	$(\rho N_{20})(\rho F)/(\rho F_{20})$

Parameters and constants for flow equations (continued)

S1	=	ρS
S2	=	ρN
ΔS	=	S2 - S1
EEC	=	180 (varies due to settling)
EWC	=	183 (varies due to settling)
B	=	15.0 (for existing culverts)
Y1	=	ES - EEC
Y2	=	Y1 - ΔH
y1	=	-6.30Y2 - 5.84(S2 - S1) • Y1 + 7.09Y1
y2	=	6.39Y2- 5.94(S2 - S1) • Y1 - 6.23Y1
CFS	=	3.55[Y1 - (y1 + y2)]/(Y1 - Y2) - 1.02

East culvert discharge

$$Q1C = B \cdot y1 \left[\sqrt{\left[Y1 - y1 - y2 - CFS\,\frac{(V2C)^2}{2g}\right] \cdot \frac{2g}{(1 + CFS)} + \left(\frac{CFS(V2C)^2}{1 + CFS}\right)} - \frac{CFS(V2C)}{(1 + CFS)}\right]$$

$$CFS' = 3.83[Y1 - (y1 + y2)]/(Y1 - Y2) - 1.19$$

$$Q2C = B \cdot y2\left[\sqrt{\left[Y2 - y2 - y1 \cdot \frac{S1}{S2} - CFS'\frac{(V1C)^2}{2g}\right] \cdot \frac{2g}{(1 + CFS')} + \left(\frac{CFS'(V1C)}{1 + CFS'}\right)^2} - \frac{CFS'(V1C)}{1 + CFS'}\right]$$

West culvert discharge

$EWC = 183$

$EEC = EWC$

Repeat steps given for east culvert

Causeway fill discharge

$$Q1F = 6.9835 - 1675.0\Delta S + 158.97\Delta H + 45535.\Delta S^2 - 3773.3\Delta S\Delta H + 14.010\Delta H^2 - 429070.\Delta S^3 + 34904.\Delta S^2\Delta H - 631.20\Delta S\Delta H^2 + 48.556\Delta H^3 + 1302000.\Delta S^4 - 105270\Delta S^3\Delta H - 176.07\Delta S\Delta H^3 - 5.4593\Delta H^4 + 3352.1\Delta S^2\Delta H^2$$

$$y2F = 19.307 + 242.23\Delta S - 35.429\Delta H - 4339.9\Delta S^2 + 407.50\Delta S\Delta H + 14.332/\Delta H^2 + 19021.\Delta S^3 - 1466.8\Delta S^2\Delta H - 45.647\Delta S\Delta H^2 - 3.8069\Delta H^3$$

$$Q2F = [12.1629 + 1290.3\Delta S - 113.24\Delta H - 19649.\Delta S^2 - 912.81\Delta S\Delta H + 186.17\Delta H^2 + 195100.\Delta S^3 + 20974.\Delta S^2\Delta H - 1861.6\Delta S\Delta H^2 - 18.802\Delta H^3 - 629690.\Delta S^4 - 66502.\Delta S^3\Delta H + 308.06\Delta S\Delta H^3 - 15.187\Delta H^4 + 2865.3\Delta S^2\Delta H^2]\,[1. - (4199.5 - ES)/y2F]$$

Total flow—North (M • Δt)

$$M \cdot \Delta t = [(Q1C)_E + (Q1C)_W + Q1F]\,\Delta t \cdot 1.98$$

Total flow—South (N • Δt)

$$N \cdot \Delta t = [(Q2C)_E + (Q2C)_W + Q2F]\,\Delta t \cdot 1.98$$

Net flow through causeway

$$QS \cdot \Delta t = (M - N)\Delta t$$

Water balance

Simulated evaporation

$SCE = 1 - 0.778\ CS/\rho S$

$SCEN = 1 - 0.778\ CN/\rho N$

E = (Any simulated evaporation rate for south part for time interval)

F = (Any simulated evaporation rate for north part for time interval)

$EOS = [(E)\,(AS)\,(SCE)/(0.88)]$

$EON = [(F)\,(AN)\,(SCEN)/(0.78)]$

Simulated inflow

QIN = IR(QINB) (Any simulated net inflow rate to south part for time interval)

New volumes for north and south parts

$NEWVS = VS + QIN \cdot \Delta t - QS\Delta t - EOS \cdot \Delta t$

$NEWVN = VN + QS\Delta t - EON \cdot \Delta t$

Salt balance

TL = LN + LS - LNPPT (LSPPT = 0 for all simulated conditions)

$(LC) = LN - [M(TL)/NEWVS] \cdot [1/(M/NEWVS + N/NEWVN)]$

$NEWLN = (LC)\exp[-(M/NEWVS + N/NEWVN)\Delta t] + [M(TL/NEWVS)]/[M/NEWVS + N/NEWVN]$

$LNMAX = 483 \cdot VN$

$LNPPT = NEWLN - LNMAX$

If LNPPT < 0 LNPPT = 0

MAXSOLN = LNMAX - NEWLN

If MAXSOLN > 0 ASOLN = 0.01 • MAXSOLN

If MAXSOLN < 0 ASOLN = 0

If LNMAX > NEWLN, NCLNPPT = CLNPPT - ASOLN

If LNMAX < NEWLN, NCLNPPT = CLNPPT + LNPPT

If NEWLN > LNMAX, LN = NEWLN - LNPPT

If NEWLN < LNMAX, LN = NEWLN + ASOLN

If NEWLN < LNMAX, NEWTL = TL - LNPPT

Salt balance (continued)

If NEWLN > LNMAX, NEWTL = TL + ASOLN

LS = NEWTL - LN

Compute NEW: ES, EN and ΔH for next time interval

$$ES = \sqrt{NEWVS/25079.62 - 201.277} + 4186.393$$

$$EN = \sqrt{NEWVN/10983.23 - 224.32} + 4182.592$$

$$\Delta H = ES - EN$$

END OF CYCLE

BASIC DATA

Table 6. Operation and sample logs for test wells in the Southern Pacific Transportation Co. causeway. (Logs by C. T. Sumsion.)

Well 1 - Operation Log

Milepost location 746.2

Altitude of the causeway surface at the well: 4,205.2[1] feet above msl

Altitude of the top of the casing: 4,210.17 feet above msl

Date	Time	Depth (feet below causeway surface)	Remarks
6/2/71	7:30 a.m.	0	Began drilling
	10:10	6.5	
	10:15	6.5	Added casing
	10:47	6.5	Resumed drilling
	11:30	12	
	11:30	12	Stopped drilling
	2:00 p.m.	12	Resumed drilling
	2:30	18	
	3:00	19	Slow drilling on boulder
	3:30	19	
	6:00	20-22	Stopped drilling
6/3/71	7:30 a.m.	20-22	Resumed drilling
	9:35	27	
	9:50	32	
	10:05	36	
	10:15	36-38	Stopped drilling
	11:05	36-38	Resumed drilling
	11:25	36-38	Stopped drilling
	12:20 p.m.	36-38	Resumed drilling
	12:40	40	
	1:05	40-45	Stopped drilling
	1:50	40-45	Resumed drilling
	2:00	50	
	2:13	53	
	2:35	55	Stopped drilling
	3:20	55	Resumed drilling
	4:20	60-65	On boulder
	5:45	60-65	Still on boulder, stopped drilling
6/4/71	7:45 a.m.	65	Resumed drilling
	6:00 p.m.	67	Completed well

[1] The elevation of the causeway surface has been raised about 5 feet at this site since the well was drilled.

Note: From about 20-60 feet no boulders of any significance encountered–mostly sand and gravel. Increasing amounts of fine materials below 45 feet. No salt crystals observed in field but possibly evaporites in matrix.

Well 1 - Sample Log
(all bailed samples)

Feet	
0 - 6.5	Quartzite, 50 percent, white and tan to gray, and ranging in size from coarse sand to fine pebbles, angular. Matrix of clay and evaporites contains individual salt crystals.
6.5 - 12	Quartzite, 50 percent, coarse sand to fine pebbles, angular. Matrix of clay and evaporites.
12 - 18	Quartzite, 90 percent, coarse sand to fine pebbles, angular. Unidentified dark minerals, 1 percent, coarse sand, angular. Matrix predominantly of evaporites with some clay; evaporites appear as crystals as well as a coating on quartzite surfaces.
18 - 27	Quartzite 70 percent, coarse sand to fine pebbles, angular. Matrix a mixture of amorphous evaporites and clay.
27 - 32	Quartzite, 80 percent, coarse sand to fine pebbles, angular. Matrix predominantly of evaporites with some clay.
32 - 36	Quartzite, 90 percent, coarse sand to fine pebbles, angular. Matrix of evaporites with some clay.
36 - 40	Quartzite, 50 percent, coarse sand to fine pebbles, angular. Matrix mainly of evaporites with some clay.
40 - 45	No sample.
45 - 50	Quartzite, 60 percent, coarse sand to fine pebbles, angular. Matrix of clay and evaporites.
50 - 53	Quartzite, 60 percent, coarse sand to fine pebbles, angular. Matrix of clay and evaporites in which salt appears in discrete, medium-sand-sized clusters.
53 - 55	Quartzite, 70 percent, coarse sand to fine pebbles, angular. Matrix mostly of evaporites. Evaporites appear as crystals as well as coating on quartzite surfaces.
55 - 60	Same as preceding interval.
60 - 65	Same as 53-55 interval.
65 - 67	No sample. Driller reported a boulder underlain by black mud having sulfurous odor in this interval.

Table 6. (continued)

Well 7 - Operation Log

Milepost location 748.0

Altitude of the causeway surface at the well: 4,207.8 feet above msl

Altitude of the top of the casing: 4,210.33 feet above msl

Date	Time	Depth (feet below causeway surface)	Remarks
6/18/71	2:30 p.m.	0	Began drilling
	3:00	4	
	3:30	6	
	5:45	10-12	Stopped drilling
6/21/71	7:30 a.m.	10-12	Resumed drilling
	10:00	20	Stopped drilling
	10:50	20	Resumed drilling
	11:15	30	Stopped drilling
	11:20	30	Resumed drilling
	11:35	30-35	Stopped drilling
	1:20 p.m.	30-35	Resumed drilling
	1:25	35	Stopped drilling
	2:10	35	Resumed drilling
	3:15	40	Stopped drilling
	3:20	40	Resumed drilling
	3:45	45	
	6:00	50-55	Stopped drilling
6/22/71	7:45 a.m.	50-55	Resumed drilling
	10:30	65	Stopped drilling
	11:15	65	Resumed drilling
	11:45	66	Stopped drilling, went through boulder 65-66 feet
	1:00 p.m.	66	Resumed drilling
	2:00	68	Completed well.

Note: Samples examined in field for presence of salt crystals. No significant amounts of salt crystals observed. A few were observed but probably are due to partial desiccation of brine. There were some amorphous evaporites evident in some of the samples. Attempts to take undisturbed core samples not successful. Driller will attempt to take core samples on next site using set of larger drilling jars.

Well 7 - Sample Log

Feet

0 - 6 Bailed, unwashed. Quartzite, 50 percent, white to gray, fine sand to fine pebbles, angular. Matrix predominantly of clay with some evaporites.

6 - 15 Bailed, unwashed. Quartzite, 50 percent, fine sand to fine pebbles, angular. Matrix predominantly of clay with some evaporites.

15 - 20 Bailed, washed. Quartzite, fine to coarse pebbles, angular to well rounded. Evaporites with some clay encrust about 90 percent of quartzite surfaces. A few smaller particles cemented to larger ones; as a whole, sample is weakly cemented.

Well 7 - Sample Log (continued)

Feet

15 - 20 Bailed, unwashed. Quartzite, 60 percent, fine sand to coarse pebbles, angular to well rounded. Matrix is a mixture of clay and evaporites; well cemented.

20 - 30 Bailed, washed. Quartzite, coarse sand to coarse pebbles, angular. Evaporites encrust quartzite surfaces, with some clay; sample weakly cemented.

20 - 30 Bailed, unwashed. Quartzite, 70 percent, fine sand to coarse pebbles, angular. Matrix a mixture of clay and evaporites; evaporites predominate, encrusting some pebbles; sample well cemented.

30 - 35 Bailed, washed. Quartzite, coarse sand to medium pebbles, angular. Evaporites with some clay encrust surfaces of quartzite; samples weakly connected.

30 - 35 Bailed, unwashed. Quartzite, 90 percent, fine sand to coarse pebbles, angular. Matrix mainly of evaporites with some clay; evaporites encrust quartzite particles; sample well cemented.

35 - 40 Bailed, washed. Quartzite, coarse sand to coarse pebbles, angular. Evaporite particles, clusters, and crystals cling to quartzite surfaces as cementing material, but sample weakly cemented.

35 - 40 Bailed, unwashed. Quartzite, 90 percent, coarse sand to medium pebbles, angular. Matrix mainly of evaporites with some clay; weakly cemented.

40 Bailed, washed. Quartzite, coarse sand to very coarse pebbles, angular to rounded. Evaporite crust on 15 to 20 percent of quartzite surfaces; not thickly encrusted.

40 Bailed, unwashed. Quartzite, 90 percent, coarse sand to coarse pebbles, angular to rounded. Matrix mainly of evaporites with some clay; encrusts most quartzite particles; sample moderately well cemented.

40 - 45 Small sample adhered to drilling tool. Quartzite 30 to 40 percent, fine sand to fine pebbles, angular. Matrix of clay and evaporites; sample well cemented.

45 - 50 No sample.

50 - 55 Bailed, unwashed sample collected by driller. Quartzite, 90 percent, coarse sand to coarse pebbles, angular. Matrix of evaporites and some clay encrusts quartzite particles; sample weakly cemented.

55 - 60 Bailed, unwashed. Quartzite, 90 percent, coarse sand to very coarse pebbles, angular. Matrix of clay and evaporites, encrusts quartzite; sample very well cemented.

Table 6. (continued)

Well 7 - Sample Log (continued)

Feet

60 - 65 Bailed, washed. Quartzite, coarse sand to coarse pebbles, angular. Quartzite surfaces only slightly encrusted with evaporites; sample particles not cemented.

60 - 65 Bailed, unwashed. Quartzite, 60 percent, fine sand to very coarse pebbles, angular. Matrix of evaporites and clay, with more clay than in 55-60 feet interval; sample well cemented.

66 - 68 Driller reports sample taken off drilling bit; looks like salt crust and bottom-mud mixture; sample has odor typical of lake-bottom muds (sulfurous).

Well 8 - Operation Log

Milepost location 749.8

Altitude of the causeway surface at the well: 4,207.5 feet above msl

Altitude of the top of the casing: 4,209.65 feet above msl

Date	Time	Depth (feet below causeway surface)	Remarks
6/23/71	1:15 p.m.	0	Began drilling
	2:00	5	
	6:00	18	Stopped drilling
6/24/71	7:45 a.m.	18	Resumed drilling
	9:30	30	Stopped drilling, took core (see field observation below)
	11:00	30.5	Resumed drilling
	12:00	43	Stopped drilling
	12:45 p.m.	43-43.5	Took core
	1:00	43.5	Resumed drilling
	1:30	45-50	Stopped drilling
	2:20	45-50	Resumed drilling
	2:30	50	Stopped drilling
	2:34	50	Resumed drilling
	2:45	55	Stopped drilling
	3:40	55	Resumed drilling
	3:55	58	Stopped drilling
	4:00	58	Resumed drilling
	4:25	63	Stopped drilling
	5:05	63	Resumed drilling
	6:00	66	Completed well.

Note: Core at 30-30.5 feet contained several large pieces composed of clay, sand, and gravel up to 2 inches in diameter. I examined the core carefully with a hand lens. I detected four or five salt crystals (halite-about like table salt in size). These crystals could have formed from drying of the brine after the matrix was broken open and exposed to the air. Dousing of the sample indicated there were considerable amounts of soluble material in the clay matrix. The clay was white to pinkish in color.

Well 8 - Sample Log

Feet

0 - 5 Bailed, unwashed. Quartzite, 50 percent, white to gray, medium sand to medium pebbles, angular. Matrix of clay and evaporites; sample well cemented.

5 - 10 Bailed, unwashed. Quartzite, 90 percent, coarse sand to very coarse pebbles, angular to rounded. Sample well cemented by matrix of clay and evaporites.

10 - 15 Bailed, unwashed. Quartzite, 80 percent, coarse sand to very coarse pebbles, angular. Sample well cemented by matrix of clay and evaporites; more clay than preceding interval.

15 - 20 Bailed, unwashed. Quartzite, 80 percent, coarse sand to coarse pebbles, angular. Sample moderately well cemented by clay-evaporite matrix.

20 - 25 Bailed, washed. Quartzite, coarse sand to medium pebbles, angular. Sample relatively clean; not cemented.

20 - 25 Bailed, unwashed. Quartzite, 90 percent, coarse sand to medium pebbles, angular. Sample moderately well cemented by matrix of evaporites and clay; evaporites predominate.

25 - 30 Bailed, washed. Quartzite, fine sand to fine pebbles, angular. Sample clean with slight evaporite coating on quartzite; not cemented.

25 - 30 Bailed, unwashed. Quartzite, 60 percent, fine sand to fine pebbles, angular. Sample moderately well cemented by matrix of clay and evaporites.

30 - 30.5 Core, unwashed. Quartzite, 60 percent, fine sand to very coarse pebbles, angular. Sample very well cemented by matrix of clay and evaporites.

30 - 30.5 Core, washed on surface to remove residue from brine. Sample same as unwashed core, 30-30.5 feet.

30 - 30.5 Core, washed. Same composition as core, unwashed, 30-30.5 feet.

30 - 43 Bailed, washed. Quartzite, fine pebbles to coarse pebbles, angular. Sample weakly cemented by matrix of evaporites and clay.

30 - 43 Bailed, unwashed. Quartzite, 90 percent, coarse sand to very coarse pebbles, angular. Sample moderately well cemented by matrix of clay and evaporites.

43 - 43.5 Core, washed. Quartzite, 95 percent, coarse sand to coarse pebbles, angular to rounded. Evaporites coat quartzite surfaces and cement some particles, but sample is weakly cemented.

43 - 43.5 Core, unwashed. Quartzite, 95 percent, coarse sand to medium pebbles, angular to rounded. Sample weakly to moderately cemented by matrix of clay and evaporites.

Table 6. (continued)

Well 8 - Sample Log (continued)

Feet

43 - 50 Bailed, washed. Quartzite, very coarse sand to very fine pebbles with some coarse pebbles, angular to rounded. Particles slightly coated by evaporites; weakly cemented.

43 - 50 Bailed, unwashed. Quartzite, 90 percent, very coarse sand to very coarse pebbles, angular. Sample weakly to moderately cemented by matrix of clay and evaporites.

50 - 55 Bailed, washed. Quartzite, coarse sand to coarse pebbles, angular. Sample is weakly cemented by evaporites.

50 - 55 Bailed, washed, residue from wash water. Quartzite, medium-fine sand to very fine pebbles, angular. Particles coated by evaporite and weakly (about 15 percent of sample) cemented.

50 - 55 Bailed, unwashed. Quartzite, 80 percent, medium sand to very fine pebbles, angular. Quartzite heavily coated by matrix of clay and evaporites.

55 - 58 Bailed, washed. Quartzite, very coarse sand to very fine pebbles, angular. Matrix of evaporites and clay adhere to 20 to 50 percent of quartzite particles.

55 - 58 Bailed, washed, residue from wash water. Quartzite, medium-fine to coarse sand, angular. Evaporites coat 10 to 15 percent of quartzite particles.

55 - 58 Bailed, unwashed. Quartzite, 80 percent, coarse sand to coarse pebbles, angular. Sample well cemented by matrix of clay and evaporites.

58 - 63 Bailed, washed. Quartzite, coarse sand to medium pebbles, angular. Sample clean, but weakly cemented by evaporites.

58 - 63 Bailed, unwashed. Quartzite, 80 percent, very fine to medium pebbles. Sample well cemented by matrix of clay and evaporites.

63 - 66 Driller reported lake-bottom muds in this interval.

Well 9 - Operation Log

Milepost location 751.5

Altitude of the causeway surface at the well: 4,207.5 feet above msl

Altitude of the top of the casing: 4,209.60 feet above msl

Date	Time	Depth (feet below causeway surface)	Remarks
7/7/71	1:00 p.m.	0	Began drilling
	2:00	7	
	2:05	7-10	Stopped drilling

Well 9 - Operation Log (continued)

Date	Time	Depth (feet below causeway surface)	Remarks
	4:30	7-10	Resumed drilling
	5:00	10	
	6:00	10-15	Stopped drilling
7/8/71	7:15 a.m.	10-15	Resumed drilling
	9:30	30	Stopped drilling, took core (see field observation below)
	10:10	30.5	Resumed drilling
	11:30	40	Stopped drilling
	11:45	40	Resumed drilling
	12:00	40-45	Stopped drilling
	12:45 p.m.	40-45	Resumed drilling
	2:45	52	Stopped drilling, took core
	3:00	52.5	Resumed drilling
	3:15	54	Completed well

Note: Core at 30-30.5 feet was composed of large angular quartzite rocks up to 3 inches maximum width with fine white-to-grayish material adhering to them. Dousing of the fine material with fresh water indicated it to be readily soluble.

The core at 52-52.5 feet is composed mostly of material ranging from gravel (1-2 inches) to sand with some clays and evaporites. Sample appears to contain more clay and soluble material than the core at 30-30.5 feet.

Well 9 - Sample Log

Feet

0 - 7 Bailed, unwashed. Quartzite, 50 percent, white to gray, coarse sand to fine pebbles. Matrix of buff-colored clay and evaporites; sample very well cemented by matrix.

7 - 10 No sample.

10 - 15 Bailed, washed. Quartzite, 50 percent, coarse sand to medium pebbles, angular. Sample well cemented by matrix of clay and evaporites.

15 Bailed, unwashed. Quartzite, 40 percent, coarse sand to fine pebbles, angular. Sample well cemented by matrix of clay and evaporites.

15 - 20 Bailed, washed. Quartzite, coarse sand to coarse pebbles, angular. Evaporite crystals and particles cover about 25 percent of quartzite surfaces. Sample weakly cemented by evaporites.

15 - 20 Bailed, unwashed. Quartzite, 60 percent, coarse sand to coarse pebbles, angular. Sample well cemented by matrix of clay and evaporites.

20 - 30 Bailed, unwashed. Quartzite, coarse sand to very coarse pebbles, angular. Sample not cemented, about 60 percent of quartzite coated with clay and evaporite matrix.

30 - 30.5 Core, washed. Quartzite, 60 percent, coarse sand to coarse pebbles, angular. Sample well cemented by matrix of clay and evaporites.

Table 6. (continued)

Well 9 - Sample Log (continued)

Feet

30 - 40 Bailed, washed. Quartzite, coarse sand to coarse pebbles, angular. Evaporite and clay matrix adheres to about 30 to 40 percent of quartzite surfaces, sample not cemented.

30 - 40 Bailed, unwashed. Quartzite, 85 percent, coarse sand to coarse pebbles, angular. Sample well cemented by matrix of clay and evaporites.

40 - 50 Bailed, washed. Quartzite, coarse sand to medium pebbles, angular. Sample weakly cemented by matrix of evaporites and clay; very little of matrix remains after washing.

40 - 50 Bailed, unwashed. Quartzite, 90 percent, coarse sand to medium pebbles, angular. Sample weakly cemented by matrix of evaporites and clay.

50 - 52 No sample.

52 - 52.5 Core, unwashed. Quartzite, 70 percent, coarse sand to very coarse pebbles, angular. About 1 percent of coarse sand composed of unidentified dark minerals. Sample well cemented by matrix of evaporites and clay.

52 - 52.5 Core, washed. Quartzite, 65 percent, coarse sand to small cobbles, angular. Sample well cemented by matrix of evaporites and clay.

52 - 52.5 Core, broken into fragments and thoroughly washed. Quartzite, coarse sand to very coarse pebbles, angular. About 10 percent of sample is residual matrix of evaporites and clay; sample uncemented.

52.5 - 54 Driller reports soluble white material adhering to bit of drilling tool from bottom of well at 54 feet.

Well 10 - Operation Log

Milepost location 741

Altitude of the causeway surface at the well: 4,208.5 feet above msl

Altitude of the top of the casing: 4,210.51 feet above msl

Date	Time	Depth (feet below causeway surface)	Remarks
7/9/71	11:00 a.m.	0	Began drilling
	12:00	0-5	Stopped drilling
	12:30 p.m.	0-5	Resumed drilling
	6:00	18	Stopped drilling
7/12/71	8:00 a.m.	18	Resumed drilling
	10:00	28	Stopped drilling
	11:00	28	Resumed drilling
	11:30	30	Stopped drilling, took core (see field observation below)
	12:45 p.m.	30.5	Resumed drilling,
	2:00	44	
	5:45	50-55	Stopped drilling, took core
7/13/71	7:45 a.m.	50-55	Resumed drilling
	11:00	62	Completed well

Well 10 - Operation Log (continued)

Note: Core at 30-30.5 feet had material ranging from 2-3 inch angular rocks to fine sand. Some soluble material present but not in significant quantity.

Well 10 - Sample Log

Feet

0 - 15 No sample.

15 - 20 Bailed, unwashed. Quartzite, 40 to 50 percent, white to light gray, fine to coarse sand, angular. Limestone, 10 to 20 percent, medium to dark gray, very coarse sand to fine pebbles, angular. Sample well cemented by matrix of evaporites and clay.

20 - 25 No sample.

25 - 28 Bailed, washed. Limestone, dark gray, coarse sand to fine pebbles, angular. Evaporites encrust about 15 percent of particle surfaces; sample very weakly cemented by evaporites.

25 - 28 Bailed, unwashed. Limestone, 60 percent, dark gray, fine sand to fine pebbles, angular. Sample well cemented by matrix of evaporites and clay.

28 - 30 Bailed, washed. Limestone, 100 percent, dark gray, coarse sand to coarse pebbles, angular. Evaporites coat 10 to 15 percent of particle surfaces as a thin film.

28 - 30 Bailed, unwashed. Limestone, dark gray, coarse sand to small cobbles, angular. Evaporites and clay encrust about half of particle surfaces; sample weakly cemented.

30 - 30.5 Core, unwashed. Limestone, dark gray, very coarse sand to very coarse pebbles, angular. Particles encrusted with evaporites and clay; sample moderately well cemented.

30 - 30.5 Core, washed. Limestone, dark gray, one fragment consisting of a small cobble, angular. Sample encrusted with evaporites.

30 - 40 No sample.

40 - 45 Bailed, unwashed. Limestone, dark gray, coarse sand to very coarse pebbles, angular to rounded. Sample weakly cemented by evaporites and clay.

40 - 45 Bailed, washed. Limestone, 80 percent, dark gray, coarse sand to very coarse pebbles, angular to rounded. Sample well cemented by matrix of evaporites and clay (about three times as much as preceding sample).

45 - 50 No sample.

50 - 50.5 Core, unwashed. Limestone, 60 percent, dark gray, coarse sand to coarse pebbles, angular. Sample well cemented by matrix of evaporites and clay.

50 - 50.5 Core, unwashed (second sample). Limestone, 60 to 70 percent, dark gray, coarse sand to very coarse pebbles, angular. Sample very well cemented by matrix of evaporites and clay.

50 - 50.5 Core, washed. Limestone, 60 percent, dark gray, coarse sand to very coarse pebbles, angular. Sample very well cemented by matrix of evaporites and clay; has the appearance of' an unwashed sample.

50 - 62 No sample. Driller reports black lake mud on bit of drilling tool from bottom of well.

Table 7. Compilation of data for flows in the east culvert of the Southern Pacific Transportation Co. causeway.

The specific gravities and temperatures of the north and south flows are representative of samples taken from the unmixed zone either above or below the interface between the north and south flows. Near the interface is a zone of mixing where the temperatures and specific gravities are gradational. The mixing zone varies from about 2 feet above the interface to about 2 feet

Obser-vation number	Date of observation	Stage difference of water surface at time of discharge measurement (south part minus north part, feet)		Attitude of south part at Promontory Point (feet above mean sea level at time of discharge measurement)
		As measured across causeway near culvert	As determined from continuous recorders at Promontory Point and Saline	
1	10-24-68	0.82	0.64 ± 0.08	4,194.20
2	11-15-68	—	.78 ± .10	4,194.42
3	12-5-68	.82	.79 ± .05	4,194.50
4	1-7-69	.68	.79 ± .08	4,194.88
5	1-16-69	.88	.78 ± .08	4,195.06
6	2-5-69	.84	.78 ± .05	4,195.44
7	2-18-69	.77	.80 ± .05	4,195.71
8	3-4-69	—	.45 ± .05	4,195.95
9	3-26-69	—	1.08 ± .05	4,196.51
10	4-23-69	1.53	1.40 ± .20	4,197.10
11	5-13-69	1.17	1.12 ± .08	4,196.95
12	6-4-69	1.12	1.05 ± .01	4,196.77
13	6-17-69	1.04	.88 ± .02	4,196.55
14	7-15-69	1.03	.95 ± .02	4,196.32
15	8-6-69	—	.80 ± .02	4,195.97
16	8-19-69	1.05	.86 ± .05	4,195.68
17	9-15-69	.74	.70 ± .03	4,195.27
18	10-15-69	.70	.75 ± .02	4,194.91
19	12-15-69	1.00	.96 ± .02	4,195.42
20	1-15-70	.97	.92 ± .02	4,195.63
21	2-17-70	—	.66 ± .25	4,196.00
22	3-16-70	.85	.86 ± .04	4,196.25
23	5-15-70	1.00	.95 ± .01	4,196.20
24	6-16-70	1.11	1.06 ± .04	4,196.27
25	7-16-70	.85	.80 ± .10	4,195.82
26	8-17-70	.78	.80 ± .05	4,195.30
27	9-16-70	.79	.75 ± .05[1]	4,194.84
28	10-27-70	.80 ± 0.05	.76 ± .03	4,194.75
29	11-16-70	.94 ± .01	.91 ± .03	4,195.02
30	12-2-70	.93 ± .10	1.19 ± .15	4,195.35
31	12-2-70	.33 ± .20	—	4,195.45
32	12-15-70	1.09 ± .05	1.09 ± .03	4,195.50
33	1-15-71	1.08 ± .05	1.06 ± .20	4,195.68
34	2-23-71	1.34 ± .05	1.29 ± .05	4,196.59
35	3-10-71	1.25 ± .05	1.23 ± .05	4,196.67
36	4-15-71	1.03 ± .03	1.07 ± .10	4,196.96
37	5-18-71	1.31 ± .06	1.40 ± .10	4,197.77
38	5-26-71	1.52 ± .10	1.51 ± .05	4,197.80
39	6-8-71	1.41 ± .05	1.23 ± .05	4,197.82
40	6-14-71	1.36 ± .05	1.31 ± .03	4,197.93
41	7-15-71	1.32 ± .05	—	—
42	8-16-71	1.06 ± .05	.92 ± .05	4,197.13
43	9-1-71	1.10 ± .05	.93 ± .05	4,196.97
44	9-15-71	.98 ± .05	.95 ± .02	4,196.90
45	11-2-71	1.29 ± .05	1.43 ± .10	4,197.20
46	11-15-71	1.28 ± .05	1.20 ± .05	4,197.2[1]
47	12-15-71	1.41 ± .02	1.22 ± .08	4,197.56
48	1-17-72	1.15 ± .01	1.07 ± .05	4,197.91
49	2-15-72	1.22 ± .02	1.13 ± .02	4,198.30
50	3-16-72	1.29 ± .01	1.37 ± .01	4,198.84
51	4-21-72	1.46 ± .02	1.52 ± .02	4,199.26
52	5-15-72	1.56 ± .01	1.67 ± .01	4,199.47
53	6-15-72	1.50 ± .04	1.43 ± .03	4,199.25
54	7-21-72	1.33 ± .05	1.20 ± .10	4,198.72
55	8-15-72	1.05 ± .10	1.00 ± .10	4,198.20
56	9-15-72	1.14 ± .02	1.07 ± .02	4,197.85

[1]Estimated.

Table 7. (continued)

below the interface at the measuring section. The culvert is concrete, rectangular in shape, 15 feet wide, and the bottom slope is zero. The measuring section is on the north side of the culvert about 50 feet from the north end. The culvert is 136 feet long and joins the north and south parts of the lake through the causeway. The depth of the culvert opening is 25.7 feet.

Water flowing north through culvert				Water flowing south through culvert (below north flow)			
Specific gravity	Tempera-ture (°C)	Discharge (cfs)	Mean depth (±0.5 ft), from water surface to inter-face with south flow at measuring section	Specific gravity	Tempera-ture (°C)	Discharge (cfs)	Mean depth (±0.5 ft), from interface to bottom of culvert at measuring section
1.157	—	424	9.0	1.230	13.0	52	4.4
1.156	—	453	9.5	1.232	7.0	41	4.0
1.154	4.0	503	10.0	1.232	7.0	32	3.7
1.157	1.5	438	10.5	1.226	1.5	18	3.3
1.150	1.0	521	10.5	1.225	2.0	28	3.3
1.150	1.0	500	10.0	1.221	1.0	43	4.6
1.135	3.0	556	10.5	1.221	3.0	42	4.5
1.140	4.5	213	7.0	1.211	5.0	226	8.2
1.121	6.0	684	11.5	1.217	7.0	43	4.5
1,116	16.0	1,100	15.0	1.215	12.0	0	1.6
1.127	19.0	810	12.0	1.221	18.0	40	4.3
1.127	22.0	627	10.5	1.222	22.0	62	5.7
1.130	22.0	514	9.5	1.227	22.0	104	6.3
1.129	26.0	614	10.0	1.225	23.0	71	5.7
1.139	24.0	504	9.5	1.226	22.0	89	6.0
1.142	24.0	508	9.5	1.226	22.0	79	5.6
1. 145[1]	23.0[1]	412	8.5	1.225[1]	22.0[1]	95	6.1
1.155	8.0	471	9.0	1.230	12.0	56	5.4
1.140	3.0	556	10.0	1.232	4.5	40	4.8
1.140	1.0	507	9.5	1.222	2.5	28	4.0
1.136	4.0	292	6.7	1.215	4.0	46	8.6
1.136	6.0	498	10.5	1.221	6.5	27	5.0
1.134	13.5	594	10.0	1.221	12.5	29	4.7
1.130	18.0	643	10.5	1.226	17.0	26	3.7
1.133	24.0	452	8.5	1.225	22.0	29	5.4
1.137	25.5	476	9.0	1.228	25.0	24	4.6
1.145	16.5	439	8.7	1.232	17.0	20	2.9
1.146	9.5	429	8.7	1.229	11.0	24	3.0
1.144	6.5	522	10.0	1.232	9.0	24	2.0
1.133	5.0	640	11.2	—	6.0	18	1.4
1.133[1]	—	1[1]	—		—	289	13.0
1.145	5.0	619	—	—	—	—	—
1.137	-1.0	591	10.5	1.204	.0	25	2.4
1.128	2.0	682	13.0	—	2.5	20	1.1
1.132	4.0	730	14.2	—	—	9	.5
1.124	10.0	618	10.4	1.195	10.5	38	4.2
1.116	14.0	825	12.5	1.178	14.5	45	2.2
1. 108[1]	14.0[1]	835	11.0	1.179	16.0	41	4.1
1.101	18.0	711	9.8	1.193	18.0	45	6.0
1.106	18.5	767	10.5	1.185	19.0	44	5.3
1.108	23.5	734	10.5	1.198	23.0	45	3.5
1.110	26.0	549	9.0	1.214	26.5	38	4.5
1.112	22.5	478	8.5	—	—	—	4.5
1.114	20.0	498	8.0	1.218	21.0	42	6.5
1.116	7.5	703	10.5	1.195	7.0	59	4.5
1.114	7.0	653	10.0	1.210	7.0	49	5.0
1.108	.0	696	10.0	1.190	1.0	51	5.0
1.100	-1.0	545	9.0	1.186	.0	45	5.5
1.100	.5	572	9.5	1.212	1.5	41	6.0
1.091	10.0	784	10.5	1.192	7.0	61	6.0
1.088	9.0	942	11.2	1.214	8.5	88	5.2
1.094	16.5	986	11.3	1.200[1]	16.5	73	4.6
1.090	23.0	764	10.0	1.200[1]	22.5	63	5.9
1.094	24.0	594	9.5	1.201	24.5	62	6.0
1.097[1]	25.5[1]	473	7.6	1.202[1]	—	84	7.5
1.104	20.0	532	8.2	1.208	21.0	69	6.5

[1]Estimated.

Table 8. Chemical analyses of water from culverts, test wells, and miscellaneous sites in the vicinity of the Southern Pacific Transportation Co. causeway.

Location	Date	Depth below water surface (ft)	Temperature (°C)	Grams per liter							Density (g/ml at 20°C)	Field specific gravity
				Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue at 180°C)		
East culvert	8-17-70	4.5	25.5	7.5	62	4.8	0.034	16	110	211	1.133	1.137
	9-17-70	13.0	25.0	15	100	9.2	.064	30	180	352	1.219	1.228
	9-16-70	4.0	16.5	8	64	5.1	.032	17	120	218	1.139	1.145
	9-16-70	11.0	17.0	16	97	9.6	.067	31	180	356	1.220	1.232
	10-27-70	4.0	9.5	8	78	5.0	.033	17	110	216	1.137	1.146
	10-27-70	10.8	11.0	16	98	9.6	.065	31	180	348	1.218	1.229
	11-16-70	5.0	6.5	7.5	60	4.9	.032	16	110	208	1.131	1.142
	11-16-70	11.0	9.0	15	98	9.9	.063	31	180	351	1.216	1.232
	12-2-70	5.5	5.0	7.3	56	4.2	.030	15	99	190	1.121	1.133
	12-2-70	11.8	—	12	86	8.6	.053	26	160	307	1.193	—
	12-15-70	6.5	5.0	7.7	62	4.5	.031	16	110	210	1.134	1.145
	1-15-71	5.0	-1.0	7.5	55	4.2	.030	13	100	191	1.122	1.135
	1-15-71	12.0	0.0	12	81	7.5	.055	18	160	297	1.187	1.204
	2-23-71	6.5	2.0	6.2	55	3.8	.029	12	90	177	1.112	1.125
	3-10-71	7.0	4.0	6.5	58	4.2	.030	12	65	186	1.119	1.129
	4-15-71	5.0	10.0	6.3	55	4.2	.029	12	92	181	1.118	1.124
	4-15-71	13.5	10.5	11	88	7.7	.051	20	150	292	1.179	1.195
	5-18-71	6.0	13.0	5.8	53	3.5	.027	12	92	171	1.109	1.117
	5-18-71	14.0	14.5	11	83	6.9	.047	20	140	277	1.172	1.178
	5-26-71	5.5	17.0	5.1	48	3.4	.025	11	80	180	1.101	1.105
	5-26-71	14.0	16.0	10	85	6.9	.047	20	140	282	1.176	1.177
	6-8-71	5.0	18.0	5.1	47	3.2	.025	11	78	153	1.096	1.102
	6-8-71	15.0	18.0	11	91	7.4	.052	22	160	306	1.190	1.193
	6-14-71	5.0	18.5	5.5	51	3.5	.026	11	85	157	1.105	1.106
	6-14-71	14.9	19.0	10	88	7.4	.049	20	150	134	1.186	1.185
	6-24-71	3.0	—	5.3	48	3.7	.026	11	82	158	1.099	—
	6-24-71	Bottom	—	13	09	8.1	.058	26	180	334	1.207	—
	7-15-71	5.0	23.5	5.8	51	3.6	.026	11	88	168	1.104	1.108
	7-15-71	13.5	23.0	11	91	7.3	.051	22	160	309	1.193	1.198
	8-16-71	4.5	26.0	5.7	52	3.7	.027	11	90	—	1.110	1.110
	8-16-71	13.0	26.5	13	100	8.2	.056	24	180	340	1.212	1.214
	9-15,11	4.0	20.0	5.9	52	3.6	.027	14	94	172	1.109	1.114
	9-15-71	15.0	21.0	13	100	8.1	.063	28	190	347	1.217	1.218
	11-2-71	5.0	7.5	5.7	52	3.6	.027	14	94	172	1.110	1.116
	11-2-71	13.0	7.0	11	94	6.4	.048	22	150	275	1.175	1.184
	11-15-71	4.0	7.0	5.8	58	4.0	.027	14	96	170	1.107	1.114
	11-15-71	15.0	7.0	13	100	8.9	.058	23	180	328	1.204	1.210

Table 8. (continued)

Location	Date	Depth below water surface (ft)	Temperature (°C)	Grams per liter: Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue at 180°C)	Density (g/ml at 20°C)	Field specific gravity
	12-15-71	5.0	0.0	5.7	55	3.4	0.025	13	89	160	1.103	1.108
	12-15-71	14.5	1.0	11	89	7.6	.049	20	150	277	1.176	1.190
	1-17-72	4.5	-1.0	4.8	50	2.9	.022	12	80	144	1.092	1.100
	1-17-72	14.0	0.0	11	83	7.3	.051	18	150	271	1.169	1.186
	2-15-72	5.0	.5	5.0	45	3.2	.020	11	79	146	1.093	1.100
	2-15-72	14.5	1.5	12	95	8.0	.051	17	180	319	1.205	1.212
	3-16-72	5.0	10.0	4.6	40	2.9	.018	9.2	72	133	1.085	1.091
	3-16-72	16.5	7.0	11	84	7.1	.041	18	160	286	1.180	1.192
	4-21-72	5.5	9.0	4.2	37	2.8	.023	10	67	127	1.079	1.088
	4-21-72	16.5	8.5	11	97	8.2	.056	24	180	336	1.205	1.214
	5-15-72	5.5	16.5	4.0	40	2.9	.020	9.5	72	126	1.078	1.084
	5-15-72	15.0	16.5	7.9	70	5.5	.042	18	130	241	1.152	1.160
	6-15-72	5.0	23.0	4.9	42	3.1	.024	10	76	140	1.090	1.090
	6-15-72	15.3	22.5	9.7	81	8.3	.048	20	150	273	1.171	1.170
West culvert	8-17-70	5.4	26.0	7.5	62	4.9	.034	16	110	208	1.132	1.135
	4-15-71	7.0	10.0	6.2	53	3.5	.029	12	95	—	1.115	1.123
	5-18-71	7.5	13.0	6.1	54	3.6	.028	12	90	172	1.109	1.118
	9-7-71	4.0	20.0	6.1	53	3.9	.029	15	96	176	1.111	1.115
	9-7-71	12.5	—	13	100	8.1	.058	28	190	348	1.216	—
	2-15-72	5.0	0.0	5.5	47	3.5	.022	11	85	157	1.100	1.106
	2-15-72	15.0	1.0	11	83	6.9	.043	16	160	283	1.178	1.188
	3-16-72	7.0	9.5	4.8	43	3.1	.019	10	76	142	1.090	1.092
	3-16-72	15.0	6.0	5.2	46	3.4	.021	11	83	153	1.098	1.107
Well 1	6-24-71	5.0	25.0	5.2	49	3.4	.026	12	84	161	1.101	1.104
	6-24-71	20.0	23.0	13	100	8.4	.059	26	180	341	1.210	1.208
	11-19-71	4.2	6.0	5.6	52	3.6	.026	13	92	169	1.107	1.117
	11-19-71	19.2	6.0	13	99	7.8	.060	27	180	335	1.208	1.220
	2-28-12	Upper zone	—	3.7	32	2.4	.020	7.9	60	108	1.069	—
	2-28-72	30.0	—	12	93	8.2	.063	20	180	316	1.198	1.208
	6-2-72	6.3	—	4.6	40	3.1	.024	11	74	137	1.086	—
	6-2-72	21.3	—	12	99	8.1	.058	26	180	334	1.208	
	6-12-72	31.2	—	12	100	8.3	.055	24	190	337	1.208	—
Well 7	6-23-71	3.0	23.0	6.1	54	3.6	.028	13	90	177	1.112	1.118
	6-23-71	30.0	20.0	13	110	8.6	.059	31	180	349	1.217	1.210
	6-13-72	28.9	—	12	100	8.2	.057	24	180	334	1.210	—
Well 8	9-28-71	2.1	16.5	5.9	53	3.7	.030	14	96	175	1.112	1.110
	9-28-71	37.1	15.0	13	110	7.7	.055	54	180	368	1.233	1.230
Well 9	8-27-71	3.6	26.5	5.9	53	3.8	.028	12	90	173	1.110	1.113
	8-27-71	25.6	26.5	13	100	8.6	.058	25	180	349	1.219	1.220

Table 8. (continued)

Location	Date	Depth below water surface (ft)	Tempera-ture (°C)	Grams per liter Magne-sium (Mg)	Sodium (Na)	Potas-sium (K)	Lithium (Li)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue at 180°C)	Density (g/ml at 20°C)	Field specific gravity
Well 10	10-5-71	1.5	15.0	5.4	48	3.4	0.027	13	87	160	1.102	1.113
	10-5-71	15.5	17.5	14	100	8.5	.064	29	190	347	1.219	1.215
	2-28-72	2.4	—	4.3	39	3.0	.024	10	71	134	1.083	—
	2-28-72	17.4	—	10	92	8.4	.055	20	180	324	1.202	—
	5-31-72	2.3	—	4.5	40	3.0	.024	11	73	136	1.085	—
	5-31-72	17.3	—	12	99	8.0	.059	24	180	325	1.208	—
1/4 mile north and west of east culvert	5-26-72	25.0	—	11	100	8.4	.055	24	180	336	1.208	—
At trestle south of west culvert	5-26-72	31.0	—	11	98	7.8	.057	28	180	332	1.205	1.214
200 ft south of fill at well 1	5-26-72	28.0	19.5	12	94	7.8	.058	25	180	324	1.201	1.210
35 ft south of fill, at well 1	6-12-72	27.0	—	11	90	6.9	.052	22	160	296	1.186	—
30 ft south of fill at well 3	6-16-72	21.0	—	11	95	7.3	.053	22	170	312	1.194	—
150 ft southeast of fill at well 3	6-16-72	28.0	—	11	90	7.3	.054	23	176	313	1.195	—
30 ft south of fill at well 4	6-16-72	21.0	—	12	99	8.6	.057	24	180	333	1.208	—
75 ft south of fill at well 4	6-16-72	23.0	—	4.9	43	3.1	.025	10	79	144	1.092	—
20 ft south of fill at well 5	6-16-72	16.0	—	4.9	44	3.2	.024	11	81	140	1.089	—
30 ft south of fill at well 5	6-16-72	17.0	—	12	100	8.1	.058	24	180	304	1.211	—
60 ft south of fill at well 7	6-13-72	29.0	—	12	100	7.9	.058	26	180	342	1.211	—
At trestle south of well 1	5-26-72	.0	18.5									1.098
		20.0	17.5									1.098
		25.0	16.5									1.148

Table 8. (continued)

Location	Date	Depth below water surface (ft)	Tempera-ture (°C)	Grams per liter							Density (g/ml at 20°C)	Field specific gravity
				Magne-sium (Mg)	Sodium (Na)	Potas-sium (K)	Lithium (Li)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue at 180°C)		
		30.0	15.5									1.210
Edge of fill south of well 1	5-26-72	20.0	19.0									1.092
		23.0	19.0									1.094
		28.0	19.5									1.210
1,000 ft South of well 4	6-16-72	21.0	—									1.088
		23.0	—									1.090
		25.0	23.0									1.140
		29.0	—									1.204
1/4 mile north and west of east culvert	5-26-72	.0	19.5									1.160
		1.0	19.5									1.170
		5.0	19.5									1.210
		25.0	17.5									1.214
1,000 ft north of east culvert	5-26-72	.0	19.0									1.180
		25.0	18.0									1.212
50 ft south of of east culvert[1]	5-26-72	.0	20.0									1.090
		15.0	18.0									1.094
		20.0	18.0									1.092
		25.0	16.5									1.132
		28.5	17.0									1.208
At trestle south of west culvert	5-26-72	.0	17.5									1.096
		20.0	17.5									1.110
		25.0	17.5.									1.148
		27.0	17.5									1.196
		29.0	15.5									1.212
		31.0	15.5									1.214
100 ft south of west culvert	5-26-72	.0	18.0									1.092
		15.0	18.0									1.094
		20.0	17.5									1.100
		25.0	17.5									1.120
		27.0	18.5									1.180

[1] No dense brine in south end of east culvert.

Table 9. Mean daily difference of stage, in feet, across Southern Pacific Transportation Co. causeway, 1969-1972 water years (figures for 1969-1970 represent difference between continuous recorders at Promontory Point and Saline; figures for 1971-1972 represent difference between continuous recorders at the cast culvert).

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1969												
1	—	0.60	0.62	0.69	0.75[1]	0.77[1]	1.05[1]	1.05[1]	1.03	0.96	0.88	0.82
2	0.49	.62	.61[1]	.69	.79[1]	.79	1.21[1]	.89[1]	1.08	.98	1.01[1]	.86
3	.49	.62[1]	.70	.70	.85	.79[1]	.96[1]	1.17[1]	1.06	.90	1.00[1]	.85[1]
4	.57	.52[1]	.68	.72	.81	.54[1]	1.17	1.09[1]	1.03	.93	.93[1]	.77[1]
5	.53	.58	.67	.70	.82	.85[1]	1.23	1.04[1]	1.03[1]	.95	.73[1]	.80
6	.48	.53	.67	.67	.82[1]	.75[1]	1.22[1]	1.17[1]	1.01[1]	.83[1]	.81	.79
7	.36[1]	.60	.71	.57[1]	.79[1]	.69[1]	.83[1]	1.15[1]	1.05[1]	.98[1]	.88	.78
8	.38[1]	.60[1]	.68	.46[1]	.80	.86	1.12	1.16[1]	1.09[1]	.95[1]	.84	.79[1]
9	.55	.27[1]	.70	.67	.81	.89[1]	1.14	1.19	1.04[1]	.99[1]	.88	.79
10	.57	.57[1]	.76[1]	.65	.80	.91[1]	1.07[1]	1.18	.80[1]	.99	.91[1]	.73[1]
11	.69[1]	.63	.51[1]	.66	.79	.84	1.01[1]	1.15	.92	1.01	.86[1]	.74[1]
12	.75[1]	.53[1]	.61	.65	.81[1]	.86	1.14	1.17	.96[1]	1.00	.80[1]	.73
13	.60[1]	.50	.73	.74	.69[1]	.81	1.03[1]	1.07[1]	.86[1]	1.05[1]	.83	.75
14	.53[1]	.57	.69[1]	.75	.76	.84	.97[1]	1.02[1]	.86[1]	1.05[1]	.86	.65[1]
15	.37[1]	.60[1]	.75[1]	.75	.76	.86	.61[1]	1.06[1]	.85[1]	.97[1]	.93[1]	.70[1]
16	.25[1]	.50[1]	.68[1]	.70	.78	.88	1.13[1]	1.19	.98[1]	.98[1]	.97[1]	.78[1]
17	.47	.60	.60[1]	.72	.82	.87	1.22	1.26	.92	.98[1]	.86[1]	.74
18	.45[1]	.64	.87[1]	.77	.83	.58[1]	1.03[1]	1.19[1]	.91[1]	.99	.88[1]	.84
19	.46	.60	.88[1]	1.18[1]	.83	.87[1]	1.22[1]	1.06[1]	.90[1]	.98	.93[1]	.77[1]
20	.42[1]	.66	.53	1.14[1]	.78	.96	1.18[1]	.99[1]	.81[1]	.98[1]	.93[1]	.63[1]
21	.45[1]	.66	.57	1.31[1]	.83	.96	1.18	1.10[1]	.89[1]	.98[1]	.87	.66[1]
22	.54	.70	.75	.88[1]	.83	1.00[1]	1.20[1]	1.14	.81[1]	.97	.91[1]	.71[1]
23	.53	.69	.70[1]	.78[1]	1.05[1]	.47[1]	1.37[1]	1.20[1]	.88	.93	.88	.761[1]
24	.55	.54[1]	.70[1]	.90	1.21[1]	.79[1]	.73[1]	1.20	.53[1]	.95	.88	.70[1]
25	.57	.55[1]	.70[1]	.83	.94[1]	1.08	.98[1]	1.20	.82[1]	.92[1]	.83[1]	.73[1]
26	.54	.61	.67[1]	.98[1]	.81	1.08	.86[1]	1.19[1]	.78[1]	.86	.84[1]	.73[1]
27	.58	.69	.69	.88[1]	.83	1.10[1]	1.15[1]	.92[1]	.83[1]	.90[1]	.78[1]	.73
28	.60	.66	.82[1]	.91[1]	.83	1.00	1.18	.93[1]	.82[1]	.87[1]	.97[1]	.73[1]
29	.59	.72	.57	.57[1]	—	1.06	.97[1]	1.09[1]	.87[1]	.98[1]	.67[1]	.71[1]
30	.48[1]	.70[1]	.72	.84[1]	—	1.11	1.18[1]	.95[1]	.89	.92	.79[1]	.65[1]
31	.58	—	.72	.78[1]	—	1.06	—	.81[1]	—	.92	.82	.75
Mean	.51	.60	.69	.78	.83	.87	1.08	1.10	.91	.96	.87	.75
1970												
1	0.74	0.87	1.01	0.78[1]	0.88[1]	1.27[1]	0.93[1]	0.92	1.00	0.95	0.75	0.69[2]
2	.33[1]	.95	1.01	.95	1.06[1]	.92[1]	.70[1]	1.00	1.00	.96	.68[1]	.71[2]
3	.48[1]	.96	1.00	.96[1]	1.10[1]	.93[1]	.78[1]	.98	1.01	.94	.68[1]	.72[2]
4	.50[1]	.98	.98[1]	.86[1]	1.06[1, 2]	.96[1]	.95	.97	1.06[1]	.95	.72[1]	.73[1, 2]
5	.76	1.05[1]	.85[1]	.89[1]	1.05[2]	.91[1]	.93	.99[1]	1.05[1]	.95[1]	.73[1]	.72[2]
6	.76	1.17[1]	.99	.91	1.06[2]	.96	.92	.98	.99[1]	.91[1]	.77[1]	.71[2]

[1] Storm day maximum variation in stage more than 0.1 foot.
[2] Estimated.

Table 9. (continued)

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
7	0.78	1.08[1]	0.97	0.89	1.06[2]	0.96	0.80[1]	0.74[1]	1.04[1]	0.90[1]	0.79	0.71[1, 2]
8	.72[1]	.96[1]	1.05[1]	.88	1.06[2]	.88[1]	.90[1]	.85[1]	1.07[1]	.88[1]	.72[1]	.64[1, 2]
9	.63[1]	.97	.96[1]	.87[1]	1.05[2]	.94[1]	.90	.83[1]	.95[1]	.92[1]	.70[1]	.62[1, 2]
10	.46[1]	.98	.99[1]	.88[1]	1.05[2]	.85[1]	.90	.75[1]	.77[1]	.87[1]	.70	.68[2]
11	.51[1]	.97	.99[1]	.86	1.04[2]	.90[1]	.70[1]	.82[1]	.82[1]	.86[1]	.70	.64[2]
12	.86[1]	.99	.98[1]	.86	1.04[2]	.86[1]	.88	.80[1]	.99[1]	.88	.72	.64[2]
13	.77[1]	.98	.98[1]	.87	1.02[1, 2]	.99[1]	.90[1]	.70[1]	1.10[1]	.80[1]	.73	.65[2]
14	.75[1]	1.00	.97[1]	.87	1.04[2]	.96[1]	.73[1]	.82[1]	.96[1]	.75[1]	.70	.68[2]
15	.75	1.01	.96[1]	.90	1.04[2]	.81[1]	.75[1]	.90	.95[1]	.84	.71	.70[2]
16	.84	.90[1]	.94	.95[1]	1.04[2]	.87[1]	.80[1]	.97	.97[1]	.85[1]	.74	.76
17	.83	.68[1]	.92	.95[1]	.97[1]	.38[1]	.69[1]	1.00	.95[1]	.92[1]	.75[1]	.75
18	.75	1.02	.93	.94[1]	.96[1]	.70[1]	.66[1]	1.01	.92[1]	.85[1]	.73[1]	.77
19	.83	1.05	.92[1]	.93[1]	1.00	.89	.55[1]	.98[1]	.98	.81[1]	.69[1]	.63[1]
20	.84	1.05	.94[1]	.95[1]	1.04	.99	.60[1]	1.01[1]	1.00	.82[1]	.63[1]	.60[1]
21	.84	1.01	.93[1]	.96	1.04	.96[1]	.83[1]	.87[1]	1.00	.98[1]	.65[1, 2]	.55[1]
22	.83	.99	.78[1]	.99	1.04	.99[1]	.85[1]	.95[1]	1.01	.85[1]	.64[2]	.68[1]
23	.87	1.06	.85[1]	.98	1.04	1.00[1]	.85[1]	.86[1]	1.07[1]	.80	.64[2]	.66[1]
24	.90	1.08	.86[1]	.88[1]	1.03	.63[1]	.83[1]	.97[1]	1.05[1]	.82	.65[2]	.52[1]
25	.88	1.07	.87[1]	1.01[1]	1.04	.84[1]	.85[1]	.97	1.07	.82[1]	.65[2]	.64[1]
26	.89	1.05	.78[1]	1.00[1]	1.04	.73[1]	.58[1]	.98	1.06	.86[1]	.66[2]	.70
27	.92	1.07	.72[1]	.83[1]	1.06	.70[1]	.70[1]	.89[1]	.95[1]	.78[1]	.66[2]	.70
28	.73[1]	1.06	.76[1]	.68[1]	1.24[1]	.88[1]	.77[1]	1.00[1]	1.00[1]	.75[1]	.66[2]	.71
29	.85[1]	1.05	.91[1]	1.00[1]	—	.85[1]	.87[1]	.93[1]	.83[1]	.78[1]	.67[2]	.71
30	.96	1.03	.99	1.01	—	.90[1]	.88[1]	.80[1]	.96[1]	.79[1]	.68[2]	.72
31	.96	—	.91[1]	1.06	—	.75[1]	—	.89	—	.72	.69[2]	—
Mean	.76	1.00	.93	.91	1.04[2]	.87	.80	.91	.99	.86	.70[2]	.68[2]
1971												
1	0.73[3]	0.85	0.95[1]	0.93[3]	1.27[3]	0.87[1]	1.21[1]	—	1.22[1]	—	1.15	0.87[1, 3]
2	.73[3]	.86	.83[1]	.32[1, 3]	1.15[1, 3]	1.31[1]	1.30	—	1.24	1.24[1, 3]	1.17	.60[1, 3]
3	.73[3]	.90[1]	.89[1]	.65[1, 3]	.97[1, 3]	1.30[3]	1. 17[1]	—	1.24[1]	1.23[1, 3]	1.07[1]	.85[1, 3]
4	.72[3]	.97[1]	.95[1]	.98[1, 3]	1.34[1, 3]	1.19[1, 3]	1.23	—	1.25[1]	1.30[1, 3]	1.20[1]	.92[3]
5	.73[1, 3]	.85	.99	1.15[1, 3]	1.21[1, 3]	1.10[1, 3]	1.25	—	1.24[1]	1.26[3]	1.15[1]	.98[3]
6	.57[1, 3]	.81	.95	.99[1, 3]	1.33[3]	1.23[3]	1.28	—	1.30[1]	1.16[1, 3]	1.04[1]	.83[1, 3]
7	.53[1, 3]	.76[1]	.96	.98[3]	1.35[1, 3]	1.28[3]	1.23[1]	—	1.31	1.20[1, 3]	1.12[1]	.82[1, 3]
8	.73[3]	.80	.97[1]	.87[3]	1.31[3]	1.29[1, 3]	1.22	—	1.29[1]	1.24[1, 3]	1.09[1]	.94[3]
9	.79[1, 3]	.87	.95[1]	.93[3]	1.32[3]	1.30[3]	1.25[1]	—	1.261	1.29[1, 3]	1.09[1]	.99[3]
10	.49[1, 3]	.81[1]	1.04[1]	.90[1, 3]	1.31[1, 3]	1.29[3]	1.19	—	1.18[1]	1.20[1, 3]	1.06	.97
11	.84[3]	.94[1]	1.06	1.05[3]	1.30[3]	1.40	1.20[1]	—	1.20[1]	1.21[1, 3]	1.10	1.08
12	.70[1, 3]	.85[1]	1.05	.95[1, 3]	1.31[3]	1.37[1]	1.15[1]	—	1.33	1.20[1, 3]	1.11	1.06
13	.69[3]	.90[1]	1.08	1.10[1, 3]	1.32[3]	1.27[1]	1.19	—	1.32	1.26[3]	1.14	1.08
14	.66[1, 3]	.80[2]	1.04[1]	1.15[1, 3]	1.33[3]	1.23[1]	1.19	—	1.23	1.28	1.09	1.05[1]
15	.77[3]	.92[2]	1.08[1]	1.08[1]	1. 34[1, 3]	1.21[1]	1.15[1]	—	1.26	1.30	.93[1]	1.03
16	.78[3]	.97[2]	1.11[1]	1.09	1.29[3]	1.28	1.22[1]	—	1.29	1.33	1.06[1]	1.07[1]
17	.79[3]	.98	1.11	1.06	1.31[3]	1.10[1]	1.18[1]	—	1.27	1.31[1]	1.05[1]	1.01[1, 3]
18	.79[3]	.94[1]	1.08	1.10	1.30[1, 3]	1.27[1]	1.20[1]	1.37[3]	1.26	1.28	1.05	1.01[1, 3]
19	.80[1, 3]	.93[1]	1.14	1.06	1.10[1, 3]	1.31	1.20[1]	1.38	1.30	1.28	.95[1, 3]	1.06[3]

[1] Storm day, maximum variation in stage more than 0.1 foot.
[2] Estimated.
[3] One or both of gages at east culvert not functioning; stage difference computed from continuous recorders at Promontory Point and Saline.

Table 9. (continued)

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
20	0.86[1,3]	0.99	1.12	1.06	0.86[1,3]	1.29	1.22	1.22	1.30	1.26	0.97[1,3]	0.91[1,3]
21	.83[1,3]	.90[1]	1.13	1.08[1]	1.31[3]	1.27	1.15[1]	1.20[1]	1.33	1.26[1]	.98[1,3]	.89[1,3]
22	.82[1,3]	.96	1.01[1]	1.13[1]	1.39[3]	1.24[1]	1.2[2,3]	1.22[1]	1.33	1.23[1]	.96[1,3]	.96[3]
23	.81[1,3]	1.00	1.12	1.15	1.35	1.24[1]	1.2[1,2,3]	1.24[1]	1.32	1.24	.69[1,3]	1.00[3]
24	.79	.98	1.07	1.12	1.40[1]	1.20[1]	1.1[1,2,3]	1.36	1.28	1.32	.90[3]	1.03[3]
25	.80	.86[1]	1.10	1.15	1.21[1]	1.28	1.2[1,2,3]	1.38	1.27	1.24	.90[3]	.93[1,3]
26	.77[1]	.96[1]	1.10	1.14	1.23[1]	1.24[1]	1.2[1,2,3]	1.40	1.14[1]	1.21	.90[3]	.88[1,3]
27	.82[1]	1.06[1]	1.02	1.14	1.25[1]	1.11[1]	1.3[2,3]	1.33	—	1.20	.90[3]	.86[1,3]
28	.84	.99[1]	1.06	1.16	1.32[1]	1.24	1.3[2,3]	1.18[1]	—	1.23	.91[3]	.98[3]
29	.95	1.09[1]	1.00[1]	1.16	—	1.27	—	1.25[1]	—	1.17	.90[1,3]	.78[1,3]
30	.84	.88[1]	1.03[1]	1.16	—	1.19[1]	—	1.22[1]	—	1.18	1.04[1,3]	.85[1,3]
31	.85	—	1.03	1.21	—	1.14[1]	—	1.26[1]	—	1.17	1.10[1,3]	—
Mean	.75	.91	1.03	1.03	1.26	1.27	1.21[2]	1.29[2]	1.25[2]	1.24	1.02	.94
1972												
1	0.83[1,3]	1.4[1,2,3]	1.41	1.23	1.03[1,3]	—	1.32	1.61	1.50[1]	1.38	1.22[1]	1.03[3]
2	.96[3]	1.4[1,2,3]	1.43	1.04[1]	1.18[1,3]	1.44[3]	1.22[1]	1.63	1.59[1]	1.36	1.15[1]	1.03[1,3]
3	1.03[3]	1.37	1.39	1.05[1]	1.23[3]	1.37[1,3]	1.27	1.60	1.57[1]	1.35	1.02[1]	1.04[3]
4	1.01[3]	1.34	1.45	1.22	1.19[3]	1.34[3]	1.34	1.58	1.56[1]	1.40	1.16	1.13[1,3]
5	1.01[3]	1.43[1]	1.49[1]	1.22	1.16[3]	1.33[3]	1.31[1]	1.53	1.56	1.37	1.19	.98[1,3]
6	1.02[3]	1.39	1.39[1]	1.19[3]	1.16[3]	1.29[1,3]	1.46[1]	1.54[1]	1.62[1]	1.40	1.19	.99[1,3]
7	1.01[3]	1.33	1.74[1]	1.18[3]	1.15[3]	1.35[3]	1.32[1]	1.62[1]	1.60[1]	1.37	1.16	1.03[3]
8	1.02[3]	1.37	1.54[1]	1.17[3]	1.14[3]	1.35[3]	1.33	1.59[1]	1.55[1]	1.37	1.16	1.08[3]
9	1.06[3]	1.37	1.41[1]	1.14[1,3]	1.04[1,3]	1.25	1.36[1]	1.58[1]	1.57[1]	1.34[1]	1.17	1.09[1,3]
10	1.07[3]	1.38	1.43[1]	1.02[1,3]	1.13[3]	1.19	1.30	1.52	1.62[1]	1.38	1.17	1.07[1,3]
11	1.06[3]	1.38	1.35	1.14[1,3]	1.16[3]	1.21	1.30[1]	1.56	1.41[1]	1.32	1.19	.95[1,3]
12	1.00[1,3]	1.37[1]	1.34[1]	.86[1,3]	1.14[3]	1.23	1.32[1]	1.54	1.49	1.36	.73[1]	.90[1,3]
13	1.09[3]	1.43[1]	1.32[1]	.97[1,3]	1.04[1,3]	1.23[1]	1.78[1]	1.53	1.50[1]	1.33	1.08[1]	. 95[1,3]
14	.93[1,3]	1.30[1]	1.31[1]	1.13[3]	1.14[1,3]	1.17[1]	1.60[1]	1.62	1.51	1.33	.63[1]	1.03[3]
15	.95[1,3]	1.40[1]	1.31[1]	1.15[3]	—	1.26	1.42[1]	1.57	1.46[1]	1.31	1.09[1]	1.06[3]
16	1.25[1,3]	1.55[1]	1.31[1]	1.13[3]	—	1.28	—	1.56	1.57[1]	1.29	1.12[1]	1.07[3]
17	1.09[1,3]	1.49[1]	1.35	1.13[3]	1.17[3]	1.27	1.19[1]	1.54[1]	1.57[1]	1.29[1]	1.12	1.07[3]
18	1.01[1,3]	1.36	1.30	1.12[3]	1.18[3]	1.34[1]	1.77[1]	1.46[1]	1.46[1]	1.37[1]	1.13[1]	1.06[1,3]
19	1.15[3]	1.37	1.27	1.16[1,3]	1.18[3]	1.30[1]	1.75	1.50[1]	1.47[1]	1.24[1]	1.55[1]	.96[1,3]
20	1.13[3]	1.37	1.24	1.13[3]	1.19[3]	1.29	1.88	1.51[1]	1.50	1.12[1]	1.59[1]	1.02[1,3]
21	1.06[1,3]	1.39	1.20	1.08[1,3]	1.19[3]	1.29	1.51	1.45[1]	1.46	1.21[1]	1.12	1.10[3]
22	1.17[3]	1.39	1.31[1]	1.08[1,3]	1.18[1,3]	1.39[1]	1.52	1.40	1.48[1]	1.25	1.13	1.01[1,3]
23	1.23[3]	1.41	1.22[1]	.83[1,3]	1.23[3]	1.35[1]	1.56	1.47	1.45[1]	1.26	1.21[1]	.92[1,3]
24	1.14[1,3]	1.40	1.30[1]	1.06[1,3]	1.30[1,3]	1.35	1.64[1]	1.43	1.44[1]	1.31[1]	1.10	.91[1,3]
25	1.09[1,3]	1.38	1.27[1]	1.14[3]	—	1.40[1]	1.54[1]	1.39	1.40[1]	1.28[1]	1.08	1.02[1,3]
26	1.21[1,3]	1.42	1.13[1,3]	1.07[1,3]	1.35[3]	—	1.61[1]	1.41	1.43[1]	1.30[1]	1.09	1.05[3]
27	1.1[1,2,3]	1.35[1]	1.18[3]	1.12[1,3]	1.29[3]	—	1.59	1.42	1.43	1.23[1]	1.03[3]	1.02[1,3]
28	1.1[1,2,3]	1.38[1]	1.20[3]	.97[1,3]	1.28[3]	—	1.65	1.40	1.40	1.21	1.05[1,3]	1.06[1,3]
29	1.0[1,2,3]	1.41	1.19[3]	1.17[3]	1.33[1,3]	—	1.69[1]	1.41	1.41	1.20	1.07[1,3]	1.03[3]
30	1.3[2,3]	1.37	1.17[1,3]	1.21[3]	—	—	1.76[1]	1.44	1.37	1.17[1]	1.02[3]	1.01[3]
31	1.3[2,3]	—	1.21	1.21[3]	—	—	—	1.40	—	1.20[1]	1.04[1,3]	—
Mean	1.07[2]	1.39	1.33	1.11	1.19	1.28	1.48	1.51	1.50	1.30	1.15	1.02

[1] Storm day, maximum variation in stage more than 0.1 foot.
[2] Estimated.
[3] One or both of gages at east culvert not functioning; stage difference computed from continuous recorders at Promontory Point and Saline.

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THE UTAH GEOLOGICAL AND MINERAL SURVEY, a Division of the Utah Department of Natural Resources, operates with a professional staff under the guidance of a policy-making Board appointed by the Governor of Utah from various representatives of industry and the public as specified by law.

The Survey is instructed to investigate areas of geologic and topographic hazards, to survey the geology and mineral occurrences, and to collect and distribute reliable information concerning the mineral industry and mineral resources, topography and geology of the state so as to contribute to the effective and beneficial development of the state. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-1 through 12*, describes the Survey's functions.

Official maps, bulletins, and circulars about Utah's resources are published. (Write to the Utah Geological and Mineral Survey for the latest list of available publications.)

THE LIBRARY OF SAMPLES FOR GEOLOGIC RESEARCH is a library for stratigraphic sections, drill cores, well cuttings, and miscellaneous samples of geologic significance. Initiated by the Utah Geological and Mineral Survey in cooperation with the departments of geology of the universities in the state, the Utah Geological Society, and the Intermountain Association of Petroleum Geologists, the library was made possible in 1951 by a grant from the University of Utah Research Fund and is maintained by donations of collections from mineral resource companies operating in Utah. It collects, catalogs, and systematically files geologically significant specimens for library reference, comparison, and research, particularly cuttings from important wells and exploratory holes drilled in Utah, and from strategic wells in adjacent states. For catalogs, facilities, hours and service fees, contact the Utah Geological and Mineral Survey.

THE SURVEY'S BASIC PHILOSOPHY is that of the U. S. Geological Survey, i. e., our employees shall have no interest in lands within Utah where there is a conflict of interest deleterious to the goals and objectives of the Survey; nor shall they obtain financial gain by reason of information obtained through their work as an employee of the Survey. For permanent employees this restriction is lifted after a two-year absence; for consultants employed on special problems, there is a similar time period which can be modified only after publication of the data or after the data have been acted upon. For consultants, there are no restrictions beyond the field of the problem, except where they are working on a broad area of the state and, here, as for all employees, we rely on their inherent integrity.

Directors:
William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961