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The Great Salt Lake and Utah's Water Resources

Utah Water Research Laboratory

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AWRA

AMERICAN WATER RESOURCES ASSOCIATION

Utah Section

THE GREAT SALT LAKE AND UTAH'S WATER RESOURCES

Proceedings of

The First Annual Conference of the Utah Section

of the American Water Resources Association

Held at the Hotel Utah, Salt Lake City, Utah

November 30, 1972

Sponsored in cooperation with
Utah Water Research Laboratory at Utah State
University and
Utah Division of Water Resources

Utah Section

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ACKNOWLEDGMENTS

The success of the First Annual Conference of the Utah Section, American Water Resources Association (AWRA) was dependent upon the efforts of many people. We were grateful for the presence of Dr. Thad G. McLaughlin, Director of the Mountain District, and who also represented the National Office of AWRA. In his opening remarks to the more than one hundred people who attended the Conference, Dr. McLaughlin outlined briefly the goals and objectives of AWRA, and thus set the stage for the interdisciplinary nature of the Conference. Later in the Conference during a brief business session, he introduced and inducted the new officers of the Section for the coming year.

Sincere appreciation is expressed to the directors of the sponsoring agencies for the direct support which they provided -- Dr. Jay M. Bagley, Director of the Utah Water Research Laboratory, and Dr. Daniel F. Lawrence, Director of the Utah Division of Water Resources. Gratitude is also expressed to the Governor of the State, Governor Calvin L. Rampton, who took time from his busy schedule to present a very timely and relevant keynote address to the Conference on the subject of making policy decisions regarding the water resources of the Great Salt Lake.

Gratitude is expressed to those who acted as chairmen of sessions, and to those who presented papers on the program. As indicated by these proceedings, the papers were of a high quality and much thoughtful discussion was stimulated. Special thanks is accorded to those who served on various committees, particularly to Dr. A. Bruce Bishop, who served as Chairman of the Program Committee and who also assisted in many other ways, including taking much of the initiative in the publishing of these proceedings.

During the first year of operation the Utah Section, AWRA, adopted a set of bylaws, membership increased from about ten to nearly thirty members, and a successful annual conference was held. At elections conducted during the Annual Conference, new section officers were elected for the coming year, with Daniel F. Lawrence as President, George B. Coltharp as Vice-President, and Robert S. Johnston as Secretary-Treasurer. We wish these new officers every success in the coming year, and hope that the Conference of the Utah Section on November 30, 1972, will be the forerunner of many successful Annual Conferences in the future.

J. PAUL RILEY, President
Utah Section, American Water
Resources Association, 1971-1972

GEORGE B. COLTHARP
Secretary-Treasurer
Utah Section, American Water
Resources Association
1971-1972

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Secretary of the Utah Section: George B. Coltharp

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INTRODUCTION

J. Paul Riley[1]

It is appropriate to introduce these proceedings with a brief description of the history and objectives of the American Water Resources Association (AWRA). Quoting from a recent information brochure published by the AWRA, it is a non-profit, scientific organization that was incorporated in the State of Illinois in March, 1964, with headquarters in Urbana, Illinois. A major factor in the establishment of AWRA was the need for an organization to encourage and foster interdisciplinary communication between professionals of diverse backgrounds working on all aspects of water resources problems.

The principal objectives of AWRA are stated briefly as follows:

1. The advancement of water resources research, planning, development, management, and education.
2. The establishment of a common meeting ground for engineers, and physical, biological, and social scientists concerned with water resources.
3. The collection, organization, and dissemination of ideas and information in the field of water resources science and technology.

Approximately two years ago the directors of the AWRA, in an attempt to promote increased participation and multi-disciplinary involvement at the local level, divided the area of the United States into districts, each of which contains several states. Districts were further divided into state sections. The Utah Section lies within the Mountain District, which also contains the state sections of Montana, Wyoming, Colorado, and New Mexico.

At a business meeting of the Utah Section which was held on November 17, 1971, bylaws were adopted. A primary objective of the Utah Section as set out by the bylaws is to provide a common forum in which professionals in water resources and related areas can meet to discuss and exchange ideas pertaining to all aspects of water resources research and management, specifically as they related to problems in Utah. In selecting the Great Salt Lake and Utah's water resources as the theme of the First Annual Conference of the Utah

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[1] Professor, Utah Water Research Laboratory, Utah State University, Logan, Utah, and President, Utah Section, American Water Resources Association, 1971-72.

Section, the program committee very adequately fulfilled a requirement necessary to meeting the terms of the objectives set out above. In his keynote address, Governor Calvin L. Rampton pointed out that the Great Salt Lake has had a history of public interest from much concern to apathy, but that now the State is being faced with some crucial policy questions. Typical of these policy questions are: Should oil drilling in the lake be permitted? and Should the railway causeway be opened to allow equalization of salinity within the waters of the lake? It is hoped that this First Annual Conference of the Utah Section, AWRA, will be the first of many successful conferences of this Section which bring together people with widely varied backgrounds but all with a common concern for particular water resource problems within the State of Utah.

A PRELIMINARY LIMNOLOGICAL HISTORY OF GREAT SALT LAKE

Donald C. Grey[1] and Richmond Bennett[2]

Introduction

Great Salt Lake and its pluvial ancestors have responded in dramatic fashion to the climatic changes of the late Quaternary. Lake Bonneville's shorelines are prominent features of its basin and are world famous. They inspired the first monograph of the U. S. Geological Survey (Gilbert, 1890). While many observations and interpretations of the sediments (e. g., Eardley, 1967; Eardley, Gvosdetsky, and Marsell, 1957; Eardley and Gvosdetsky, 1960) have been made, the chronology (Broecker and Orr, 1958; Broecker and Kaufmann, 1965) and details of the variations are still poorly known.

Lake Bonneville has been a thousand feet deeper than the present Great Salt Lake. Elevated terraces point to numerous stillstands during rises or falls (Morrison, 1965) of the lake. These terraces are, in large part, topographically controlled, but the rises and falls of the lake are controlled by the water budget.

There is as yet no agreement as to the intensity or nature of the climatic changes which define and characterize the Pleistocene Epoch, nor as to the causes of the changes. It is not yet possible to predict future fluctuations of Great Salt Lake. However, the lake is no doubt very sensitive to changes in climate, and it would be of great interest to know the climatological history contained in its sediments, and to try to estimate the likelihood that it will rise again.

The highest levels of the lake appear to have been reached at intervals of thousands of years, although Broecker and Kaufmann (1965) hypothesize that the lake went from maximum to near dessication and back to maximum in a period less than 2500 years. Langbein (1961), in his study of closed lakes, points out the short response time of Great Salt Lake, which is entirelv in accord with such a concept, though one cannot say yet whether such a change

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[1] Laboratory of Isotope Geology of the University of Utah, Salt Lake City, Utah.

[2] Chemistry Department of Montana State University, Bozeman, Montana.

actually took place until better time scales are established. It does appear that lesser fluctuations of the lake take place in much shorter time periods.

The nature and time-scale of the climatic variations of glacial and post-glacial times in the Bonneville Basin are but poorly known, despite the great volume of literature on the subject. The reasons are two: First, there are very few solidly established dates related to observed features, and second, the evidence for climatic change has been mainly subjective.

Evidence of past lake conditions has been mainly from two sources - the shoreline geomorphological features and the lake sediments. Shoreline features are hard to date, and sediments, while easier to date, are harder to relate to lake depths and climatic conditions.

Cores taken from the deepest part of Great Salt Lake (Schreiber, 1958; Mehringer, Nash and Fuller, in press) show no evidence of complete dessication in post-glacial times. Thus there seems to be a complete record contained in the sediments, to the extent that this record can be read and interpreted. The data are in many forms, including the physical and chemical nature of the sediment material, the microfossils, the stable- and radioactive-isotope data and the paleomagnetic variations (Eardley et al., 1973). The paleomagnetic variations and the radiometric data provide a chronological framework, aided by layers of volcanic ash which are chemically identified and correlated with radiometrically dated deposits elsewhere (Mehringer et al., in press).

Many of the aforementioned types of data are quite familiar to hydrologists. Perhaps the applications of stable-isotope data to paleolimnological studies are not so familiar. Indeed, the detailed application of stable-isotope studies is new and developing rapidly, and much of the work reported in this paper is new research. It is, therefore, the main purpose of this paper to present mainly the stable-isotope research, with such data from other fields as necessary for amplification and explanation.

Stable Isotopes

Many elements have more than one isotope. The three elements of greatest significance in limnological studies are sulfur, carbon and oxygen. Sulfur has isotopes of masses 32, 33, 34, and 36 atomic-mass units, with 32 the most abundant and 34 the next most abundant. Carbon has isotopes of mass 12 (the most abundant) and mass 13 a.m.u. Oxygen has isotopes of masses 16, 17, and 18 a.m.u., with 16 the most abundant and 18 next. Because of the different masses of the isotopes, the reaction kinetics of the isotopes are different, with the result that the end products of a physical or chemical reaction may have slightly different ratios of isotopic abundances. This change of composition is called isotopic fractionation.

The isotopic composition of an element is usually expressed in terms of the ratio of the abundance of a lesser isotope to the abundance of the principal isotope. For sulfur, the isotopic character is expressed by the ratio S^{34}/S^{32}; for oxygen, O^{18}/O^{16}, and for carbon, C^{13}/C^{12}. However, it is easier to use such values if they are expressed by comparison with a standard than simply as absolute values. Conventionally, a difference (delta) notation is employed, which expresses the relative amount by which the isotopic composition of a sample varies from that of an accepted standard. Thus, one defines for carbon the δC^{13} value to be

$$\delta C^{13} = \frac{(C^{13}/C^{12})_x - (C^{13}/C^{12})_s}{(C^{13}/C^{12})_s} \times 10^3 .$$

The subscript "x" refers to the sample, while the subscript "s" refers to the standard. The factor of 10^3 converts the relative difference to a per mille (abbreviated permil or symbolized ‰) departure from the standard. Occasionally, δ values will be expressed as a percent departure, using, of course, a factor of 10^2.

For carbon, the most generally used standard, and the one used in this report, is a marine fossil known as the Peedee Belemnite, or PDB for short, which was introduced by the University of Chicago group many years ago. For sulfur, the international standard is a sample of troilite from the Canyon Diablo meteorite. For oxygen, two standards are in common use; one is the oxygen from the PDB carbonate, which is the one used in this report, and the other is the oxygen from Standard Mean Ocean Water (SMOW). SMOW measures about 29.6 permil with respect to PDB.

Kinetic theory suggests that the reaction rates of isotopes will vary inversely as the square root of their masses, so that one expects C^{12} to react about 4 percent faster than C^{13}. The differences for O^{16} and O^{18} are somewhat less, and for sulfur still less. However, the theoretical reaction rates are not always accurate guides to the actual rates in nature, because equilibrium may not always be obtained. Kinetic theory also predicts that the amount of fractionation in a reaction will decrease as the temperature of the reaction increases, and this is generally true. Biological fractionation, which takes place at relatively low temperatures, is usually strongly fractionating, although the total fractionation may vary considerably with nutrient availability and other factors.

Isotope Fractionation in Closed Lakes

The isotopic composition of elements in a closed lake, or even an open lake, will generally be different from that of the affluent elements, because of the fractionating processes in the lake. Evaporation of water will selectively remove the lighter isotopes of oxygen and hydrogen, leaving the lake water isotopically heavier than the affluent stream water. Evolution of CO_2, with the precipitation of carbonates, will tend to leave the lake water heavier in carbon isotopes than the stream water. The reduction of dissolved sulfates by anaerobic bacteria, such as Desulfovibrio desulfuricans, will tend to release isotopically light sulfides (Grey and Jensen, 1972), leaving the sulfates isotopically heavier. The processes of carbonate or sulfate precipitation are not strongly fractionating, but they contribute to increasing isotopic mass in solution.

Generally speaking, the processes of dessication lead to heavier isotopes in the lake, with light isotopes being introduced through the inflow. Thus a rising lake tends toward lighter isotopes, while a falling lake tends toward heavier isotopes. The amount of change depends upon the rate at which fractionation occurs, the rate of inflow, and the time which the element spends in the lake.

Characteristic Times

There are several characteristic time quantities which must be considered in connection with the amount of variability to be expected from the stable isotopes in a lake. Among these are the residence time of the element in the lake, the time required for isotopic equilibration, and the time required for a significant change in lake level. If the time required for isotopic equilibration is longer than the mean residence time in the lake, the element will not become equilibrated before removal, and hence will not reflect the lake conditions completely.

The mean residence time for oxygen (or hydrogen) in the present Great Salt Lake is easily determined. The present lake has an average depth of about 17 feet, and the annual evaporation appears to be about 40 inches. 17 divided by 3.33 gives about 5.1 years. From the amount of annual input of inorganic carbon and the amount of inorganic carbon in the lake, the residence time for carbon is about 9 years based on data published by the Utah Geological and Mineralogical Survey (1963, 1964, 1968). For sulfur, the residence time is more nearly a thousand years. It is to be expected that carbon and oxygen would show much greater variability in their isotopes than would sulfur. It is also to be expected that carbon and oxygen would be able to respond to much shorter changes in the water budget than would sulfur.

The isotopic equilibration time is harder to measure. It is defined as follows: Assume the lake has had a steady rate of inflow and evaporation, and hence a constant depth, for some time, and that the isotopic values have reached constant conditions. Then imagine that a sudden change of inflow occurs, resulting in a new rate of inflow and a new lake level which are then maintained constant until the isotopic values once again become constant. The time required for the isotopic values to accomplish all but 1/e times the total change is the equilibration time. This time would be different for each element. Since nature does not often provide such an experiment for our observation, the equilibration time must be estimated from mathematical models of the system and the observed behavior.

The effects of a climatic change, and a concomitant change in water budget, on the isotopic composition of the lake will depend on the time scale of the change. A given change spread over a 500-year time period will have different results from those produced by the same change in a 50-year period.

Clearly, the above-defined times are inter-related insofar as the expression in terms of stable isotopes is concerned. These relationships are best understood in terms of the systems-analysis model of the lake and its input system, which will be published in detail elsewhere. While informative, these details are not essential to the present discussion, which may be regarded simply as an empirical observation that the isotope values change with the water budget of the lake, and hence can be used as paleolimnological indicators.

It should be pointed out that the oxygen in the dissolved carbonates exchange freely and rapidly with that in the water, so that the oxygen isotopes in carbonate sediments have the same abundance as those in the water. On the other hand, the oxygen in sulfate does not exchange rapidly with that in the water, so that the oxygen isotopes in the sulfate sediments do not reflect those in the water.

Changes in Residence Time

When the volume of a lake changes, it is to be expected that the residence times of the various elements will also change. The residence time for oxygen is given by

$$T_o = V_L / I \quad , \tag{1}$$

where T_o is the residence time, in years, V_L is the volume of water in the lake, in cubic feet, and I is the annual inflow in cubic feet per year. As the inflow increases, so does the volume. The manner of the increase in volume is determined mainly by topography, but the two increases tend to offset each other to a degree, so the change in residence time for oxygen is not as great as for some of the other elements.

For carbon,

$$T_c = C_L V_L / C_I I \quad , \tag{2}$$

where C_L is the concentration of carbon in the lake water, and C_I is the concentration of carbon in the affluent water. C_I probably does not change greatly with increasing I, but C_L will probably increase somewhat with volume of the lake because of the generally increased solubility of inorganic carbon in water of lower salinity. Thus the residence time for carbon will tend to increase with increasing water budget.

For sulfur, the situation is rather different from those for carbon and oxygen. The present lake is nearly saturated with sulfate, which probably represents the result of concentrating a large volume of fresh water. Thus, if the lake were to fill again, the total amount of sulfate in the lake would probably not be drastically greater than it is at the present time. Assuming that the concentration of sulfate in the affluent streams did not change greatly with increased water budget, the residence time of sulfur can be expected to decrease somewhat as the lake becomes deeper. In no case is it likely that the residence time for any of the three elements under consideration would change by as much as an order of magnitude.

Because of the changing residence times, it seems likely that carbon isotopes will show slightly lower variability when the lake is high, oxygen will change but little, and sulfur will change almost not at all.

Isotopic Paleotemperatures

There have been numerous attempts (e.g., Emiliani, 1966) to use the fact that isotopic fractionation is a temperature-dependent process to calculate the temperature of ancient waters from the isotopic composition of oxygen in carbonate sediments. The amount of fractionation of oxygen in going from water to carbonate as a function of temperature can be measured in the laboratory, and results in the relation

$$T = a(\delta O^{18}_c - \delta O^{18}_w) + b(\delta O^{18}_c - \delta O^{18}_w)^2 \ .$$

The subscripts "c" and "w" refer to carbonate and water, respectively, and a and b are empirical coefficients. The difficulty lies in the fact that both the temperature and composition of the water are unknown. In the oceans, it is possible to assume that the isotopic composition of the water is nearly constant for small changes in volume, but this is clearly not so in lakes, nor is it true in the ocean for large variations such as occur between glacial and non-glacial times. The situation is further complicated by the fact that fractionation in biogenic carbonates is often subject to variations from causes other than temperature, such as those due to nutrient availability.

Theoretically, it would be possible to determine paleotemperatures if two oxygen-bearing sediment phases, both precipitated in equilibrium with the water, were measured and the water value eliminated between the equations. Unfortunately, such pairs are generally not available. The sulfates and carbonates in Great Salt Lake are very likely not both in equilibrium with the water at the same time because of the enormous difference in exchange times between the radicals and the water, and the very different residence times for the carbon and sulfur.

The Sources of the Data

In order to evaluate the potential of stable-isotope data for paleolimnology, a number of studies were done at the Laboratory of Isotope Geology. In addition to a number of studies in related areas, which provided a considerable volume of inferential data, samples of Great Salt Lake water and sediment cores were analyzed for isotopic content. A deep, land-based core obtained near Saltair was analyzed for carbon and oxygen isotopes in carbonates, and the results compared with the inferred lake conditions which Eardley and Gvosdetsky (1960) obtained from the lithologic and microfossil data. This study established that the carbon and oxygen isotopes did indeed vary appreciably and in an apparently systematic manner with lake conditions. A second series of measurements of sulfur isotopes in another deep core from the Burmester area showed that the gypsum layers in the evaporite sequences in this core did indeed reflect the expected heavy isotope values expected of a dessicated lake (Eardley, et al., 1973).

When the preliminary studies gave encouraging results, it was decided to make more detailed studies of two cores relating to late-glacial and post-glacial times which had been obtained by Dr. Mehringer (Washington State University) for palynological studies. These were a land-based core obtained from the marsh at Hogup Spring on the west side of Great Salt Lake, and a second core which came from the deepest part of Great Salt Lake, about five miles north of Bird Island.

The Hogup Spring core bottomed about four meters below the surface in oolitic sand. Above the sand were nearly two meters of clays and silts which appeared to have been deposited in deep water. These contained appreciable carbonate, except at the very top, where humic acids had removed the carbonate. Over the clays, there was a depositional hiatus followed by the deposition of organic materials from the vegetation mat that grew over the area after the retreat of the lake and the emergence of the spring marsh. The organic material was interrupted by three small bands of clay, which suggested short-term rises of the lake to above the level of Hogup Spring, which is about 50 feet above present lake level. Radiocarbon measurements suggest that the oolitic sand was deposited about 25,000 years ago, the lower organic material at around 4500 years ago, and the three small clay bands around 2700 years ago (Mehringer, personal communication).

The core from Great Salt Lake consisted of clays throughout, except for a 1-cm layer of volcanic ash near the bottom of the core at 1.69 meters, and a 3-cm layer salt crust at the top. This ash was analyzed by electron microprobe

(Mehringer, Nash and Fuller, in press) and appears to be Mazama ash, which is radiocarbon dated at about 7000 years old. The upper 16 cm of the core was disturbed due to the crushing of the salt crust which has recently started to form on the lake bottom, probably as a result of the construction of the railroad causeway. The crust fragments were pushed into the sediments by the core barrel and disturbed the upper material.

The Hogup Spring core was analyzed throughout the carbonate zone at intervals of 2 cm. The carbon and oxygen isotopes were measured, and the results are shown in Figure 1. The isotopes are relatively heavy near the bottom of the core, then assume lighter values, suggesting a rise in the lake level after about 25,000 years ago. After rising, the isotopes began to return toward heavier values. The pollen studied by Mehringer showed increased boreal forest elements when the isotopes were light. The obvious inference is that the Hogup Spring core contains a record of the beginning of the pluvial episode associated with the Late Wisconsin glaciation. A complete report on the site is in preparation.

The Great Salt Lake core was analyzed for oxygen, carbon, and sulfur isotopes. Total carbonates, and many types of pollen were also measured. The microbiological data will be published elsewhere, but are consistent with the isotope-data interpretations given here. It can be seen from Figure 2 that the three stable isotopes show excellent correlation in the direction of their variations. There is also good agreement with the total carbonate content. The carbon and oxygen, as expected, show more variability than the sulfur.

7000 Years of Water Budget

The concomitant variations of the isotopes and the carbonate content of the core materials gives considerable credence to the belief that these variables are reflecting the hydrologic water budget of the lake. The shifts toward lighter isotopes and lower carbonates signify freshening water conditions, while the opposite shifts signify dessication. Because of the good correlation between the various indicators, it is possible to combine them into a single variable. This was done by first normalizing the curves to have a common average value and common standard deviation, and then averaging the data together. The result was the qualitative "water budget" curve in Figure 2. The curve could be made quantitative if several points on the curve could be calibrated against

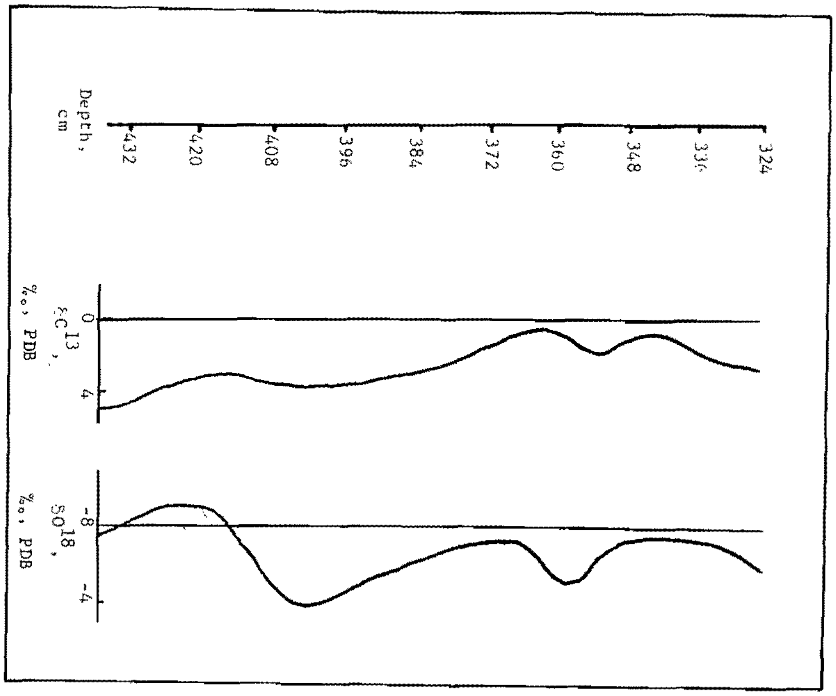

Figure 1. Carbon- and oxygen-isotope values in the Hogup Spring core.

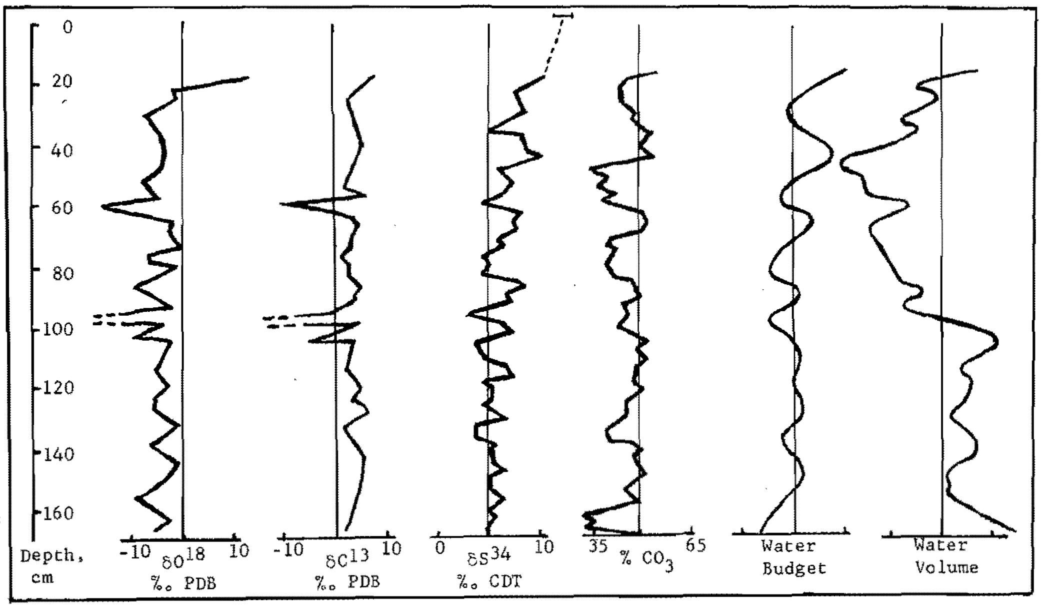

Figure 2. Isotope and lithologic data for Great Salt Lake Core, with qualitative water-budget and water-volume curves. The 169-cm level is Mazama ash, with an age of 7000 years. Top part of core damaged. Present sulfur-isotope values in lake water shown at top of δS^{34} curve.

known lake conditions.

The general trend of the curve is towards dessication during most of the 7000-year period, with appreciable variability. Between 150 cm and 104 cm depth in the core, the sediments show that the lake was relatively steady, followed by values indicating rises between 104 cm and 72 cm in the core, with generally dessicating, but rather variable, conditions toward the present time.

By integrating the water-budget curve, one obtains a qualitative record of the lake volume, approximately. The final curve in Figure 2 is the water-volume curve. The peak at about 44 cm depth in the core represents the highest rise of the lake in the 7000-year record. This probably corresponds to the clay bands in the Hogup Spring core. Mehringer (personal communication) has obtained several radiocarbon measurements on the Great Salt Lake core material, and finds that the foregoing interpretation is quite consistent with the radiocarbon data.

If the calculated peak at 44 cm depth in the core does indeed represent the flooding of the Hogup Spring level, then some bounds can be placed on the water depth because, while Hogup Spring appears to have been drowned, Danger Cave was not flooded at this time (Jennings, 1957). Since Danger Cave is about 125 feet above the present lake level, the rise indicated in the volume curve must have taken the lake to a depth between 50 and 125 feet above present lake level.

Hydrologic Equilibrium in Closed Lakes

Langbein (1961) has published a brief but very useful summary of the theoretical hydrology of closed lakes, which will not be repeated here, but it is worthwhile to make a few observations. First, it should be pointed out that the area of the lake, rather than its depth, is the important parameter in describing the water budget. The inflow to the lake is a result of direct precipitation into the lake, groundwater inflow (or outflow), and runoff in the drainage basin. The only outlet, except for some groundwater outflow at high levels, is evaporation, which is a function of area. The inflow is expressed by

$$I = R_b (A_b - A_L)f + G + A_L R_L \quad , \qquad (3)$$

where I is the inflow in cubic feet per year, R_b is the mean annual precipitation over the basin, other than the lake, f is the average fractional runoff in the basin, A_b is the area of the basin, A_L is the area of the lake, and R_L is the annual precipitation over the lake, measured in feet per year.

The evaporation from the lake is given by the relation

$$O = E_L A_L \quad , \qquad (4)$$

where O is the outflow (by evaporation), in cubic feet per year, and E_L is the mean annual evaporation over the lake (taking into account the Raoult Effect when brine concentration is high), measured in feet per year.

When the lake is at a stillstand, the inflow equals the evaporation, so I = O, and

$$A_L = \frac{G + R_b f A_b}{E_L + R_b f - R_L} \quad . \qquad (5)$$

It can be seen that, with f and A_b constant, and G probably no more than a few percent of the runoff term (see estimates of the present importance of this term elsewhere in this volume), the evaporation and rainfall are the controlling factors of the area, but not of the depth or volume, per se. For a simple expression, assume the average rainfall over the lake and over the basin to be the same, and let the groundwater inflow be about 8 percent of the surface inflow, let f be about 0.20, as would be common for the present arid climate. Then equation (5) simplifies to

$$A_L = \frac{1.08\, f\, R\, A_b}{E_L - R\,(1 - f)} \quad , \qquad (6)$$

or

$$A_L = \frac{1.08\, f\, A_b}{E_L/R - (1 - f)} \quad . \qquad (7)$$

Now evaporation and precipitation are not independent quantities, climatically speaking, because more precipitation is usually accompanied by decreased evaporation. For a number of stations in the arid western states, an approximate formula is

$$E = 10.83 - 7\,R \quad . \qquad (8)$$

The numbers 10.83 and 7 are not very accurate, and, of course, if high levels of rainfall are sustained for an appreciable time, vegetative cover changes, as do other factors, and the arid-land equation no longer applies. Substituting equation (8) into equation (7) gives

$$A_L = \frac{0.028\ A_b}{\frac{1.39}{R} - 1} \quad . \qquad (9)$$

The equation, while not to be taken as numerically accurate, serves to point up the possibility that a critical amount of rainfall exists such that, as the rainfall in the basin increases toward this critical value (1.39 feet in the example), the lake is capable of extending its area almost indefinitely. The relationship may have a bearing on Langbein's (1961) comment that Russell had noted closed lakes only exist in areas where the rainfall is less than about 20 to 25 inches.

For a given basin, there is a simple relationship, determined by the topography of the basin, between the depth and the area and volume. Since the area is the controlling factor in closed lakes, one should perhaps treat it as the independent variable. If one plots depth as a function of area for the Bonneville Basin, he finds several levels which a slight increase in depth results in a large increase in area. One such level is around 4197 feet. The lake almost doubles its area in rising from 4195 to 4200 feet.

The lake levels at which a small increase in depth causes large changes in area tend to be levels of stability. When the lake is at one of these levels, an increase in water budget will produce a large change in area, and hence in evaporation, which will tend to offset the increase in water budget. Similarly, a decrease in budget will cause a large decrease in evaporation, resulting in a stabilizing countereffect.

Equation (9) can be solved for R to find the amount of rainfall needed to support a given area of lake:

$$R = \frac{1.39\ A_L}{A_L + 0.028\ A_b} \quad .$$

It can thus be seen that when topographic conditions dictate a large change in area for a small increase in depth, there must be a relatively large change in rainfall to get past such a stability barrier. While the above equations are far too simple to provide quantitative estimates of the changes necessary, they serve to provide a qualitative picture of the action of stability (or stillstand) levels.

Conclusion

A close-interval study of stable-isotope values and lithologic data, particularly when combined with information from other disciplines, appears to be capable of producing detailed information about the hydrologic history of a closed lake. The method might quite possibly be of use in open lakes, also, but has not been tried in such a setting yet.

It is not possible to recover actual temperatures from isotopic studies of sediments in most cases, but it is possible to recover detailed water-budget data, which has certain general climatic significance.

Data from the present study seem to suggest that Great Salt Lake rose more than fifty, but less than 125, feet above its present level within the last three thousand years, during one of the so-called "Little Ice-Age" events. The present level seems to represent about the lowest level reached by the lake in the last 7000 years, and is an unusual condition.

Based solely on the fact that the lake has spent very little time at such a low level in the past, one might infer that the lake will most probably rise again.

Acknowledgments

The experimental work reported herein was supported by, and performed in, the Laboratory of Isotope Geology, University of Utah. Portions of the Saltair core were graciously donated by the late Professor Armand Eardley. The Hogup Spring core and Great Salt Lake core materials were supplied by Professor P. J. Mehringer.

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WATER BUDGET OF THE GREAT SALT LAKE[1]

J. N. Steed[2] and B. Glenne[3]

Abstract

This paper is a summary of an investigation conducted of the monthly and annual water budget of Great Salt Lake in the period 1944-1970. The main factors of surface inflows, precipitation, groundwater, evaporation, transpiration and storage changes are evaluated and balanced with an error term. Possible sources of error and inaccuracies are discussed. The purpose of the paper is to furnish data for rational development and conservation of Great Salt Lake's resources.

KEY WORDS: Water budget, Inflows, Outflows, Storage change, Streamflow, Precipitation, Groundwater, Evaporation, Transpiration.

Introduction

Great Salt Lake, the largest terminal lake in the United States, has received little attention as a tentative comprehensive water resource. Historically it has been exploited mainly for mineral extraction, limited recreation, and as a sink for man's waste products.

Recent qualitative and quantitative changes in Great Salt Lake caused by man's interference with its circulation and inflow quantities have underlined the delicate balance existing in the lake, Madison (1970), United States Geological Survey (1970). Environmental fragility as well as a growing competition for water in the Western United States have drawn attention to the relatively large volumes of water in our terminal lakes, i.e., Great Salt Lake, Salton Sea, Mono Lake, Pyramid Lake, Goose Lake, Walker Lake, etc.

Along the Wasatch Front Range in Utah an expanding population is increasing its demands for municipal and industrial waters and has created an

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[1] This paper is a summary of James N. Steed's Master of Science thesis submitted in August 1972. James N. Steed passed away on October 14, 1972. May this paper honor his talents and memory.

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earnest search for more water (Bear River Plan, Central Utah Project). Whether Great Salt Lake is to be used as a water resource or as a waste sink, it is important that we understand the ramifications of our plans and activities.

This paper attempts to furnish some of the basic data regarding the water balance in Great Salt Lake so that we may better anticipate environmental lake changes and optimize development and conservation of this important natural resource.

Water Budget Equation

Steed (1972) wrote the general equation for Great Salt Lake's water budget as:

$$\text{Inflows} - \text{Outflows} \pm \text{Storage Change} = \text{Error}$$

in which, Inflows equal Precipitation plus Groundwater Inflows and Surface Water Inflows (Streamflows); Outflows equal Evaporation plus Transpiration Losses (no surface outflows since Great Salt Lake is a terminal lake). Time Increment equals one month or one year, and Rate of Storage Change equals change of lake volume during time increment. Error is the measure of inaccuracy involved in the evaluation procedure. Units employed are acre-feet per month or year.

The terms outlined above were evaluated for Great Salt Lake for a 27-year period from 1944 to 1970. A schematic representation of the specific terms involved in the water budget equation is shown in Figure 1.

Surface Inflows

The major surface inflows are the Bear River, the Weber River and the Jordan River. There are also smaller streams as well as industrial plants that discharge into the Great Salt Lake. These include: Farmington, Centerville, Holms, Ricks, Parrish, Stone and Mill Creeks; American, Chevron, Husky and Phillips Petroleum; Union Pacific, Utah Power & Light, and Salt Lake Stock Yards; as well as various drains and canals. Generally they contribute less than 5 percent of the total flow of the Jordan, Weber, and Bear Rivers to the surface inflow. Many of the streams are used for agricultural purposes and by phreatophytic vegetation near the lake shore so that significant flows do not reach the lake.

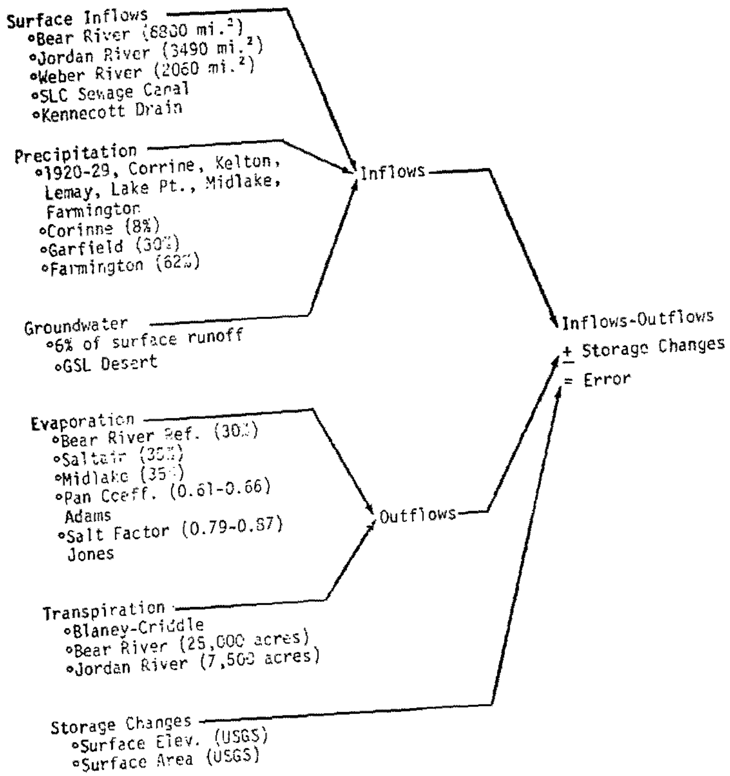

Figure 1. Great Salt Lake's water budget schematic representation.

Two other sources contribute surface inflow to the Great Salt Lake. The Salt Lake City Sewage Canal and Kennecott Drain. For purposes of this study the inflows of the Jordan, Weber and Bear Rivers, the Salt Lake City Sewage Canal, and Kennecott Drain will constitute the surface flows into the Great Salt Lake.

Annual surface inflows are tabulated in Table 1. Data were mainly taken from United States Geological Survey (1900-1970). For monthly flows and specific streamflows see Steed (1972).

Groundwater Inflows

Little information exists on groundwater inflows to Great Salt Lake. Estimates of groundwater inflows from the Bear, Jordan and Weber Rivers vary from 3 percent to 10 percent of the surface inflows. Hill, et al. (1970), Haws,

Table 1. Great Salt Lake's Annual Water Budget 1944-1970 (in 1000 acre-feet/year).

Water Year	Surface Inflows	Groundwater Inflows	Precipitation Inflows	Transpiration Outflows	Evaporation Outflows	Storage Change	Error
1944	1465	196	748	150	2393	+138	-273
1945	1580	203	720	152	2456	+148	-253
1946	1956	225	663	153	2484	+148	+ 60
1947	1795	228	887	148	2526	+605	-370
1948	2088	233	691	151	2714	0	+147
1949	2035	252	769	151	2613	+404	-113
1950	2816	265	818	148	2784	+776	+190
1951	2818	265	918	152	3143	+742	- 36
1952	3373	298	914	150	3156	+1199	+ 80
1953	2167	226	866	154	3370	-619	+355
1954	1160	166	608	155	3355	-1500	- 76
1955	1161	166	747	149	2589	-680	+ 15
1956	1624	193	628	156	2651	-485	+124
1957	1756	201	935	150	2440	0	+303
1958	1755	201	569	159	2699	-237	+ 37
1959	1089	161	618	153	2312	-716	+119
1960	1056	147	382	153	2367	-728	-207
1961	753	129	417	153	2177	-1058	+ 28
1962	1422	169	610	150	1961	+304	-214
1963	1102	150	530	153	1966	-425	+ 88
1964	1582	191	604	145	1844	+671	-283
1965	1916	223	656	148	1869	+767	+ 11
1966	1625	193	404	154	2403	-236	- 99
1967	1620	193	624	153	1965	+277	+ 42
1968	1694	198	787	150	2149	+311	+ 68
1969	2251	255	684	156	2477	+597	- 40
1970	1723	223	700	152	2458	-242	+278
mean	1755	206	685	151	2493	+ 1	- 1
coeff. of variation	0.334	0.194	0.222	0.0265	0.168	644	-184

et al. (1970), and Hely, et al. (1971). After considerable contemplation it was decided upon to use 6 percent of the respective monthly surface inflows as the groundwater contributions from the Bear, Weber, Jordan and other significant surface inflows.

The groundwater inflows from the Great Salt Lake Desert most recently have been investigated by Foote, et al. (1971). Their work was used to estimate the Great Salt Lake Desert's contribution to groundwater inflows.

Annual groundwater inflows are tabulated in Table 1. For monthly inflows and further details see Steed (1972).

Precipitation Inflows

The records of precipitation, U. S. Weather Bureau (1915-1970), for the study period (1944-1970) show only stations on the east side of the lake. These locations are poorly located in terms of trying to obtain a representative value for precipitation.

During the 1920's the U. S. Weather Bureau collected records from stations around the entire Great Salt Lake. For this reason, the 10-year time period from 1920-1929 provides the basis for estimating the average precipitation distribution over the lake. Six strategically located stations have 10 years of data upon which a Thiessen Diagram can be made. These stations are Corinne, Kelton, Lemay, Lake Point, Farmington, and Midlake. The results obtained were correlated to the records from the stations at Corinne, Garfield (used as Lake Point) and Farmington, which are the three stations with records common to both time periods. Average weighting factors of 8.15 percent for Corinne, 61.6 percent for Garfield and 30.25 percent for Farmington were used with precipitation records at these stations to obtain average lake precipitation data.

To calculate the monthly water volume that is added to the lake by precipitation, the monthly precipitation was multiplied by the surface area corresponding to the particular water stage. The surface area was read off a set of curves prepared by the United States Geological Survey showing water stage - surface area and water stage - volume relationships.

Annual precipitation inflows are tabulated in Table 1. For monthly inflows and further details see Steed (1972).

Evaporation Outflows

Evaporation outflows were calculated using Class A pan evaporation data from three stations; namely, Saltair, Midlake, and Bear River Refuge (U.S. Weather Bureau, 1915-1970). The data had to be correlated with other stations and wind-temperature data to complete the records. The records were then weighted and multiplied by a pan coefficient and a salt factor to obtain representative lake evaporation in inches per month. This figure was then multiplied by the appropriate surface area to give the monthly evaporation in acre-feet.

The pan coefficient problem for the Salt Lake area has been studied by Adams (1934) and Peck and Dickson (1965). Adams found values of 0.61 - 0.66 to be representative. In this study a value of 0.61 was used in for the spring months, a value of 0.66 for the fall months, and a value of 0.65 for the rest of the year.

The decrease of evaporation with increasing salt content has been investigated by Jones (1933). His results are shown in Figure 2. The water stage - salt concentration relationship was established using data by Thomas (1914), Eardley (1957), and Hahl (1969).

A Thiessen map indicates that weighting factors of 40 percent, 40 percent and 20 percent should be used for the evaporation station records at respectively, Midlake, Saltair, and Bear River Refuge. However, in order to minimize the error term in the water budget equation for the 27-year study period weighting factors of respectively, 35 percent, 35 and 30 percent were used. The water budget is rather sensitive to the choices of evaporation coefficients and weighting factors.

Annual evaporation outflows are tabulated in Table 1. For monthly outflows and further details, see Steed (1972).

Transpiration Outflows

Transpiration from Great Salt Lake is primarily associated with the growth of phreatophytes. Transpiration was calculated using the empirical Blaney-Criddle equation. A typical year gives an annual consumptive use of about 56 inches, Hely, et al. (1971).

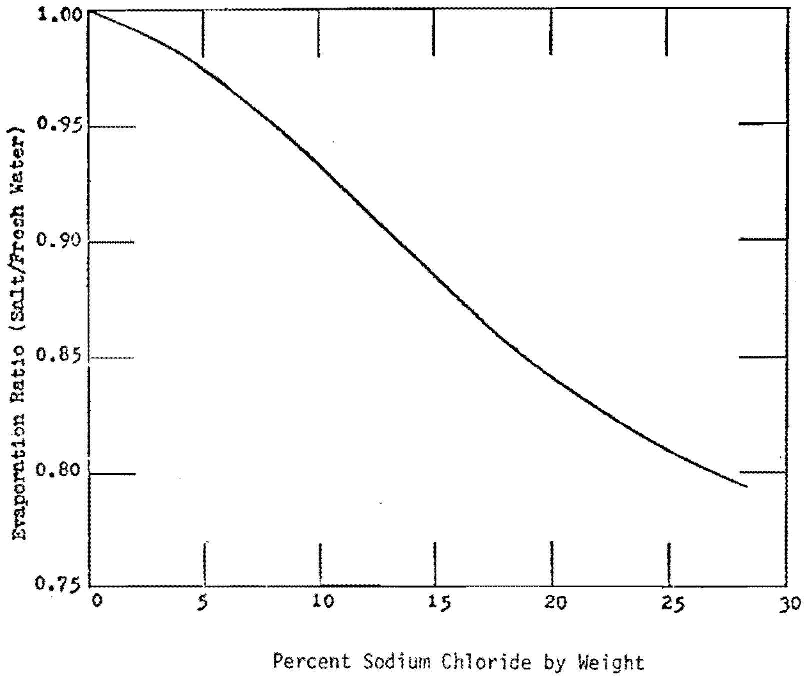

Figure 2. Salt factor vs. percent salt, after Jones (1933).

The areas covered by phreatophytes were estimated as 25,000 acres in the Bear River Refuge and 7,500 acres around the mouth of the Jordan River.

Annual transpiration outflows are tabulated in Table 1. For monthly outflows and further details see Steed (1972).

Storage Changes

The water stage-volume relationship for Great Salt Lake has been tentatively established, United States Geological Survey (1970). By knowing the water stages at the beginning and the end of the time increment the storage change was established from the water stage-volume relationship.

Annual storage changes are tabulated in Table 1. For monthly storage changes and further details see Steed (1972).

Results

Table 1 indicates that evaporation and surface inflows are the largest terms in Great Salt Lake's water budget equation while transpiration and groundwater inflows are relatively unimportant. While the mean error has been reduced to essentially nil by adjusting the evaporation station weighting factors it is interesting to observe that the standard deviation of the error term is only about 7.4 percent of the mean evaporation term. Without extensive further study it is difficult to distinguish between predictable and random error.

Table 2 shows the average error term calculated on a monthly basis. It appears from Table 2 that the evaluation procedure used overestimates the difference between Inflows and Outflows in the winter months while it underestimates the same difference in the summer months. Perhaps this inaccuracy is due to inaccuracies in determining seasonal differences in precipitation and/or evaporation over the lake.

Conclusions

Previously, Peck (1951), Palmer (1966), and Bagley (1967) have made estimates of Great Salt Lake's average annual water budget. It is hoped that the results reported herein and by Steed (1972) will further contribute to our understanding of Great Salt Lake's monthly and annual water budget.

The results reported herein should not be interpreted as scientific facts, but rather as rational estimates produced for engineering purposes. Extensive further research is needed before we can fully understand all the intricate mechanisms which conceal Great Salt Lake's delicate water balance.

Acknowledgement

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Table 2. Average Monthly Water Budget Errors. (Values in 1000 Acre-Feet/Month).

Month	Average Error	Standard Deviation
October	+74	52
November	+32	76
December	+18	70
January	+12	75
February	-61	86
March	-56	119
April	-36	90
May	-37	82
June	-54	95
July	-44	62
August	+75	72
September	+72	74

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SURFACE INFLOW TO GREAT SALT LAKE, UTAH[1]

Ted Arnow and J. C. Mundorff[2]

Abstract

During 1960, 1961, and 1964 the Bear, Weber, and Jordan River systems contributed about 90 percent of the surface discharge and about 80 percent of the surficial dissolved-solids load that entered Great Salt Lake, Utah. During years of average streamflow, a total of more than 500,000 acre-feet of water suitable for public supply and more than 1,350,000 acre-feet of water suitable for irrigation discharges in the Bear River past Corinne, the Weber River past Plain City, and the Jordan River past Cudahy Lane. During January-October 1972, water from the Weber River system generally had dissolved-solids concentrations of less than 500 mg/l (milligrams per liter) as determined at four sites in the Ogden Bird Refuge. The outflow from Farmington Bay, which includes Jordan River discharge, had concentrations ranging from about 8,700 to 97,000 mg/l, and water entering the lake from the Bear River at the Great Salt Lake Minerals and Chemicals Corp. bridge had concentrations ranging from about 1,900 to 13,000 mg/l. Except for Lee Creek, which had observed concentrations ranging from about 39,000 to 121,000 mg/l, the minor tributaries to Great Salt Lake had concentrations of less than 5,000 mg/l.

KEY WORDS: Great Salt Lake, Lake inflow, Saline lakes, Lakes.

Introduction

The major surface inflow to Great Salt Lake is from the Bear, Weber, and Jordan River drainage systems. The U.S. Geological Survey has operated gaging stations upstream from the lake on the main stems of these streams in cooperation with the Utah State Engineer for many years; but in 1960, 1961, and 1964 the Geological Survey, in cooperation with the University of Utah and the Utah Geological and Mineralogical Survey, made a special study to determine the actual amount of water that was entering the lake from these streams and other surface sources around the lake. The information from this study was summarized in a report by Hahl (1968).

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[1] Publication authorized by the Director, U.S. Geological Survey.

[2] U.S. Geological Survey, Salt Lake City, Utah.

In the preparation of a State water plan, consideration has been given to the concept of diverting some of the water that now enters the lake for use upstream. Starting in 1971, in cooperation with the Utah Division of Water Resources, the Geological Survey has been measuring the major surface inflow to the lake as close to the lake as feasible.

In the following discussion we use the term "surface inflow" to include two things: surface discharge (quantity of water) and the surficial dissolved-solids load that enters the lake in streams, canals, drains, and springs that are near the water's edge.

Inflow During 1960, 1961, and 1964

Distribution of inflow by percentage

Our study in 1960, 1961, and 1964 indicated that the Bear, Weber, and Jordan Rivers carried about 85 percent of the surface discharge to the lake and about 60 percent of the dissolved-solids load. (See Table 1.)

The Bear River carried more than half of the water and almost 40 percent of the load. The Weber River carried about 17 percent of the water but only about 6 percent of the load. The Jordan River carried about 15 percent of the water and 15 percent of the load. The sources of surface inflow excluding the three main-stem rivers carried only about 15 percent of the water, but they carried about 40 percent of the load.

We then considered the lake in terms of five drainage systems. (See Figure 1.)

1. Bear River - Consisting of the Bear River itself and all other streams, drains, and canals that emptied into the Bear River Bay.
2. Weber River- Consisting of the Weber River itself and the sloughs and drains in the Weber River delta area.
3. Davis County-Miscellaneous streams, sewage canals, and springs discharging into the Farmington Bay area.
4. Jordan River-Consisting of the Jordan River itself, the Surplus Canal, and all streams, drains, and canals discharging to the lake from Salt Lake County.
5. Other - Everything else around the lake that we could measure or estimate. Primarily the entire western part of the lake.

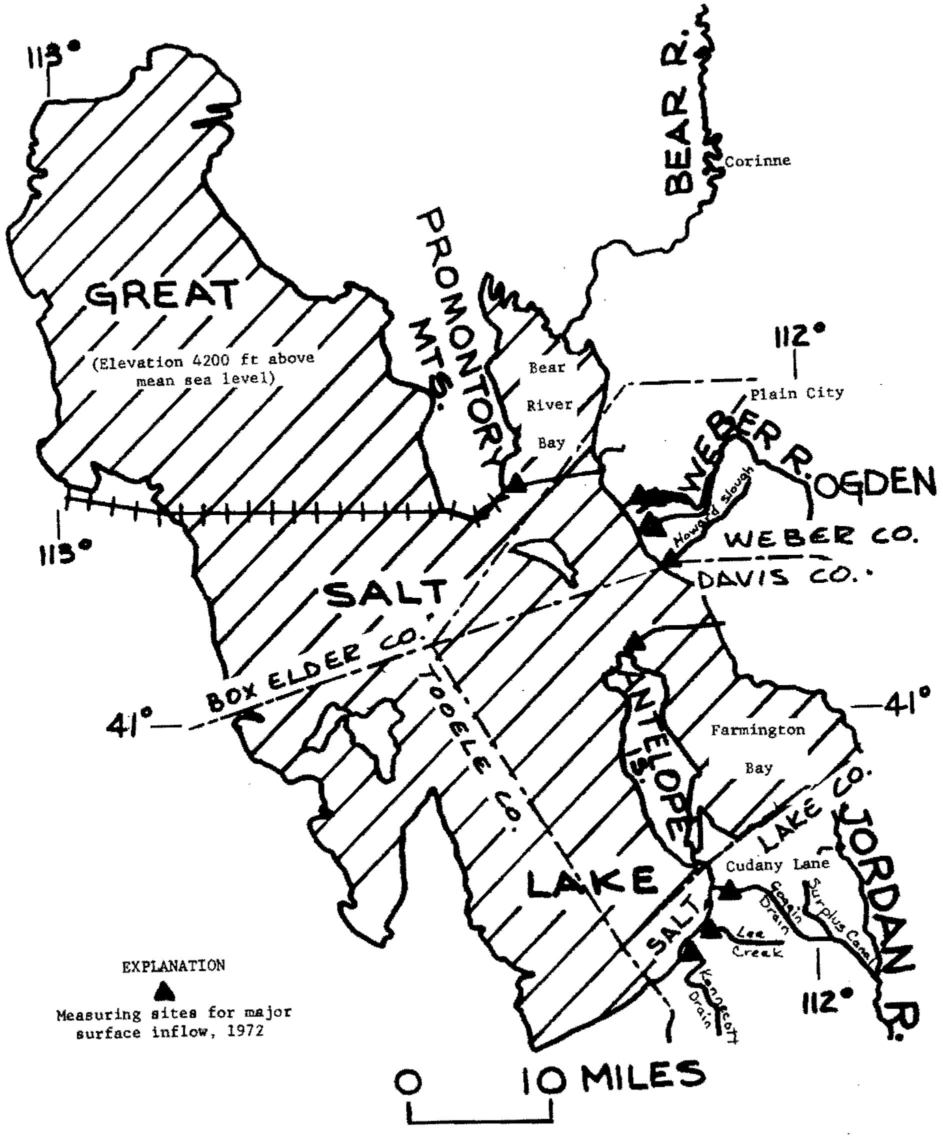


Figure 1. Great Salt Lake.

Table 1. Surface inflow to Great Salt Lake from streams, in percent, 1960, 1961, and 1964.

UNIT	1960		1961		1964	
	DISCHARGE	LOAD	DISCHARGE	LOAD	DISCHARGE	LOAD
BEAR R.	53	37	55	38	53	37
WEBER R.	17	6	11	4	23	9
JORDAN R.	15	17	16	16	11	13
SUB-TOTAL	85	60	82	58	87	59
OTHER	15	40	18	42	13	41

Table 2. Surface inflow to Great Salt Lake from stream systems, in percent, 1960, 1961, and 1964 [Data adjusted for changes in lakeshore marshlands].

SYSTEM	1960		1961		1964	
	DISCHARGE	LOAD	DISCHARGE	LOAD	DISCHARGE	LOAD
BEAR R.	52	46	54	46	53	40
WEBER R.	16	4	10	3	23	5
JORDAN R.	22	29	25	29	16	30
SUB TOTAL	90	79	89	78	92	75
DAVIS CO.	4	1	4	1	3	1
OTHER	6	20	7	21	5	24

During the 3 years of our study we found that the three drainage systems associated with the Bear, Weber, and Jordan Rivers contributed about 90 percent of the surface-water discharge and about 80 percent of the surficial dissolved-solids load that entered the lake. (See Table 2.) About 60 percent of this load was sodium and chloride.

The Bear River system contributed more than 50 percent of the water and about 45 percent of the load. The Weber River system contributed about 16 percent of the water but only 4 percent of the load. The Jordan River system contributed about 20 percent of the water and about 30 percent of the load. The sources in the western part of the lake contributed only about 6 percent of the water but they added more than 20 percent of the load.

A significant point to note is that regardless of how the data were considered, we observed that the Weber River area contributed a significant quantity of water but only a small quantity of dissolved-solids load.

Distribution of inflow by quantity

Now let's see how these percentages relate to actual quantities of inflow.

We examined our gaging station records on the three rivers for the period 1934-64, and we found that the 1964 water year was about an average year of stream discharge for the 31-year period. During the 1961 water year, surface discharge to the lake was about the lowest observed during the 31-year period.

During the low-discharge year of 1961, the water discharge to the lake was about half that of the average year of 1964, and the dissolved-solids load was about 60 percent. (See Table 3.) Unfortunately, we have no information about the relationship during a year of unusually high discharge.

For those who don't readily visualize the quantities in Table 3, the 1,700,000 acre-feet of discharge in 1964 is almost exactly twice the amount of water in Utah Lake and 3 1/2 million tons of dissolved solids if precipitated at one time would cover a square mile to a depth of 2.5 feet or fill 70,000 standard railroad box cars. Two Utah Lakes and a loaded freight train extending from here to Sacramento, California--that's the approximate inflow to Great Salt Lake during an average water year such as 1964.

Suitability of water for further use

The water that enters Great Salt Lake in the three main streams is quite different in chemical quality from the water in the headwaters of these streams. (See Figure 2.) Most of the runoff in the three streams originates as snowmelt or rainfall on the Uinta Mountains and Wasatch Range, and this runoff is low in dissolved solids and of the calcium bicarbonate type--suitable for most any use.

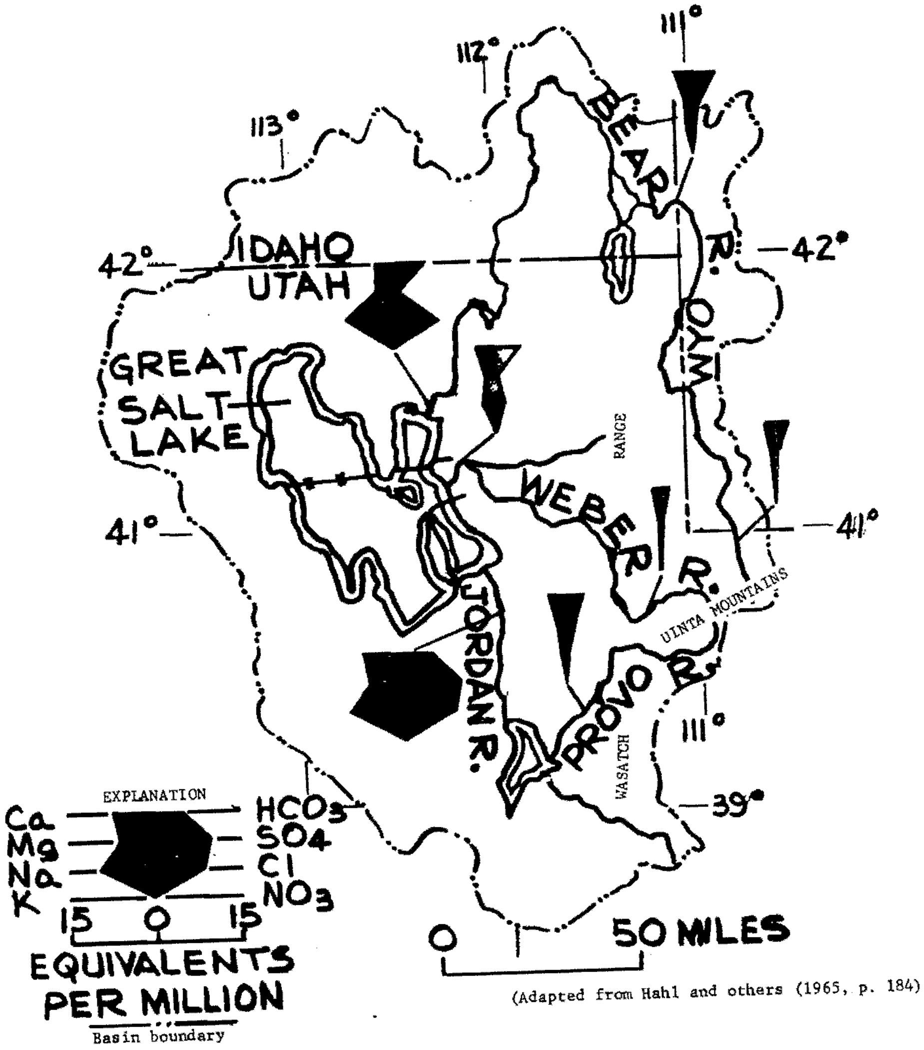
In the lower reaches of the Bear and Jordan Rivers, however, the dissolved solids increase because of evapotranspiration, return flows from irrigated lands, discharge of industrial and municipal wastes, and groundwater inflow; and the water type changes in these two streams as the major dissolved constituents become sodium, chloride, and sulfate. In the Weber River, however, the dissolved solids do not greatly increase and the water type remains the same.

What does this mean in terms of the quality of the water that discharges to the lake?

Much of the water that passes the Weber River measuring site near Plain City is suitable for public supply--that is, it meets the inorganic chemical standards recommended by the U.S. Public Health Service (1962, p. 7) for drinking water. Table 4 shows that in the 3 years of our study, the water flowing in the Weber River near Plain City met the Public Health Service standards 84 percent of the time. That is, 84 percent of the time, the concentrations were equal to or less than those shown--as compared to the Public Health Service standards given at the head of the column.

The water in the Bear River at Corinne was suitable for public supply 12 percent of the time.

The last two columns in Table 4, dissolved solids and SAR (sodium-adsorption ratio), are an indication of the suitability of the water for irrigation. Waters with less than 500 mg/l (milligrams per liter) of dissolved solids and with an SAR of less than 10 are suitable for irrigation on most soils; and waters with 500 to 1,000 mg/l of dissolved solids and with an SAR of less than about 6 are suitable for irrigation of soils having unrestricted internal drainage. On the basis of what is shown in Table 4, water from the Bear River at Corinne was suitable for irrigation 69 percent of the time, 84 percent of the time in the Weber River near Plain City, and 12 percent of the time in the



(Adapted from Hahl and others (1965, p. 184)

Figure 2. Chemical quality of water in the Great Salt Lake basin.

Table 3. Surface inflow to Great Salt Lake from major stream systems, in thousands of acre-feet and thousands of tons, 1961 and 1964.

SYSTEM	1961 (LOW)		1964 (AVERAGE)	
	DISCHARGE	LOAD	DISCHARGE	LOAD
BEAR R.	436	1,010	913	1,388
WEBER R.	80	75	398	200
JORDAN R.	204	650	281	1,072
DAVIS CO.	35	24	64	40
OTHER	60	480	86	842
TOTAL	810	2,200	1,700	3,500

Table 4. Inflow to Great Salt Lake from major streams and durations for selected chemical parameters, 1960, 1961, and 1964.

Percentage of time: The percentage of time that the concentrations were less than or equal to those shown.
[Numbers in parentheses are standards recommenced by the U.S. Public Health Service (1962, p. 7) for drinking water.]

SOURCE	PERCENTAGE OF TIME	Mg/liter				SAR
		SO_4	Cl	NO_3	SOLIDS	
		(250)	(250)	(45)	(500)	
BEAR R.	69	63	280	3.9	862	4.6
	99.9	261	1,950	1.8	4,040	23
	12	51	128	.2	505	2.9
WEBER R.	1	24	26	2.3	200	.6
	84	36	98	17	500	1.9
JORDAN R.	12	289	200	.3	897	3.1
	99	742	350	7.8	1,820	3.1
	3	99	71	2.5	407	1.4

Jordan River at Cudahy Lane.

In a year of average streamflow such as 1964, the combined flow of the three rivers that had a dissolved-solids concentration of less than 1,000 mg/l and thus is regarded as suitable for irrigation of many soils, was at least 1.35 million acre-feet, which is about one-third of the present total quantity of water diverted each year for irrigation in the entire State. The combined flow of the Bear and Weber Rivers that is suitable for public supply, from the standpoint of inorganic chemical quality, is about 1/2 million acre-feet. That is more than 1 1/2 times the present quantity of water diverted for public supply in the entire State of Utah.

At its worst, none of the water in the three rivers could be considered highly mineralized, as compared to ocean water which contains about 36,000 mg/l and the Great Salt Lake itself which now contains about 150,000 mg/l in the upper layer in its south part and about 330,000 mg/l in its north part.

Inflow During 1972

The detailed water-quality data collected during the period January-October 1972 confirm our past knowledge that the surface streams supply the lake with water that contains an extremely wide range in concentrations of dissolved solids. The data also support the earlier finding that the surface source of the water of best chemical quality entering the lake is the Weber River.

Weber River

Water from the Weber River had dissolved-solids concentrations of a maximum of 514 mg/l and generally less than 500 mg/l as determined at the four sites in the Ogden Bird Refuge. On Figure 3, representative samples for the Weber River are shown by the solid circles. The total dissolved-solids concentrations of the waters represented by these circles are proportional to the radii of the circles as indicated by the scale on the illustration. Fluctuations in percentages of the major cations (lower left) are appreciably greater than fluctuations in percentages of major anions (lower right) and the water type is generally either calcium magnesium bicarbonate or calcium sodium bicarbonate.

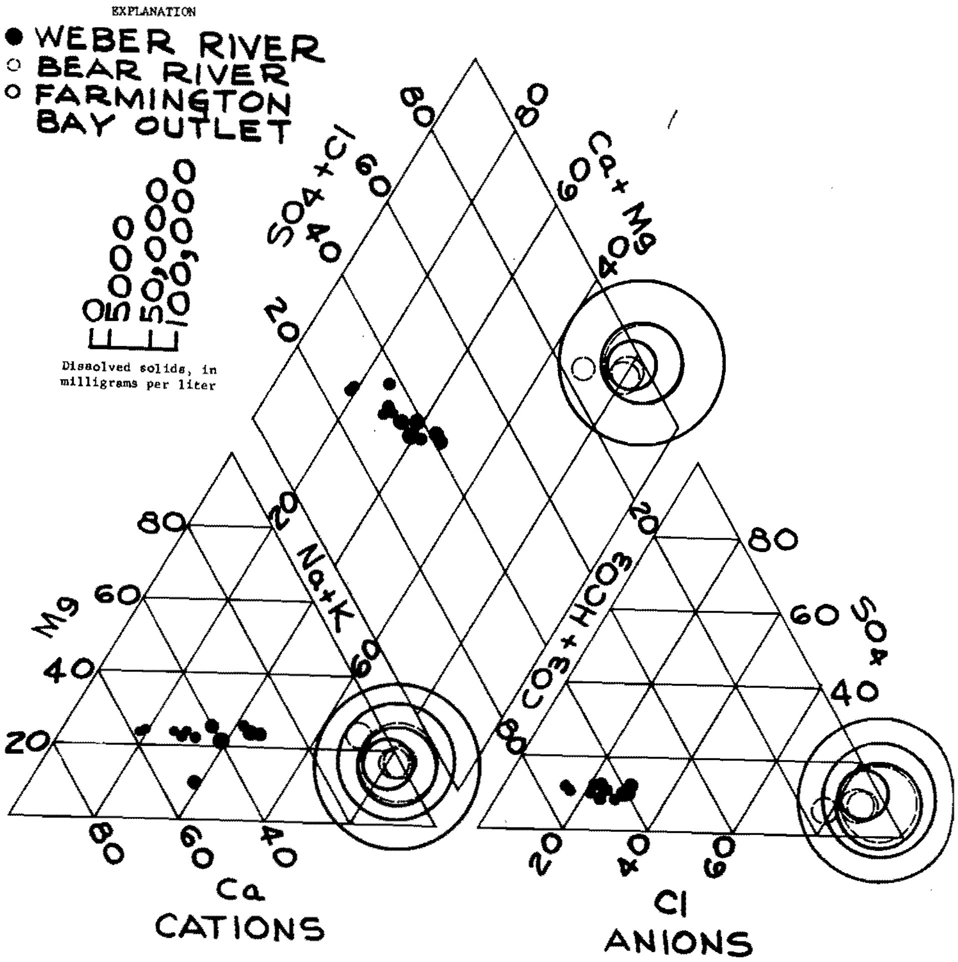


Figure 3. Percentage composition of anions and cations (equivalents per million) for the Weber and Bear Rivers and Farmington Bay outlet.

Farmington Bay

Water from the Jordan River, together with other inflow to Farmington Bay, moves through Farmington Bay and into Great Salt Lake at the bridge on the Antelope Island-Syracuse causeway. Concentrations ranged from a minimum of about 8,700 mg/l to about 97,000 mg/l. The large open circles at the right side of each part of Figure 3 show the wide range and high concentrations representative of water flowing into the lake at this Antelope Island causeway station. The water is definitely sodium chloride in type. Magnesium and sulfate are present in significant concentrations but are minor relative to sodium and chloride. Calcium and bicarbonate are relatively very low and are present in concentrations common in many normal stream waters.

Two-directional flow is common at this site, and a dense lower layer of brine commonly is observed as underflow at the bridge. This lower-stratum water flowing southward from Great Salt Lake into Farmington Bay had dissolved-solids concentrations ranging from 136,000 to 152,000 mg/l. This water is also sodium chloride in type. This southward-flowing brine mixes with the water in Farmington Bay near the causeway and undoubtedly causes the water flowing north from the bay at the Antelope Island bridge to have an appreciably higher salinity than the water entering the bay from the Jordan River and other sources.

Bear River

Water from the Bear River moves into the lake at the Great Salt Lake Minerals and Chemical Corp. bridge. Dissolved-solids concentrations ranged from a minimum of about 1,900 mg/l to a maximum of about 13,000 mg/l for southward-flowing water from the Bear River system. As is apparent from the data in Figure 3 that represent water from the Bear River, these waters are not greatly different chemically from those observed entering Great Salt Lake from Farmington Bay, but the range in dissolved-solids concentrations is much less.

Complex multidirectional flow to and from the Great Salt Lake also occurs at this site, but the quantity of water moving out of the lake is much less than at the Antelope Island causeway. The very slowly northward-moving or stagnant bottom layer of water at this site had dissolved-solids concentrations ranging from about 20,000 to 291,000 mg/l.

Minor tributaries

The minor tributaries to Great Salt Lake show a wide range in dissolved-solids concentrations. (See Table 5.) Kennecott Drain had observed concentrations ranging from about 2,300 to 4,300 mg/l. Lee Creek ranged from about 39,000 to 121,000 mg/l. Goggin Drain ranged from about 1,100 to 2,400 mg/l and Howard Slough from about 430 to 810 mg/l.

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Table 5. Approximate range of dissolved solids, in milligrams per liter, in major surface inflow to Great Salt Lake, January-October 1972.

SOURCE	MINIMUM	MAXIMUM
KENNECOTT DRAIN	2,300	4,300
LEE CREEK	39,000	121,000
GOGGIN DRAIN	1,100	2,400
HOWARD SLOUGH	430	810
FARMINGTON BAY	8,700	97,000
WEBER RIVER	140	520
BEAR RIVER	1,900	13,000

FLUCTUATIONS OF THE SURFACE ELEVATION OF GREAT SALT LAKE, UTAH[1]

Leon J. Jensen and Ted Arnow[2]

Abstract

The surface elevation of Great Salt Lake changes continuously in response to climatic changes and tends to maintain an equilibrium between surface and groundwater inflow and loss by evaporation. For the period 1847-75, the lake elevation was computed indirectly from observations made by local residents at the southern end of the lake. During most of the period 1876-1938, the elevation was measured periodically at staff gages at different places along the southern and eastern shores of the lake. Since 1938, the elevation has been determined continuously by a recording instrument at the southern end of the lake. The consumptive use of water as a result of man's activities in the drainage basin of Great Salt Lake since 1847 has resulted in a lowering of the lake-surface elevation by slightly more than 5 feet. Since 1959, a permeable causeway has divided the main body of the lake into two parts. The causeway interrupts the formerly free movement of water in the lake, and this has resulted in a difference of surface elevation between the two parts. The maximum difference of elevation recorded was 1.7 feet in May 1972.

KEY WORDS: Great Salt Lake; Lake stages; Lakes; Lake shores.

Introduction

The surface elevation of Great Salt Lake changes continuously in response to climatic changes which include direct precipitation on the lake, and tends to maintain an equilibrium between surface- and groundwater inflow and loss by evaporation. During a period of dry years, the level drops and the surface area decreases rapidly, so that the total volume of evaporation is considerably diminished. Thus, less inflow is required to maintain an existing lake level. Likewise, during a period of wet years, the level rises and the surface area is materially increased, resulting in a larger volume of evaporation to compensate for the greater inflow. Therefore, these factors are always seeking to stabilize the lake elevation. Also the result of man's activities in the drainage basin of Great Salt Lake has had an effect on the elevation of the lake.

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[1] Publication authorized by the Director, U. S. Geological Survey.

[2] U. S. Geological Survey, Salt Lake City, Utah.

Fluctuations of Lake Elevation

Historic record

The historic record of lake elevations began in 1847. When the early pioneers reached the Great Salt Lake basin, the elevation of Great Salt Lake was about 4,200 feet above mean sea level. A series of wet years from 1862 to 1868 raised the stage of the lake almost 12 feet (Figure 1); that 7-year period probably provided a greater water supply to the Great Basin, and in general to the western United States, than any similar period during the past several hundred years. The lake rose to a maximum recorded elevation of nearly 4,212 feet in 1873, but during a series of dry years from 1874 to 1905, the elevation declined almost 16 feet. Since 1905, the lake level has fluctuated between about 4,191 and 4,205 feet; the greatest lowering was during the drought period of the late 1920's and early 1930's when the elevation decreased 11 feet. The lowest elevation recorded was 4,191.35 feet in the fall of 1963, and since then, through 1972, the elevation has risen to a maximum of 4,199.7 feet in May 1972. Great Salt Lake elevations are published regularly by the U.S. Geological Survey (1971, p. 125).

Source of record

The first direct determination of the levels of the lake was begun in September 1875. Prior to this time only traditional information is available. For the period 1850-75, the lake elevation was computed indirectly from observations made by local residents at the southern end of the lake. The conditions of the fords (sand bars) from the mainland to Antelope Island and to Stansbury Island were obtained by Gilbert (1890, p. 240,241) from stockmen who used these bars to get stock to and from the islands. To tie in the traditional data to actual record, Gilbert made observations on Antelope bar on October 19, 1877, and related the water elevation there to the gage reading at Black Rock gage. During most of the period 1876-1938, the elevation was measured periodically at staff gages at different places along the southern and eastern shores of the lake (Figure 2). Since 1938, the elevation has been determined continuously by a recording instrument at the Salt Lake County boat harbor at the southern end of the lake. Gages and their period of record are as follows:

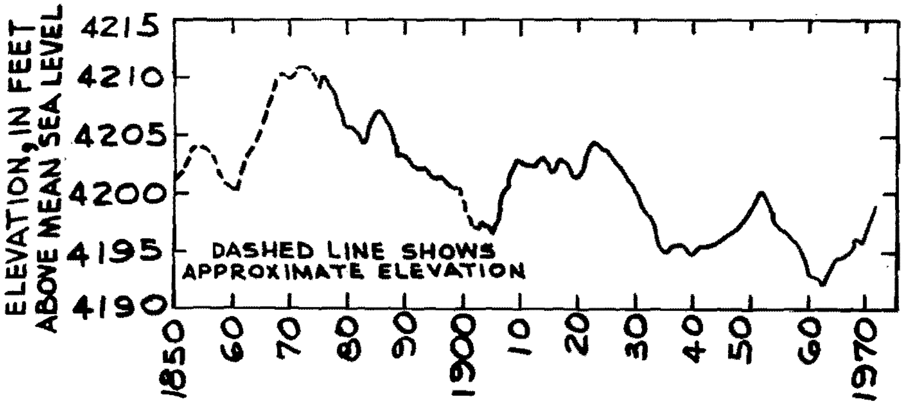

Figure 1. Fluctuations of Great Salt Lake for period 1850-1972.

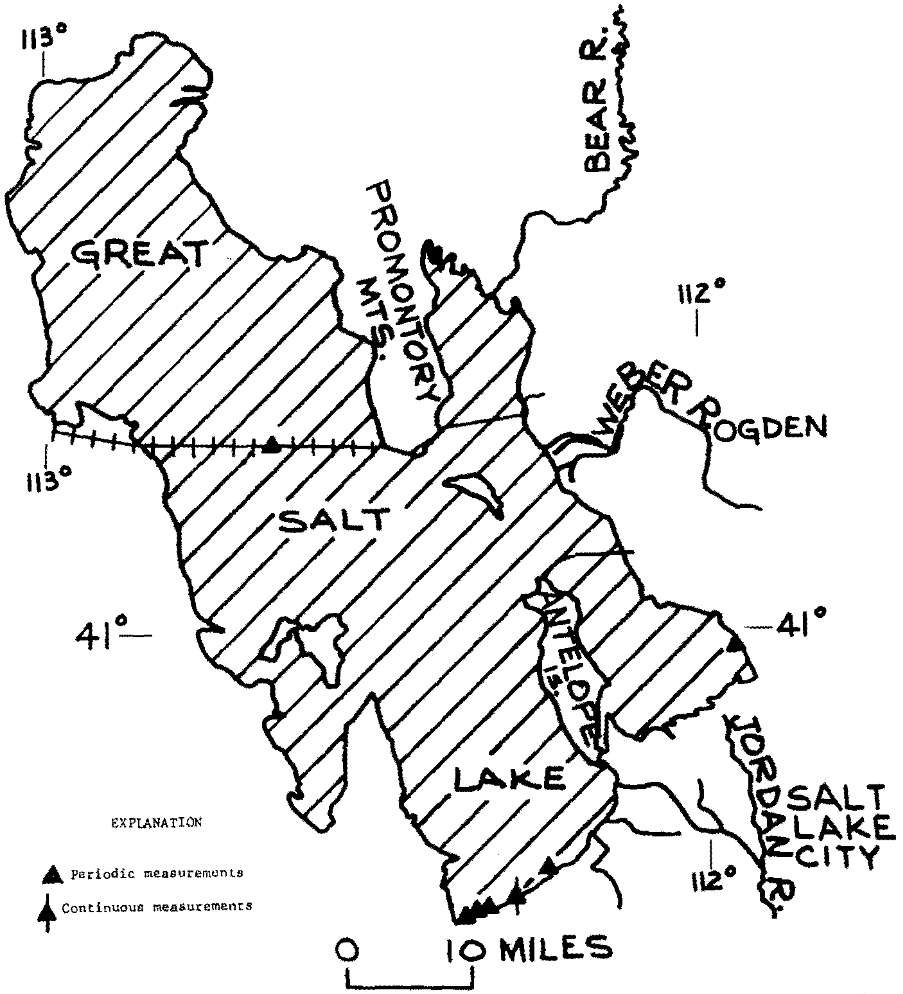

Figure 2. Location of gages used to determine the elevation of Great Salt Lake, 1875-1972.

Gage	Period of Record
Black Rock	1875-1876
Farmington	1876-1879
Lakeshore	1879-1881
Garfield	1881-1901
Midlake	1902-1903
Saltair	1903-1938
Boat Harbor	1939-1972

Effect of Man's Activities on the Lake Elevation

Consumptive use of water

Although the major fluctuations of lake elevation are caused by climatic variations, the consumptive use of water as a result of man's activities in the drainage basin of Great Salt Lake since 1847 has resulted in a lowering of the lake surface. An evaluation of this effect was made in 1969 by the U. S. Geological Survey and the Utah Department of Natural Resources (Whitaker, 1971). The elevation in 1965 would have been about 5 feet higher than the observed elevation had there been no consumptive use of water because of man's activities in the basin.

Figure 3 shows the effect of consumptive use of water, resulting from man's activities, on historic elevations of Great Salt Lake, 1850-1965. The difference in 1965 was 5.28 feet. That is, the lake surface was 5.28 feet lower than it would have been if man had not caused evapotranspiration of water by impounding it in reservoirs and diverting some of it for irrigation and other uses.

The railroad causeway

During 1957-59, the Southern Pacific Co. constructed a causeway to carry its railroad lines across Great Salt Lake. The causeway is constructed of permeable quarry-run rockfill capped with boulder-sized riprap. The causeway is breached by two culverts, each 15 feet wide, which allows brine to flow through the causeway. The causeway divides the lake into two sections. About one-third of the lake lies to the north of the causeway, but more than 95 percent of the fresh-water surface inflow enters the lake south of the causeway. The inflow for each part is the sum of surfacewater inflow, groundwater inflow, precipitation, and inflow through the causeway. The outflow for each part is the sum of evaporation and outflow through the causeway to the other part. Because of the complex interrelationships among variable inflow

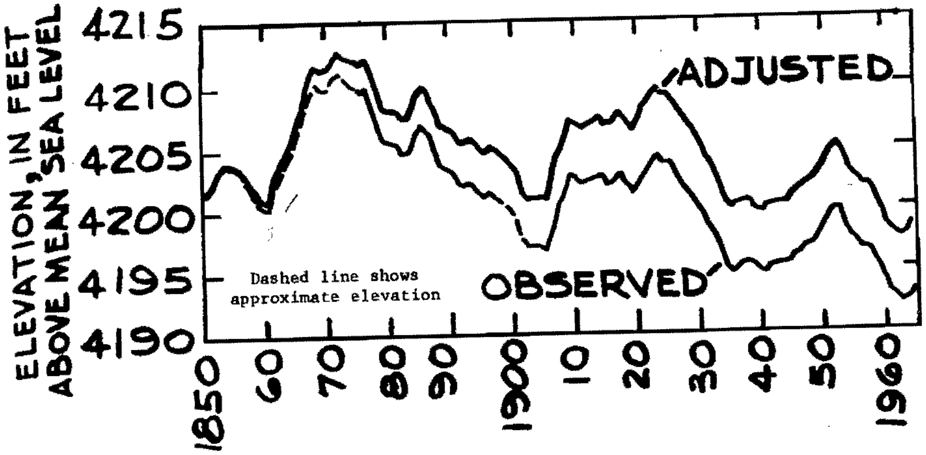

Figure 3. Effects of consumptive use of water, resulting from man's activities, on historic elevations of Great Salt Lake, 1850-1965.

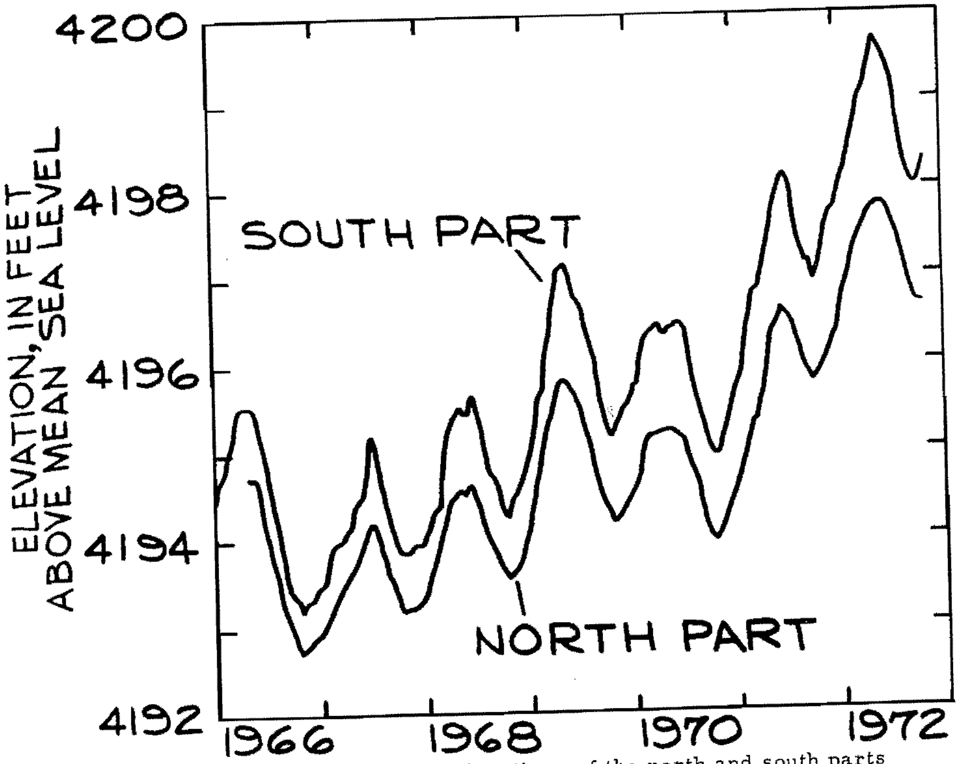

Figure 4. Relationship between the elevations of the north and south parts of Great Salt Lake, 1966-1972.

relative to volumes and areas, evaporation, and two-way flows through the causeway affected by salinity differences, a difference of water-surface elevation has developed between the two parts of the lake. The maximum difference of elevation recorded was 1.7 feet in May 1972. (See Figure 4.)

Effect of Storms on the Lake Elevation

Figure 5 shows a continuous recording of the elevation of the lake at the boat harbor. This period covers 8 days and shows the effects of storms on the lake. To compensate for wind effect and seiches, elevations given for the gage were taken from a mean slope line defined by several days gage-height graph preceding and following the 1st and 15th of each month. Wind effects may cause substantial changes in elevation which are not shown in the published elevations.

Relations of Lake Elevation, Volume, and Surface Area

Figure 6 shows relations among elevation, area, and volume of Great Salt Lake prior to 1957 (Hahl and Handy, 1969, p. 10). These parameters are greatly affected by evaporation from the lake surface. The rate of evaporation varies inversely with the concentration of dissolved solids in the water, and the concentration of dissolved solids varies inversely with the volume of water in the lake. In addition, the volume of water evaporated is directly proportional to the surface area, which varies directly with lake stage. It is obvious, for example, that because of the greater surface area the amount of water evaporated at the maximum recorded elevation of 4,212 feet (6 million acre-feet) was much greater than that evaporated at the minimum elevation of 4,191.35 feet (approximately 1.9 million acre-feet).

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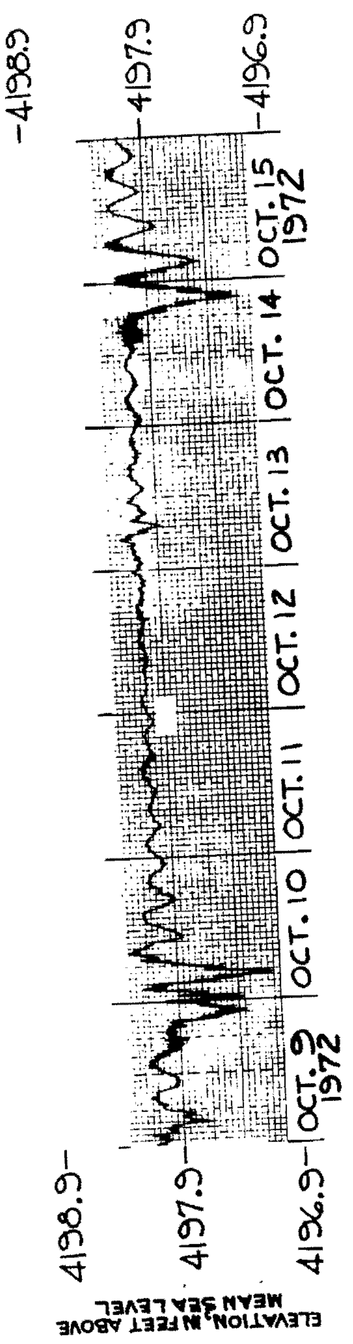

Figure 5. Continuous record of the elevation of Great Salt Lake, October 9-15, 1972.

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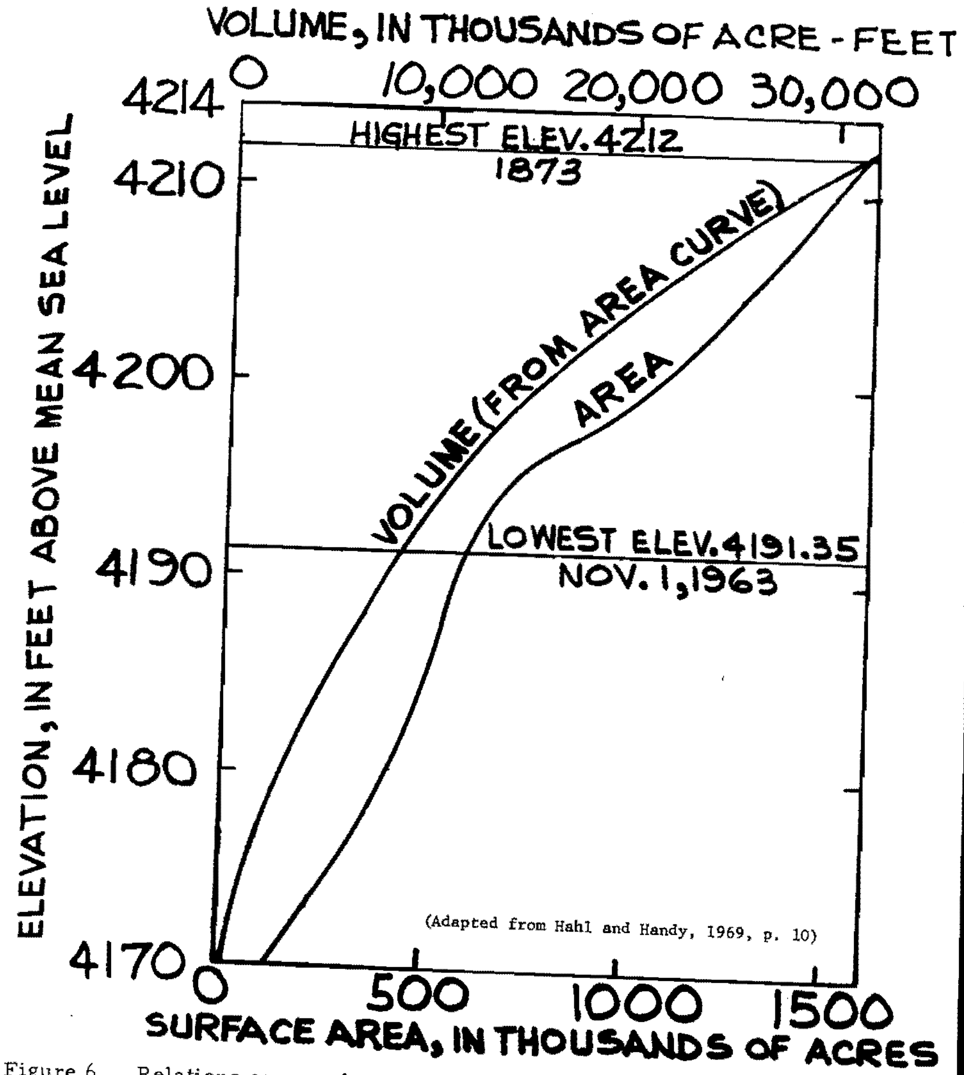

(Adapted from Hahl and Handy, 1969, p. 10)

Figure 6. Relations among elevation, area, and volume of Great Salt Lake prior to 1957.

SOME PHYSICAL CHEMICAL CHARACTERISTICS OF THE GREAT SALT LAKE

Anching Lin[1], Po-cheng Chang[2], and Paul Sha[3]

Abstract

Results of some work done on the Great Salt Lake during the summer months of 1972 are presented. The detailed vertical profiles of temperature, dissolved oxygen, conductivity and pH values were measured among 17 buoy stations installed at the south end of the lake. Several phenomena related to the deep brines of the lake seem to indicate some clues for the source of deep brines of the Great Salt Lake. Comparative study between the Great Salt Lake and the Dead Sea has proven to be very informative both in the mineral and the hydrological aspects of the two similar bodies of water.

Introduction

The Great Salt Lake has recently received considerable public attention as a result of the conflicts in development among existing mineral industries and other future prospects for oil and gas exploration.

The abundance of mineral wealth of the lake has naturally directed people's interest in the chemical and mineralogical investigations in the past as evidenced by the many theses on the chemical analysis of the lake water done in the universities and the considerable amount of invaluable information collected by the lake-related industries. However, the lake has received very little attention as far as the study of its physical environment is concerned. The bottom topography has never been defined in enough detail and a navigation chart is not yet available. The nature of the lake's circulation and the transport mechanisms are practically unknown. The precise definition of the effect of the causeway still remains to be determined.

The lack of such information virtually mystifies the outlook of the lake and accordingly, controversies prevail. It is impossible at the moment to provide a proper management program for a desirable future development of the lake.

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Research work of significant scale did not begin until the latter part of the 1960's. The following two papers are the most comprehensive to date. Hahl and Handy (1) reported on the chemical and physical variations of the lake brines for the period of 1963-1966. It was the first published paper on the nature of brine distribution in the lake. It classified in detail the different types of brines in the lake and also noted the effect of the causeway on the balance of brines between the north and south arms of the lake. Subsequently R. J. Madison (2) performed the first field investigation of the seepage flow through the causeway in 1969.

The present paper reported on some of the results collected on the lake during the summer months of 1972, together with some pertinent observations. Some emphasis was placed on the comparison between the Great Salt Lake and the Dead Sea.

Field experiments

Since navigation aides on the lake were not established, installation of marker buoys became necessary. Seventeen marker buoys were thus set up at the south end of the lake for this phase of the study. The buoy units were made of concrete blocks as sinkers, and two-inch PVC pipes as flotations to surface as markers. The position of each station was determined by triangulation from stations on shore with transits.

Figure 1 indicates the relative positions of the stations on which work was performed one time or another during the course of the study. The stations labeled with numerals were the semi-permanent marker buoys where regular runs were made. The rest of the stations were labeled with letters of the alphabet.

The major instrument used in the study was a Martek Mark II water quality monitor. It was equipped to measure the temperature, the dissolved oxygen, the conductivity and the pH value. The sensor head was lowered and readings taken on each chosen station at an increment of 6 inches at the halocline and deeper layers, and 12 to 24 inches at the surface layers. The results were processed through UNIVAC 1108 computers and end results displayed in graphs by a Gerber plotter. Figures 2 through 5 are the typical results of such plots, and general features of these results will be discussed in the paper. Note that the identification of year-month-date-station references were provided on the

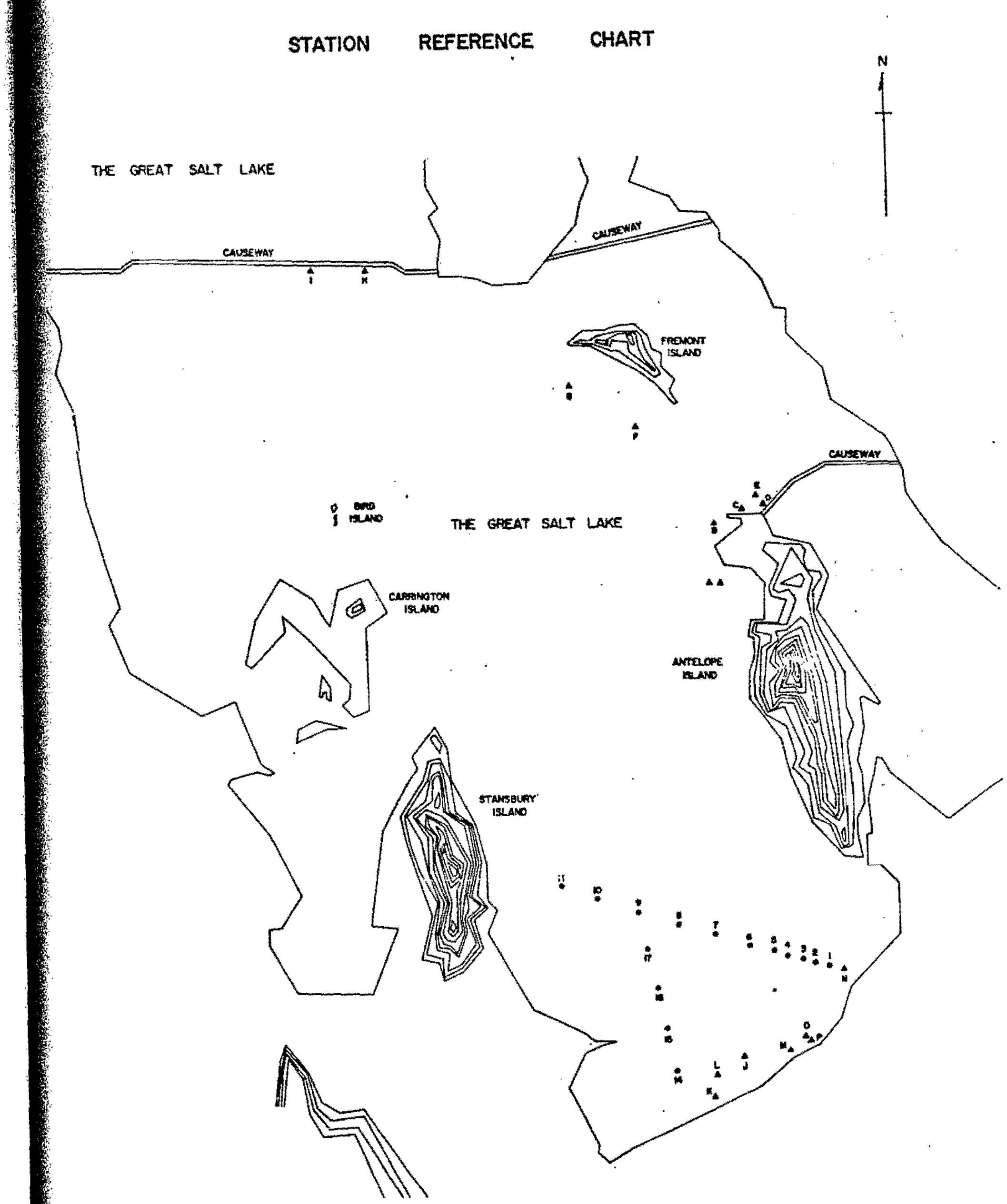

Figure 1 Reference Chart

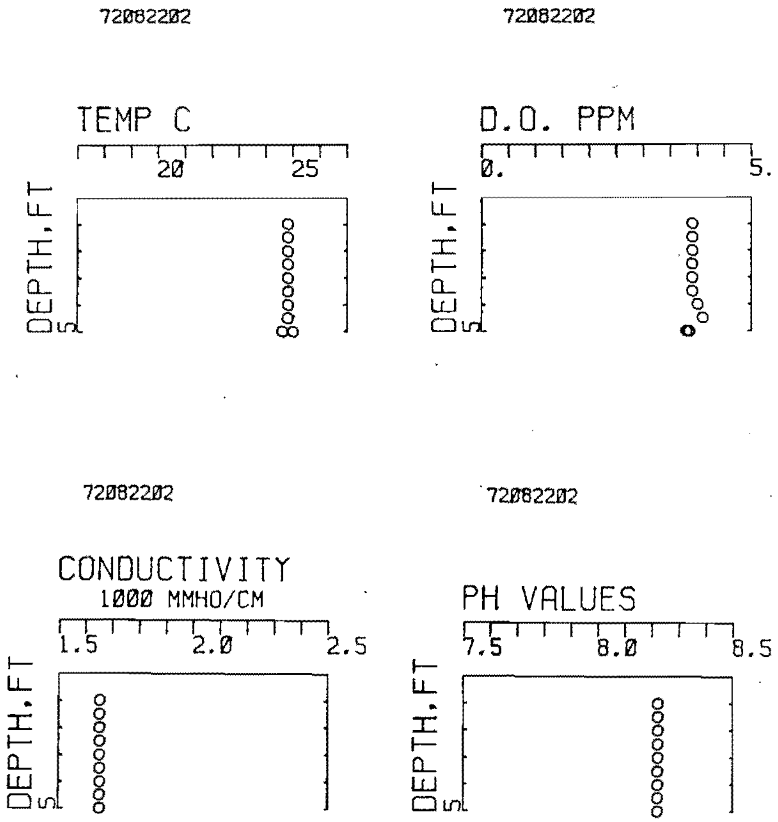

Figure 2

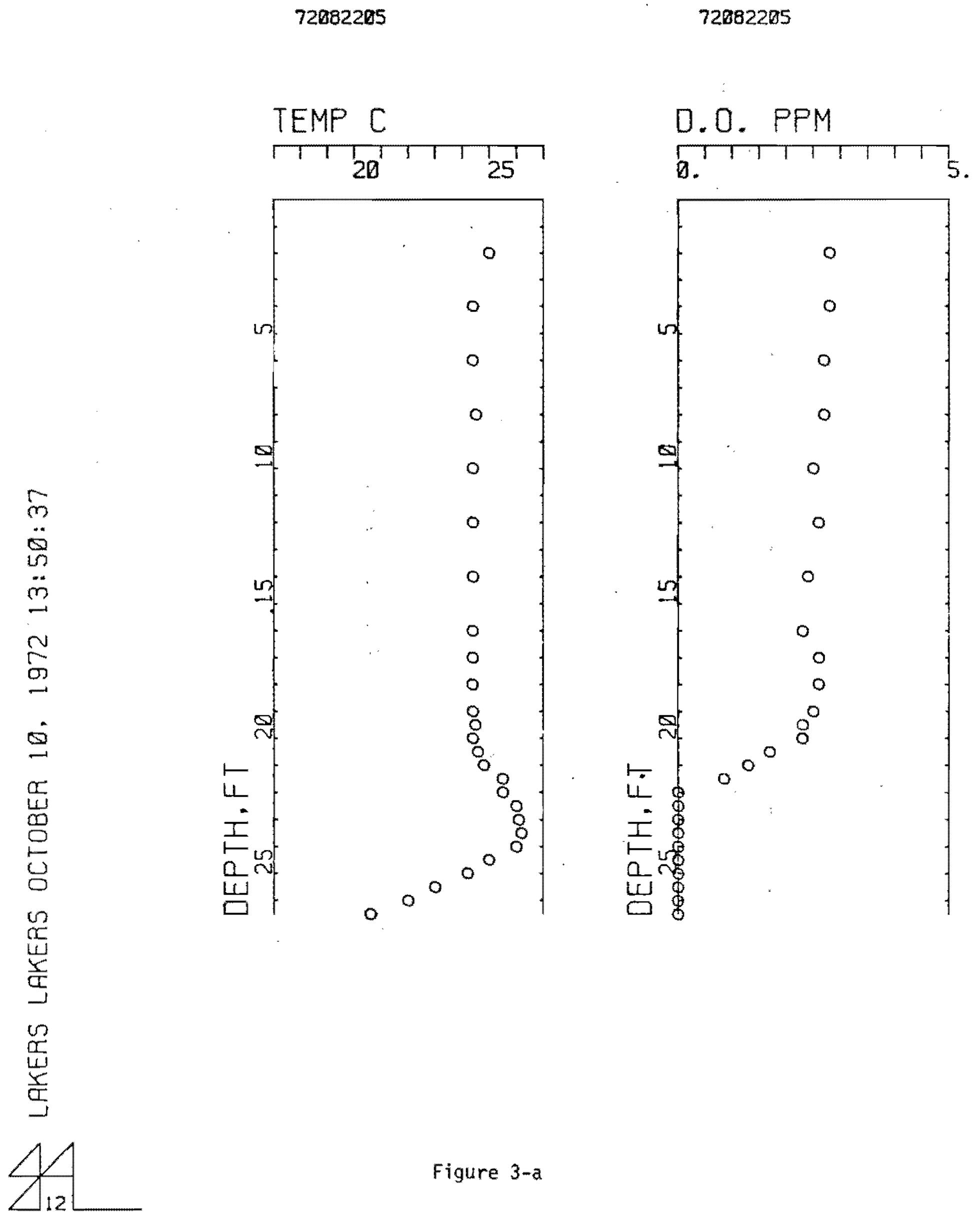

Figure 3-a

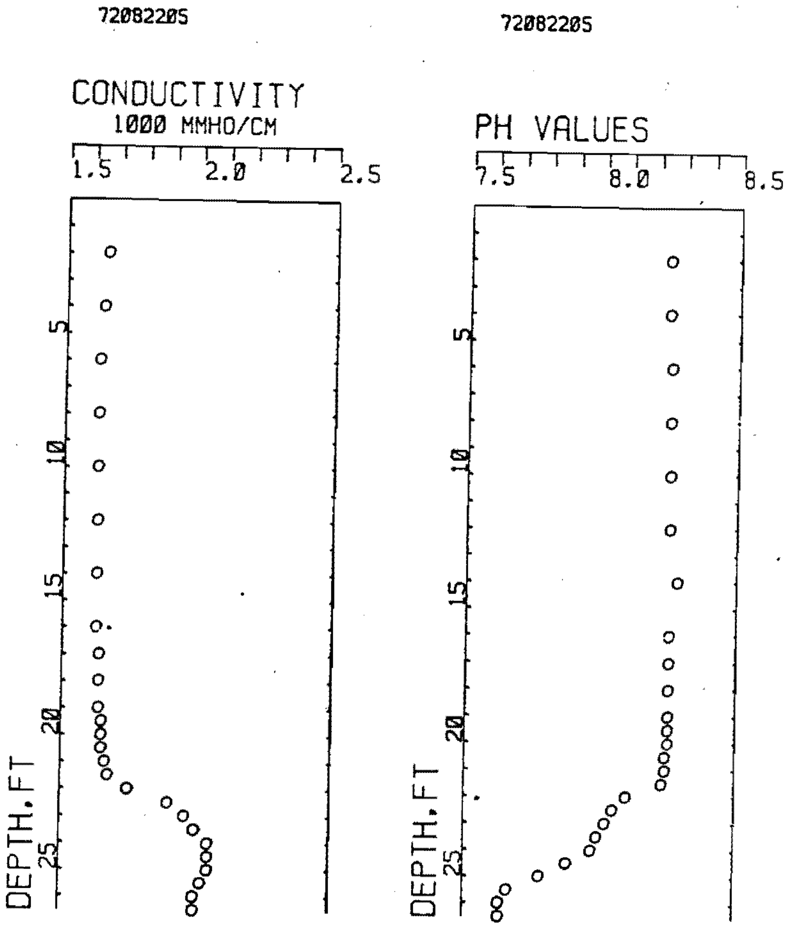

Figure 3-b

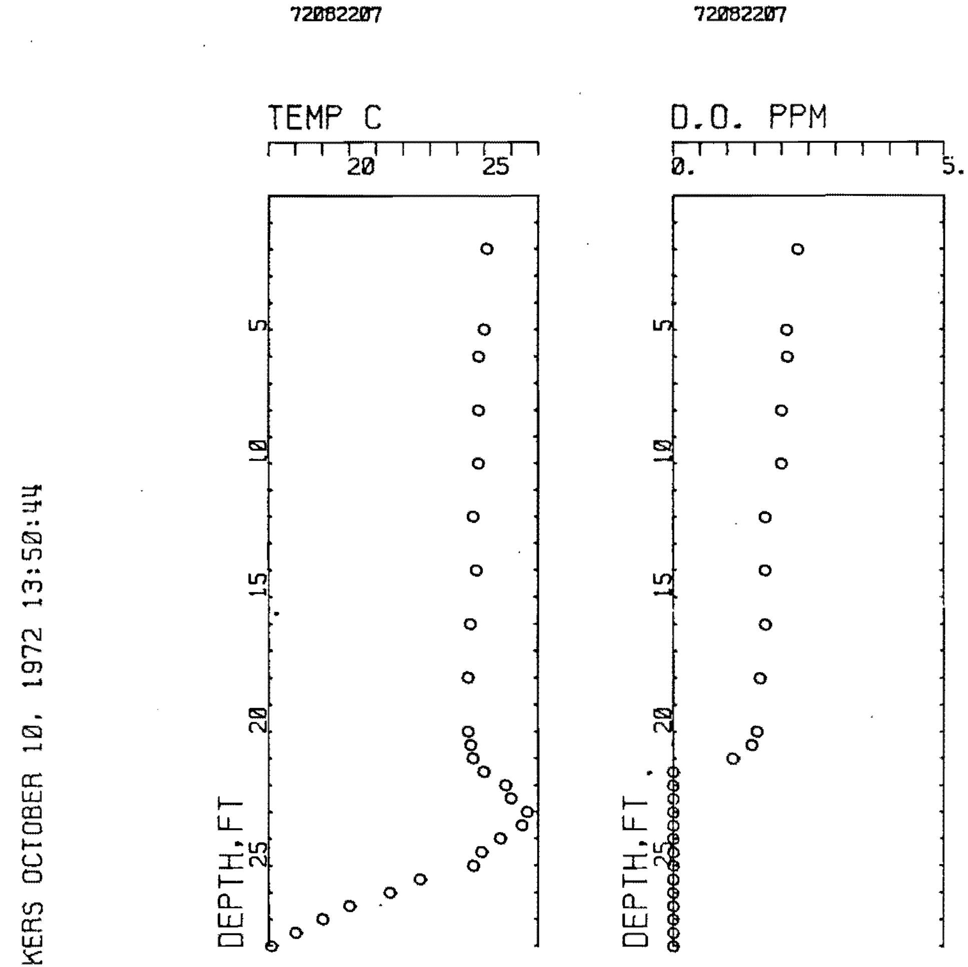

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Figure 4-a

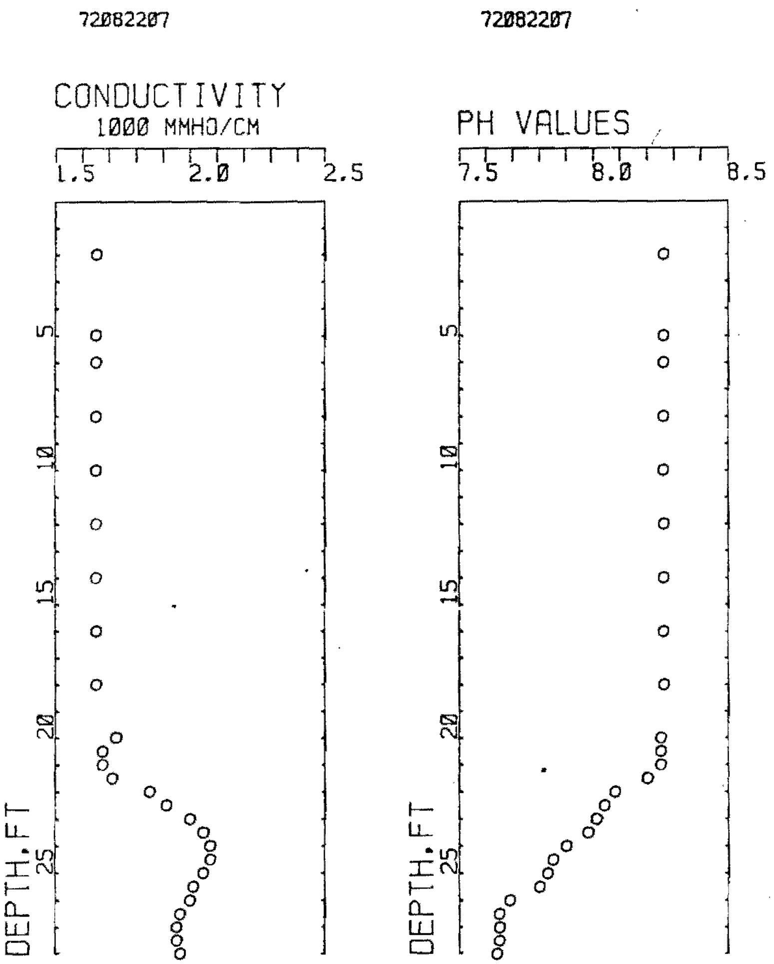

Figure 4-b

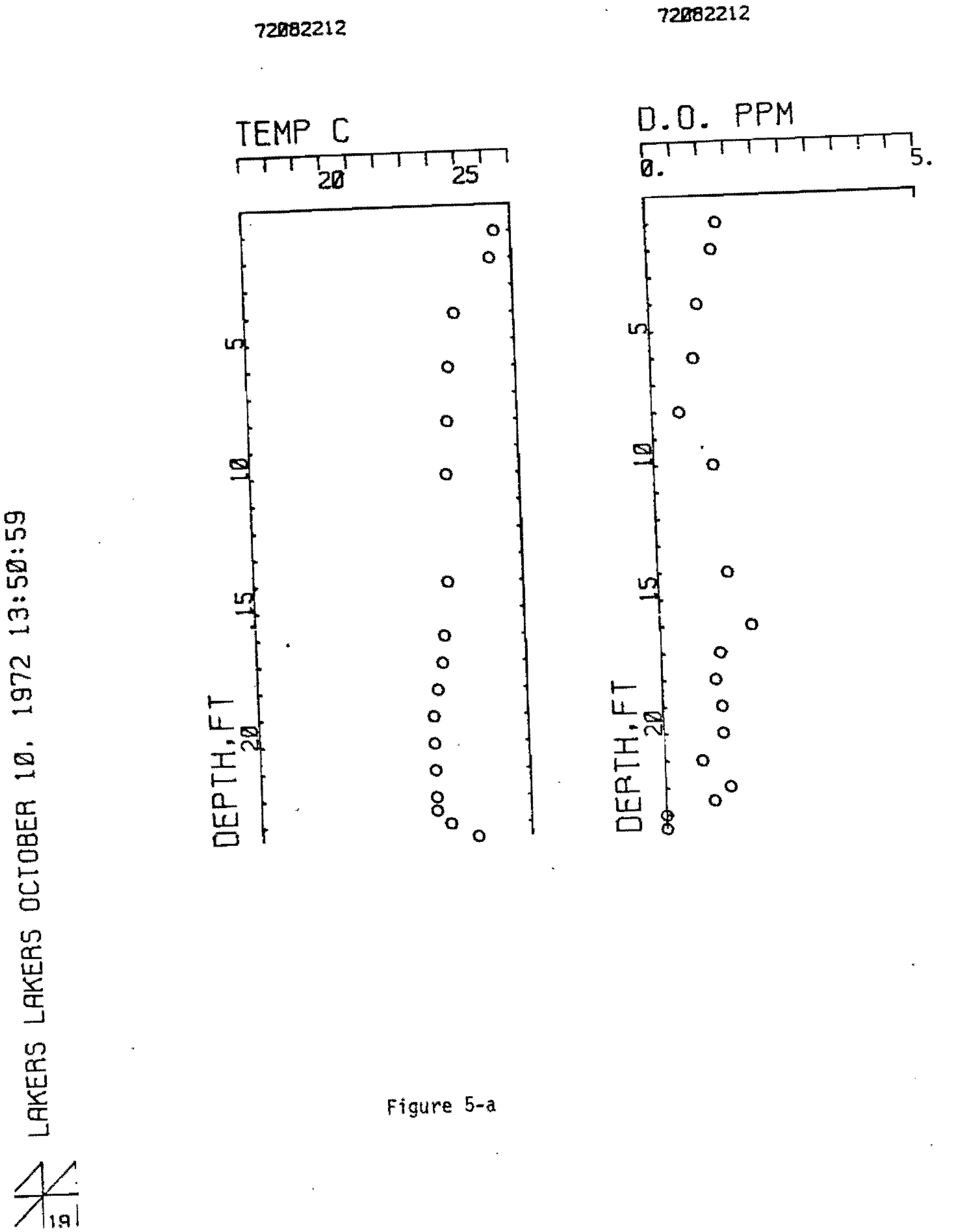

Figure 5-a

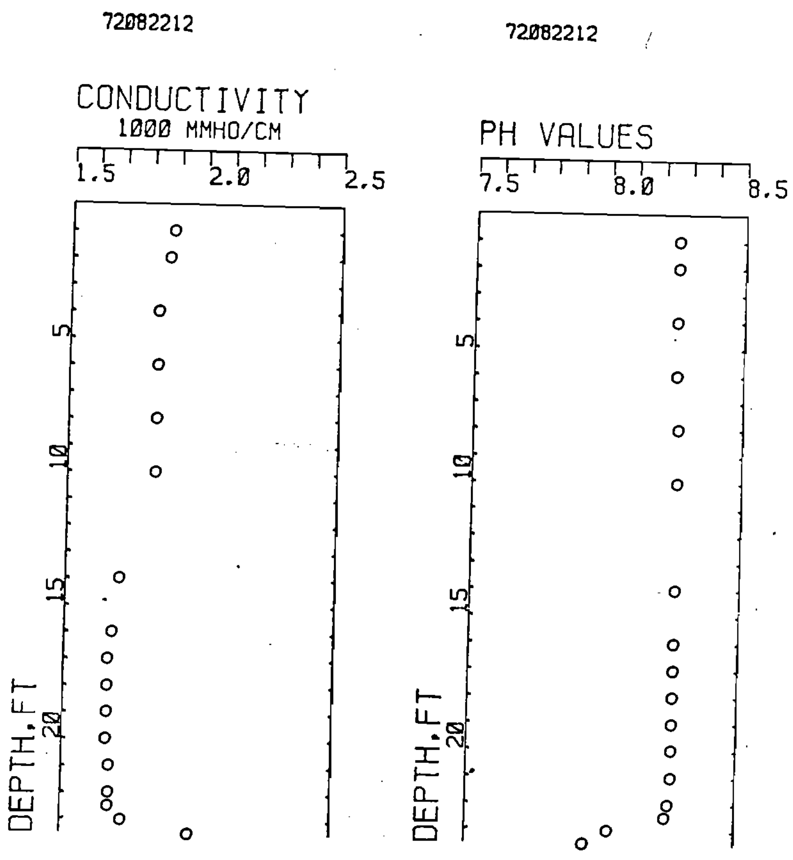

Figure 5-b

upper left hand corner of the figures. Note also that all the measurements were made during the daytime from 9:00 A. M. to 5:00 P. M.

Temperature and dissolved oxygen

The temperature of the lake water was quite uniform in a depth up to 20 feet, except for the uppermost two feet where the temperature responded immediately to the conditions on the surface. However, the temperature at a depth below the halocline, usually beginning at a depth of 22 feet, was observed to be as much as 10°C below the surface temperature. By way of comparison, the layer of uniform temperature in the Dead Sea (3) extended on the other hand, to a depth of 75 feet with a total depth of 230 feet. For a lake so shallow as the Great Salt Lake, one would expect the temperature distribution to be more uniform in depth than was observed. Note that the Great Salt Lake is located at 41°N 112°W while the Dead Sea is at 32°N 35.5°E. The average temperature in the summer on the Dead Sea ranges from 34°C to 36°C. The temperature at 60 feet to 90 feet in the Dead Sea could be as much as 15°C lower than the surface temperatures during the month of August.

The fact that deep brine of the Great Salt Lake could be as much as 10°C lower than the surface within a short 25 feet could suggest two lines of thinking: (a) it is the natural environment of the lake resulting from the lack of mixing of the deeper and the shallower waters and insufficient penetration of solar heat to warm the bottom of the lake; or (b) the deep brines come from the underground as springs and thus have completely different temperatures from the surface. This could be a very crucial observation as far as the source of the deep brines is concerned.

The amount of dissolved oxygen in the lake water of course depends on the dynamic state of the lake, such as time to the previous storms and wave conditions. For the measurements were made under relatively calm conditions and the results revealed that there is definitely a tongue of higher concentration D. O. along the vicinity of the first 5 stations, and this seems to correlate with the few fresh water inflows from the east bank of the lake. Typical values of D. O. was 3.5 ppm on the surface layers of the first 5 stations and 1.5 ppm on the rest of the stations. The D. O. values at the bottom layers were invariably zero. For comparison, the corresponding values of D. O. on the surface layers of the Dead Sea were estimated to be 1.4 ppm.

Total dissolved solids, conductivity and pH values

The dissolved salts in the Great Salt Lake ranged from 324 gm/l in 1962 to 170 gm/l in 1971, averaging 230 mg/l. The dissolved salts in the Dead Sea averaged 290 gm/l at the surface and 326 gm/l at depths greater than 300 feet and the ocean contains 35 gm/l. Thus the brines in the Dead Sea are considerably denser.

The total dissolved solids were measured with a conductivity probe; no attempt was made on the chemical analysis. Nevertheless, conductivity alone can be used at least for comparative analysis. It is pertinent to point out the fact that, although there are four different types of brines as classified by Hahl and Handy, there are only actually two distinct types of brines if one reconsiders the data of Hahl and Handy (1), as follows:

Compute the percentage composition of different chemicals in terms of total dissolved solids, and one may conclude that there are only the south arm brine and the north arm brine, as indicated in Table 1. That is, for instance, if average percentages of Na are computed to be 31.453 percent for the 155 samples collected in the south arm, irrespective of deep brines or shallow brines, the standard deviation is correspondingly 0.684 percent. Thus the total dissolved solids and hence the conductivity, is indicative of the chemical compositions and could be used to our great advantage for ionic budget computations.

Table 1.

CHEM. COMP.	THE GREAT SALT LAKE			
	SOURTH ARM		NORTH ARM	
	MEAN %	S. D.	MEAN %	S. D.
Cl	54.939	0.492	54.569	1.014
Na	31.453	0.684	29.558	0.543
So_4	7.963	0.422	8.757	0.916
Mg	3.586	0.244	4.491	0.168
K	2.059	0.235	2.625	0.118

The conductivity on the surface layer up to a depth of 22 feet is practically uniform; from the depth of 22 feet down, the halocline begins. According to the results, the deeper brines contain as much as 50 percent more total dissolved solids than the surface brines. Traces of light brines were observed within 12 inches of the surface at stations close to the east bank of the lake, and apparently originated from the fresh water inflows of the few creeks and drainage ditches.

The pH values were observed to be very stable on the surface layer averaging about 8.30 and the values started to decrease from the depth of 20 feet on down, and reached a value of 7.65 at the bottom in typical deep water zones. In comparison again, the pH values in the Dead Sea range from 6.1 to 6.7 for surface water, and average about 6.2 for water deeper than 120 feet.

Horizontal distribution of conductivity

Conductivity distributions in the horizontal extent at prescribed depths were presented in Figures 6 through 8. The area of the circles represent the conductivity in excess of the surface value at the station located at the center of the circle. The brines of the surface layers are more diluted around stations closer to the Silver Sands Beach as indicated in Figure 5. At the halocline the distribution is somewhat irregular, as shown in Figure 6, and this is the layer where the conditions are less stable. The variation of conductivity in the deep layers where heavy brines are located are quite subtle and deserve very close examination. It is found that the heaviest brine does not necessarily berth at the bottom of the deepest portion of the lake. Instead, it was monitored around two stations where the total depth is two feet less than some of the neighboring stations. This observation could have several interpretations; e.g., (a) it could suggest the redissolving of the deposited salt; (b) it could indicate the occurrence of heavy brines seeping from the bottom of the lake; (c) it could be related to the return flows from the north arm of the lake through the causeway. It is believed that detailed structure of the deep brines in terms of the temperature and brine concentration is the key to answer the mystery of the source of the deep brines.

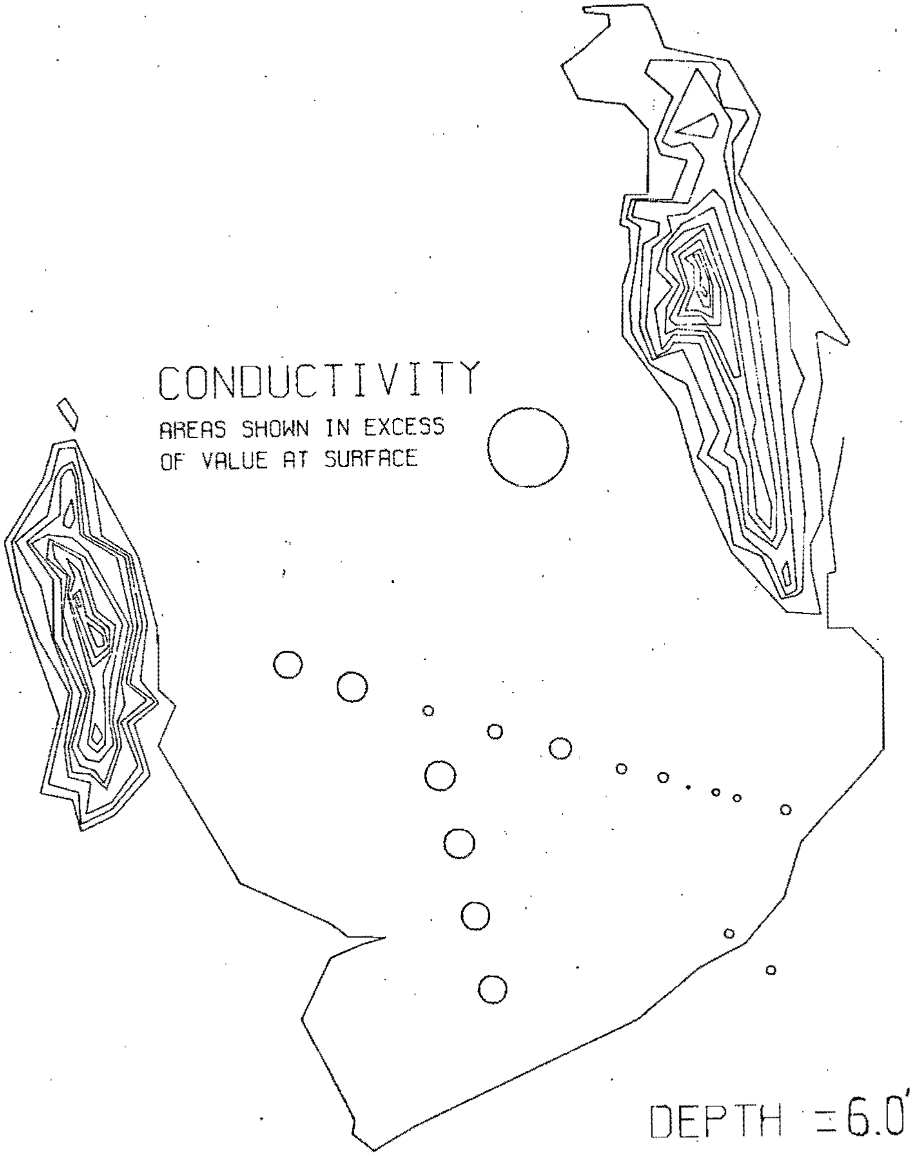

Figure 6

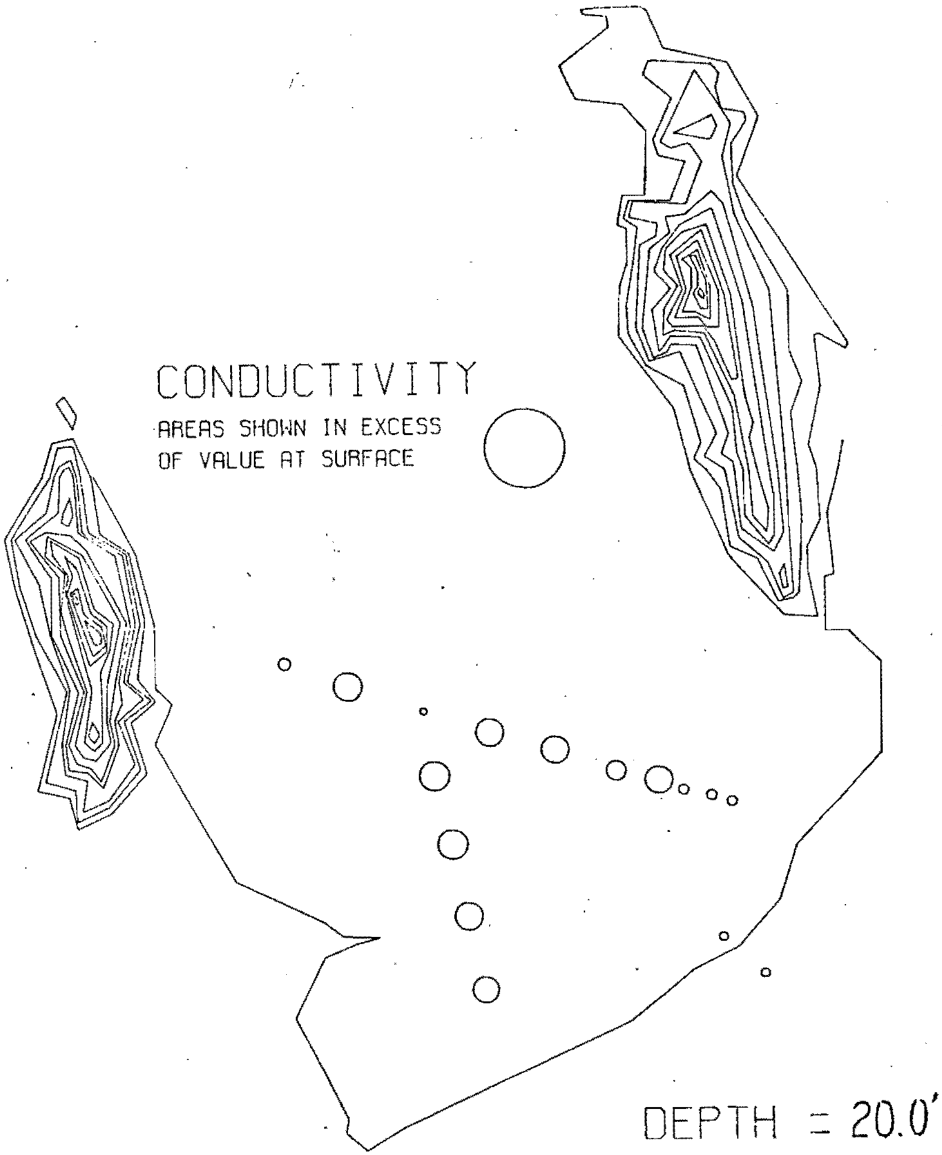

Figure 7

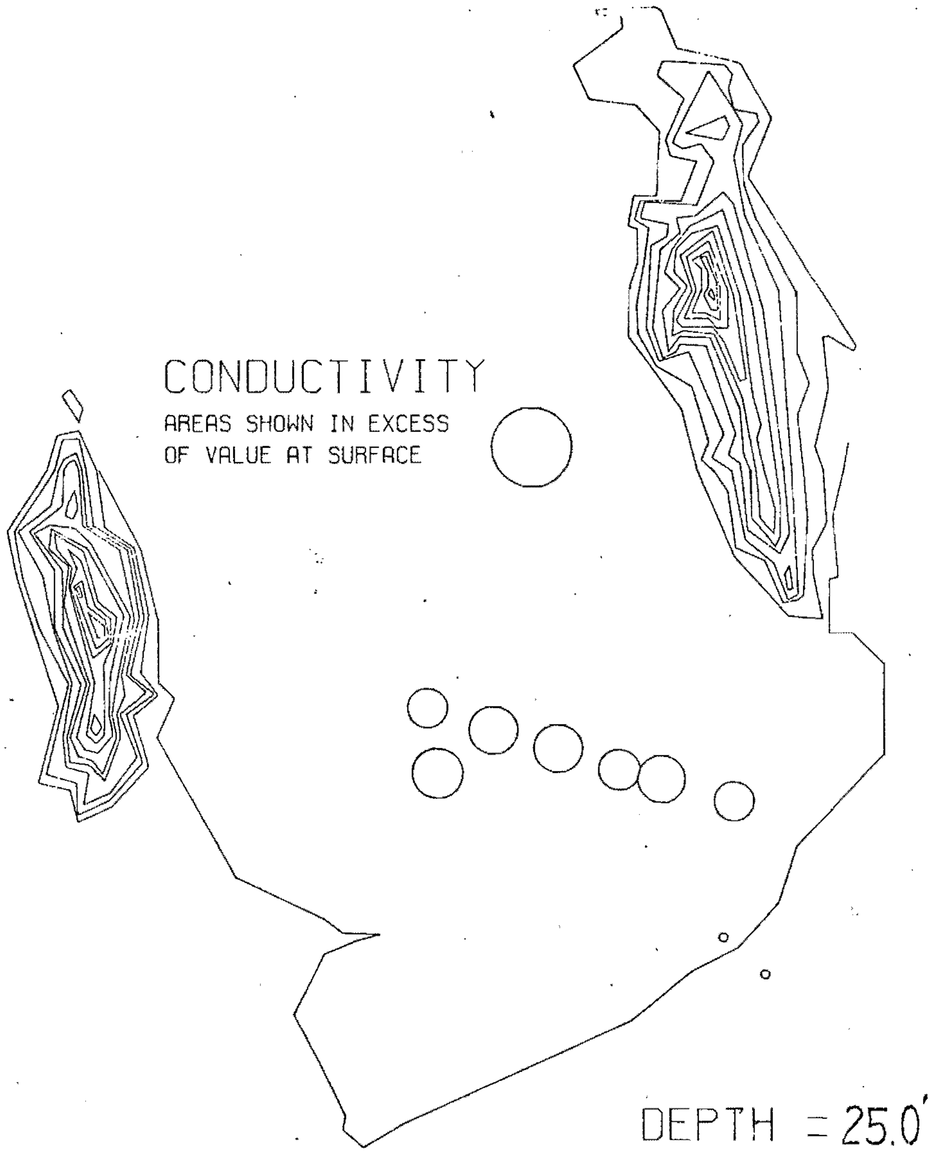

Figure 8

Conclusion

There are two major points in this study which warrant emphasis:

(1) detailed structure of temperature, dissolved oxygen, conductivity and pH values were for the first time obtained and as a result one was able to observe some of the very subtle characteristics of the lake water; more extensive study of the same kind will lead to the revelation of some puzzles related to the lake, such as the source of the deep brine in the south arm of the lake;

(2) comparative study of the lake between the lake and the Dead Sea proved to be very fruitful. There are many similarities between the two bodies of water and advantages should be taken of the fact that the Dead Sea was studied substantially more, and many of the experiences on the Dead Sea could be useful to the research workers on the Great Salt Lake.

Acknowledgments

This work is sponsored by the National Science Foundation under grant No. GA3086. The authors are indebted for the abundant administrative support from Dr. J. E. Fitzgerald, Department Chairman of Civil Engineering. Without the superb craftsmanship of Mr. Blaine Fullmer and Mr. Toney Howard, this work would not have succeeded. The authors are also very thankful to the many useful discussions and comments offered by Dr. William P. Hewitt and Dr. James A. Whelan of the Utah Geological and Mineralogical Survey.

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COMMUNITY STRUCTURE AND ECOSYSTEM ANALYSIS OF THE GREAT SALT LAKE

D. W. Stephens and D. M. Gillespie[1]

Abstract

The construction of an earthfill causeway across the Great Salt Lake resulted in development of two basins within the lake. The northern basin supports a depauperate biota consisting primarily of an alga, Dunaliella salina, several protozoa, and bacteria. The southern basin exhibits two energy flow systems with only minor interactions: The planktonic system with a single phytoplankter, (Dunaliella viridis), and a single zooplankter, (Artemia salina); and a benthic system of blue-green alga (Coccochloris elebans), detritis, and brine fly larvae, (Ephydra). The only outflow from either system occurs when birds feed upon the shrimp or fly larvae. The Dunaliella population seems to be limited early in the calendar year by temperature and light. Dunaliella viridis reaches its peak population density (24- x 10^6/liter) in April and its decline to less than 1 x 10^6/liter occurs in May and June as a consequence of the rapidly expanding Artemia salina population. The availability of the nutrients nitrogen and phosphorous does not seem to be a limiting factor for Dunaliella.

KEY WORDS: Ecosystem; Brine shrimp; Artemia salina; Dunaliella; Energy flow; Plankton.

The Great Salt Lake is a prime example of an extremely rigorous environment. Due to its shallowness (< 9 m), the temperature ranges from freezing to near 40°C over a year's time interval. Coupled with this is the topography of the surrounding area which drains most waters in the Bonneville Basin into the lake. Anything soluble in water or capable of transport by water is carried to the lake, including partially treated sewage and industrial wastes of communities from Spanish Fork to Logan. The more hostile and demanding the environment, the fewer are the types of organisms which are capable of inhabiting it. In fact, the existance of relatively few types of organisms but large numbers of them in a body of water is currently used by some as an indicator of a specialized or a polluted system. The lake superficially appears as a grossly polluted system but one relatively capable of self perpetuation because of the adaptations of the biota within it.

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It is very fortunate for the communities bordering the lake that three large sewage lagoons exist to partially stabilize the wastes which are discharged into the lake. These lagoons, Bear River Bay and Ogden Bay, which receive drainage waters from the northern section of the Bonneville Basin, and Farmington Bay, receiving southern basin waters, effectively oxidize much of the organic material produced by the human communities along the Wasatch Front and thereby reduce the loading that would be placed on the Great Salt Lake.

The lake is very susceptible to changes brought about by man because it is such a simple ecosystem. The construction of the railroad causeway in 1957 resulted in the division of Great Salt Lake into north and south basins, creating ecologically two separate lakes due to salinity imbalance. Due to inflow and evaporation characteristics, there is a net migration of water and salts to the northern basin where the brine remains at or near saturation most of the time. The salinity problem was first reported by T. C. Adams in 1964.

The extremely harsh environment of the north end results in a very simple ecosystem consisting basically of the alga, Dunaliella salina Teodoresco, several protozoa, and bacteria. Visual comparisons of the north versus the south end show the pink color of northern basin waters to be due to the large number of the alga, D. salina which possesses a red pigment.

The southern portion of the lake is slightly less saline and therefore is not quite as rigorous an environment as the north. This fact is evident in looking at the ecosystem which has developed. There are two basic biotic systems operating in the southern portion: a planktonic system consisting of the alga Dunaliella viridis Teodoresco, brine shrimp Artemia salina (L.), and several protozoa and bacteria (Figure 1); and a benthic sequence consisting of the blue-green alga Coccochloris elebans Drout and Daily, detritis, and the brine flies Ephydra spp. (Figure 2). The two systems are linked in that brine fly larvae will feed on detritis consisting of dead Dunaliella and Artemia, and Artemia will feed on the blue-green alga and shrimp fecal pellets when Dunaliella populations decline. The only outflow from either system occurs when birds (primarily gulls, Larus spp.) feed upon the brine shrimp or brine flies and when the brine flies emerge and leave the lake.

In any balanced ecosystem, there must be factors which limit the excess growth of constituent populations. In most systems the availability of nutrients acts as the controlling device. Our work with the large populations of Dunaliella

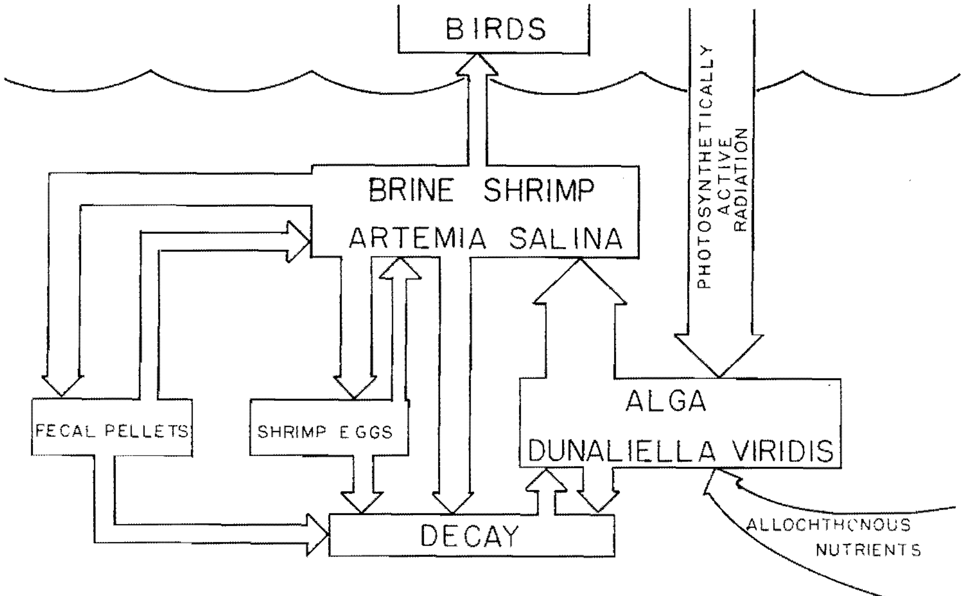

Figure 1. Energy flow - planktonic sequence.

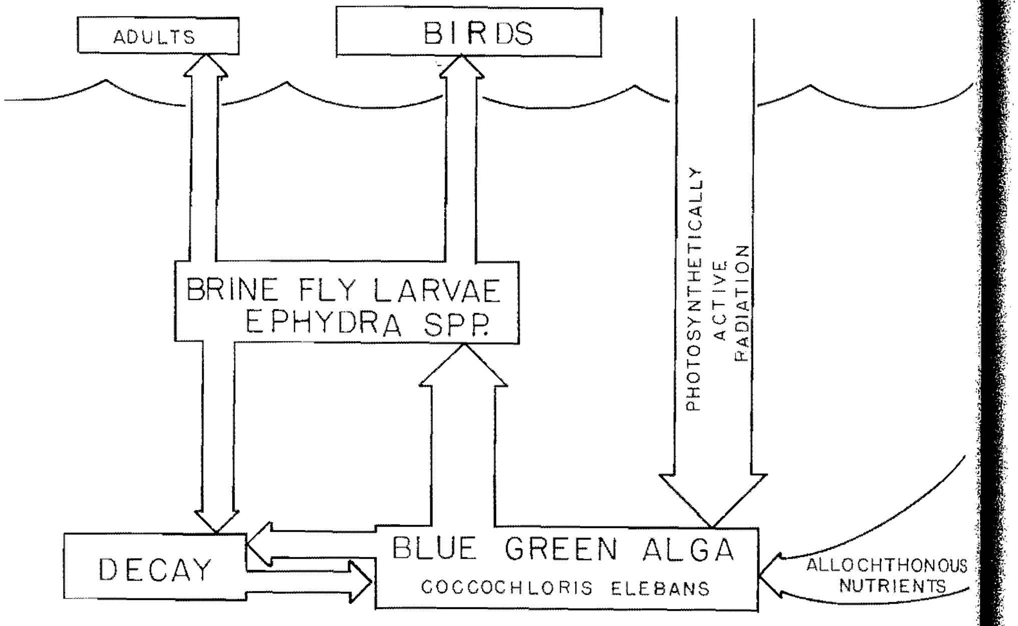

Figure 2. Energy flow - benthic sequence.

indicate that this may be the case, but inherent limiting factors such as competition for CO_2 and self shading due to the tremendous populations may also be operative. The algae appear to be present all year with resting stage zoospores making up the majority of the population from November to February. As the water temperature warms to 5° - 10°C and the incident solar intensity approaches 200 Langleys per day, the Dunaliella begin active growth and reproduction. Data from 1971 (Figure 3) show that Dunaliella populations increased from 1 million/liter to 75 million/liter in the period from January to March. From March to April, the population grew to 236 million/liter. Algal populations are typically limited by the availability of the nutrients nitrogen and phosphorus. Data (Coburn, 1972) available on the nitrogen and phosphorous loading contributed by the sewage enriched waters of the Jordan River over a five-year period shows that on an average, 8,680 # NO_3 and 3,047 # PO_4 enter from the Jordan each day. Influent water quality from the Jordan is believed to be fairly representative of the Weber River and Bear River. This has led us to believe that these nutrients are not limiting. We are currently testing this hypothesis.

A definite limitation on Dunaliella population increase is light. During January through April, the algal population is low enough to permit light to extend to near the bottom of the lake. (There is some colloidal suspension of salt crystals which may limit full penetration.) This allows algae at all depths to actively photosynthesize and increase their numbers. During May, the numbers of algae become so great that they effectively block out most of the photosynthetically active light from depths greater than one meter.

In attempting to locate a limiting factor, we have examined the population dynamics of the brine shrimp, Artemia salina. This organism is present in the lake at all times when the water temperature is above 9°C. Active Artemia appeared in April, 1971, when the water temperature ranged from 9-14°C. The first generation appeared from thick-walled winter eggs laid in the summer and fall of 1970. During April and May, 1971, the Artemia population increased from 0.01/liter to 20/liter. Artemia is an efficient filter feeder and grazes heavily on Dunaliella. One study (Mason, 1963) has shown that one Artemia may consume up to 10 million cells per day of a related species, Dunaliella tertiolecta. During the peak period of the Artemia population in June, the algae had dropped from 300 million/liter in late May to less than 1 million/liter. It fluctuated near this level throughout the remainder of the year.

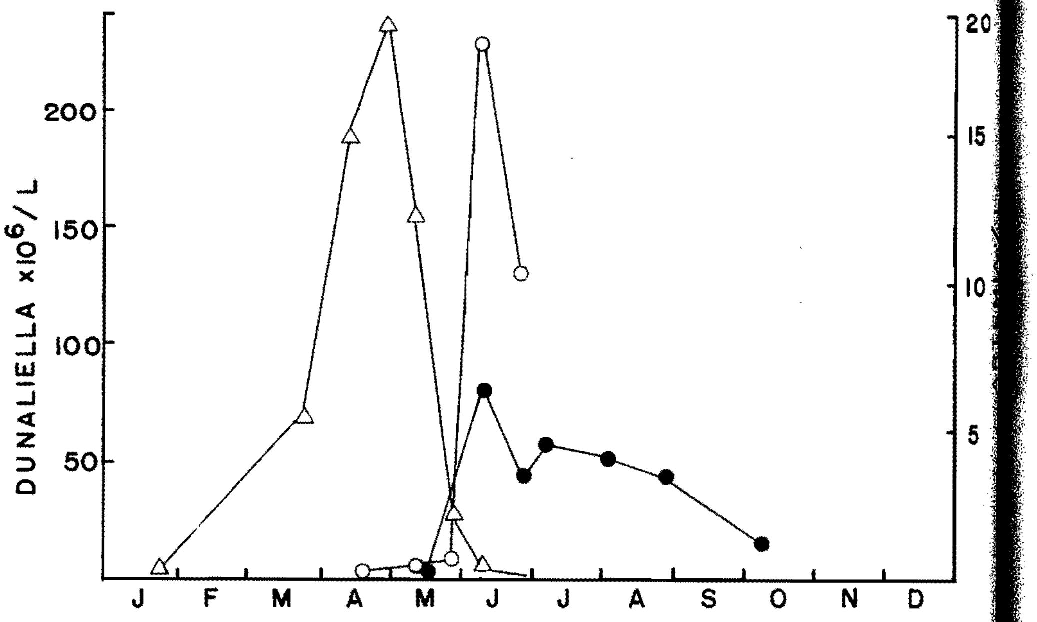

Figure 3. Plankton concentration: △ Dunaliella 1971; o Artemia 1970; o Artemia 1971.

The Artemia population declined from 20/liter in late June to 10/liter in July, following the great reduction in its primary food source, Dunaliella. It is this "food stress" which initiates the production of thick-walled durable eggs which survive through the winter. Artemia have the ability to "store" food by forming fecal pellets. These are normally formed from undigested foods and wastes released by the shrimp as it feeds. The pellets possess a greater density than the water and sink to the bottom. As normal food sources become scarce, the shrimp has only to feed upon the fecal pellets on the lake bottom in order to obtain sufficient energy for metabolism. In addition, the shrimp may also feed to some extent on the blue-green algae growing on the calcareous bottom reefs.

We have little information on the benthic community, consisting primarily of brine fly larvae, Ephydra spp., and blue-green algae, Coccochloris elebans. It would seem that the alga is limited by light early in the year, and grazing by the brine fly larvae. The limitations upon the larvae are most likely temperature and the availability of algae.

Wirick and Gillespie (in press) have presented a mathematical model of the lake ecosystem. The model is an extrapolation of species parameters for the planktonic sequence which give a simulation of the actual community. We are currently studying carbon fixation and biomass production, and it is believed that these values will be very high, especially in the spring, indicating a highly productive system.

The question arises: Is this highly productive system with its low degree of species diversity actually very stable? There have been no catatastrophic events occur on the lake during recent times except the chemical and physical changes wrought by the causeway. Essentially the same population structure has existed since pre-white man times. It would seem that the yearly fluctuations in salinity and temperature are sufficient to upset the balance of the system, yet the community has evolved a limiting cycle which adequately maintains a stable structure. The massive discharges of organic materials that reduce species diversity in most systems only enhance population growth by providing nutrients in the Great Salt Lake, although the cumulative effect of this accelerated eutrophication could be disastrous. All of these factors indicate to us that in this extremely rigorous environment, species diversity is reduced but stability is maintained by the flexibility and large gene pool of the constituent populations. This has resulted in not only numerous physiological adaptations, but also development of resting stages which allow perpetuation of the population through the most demanding of circumstances.

What of man's influence on this unique resource? Most evident is the railroad causeway and its effect on salinity. The density of the south end averages approximately 1.17 g/ml for the zone down 5-6 m. The north end has a greater density of 1.22 g/ml (Hahl and Handy, 1969). While the north end will not gain appreciably in density because it is at saturation with regards to the most prevalent ions, the south end is becoming less dense due to fresh water inflow and salt migration to the north end through the culverts. Brine shrimp winter eggs have a neutral bouyancy in waters with a density of about 1.15 g/ml. In the past the eggs have floated on or near the surface allowing hydration with fresh water inflows to the lake in the spring. This contact with fresh water seems to stimulate hatching and promotes population growth early in the spring. Our field data from 1972 has shown that the density has at times been as low as 1.12 g/ml and there have been large numbers of brine shrimp eggs collected at or near the bottom of the lake. This indicates a lag in reproductive adaptation to the rapidly changing density. Our data are too sparse to permit accurate predictions of long-term effects on the shrimp populations.

The possibility that the lake may actually dry up due to man also exists. As more water is diverted for rural and urban useage, more of it is lost through evaporation, transpiration, and to aquifers. This may be partially counteracted by the increase in paving and development which reduces open soil and plant life, allowing greater runoff with reduced transpiration and charging of aquifers. The lake has grown measureably smaller since the 1870's and overall this will probably continue. Another effect of human population increase is noted in the quality of the return flows to the lake. Currently, there are a myriad variety of most chemical elements being discharged from industrial and domestic sources to the lake. Many of these substances are toxic and if their concentration reaches a critical level, they will effectively eliminate the flora and fauna of the Great Salt Lake and its three adjacent sewage lagoons. What will then occur will probably be analogous to the situation when a septic tank "dies", fills, and overflows.

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AN INDEX APPROACH TO FORECASTING THE SPRING PEAK LEVEL OF THE GREAT SALT LAKE

Aaron L. Zimmerman[1]

Abstract

Throughout the period of recorded history the fluctuating level of the Great Salt Lake has been a reflection of the changing climate of the Great Salt Lake Basin and, to a lesser extent, the changing uses and development of the basin's water resources.

Although the long term trend in the level of the Great Salt Lake the past hundred years is downward there are cyclical periods of rise and fall. These periods vary in length from a few years to more than ten. The latest rising period in the mid 1960's and early 1970's resulted in lake level of 4198.2 above mean sea level feet at the peak of the spring rise in 1971, a level more than 6 feet higher than the lowest level in recorded history which occurred in 1963. In response to the need for an estimate of how high the lake's level would be at time of peak in the spring of 1972, in the fall of 1971 the National Weather Service River Forecast Center made a study of the characteristics of the lake's rise from lowest level in fall to highest level the following spring for the period 1930-1971. An objective procedure was developed to forecast the spring peak at any time after December 1; forecasts of the 1972 spring peak were prepared and issued at the first of each month, December through May.

A description of the procedure, discussion of the parameters used in the prediction, examination of the procedural errors for the period of record, limitations imposed by the "state-of-the-science" of precipitation and weather prediction, will be the main topics of the presentation planned. As will be illustrated in the presentation, major year-to-year differences in the level of the lake result largely from the variations of inflow from the large rivers emptying into the lake and also from variations in the precipitation falling on and in very close proximity to the lake.

The winter rise (arbitrarily defined as rise between December 1 and March 1) averages 8/10 foot. The spring rise (March 1 to peak) averages 7/10 foot; it has a significantly greater range than the winter rise and is less predictable. The forecast procedure to be presented is based upon using index values of precipitation and streamflow for prediction of the lake level. The forecast itself can be predicted upon differing suppositions about precipitation subsequent to the time of forecast. The forecast of "most probable" is defined as that which will occur if "normal" subsequent conditions are observed.

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The fluctuations in the level of the Great Salt Lake from year to year are in a large measure a reflection of the varying annual precipitation falling in the Great Salt Lake Basin (Peck and Richardson, 1966). The cyclical characteristics of the past rising and falling trends in the lake level have provided a continuing source of speculation about the future. However, past weather-related cyclical variations, unfortunately, are too unreliable to be of much value in predicting when the cycle will change. Since 1969, when a major seasonal rise of 2.9 feet brought the lake level up to 4197 feet above mean sea level for the first time since 1958, there has been an increasing interest in the present upward rise which began in the early 1960's. In mid-May 1972 the lake level reached 4199.7 feet, highest since 1953. The recent high levels of the lake are affecting lakeshore resort owners, the maintenance of the Antelope Island road, and the efficient operation of evaporation ponds along the lake's periphery.

While weather prediction in the time frame of the next several months is presently beyond the state of the science of meteorology, a large part of the inflow to the Great Salt Lake lags behind the precipitation occurrence. This allows some predictive time in anticipating the magnitude of the seasonal (low point in fall to high point in spring) rise.

Methods for predicting the peak spring lake level have been developed in the past, but to the author's knowledge have been used very little (Peck, 1954). The procedure outlined in this paper can be best described as an "index" approach to prediction. There is no reason to believe that the method represents the best index, because only limited exploration of all the past available data was made. But, the obvious relationships between precipitation on and near the lake and lake level, and between surface inflow to the lake and lake level are treated in time intervals which allow prediction of the high spring lake level, with reasonable accuracy, by December 1. The take-off point for the prediction of a following spring's high lake level is the low point the preceding fall. The rise from low point in fall, usually about November 1, to high in spring, usually around June 1, is arbitrarily divided into three periods: (1) the fall rise (low point to December 1), (2) the winter rise (December 1 to March 1), and (3) the spring rise (March 1 to high point). The period of study for the predictive procedure is from 1931-1971. The procedure was used to predict the spring high level in 1972, with good results.

The fall change in the lake level is quite highly correlated with fall precipitation (September through November) on the lake and in its immediate vicinity (Figure 2). The fall change averages less than .2 foot rise for the 42-year period (1931-71); it has equalled or exceeded .3 foot in twelve of these years, with the maximum fall rise of .6 foot in 1971, or water year 1972.

The winter rise, December 1 to March 1, has averaged .8 foot in the 42-year period, ranging from a low of .3 foot in 1933 and 1955 to 1.5 feet in 1969. The winter rise has equalled or exceeded 1.0 foot in ten years and has been less than .5 foot in only six years. The average winter rise in the three-month period December 1 to March 1 represents almost one-half of the average total seasonal rise of 1.7 feet. The winter rise is quite highly correlated with fall and winter precipitation in the lake area, and the lower limits of the winter rise are highly correlated with the fall streamflow on the lower Bear River, the major winter contributor to river inflow to the lake. Figures 3 and 4 illustrate these correlations.

The spring rise, March 1 to peak, has averaged .7 foot in the 42-year period and it is quite highly correlated with the March-June runoff from the major rivers feeding the lake and with spring precipitation. The range of the spring rise is large, from zero in two years (no rise after March 1) to 2.1 feet in 1964, and 1.0 foot or more in twelve years. During June 1964 and 1967 a rise of .7 foot occurred. These were the wettest Junes in weather history in the vicinity of the lake, indicating the major effect from excessive rains in late spring. Figures 5 and 6 illustrate the spring rise correlation with both March-June runoff into the lake from the major rivers and spring precipitation, March-June.

Perhaps the most valuable index tool for forecasting the winter rise in the Great Salt Lake stems from the hydrologic characteristics of the Lower Bear River Basin. The Bear contributes, on the average, about 75 percent of the surface runoff into Great Salt Lake during the winter season. Unlike most of the rivers flowing into Great Salt Lake it has a relatively high winter flow. For example, at Colliston the four-month November-February average flow for the 42-year (1931-71) period is 305,000 acre-feet, which is about 70 percent of the total which occurs in the four-month spring runoff period, March-June. By contrast on the Weber near Plain City the November-February flow is only 33 percent of the March-June flow and in the Six Creeks near Salt Lake

FIGURE-1

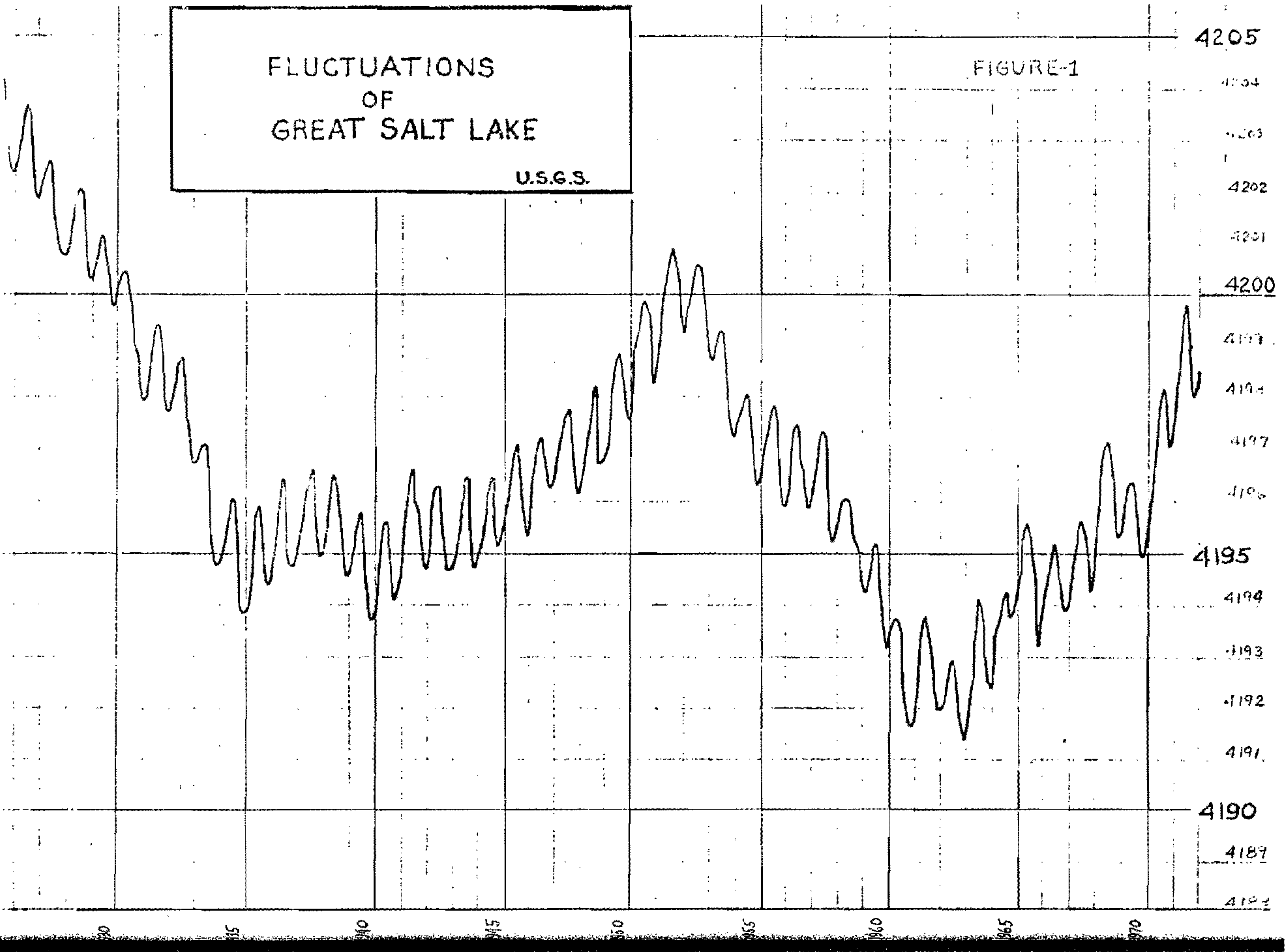


FIGURE-2

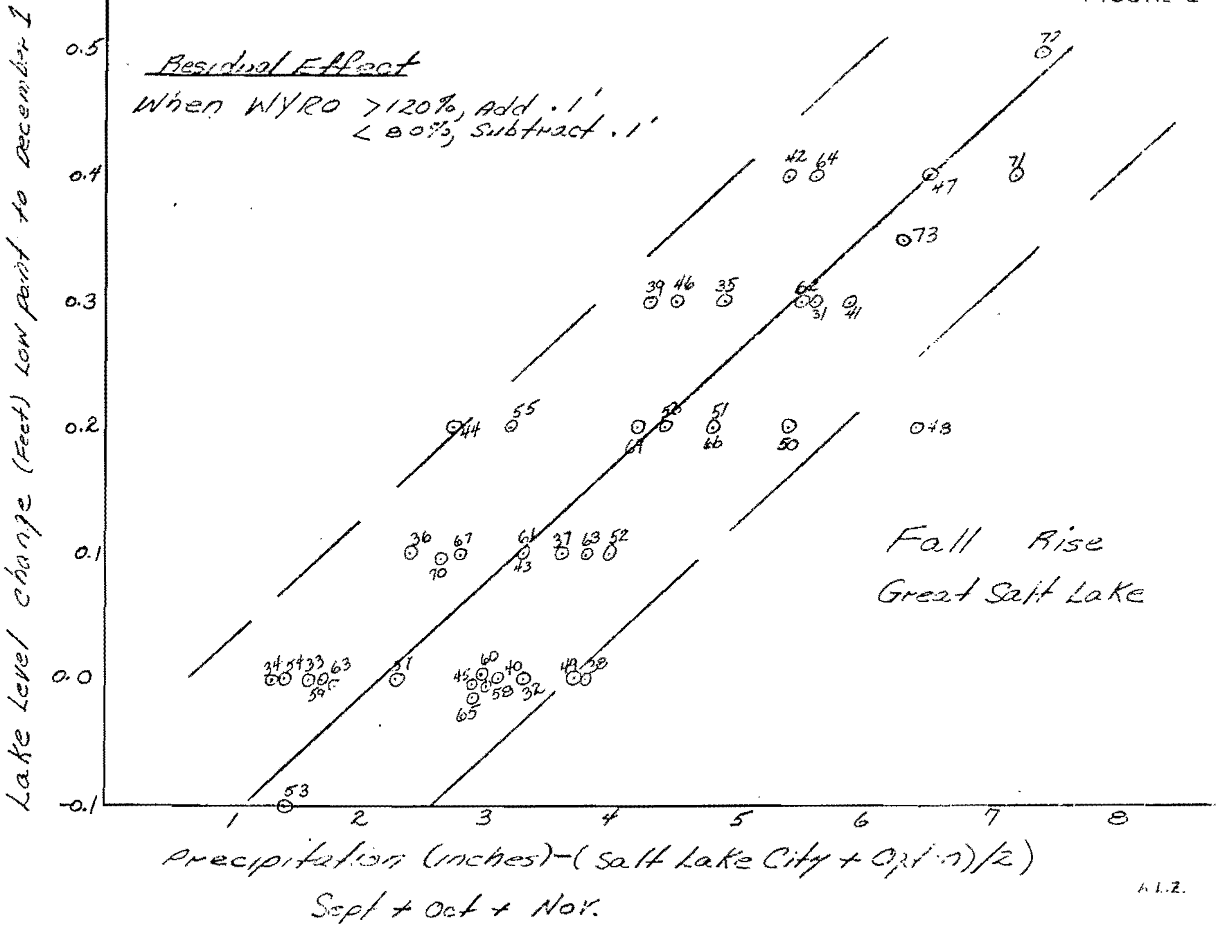


FIGURE-3

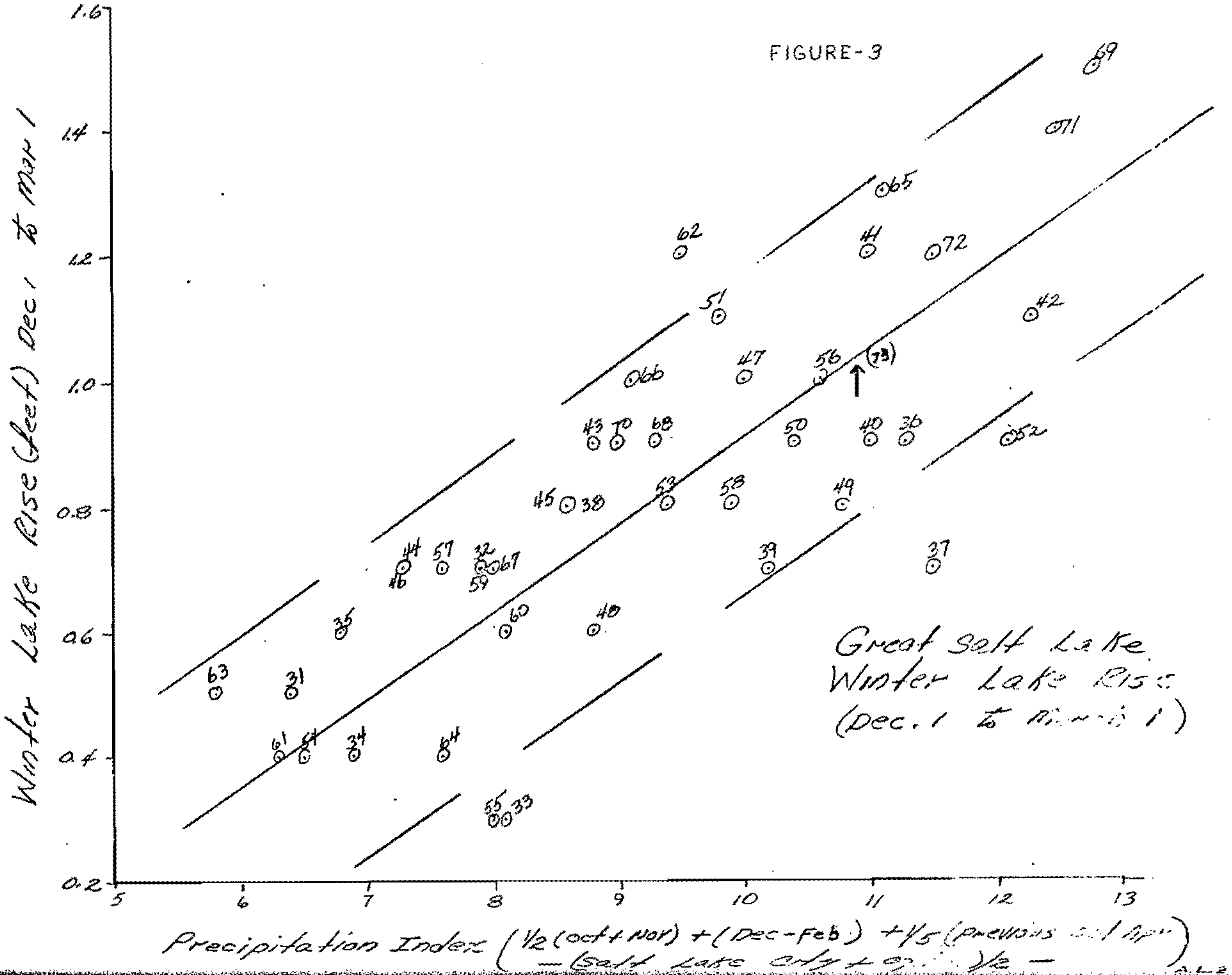


FIGURE-4

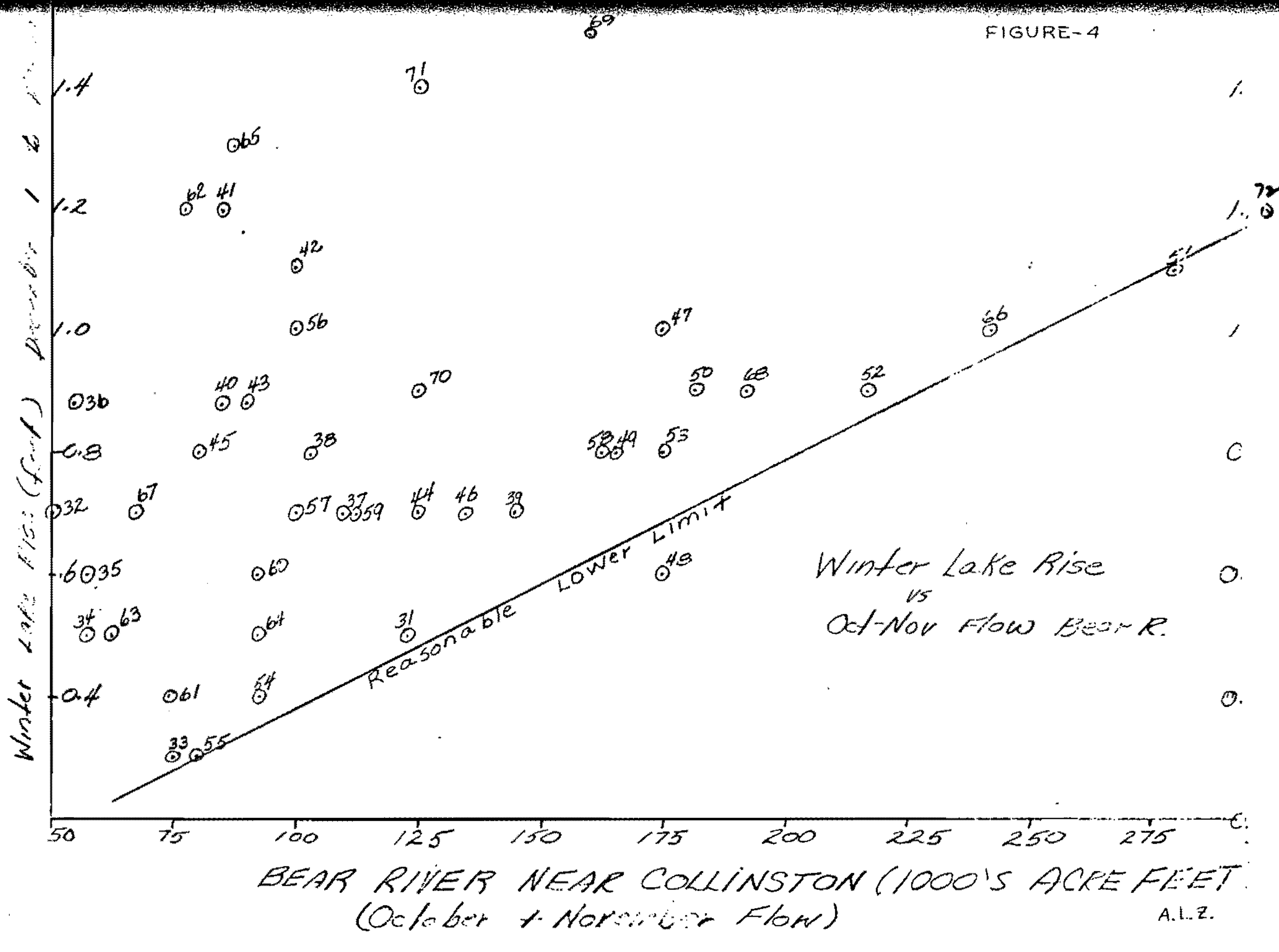


FIGURE-5

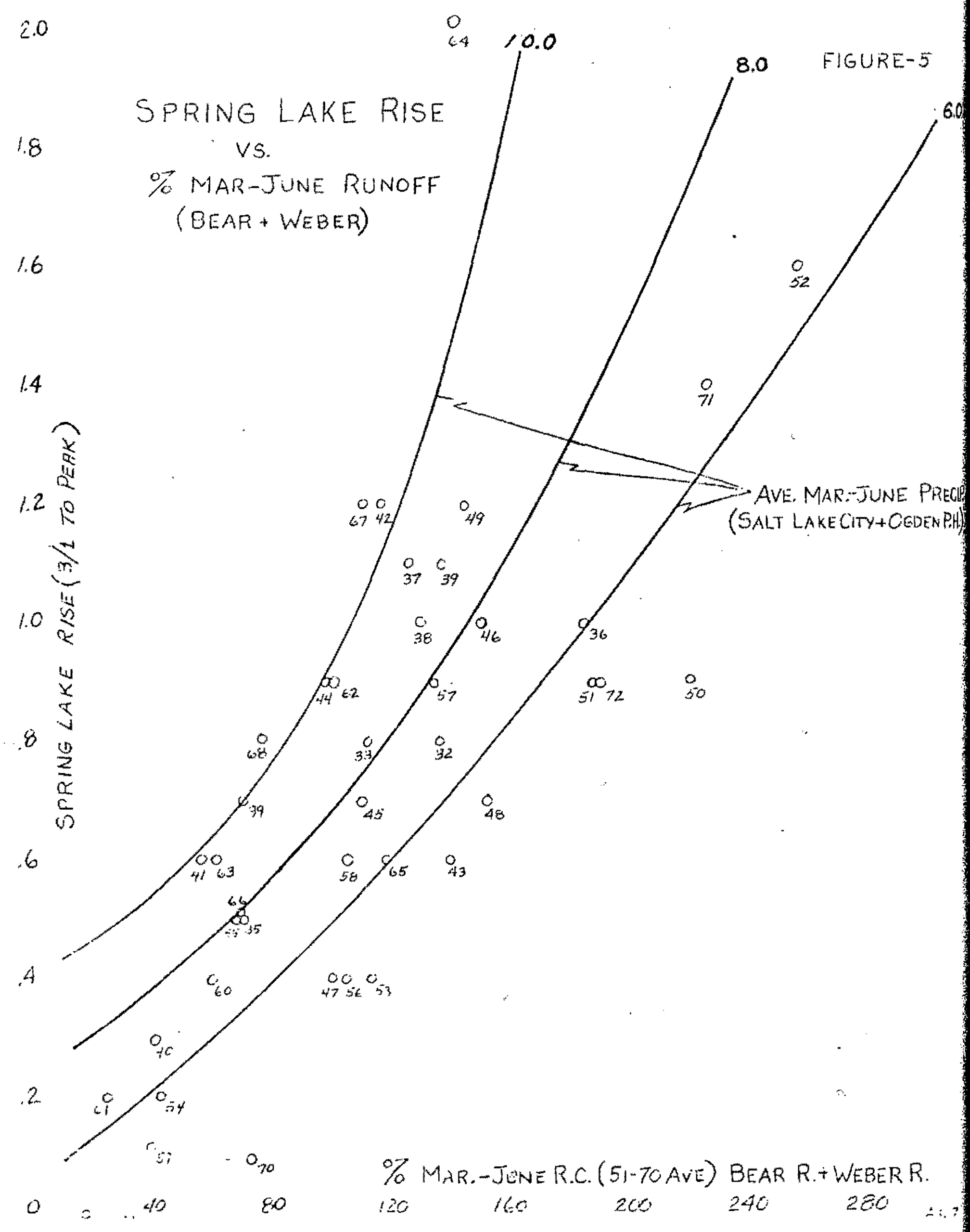
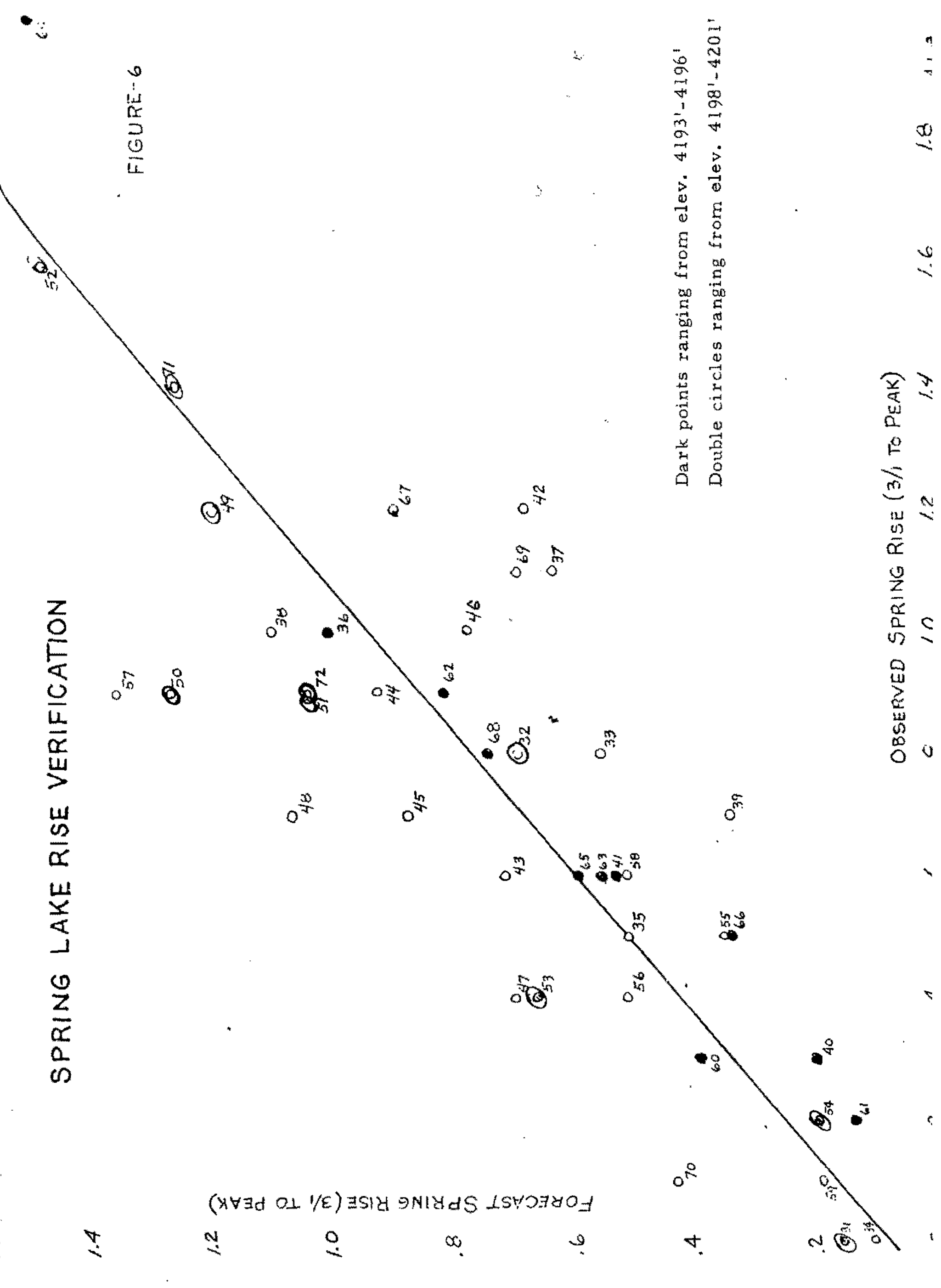


FIGURE-6

SPRING LAKE RISE VERIFICATION

Dark points ranging from elev. 4193'-4196'

Double circles ranging from elev. 4198'-4201'



City 18 percent. Excepting during infrequent periods when there is release from Utah Lake, the Jordan River has very low winter flow. Even more important from the predictive standpoint, the winter flow in the Lower Bear is well indexed by the October-November fall flow as evidenced by Figure 7.

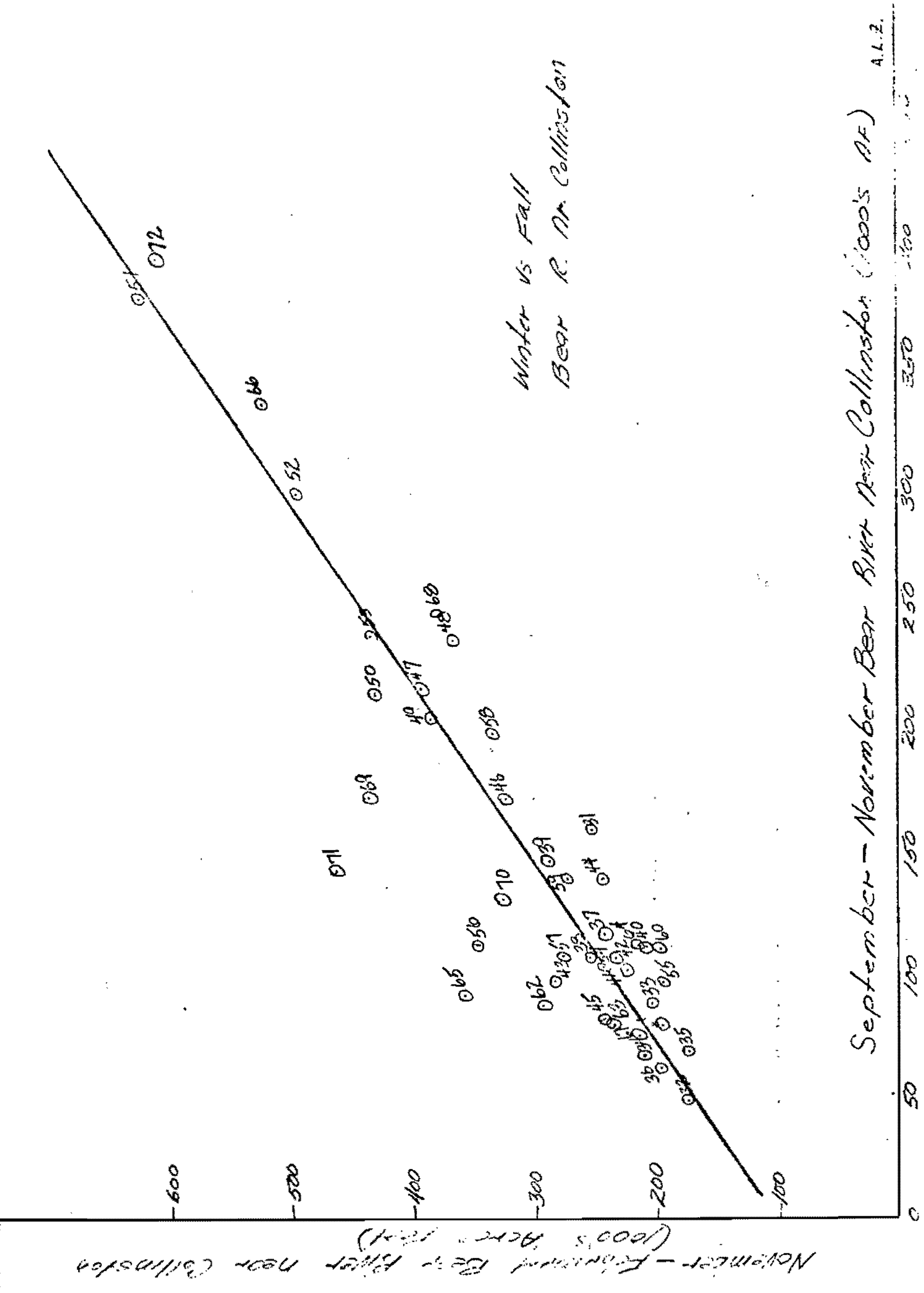
The relatively high predictability of the winter flow on the lower Bear River as early as December 1, as shown in Figure 7, provides a good estimate of winter inflow to the Great Salt Lake. By December 1 the winter operation of Bear Lake and Utah Lake is quite well firmed up - whether they will store or release water is quite predictable.

The spring rise in the Great Salt Lake, as previously indicated, is significantly less predictable on March 1 than is the winter rise on December 1. There are several reasons. One is the marked variability in consumptive water use in late spring, which is a function of the lack or excess of spring rain. Another reason is the climatological variability of spring precipitation in this area; still another is probably the larger variation in lake evaporation in the spring months than in the winter months.

The forecast method described herein relates lake level change to the gage reading at the County Boat Harbor Gage. The lake elevation-volume relationship (Figure 8) indicates a significantly changing slope from elevations of 4194 to 4202 feet. In the two-foot interval between 4194 and 4196 feet, the volume is about 1,400,000 acre-feet, while between 4198 feet the volume is approximately 1,800,000 acre-feet, an increase of about 30 percent. The effect of increased lake area with elevation should not be ignored in any predictive procedure, but there are complications in the elevation-volume relationship in Figure 8. The tilt in the lake brought about by the causeway built in the late 1950's is shown in Figure 9. Undoubtedly the lag in equalizing levels of the lake on both sides of the causeway in rapidly rising or falling trends affects the elevation-volume relationship.

The plotted points in Figure 6 are distinguished to indicate peak levels in the 4193 to 4196 foot range, 4196 to 4198, and 4198 to 4201. There is a tendency for the general elevation-volume relationship to show up in the spring rise plot, with the forecast rise to be slightly high above 4198 and low below 4196 feet.

From indications, as of November 30, 1972, assuming near normal winter weather, the lake was forecast to rise about one foot to a level of around 4199.5



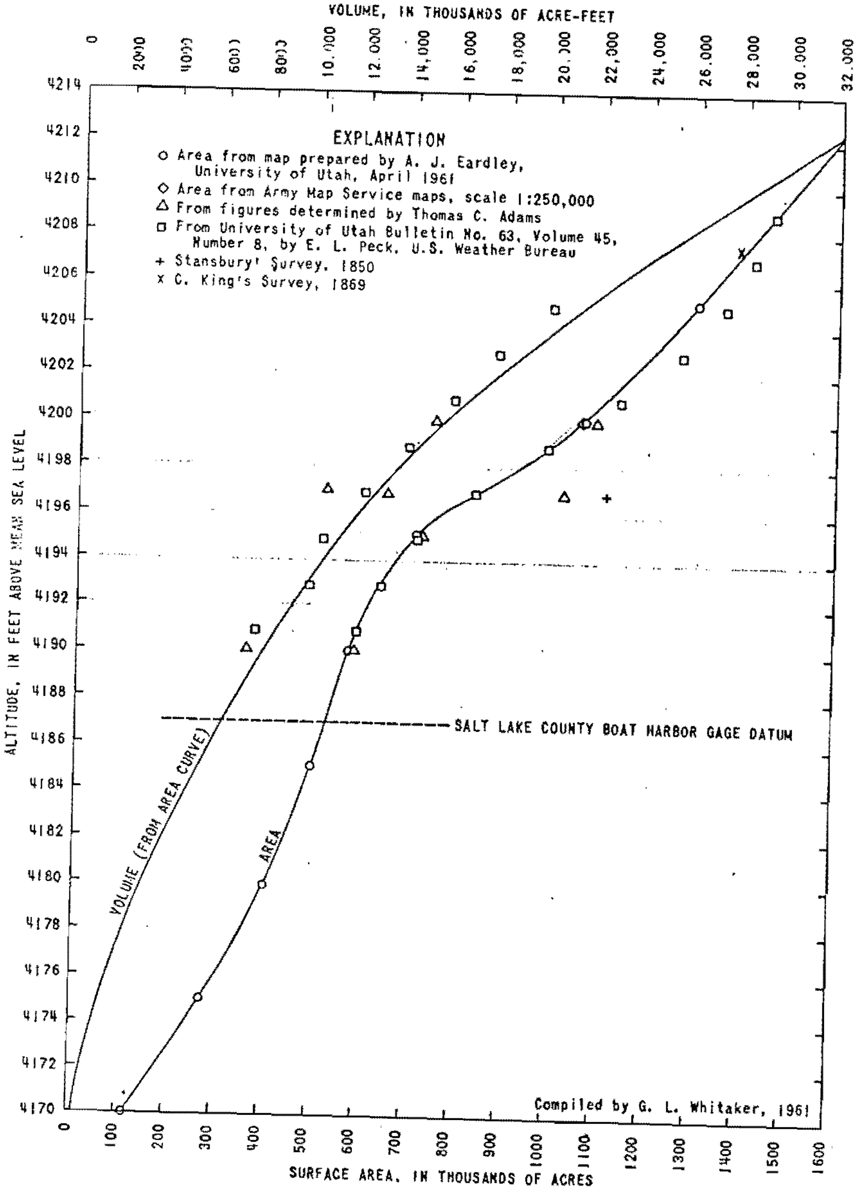
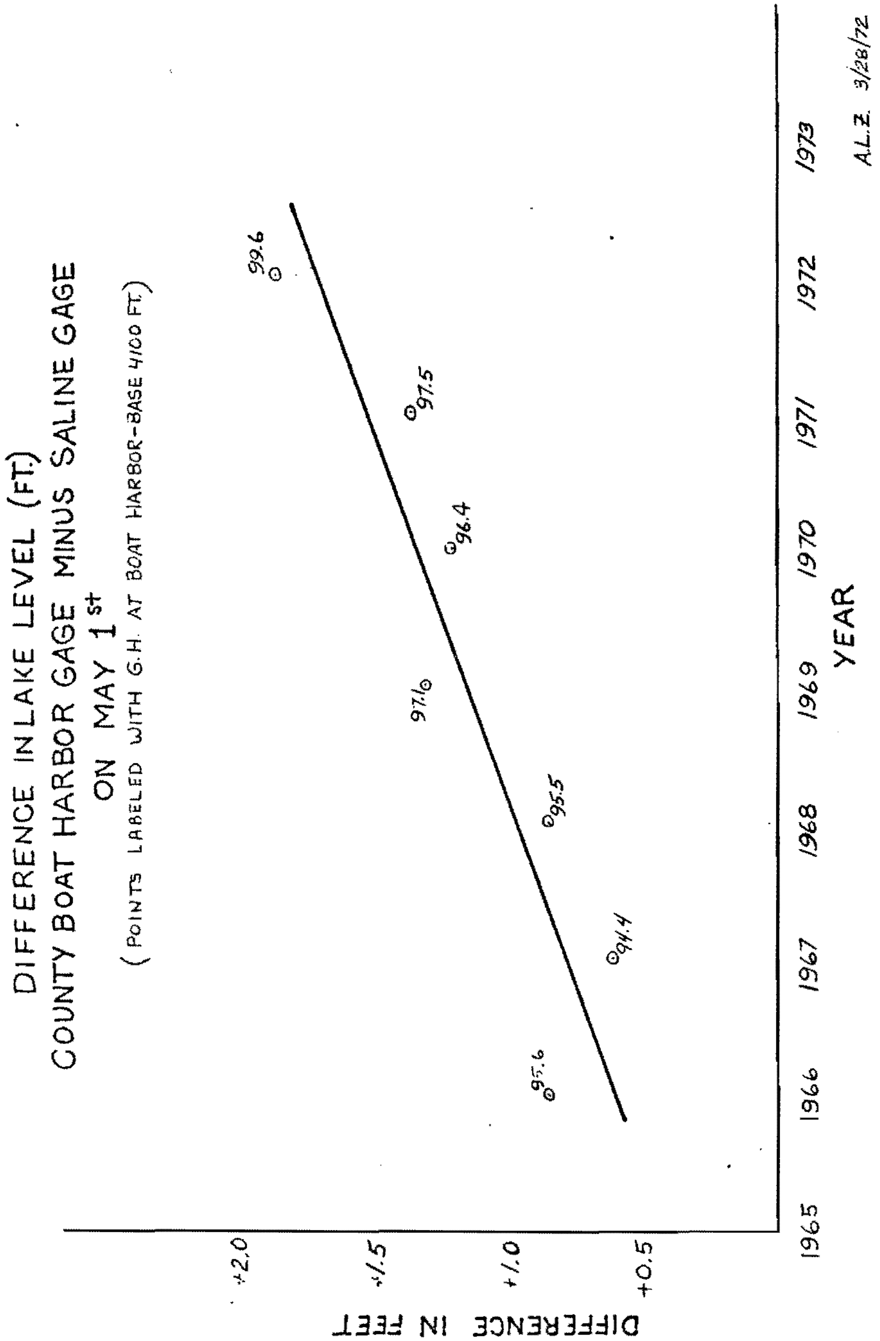


FIG. 8 — Relations among surface altitude, surface area, and volume of Great Salt Lake prior to 1957.

FIGURE-9



by March. An average spring rise of .7 foot would bring the lake above 4200 feet at time of peak and 4200.5 was well within reach. As of November 30, 1972 it appeared that only a very dry winter and spring would hold the lake to a level lower than that reached in spring of 1972.

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FORECASTING THE LEVEL OF GREAT SALT LAKE FROM SCS SNOW SURVEY DATA

Joel E. Fletcher[1]

Abstract

The annual volume of Great Salt Lake inflow and the elevation of the spring peak level of the lake may be determined from normalized snow water equivalent, normalized 1 January reservoir storage, normalized September precipitation and normalized October inflow to the lake. A multiple graphical procedure is used which is sufficiently simple for subprofessional personnel to use. The precision is similar to that obtained in conventional water-year runoff forecasts.

Introduction

Two types of forecasts for the level of Great Salt Lake have been required. The first of these is the annual volume of inflow and the second of these is the volume of inflow from 1 January to the peak elevation of the lake. The basic data available from which forecasts may be readily made are: (1) the snow water equivalent for a large number of snow courses at a wide variety of elevations and locations on the watersheds of the Great Salt Lake, (2) the September precipitation on the watershed to reflect the surface antecedant conditions, (3) the October streamflow to be an index of deep mountain storage or snow water carryover, and (4) the reservoir storage at the time of forecast to represent the surface storage.

Snow Water Equivalent or Storage Precipitation

It was desirable to have a procedure which laymen could use, so rather than weight individual snow courses for elevation aspect, etc., the snow water equivalent at each published station on the Great Salt Lake watershed was divided by its 2.33 year depth to render all values in a dimensionless form. These dimensionless values were then multiplied by 100 to put them in the form of percent of normal.

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In practice each snow course may not appear in a particular snow survey report but there is always a relatively large number so the arithmetic mean of all the available percent normal snow water equivalent was plotted against the percent of normal total annual inflow or percent normal 1 January to peak total inflow to the lake. The curves Figure 1 and 2a and b are for the 1 April percent of normal snow water equivalent versus the percent of normal annual inflow to Great Salt Lake (GSL) and the 1 January to peak inflow respectively.

Figure 3 shows a cumulative curve of the mean amount of snow water equivalent in terms of the 1 April amount falling during the periods of time from 1 October to 1 April inclusive. To use this curve, let us assume that we need the forecast from 1 January. To be 100 percent of normal by 1 April and no further precipitation occurs requires the 1 January value to be 213 percent of normal or the 1 February amount to be 150 percent of normal and so on. Such a procedure makes it possible to assume any percentage of normal precipitation from the forecast time to 1 April and still get an April 1 percent of normal snow water equivalent.

Reservoir Storage

The second parameter in the forecast procedure is the 1 October reservoir storage. Each reservoir content value is normalized and weighted for capacity. The weighted values are then added and divided by the total of all capacities reported to get the percent normal reservoir storage. This percent of normal reservoir storage value is then plotted against the deviations from the curves of Figure 1 called Δy_1 to obtain Figure 4. Figure 4 is used by entering the figure with the percent of normal reservoir storage, proceeding vertically to the curve thence horizontally to read Δy_1 which is the percentage of snow water equivalent which must be added to the original water equivalent to correct for the reservoir storage.

Mountain Groundwater Storage

The total October inflow to the GSL is considered to be an index of the deep mountain groundwater storage. The deviations from the curve in Figure 4 are considered to be Δy_2 and are plotted against October inflow in Figure 5. The Δy_2 values corresponding to the October streamflow are read from

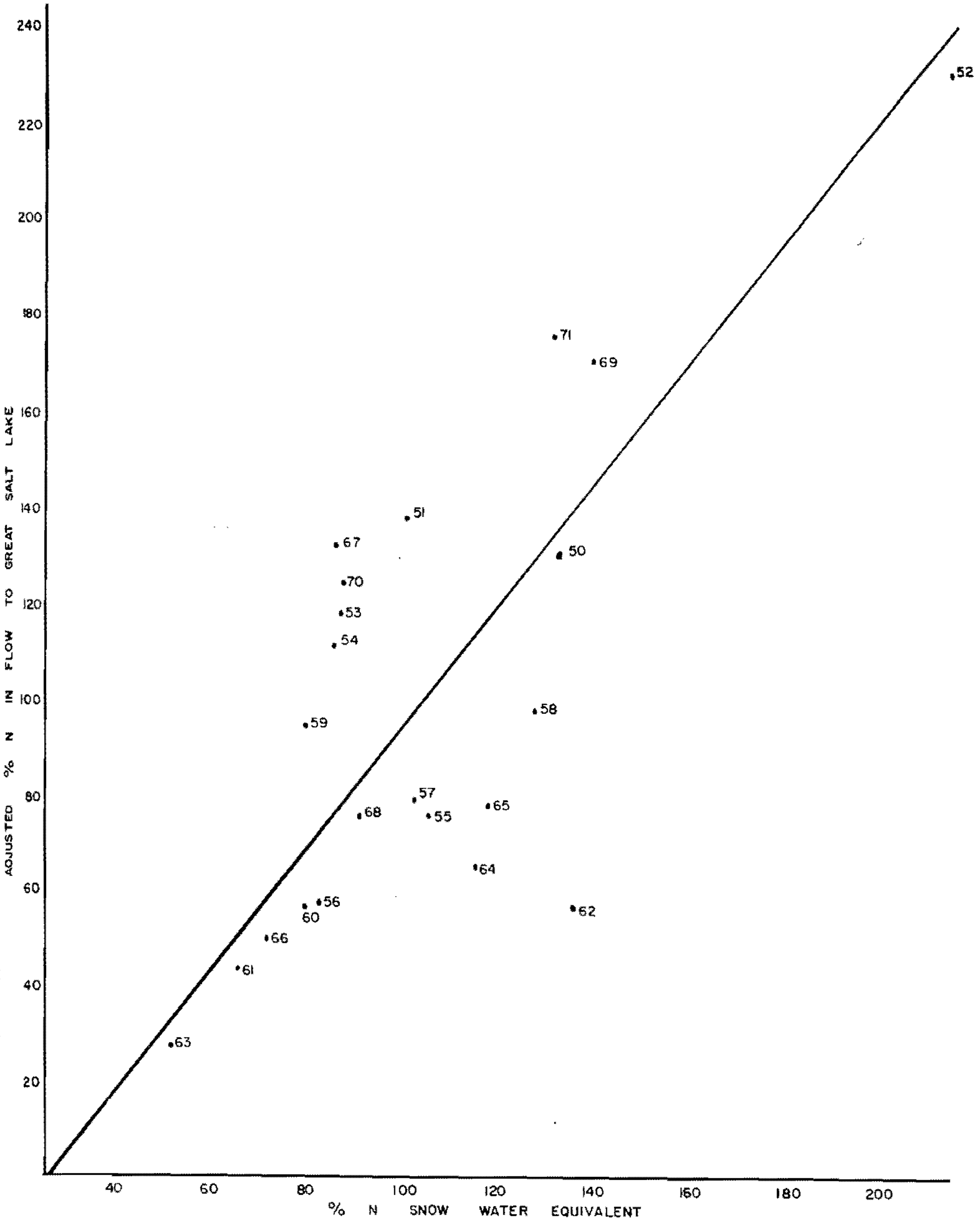

Figure 1. The relationship of adjusted percent of normal inflow to Great Salt Lake to percent of normal snow water equivalent on its watershed.

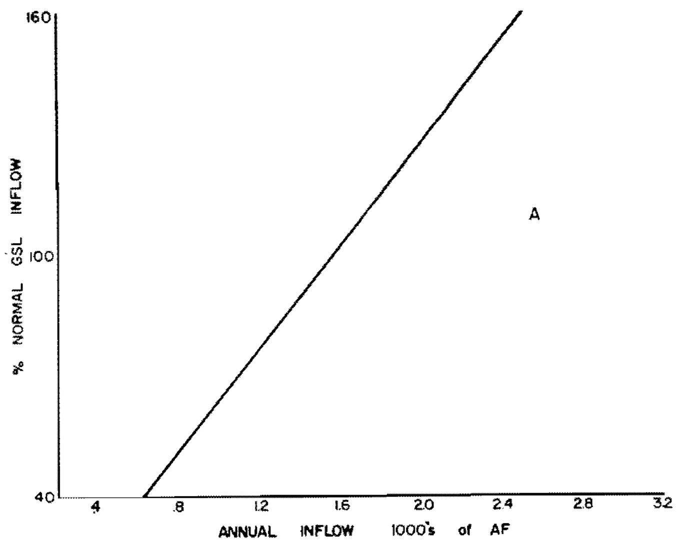

Figure 2a. The relation between percent of normal inflow to Great Salt Lake and the volume of annual inflow.

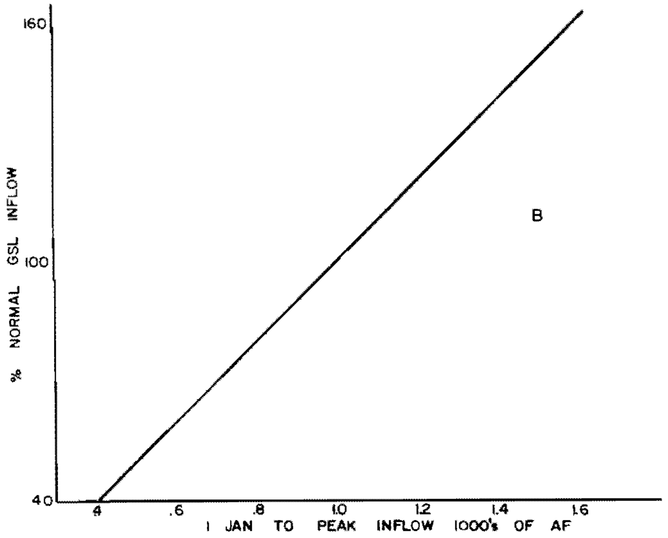

Figure 2b. The relation between the percent of normal inflow to Great Salt Lake and the volume of 1 January to peak inflow.

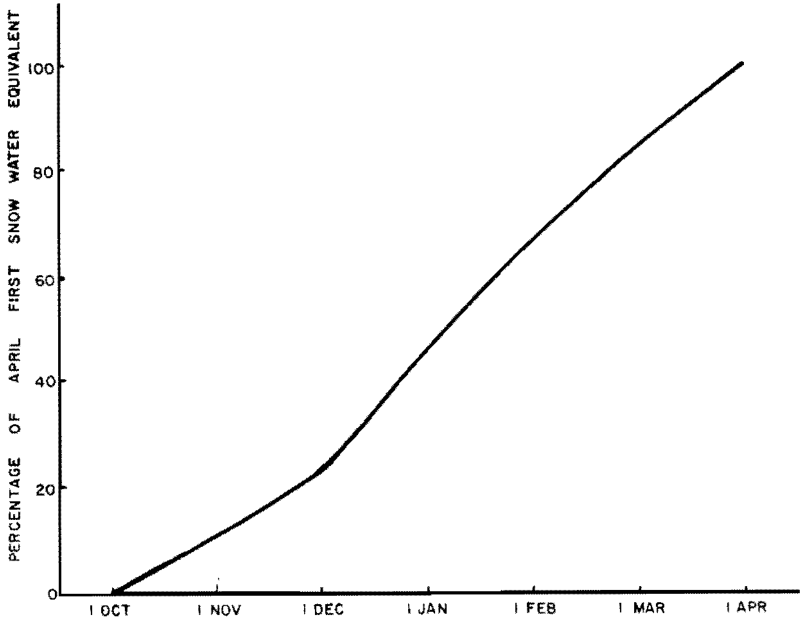

Figure 3. The relation between cumulative percent of 1 April normal precipitation or snow water equivalent and time after 1 October.

Figure 5 and as for the reservoir storage are added to the snow water equivalent percent of normal.

September Precipitation

The percent of normal September precipitation amounts on the watershed of the GSL is used as an index of the antecedent moisture conditions prior to snow accumulation. The deviations in the curve in Figure 5 are called Δy_3 and are plotted against the percent normal September precipitation in Figure 6. The Δy_3 values are read from Figure 6 and again added to the snow water equivalent.

Forecast

After obtaining the required percent normal snow water equivalent as a sum of the measured snow water equivalent, reservoir storage, October streamflow and September precipitation, Figure 1 or 2 is entered to obtain the percent of normal GSL inflow for the water year or 1 January to peak. Armed with this inflow, Figure 7 is entered with the 1 January GSL level

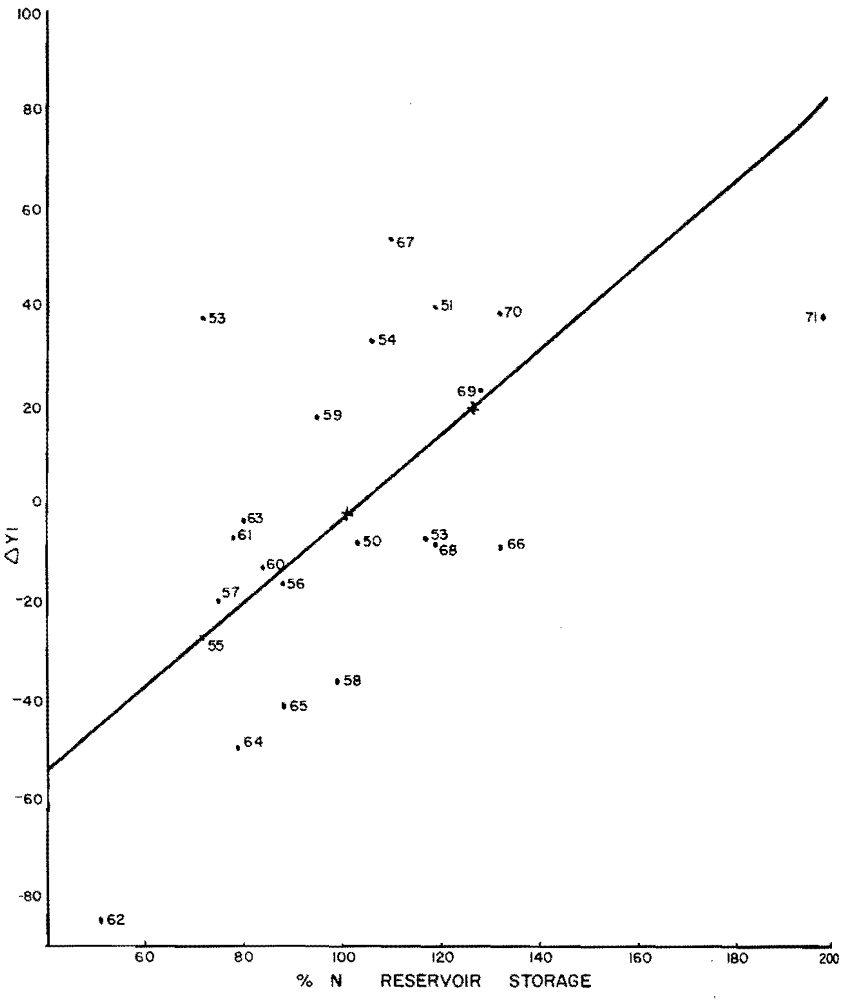

Figure 4. The relation between the deviations (Δy_1) from the curve in Figure 1 and the percent of normal reservoir storage.

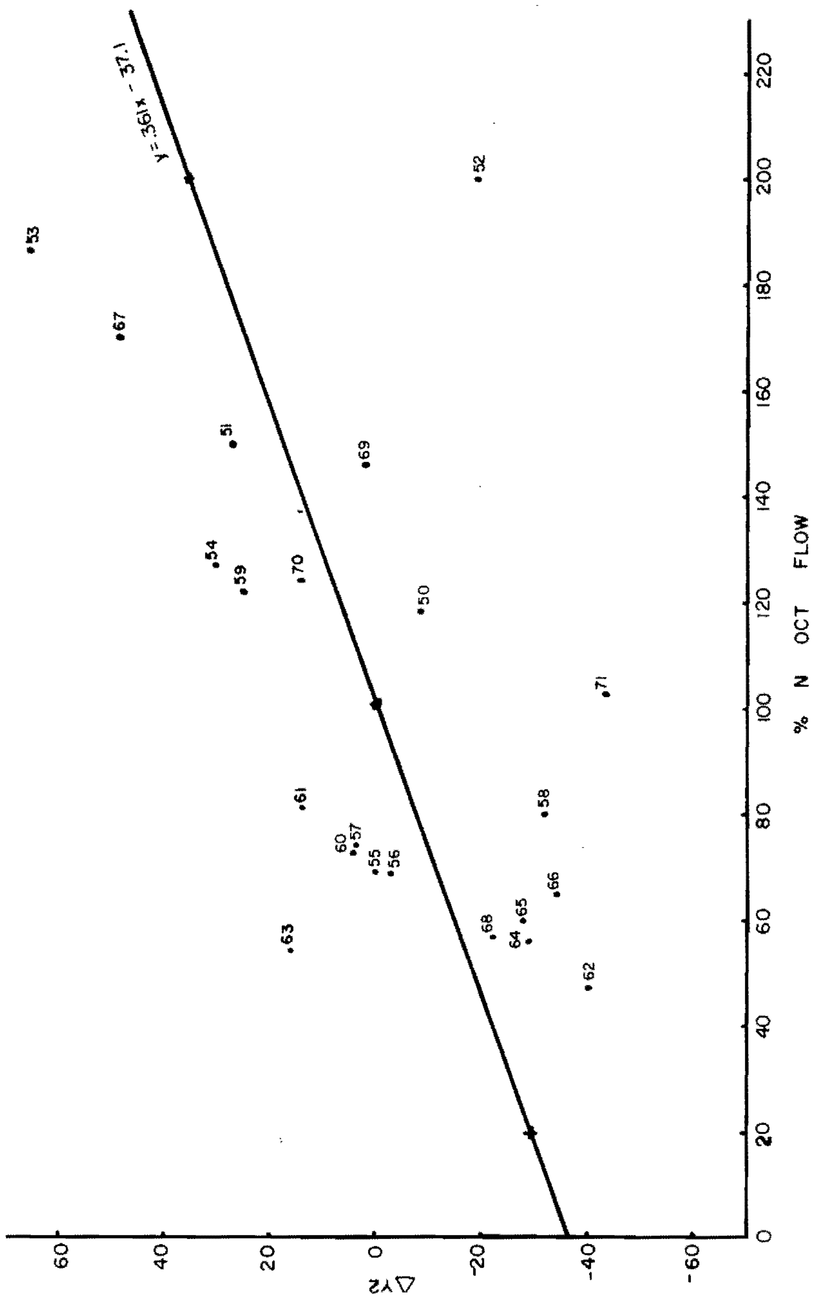

Figure 5. The relation between the deviations (Δy_2) from the curve in Figure 4 and the mountain ground water storage.

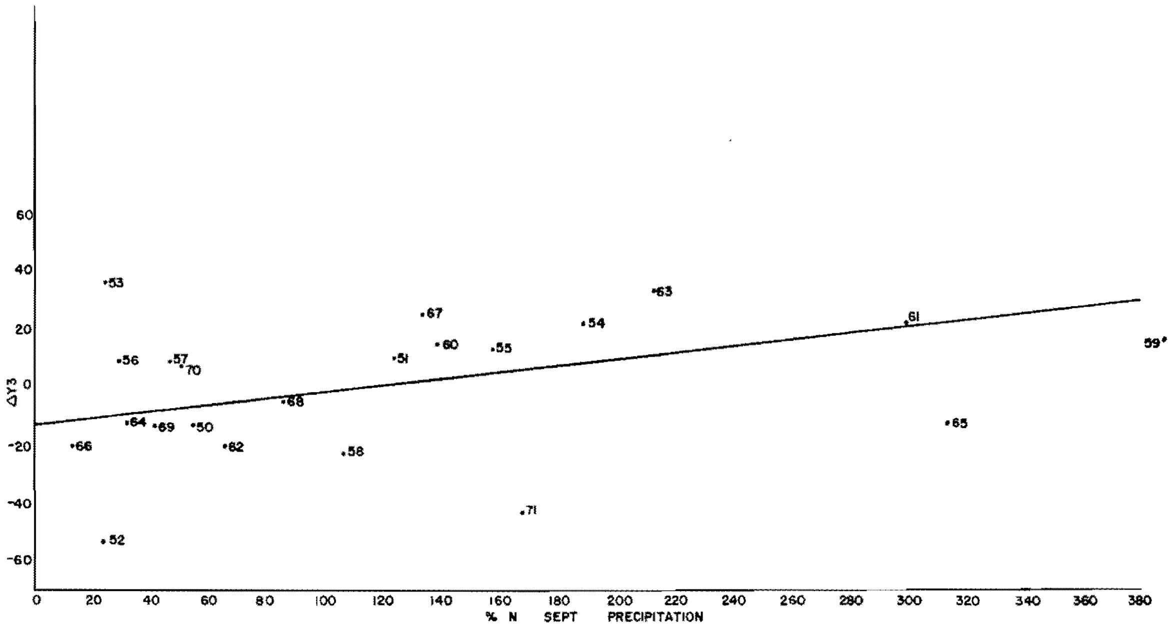

Figure 6. The relation between the deviations (Δy_3) in Figure 5 and the percent of normal September precipitation.

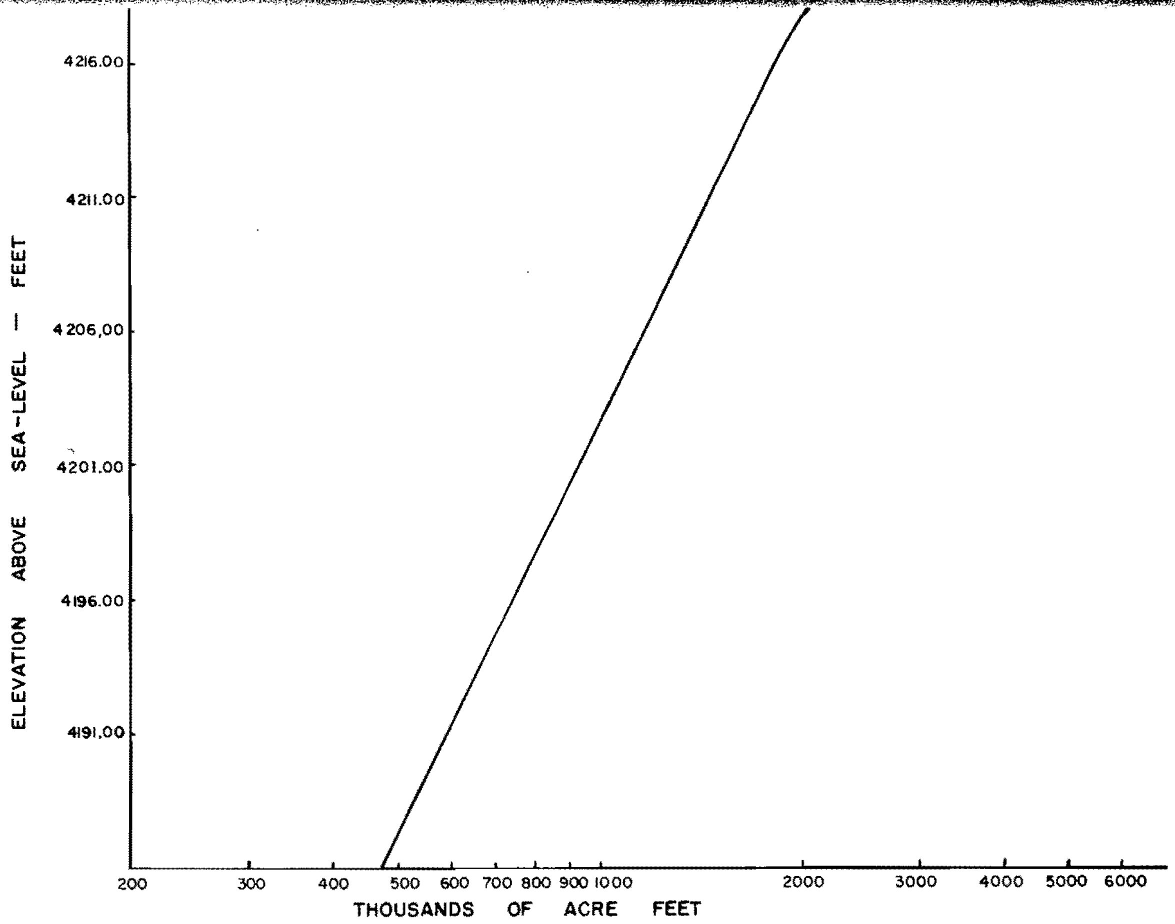

Figure 7. The relation between elevation of Great Salt Lake and the volume of 1 foot depth of the Lake.

and the inflow divided by the acre feet per foot to get the gross rise in feet. This figure must be reduced by the estimated evaporation for the period and increased by the precipitation.

It must be remembered that both the reservoir storage and snow water equivalent are subject to change after 1 January so any forecast must consider both. The author recommends that the assumptions used for these two parameters be stated with each forecast. We must remember that the most likely amount to occur is the modal amount or the 1.53 year event.

It must be remembered also that the south arm of the lake rises quicker than the north arm and also falls quicker. It appears that the present procedure gives results consistant with the usual flow forecasts and may be used by a layman with a minimum of instruction.

THE HYDROLOGIC EFFECT OF CONTOUR TRENCHING

Robert D. Doty[1]

Abstract

Watersheds along the crest of the Wasatch Mountain range in Utah were so severely overgrazed, burned, and deforested during the first third of this century that accelerated erosion resulted in frequent mud-rock floods during high-intensity summer rainstorms. Rehabilitation practices, initiated in the early 1930's, included contour trenching. Trenching is still used where watershed conditions indicate that it is necessary to stabilize the soil until protective vegetation can be reestablished. During recent years trenching has been questioned by water users who fear that it could eventually reduce water yields. In 1964, research was begun to determine what effects trenching might have on the timing and the volume of water yields other than the recognized reduction of peak flows from summer storms. Results indicate total annual yields and timing of those yields are not significantly affected by trenching. The value of the trenches to dramatically reduce sediment and peak flows produced by high-intensity summer storms was reaffirmed.

KEY WORDS: Contour trenching, Streamflow, Flood control, Water yield, Utah, Watershed management, Vegetation establishment.

Background

Settlement of the Salt Lake Valley has always been closely associated with the surrounding mountains and the streams issuing from their canyons. Copious amounts of rain and snow fall in the mountains and produce an abundant supply of water that is used for irrigation and domestic purposes and then flows into the Great Salt Lake (Croft and Bailey, 1964). Even though the mountain-valley relationship may be apparent today, it was only a short time ago that exploitation of these mountain watersheds reduced the vegetation and upset the hydrologic balance.

The early settlers in Salt Lake Valley depended heavily on the Wasatch Mountains for water and also for timber and livestock forage. Indiscriminate consumption of the timber and forage, along with frequent fires, resulted in destruction of the protective vegetation that covered critical watershed land in

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the high mountains. When most of the protective cover was removed, mud-rock floods increased in size and frequency. Few among us have seen firsthand the mud-rock floods which issued from nearly every canyon along the Wasatch Front during the first third of this century (Figure 1). Now homes dot these mud-rock deposits. Severe floods occurred in 1923 and again in 1930 (Berwick, 1962; Cannon, 1931). By 1930 the local people were distraught over the flood destruction and pressured officials into establishing a flood control commission which studied the problem and recommended watershed management as a solution. This ushered in an era of flood control work and environmental rehabilitation.

Most of these flood control efforts were concentrated on high mountain areas where the source areas of the floods were located (Bailey, 1935; Bailey et al., 1947). Depletion of plant cover in these areas caused exposure of the fine soil material that had accumulated over the centuries under protective vegetation. This soil was picked up and carried away by raindrop splash and overland flow during high-intensity summer storms. A flow of water having a high eroding power was created and, in turn, this flow picked up more and larger material as it concentrated in the stream channels of the steep mountain slopes. This process resulted in mud-rock floods which were dropped at the mouth of canyons below. Attempts to revegetate the source areas often failed because frequent storms continued to erode the soil before the plants became well established. Contour trenching was developed as a technique to stop overland flow of water from high-intensity summer rainstorms before it had an opportunity to concentrate.

Technique and Application

The USDA Forest Service, and to some extent other land management agencies, have used contour trenching since the 1930's to stabilize land areas that are prone to severe erosion. Within the Great Salt Lake basin approximately 20,000 acres of flood source lands that generally yield large quantities of water have been contour trenched. Trenches are used as an emergency measure to hold soil material in place where removal or loss of vegetation has resulted from misuse such as overgrazing or fire. Trenches cannot be successfully used on steep rocky slopes where vegetation has never become established and consequently no soil profile has developed, even though these

slopes may be producing surface runoff and flashy streamflows.

Trenches are generally constructed by following the contour and digging a series of terraces which are then cut out to form a trench, or depression, capable of holding all runoff water from the slope above (Figure 2). A formula that is based on infiltration, precipitation intensity, and precipitation duration expected on the site being treated is used to calculate spacing and capacity of the trenches.

Contour trenching is not as frequently nor as extensively used today as it was a decade or two ago. The grossly abused lands were rehabilitated by trenching during the 1930's, 40's, and 50's. Today we have better management practices such as control of fires on high risk areas and proper livestock grazing management, and the need for contour trenches to effect emergency land treatment has been reduced.

Effect on Yields and Quality of Water

Most of these contour trench networks, even the old ones, have some potential for holding water on the mountainside and thus reducing the total yield. Because the 20,000 acres of trenches are located in normally high water-yielding areas, questions have been raised as to their effect on total water yields. Bailey and Copeland (1960) studied water yields from a pair of large drainages on the Davis County Experimental Watershed. One of these was overgrazed, then contour trenched and rehabilitated; the other was maintained as a well-managed control watershed. They found that trenching and regrowth of vegetation did reduce annual runoff. This was apparently due to utilization of the trapped runoff by the dense vegetation. However, this was considered a return to natural conditions; therefore, the reduction was a necessary cost of proper watershed management. Questions raised from this earlier work (Bailey and Copeland, 1960) prompted us in 1964 to begin a detailed research effort on the hydrologic response of watersheds to trenching.

Current research into the relationship of contour trenching to the Great Salt Lake and its tributaries considers three factors: (1) Are the trenches effectively doing their intended job of trapping overland flow and preventing erosion and mud-rock floods? (2) Do the trenches affect water yields? (3) Do the trenches affect water quality?

Figure 1. Flood debris resulting from the 1930 flood that emerged from Parrish Canyon, Davis County, Utah.

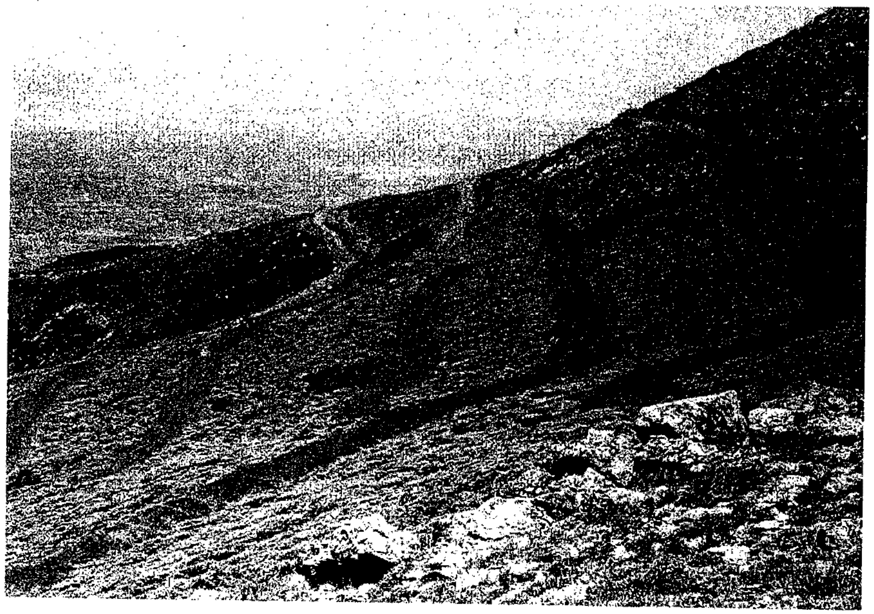

Figure 2. Contour trenches on Halfway Creek watershed, Davis County Experimental Watershed, Utah.

The primary function of trenches is to prevent overland flow and thus reduce or eliminate as many mud-rock floods as possible. The potential size and duration of these floods are important for assessing the value and effectiveness of contour trenching. To accomplish such assessment, over 100 storm events have been analyzed to obtain an understanding of the nature of storm flows from small mountain watersheds along the Wasatch Front. When the rain-produced hydrograph is compared with a snowmelt runoff hydrograph two things become apparent (Figure 3): (1) The snowmelt hydrograph extends over a period of weeks or months producing 60 to 70 percent of the total annual flow; (2) The rain-produced hydrograph lasts only minutes or hours and accounts for less than 1 percent of the total annual flow. Furthermore, the rain-produced hydrograph has high and sharp instantaneous peaks which often exceed the snowmelt peak flows by several magnitudes. The success of contour trenches is dependent on their ability to trap overland flow from rainstorms; which, as mentioned earlier, is a relatively small amount of the total annual streamflow. During the summer months, when the mantle is dry, this trapped flow is stored in the soil in and near the trenches and is then lost through evapotranspiration. Thus, the high but narrow peaks from the rain-produced hydrograph are removed. Even if contour trenching stopped all of the water produced as overland flow from summer rainstorms it still would have no appreciable effect on annual flows into the Great Salt Lake Valley.

The trenches, of course, are permanent year-round fixtures and are located in high water-yielding areas; thus, their potential for retaining snowmelt must also be considered. Any substantial loss of snowmelt could result in a large reduction of total annual flows. However, recent research on the Davis County Experimental Watershed has indicated that this does not occur. The soils there are pervious enough to allow the snowmelt to filter through the mantle and escape the trenches before being lost by evapotranspiration (Doty, 1971). Six years of soil water measurements on and adjacent to a contour-trenched area revealed that some redistribution of soil water from snowmelt occurred following trenching (Doty, 1972). Nevertheless, trenching did not alter the soil water conditions sufficiently to significantly change total water yields from the drainage. A reduction in evapotranspiration from trench bottoms was offset by an increased water loss in the cut-bank and trench fills. No change in the amount of soil water produced by snowmelt was apparent in

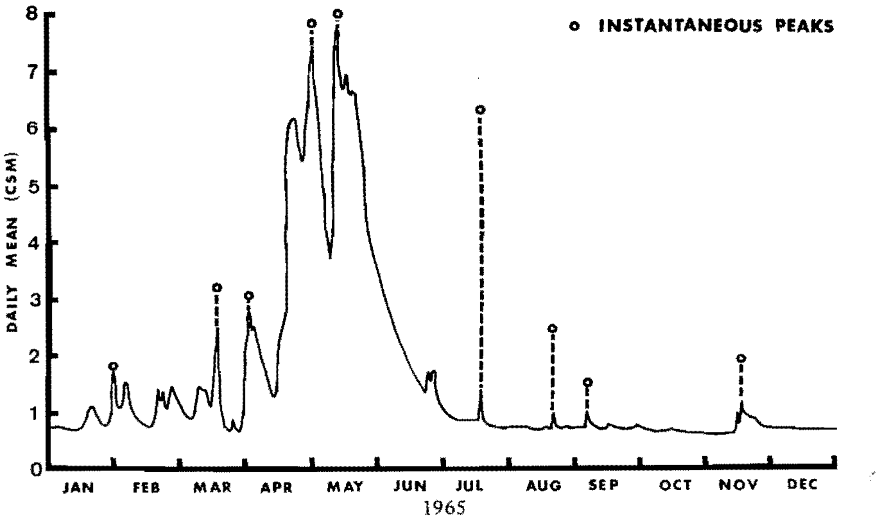

Figure 3. Hydrograph on Halfway Creek, Davis County, Utah (1965).

areas between the trenches. Also, a study to determine any variance in snow accumulation as related to contour trenching revealed no significant change between trenched and nontrenched areas (Doty, 1970). This study revealed that increases in the water content of the snow in the trenches was offset by reductions on the fill slope. A more important factor related to snowmelt distribution concerned revegetation. The redistribution of snow caused by the trenches affected both temperatures and water content of the soil at critical growing periods the following spring.

The major damage resulting from the summer rain-produced floods is the large quantity of silt and rock deposited at the mouths of canyons in developed areas. Unlike snowmelt floods, which produce large quantities of water and some sediment, the rain-produced floods result in large amounts of sediment but small amounts of water. Consequently, by reducing or stopping such floods at their source through contour trenching and rehabilitation of the mountain watersheds, most of the sediment produced by these mountain streams has been eliminated and the quality of water restored. On these watersheds the presence of a deep soil mantle supporting a good cover of vegetation provides a natural filter which prevents most potential pollutants from reaching the

mountain streams. A system of management that maintains these conditions is obviously essential for providing high quality water.

In Utah it appears that although contour trenching and other watershed rehabilitation measures have changed water yields very little they have done much toward reducing flood damages and improving the quality of water entering the Great Salt Lake Valley and other developed areas.

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POLLUTION INPUT FROM THE LOWER JORDAN BASIN TO ANTELOPE ISLAND ESTUARY

Alan A. Coburn[1] and David W. Eckhoff[2]

Introduction

Antelope Island Estuary is a shallow body of water at the southeastern corner of Great Salt Lake. The estuary is unusual because its outflow, which is to one of the world's major hyper-saline lakes, is confined by a man-made causeway with an extremely narrow aperture. The causeway severely restricts the interchange of estuary and lake waters, although (because of density gradients) there is an inflow of lake water beneath the outflowing estuary discharge.

This restriction of hydraulic mixing has compounded the problems caused by polluted inflows to the estuary. At one time virtually the entire estuary was a dense brine, but the causeway has radically changed the situation. Currently the salinity of the estuary varies from "fresh water" conditions at the head to those of typical ocean water adjacent to the causeway. A dense brine wedge underlies the less saline surface waters throughout much of the estuary.

There is concern that the man-made conditions of Antelope Island Estuary may lead to extremely undesirable consequences. A host of organisms, which could not survive in the brine of Great Salt Lake, have invaded the estuary. While some are undoubtedly welcome, the impact of others is subject to question. Particularly when the potential build-up of pollutants in the estuary is considered.

The Lower Jordan River and related waterways receive the secondary treated sanitary wastes of approximately 500,000 people. Numerous and diverse wastes from industries, the urban runoff from metropolitan Salt Lake City and the irrigation return water from numerous farms. The problem is three pronged: first, population, industrialization and the spectrum of pollutants are increasing; second, the water available for transport, dilution, and ultimate disposal is nearly constant; and finally, the ultimate receiving body is a diked bay with a limited outflow into a dead sea and within a very few miles of downtown Salt Lake City. Consequently, the constituents are likely being concentrated with their ultimate effect being unknown.

The problem is further complicated by the fact that there is incomplete monitoring of major streams for flow, chemical, physical and biological characteristics, so as to be able to meaningfully assess the long range impact on the receiving body and to isolate problem areas and assess trends in water quality. It is our contention that continued disregard for the ultimate water quality of Antelope Island Estuary may lead to the development of an 80,000 acre, mismanaged wastewater lagoon, upwind from metropolitan Salt Lake City. It is also possible, that continued disregard for the trends in Jordan River water quality, in addition to leading to degradation of Antelope Island Estuary, will deprive the residents of the Wasatch Front of a natural, multipurpose recreational area. The Jordan River Parkway proposal is in jeopardy of not realizing its full potential if there is not due consideration for water quality. It is time that the Jordan system be realized for its potential as a water resource and not merely as the brunt of jokes and the transporter and dilutor of wastes.

Objectives and Specific Goals

The overall objective of the study was to quantitatively assess the magnitude of pollution in the Lower Jordan Drainage Basin, to determine mass rates of pollutional input to Antelope Island Estuary, and to determine significant trends in concentrations and mass flow rates of key pollutants.

In order to achieve this objective, it was necessary to establish several specific study goals. These were:

(1) To delineate a reach of the Lower Jordan system, across which mass balances of pollutants could be carried out;

(2) To establish a sampling program, consisting of both flow measurement and water quality analysis, which would permit accurate mass balances and quantitative estimates of pollutional inputs between the boundaries of the system;

(3) To analyze historical water quality and quantity data, so that reliable estimates of pollutional trends could be made; and

(4) To develop a recommended program of continuing monitoring,

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[2] Professor, Civil Engineering Department, University of Utah, Salt Lake City, Utah.

so that adequate water quality information will be available on a routine basis for future water quality management decisions.

Scope and Methodology

The area of study was limited to the Lower Jordan River Basin, with the boundaries being essentially the southern and northern city limits of Salt Lake City. Figure 1 shows the relationship of the study area to Antelope Island Estuary, the major streams of the drainage system, and the monitoring points used in the study.

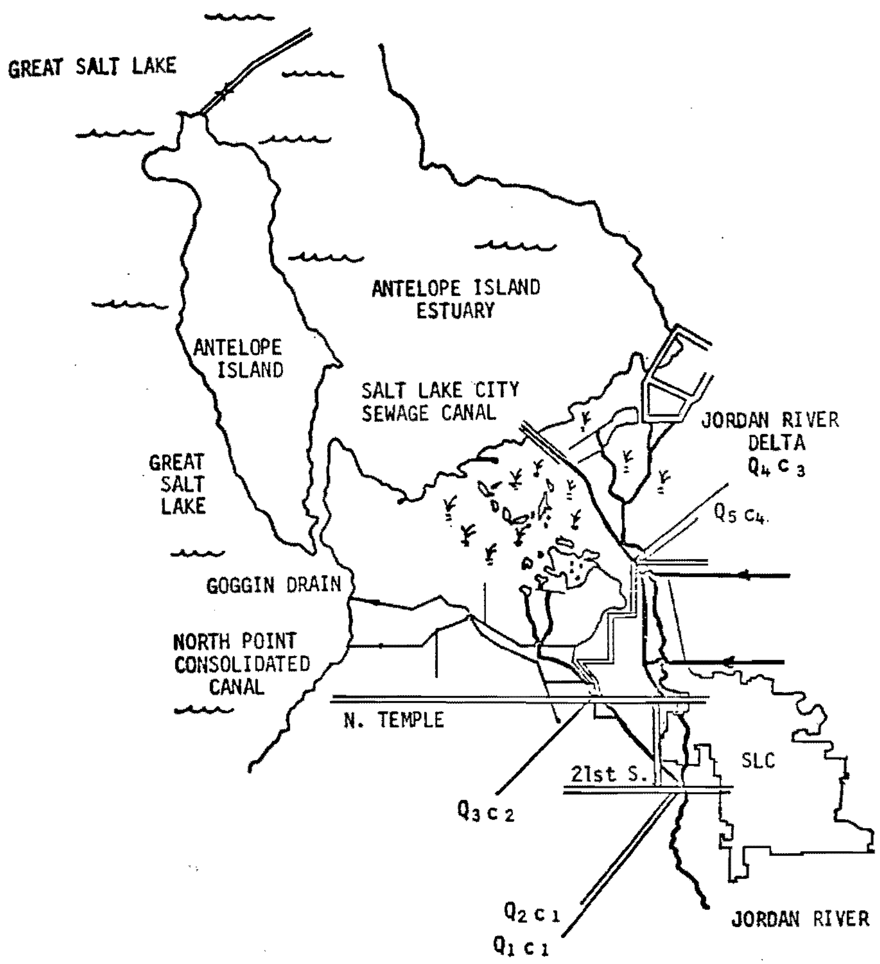
The single upstream sampling station was located at the point of diversion of the surplus canal from the Jordan River, viz. 21st South Street. This point was selected because of continuous flow monitoring by U. S. G. S., and because the Utah Division of Health has a record of periodic quality monitoring at the location. Additional sampling was carried out at this station during the course of the study.

The downstream boundary point on the surplus canal was at North Temple near the Salt Lake International Airport. The Jordan River was monitored downstream at Cudahy Lane.

The other major discharge to Antelope Island Estuary from the study area is the Salt Lake City Sewage Canal. Its flow originates entirely within the boundaries of the study area and consists of municipal water pollution control plant discharges, miscellaneous industrial wastes, and surface drainage from the northwestern sector of Salt Lake City and southern Davis County. It was also monitored at Cudahy Lane.

Monitoring consisted of flow rate determinations at those sites not permanently gauged and grab sampling for physical, chemical, and biological analyses. Mass discharges were determined from the product of flow rate (Q-values) and concentration (c-values). In situ analyses included temperature, dissolved oxygen (DO), and pH. Laboratory analyses were performed on the grab samples and included:

Biochemical Oxygen Demand (BOD)
Chemical Oxygen Demand (COD)
Coliforms (MPN)
Turbidity



$Q_1\ c_1$ = MASS DISCHARGE OF JORDAN RIVER @ 21st S.
$Q_2\ c_1$ = MASS DISCHARGE OF SURPLUS CANAL @ 21st S.
$Q_3\ c_2$ = MASS DISCHARGE OF SURPLUS CANAL @ N. TEMPLE
$Q_4\ c_3$ = MASS DISCHARGE OF SALT LAKE CITY SEWAGE CANAL @ CUDAHY LANE
$Q_5\ c_4$ = MASS DISCHARGE OF JORDAN RIVER @ CUDAHY LANE

Figure 1. The Lower Jordan Basin and study area.

Total Dissolved Solids (TDS)

Suspended Solids (SS)

Specific Conductance

Total Kjeldahl Nitrogen (TKN)

Nitrate Nitrogen

Phosphates

Sulfates

Chlorides

Hexane Extractable Materials (HEM) - "Oil and Grease"

Various Pesticides

These analyses were performed on samples obtained between January and May 1972. Additional analyses were performed on Division of Health data for the period 1967 to 1972.

Summary, Results, and Conclusions

1. The flow of the Jordan River increases markedly at 21st South and Cudahy Lane in the spring months due to spring and storm runoff. Figure 2 shows the water quantity variations over the years 1964 through the spring months 1972. It is especially important to note that there is no consistent relationship during the months of April, May and June because of the volatile spring runoff from the Wasatch Front through Emigration, Red Butte, Parley's and City Creek Canyons.

2. There are high BOD discharges being generated to the south of 21st South on the Jordan River and mass discharges are increasing beyond that expected because of increased flow. These can be attributed to the increased population and consequent increased wastewater generation without increased BOD removal efficiencies in the wastewater treatment plants to the south. This fact is further evidenced in the increased coliform levels. Figure 3 shows these variations over the last five years. Note especially the increasing trends in all the constituents, notably, coliforms and total dissolved solids and suspended solids.

3. High BOD increases in the sewage canal indicate large amounts of organic matter are being discharged. No definite conclusions can be drawn, but the problem should be examined. Based on a population of 300,000, 0.2

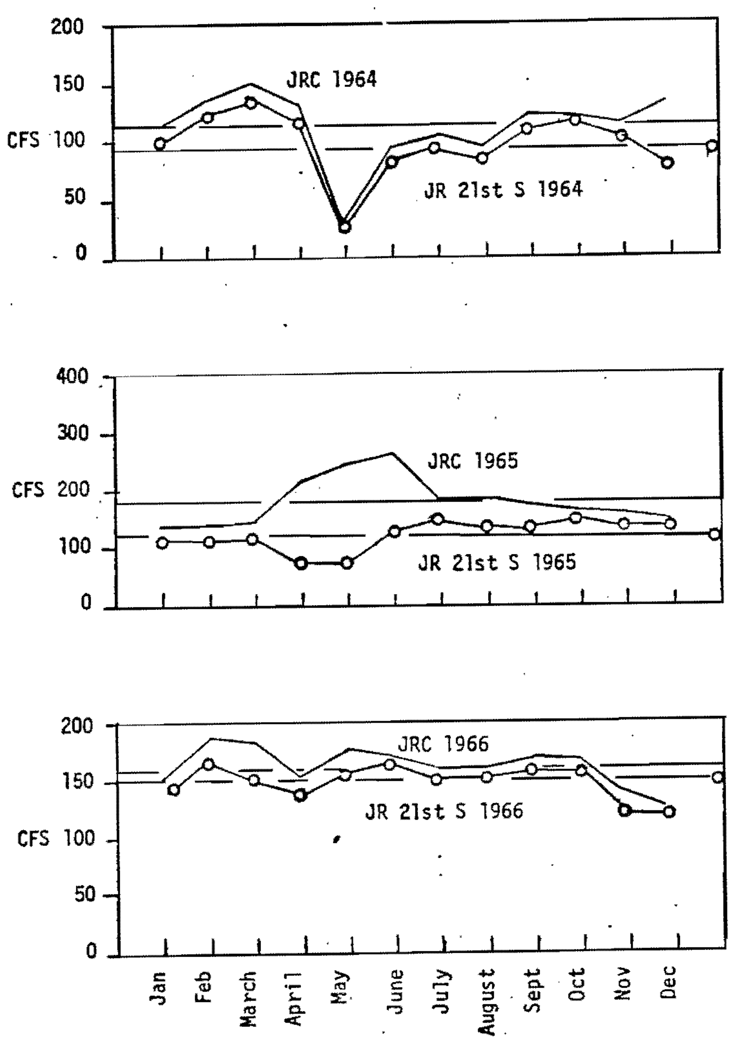
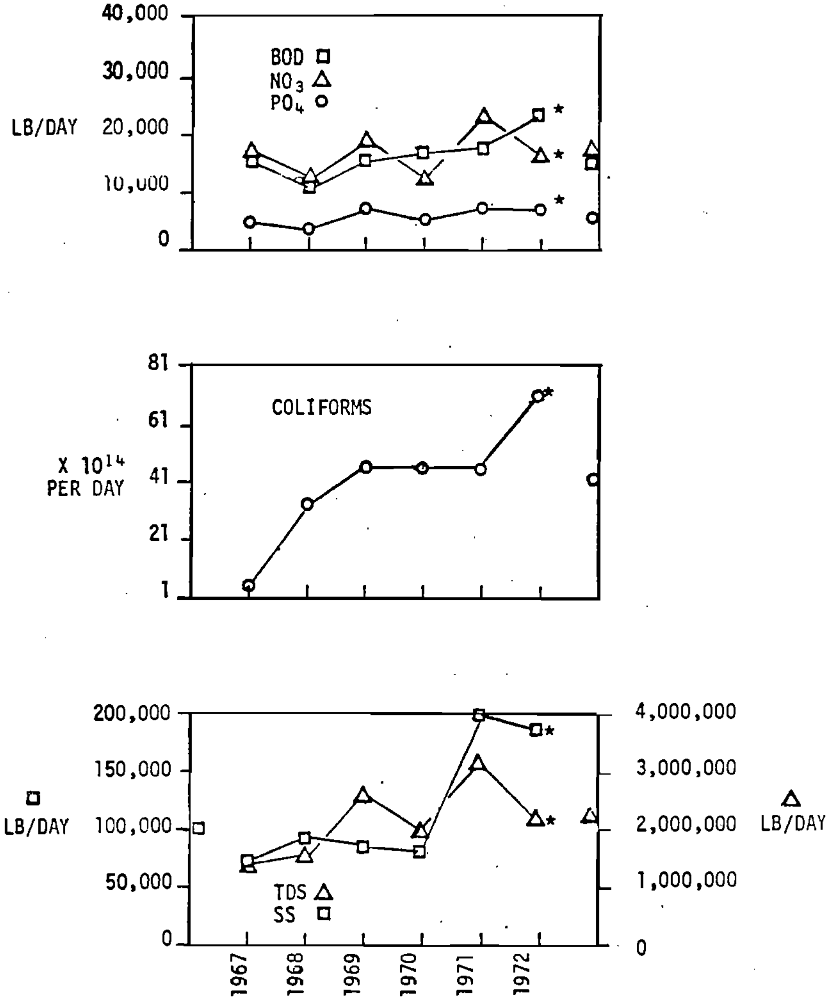


Figure 2. Annual flow variations of the Jordan River at Cudahy (JRC) and the Jordan River at 21st South (JR 21st S).



* Not included in the computation of the average; applies to the first five months of 1972 only.

Figure 3. Annual fluctuations in mass discharge for the surplus canal at 21st south.

pounds per capita per day of BOD are being discharged via the sewage canal to Antelope Island Estuary.

4. There are indications of non-biodegradable organic wastes in all streams. This is evident in that the COD to BOD ratio is around 3:1. There may also be problems of toxicants inhibiting full BOD exertion in lab.

5. High suspended solids levels at 21st South and increases downstream indicate irrigation return waters and urban runoff are of major importance. (See Figure 4.)

6. Nutrient of levels, i.e., phosphate and nitrate concentrations, are sufficient to cause algal blooms which might also be a prime consideration as to future recreational use of the Jordan River. This impending problem of nutrient control should be a foremost consideration in the improvement of wastewater quality management in the Salt Lake Valley.

7. Results as shown in Figure 4 indicate a high BOD source or sources discharging to the surplus canal between the 21st South and the North Temple station which, because of the magnitude, require further investigation.

8. There is a trend to lower mass discharges of most pollutants in the Jordan River between 21st South and Cudahy Lane. Figures 4 and 5 clearly show the decreasing trends in most constituents.

9. Sulfate levels are high in all streams. It can be concluded that should extensive anerobic conditions develop in any of the streams due to low flows or sedimentation, or should extensive anerobic conditions develop in the sink, Antelope Island Estuary, that the potential for odor problems inherent in the anerobic reduction of sulfate is high. Noticeable amounts of H_2S (hydrogen sulfide gas) are apparent and have been apparent on the surface of the Antelope Island Estuary in previous studies.

10. Chloride levels are high. The impact of home water softening, salting icy streets, and agricultural return water is being felt. Chloride levels have, in the sewage canal, nearly reached concentrations where it would be classified as a salt water stream. Based on a population of 300,000 discharging to the sewage canal, chlorides are being released at the rate of one pound per capita per day.

11. Pesticide data indicate considerable use of pesticides especially Deildrin, OP-DDT, and PP-DDT, although levels observed are not known to be dangerous. It should be remembered, however, that DDT has been virtually

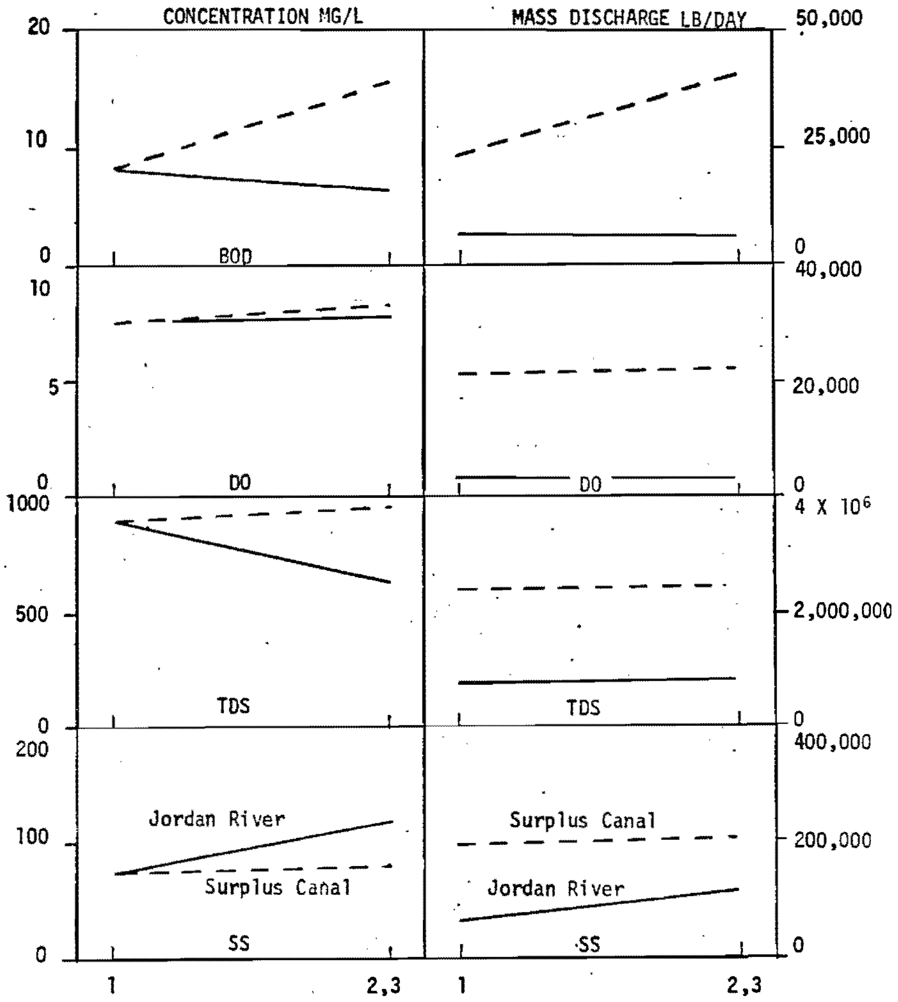


Figure 4. BOD, DO, TDS, SS vs. distance, January 1972 through May 1972*.

*Average 1 = Jordan River and Surplus Canal at 21st South
2 = Jordan River at Cudahy Lane
3 = Surplus Canal at North Temple

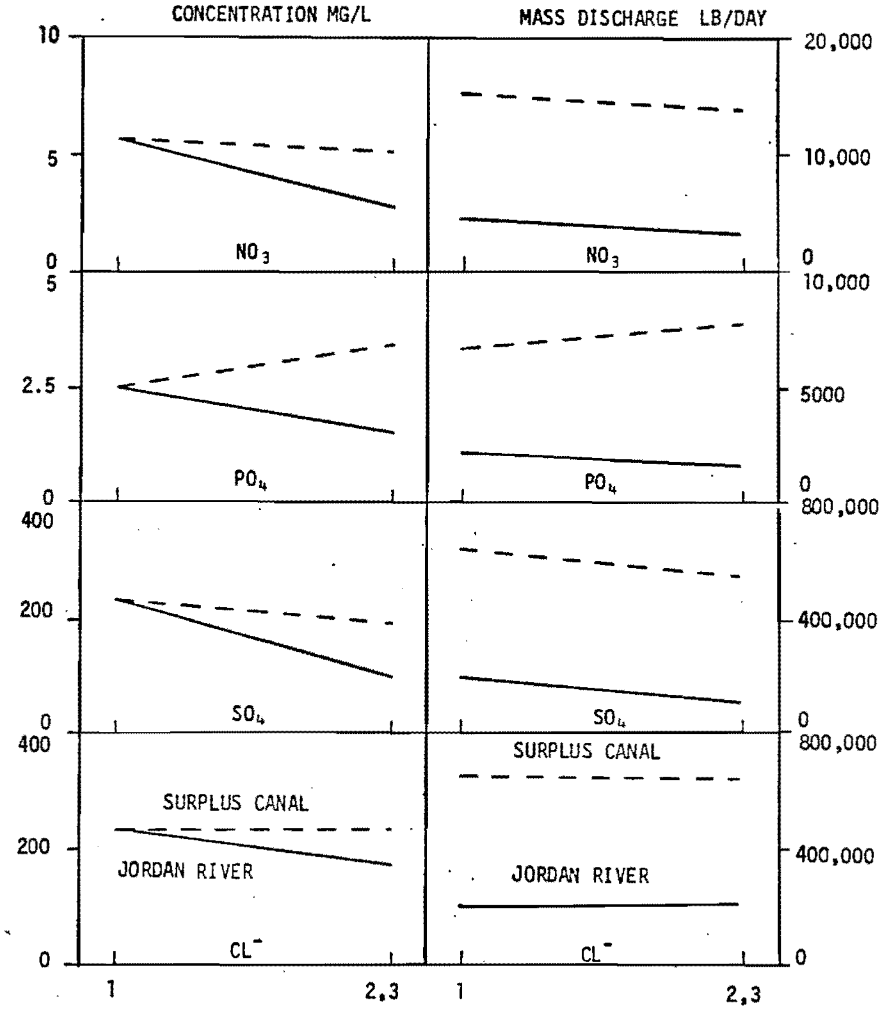


Figure 5. Anions: No$_3^-$; PO$_4^-$, CL$^-$, SO$_4^=$ vs. distance, January 1972 through May 1972*

*Average

banned from use. The Salt Lake City sewage canal exhibited higher concentrations of most all of the pesticides detected than did any of the other streams. Figure 6 shows the relatively larger amounts contributed by the Salt Lake City sewage canal and the increases observed as the spring runoff increased.

12. For the period of supplementary studies, there was above normal precipitation and consequently, above normal runoff. This point should be remembered when analyzing data from January to May 1972. Figure 7 is an extremely important figure as it shows the increasing trends discharged BOD and suspended solids over the last five years to Antelope Island Estuary. The ultimate impact of these trends has not been discussed in previous studies. Figure 8 shows the relative amounts of BOD being discharged by the three major streams. Note the increasing amounts in the surplus canal, which is water diverted at 21st South and water mainly from the southern part of Salt Lake County. Notice in Figure 9 the relative amounts of suspended solids being contributed by these three streams. The increasing trend is again apparent in the surplus canal.

Recommendations

Based on these results and conclusions, the following recommendations are submitted:

1. It is recommended that a continuous stage recorder be installed and routine chemical sampling and analysis of the Salt Lake City sewage canal at or near Cudahy Lane be instituted.

2. It is recommended that a continuous stage recorder be installed on the Jordan River at or near Cudahy Lane. This is necessary in order to meaningfully analyze the pollution loads being carried by the Jordan River into Antelope Island Estuary. It is also requisite to meaningfully determine what the ultimate impact will be on the Antelope Island Estuary.

3. It is recommended that COD, HEM or ANE and TKN become routine tests in selected instances as they measure pollution parameters of considerable importance. It is known that there are many other significant pollution parameters and they should be likely applied where required, especially in streams absorbing wastewater inflows.

4. It is recommended that bioassays become a part of the routine analysis for pollution. This would allow the analyst to look at what combinations of pollutants do to the aquatic ecology in the stream. This is virtually impossible

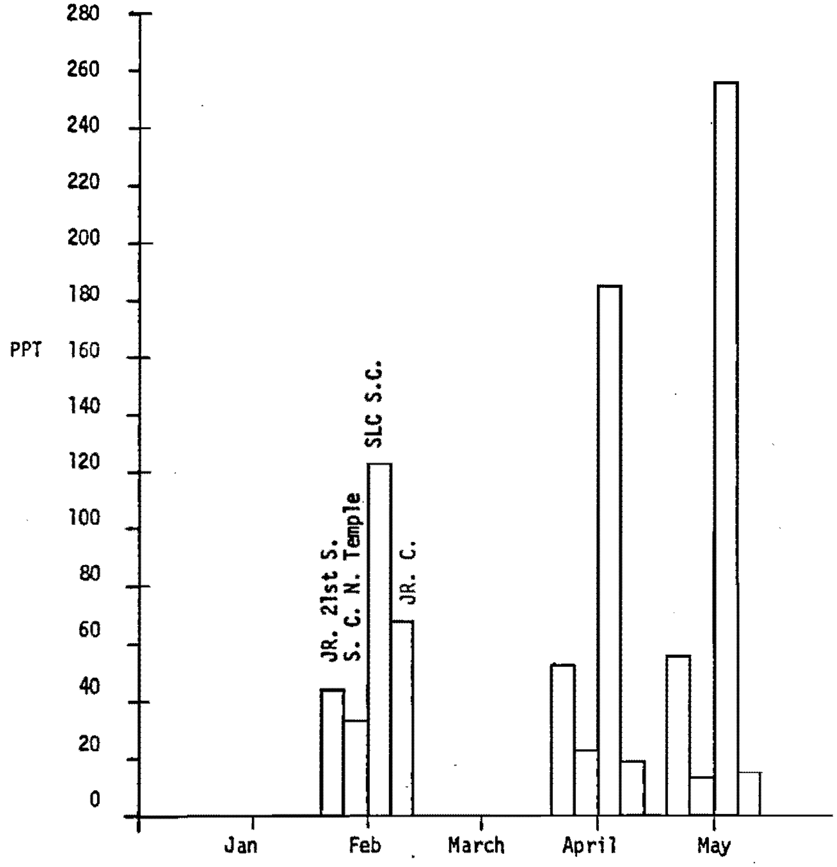


Figure 6. Total DDT variation with time, 1972.

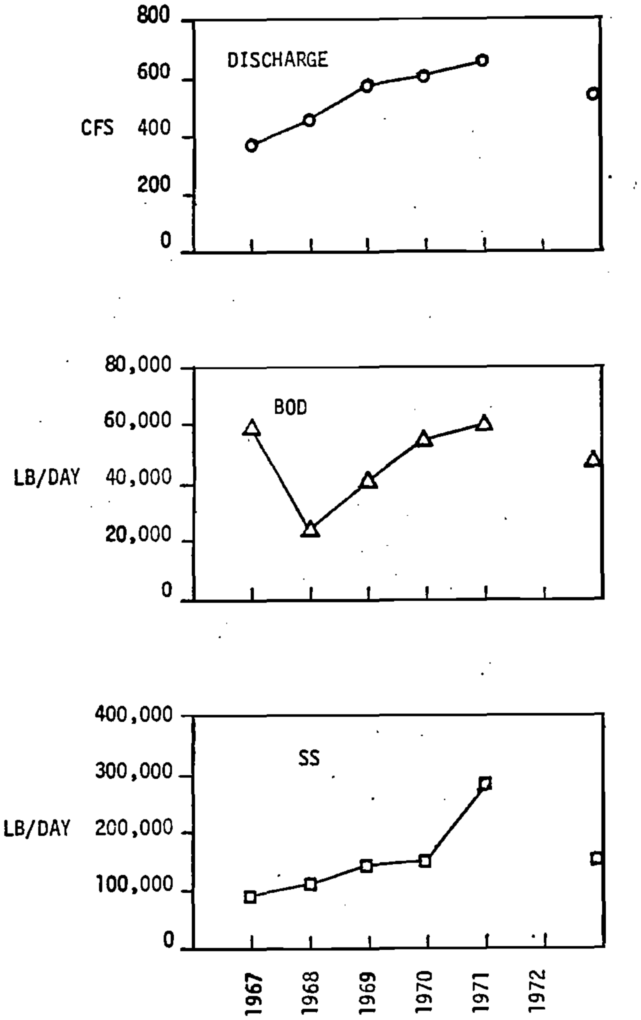
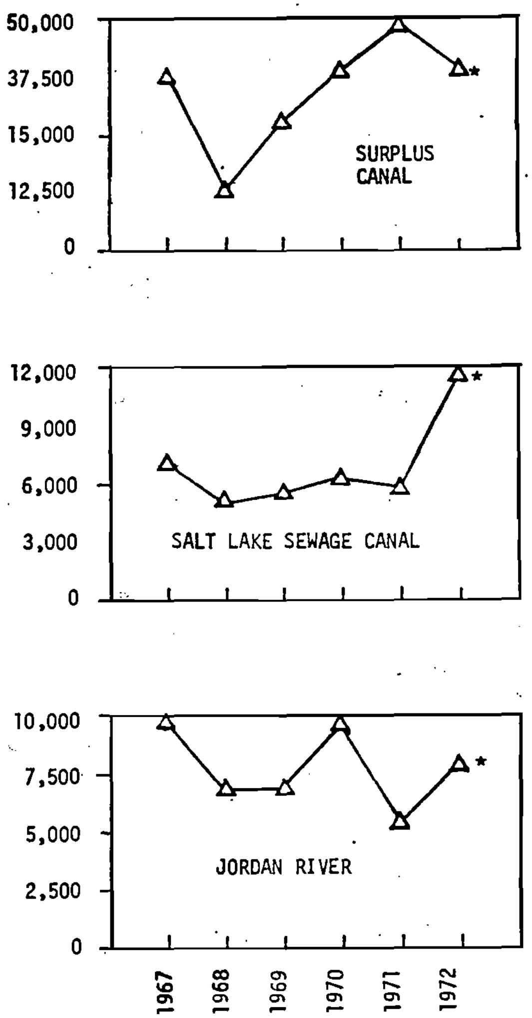
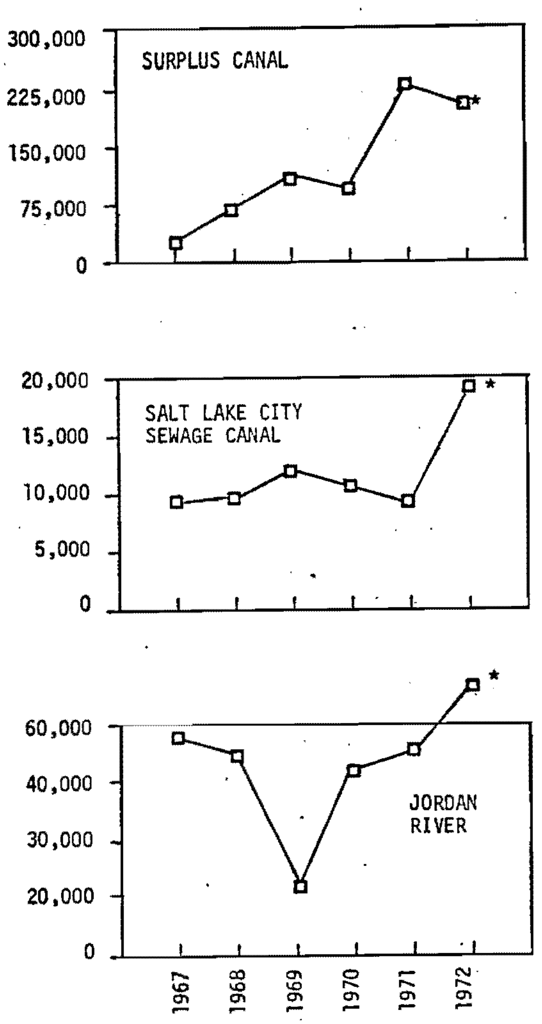


Figure 7. Annual mass discharge to Antelope Island Estuary, 1967-1971.



* For the first five months of 1972 only.

Figure 8. Average annual mass discharge of BOD to Antelope Island Estuary (lb/day)



* For the first five months of 1972 only

Figure 9. Average annual mass discharge of SS to Antelope Island Estuary (lb/day)

to specify with routine chemical analyses.

5. It is recommended that a field DO be taken so some biological suitability can be assessed for the stream. In order to keep these streams healthy, a biota must be kept healthy and the dissolved oxygen is a critical factor in this regard.

6. It is recommended that there be implemented a periodic pesticide monitoring system in the Lower Jordan Basin and in Antelope Island Estuary. Since concentrations without discharge are difficult to assess, it is recommended that the sampling scheme be revised so samples are taken at points of known discharge or where discharge is measured at water quality sampling points. This would enable the analyst to assess any quality and quantity changes of pollutants across a system boundary and to take into account any dilution or other increased assimilative capacity in the stream.

7. It is recommended that Antelope Island Estuary be sampled at appropriate points so as to determine changes in water sediment quality.

8. It is recommended that periodic sampling of sediments at selected locations be implemented to determine hydrogen sulfide, volatile suspended solids, and pesticide concentrations. It is important to analyze for hydrogen sulfide to determine the amount of anerobic decomposition occuring in the sediment. It is important to determine the volatile suspended solids content in order to determine the potential for anerobic decomposition and the present dissolved oxygen levels in the stream. Pesticide levels in the sediments are important because pesticides, being hydrophobic, attach themselves to sediments and settle to the bottom and therefore may be "lost" within the system but have no less effect on water quality for impact on the biota.

9. It is recommended that standardized <u>in situ</u> observations of the observer be noted and recorded at sampling, i.e., oil sheen, floating debris, aquatic life, algal growths, etc. Many of these environmentally and aesthetically significant pollution symptoms are not readily quantified.

10. It is recommended that bridges be lighted in order to deter people from throwing refuse, dead animals, etc., over the side at night.

11. It is recommended that the high sources of BOD on the Salt Lake City sewage canal be isolated and abated if water quality in Antelope Island Estuary is determined to be important.

12. It is recommended that sources of high BOD, suspended sediment, and hexane extractable materials to the south of 21st South be identified.

13. It is recommended that urban runoff, irrigation return water, and agricultural runoff be thoroughly examined to assess their impact on stream quality, especially recording concentrations of nutrients, suspended sediment, total dissolved solids, coliforms, and chlorides.

14. It is recommended that more extensive tests for sulfate and the potential for development of an anerobic environment in the Lower Jordan Basin and Antelope Island Estuary be instituted.

15. It is recommended that investigation of types, areas, and times of pesticide use be initiated. Many of the chlorinated hydrocarbon pesticides are persistent in the environment and have impacts on the ecology yet to be discovered.

16. It is recommended that a thorough study be instituted to determine the nutrient levels and consequent density and types of aquatic growths.

Conclusion

In conclusion, there is an obvious need for a comprehensive master plan to develop goals and objectives for the future use of the Great Salt Lake as a valuable resource, whether its use be recreation, mineral extraction, etc. A study is required to determine the interactions of each of these uses so the resources can be fully utilized.

Acknowledgments

The assistance of the Utah Division of Health in consultation and in the conduct of pesticide analyses is gratefully acknowledged. Particular thanks are due Mr. Cliff Crane and Dr. Melvin Gortatowski.

A STUDY OF THE DISTRIBUTION OF COLIFORM BACTERIA IN THE FARMINGTON BAY ESTUARY OF THE GREAT SALT LAKE

John Vander Meide and Paul S. Nicholes[1]

Abstract

The Farmington Bay Estuary, east of Antelope Island, has been the Salt Lake and Davis County cesspool for many years. Prior to the construction of the present day sewage disposal plants, which treat sewage from all cities and most of the towns in these two counties, raw sewage entered the lake estuary either via the streams entering the lake area or via sewage canals.

The most recent study of coliforms in the waters of the estuary was in 1965 before the establishment of the Syracuse causeway. This causeway has changed the characteristics of the estuary and thus necessitated a further study of the health hazards as well as the esthetic characteristics of the water of the estuary.

Samples of water were taken in the estuary at 13 sampling points and at three depths at each sampling point. Sampling points included the area north of the Syracuse causeway and south to the Salt Lake City sewage canal and the Jordan River. Sampling depths included the first 10 mm of surface water, the water at two feet (200 mm) and bottom sludge. Samples were taken weekly over a period of six weeks and analyzed for coliform bacteria.

It was found that the surface and 200 mm samples were generally negative until the sampling points were deep into the less saline waters of the sewage canal or the Jordan River. This was not true of the bottom sludge. The saline water apparently has not penetrated the raw sewage sludge of many years deposit and coliforms were found in abundance even where the salt content of the water was great enough to markedly inhibit the growth of coliform bacteria.

Studies of the inhibitory effect of various concentrations of Great Salt Lake water on coliform organisms isolated from the estuary were carried out. Broth prepared using 6 percent estuary water as the fluid part of the medium completely inhibited lactose fermentation and inhibited growth in a large percentage of the tubes.

Experiments were carried out which proved that the bottom sludge from the areas of greatest sewage deposit, when diluted and sterilized, would act as a source of nutrient not only for coliform bacteria isolated from the estuary water, but for gastrointestinal pathogens as well.

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It is proposed that the accumulated raw sewage deposits sequester gastrointestinal bacteria, and viruses; that the organic matter of the accumulated deposit will support the growth of these bacteria, and that these microorganisms may seed the waters of the estuary for several years to come contributing to possible health hazards and certainly detracting from the esthetic quality of the area.

Introduction

The Great Salt Lake holds for many of us a great deal of interest. It is an extremely hostile environment for many forms of life, yet there are a few creatures which have adapted themselves to this environment. A study by a group of students during the summer of 1971 produced some very interesting data on the biological forms associated with the lake. This study attempted to measure and predict the impact which the human population surrounding the lake has had, and might have in the future, on one specifically defined area of the Great Salt Lake. The material of this specific presentation is one part of this student study, namely, the coliform content of the lake at different depth levels including bottom muds and sand in the Farmington Bay Estuary.

For many years--ever since Salt Lake City has become large enough to force public collection and disposal of sewage--the liquid refuse of the city has been dumped into the Farmington Bay. Until very recently, this refuse was gathered by the Salt Lake City sewage system and lead by a canal to a spot near the mouth of the Jordan River and allowed to flow untreated into the brine of Farmington Bay. Also, until recently, the entire liquid sewage refuse of the Wasatch Front towns and cities from Layton on the north to the towns of the Southern Utah Valley, where collection systems existed, ended up untreated, except for dilution, in the estuary. This practice has resulted in a sewage delta of rather large proportions in a very localized area.

Man's further impact on the lake, and one which may produce ecological changes of some magnitude, has been the construction of the causeway from Syracuse across the intervening span of water to the southern tip of Antelope Island where the Great Salt Lake State Park has been established and is being developed. The construction of the causeway has, of course, introduced a possible barrier to natural exchange of water from the estuary to the main body of the lake. It was proposed, therefore, that the general fluid flow would be through the one opening into the lake and that the Farmington Bay Estuary

would ultimately become a fresh water body. One of the largest flows of fresh, non-saline water into the lake is into the estuary. This is the main drainage of the Wasatch Front mountains from Layton and Farmington on the north to the Southern Utah Valley. Even though the waters of the streams along the front are used extensively for irrigation and culinary purposes, except for that lost by evaporation, it must all end up in the estuary, and we might add, at the same time carry much of the liquid refuse of the large human population now dwelling along the front.

It should also be pointed out that additional water other than the natural stream drainage is added to the estuary now that reclamation projects have diverted large amounts of water from other drainage areas. Projects such as the Strawberry Reservoir and the Deer Creek Project, to name the two larger ones, are good examples.

We were curious as to the possible contribution of the large deposits of "unspoiled" sewage to a fresh water lake in the estuary, and whether or not this material would increase the coliform index with an accompanying hazard of fecal pathogens, should the salinity of the water drop below a level detrimental to nonhalophilic or salt tolerant microorganisms. It was possible that a health hazard existed, and surely that there would be an esthetic impact upon the estuary when storms stirred up the sewage deposits and sent them floating in fresh water to the bathing beaches of the estuary, should the latter be established.

The microflora of the lake has been studied in the past. Studies of microbiological importance have been few. Elfriede Frederick prepared a masters thesis in 1924 which presented a description of a few strains of halophilic bacteria which she was able to culture from the lake. In 1936, W. W. Smith reported on the "Evidence of a Bacterial Flora Indigenous to the Great Salt Lake." In this thesis, he pointed out that the high salinity of the lake was very detrimental to becteria of soil or human origin, whether in sewage or from the bathers in the lake. This comment, though, did not take into consideration the large deposition potential of the raw sewage entering the lake in a single small area.

Other publications discussing the pollution of the lake have appeared over the years, but time and space are inadequate to discuss them. One report, though, should be mentioned, and this is one entitled "A Preliminary

Investigation of Pollution of Great Salt Lake east of Antelope Island." This was a joint study carried out by the Utah State Department of Health and the Davis County Health Department three years before the completion of the dirt fill causeway. Our work is to some extent a repetition of that described by the report, but extends coverage to take into consideration bottom sludge samples. In essence, the report concluded that "the studies recently completed in Great Salt Lake area east of Antelope Island and north to the end of Syracuse Road indicated positive evidence of sewage pollution in the lake water to such an extent that bathing should not be approved in any of this area for this season."

Procedures

A. Samples

The accompanying map shows the sampling points on the estuary. (Figure 1.) Three sampling points were north of the Syracuse causeway, numbered 1, 2, and 3. The other 10 were in the estuary with sampling points numbers 12 and 13 practically in the mouth of the sewage canal. Thus the samples tended to be progressively reduced in salinity from 1 through 13. Samples were taken at the surface (not more than 2 inches deep), at 2 ft. below the surface and from the lake bottom. The latter sample usually, if not always, collected bottom debris.

B. Sampling device

Samples were collected in sterile "coke" bottles. (Figure 2.) Each sampling bottle was fitted with a rubber stopper through which a glass tube extended. The latter was bent at a 90° angle and then bent back on itself 180°. At the 180° bend the glass was scored with a file to facilitate breaking at that point. The end of the tube distal to the stopper was sealed and a long string attached with tape at the sealed end. A quick jerk on the string would snap the tube at the scored point and would allow water to enter the bottle. The whole sampling device was then attached to a weight to sink it to any desired depth.

A wire, marked for desired sampling depths, was used to suspend the assembled samples in the lake (Figure 3).

The sampling device was autoclaved with the stopper and tube very loosely set into the mouth of the bottle. At the time of removal from the sterilizer, the stopper was immediately seated firmly into the bottle mouth.

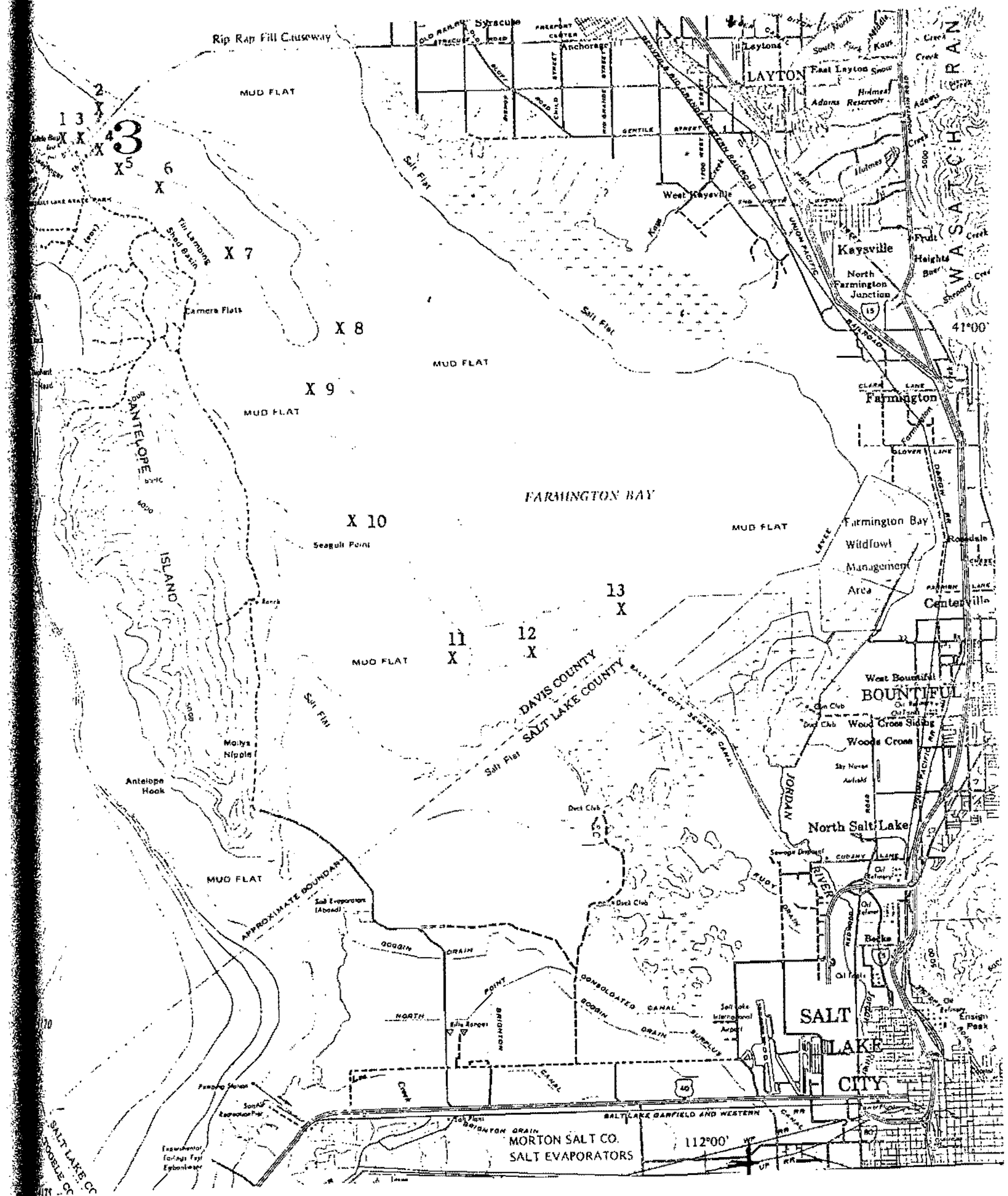

Figure 1. Sampling sites in Farmington Bay Estuary, Great Salt Lake.

Figure 2

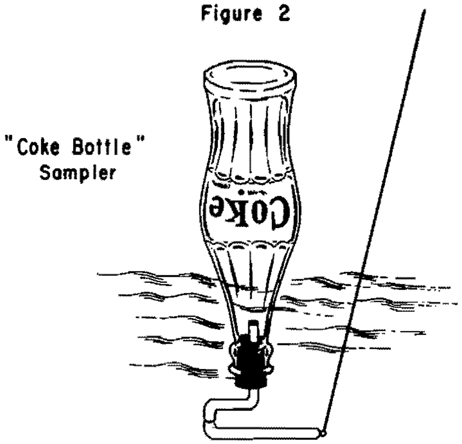

Figure 2. "Coke Bottle" sampler.

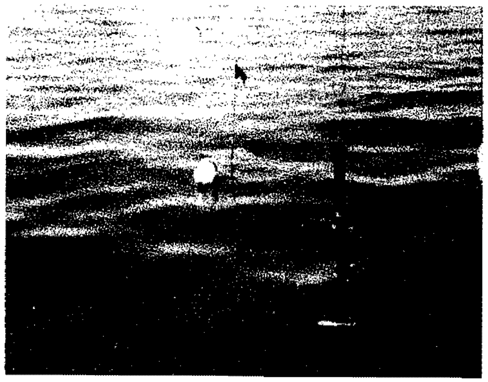

Figure 3.

The air had been removed from the bottle by the sterilization and had been replaced with steam, when the steam condensed it left a partially evacuated bottle. During sampling, as the sealed glass tube was broken under water, the vacuum in the bottle was replaced with water at the depth of suspension. As the sample was brought to the surface, the decreased pressure allowed a bit of the sample in the sample tube to be forced outward, thus, there was minimal contamination of the sample from brine or water at lesser depths.

The sample tubes were immediately plugged with sterile cotton, and the samples iced for transport to the laboratory.

Surface samples were obtained by holding the sample bottle with the scored point of the tube within 2 inches of the surface of the water. On choppy water it was difficult to obtain surface samples in this manner, therefore, a small catamaran was constructed which floated the sampler with the scored point of the sampler tube just below the surface (Figure 4).

All bottles usually filled within 70 percent of their total volume.

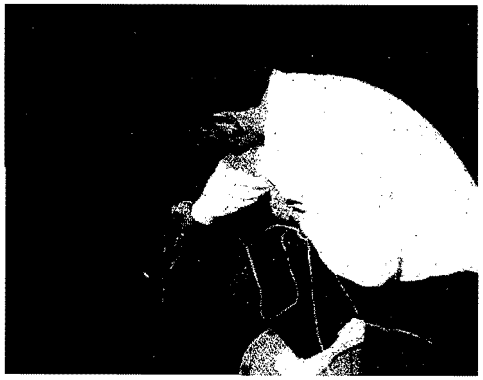

Figure 4.

C. Determination of MPN

The MPN was determined by the multiple tube method described in the "Standard Methods for Examination of Water and Waste Water." U.S. Public Health Association, Inc. 12th Ed., 1965.

Millipore counts were attempted, but found to be impractical because the pores plugged after the first few ml of brine were filtered. This was especially true of the bottom samples.

There was some concern as to the toxicity of the brine for the coliforms, especially in the 10 ml samples. It was determined that there was adequate dilution with the double strength lactose broth to allow growth of the organisms.

All positive gas producing organisms were subjected to confirmation tests for *E. coli* with final identification confirmed with the use of TSI agar and IMViC tests.

D. Effect of Brine Concentration on Growth of Coliforms (Kill Tests)

Two samples of lake brine were used to test the bactericidal effect of the lake water; one contained 96,900 ppm NaCl, the other 91,700 ppm. A series of tubes was set up using from 0 to 10 ml of lake water. The total volume of each tube was then brought to 10 ml with sterile distilled water. Lactose was then added to each tube to a concentration of 13 gm/liter. Actively growing cultures of *E. coli* isolated from the lake or from the U. of U. Department of Microbiology stock cultures were used as inoculum for the brine lactose tubes. Twenty-four sets were tested, each with a different confirmed coliform.

E. Growth Curves of Various Microorganisms Utilizing Bottom Debris as the Sole Source of Nutriments.

Flasks containing sterilized bottom debris collected at station 13 were inoculated with the following microorganisms:

E. coli	(U. of U. stock culture)
S. typhimurium	(U. of U. stock culture)
S. typhi	(U. of U. stock culture)
Shig. dysenteriae	(U. of U. stock culture)
Coliform No. 1	(Isolate from lake)
Coliform No. 2	(Isolate from lake)

Plate counts of viable organisms were made from these cultures at 0, 6, and 18 hours in order to determine a growth rate, if any, of each of the species of microorganisms. It is to be noted that 3 human pathogens were used in these experiments.

F. Tributary Samples

One set of samples from 28 different streams and canals flowing into the estuary were taken during the week of 25 July 1971. The MPN for this set of samples was determined.

Results

The most effort of the summer's work went into the sampling and determination of the coliform MPN at each of the 13 sampling stations. Table 1 presents the mean MPN for each station as determined for the surface, at a depth of 2 feet and at the bottom of the lake. Invariably, the bottom sample included debris from the lake bottom mud or sand. As was expected the greatest number of coliforms was found in the area nearest the mouth of the sewage canal, and the greatest concentration was found in bottom sludge.

As may be noted in the table, coliforms were isolated from bottom material at station No. 2 which was north of the causeway.

We had anticipated finding larger numbers of coliforms in surface samples, assuming that the surface waters were lower in saline content. Except at stations 11, 12, and 13, this was not the case.

The results of the tests for the toxicity of lake water for 24 different strains of confirmed coliforms (Table 2) showed that concentrations of NaCl above 6.78 percent allowed no growth. At the latter concentration only 3 of the 24 grew to show increased turbidity in the tubes. At a NaCl concentration of 5.81 percent, 9 of the strains failed to grow while 15 grew but produced no gas. At 4.95 percent NaCl, 4 strains failed to grow, 11 grew but produced no gas, while 9 grew and produced gas. At 3.88 percent NaCl only 1 organism failed to grow, 6 grew without gas production and 17 grew and did produce gas. Most of the strains grew and produced gas at concentrations below 3.88 percent. Strain 17 appeared to be less salt tolerant than the other strains and failed to grow at all at 2.91 percent NaCl, but did show growth at 1.94 and 0.97 percent. Strain 24 produced no gas at any concentration of NaCl, and failed to grow in NaCl concentration above 4.95 percent.

Table 3 presents the results of the experiment to demonstrate the ability of coliform organisms to grow in a broth where sole nutriment was obtained from the bottom sludge collected at sampling station No. 13. Of all the

Table 1. Average M. P. N. coliforms at each sampling station (five samplings).

Station #	Surface	2 ft.	Bottom
1	0	0	0
2	0	0	1.3^{a}
3	0	0	0
4	0	0	0
5	0	0	0.4^{b}
6	0	0	0
7	0	0	4.4^{d}
8	0	0	3.1^{c}
9	0	0.4^{b}	28.5
10	0.4^{b}	0.4^{b}	8.1
11	1.6^{c}	0.4^{b}	330
12	2.5^{c}	2.5^{d}	717
13	357	188	1328

a. 2 of 4 samples +
b. 1 of 5 samples +
c. 2 or 5 samples +
d. 3 of 5 samples +

Table 2. Growth of 24 strains of coliforms in Great Salt Lake water with added lactose.

%NaCl	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
9.69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6.78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	0	-	0	-	-
5.81	0	-	0	0	0	0	0	0	0	-	-	-	-	0	-	-	-	0	0	0	0	0	0	-
4.95	0	0	θ	0	θ	θ	θ	θ	θ	-	0	0	-	0	θ	θ	-	θ	0	0	0	0	0	-
3.88	0	0	θ	θ	θ	θ	θ	θ	θ	0	0	θ	0	θ	θ	θ	-	θ	θ	θ	θ	θ	θ	0
2.91	0	0	θ	θ	θ	θ	θ	θ	θ	-	θ	θ	θ	θ	θ	θ	-	θ	θ	θ	θ	θ	θ	0
1.94	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	0	θ	θ	θ	θ	θ	θ	0
0.97	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	0
0.00'	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	θ	0

0 Indicates growth in lactose broth
θ Indicates growth with gas production within 24 hrs.
\- Indicates no growth

Table 3. Growth of various microorganisms with sterile bottom sludge as sole nutriment.

Organisms	Time 0	6 Hrs.	18 Hrs.
E. coli	7	341	greater than 10,000
S. typhimurium	9	74	greater than 10,000
S. typhosa	18	19	420
Shig. dysenteriae	no growth		----
Coliform #1	31	290	greater than 10,000
Coliform #2	5	78	greater than 10,000

organisms tested, which included stock cultures of human pathogens as well as 2 strains isolated from lake brine, Shigella dysenteriae was the only organism which failed to reproduce.

The MPN determinations of the various "tributaries" of the estuary are not presented in tabular form. Suffice it to say that of some 28 streams and canals flowing into the estuary, every single one was found to be polluted with E. coli, the lowest MPN being 70 per 100 ml of H_2O and the highest > 1,600,000. Many streams showed counts greater than 1,600. This was but a single sampling, and dilutions were not prepared to determine more accurately the numbers of coliforms present. Many of these streams could have been, and possibly were, polluted with sewage, and the MPN of coliforms was more than likely in excess of 10^6 organisms.

Discussion and Conclusions

It was found by this student group that there is a flow of brine from the main part of the lake through the causeway bridge into the estuary. Also that the water has a greater saline content now than it did in 1965 when the State Department of Health and the Davis County Department ran their survey of the area. This may account for the lower MPN counts of coliforms generally found in the present survey--at least in the surface samples.

There is no doubt that the sewage deposits contain large numbers of coliforms, and that should the inflow of fresh water be adequate to make a fresh water lake of the estuary, then these and possibly sequestered human pathogens could conceivably make the estuary a dangerous and certainly non-esthetic recreation area for years to come. It was shown by these experiments that the coliforms there have become quite salt tolerant, and that there are adequate nutrients in the bottom sludge to maintain the multiplication of sequestered coliforms and organisms generally conceded to be human pathogens. This is true also for new coliforms and pathogens being continually deposited in the lake from the streams and drainage canals feeding the estuary.

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A HELE-SHAW MODEL STUDY OF SEEPAGE FLOW THROUGH THE CAUSEWAY OF THE GREAT SALT LAKE

Anching Lin[1] and Sang-Myung Lee[2]

Abstract

The hydrodynamic nature of the seepage flow through the causeway is described. The method of viscous flow analogy (or the Hele-Shaw model study) was introduced and applied to the investigation of the exchange of brines through the causeway. The model study provides an independent method that can develop all the necessary information concerning the effect of the causeway. Coupled with field investigations, the Hele-Shaw model study offers a most effective and economical approach for the development of pertinent data for the management of the Great Salt Lake. The study of seepage movement was was documented in 16mm movie films.

Introduction

Ever since the construction of the Southern Pacific Railroad causeway on the Great Salt Lake in 1957, the balance of brines in the lake has undergone a drastic change as first noted by T. C. Adams (Adams, 1964).

The brines in the north arm of the lake (relative to the causeway) have been observed to stay steadily at a state of near saturation, while those in the south were near saturation during the early 1960' s and were very much diluted in the last three years. The dilution of brines in the south obviously resulted from the increased amount of fresh water inflows to the lake.

The cyclic recurrence of wet and dry hydrologic conditions will continue to influence the physical environment of the lake. The precise effect of the causeway on the balance of brines in relation to the cyclic hydrologic event will have to be defined in order that the developable mineral resources on the lake may be assessed and future plans for mineral exploration may be established.

Madison of the U.S. Geological Survey conducted a field investigation on the effect of the causeway in 1969 (Madison, 1970). The study pointed out the many problems associated with the causeway, yet precise effects of the causeway were not defined.

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This paper introduces a Hele-Shaw model study in order to investigate in detail the mechanism that governs the seepage flow through the causeway.

The Hele-Shaw Model

Hele-Shaw, in 1898, suggested the use of viscous flow analogy to study the potential flows to which the seepage through the causeway belongs. The analogy is made possible by comparing the dynamic equations of motion between the flow through porous media and the flow in a very thin gap, called Hele-Shaw cell. That is, if one builds a Hele-Shaw model which is geometrically similar to a prototype, e.g., the shape of the cross-section of the causeway, the flows through the model and the prototype are similar and conditions in the model can be interpreted and utilized in the prototype if the proper modelling laws are acknowledged (DeWiest, 1965):

$$\lambda_K \sim \frac{\lambda_L}{\lambda_T}$$

where λ_K, λ_L, λ_T are the ratios of permeability, length and time between the model and the prototype. Here the permeability of the model is defined as $K_m = \frac{ga^2}{3\nu}$, a being the thickness of the Hele-Shaw cell and ν the viscosity of liquid used in the model. See attached bibliography for the theory and typical applications of Hele-Shaw model study.

The Causeway and the Model Study

The Southern Pacific Railroad causeway is a rock-filled structure; over the years, new materials have been added to the original structure to stabilize the slope. Thus the causeway mainly composed of two parts: (a) the core portion consisting of more compact materials, and (b) the cover portion on the slope resulting from newly added material and through which water flows with little resistance. It is the core portion that is responsible for the dynamic consequence of the causeway and thus the modelling is focused on the core portion.

A Hele-Shaw cell was built to the estimated proportions of the core portion of the causeway with a side slope of 1.5 units in horizontal direction versus 1.0 unit in the vertical. The overall base dimension of the model is about 24 inches and the working thickness of the Hele-Shaw cell was chosen to be 1/8 inch. The cell was constructed with transparent plexiglas for the convenience of visualization.

The presence of two different brines on two sides of the causeway created the two-phase seepage flow through the bottom of one side to the other side of the causeway, and an opposite flow of the lighter brines on the upper layer.

The steady-state situations of the two-phase seepage flow in the causeway were simulated in the model by maintaining a constant head difference through pumping by two polystaltic pumps. Dye materials were introduced to track the seepage motion. The movement of liquid in the model (as well as in the prototype) is typically very slow, therefore the model study was carried out by first completely recording the fluid motion in 16mm movies with a time lapse device and then each movie frame was examined to extract such information as velocity distributions and seepage volumes.

Results

The most important parameters which determine the seepage characteristics are the density ratios of the two brines and the relative liquid-head difference between the two sides of the structure. It was observed, as expected, that there were two extremes that might occur: i.e., when head difference was too small or too large, the seepage flow would involve the one-way movement of either lighter liquid or heavier liquid without exchange between the two.

Normally, the flow takes place in between the extremes. Depending on the density ratio and relative head differences, there are exchanges of fluids between the two sides of the model. And the result of such observations can best be summarized in Figure 1. Note that the subscripts 1 and 2 are associated with conditions to the left and to the right, respectively, of the model structure (or the south arm and the north arm of the actual causeway). The curve was developed for $\rho_1/\rho_2 = 0.777$. From the curve, one could predict the ratios of rates of seepage volume Q_1/Q_2 for a given relative head difference $\Delta H/H_1$. Figures 2 through 5 give the actual steady state configurations of the five runs performed and also define the symbols mentioned in the study.

Figures 2, 3, and 4 demonstrate the fact that there are exchanges of liquids between the two sides of the structure. Figure 5 indicates the case, due to excessive head differences, where there is only one-way migration of the lighter liquid.

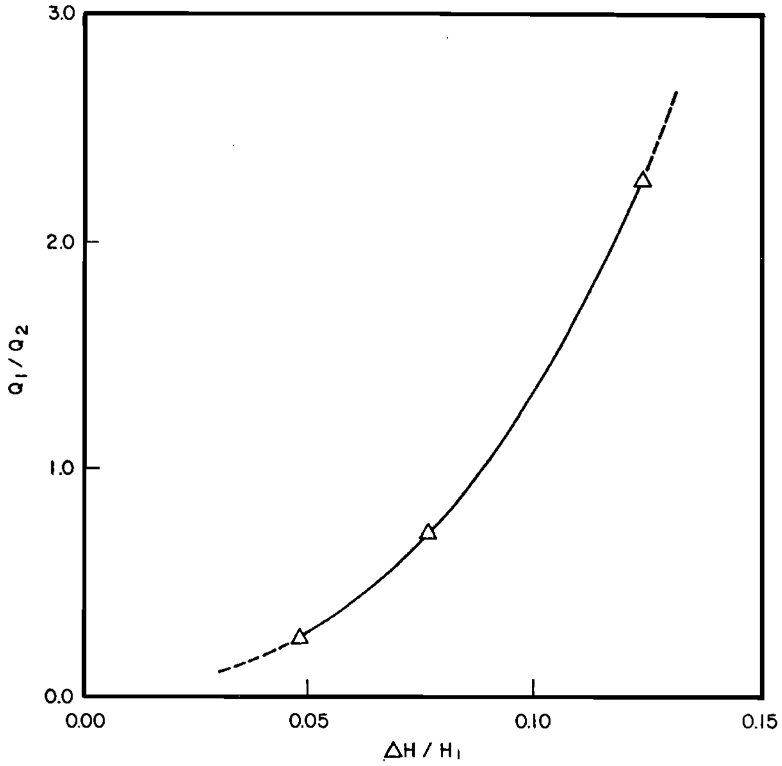


Figure 1. Ratio of seepage volumes versus density ratios.

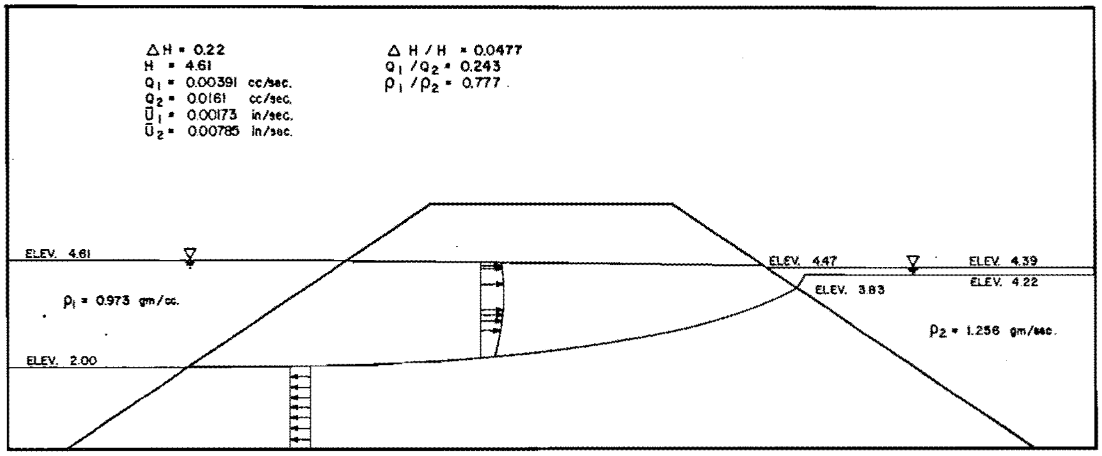
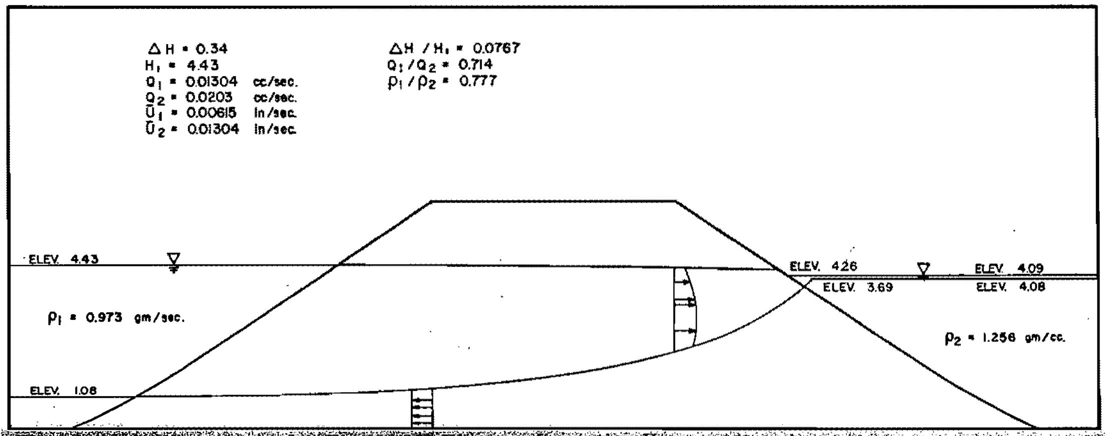


Figure 2. Flow configuration I.



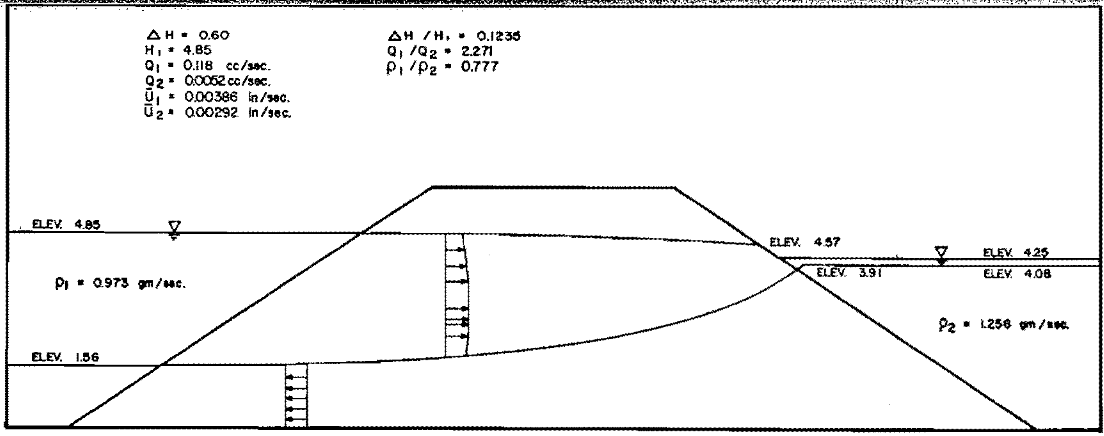


Figure 4. Flow configuration III.

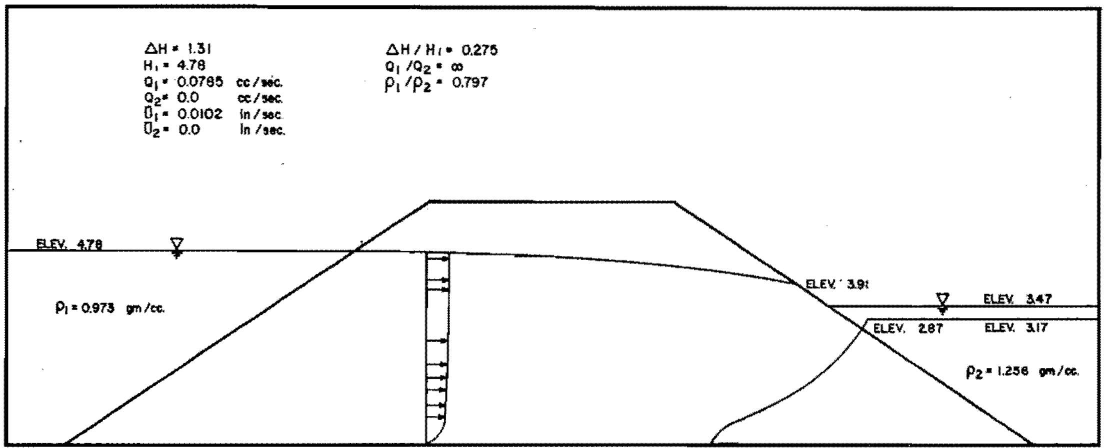


Figure 5. Flow configuration IV.

The velocity vectors shown are the results of study on movie films taken. The integration of the velocity profiles then gives the rates of seepage volume. The results presented in dimensionless form such as Q_1/Q_2, $\Delta H/H_1$, etc., are readily applicable to the prototype without having to consider the modelling laws.

One may consider the year 1972 as an illustration. The head difference between the south arm and the north arm of the lake has been quoted as 1.8 feet and the water depth at the south side of the causeway averages, say, 25 feet. Then, the relative head difference $\Delta H/H_1$ is estimated to be 0.07 (or 7 percent). If the density ratio were 0.777, then the ratio of exchange volume Q_1/Q_2 would have been about 0.50 (from Figure 1). Or equivalently, if the density of the brines in the south were diluted to 78 percent of that in the north, then relative head difference 0.07 would have indicated that heavier brines were migrating two times as much from the north to the south than the much diluted brines from the south to the north. Of course, the actual density ratio is about 0.90 and the ratio of seepage volumes will be higher than 0.50.

From a consideration similar to Ghyben-Herzberg's (DeWiest, 1965), and working from Figure 1 the ratio of seepage volume should be close to one. That is, the volumes of brines migrated from the south are almost balanced by those from the north.

Future extension of the work will have to include more density ratios and wave effects. However, before the actual parameters of the field environment including physical and hydrological are developed and incorporated to the model study, any unplanned extensive study may prove to be only a futile academic exercise.

Conclusion

The model study offers a simple and direct approach to the investigation of the dynamic behavior of seepage flow through the causeway. It is by far the most effective and economical way for the treatment of seepage flows involving the exchange of two-phase fluids.

Coupled with field investigations, the model study should provide all the information that is needed to assess the impact of the causeway.

The advantages of the model study can be summarized as follows:

(1) The model study provides comprehensive details of the seepage parameters, such as velocity distributions, exchange of seepage volumes, location of interface, etc.;

(2) The execution of the experiment and the interpretation of the results are simple and straightforward. The movies made on the fluid movement can be accepted readily as results;

(3) It is possible to incorporate the wave effects to the study with little additional work.

It is suggested then that future model study be designed to relate the actual field environment including all the possible head and density differences resulting from cyclic hydrological conditions, and the wave effects should also be investigated.

Acknowledgement

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NUTRIENTS, ALGAL GROWTH, AND CULTURE OF BRINE SHRIMP IN THE SOUTHERN GREAT SALT LAKE[1]

Donald B. Porcella[2] and J. Anne Holman[3]

Abstract

The overall objective of this study was to measure nutrients in Great Salt Lake waters and to determine how the alga, Dunaliella sp. responds to nutrients. The relationship between food supply (algae) and the growth and reproduction of brine shrimp Artemia sp. was also studied.

Based on chemical analyses inorganic nitrogen is apparently the limiting factor for growth in the samples of Great Salt Lake water. Carbon may also be limiting. Phosphorus, iron and other trace elements seem to be in abundant supply. These observations were confirmed by algal bioassays.

Brine shrimp were fed on several concentrations of Dunaliella sp. as well as on yeast cells. Growth and reproduction of the brine shrimp on algae alone was superior to yeast alone. The optimum utilization by the brine shrimp was about 1,000 algal cells per brine shrimp per day. Different concentrations and ages of added algae had no apparent effect on whether the mature brine shrimp produced live young (nauplii) or resistant cysts.

It can be concluded that a feasible aquaculture based on Dunaliella sp. and Artemia sp. can be developed for brine shrimp isolated from the Great Salt Lake. Production of algae and brine shrimp in lake enclosures may be increased by addition of specific nutrients.

KEY WORDS: Great Salt Lake, Productivity, Nutrients, Aquaculture, Carbon, Nitrogen, Phosphorus, Dunaliella sp., Artemia sp. (Brine Shrimp).

Introduction

Because of the high salt content of the Great Salt Lake waters, it is considered a harsh environment for most microorganisms and higher plants and animals (Brock, 1969). A harsh environment actually could be defined as one where the environment has not existed as a permanent entity long enough to allow the evolution of a wide variety of organisms. Thus in harsh environments very simple and specific food chains exist which have little or no competition with other species for resources in short supply. The Great Salt Lake environment is one of these environments and appears to be ideally suited for maximizing flow of energy and production in a food chain.

There are a few species which have been selected for, and which dominate and compete for energy and nutrients, and carry out their full life-cycle in the waters of the lake. These include various kinds of "salt-loving" bacteria and algae and the brine shrimp, Artemia sp. At present the economic potential of the Great Salt Lake for aquaculture depends on methods for growing brine shrimp and selling them to the large market of tropical fish fanciers. Feasible aquaculture is based on the proposition that increased concentrations of nutrients would lead to higher bacterial and algal populations and therefore higher production of brine shrimp. As a whole the Great Salt Lake is relatively nutrient poor and does not receive large influxes of nutrients from pollution. Thus, the opposite side of the increased nutrient question, eutrophication or increased nutrient concentrations with the resultant overproductivity problems, apparently does not occur in the lake.

The complicating factor in the Great Salt Lake is that the availability of nutrients which are required by algal populations is also affected by the high concentration of salts. There is not only the possibility of salt concentration affecting the activity of specific nutrients needed for growth of microorganisms, but the biological fixation of various kinds of nutrients is probably affected by the lack of species of sufficient variety to fix nutrients. Therefore, to develop a feasible aquaculture it is necessary to understand the inputs and cycling of various nutrients, to understand how they are utilized by the producer forms of the food chain (algae), and finally to determine the role of producers in supporting the brine shrimp. Only in this way can a viable brine shrimp processing industry be developed. Because brine shrimp feed on any particle within the appropriate size range, bacteria and detritus are foods also. These usually depend on producers for their growth.

The overall objective of this study then was to measure nutrients in Great Salt Lake waters and determine how the algal species of interest respond to nutrients. Then the relationships between food supply (as algae) and growth of brine shrimp were to be estimated.

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Materials and Methods

Sampling

Samples were obtained from a sampling site in the Great Salt Lake adjacent to the Magnesium Division Plant of NL Industries at the south end of the lake to the west of Stansbury Island. Because of the isolation of the sampling point, it is not polluted and probably represents the lake itself. Samples were collected at various intervals primarily during the spring and summer months of the years 1971 and 1972 at this site and returned to Utah State University for analysis.

Chemical analyses

Samples were routinely analyzed for pH, inorganic forms of nitrogen (nitrate, nitrite, ammonia), and orthophosphate. Chemical analytical techniques were largely taken from methods for sea-water analysis (Strickland and Parsons, 1968). Because of the high salt content it was not possible to directly analyze the water and samples were first diluted to approximately ocean-water salt concentrations by dilution to 20 percent with deionized distilled water. To ensure that dilution was not changing the concentrations of the nutrients of interest, standard addition techniques were performed. The standard addition techniques indicated that dilution did not affect the results.

Bioassays

Bioassay techniques using procedures adapted from the Algal Assay Procedures: Bottle Test as published by the Environmental Protection Agency (1971) were utilized to determine the algal growth response to the nutrient milieu in the samples. This technique utilized the addition of a known algal species to the sample of the water, and then the observance of growth with time in constant volume cultures (batch cultures). Algal biomass was measured using relative fluorescence (chlorophyll a estimates), optical density (turbidity), cell counts, and pH.

The test alga utilized in this study was a green flagellate identified as Dunaliella sp. It was isolated from samples obtained from the sampling site and maintained in Great Salt Lake water until an artificial Great Salt Lake water had been developed. The artificial Great Salt Lake water is a medium made up with standard freshwater algal nutrients (NAAM) plus added quantities of sodium chloride and sodium bicarbonate, as shown in Table 1.

Brine shrimp were measured using a Whipple micrometer or clear ruler, counted, and identified as to stage in life-cycle.

Table 1. The Simulated Great Salt Lake (SGSL) Water used as artificial medium for Dunaliella. Final concentrations in culture.

A. Salinity and inorganic carbon

1. 200 g NaCl per liter (Culligan supplied water softener regenerant is used as the source of NaCl)
2. 0.5 g $NaHCO_3$ per liter

B. Basic freshwater medium (NAAM, refer EPA, 1971)

3. Macro-elements

$NaNO_3$	25.5 mg/l
K_2HPO_4	1.044
$MgSO_4 \cdot 7H_2O$	14.7
$CaCl_2 \cdot 2H_2O$	4.41
$MgCl_2$	5.7

4. Micro-elements

H_3BO_3	186.	µ g/l	(B, 33)*
$MnCl_2$	264.		(Mn, 114)
$ZnCl_2$	33.		(Zn, 15)
$CoCl_2$	0.78		(Co, 0.35)
$CuCl_2$	0.01		(Cu, 0.003)
$Na_2MoO_4 \cdot 2H_2O$	7.26		(Mo, 2.88)
$FeCl_3$	96.		(Fe, 33)
$Na_2EDTA \cdot 2H_2O$	300.		

*Actual elemental concentrations of trace elements

Results and Discussion

Field studies: chemical analyses

Orthophosphate and inorganic nitrogen are usually considered of primary interest in algal growth. Carbon is the most important component of algal cells, but in most environments is not limiting (Goldman, et al., 1972). The relative importance of carbon, nitrogen, and phosphorus can be deduced from the following estimate of composition by weight of marine plankton (e.g., see Stumm and Morgan, 1970): $C_{41} N_{7.2} P$. Because of the high salt content of Great Salt Lake water, it was considered that carbon might be a limiting factor and monitoring of pH was utilized as a method of determining whether carbon was indeed limiting.

The measurement of pH to indicate carbon limitation in the water samples is the only simple alternative to comprehensive studies of carbon utilization in the natural water (e.g., Verduin, 1956). Rises in pH indicated that CO_2 was being removed from the bicarbonate buffer system and there was a direct correlation between qualitative increases in algal (not always Dunaliella sp.) population and increased pH (Figure 1). Simultaneously, there was a reduction in inorganic nitrogen concentration when pH increased, indicating utilization of nitrogen by growing algae. Thus, the expected cause and effect relationship between high algal populations and changes in inorganic nitrogen and carbon (pH) was shown by the samples. However, orthophosphate concentrations do not respond in this way, and in fact remain quite high and relatively constant for all samples. The low algal requirement for phosphorus and the relatively high concentrations of phosphorus in the water would likely preclude noticeable changes in orthophosphate concentration.

These observations indicate that there is a possibility of more than one limiting factor, i.e., nitrogen and inorganic carbon concentrations may be operating at the same time to control the production of algae in these samples of Great Salt Lake waters.

During the period of time when these observations were made, the salt content of Great Salt Lake water in terms of specific gravity varied from about 1.11 in 1971 to 1.10 in 1972; apparently the reduction in specific gravity was the result of an influx of fresh water during the high runoff periods of 1972.

Nitrogen is one of the nutrients which is most limiting for algal growth, and the variations in the different inorganic forms of nitrogen reflect this requirement. As can be seen in Figure 2, the most abundant form in the samples was ammonia nitrogen, followed by nitrate and then nitrite nitrogen. Because nitrite is unstable in aerated environments and quickly is oxidized to nitrate, it is expected that nitrite would not be at very high levels. However,

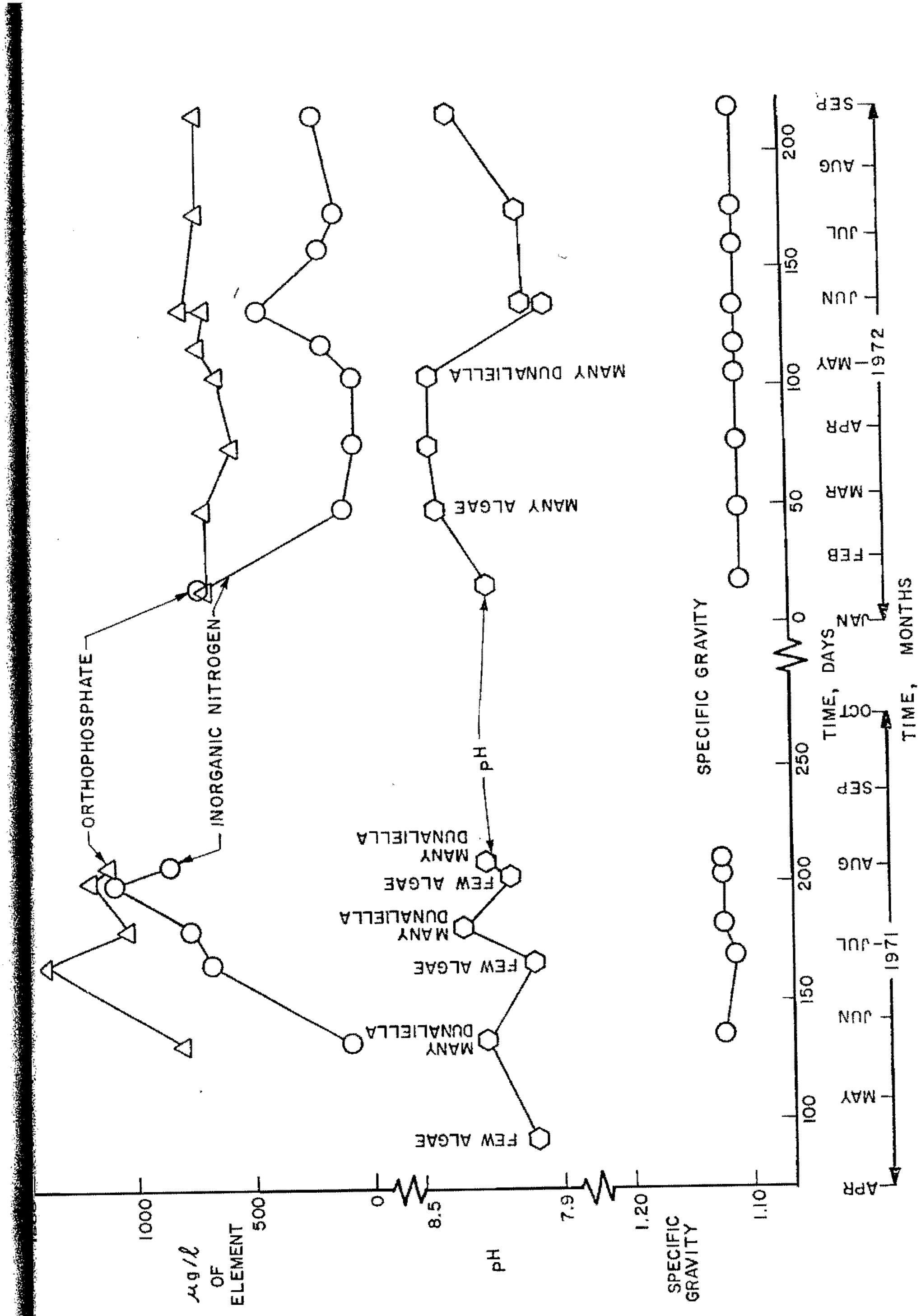

Figure 1. Changes in pH, inorganic nitrogen, and orthophosphate phosphorus in Great Salt Lake water supplies.

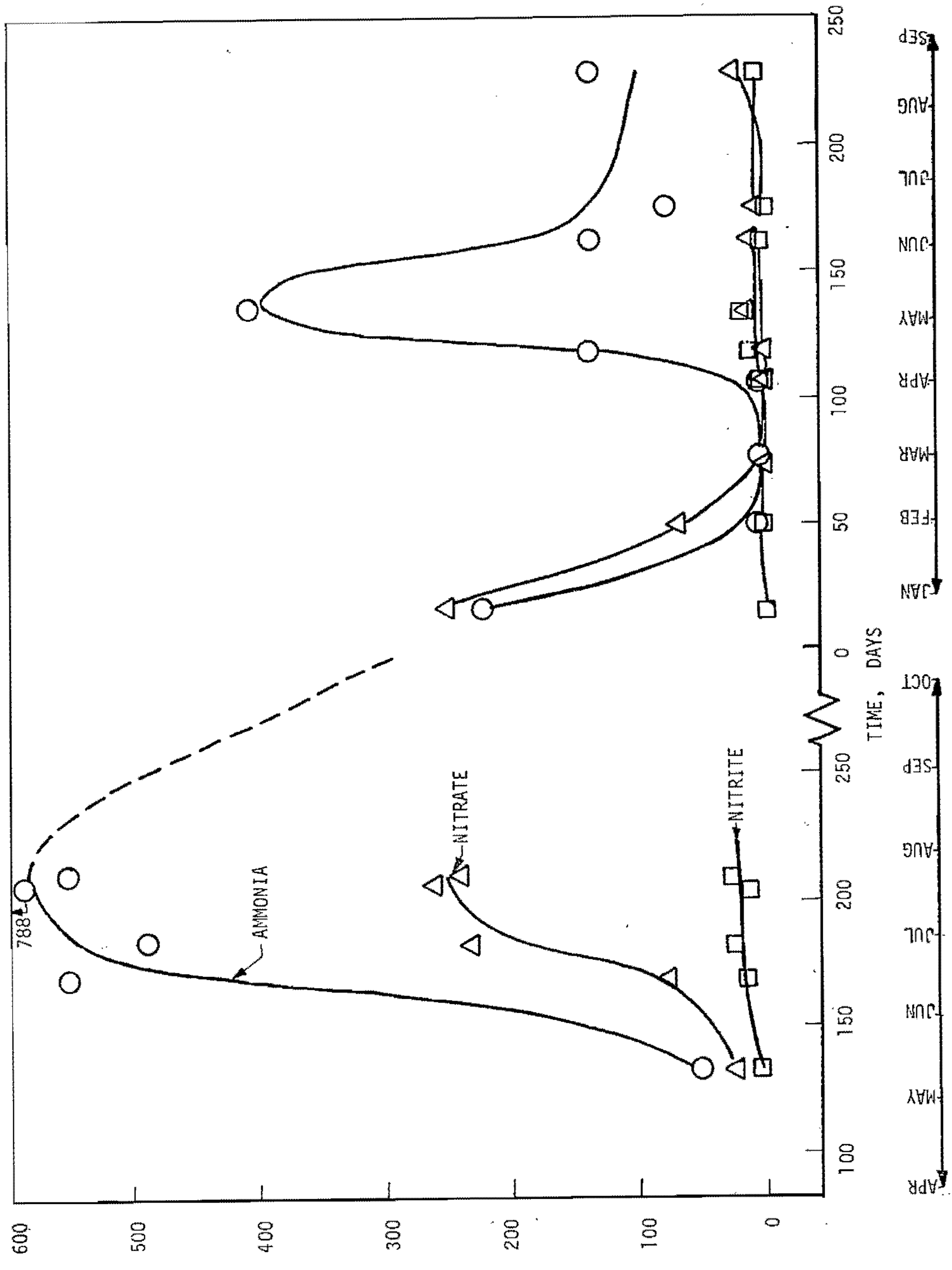

Figure 2. Variation in ammonia, nitrate, and nitrite nitrogen in Great Salt Lake water samples.

an increase in its concentration indicates that nitrification, i.e., the oxidation of ammonia to nitrate is occurring.

In the spring months the concentration of ammonia increased rapidly to relatively high levels. This was followed by increases of nitrate, apparently as a result of nitrification. The source of ammonia was probably primarily from decomposition of nitrogenous organic compounds in the sediments of Great Salt Lake. Observations of sediments in the area sampled indicated that anaerobic layers exist in the bottom sediments and this was the probable source of most of the ammonia input to the system. Thus, the probable cycle of nitrogen in the Great Salt Lake consists of the utilization of inorganic nitrogen compounds by growing algal populations, their subsequent consumption by brine shrimp (primarily) and deposition in the sediments, and decomposition through bacterial action under anaerobic conditions to produce ammonia. Probably, there is minimal input of nitrogen into the area sampled, and it is only this recycling which provides nitrogen for algal growth. Algal growth probably accounts for why the inorganic nitrogen concentrations in the samples were reduced to nearly zero and therefore why nitrogen is probably one of the important limiting nutrients in Great Salt Lake. Therefore, additions of sewage effluents which contain nitrogen to the sampling area would lead to increases in nitrogen concentration and thus productivity in the Great Salt Lake.

Field studies: bioassays

The samples of Great Salt Lake water were also analyzed by using algal bioassay techniques to confirm that nitrogen was the limiting nutrient in Great Salt Lake water and not some other factor that we were not able to measure easily using analytical chemistry. It must be noted that it is not possible to bioassay for the effects of carbon with the bioassay technique (Porcella, 1969). This is because carbon is considered an extrinsic limiting nutrient in that it is supplied by sources extrinsic to the water sample itself; that is, it comes as a gas from sediment microbial activities, from inorganic carbon sources in the air, and from metabolism of microorganisms in the water as well as from the inorganic carbon compounds of the water.

The technique of bioassaying for limiting nutrients is still developing and is called 'spiking' (EPA, 1971). This technique involves splitting a sample of water into several parts and then adding various specific nutrients to the subsample and observing the effects on the resultant algal growth. In our experiments, we utilized 1) a control (with no additions), 2) a complete control (addition of all the nutrients), and the additions of 3) nitrogen as ammonia, 4) phosphorus as orthophosphate, and 5) iron and trace elements as the remainder of the complete medium (refer Table 1). Results from these five subsamples showed that in most cases the Great Salt Lake water was responsive to additions of nitrogen and only on rare exceptions to additions of either phosphorus or trace elements (Figure 3). Thus the supposition that nitrogen is the limiting factor under natural conditions as indicated by the chemical analyses was supported by the bioassay result.

The medium developed for maintaining cultures of Dunaliella sp. is also the basic medium utilized for maintaining stocks for freshwater algae (EPA, 1971). However, estimates of growth obtained with Dunaliella sp. showed that only about one-third of the growth was obtained as compared to freshwater green algae (Weiss and Helm, 1971). This indicates that not all of the nutrients are available for utilization by the algae. It may be that nutrients are available to algae as activity rather than purely as concentration and thus that salinity would limit the availability of nutrients (Stumm and Morgan, 1970). This result would affect the nutrient addition requirement for aquaculture as well as being an important area of research for algal growth kinetics.

Dunaliella and brine shrimp growth

The development of laboratory cultures of Dunaliella sp. enabled the study of algae as food for brine shrimp and of the effects of the algae on brine shrimp growth and reproduction. The effect of varying concentrations of algae on growth of brine shrimp are shown in Table 2, and indicate that larger brine shrimp are obtained with higher food concentrations. Although longevity was not appreciably affected by food level within a concentration range of 100 algal cells per ml to 300 cells per ml, the size of the brine shrimp was significantly affected. At these higher algal concentrations the brine shrimp all lived about three months--their approximate physiological longevity; at 50 cells per ml the median survival was about one month; in brine shrimp cultures maintained on daily additions of unfiltered Great Salt Lake water the median survival time was nine to ten days. Thus at least for the samples we collected, there was

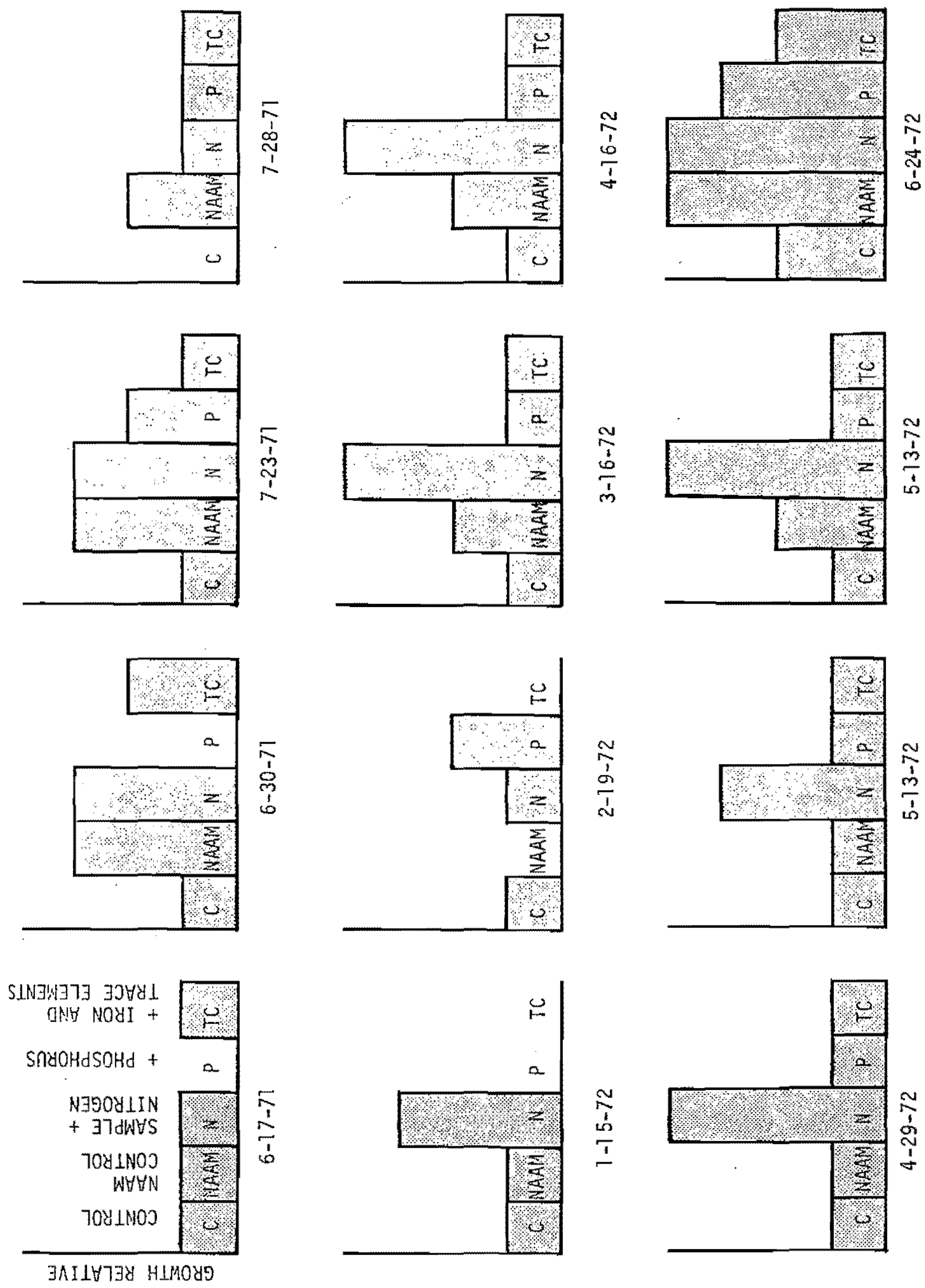

Figure 3. Relative growth in Great Salt Lake bioassays. Samples from 1971 and 1972.

Table 2. Effect of food concentration and supply on Brine Shrimp growth.

Mean Increase in Length Over Life Cycle, mm					
	Food Type				
Amount of food added	ALGAE	ALGAE		YEAST	
	Experiment 1	Experiment 2			
Initial size of brine shrimp*	3.5	3.0	4.0	3.0	4.0
Control (GSL alone)	Died	-	-	-	-
100 Cells/ml	1.7	-	-	-	-
200 Cells/ml	2.3	5.7	2.5	2.4	2.8
300 Cells/ml	2.8	-	-	-	-

*3.0 mm brine shrimp are immature; 3.5 and 4.0 mm are mature.

insufficient food supply in the Great Salt Lake. The Dunaliella sp. are apparently a much better source of nutrition than yeast, an accepted laboratory food for brine shrimp. The comparison with yeast addition indicates that the nutritional deficiency in yeast exerts its effect on immature brine shrimp, and that either yeast or algae are approximately equivalent food sources for the adults.

Estimates of the mean generation time of brine shrimp populations in their natural state indicated a mean generation time of about 20 to 30 days. Apparently because of the abundance of food the mean generation time in the laboratory was about 14 to 21 days. Thus, laboratory aquaculture provides a good opportunity for the control and economic production of brine shrimp.

Another important question concerns the effect of food supply on the life-cycle of the brine shrimp (Figure 4). Brine shrimp have a choice of two methods of reproduction, cyst (which later hatch) production, or live young. From an aquaculture point of view, it would be desirable to know how to control the production of cysts or live shrimp depending on the market for live food or hatched young. Several investigators have indicated that food stress or food type have some effect on mode of reproduction by brine shrimp (Wirick and Gillespie, 1972). As a result, an experiment was designed to feed brine shrimp utilizing algal cultures of varying age. It has been shown that significant variations in composition of algae occur with age of the culture (e.g., Foree and Barrow, 1970; Porcella, et al., 1970). Using batch algal cultures

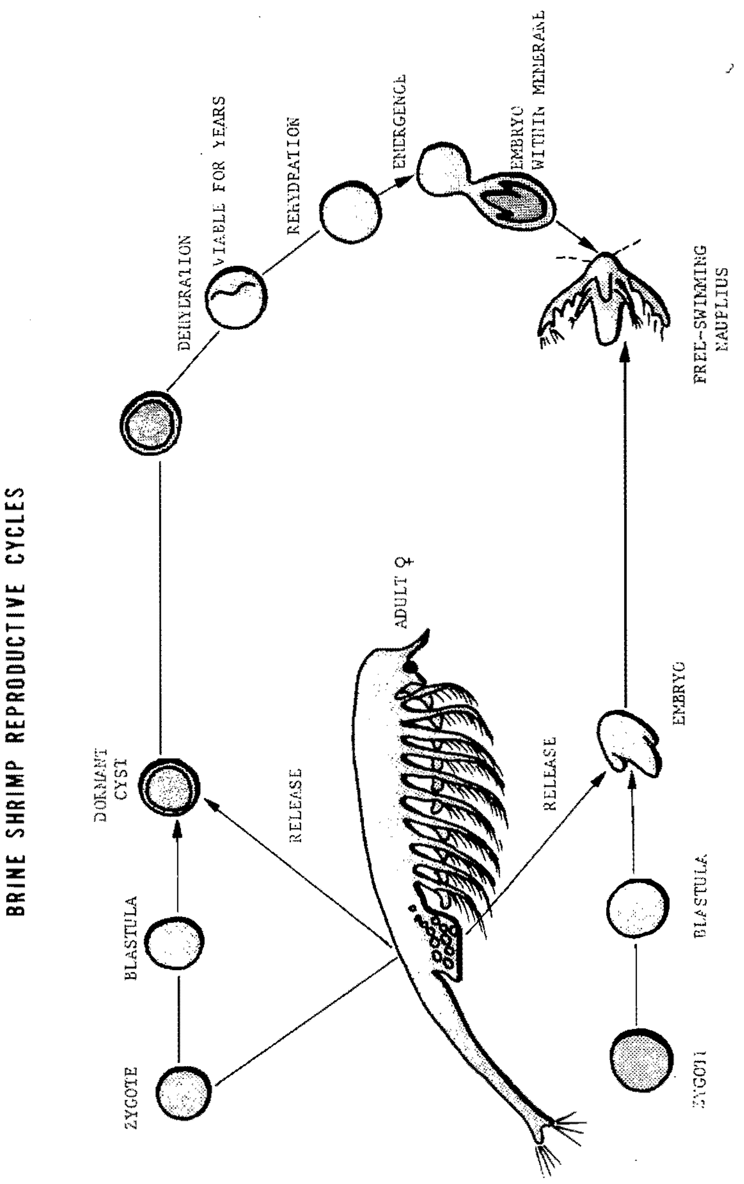

Figure 4. Brine shrimp reproductive cycles.

of age 7, 14, 21, and 28 days, adult brine shrimp were fed during their reproductive life to determine the effect of mode of reproduction and numbers of young produced. There was no apparent effect of algal culture age on either parameter. Varying food level concentrations of the different aged algal cultures produced no effect on mode of production either.

Conclusions

1. Both chemical and bioassay results indicated that inorganic nitrogen is apparently the limiting factor for growth in the samples studied.
2. Phosphorus and iron and other metals seem to be in abundant supply relative to nitrogen.
3. Analyses of field samples by pH indicate that carbon may also be limiting in the Great Salt Lake itself.
4. Growth and reproduction of brine shrimp on Dunaliella sp. alone was superior to yeast alone. Thus the algae can be used for brine shrimp aquaculture.
5. The relationships between optimum algal additions to cultures of brine shrimp and rates of brine shrimp population increase indicated that optimum utilization of algae was about 1,000 algal cells per brine shrimp per day, but greater growth of brine shrimp occurred at additions of 2,000 and 3,000 algal cells per brine shrimp per day.
6. However, different concentrations and ages of added algae had no apparent effect on the mode of brine shrimp reproduction.
7. It can be concluded that a feasible aquaculture based on algae and brine shrimp can be developed for brine shrimp isolated from the Great Salt Lake. Addition of the specific limiting nutrients to the Great Salt Lake or to enclosures of Great Salt Lake water would probably increase the production of brine shrimp under natural lake conditions.

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INSECT PROBLEMS ASSOCIATED WITH WATER RESOURCES DEVELOPMENT OF GREAT SALT LAKE VALLEY

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Abstract

Insect pests and/or vectors are already numerous in many areas in the Salt Lake Valley at certain times each year. Their numbers will probably increase with increased water resource development unless an integrated control program including water management, habitat modifications and use of chemicals is included in plans for future water development for the Salt Lake Valley.

KEY WORDS: Brine flies, Habitat modification, Integrated control, Leptoconops kerteszi Kieffer, Mosquito production, Water management.

Introduction

Problems caused by insects associated with the Great Salt Lake, especially those related to mosquitoes, biting gnats and brine flies, have received a great deal of publicity. Numerous species of insects and related arthropods which are pests, potential vectors or pathogens are associated with the development and use of the Great Salt Lake and its tributaries. Some of the most important ones are mosquitoes, midges, biting gnats, brine flies, blackflies or buffalo gnats, deerflies, and horseflies. These insects are dependent on water and their numbers are related to kinds and amounts of water available which is determined largely by water use and management. This report deals mainly with problems associated with mosquitoes, biting gnats and brine flies, with a brief treatise on the midges, deerflies and horseflies.

As the human population of Salt Lake Valley increases, there is a proportionate increase in the use and development of our water resources. Housing developments are now situated in areas which were primarily agricultural, marsh, and desert areas. Parks and other recreational facilities are being developed along the Jordan River, mountain streams and canyons, and fresh-water marshes on the shores of the Great Salt Lake. Industries have been established throughout the Salt Lake Valley. All of these add to the rate of population increase in this area.

Related to development of water resources and increase in population density are two aspects of insect problems which need to be understood and included in the development program: (1) as water resources are developed, the number of insects associated with aquatic environments such as mosquitoes, midges and blackflies usually increases, as well as the numbers of biting gnats, deerflies and horseflies; and (2) with an increase in the population in a given area, there is an increase in the number of people who are exposed to the insect pests and/or vectors.

Tipton and Saunders (1971) reviewed the arthropod-borne diseases endemic in the state. They pointed out the potential dangers of exposure to plague, tularemia and several types of encephalitides in several counties in northern Utah. Suitable vectors for these diseases are present in most counties surrounding the Great Salt Lake. With an increase in the number of people visiting these areas, an increase in the incidence of these diseases in man and other animals is possible.

Extensive fresh water marshes border the Great Salt Lake on the south, east, and north, with the western shore of the lake being largely desert with few streams or marshy ground. The marshes comprise a strip of ground varying in width from 2 to 18 miles wide extending along the shores for approximately 100 miles. The water creating these marshes is run-off from precipitation, drainage from irrigation, industrial and municipal facilities. This water has been impounded by dikes to sustain existing and create additional marsh land.

These extensive man-made marshes have been developed by sportsmen as habitat for wildlife and other recreational activities, by ranchers for livestock grazing, harvesting of salt grass and storage of irrigation water. Within this area are five water management refuges operated by the Utah State Division of Wildlife Resources, one federal migratory bird refuge, numerous privately owned and operated gun, fur and reclamation clubs, and one Bureau of Reclamation water storage project.

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Mosquitoes--Diptera: Culicidae

Rees (1964) commented on water resource development and use and mosquito control, and stated that mosquito production in Utah is largely dependent upon and attributed to water development and use by man. Fifty to eighty percent of the mosquitoes produced in those parts of Utah inhabited by man are the result of man-made situations which are created from the development and use of water. He further stated that if mosquito prevention measures were better understood and incorporated into water development plans, the mosquito problem could not only be reduced, but could be eliminated in many areas with little additional expense and without curtailment of water development.

Gartrell et al. (1972), of the Tennessee Valley Authority, reported that increased potential for production of mosquitoes is an undesirable consequence of many types of water resource management projects. Control is required in many cases to safeguard public health and prevent nuisances that would interfere with full realization of the purposes for which the projects are undertaken.

Rees and Collett (1959) reported an epidemic of Western Equine Encephalitis in northern Utah and concluded that 1) in Utah in 1958 a recognized outbreak of WEE occurred in man; 2) it was accompanied by a tremendous increase in the number of *Culex tarsalis* mosquitoes; 3) *Culex tarsalis* mosquitoes avidly fed on man in considerable numbers during this period; and 4) some *C. tarsalis* mosquitoes harbored the WEE strain of virus.

Smart et al. (1972) isolated Western Equine Encephalitis virus from pools of *Culex tarsalis* and *Aedes dorsalis*, and the California group virus from *A. dorsalis* and *Culiseta inornata* mosquitoes. Most of these mosquitoes were from Skull and Tooele Valleys south and southwest of the Great Salt Lake.

Tipton and Saunders (1971) reported other arboviruses which have been isolated from mosquitoes in Utah. They include Hart Park-like virus isolates from *Culex tarsalis*, California encephalitis group virus isolates from *Anopheles freeborni*, *Culiseta inornata*, *Aedes dorsalis*, *A. nigromaculus*, *Culex erythrothorax*, and *Culex tarsalis*, and Cache Valley virus isolates from *Culiseta inornata* and *Anopheles freeborni*.

All of the forementioned mosquitoes are common in the Salt Lake Valley, and all readily feed on human hosts except *Culiseta inornata* which only occasionally feeds on humans.

It is evident from the forementioned references that development of the water resources in the Salt Lake Valley could result in an increase in mosquito problems with an increase also in the danger from encephalitis infections. This could be a serious obstacle to the full development of these water resources. With proper planning and water management the problems associated with mosquito production can be largely reduced or eliminated.

Biting Gnats--Diptera: Ceratopogonidae

Leptoconops kerteszi Kieffer is a species of minute, biting gnat present in abundance in the western United States and other parts of the world where suitable habitats exist. Common names such as "midges," "punkies" and "no-see-ums" reflect the small size of these gnats. In Utah they are produced in many diverse habitats but most commonly and in countless numbers in the moist oolitic sand along the shores of the Great Salt Lake. In these areas, particularly in the spring of the year, the adult gnats become extremely numerous and annoying, and the females inflict painful bites on man and other animals. Consequently, some recreational areas along the shore of the lake are rendered undesirable during periods of peak emergence.

Rees and Smith (1950, 1952) and Rees et al. (1969) reported that at the Salt Lake Refining Company north of Salt Lake City, and the Marquardt facility at Little Mountain west of Ogden, biting gnats were so numerous as to be responsible for a 20 percent loss of efficiency of outside workmen.

At the construction site of National Lead's magnesium extraction facilities on the western shore of the Great Salt Lake at Lake Side during 1970 and 1971, workmen threatened to walk off the job if some control measures for these biting gnats were not put into operation.

Hansen (1969) reported on these biting gnats at the solar pond complex on the eastern shore of the Great Salt Lake, owned and operated by the Great Salt Lake Minerals and Chemicals Corporation. He stated that these gnats are despised because of their blood-sucking bite. He reported that they are not repelled by chemical repellants and will quickly drive away anyone who is not protected by nets, clothing, or other protective devices. An Ogden salvage firm found it difficult to hold employees much over a few days while they worked at Promontory Point. Visitors to that area during May, June and July are usually driven away. Tourists have been heard to refer to these gnats as "teeth with wings."

Rees et al. (1969) reported that adult *Leptoconops kerteszi* are widespread throughout the state of Utah, and the annoyance caused by these gnats is more extensive and severe than previously suspected. The flight range apparently exceeds ten miles in certain areas. In some study areas, adults have been present from May through September, but the peak adult gnat population in most localities occurs in a six to eight week period from early May through June. If soil moisture remains high, the length of the adult season may be lengthened.

Lawyer (1971) reported a broad distribution of *Leptoconops kerteszi* in Utah collections of adults from valleys, near streams, lakes and reservoirs, but most commonly in large numbers in the vicinity of the Great Salt Lake. Rees et al. (1970) reported that these gnats have not been collected at elevations over 7,000 feet.

Control of these gnats is possible but requires extensive surveys, and control measures are often expensive with variable levels of success (Rees et al., 1970).

Brine Flies--Diptera: Ephydridae

Jorgenson (1956) reported that 69 species representing 24 genera of the family Ephydridae occur in Utah. Aldrich (1912) recognized two species of the genus *Ephydra* in the Great Salt Lake; *E. gracilis* Packard is the most abundant and smaller species, and *E. hians* Say, the larger species is less abundant but widely distributed.

The early reports of Fremont (1845), Captain Stansbury (1852) and others indicate that these flies have always been abundant in the Great Salt Lake. The present increase in their numbers may be the result of a cyclic increase, increased water level resulting in a dilution of the salt water, increased organic pollution entering the lake, or an increased awareness of the fly population due to a recent increase in the number of people exposed to these insects.

Mr. John Silvers, proprietor of Silver Sands Beach, reported, "My sons and I have boated and roamed the Great Salt Lake and all the islands many times. On some occasions we did encounter the brine fly but never in mass on the south shores of Great Salt Lake. Now we have noticed the hatch steadily increasing from year to year. This hatch must be appreciably reduced before shoreline resorts, such as Silver Sands Beach, can justify development and continued facility improvement . . . . Almost without exception during the

heart of the tourist season, which is June, July and August, the brine fly is multitudinous and there are times when the entire beach and picnic areas are vacated by our patrons because of this obnoxious insect . . . Not only do the bodies of the fallen insects we kill blacken our entire beach by the water's edge, but likewise the very much alive brine flies cover the Great Salt Lake waters for a good block or so out from the shore and oftentimes sweep over the higher beach areas and spread out like a huge brown blanket for miles around the south end of the Lake. On numerous occasions the air has been so thick with these insidious creatures that many of our patrons in their cars refused to open their windows or doors and often leave our beach resort saying that they will never return (Hansen, 1969)."

The management of Great Salt Lake Minerals and Chemicals Corporation, in a letter to Utah Industrial Services Agency, University of Utah, stated: "We presently have two problems with the insects at our solar pond complex. One is caused by the super abundance of flies that plug up the radiators of vehicle cooling systems, and the cooling systems at the pump stations and motor control stations. On occasion these flies are so dense that the truck radiator can become plugged in less than a day. These flies have caused damage to this equipment which has resulted in down time. While these particular flies do not bite, they occur in such abundance that they are occasionally inhaled, caught in the eyes, or crawl into the ear channel (Hansen, 1969)."

To better understand the biology of the brine fly and the extent of the problem caused by these flies, a study was conducted during 1969 and 1970. Results of this study were reported by Winget, Rees and Collett (1969, 1970). Some of the important findings of this study are as follows: (1) Larvae and pupae of *Ephydra* have been found widely distributed in the Great Salt Lake wherever algal bioherms or reefs are present on the bottom. These algal reefs, according to Cohenour (1966), covered approximately 10 percent of the lake bottom or 100 square miles in 1966. (2) The brine flies have an important role in the ecological balance of the Great Salt Lake. The larvae are responsible for consuming vast quantities of algae and decaying organic matter. The pupae and adult flies are an important part of the overall food web of many animals associated with the Great Salt Lake including birds, rodents, lizards, snakes and many species of insects and other arthropods. (3) This dependence on the brine flies of so many animals should be taken into consideration whenever a control program is planned. It is impossible to fully comprehend the long-range effects that eradication or widespread reduction in the numbers of brine flies would have on the ecology of the lake.

In direct opposition to this idea of preserving ecological balance in the Great Salt Lake is the attitude that the brine flies should be eradicated at any cost.

Jorgensen (1969) stated that the position of the Utah Travel Council is that this (the brine fly) and other insects must be eradicated or the lake, one of the state's greatest tourist attractions, must be closed.

Winget, Rees and Collett (1970) recommended that it is not practical or desirable at this time to destroy the brine flies over a large area. This would be expensive, and the results would be temporary unless a major portion of the lake was treated at regular intervals for several seasons. Control is possible and practical in limited areas. A limited experimental control program funded by several governmental and private sources and directed by Larry Nielsen of the Magna Mosquito Abatement District was fairly successful during the summer of 1972. It appears advisable to continue this program on an expanded scale next year.

Midges--Diptera: Chironomidae

Nabrotzky (1968) stated that members of the family Chironomidae are becoming a serious pest in and adjoining marshes in Utah and other parts of North America. These gnats are a nuisance merely because of their great abundance. At times they appear in swarms of hundreds of thousands and may persist for several weeks. These adult gnats alight on animals present, and during population peaks are extremely annoying. Defacement of property may also take place by means of the egg masses deposited on walls, windows, and other objects where lights are present. This problem creates a nuisance as well as an expense to property owners.

Gaufin and Tarzwell (1952) reported that the Chironomidae are important as indicators of organic pollution and as pests.

Nabrotzky (1968) reported that larval abundance in Utah marshes and shallow ponds was related to water depth and bottom materials, and the majority of the larvae occur in water 18 inches in depth or less, with very few in water deeper than 36 inches.

Midge control should be included in water-use plans where dwellings are in the immediate vicinity of shallow ponds, reservoirs or marshes. Control may include biological methods, water management, habitat modifications or chemical control.

Deerflies and Horseflies--Diptera: Tabanidae

Hansen (1952) reported that in some recreational areas deerflies and horseflies are considered second only to mosquitoes as biting pests of man.

Bishop and Phillip (1952) described deerflies and horseflies as aggressive bloodsuckers attacking bathers, picnickers, and outdoorsmen, rendering many recreational areas undesirable during the period of the flies seasonal occurrence. They also reported that in 1935 on the salt marshes near Bear Lake, Utah Civilian Conservation Corpsmen working on a game refuge project found the deerflies annoying, and thirty men contracted tularemia in two weeks. As a result the camp was closed.

Francis and Mayne (1921) demonstrated experimentally that Chrysops discalis Williston is a vector of the tularemia causative organism in Utah and other western states.

Knudsen (1970) reported that on July 8, 1968, Franciscella tularensis, the causative organism of tularemia, was isolated from two pools of 100 deerflies collected from a fresh-water marsh on the southeastern shore of the Great Salt Lake. During that same month, an employee of the Salt Lake City Mosquito Abatement District contracted tularemia near this marsh. Transmission from the bite of an infected deerfly, Chrysops discalis, is suspected.

Rees et al. (1969) reported that as long as the marshes along the Great Salt Lake are utilized as they are at present, the deerfly and horsefly populations will probably remain abundant and continue to constitute an important annoyance, and remain as potential vectors of tularemia organisms to susceptable hosts inhabiting or visiting the area. He went on to state that it is evident that an appreciable reduction in the number of tabanids on these marshes can be attained by proper water management and a limited use of insecticides.

Knudsen (1970) reported that development of areas along the southeastern shore of the Great Salt Lake, which were formerly inundated by the lake but are now utilized for limited agricultural purposes and as developed marshlands, has resulted in an increase in the production of noxious insects such as mosquitoes, gnats, deerflies and horseflies.

Water management techniques appear to be more successful in controlling deerflies and horseflies than biological or chemical control.

Summary

Insect pests and/or vectors dependent on water are already numerous in many areas in the Salt Lake Valley at certain times each year. Their numbers will probably increase with increased water resource development unless an integrated control program including water management, habitat modifications and use of chemicals is included in plans for future water development in the Salt Lake Valley.

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RECREATION ON THE GREAT SALT LAKE, UTAH

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Abstract

Potential for tourism based on the Great Salt Lake is largely unrealized. The greatest problems are overcoming misconceptions and misinformation about the lake and making it attractive and accessible to visitors.

KEY WORDS: Great Salt Lake, Tourism

The Great Salt Lake has potential in tourism and the recreational field which has not been realized. As a tourist attraction, it is one of the natural wonders of our state and an object of curiosity for the vacationer to include in his itinerary.

To stretch out on the waters of the Great Salt Lake in complete relaxation is something few of us have experienced. It amazes me a health spa has not filled a pool with the waters of the Great Salt Lake for relaxation purposes.

The state's interest in development of the southern half of the Great Salt Lake should swing into action rather than remain dormant. Lack of control of the brine flies and lack of development of a clean beach area costs us, the taxpayer, untold dollars per year. We could and would hold tourists in our area for longer periods if we were to develop the Great Salt Lake as a tourist attraction and have motels/hotels there to give the tourists something to stay for. Cruising upon the lake itself has potential as evidenced by the number utilizing the only operating cruise boat at this time.

Once the railway causeway is opened and the entire approximate 1200 square miles of the lake is available for navigation purposes, boating potential on the lake will be doubled. The old Salt Lake Yacht Club Charter has been reestablished by an active group of sail-boaters. I'm sure they would all verify that the beauty, peace, and serenity of sailing on the Great Salt Lake is beyond comprehension unless experienced. The modern day sailing craft is constructed from fiber-glass and stainless steel, materials impervious to the effects of the salt. The nearness of the beautiful body of water to our capital city and surrounding communities, geographically adds to its potential for

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development. Its southern shore touching upon one of our main highway arteries, US-40, for east-west traffic is certainly no detriment.

Granted, the Great Salt Lake will never equal a fresh water lake of proportionate size for water sports such as skiing, etc. The salt is irritating to the eyes, but for a relaxing day of cruising to the power boater, the lake has much to offer. The hazard of the brine to the power boat is minimized if extra care is taken to clean and flush the craft upon removal from the water. Should one intend to operate a power driven craft regularly in the Great Salt Lake as I do, it can be outfitted with a heat exchanger at a relatively small cost.

Due to the extreme buoyancy of the water the strong possibility of the utilization of the lake for the establishment of water speeds records certainly merits inquiry. Utah could become the speed capital of the world for several kinds of water craft, as for land vehicles on the salt flats.

The water of the lake has the clarity during summer months to allow visibility to a depth of 25 feet, which certainly is indicative that the water is much less turbid than imagined by those who have never been upon the lake.

Simply having fresh water readily available for boaters and vacationers would help. All it would take would be just a bit more planning. Imagine the Bear River and the Great Salt Lake as one, and this is not a dream but a very real possibility.

The largest problem to overcome is educating the people that the hardness of the water is not such that a broken neck will be suffered from diving in, and that the lake is not a cesspool. Granted that a gallon of Great Salt Lake water is heavier than fresh water, approximately 30 oz. at a density of 1.190 specific gravity. I'm sure the effect of this is noted only in the effect of the large waves striking the shores. With the Great Salt Lake containing a present day value of $170,000,000,000 worth of minerals, this in itself should want to make people look at it. Can you imagine a hotel overlooking the lake with a sign stating "room overlooking $170,000,000,000."

The potential is there, it need only be developed and this I hope will be in a very near future for the benefit of us all.

JORDAN RIVER BASIN WATER RESOURCE ALLOCATIONS: A SYSTEMS ANALYSIS APPROACH

John E. Keith and Jay C. Andersen[1]

Abstract

The study is a mathematical programming model which is used to determine optimal allocations of water in Utah. Demand schedules for agricultural water are derived from the value of the productivity of marginal, or additional, units of water in agricultural applications. Supply schedules are developed from the costs of providing marginal, or additional, units of water to agriculture from local sources and by interbasin transfers. Supply and demand curves are compared for given levels of inflows to the Great Salt Lake to determine economically efficient allocations, with particular reference to the Bonneville Unit of the Central Utah Project. Inflows to Great Salt Lake and water salvage potentials are shown to be critical to the timing of interbasin transfers of water for agricultural purposes.

KEY WORDS: Mathematical programming, Demand, Supply, Economically efficient allocations, Inflows to Great Salt Lake, Interbasin transfers of water

The Problem

Extensive debate has been carried on concerning various programs for developing and allocating water in the Jordan River Basin, as well as other drainages in Utah. The dialogues often contain emotional arguments for or against various alternative developments and allocations, but hard looks at the social costs and benefits to all of Utah forthcoming from various projects have not been so frequently observed. This paper arises from a study which has attempted to analyze, at least in part, the economic aspects of social welfare which accrue from various alternative water allocation policies and structures.

The Methodological Approach

The method used for this analysis is mathematical programming which provides for maximization (or minimization) of a specified objective function, subject to a series of constraining equations (Hadley, 1962). By manipulating

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the coefficients in the constraints, and/or the bounds and right-hand-side values, alternative allocations and uses of given resources (variables) can be examined for their effect upon the objective function and other variables in the constraints. Results from such a model include the amounts of each variable used, the product (or profit) produced, and the shadow price - the value of an additional unit supplied - of each variable.

The methodology has limitations of course. The analysis is only as "good" as the data which determine the coefficients. In addition, the equational forms are linear, although non-linear programming is possible. The closeness with which the constraints and objective functions approximate the "real" world determines the confidence the analyst can have in his results and with which policy makers can apply them.

The economic efficiency of a policy or allocation is determined by comparisons between the cost of providing the resource in question and the benefits which accrue to the user of the resource and all of society. Economic theory has termed the cost of providing an incremental or added unit of the resource the marginal cost. The schedule relating the successive increments of resource provided with their marginal costs is the supply schedule.

The value of the increments of the resource to the user is determined by the productivity of that resource in the given application. In this sense, the "demand" for the resource is "derived" from the revenue which the user gains from an additional, or marginal, unit of the resource. The schedule relating this marginal revenue, termed the Marginal Value Product, with successive increments of resource use is the demand, or MVP, curve.

A comparison between the Marginal Cost and MVP curves, that is the supply and demand curves, yields the economically efficient allocation in that the last unit of resource applied costs precisely the amount that it produces in revenue. If less is applied, more net revenue could be obtained; if more, costs exceed revenues. If allocation policies are such as to cause supply to be unequal to demand, then the loss of revenue or the extra cost is a cost to society, or a social cost. This cost is not the only social cost or benefit from any given policy; it is, however, a measurable one.

The Model

Since much of the development of water in Utah, particularly interbasin transfers, occurs in order to satisfy agricultural demand, it is assumed that the value of water should derive from the productivity of the marginal unit of water applied to production. Arguments have been made for using the value of water in municipal and industrial (M&I) uses as the marginal value of water, but often the application of newly developed water to M&I uses in Utah serves simply to release the downstream obligations for upstream agricultural utilizations.

Since there is no change in the amount of water applied to M&I uses, the value of M&I water is constant. The only change in the system is water added to agricultural pursuits; therefore, the marginal value of the extra (newly developed) water results from its application to agriculture. Given that the agricultural uses determine the marginal value of water (demand), the following assumptions are made for the demand model:

1) Profitability of agricultural production is based upon average productivity and management capabilities of farmers in the basin under study as projected for 1980 from numerous source materials;
2) Prices and costs in the future will rise or fall at the same rate;
3) Value of water is independent of the timing of application; and
4) Rotation constraints which are typical of the basin studied are included, but corn and sugar beet upper limits are established such that more of both high profitability products are grown by the model than is presently the case.

Note that assumption 2) appears optimistic. Past trends indicate that agricultural prices would fall relative to costs of production in the future (Tweeten, 1970). The model should, therefore, overestimate the profitability of water applied to agriculture given the productivities. However, there is little doubt that timing of water application plays a critical role in agricultural production. Lake season water is certainly more productive at the margin than spring runoff water (Hiskey, 1972). Therefore, the marginal value of developed water, if it is available in the late season, will be higher than the "average" value of the marginal product used in the model. The magnitudes of the two offsetting assumptions are not known at present.

The supply function is based upon the costs of producing the marginal unit of water at the point of delivery (headgate) for each type of water development, including impoundments, canal systems, groundwater pumping and recharging and various interbasin transfer apparatus, as proposed in the Central Utah Project.

The following assumptions are made for the supply curve:

1) All M&I uses are fixed and will be supplied regardless of the level of agricultural demand;
2) All wetland (recreation, etc.) uses are fixed and will be supplied regardless of level of agricultural demands;
3) Water availability is fixed at the mean annual water yield;
4) The outflow of water to the Lower Colorado must be at least as great as compact minimum;
5) The inflow to the Great Salt Lake is varied at alternative levels to determine the cost and other effects of alternative policies;
6) Costs of development of agricultural water are net of expected costs of power production.

In the supply model, the "average" costs of water developments may overstate (or understate) costs in a specific case. A given dam construction may deviate above or below average costs per acre foot by a considerable amount. Moreover, the cost of interbasin water transfers is only a rough estimate because of the difficulty of allocating joint costs. Thus, the model may over- or underestimate marginal costs.

When the supply and demand models are brought together, the resultant allocation model will maximize the profitability of agricultural production, given the constraints in the model, so that the marginal value of water in agriculture is equal to the marginal cost of the water. By varying the assumptions, the effect of alternative activities and policies on the optimal allocation may be observed. Because the model' s precise results are based on averages and estimates, the model should be considered as indicative of general trends, not exact allocations.

The Jordan River Basin Study Area

The Jordan Basin portion of the statewide model for Utah includes some extremely critical factors for the water manager. First, M&I demands for water will most assuredly grow with an expanding population. Second, development of urban areas and their concomitant water needs will impinge upon agricultural land and water reservoirs. Third, the outflows of water to wetlands for recreation will become more important, as will potential water salvage practices. Finally, the level of inflows to, and waterline of, the Great Salt Lake, is critical to local lakeside industry and to upstream availability of water. Policies requiring alternative levels of inflow to the Great Salt Lake may affect the development or retirement of agricultural land in the Jordan Basin and water transfer plans, such as those of the Bonneville Unit of the Central Utah Project.

The Study

The Jordan Basin requirements for water in the future have been calculated using various population predictions, made by both federal and state agencies. Along with the population predictions, various levels of M&I use have been predicted. The population projections used, as reflected in M&I demand changes, include the Office of Business Economics, U. S. Department of Commerce, and Economic Research Service of the Department of Agriculture (OBERS) (Pacific Southwest Interagency Committee, 1971.) projection, the Utah Division of Water Resources (1970) projection, a 1972 revision of the Department of Water Resources 1970 projection, the 1972 OBERS projection, and a projection calculated from the median of the above projections.

Other inclusions relevant to the Basin in the model are the reduction of land area available for agriculture as a result of urbanization, and the inflows to the Great Salt Lake. Levels of the Great Salt Lake inflow are assumed to be 500,000 acre-feet/year, 850,000 acre-feet/year, and the present 1,014,000 acre-feet/year.

Other deviations from present policy are examined, as well. The primary model includes maximum sustained utilization of available groundwater in the Jordan Basin, although present legal restrictions severely restrict pumping in the basin. Other legal limitations to water use and transfer of rights are disregarded as well, and the model indicates the optimum allocations given unrestricted transfers of title and rights.

Results and Conclusions

The output of the model is indicative of the effect that alternative levels of inflow to the Great Salt Lake has upon water developments, particularly the implementation of the various units of the Central Utah Project. Given the model's assumptions, requiring inflows of greater than the present 1,014,000 acre-feet/year will necessitate immediate and large-scale development of the Bonneville Unit of the CUP, so that full capacity could be attained by about 2000 (Figure 1). By lessening the inflow requirements, these developments can be postponed considerably, and the monies can be freed for use elsewhere. If inflows are held at 850,000 acre-feet/year, full development of the Bonneville Unit will not be required until 2015, although transfers to Sevier are needed by 1973 (Figure 2). At inflows of 500,000 acre-feet/year, about 300,000 acre-feet/year less than the 1963 low of 800,000 acre-feet, full development of the Bonneville Unit is not optimal until after 2020, the present planning horizon (Figure 3).

The maximum amount of development to transfer water to the Sevier River Basin via a "Sevier Area Unit", which is a small transfer from HSU 8 (West Colorado) to HSU 4 (Jordan River) and HSU 5 (Sevier River), appears to be needed immediately in every case. This transfer occurs because the excess capacity for storage and distribution in the model was sufficient to make transferred water cheaper than local water.

When water salvage[1] is introduced in the model, the development of the Bonneville Unit is postponed at every inflow level (Figures 4, 5, 6 and 7). This salvage is included at no development cost, and may overestimate the economically feasible amount of water salvage.

When present restrictions on groundwater pumping in the basin are included in the model's constraints, the effect of salvage is offset, and timing of CUP development is almost entirely dependent upon the level of Great Salt Lake inflows (King, 1972).

Other results from the model appear to indicate that, if transfers of water from agricultural to municipal and industrial uses are possible in the Jordan River Basin, these transfers are more sensitive to projected urbanization than

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[1] Water salvage data was obtained from rough estimates by the Utah Division of Water Resources.

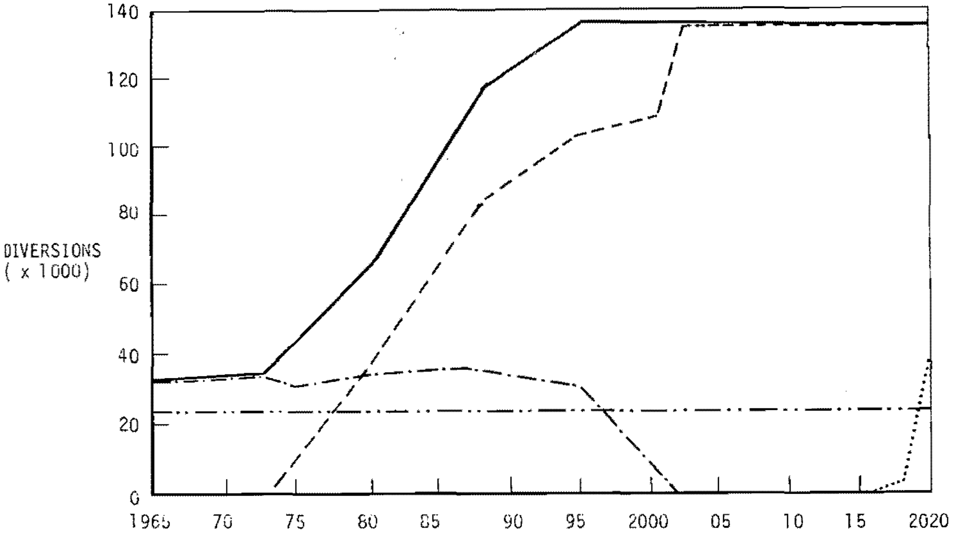

FIGURE 1. CUP DIVERSIONS
INFLO GSL = 1,014,000 (NO SALVAGE)
MEDIUM TO HIGH PROJECTIONS

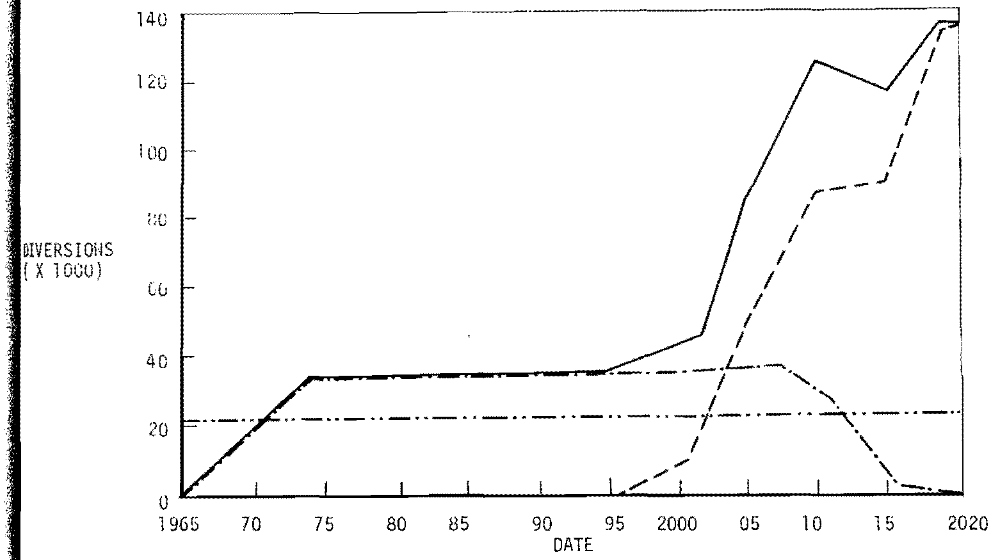

FIGURE 2. CUP DIVERSIONS
INFLOGSL = 850,000 (NO SALVAGE)
MEDIUM TO HIGH (HSU 5) PROJECTIONS

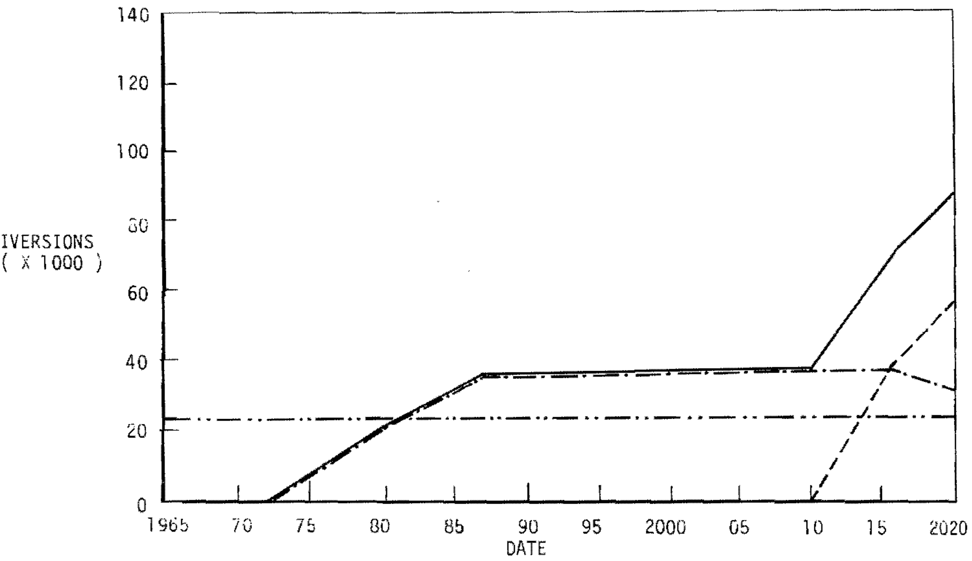

FIGURE 3. CUP DIVERSIONS
INFLOGSL = 500,000 (NO SALVAGE)
MEDIUM TO HIGH (HSU 5) PROJECTIONS

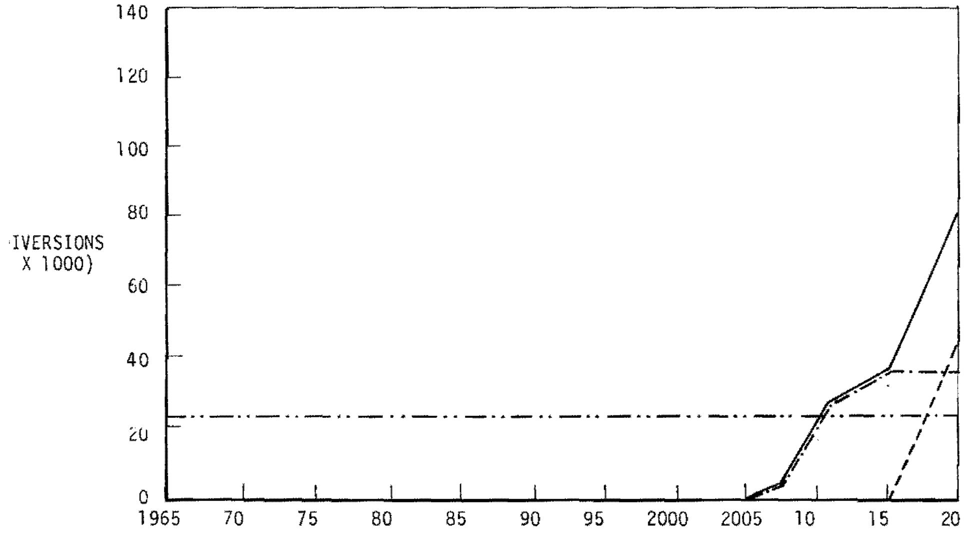

FIGURE 4. CUP DIVERSION
INFLO GSL ≤ 850,000 (W/SALVAGE)
MEDIUM TO HIGH (HSU 5) PROJECTIONS

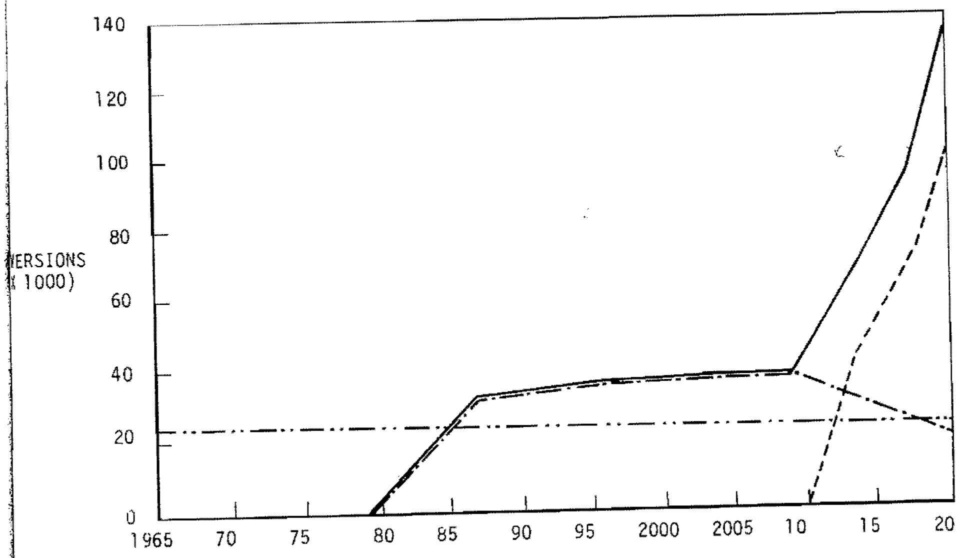

FIGURE 5. CUP DIVERSIONS
INFLO GSL = 1,014,000 (W/SALVAGE)
MEDIUM TO HIGH (HSU 5) PROJECTIONS

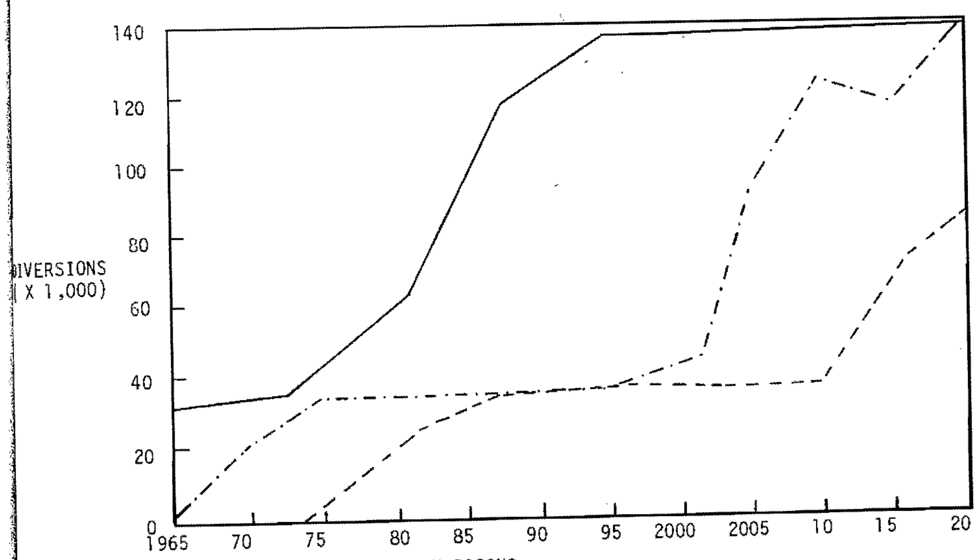

FIGURE 6. BONNEVILLE UNIT DIVERSIONS
WITH ALTERNATIVE INFLO GSL (NO SALVAGE)

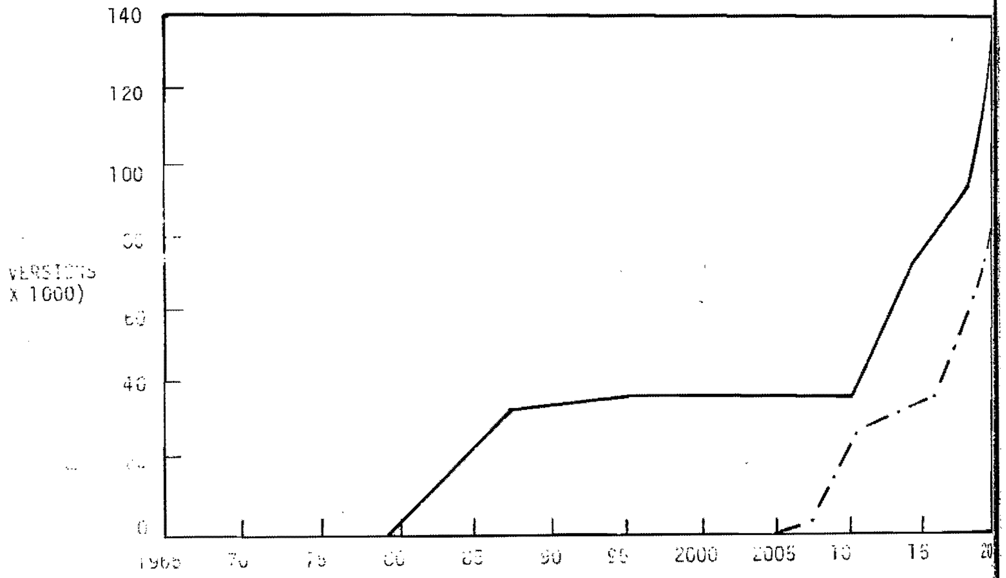

FIGURE 7 BONNEVILLE UNIT CUP DIVERSIONS WITH ALTERNATIVE INFLO GSL (W/SALVAGE)

to the levels of Great Salt Lake inflows. Prior to 2010 little reduction in presently irrigated acres is indicated at any level of inflow, with or without salvage. The development of <u>new</u> agricultural land in the Jordan, Great Salt Lake Desert, and Weber River Basins is, however, dependent upon the inflows. At 500,000 acre-feet/year or less, as much as 250,000 acres of cropland are developed prior to 1975. Population increases erode the water availability for development from that date until 2000 at which time no new land is developed. At inflows of 1,014,000 acre-feet/year, however, development of new agricultural land is limited to about 114,000 acres with water salvage or 40,000 acres without salvage in the three HSU's. The level of Great Salt Lake inflow is also critical to the amount of water available to recharge groundwater aquifers. At low levels of inflow, the maximum low cost recharge in the Jordan River and Bear River Basins is reached by 1995-2000. At the 1,014,000 acre-feet inflow, maximum recharge is not reached until 2015.

The model indicates that the level of inflow to Great Salt Lake is a critical factor in making economically optimal decisions concerning water importation through the Bonneville Unit facilities. As such, the costs of immediate

development of the Bonneville Unit must be weighed against the costs of lowering the level of the Great Salt Lake considerably. Models such as this one should help to emphasize the trade-offs which occur in policy decisions about a specific resource, such as the Great Salt Lake.

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REVIEW OF PAST STUDIES OF THE EAST EMBAYMENT AS A FRESH WATER RESERVOIR

A. Z. Richards, Jr.[1]

Abstract

From the years 1930 to 1935 there was considerable interest in the inter-islands diking project for creating a fresh water reservoir. Such men as Louis E. Fox, Theodore L. Keller, Sumner G. Margetts, Dr. Dorsey A. Lyon, J. J. Lillie, R. E. Van Liew, R. A. Hart, N. E. McLaughlan, Jacob L. Crane, Dr. Thomas C. Adams, and others made studies and wrote papers on the intriguing possibilities and problems of such a project. From 1936 to 1954 -- the war years -- there appears to be little documented interest, but in 1955 the Utah Legislature commissioned the State Road Commission to initiate studies of the advisability of constructing the inter-island dikes. An Advisory Committee was appointed and local consulting engineers were selected. They prepared two important reports under this assignment. In 1962 Douglas R. Mabey prepared an important treatise on the diking project, suggesting the use of Kennecott tailings material. In 1965 a Preliminary Master Plan was prepared by the Great Salt Lake Authority, and in 1966 the Tailings Feasibility Project was undertaken on the shore of the lake near Saltair. Harry S. Suekawa studied the Tailings Project and prepared a university thesis on the results of the test. Final comments by the writer consist of emphasizing the importance of the fresh water aspects of the East Embayment Reservoir Project and its potential for saving much of the water now running to waste into the Great Salt Lake.

Under date of May 15, 1930, Louis E. Fox and Theodore L. Keller, then in the Civil Engineering Department at the University of Utah, prepared a thesis entitled "Putting Great Salt Lake to Work." They proposed a three-part dike extending westerly from the mainland to the south end of Antelope Island, and northerly from the north end of Antelope Island to the south end of Fremont Island, and from the north end of Fremont Island to the Promontory Point mainland; the lake to be enclosed on the east side of these islands by the dike chain and the east shore mainland would be fed by the three principal water sources for the Great Salt Lake--the Bear, Weber, and Jordan Rivers. This subsequently became known as the "large project."

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In March, 1932, Sumner G. Margetts, a consulting engineer from Salt Lake City issued a paper titled "Report on Proposed Fresh Water Lake." He recommended that a smaller fresh water lake be developed in Farmington Bay by damming the 146 square mile area between the mainland and the south end of Antelope Island and between the north end of Antelope Island and the mainland at Syracuse. Mr. Margetts, to supplement the water supply from the Jordan River and all of the small streams running into Farmington Bay, diverted water from the Weber River into the proposed reservoir by means of an 11.5 mile long canal along the mainland from the outlet of the Weber River to Syracuse, Utah. This proposed project was referred to as the Farmington Bay Reservoir, or the "small project."

By July, 1933, a great deal of public interest had developed in the proposed diking project. Advisory committees and subcommittees were formed and some state and industrial sponsored general engineering studies were undertaken. Dr. Dorsey A. Lyon, at that time Director of the Utah Engineering Experiment Station, summarized these studies in his report entitled "Report of Sub-Committee Appointed to Investigate Technical Problems that Present Themselves in Connection with the Proposed Diking of the Great Salt Lake for the Purpose of Creating a Body of Fresh Water." Discussed in Dr. Lyon's report were the following items: (a) Dike Studies by J. J. Lillie which were directed to the "large project"; (b) Hydraulic Studies by R. E. Van Liew; (c) A review of all reports, and the concern of a technical subcommittee on the problems to be encountered in constructing a dike from Fremont Island to Promontory Point, as required by the "large project." Borings drilled by Lillie indicated a "very soft mud" to a maximum depth of exploration of 13 feet below the bottom of the lake at this dike location. It is interesting to note, however, that this committee recommended excavation by dredging. By hydraulic methods the lake bed material was to be deposited to form a dike with side slopes of 20 to 1 to solve a construction problem and to withstand the wave action of the lake.

In June, 1933 appeared a significant joint authorship paper by Mr. R. A. Hart, a Civil Engineer who, at that time, was Industrial Secretary of the Chamber of Commerce of Salt Lake City, and Mr. N. E. McLaughlan, City Chemist, entitled "Abstract of Report on Laboratory Tests of Feasibility of Freshening the Proposed Diked-off Portion of the Great Salt Lake." Mr. Hart previously had written a few other papers regarding various aspects of this fresh water lake development. This joint paper concluded that "neglecting possible infiltration of underground water, a period of only two years would be required to freshen the water in the proposed reservoir." Mr. Hart's studies were based on the water supply outlined by Mr. Margetts in 1932, and on the displacement of salt water by fresh water from the natural incoming supplies.

Under date of December, 1933, Jacob L. Crane, a planning consultant from Chicago, provided a summary report on the Great Salt Lake Diking Project. Mr. Crane concluded that the "smaller reservoir" known as the Farmington Bay Project would be feasible from the standpoint of engineering construction, and he recommended that the diking project be undertaken by the State of Utah. In the long range planning, Mr. Crane expected the project to be self-liquidating by the sale of fresh water to industrial and agricultural users. To finance the project, Mr. Crane proposed a federal loan through the Public Works Administration. Mr. Crane further recommended that the state obtain control of both the fresh water and the salt water lands below the meander line of the Great Salt Lake, which he considered to be about Elev. 4205.

Two years later, in July, 1935, Dr. Thomas C. Adams, Professor of Civil Engineering at the University of Utah, reported to the Utah State Planning Board on additional engineering studies that he had been commissioned to make by said Board to substantiate certain recommendations of the 1933 Crane Report. Dr. Adams pointed out that the salt content of the water in Farmington Bay Reservoir, not receiving any water from the Bear River would, at times, reach to more than 5,000 ppm, and that this would be in excess of desired values for certain agricultural uses, thereby discouraging further interest in the "small project."

The 1955 Utah Legislature, after a 20-year dormant period, the war years, pertaining to any planning for the Great Salt Lake, initiated some action which showed that public interest was again developing. The Legislature asked the Utah State Road Commission to initiate a study of the advisability of constructing the inter-island dikes. Construction estimates were undertaken by in-house planning personnel, but of primary consideration was the hydrology of the lake. Particularly the question as to whether or not nature would provide sufficient fresh water drainage into this portion of the lake during low water years to maintain either the "small project" (Farmington Bay alone) or the overall East Embayment Reservoir, "the large project." It was decided by the Commission to engage local consulting engineering services for advice on this latter question.

It was the following year, in April, 1956, under assignment from an Advisory Committee to the State Road Commission, that the engineering firms of Dames & Moore, and Caldwell, Richards & Sorensen, Inc., in a joint report, advised the Commission that the water originally contemplated by Mr. Margetts and Mr. Crane, to come from the Weber River, was no longer available because of the proposed Weber Basin Project, including the Willard Reservoir, and therefore the "small project" or Farmington Bay Reservoir, alone, no longer appeared feasible.

In 1957, a comprehensive engineering report was prepared under the direction of the same Advisory Committee to the State Road Commission entitled "An Engineering Report and Opinion on the Quantity and Quality of Water Which May Become Available for Use by Industry, Agriculture and for Improved Recreation from the East Embayment Reservoir of the Great Salt Lake if the Inter-Island Dikes Were to be Built." This study was made by Caldwell, Richards & Sorensen, Inc. In this technical, detailed engineering report, it was pointed out that there will be adequate inflow water to the "large project" reservoir in low water years (such as occurred in 1954 when only 510,200 acre feet flowed through the Bear River at Colliston) to maintain the water level in the East Embayment Reservoir at a high elevation (above 4,201). Major inflow was to come from Bear River and Jordan River. No inflow from the Weber River was considered because of the proposal to divert all of the water from this particular source in low water years to Willard Reservoir. The report did question the degree of "freshness" to be expected in the late summer months of low water years. Such water, with its increased mineral content, could continue to be used for irrigation on tolerant crops on well drained porous soils. While the lowest quality of water would only develop at intermittent periods, as is true in many irrigation systems in arid climates, during the winter and spring each year the quality of the water in the upper reaches of the reservoir would improve substantially.

It was May 15, 1957 when official copies of the comprehensive hydrological study report of the East Embayment Reservoir, referred to above, were delivered to Mr. Tom Heath of the State Road Commission. All of the important physical conditions of inflow and evaporation of both the main body of the lake and the increase area of the East Embayment Reservoir were taken into consideration. Detailed tabulations showing inflow and evaporation factors were presented in the 75-page report.

In June, 1962, the J. R. Mahoney water management study of the whole Bonneville Basin was published under the auspices of the State Land Board and the University of Utah Departments of Economics and Business. This report did not specifically cover the East Embayment Reservoir. It proposed some fantastic possibilities, of questionable practicability, for the application and use of Great Salt Lake source waters, but this particular report is very interesting reading to anyone involved in matters of the Great Salt Lake.

In January, 1963, the possibility of using "tailings" to construct the inter-island dikes was documented in Utah Engineering and Science Magazine by Douglas R. Mabey, Contract Engineer of Kennecott Copper Corporation. His article "Tailings--a New Resource?" went beyond the inter-island dikes to propose, in addition, a 54-mile dike system extending westward from Promontory Point to Carrington Island, Stansbury Island, and then from the south end of Stansbury back easterly to Saltair, regulating the entire Great Salt Lake with "tailings" dikes. Since then, an important Preliminary Master Plan and report has been prepared by Caldwell, Richards & Sorensen, and at least two significant reports on the tailings test have been published.

In 1965, under the direction of The Great Salt Lake Authority, the Preliminary Master Plan for the development of the Great Salt Lake over the next 75 years was developed. This report was widely distributed to all interested parties. It consisted of two bound parts: (I) a 32-page written report, and (II) ten sheets of maps. (200 copies were distributed.)

The 1965 Preliminary Master Plan envisioned the future disposal of tailings from Kennecott Copper Corporation by a carefully directed land fill operation in Farmington Bay. One year's quantity of tailings would cover approximately one square mile to a surface elevation of about 4,210 (eight feet above the water surface envisioned for the fresh water estuary and lake surrounding it). Farmington Bay was selected because of the large volumes of fresh water inflow from Jordan River, the Salt Lake City Sewage effluent canal, miscellaneous creeks and canals, and the lower reaches of the Weber River.

In our opinion, permanent disposition of tailings can only be successful where large supplies of fresh water are available to eventually turn the reclaimed area into an agricultural area--that is--an area where there is water to assist in sustaining vegetation--where dust can be controlled on the large finished areas of the land fill. This is only possible in Farmington Bay (see accompanying Figure 1). It should be pointed out that on the proposed 40,000 acre agri-industrial complex (63 square miles, which would take about 63 years to build) there would be abundant water always available for irrigation purposes from the adjacent fresh water estuary. The soil will be of a granular nature, non-plastic, of Kennecott origin (supplemented with organic muck from 100 years of deposition by Salt Lake City's sewer outfall canal if such is desired for the agricultural surface layer of the reclaimed land area). It will be easily drained and will be superior to the tight clay soils found many places around the lake. In addition, the raised level of fresh water will enhance all adjacent shore lands around Farmington Bay.

In 1968, a 27-page report was prepared by Caldwell, Richards & Sorensen at the completion of the Tailings Feasibility Test and was presented to the Great Salt Lake Authority at its meeting of December 19, 1968. The practicability of using tailings, and their limitations were pointed out in this report.

In April, 1970 a report titled "Study of the Kennecott Copper Corporation--Great Salt Lake Authority Tailings Test" by Harry S. Suekawa was published by Utah Geological & Mineralogical Survey.

We should look forward to other work of the Utah Geological and Mineralogical Survey, and to the Water Resources Branch of the Federal Government, and the State of Utah, as well as other government agencies and/or private individuals who may become vitally interested in the saving and using of the surplus fresh waters which run into the Great Salt Lake. We should support this cause.

Final Comments -- a Warning

During the past 10 years the emphasis has been on the chemical development of the Great Salt Lake. The "chemical gold-rush" has occurred and major new industries have come to Utah in the magnesium and industrial chemical fields. However, unless some more careful planning is done and the recreational and fresh water aspects of the lake are undertaken soon, these very

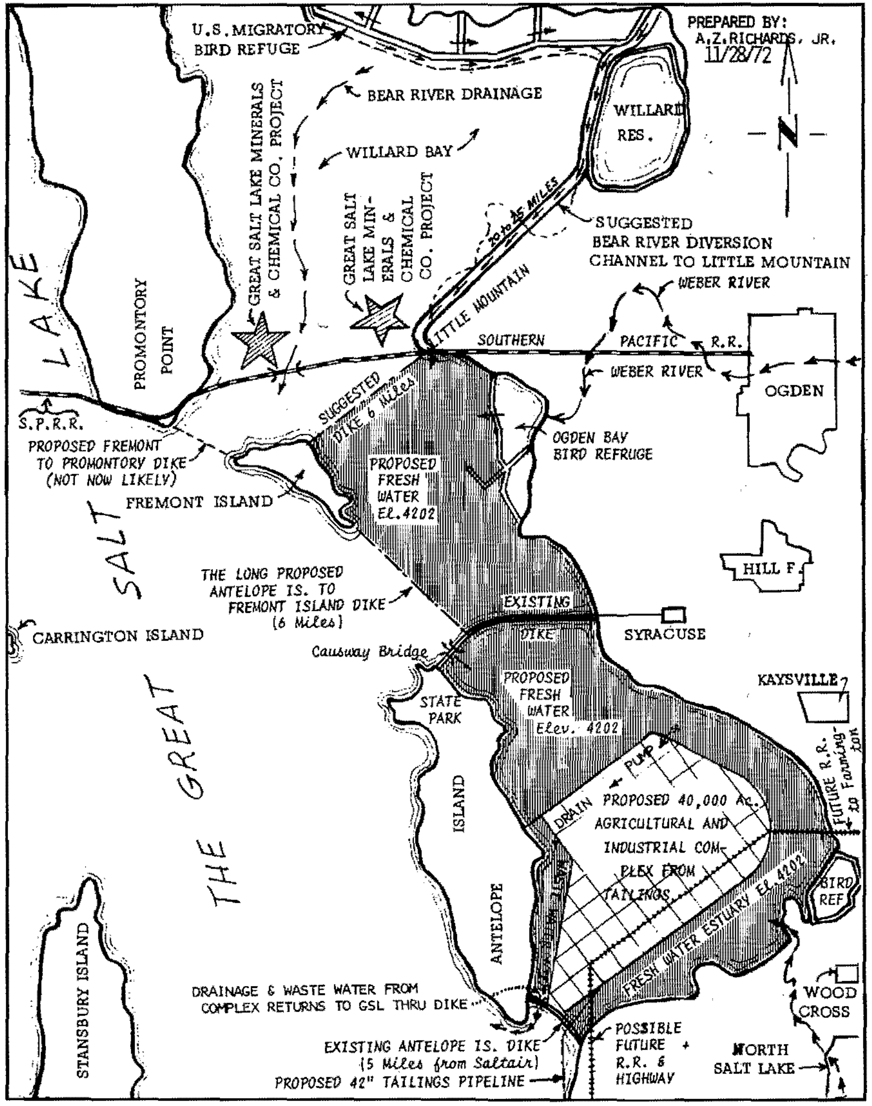

Figure 1. Suggested 6-mile long dike from Fremont Island to Little Mountain.

important primary resources will be jeopardized by the chemical projects already underway and yet proposed. Yes, it is our opinion that every available effort should be put forth to influence and assist in reviving public interest in the development of the fresh water aspects of the East Embayment Reservoir.

Major low-level reservoirs, of which Willard Reservoir is an example, are really the only great hope for saving large quantities of fresh water which now run to waste in the Great Salt Lake. A full diking program is needed to accomplish this. The Syracuse Dike, long envisioned by "dreamers", is now a fragile reality, but it needs to be enlarged and widened to assure its permanency against the destructive forces of the lake water as its surface elevation continues to rise. Antelope State Park is still in an embryo stage, with access only by the Syracuse road, but no fresh water has yet been saved.

The precedent has been set in the past five years where chemical development has been favored over fresh-water development. This should be of great concern because of the greater long-range importance of fresh water to our state and people.

A multi-million dollar chemical project has been built in the lower reaches of Willard Bay and around Promontory Point without any consideration whatsoever to the importance of these areas for future fresh-water storage needs. In the writer's opinion, this situation is destined to backfire as seriously as has the construction of the Southern Pacific land-fill railroad causeway upset the chemical balance of the lake due to inadequate foresight in the planning for the Great Salt Lake.

Briefly, it may now be impossible to store fresh water in the whole of Willard Bay without causing difficulties to the present chemical project which has been built there. (See Figure 1.) This will bring opposition from the chemical developers, and yet the importance of the whole use of Willard Bay for fresh water has been envisioned for more than 40 years (Fox & Keller report, 1930). The basic fresh-water use of this area was to be made operational by the construction of the Fremont Island to Promontory dike (3 miles long). Now it may be virtually impossible to do this without flooding the present chemical project.

Further--the 1956 Master Plan solution to the unbalanced brine density condition of the lake north and south of the S. P. R. R. was the diversion canal proposed to be built around Promontory Point to bring fresh-water overflow from the East Embayment reservoir into the north end of the lake above the railroad. By this control the lake could have been quickly balanced in respect to salinity differences. This program now, however, appears to be virtually impossible because of the existing commercial brine canal now in operation to carry saturated brine in the opposite direction, easterly, for chemical purposes.

Although warned somewhat of the above developing problem in advance, officials showed major concern only for the financial rewards promised by a chemical development in the fresh water reaches of the Great Salt Lake which should have been saved for fresh water storage as envisioned by engineers for at least 40 years.

A possible alternate to the original Preliminary Master Plan

Figure 1. shows a suggested 6-mile long dike from Fremont Island to Little Mountain. With this revised plan, the enlarging of the Syracuse Dike, and the construction of the proposed Fremont to Antelope dike, the newly formed East Embayment Reservoir would be confined to a smaller area--much easier to control. With this plan the new reservoir would hold more than 100,000 acre feet of water per top foot of water depth. In other words, four feet of depth, above Elev. 4200 would represent more than 400,000 acre feet of confined and controlled water.

It is our opinion that in a good water year the entire newly designated East Embayment could become operational with "sweet" water within two years of the completion of the necessary dikes, inlet canals, and control facilities, providing that the surplus waters of the Bear River were diverted into the newly designated East Embayment Reservoir by a 20- to 25-mile long canal from the Migratory Bird Refuge area to the proposed East Embayment at Little Mountain. Admittedly this would be costly construction, but certainly it is worth consideration in view of the road blocks to the use of the Willard Bay area as a fresh-water storage reservoir which have already been set up by the chemical development there.

More than 40 miles of lake frontage from the south Antelope Island dike to Little Mountain would be enhanced by a fresh-water shore line, and the owners of all of the frontage land would experience a bonanza in land value increase. The recreational value of the reservoir would no doubt increase almost in proportion to the rise in elevation of the water surface created by the plan.

The use of Kennecott tailings is still important and anyone interested in reviewing a most effective and valuable use of Kennecott Tailings is referred to the 1965 Preliminary Master Plan study. This envisions the placing of a 40,000 acre land fill in Farmington Bay to become an agricultural and industrial complex with initial land values which could exceed $1,000 per acre, and amount to a more than $40,000,000 land asset.

Source of Inflow	YEAR 1952 (a good year)	YEAR 1953 (a medium year)	YEAR 1954 (a poor year)
From the combined JORDAN RIVER and SURPLUS CANAL . . .	476,900 Ac.Ft.	489,700 Ac. Ft.	264,300 Ac. Ft.
From the Weber River (+)	932,000 "	395,000 "	127,000 "
From Misc. Inflow into Farmington Bay	74,567 "	64,704 "	48,274 "
From the BEAR RIVER	1,775,000 "	1,077,000 "	609,800 "
ANNUAL TOTALS (*) . . .	3,258,467 "	2,026,404 "	1,049,374 "

(*) NOTE: All of this water eventually goes to waste by evaporation.
(+) NOTE: Slaterville diversion not in operation.

Figure 2. Actual measured inflow into the Great Salt Lake.

GREAT SALT LAKE -
KEY TO UTAH'S FUTURE INDUSTRIAL DEVELOPMENT?

Joseph M. Glassett[1]

Abstract

Two companies plan to produce large annual tonnages of magnesium, magnesium chloride, chlorine, potassium sulfate, sodium sulfate, gypsum, lithium chloride, and bromine from Great Salt Lake. The production of these chemicals, and other possible chemicals, in conjunction with Utah mineral resources already well developed, may be the key to Utah's future industrial development. A feasibility study is needed to determine which of many suggested chemical products will provide the largest profit margin for future Utah enterprises.

KEY WORDS: Great Salt Lake; Industrial development; Mineral recovery; Utah minerals

Ladies and gentlemen,

A sanitation engineer visited one of the Great Salt Lake resorts and asked the manager what he did to make the water safe to drink.

"First we filter the water," replied the manager.

"That's good," said the engineer.

"Then we chlorinate it."

"Excellent!" exclaimed the engineer.

"And then," said the manager, "just for safety's sake, we drink soda pop."

College professors have a reputation for asking their students questions and then answering themselves. I would now like to proceed with my effort to answer the question posed by the title of this paper.

Introduction

During the past century Utah has gained prominence as a mineral commodity producing state. Among the states in our country, Utah ranks second in production of copper, gold, molybdenum, and asphalt; third in production of iron and uranium. Table 1 presents the values of the principal mineral commodities mined in Utah during the period 1865 through 1961.

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TABLE I (1)

VALUE OF UTAH MINERAL COMMODITIES

Commodity	Value in Millions of Dollars
Copper	3311
Coal	914
Lead	688
Silver	610
Gold	476
Petroleum	461
Zinc	283
Iron	282
Uranium, vanadium and radium	234
Molybdenum and other metals	233
Sand and gravel	99
Solid hydrocarbons	91
Stone	63
Common salt	34
Clay	28
Potash	26
Miscellaneous	200

Each of the mineral commodities listed in Table I has been responsible for the growth of satellite commodities which are hidden in the "Miscellaneous" category. For example, United States Steel Co., Geneva Works, at Orem, Utah is the state's largest producer of iron. Geneva consumes large tonnages of coal to make coke for their iron producing blast furnaces. They also produce oxygen to enrich the air to the blast furnaces. By-products resulting from these two processes have resulted in the production of liquid air, oxygen, nitrogen, hydrogen, ammonia, sulfuric acid, nitric acid, ammonium sulfate, ammonium nitrate, benzene, toluene, and other hydrocarbons.

It is anticipated that production rates of the mineral commodities listed in Table I will increase with time. Significant reserves of other mineral commodities are known and are being developed. Some of these are beryllium, manganese, mercury, thorium and the rare earths, titanium, tungsten, arsenic, antimony, bismuth, cadmium, selenium, and tellurium.

Future Utilization of Great Salt Lake Minerals

One of Utah's great ore bodies which has not been fully utilized is Great Salt Lake. This remnant of ancient Lake Bonneville contains more than 4 billion tons (2) of dissolved salts. Hahl and Langford (3) tell us that the lake contains the following concentration of ions in parts per million: 147,000 chloride, 85,700 sodium, 17,400 sulfate, 8,050 magnesium, 4,550 potassium, 327 bicarbonate, 319 calcium, 82 nitrate, 42 lithium, 28 boron, 6 fluoride, and 6 silica. According to Stokes (4) stream flow into Great Salt Lake is building the solids content of the lake at the rate of two million tons per year.

At least two companies are presently processing Great Salt Lake water to recover chemicals other than common salt (sodium chloride). N. L. Industries plans to produce (5) 45,000 tons per year of magnesium metal, 81,000 tons per year of liquified chlorine, and 48,000 tons per year of gypsum. Great Salt Lake Minerals and Chemicals Corporation (6) expects an annual production of 300,000 tons of magnesium chloride, 200,000 tons of potash (primarily potassium sulfate), 100,000 tons of sodium sulfate, 5,000 tons of lithium chloride, and 2,500 tons of bromine.

It may become economical to produce other chemicals from Great Salt Lake water other than those already mentioned. A few likely prospects are magnesium oxide, magnesium hydroxide, magnesium carbonate, potassium chloride, sodium sulfide, elemental sulfur, and calcium chloride. These chemicals are used as raw materials in many industries. The industrial development of Utah can be enhanced by attracting companies to Utah which can utilize these chemical raw materials in conjunction with Utah's other chemical resources such as: coal, oil, steel, copper, sulfuric acid, etc. A feasibility study is needed to determine the chemical products which will provide the largest profit margin. A campaign can then be launched to attract companies to Utah to produce these profitable chemical products.

The possible production of sodium sulfide from Utah resources serves as an example of how a chemical obtained from Great Salt Lake can team up with other mineral resources to obtain a chemical product. Shreve (7) tells us that sodium sulfide is made by reducing sodium sulfate with powdered coal in a reverbatory furnace at a temperature above 850°C. Utah coal reserves are readily available for use. An economic study of this process may reveal that the furnaces should be heated with natural gas from Utah's gas reserves.

Great Salt Lake Minerals and Chemicals Corporation plans to produce large tonnages of sodium sulfate from Great Salt Lake. Alternatively, Larsen (8) and Glassett (9, 10) have suggested chemical processes for winning sodium sulfate from Great Salt Lake. This example indicates how three Utah resources can be used to produce a fourth product using an accepted commercial process.

Many other suggestions similar to the production of sodium sulfide may be generated by making a study of the uses and methods of manufacture of possible chemical products obtainable from Great Salt Lake in combination with other Utah resources. After an economic feasibility study of each suggestion is made a campaign can be launched to attract companies to Utah to produce the more profitable chemical products.

Initial efforts which have been made to lay the groundwork for the needed feasibility study include the preparation of Tables II, III and IV in this paper. Table II is a preliminary listing of chemical products which can be obtained directly from Great Salt Lake water processing and some uses of these chemicals. Table III is a preliminary listing of secondary products which may be produced by utilizing the primary chemical products of Table II in conjunction with other Utah resources and some uses of these products. Table IV is a list of prospective Utah products prepared by one of my students at BYU, Mr. Robert McKee (11).

Conclusions

1. Utah has gained prominence as a mineral commodity producing state but a concerted effort by her people is needed to accelerate the industrial development of Utah.
2. The industrial development of Great Salt Lake appears to be the key to the future development of Utah's mineral resources.
3. Two lists of chemical products obtainable from Great Salt Lake water processing are presented.
4. A third and longer list of prospective Utah products from all Utah resources is presented.
5. A feasibility study is needed to generate possible chemical processing routes and to determine what chemical industries could flourish in Utah by utilizing as raw material minerals from Great Salt Lake and other Utah resources.

TABLE II

PRIMARY CHEMICAL PRODUCTS OBTAINABLE FROM GREAT SALT LAKE WATER PROCESSING AND SOME OF THEIR USES

Chemical Product	Uses
Magnesium chloride	Magnesium metal, ceramics, sizing of paper, oxychloride cement, many uses the same as calcium chloride
Magnesium hydroxide	Magnesium chloride mfg with muriatic acid, milk of magnesia and other pharmaceuticals, toilet goods
Magnesium oxide	Refractories, insulation, abrasives, vulcanizing of rubber, printing inks
Potassium chloride	Fertilizer, other potassium salt mfg
Potassium sulfate	Fertilizer expecially for citrus fruit and tobacco
Sodium chloride	Sodium compounds, water softening, food preservation, dairying, deicing streets, human diet
Sodium sulfate	Kraft paper pulp, glass, ceramics, detergents, sponges, textile dyes, bleach, photography
Calcium chloride	Settle road dust, refrigerant, drying agent
Calcium sulfate	Plaster, casting, wall board
Lithium chloride	Batteries, aluminum brazing
Bromine and Bromine compounds	Antiknock fluids, photography, Swimming pool sterilizing, medicinals, insecticides, fumigants, dyes, disinfectants, flameproofing agents

TABLE III

SECONDARY CHEMICAL PRODUCTS OBTAINABLE FROM GREAT SALT LAKE WATER PROCESSING AND SOME OF THEIR USES

Chemical Product	Uses
Magnesium metal	Alloys with aluminum for auto parts and space vehicle parts, sacrificial anodes in water heaters, etc., reducing agent in mfg of titanium, zirconium, uranium and beryllium
Magnesium carbonate	Magnesite bricks, 85% magnesia insulation, fillers in inks, paints, and varnishes
Basic Magnesium Carbonate	Tooth powders, antacid remedies, table salt coating, paint fillers, rubber accelerators
Magnesium peroxide	Antisepthic, bleaching agent
Magnesium sulfate	Epsom salts, sizing, fireproofing agent
Magnesium silicate	Asbestos, talc, filler in paper and plastics, cosmetics, toilet preparations
Potassium hydroxide	Soap, detergents, dyes
Potassium carbonate	Soap, hard glass
Potassium nitrate	Glass, pyrotechnics, slow burning black powder
Chlorine	Soap, detergents, textile bleaching, plastics, resins, elastomers, glass, petrochemicals, pulp and paper, fertilizers, explosives, solvents, antifreeze, antiknock compounds, refrigeration, organic chemicals, water and sewage treatment, pesticides, bleaching powder
Sodium hypochlorite	Disinfectant, deodorant, bleaching agent
Sodium chlorite	Bleach, oxidizing agent, water purification, odor control
Sodium carbonate	Glass, soap, detergents, chemicals, pulp and paper, water treatment, aluminum mfg
Sodium sulfide	Amino compound reducing agent, dyes, depilatory, Thiokol synthetic rubber, rayon, metallurgy, photography, engraving
Sulfuric acid	Fertilizers, leather, tin plate, petroleum refining, dying, chemicals
Sulfur	Wood pulping, medicinals, rubber, dyes, insecticides, fungicides, detergents, catalysts
Carbon disulfide	Viscose rayon, cellophane

TABLE IV

PROSPECTIVE UTAH PRODUCTS

- Ammonium Sulfate
    - Anhydrite
- Batteries
    - Alkaline Storage
        - Lithium Hydroxide
    - Battery Boxes
        - Gilsonite
    - Dry Cells
        - Zinc, Zinc Chloride, Carbon,Cardboard, Ammonium Chloride, Magnesium Dioxide, Copper Sulfate, Lead Sulfate
    - Edison
        - Potassium Hydroxide, Lithium Hydroxide, Iron
    - Lead Storate
        - Lead, Lead Oxide, Sulfuric Acid
    - Low Temperature
        - Lithium Bromide
    - Nickel-Cadmium
        - Cadmium, Cadmium Hydroxide, Potassium Hydroxide
    - Silver-Cadmium
        - Silver, Cadmium
    - Storage Devices
        - Barium Titanate
- Beryllium Recovery
    - Sodium Chloride
- Bleaching Agents
    - Magnesium, Chlorine, Calcium Oxide, Chlorine Dioxide, Barium, Peroxide, Lithium Hypochlorite, Sodium Silicates, Sodium Hypochlorite, Sodium Chlorite
    - Scouring Powders - Wools
        - Chlorine, Calcium Hydroxide, Steel Sodium Silicates
- Bromine Recovery
    - Sodium Chlorate
- Brake Linings
    - Steel, Gilsonite
- Catalyst
    - Sodium Nitrate, Silica Gel, Molybdenum, Vanadium, Sulfur Molybdate, Aluminum Hydroxide,Activated Alumina, Aluminum Phosphate, Aluminum Bromide, Lithium Molybdate, Ammonium Molybdate
    - Acrylonitrile
        - Uranium
    - Corrosion Inhibitor
        - Sodium Molybdate, Sodium Silicates
    - Ethylene to Ethanol
        - Vanadium Trioxide, Vanadium Tetroxide
    - Ion Exchange Resins
        - Uranium, Vanadium
    - Organic Oxidation Reactions
        - Vanadium
    - Polymerization
        - Vanadium, Sulfur Molybdate
    - Reactor Fuel
        - Uranium
    - Stabilizer
        - Phosphorus Pentasulfide, Lead Sulfate

- Catalyst
    - Sulfur Dioxide to Sulfur Trioxide
        - Vanadium
    - Sulfuric Acid
        - Vanadium
- Cellophane
    - Carbon Disulfide
- Cement
    - Gypsum, Anhydrite, Limestone
- Ceramics
    - Aluminum Phosphate, Beryllium, Magnesium, Molybdenum Trioxide, Uranium Dioxide, Aluminum Hydroxide, Calcium Carbonate, Gypsum, Barium Carbonate, Vanadium Pentoxide, Barium, Titanate
- Detergents
    - Chlorine, Sodium Polyphosphates, Potassium Polyphosphates, Sodium Silicates, Potassium Silicate, Magnesium Silicate, Sodium Sulfate, Benzene, Olevin
    - Liquid
        - Potassium Phosphate
- Drilling Bits (Wells)
    - Diamonds, Steel, Steel Alloys
- Drilling Muds
    - Barite, Calcium Chloride, Bentonite
    - Deflocculant Agent
        - Sodium Tripolyphosphates
- Dyes
    - Calcium Magnesium Chloride, Molybdenum, Calcium Acetate, Calcium Chromate, Barium Thiosulfate
- Electrical Equipment
    - Lithium, Barite, Fluorine
    - Digital Calculators
        - Barium Titanate
    - Dielectric Amplifier
        - Barium Titanate
    - Electrical Porcelain
        - Beryllium, Calcined Alumina, Barium Titanate
    - Electronic Tubes
        - Glass, Barium, Fluorine, Argon
    - Fluorescent Compounds
        - Vitreous Silica
    - High Voltage Equipment
        - Beryllium, Calcined Alumina, Copper, Steel
    - Insulation
        - Gilsonite, Ozokerite, Magnesium, Beryllium, Calcined Alumina
    - Printed Circuits
        - Gold, Silver, Calcined Alumina, Copper
    - Rectifiers
        - Selenium
    - Resistors
        - Beryllium Oxide
    - Semi Conductors
        - Silicon Carbide, Selenium
    - Solar Space Generators
        - Beryllium
    - Space Antennas
        - Beryllium, Steel
    - Sparking Alloys & Carbon Arcs
        - Carbon, Rare Earths
    - Switches
        - Beryllium, Copper, Steel

- TV Picture Tube
  - Barium Carbonate
- Ultraviolet Inhibitor
  - Vanadium Pentoxide
- X-ray Tube Windows
  - Beryllium

Explosives
- Barium Chlorate, Ammonium Nitrate, Sodium Nitrate, Potash, Ammonium Perchlorate, Sodium Chloride, Sodium Perchlorate, Nitric Acid, Sulfuric Acid, Potassium Sulfate
- Jato Fuel
  - Ammonium Perchlorate
- Incendiary Bombs & Shells
  - Phosphorus
- Rocket Fuel
  - Nitric Acid, Sulfuric Acid
- Oxidizer
  - Ammonium Nitrate, Ammonium Perchlorate
- Safety Matches
  - Cedar Trees, Barium Chromate, Potassium Nitrate, Phosphorus Trisulfide, Phosphorus, Sodium Chlorate, Aluminum Sodium Sulfate, Barium Nitrate
- Signal Flares
  - Calcium Phosphide, Barium Nitrate
- Smoke Columns & Screens
  - Phosphorus
- Tear Gas
  - Barium Acetone

Fertilizer
- Magnesium, Calcium Nitrate, Phosphate Rock, Phosphoric Acid, Ammonium Nitrate, Potassium Nitrate, Potassium Chloride, Potassium Sulfate
- Liquid
  - Calcium Ammonium Nitrate, Ammonium Sulfate Fluoride, Gypsum
- Trace Element Carries
  - Sodium Molybdate

Fiberboard
- Cedar Trees, Gilsonite

Filter Medium
- Calcium Carbonate, Silica

Fire Retardants
- Aluminum Sulfate, Sodium Bicarbonate, Magnesium, Bromine, Monoammonium Phosphate, Magnesium Sulfate, Sodium Phosphate
- Asbestos
  - Magnesium Silicate, Barite
- Fabrics & Wood
  - Magnesium
- Pyrotechnics
  - Calcium Nitrate, Cellulose Phosphates
- Wallboard
  - Calcium Alginate, Gypsum (Calcium Sulfate)

Floor Tile
- Gilsonite

Food Processing & Products
- Flavoring
  - Phosphoric Acid, Calcium Chlorate, Saccharin, Calcium Hydroxide, Calcium Chloride, Calcium Phosphate
- Preservatives
  - Calcium Bromide, Potassium Bisulfate

Foundary Core Compounds
- Barium Carbonate

Gas Mantles
- Magnesium, Thorium

Glass
- Silican Oxide, Aluminum Oxide, Calcium Oxide, Magnesium Oxide, Sodium Oxide, Calcium Phosphate, Potassium Oxide, Iron Oxide, Beryllium, Barium Peroxide, Aluminum Phosphate, Calcined Alumina, Barite, Sodium Nitrate
- Plate Glass
  - Gypsum
- Polishing
  - Rare Earths
- Etching
  - Fluorine
- Flash Bulbs
  - Magnesium
- Fiber Glass
- Light Bulbs
  - Copper
- Flux
  - Lithium
- Lead Glass - decorative, optical effects, tableware
- Optical Mirrors
  - Magnesium, Silver
- X-Ray Tube Windows
  - Beryllium
- Sealed Beam Headlights
  - Lithium
- High Stress Windows
  - Lithium
- Incandescent Mantles
  - Beryllium
- Optical Alloys
  - Beryllium
- Pigments
  - Vanadyl Sulfate, Lead Molybdate
- TV Tubes
  - Lithium, Barium Carbonate
- Milk Glass
  - Sodium Aluminate
- Neon Sign Tubing
  - Lithium

Glues
- Adhesives
  - Cellulose Phosphates, Sodium Silicates
- Casein Glues
  - Sodium Molybdate
- Epoxy Filler
  - Alumina
- Epoxy Resin for Stones
  - Magnesium Hydroxide, Magnesium Chloride

Grinding Wheels
- Calcined Alumina, Synthetic Diamonds, Silicon Carbide, Sodium Silica Oxide, Sodium Tetrasilicate

Heat Exchanger Medium
- Lithium Chloride, Sodium, Lithium Fluoride
- Refrigerants
  - Chlorine, Fluorine, Lithium Nitrate, Calcium Chloride, Sodium Nitrate

- Inks
    - Magnesium, Vanadium, Sodium Metavanadate, Molybdenum, Light Alumina Hydrate, Calcium Carbonate, Barite, Barium Sulfate, Vanadium Pentoxide, Aluminum Nitrate, Calcium Acetate, Lithopone, Zinc, Magnesium Oxide, Gilsonite
    - Engraving, Lithography, Printing
        - Lead, Zinc, Sodium Sulfide, Ammonium Bromide, Cadmium Bromide
- Insecticides
    - Copper Nitrate, Chlorine, Calcium Cyanide, Parathoin, Calcium Carbonate, Bromine
    - Roach & Rodent Poisons
        - Phosphorus, Tetraethyl Pyrophosphates
- Lath - Wallboard
    - Gypsum, Potassium Sulfate, Calcium Sulfate, Perlite
- Leather Tanning
    - Molybdenum Sulfate, Aluminum Sulfate, Phosphorus Pentoxide, Barium Chloride, Sodium Phosphate, Magnesium Sulfate, Sodium Bisulfate, Sodium Sulfate, Sodium Chlorite
    - Dehairing Agent
        - Barium Hydroxide
- Lube Oil Additives
    - Phosphorus Pentasulfate, Dithiophosphates, Aluminum Naphthenate Aryl Sufonyl Fluorides
    - Gasoline
        - Phosphorus Trichloride, Bromine, Chlorine
- Magnesium Recovery
    - Limestone
- Metal Products
    - Tools, Metal Springs & Diaphragms (Non-fatiguing -- non-rusting)
        - Steel, Beryllium, Copper
    - Tools (Non-sparking) (Anti-magnetic)
        - Beryllium, Steel, Copper
    - Magnesium Casting
        - Ammonium Fluosilicate
    - Cans (Soft Drink)
        - Magnesium
- Nuclear Reactors
    - Beryllium, Lead, Steel
- Paints
    - Calcium Magnesium Chloride, Chlorine, Barite, Magnesium, Calcium Tungstate, Calcium Carbonate, Molybdenum, Barium Oxide, Barium Chromate, Lithopone, Barium Sulfate, Lithium, Magnesium Silicate, Gilsonite
- Pharmaceuticals
    - Magnesium Hydroxide, Phosphorus Pentoxide, Bromine, Barium Nitrate, Sodium Phosphate, Chlorine, Magnesium, Sodium Chlorate, Vanadium Pentoxide, Calcium Phosphate, Ammonia, Potash, Helium
    - Aerosols
        - Sodium Chlorite, Chlorine, Fluorine
    - Antiacid
        - Magnesium Carbonate
    - Cosmetics
        - Magnesium Silicates
    - Deodorant
        - Sodium Hypochlorite, Aluminum Sulfate, Sodium Peroxide
    - Epsom Salt
        - Magnesium Sulfate
    - Toilet Preparations
        - Magnesium Silicates
    - Tooth Paste
        - Magnesium Carbonate

- Phosphate Recovery
    - Fluorine
- Photographic Chemicals
    - Vanadium Pentoxide, Sodium Phosphates, Uranium, Barium Thiocyanate, Aluminum Chloride, Sodium Metavanadate, Potassium Bromide, Silver Bromide, Ammonium Bromide, Ammonium Chromate, Cadmium Bromide, Potassium Perchlorate, Sodium Sulfide, Sodium Sulfates, Sodium Selenite, Copper Nitrate
    - X-Ray Development
        - Barium Sulfate
- Rubber
    - Barite,Barium Sulfate, Magnesium, Zinc Chloride, Phosphorus, Phosphoric Sulfide, Carbon Black, Tetrasodium Pyrophosphate, Lead, Calcium Silicate, Aluminum Chloride, Lithium, Sodium Sulfide, Copper Sulfate, Magnesium Silicate, Zinc Sulfide
    - Latex
        - Calcium Nitrate
    - Thiokol Synthetic Rubber
        - Sodium Sulfide
- Sanitizers
    - Chlorine, Bromine, Ammonia
    - Antiseptic
        - Magnesium, Aluminum Acetate, Sodium Bifluoride
    - Disinfectant
        - Bromine, Sodium Hypochlorite, Magnesium, Calcium Bisulfite, Calcium Carbonate
    - Fungicide
        - Copper Sulfate, Bromine
- Spark Plugs
    - Barium Steel
    - Porcelain Body
        - Beryllium, Calcined Alumina
- Steel Alloys
    - Molybdenum Trioxide, Ferro Molybdenate
- Sulfuric Acid
    - Anhydrite
- Thermal Insulation
    - Magnesium Carbonate, Perlite
    - Rock Wool
        - Limestone

6. A campaign can then be launched to try to attract companies with know-how to Utah to produce these profitable chemical products.

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POLITICAL RESTRAINTS ON RESOURCE MANAGEMENT OF GREAT SALT LAKE

Dennis L. Thompson[1]

Abstract

Great Salt Lake is a victim of incredible bad luck in its physical characteristics, environmental setting, and political management. One must understand the policy process to see where and how politics has failed to deal with the lake's problems. The policy determinants which affect the lake can be categorized as systemic (institutional), situational, and psychological (behavioral). In breaking each of these categories down, we see the tremendous complexity of looking at a single policy problem, and Great Salt Lake abounds in a multitude of problems.

The most important factor to consider is that first of all Great Salt Lake is a body of water and it must be dealt with comprehensively as a body of water. There are then many other sub-problems such as pollution, desalinization, diking, recreation, mineral production, and reliction lands.

The comprehensive planning effort put into other Western water basins has not been put into Great Salt Lake. The responsibility should be the state's; but in the vacuum the local governments have done little and the federal government has at times been a hindrance. The policy on the direction which the lake's development should take is a result of non-decisions. The state should be the moving force and it should be focused by the state water agency.

KEY WORDS: Policy process; Federal government; Local government; Policy determinants; State government; Non-decisions; Planning

Great Salt Lake is a victim of incredible bad luck. It began as an immense inland sea, but is now a perpetually diminishing vestige of its former self. This decrease in size is due to its bad luck of being located in an area of extreme aridity where it cannot even count on regular replenishment. In modern times its relatively limited sources of supply have also been diminished because of upstream demands that have been placed on the streams. Great Salt Lake is at the end of the hydrologic system which means it gets what is left over after all other uses have been allocated. Being at the end of the drainage systems has meant that the quality of water delivered to it is not

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usually of good quality. Having no outlet its water, even if delivered to it pure, is heavily salt laden. On the one hand it does not offer the fresh waters of other lakes, and on the other does not merit the more noble appelation of "sea." As it is shallow over much of its surface the receding waters have exposed a barren uninviting shoreline. Its immediate surrounding does nothing to enhance its appeal; even its air at its most accessible point is unclear and polluted. Its most prevalent wildlife is the swarming brine fly; it's too saline for even a salt water fishery.

One gets the distinct impression that Great Salt Lake was born to be a loser, and its political life has not done much to help its image.

Determinants of Public Policy

The political restraints upon Great Salt Lake can be seen generally by looking at the policy process. Then later we can identify its more specific aspects by briefly surveying the issues surrounding the lake.

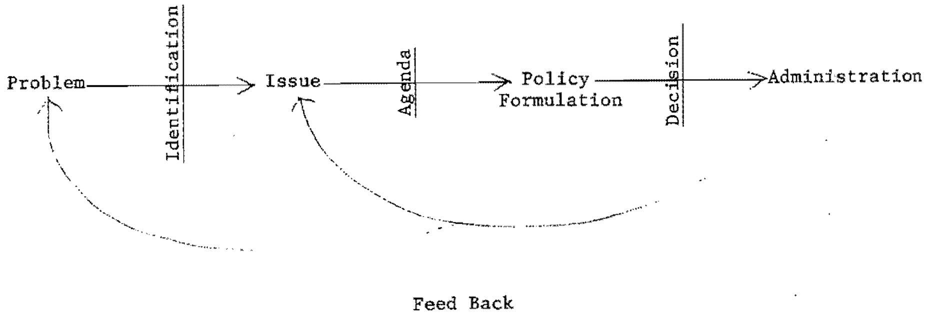

Figure 1. The policy process.

The policy process begins with problems which are not necessarily perceived. Once someone, but even then not necessarily those most acutely affected, perceives the problem as something which needs a solution and identifies it with some specificity it becomes a political issue, though the degrees of its salience or visibility are great. It is presumed that once the problem is identified and promoted conflict in some form will appear. The conflict need not be only in opposition to the problem itself; but could also be in disagreement over scope, content, or aspiration of the proposed solution. As Cobb and Elder (1972) have defined it, "An issue is a conflict between two or more identifiable groups over procedural or substantive matters relating to the distribution of positions or resources." If those concerned are successful in propelling the issue towards a public solution it is placed on the agenda of government. Again Cobb and Elder (1972) identify two basic types of political agendas: the systemic agenda and institutional agenda. They define the systemic agenda as consisting of all issues that are commonly perceived as being the legitimate concern of the existing governmental authority. To be on the systemic agenda the issue must have widespread interest. The institutional agenda consists of those issues that have been explicitly put forth for consideration of the decision-makers.

Once an issue is on the agenda of government it may or may not be acted upon, but it is in this atmosphere that a policy upon the issue, if any, is formulated. We must be prepared to accept the fact that some issues are deliberately not resolved, but result in a non-decisional policy nonetheless (Bachrach and Baratz, 1963). A policy to maintain the status quo or to do nothing has its effect upon the problem.[2]

Once a decision, or non-decision, has been reached the policy then is ready for application to the problem which is the function of administration. The administration in turn creates new problems and also puts new readily perceived unresolved issues immediately on the agenda for consideration as amendment, clarification, etc. of the original policy.

In this whole policy process there are a number of factors which can affect the solving of public problems. I call them determinants of public policy. Each can sustain or restrain policy development.

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[2] Charles O. Jones (1970) calls this process "legitimization," but it seems to me to be less descriptive than "formulation."

The policy determinants seem to logically fall into three categories: systemic, situational, and psychological (or behavioral). Systemic determinants are those which are inherent in the political system. The nature of the legislature; the executive focus; the possibility of independent judicial review; the strength and competence of the bureaucracy; the kinds and sources of support mustered by the administrative agencies; and the organizational relationships of all of these are all systemic determinants. Dror (1968) has indicated the significance of analyzing what we know about the policy-making process, what he calls metapolicy knowledge. This kind of information is also systemic as it relates to all potential policy issues in a given political system.

In the United States when dealing with a problem at the state level the systemic determinants could be those related to the state system of government as well. But in most cases there is involvement or interest on the part of both national and state or local governments, thus the nature of American federalism also becomes significant; the legal and political relationship of the state and federal governments. This is crucial in looking at Great Salt Lake.

Situational determinants are those which have to do with any given policy issue. The interests and values involved in the policy issue at hand must be traded off against a multitude of other events and issues which compete for time, attention and resources (Bauer, 1968). One could list indefinitely events and issues which could be remotely connected to the policy problem at hand. There are antecedants and consequences which must be considered; but there should also be some logical division between those which have, can or will affect the policy and those which are tendential to the problem at hand. Bauer (1968) uses the phrase "the envelope of events and issues" to denote the context within which a given problem should be analyzed. Much of this envelope will be concerned with the state of affairs--the criticality of the problem, the pressures and counter pressures extant, and the major events and issues to which the policy-makers are giving their time. Other situational determinants must be considered as well. The level of public concern, whether well-founded or not, will have important bearing on issue resolution. Interested organizations become part of the situation because they do not have a general interest in all issues, but pick and choose the causes for their involvement. Also included here is the extent to which a problem is understood, the informational aspect. This may or may not include the state of technology. If that technology is not available to properly analyze the problem or collect the needed data, the information level will not be adequate. It may be just a matter of transferral of technology from some other policy area, but this is not always evident nor is it always done (Furash, 1968). Resource supply is also particular to each issue, including the level and availability of trained personnel, money, and time. In this same vein, and particularly with natural resources issues, the state of nature is a significant situational factor. Access, pollution level, water level, and salinity are examples relevant to the Great Salt Lake.

Finally, psychological determinants are those which relate directly to the people involved. After all, policy issues are not resolved by institutions or in situations, but by people. We must always be aware of what factors affect their behavior and participation on a policy issue. These factors are much more difficult to identify or analyze than the systemic and situational ones. But by being aware of their existence and recognizing their effect, we can at least know where the secrets lie if our political understanding is incomplete after all other data has been collected. The base of psychological determinants is the values which the participants bring to political situations. A person's value judgments color his attitude toward all other factors (Davies, 1963). Also of critical importance are the capabilities which those involved possess. The political culture, which as a whole could be either systemic or situational, comes to bear on a policy issue as it effects the individuals--as they feel its demands and restraints. Akin to this latter concept is the extent to which a person has been socialized, into a political culture generally, but, more specifically, into a peculiar situation. The above, and other, factors will in turn determine how a participant perceives a problem, its alternative solutions, and their consequences. The policy participant also has a relationship to interested institutions and organizations which colors his perceptions and actions. Finally, the independent factor of communication has its effect on the individual. The level of information (situational) may be high, but there may be a lack in communication. This can result in turn from a lack of effort to communicate, an inability to understand (which often happens when technical data is transmitted), or a lack of opportunity (inadequate means of communication). The results are the same; those who are, should or could be concerned don't get the word. This means they act on partial information, are delayed, or do not act at all.

These determinants are not intended to constitute a complete list of factors affecting public policy formulation. But they are the more important ones, and do give an idea of the complexity of all the factors involved. All of these determinants may not necessarily be involved in any specific policy issue; but before taking heart, I would warn that most of them are factors to be considered to some extent in every policy determination.

The Political Issues of Great Salt Lake

With the problems of managing Great Salt Lake peppered with a profusion of policy determinants, the lake is also salted by an equally perplexing number of issues.

Great Salt Lake is first of all a body of water, though this fact has often been of secondary importance as other issues have captured greater interest. Its inflow, water level, quality, distribution, and utilization are primarily and preimminently water factors which affect all other uses of the lake and its surrounding area. Yet its problems are not usually treated as water problems and thus the institutional determinants are often not water related institutions. This in turn means that the people involved are not water related people; thus the psychological determinants will not be wetted by water either. This has made uncomfortable decisional situations, because the situational determinants remain true to reality.

The problems which have remained as water issues have not had the attention of many of the other problems. As with most of our inland bodies of water, pollution was an ongoing and unheralded fact of lake life for years. And the eutrophication of Great Salt Lake was less noticeable than in fresh water lakes. But the lake had its defenders who warned of the damage being done. From the early 60's, when it was called one of the biggest open ended cesspools in the country, to the late 60's, when much of its wastewater was put through treatment plants, its pollution input declined. Yet the pollution grows worse as it is cumulative, and the input of waste from the drainage systems continues.

Diking the lake to produce fresh water reservoirs, long discussed, is now a reality as a result of the Willard Bay development of the Weber Basin Project. But there are still other proposals for diking parts of the lake. The Lucin cutoff causeway built by the Southern Pacific Railroad was not intended to create a fresh water lake, but has made the southern end less saline than the northern

end. Desalinization for the production of sweet water and power production are still other potential uses of lake water which would bring additional interests and issues into play.

Traditionally, and probably most evident in the public eye, the lake has been used for recreation. Nostalgic reminiscences of the glorious days of Saltair provided historical and pictorial evidence that the lake was there for recreation. For decades dreams, proposals, and even some plans for the further development of the lake's boatery, swimming and beach potentials have been put forth; but alas little has been done. The interest has been mostly private, but the hindrances are public. Brine flies, pollution, receding shoreline, and the need for fresh water are problems beyond the capability of private developers.

The state, of course, did finally set aside the Great Salt Lake State Park on the north shore of Antelope Island in the face of another attempt to create a national monument on the island. This is an amazingly sparse political record of accomplishment given the almost universal agreement that recreational development of the lake should proceed. The Legislative Council, the Governor, the State Park and Recreation Commission, <u>The Salt Lake Tribune</u>, <u>The Deseret News</u>, <u>The Standard Examiner</u>, the chambers of commerce of Salt Lake City and Ogden, and county governments have not proved an adequate base for the development of a meaningful recreational development policy.

Minerals have been the most widely used resource of Great Salt Lake. Beginning with salt the trend of mineral production is constantly on the increase and now includes potash, lithium, magnesium, sodium sulphate, potassium chloride, and chlorine. And there are constant proposals for drilling for oil and some minute production at the north end of the lake shore. As with recreational proposals there are a lot of private interests which want to maintain or gain access to an eventual wealth and are ready to promise huge development to protect their interests. And some companies have built extraction plants and are producing to the extent that the state is encouraged to manage the lake for its mineral content as well as anything else.

Probably the most critical issue in the past decade has been the contradictory problem of lake land. The general problem of ownership of the lake (which to me was a non-issue issue) and specifically the reliction lands or that land which has been exposed by the receding shoreline of the lake. The ownership of the lake has been clarified by the Supreme Court in favor of the state; and the relicted lands has been settled, unsatisfactorily for the state, by Congress and awaits another Court decision.

It is evident that the planning effort and resultant political bargaining and adjustments which have been put in to most other drainage basins in the West have not been put in to the Great Salt Lake Basin. Its tributary river basins have each in turn been considered but as river basins, not as part of a larger entity. The type of research reported here today is necessary. The lake must be looked at as a whole, rather than in its parts. The lake must be looked at as a body of water rather than as a mine, or a beach, or a dumping ground. As a water entity it will tie all of its component interests together.

The lake in the past has been the victim of bad government. If governments did not want to do anything to enhance the lake, they at least should have done nothing to damage it. The problems created by federalism are especially evident in this context. On the one hand while the collective governments, federal, state, and numerous local entities have not sought to develop the potentials of the lake in concert so that the collective interests of all might be served; neither have they separately acted in good faith toward a public good for the lake.

Local governments often remind me of the parable of the talents. We do in fact give them the least authority and opportunity for broad action. But the expectation is that what is given should be used. The purpose of local government is to provide for local needs. Their talent cannot be hidden, otherwise as the parable ends (Matthew 25:28-30)

> Take therefore the talent from him, and give it unto him which hath ten talents. For unto every one that hath shall be given, and he shall have abundance: but from him that hath not shall be taken away even that which he hath.
>
> And cast ye the unprofitable servant into outer darkness: there shall be weeping and gnashing of teeth.

Need I explain.

The State of Utah comes off the best of the lot, but not unscathed. While claiming sovereignty over the lake it has not undertaken the broad-based comprehensive planning program that the basin so desperately needs. If, as I have contended here, it is primarily a water issue, the State Board of Water Resources should be the responsible governmental entity. But it did not undertake to direct, guide or participate though it was authorized to study, investigate and plan for the "full development, and utilization and promotion of the water ... resources of the state ... ." Four of the seven members of the board could be from the Great Salt Lake drainage basin. It appears that comprehensive planning and management is a victim of psychological determinants. It is difficult to get people to face conflictual situations. They do not want to deal with, let alone create it. It is easier to let sleeping dogs and dormant lakes lie.

The creation of the Great Salt Lake Authority is an example of the state's attitude. The initial legislation recognized the need for some overall look at the problems of Great Salt Lake and provided for something more than had been completely negotiated amongst the state interests or even that the authority was prepared to do. As a result the GSLA did little more than develop the Great Salt Lake Park; and it even had difficulty in doing that because of an insistent recognition in some places that the lake should be looked at in a broader context. As it became evident that the creation of a park was all that the GSLA was to be allowed or even wished to do, it also became evident that the Division of Parks and Recreation should probably be doing that. The subsequent amendment to the GSLA legislation, four years after its creation, more clearly defined its authority in line with what it was in fact doing. That is hardly decisive leadership on the part of the state. Finally the state transferred the authority to the Division of Parks and Recreation and gave it the overall duty for "planning and developing uses of the Great Salt Lake" including the "mainland, peninsula, islands, and water within the ... meander line" (Utah State Code [65]). This ignores the fact that Great Salt Lake is a water resource with multiple uses.

On the other hand the state was forced to put much of its available energy which could be allotted to Great Salt Lake to deal with the obtuseness of the federal government. When the state attempted to take affirmative action on some of the lake's problems in 1961 it was stymied by a federal contention of ownership, not only of reliction lands but of the lake itself. As Max C. Gardiner, then Director of the State Land Board, said in July, 1962,

> "The federal government should not put the state to the expense and burden of litigation to confirm such a well known fact (as the navigability of the lake)."

Furthermore, the attempts of the state at that time to clear this nonsensical hurdle by introducing legislation in Congress through its Congressional delegation were insistently fought by Secretary of the Interior Udall who wanted the state to exhaust administrative remedies before seeking legislative relief, as though the pattern of federal action to that point had implied any administrative remedy was available.

A number of years ago, Morton Grodzins, a perceptive writer on American federalism, wrote (Grodzins, 1961)

> The rhetoric of state and national power becomes easily and falsely a rhetoric of conflict. It erroneously conceives states and localities, on one side, and the central government, on the other, as adversaries. There are undoubtedly occasions when the advantage of a locality, state or region is a disadvantage to the nation as a whole. But in most circumstances at most times compatibility rather than conflict of interests is characteristic .... Federal, state, and local officials and not adversaries. They are colleagues. The sharing of functions and powers is impossible without a whole. The American system is best conceived as one government serving one people.

Scientific and technical personnel often act in harmony, but somehow, federal, state, and local officials didn't get the word. All governments must be involved and we should expect them to work as one government serving one people. Among them one group has to take the lead--I suggest that it is logically the role of the state on Great Salt Lake. Surely the management and development of Great Salt Lake can be of advantage to all Americans. Since when is a Utah advantage not an American advantage? To ask for state leadership by the water board is not to be prejudicial to any current or projected uses; but seeks comprehensive management and planning.

In the terms of Gilbert White's excellent analysis of Strategies of American Water Management (1969), where he identifies six types of strategy in light of purpose, means, and management agency, it is evident that Great Salt Lake calls for application of his sixth and most complicated strategy: ".... a merging of multiple purposes, and multiple means, including research, ..."

As I have said, I can find no evidence that the decision-making elements of Utah state government have decided what should be done with Great Salt Lake; yet the state insists it should be the one to make the decision. Decisions to lease land for ponds or drilling, to build a road or causeway, or to create a park show no pattern of a conscious decision as to what the expectations of lake use are. There is no state agency with overall planning and management responsibility for the lake, nor is there a state plan. The complex problems of the lake have pushed the decision-makers into partial solutions. But neither is there widespread public concern over the future of the lake, which means the special interests have clearer sailing to maintain their status quo or presumed future benefits. And there is some lack of information on the lake; but who wants to dig up data which has little prospect of being used.

It is amazing how many studies have been made and how much data has been collected, but how few decisions have been made. I have made no attempt to ascertain the psychological determinants which are most basically involved in the state policy process on Great Salt Lake, but without doubt many of the restraints upon the development of a state policy can be found in the make-up of a handful of individuals who either have had no interest or have had specific interests which promote non-decisions. Yes, we have an overall policy on Great Salt Lake created mostly by non-decisions and partial decisions.

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