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Expected Effects of In-Lake Dikes on Water Levels and Quality in the Farmington Bay and the East Shore Areas of the Great Salt Lake, Utah

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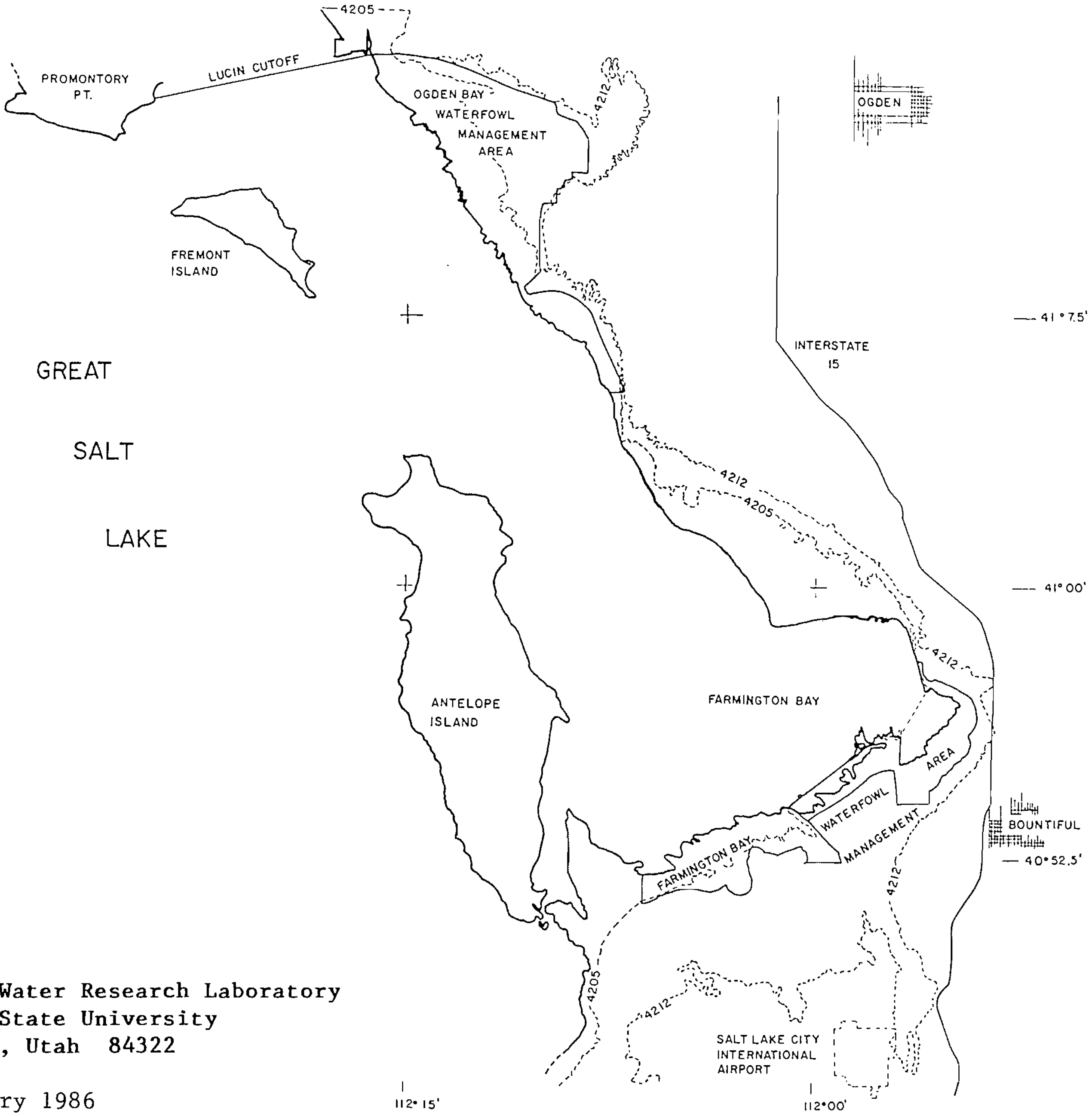

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Introduction

The Great Salt Lake is a terminal lake and as such is one of the major inland bodies of salt water in the world, and the largest lake of brine in the western hemisphere. Its unique features, including its mineral rich waters and interesting shores and islands, make it appealing to both industry and vacationers. Until recently, some of the great waterfowl sanctuaries in the U. S. existed along the easterly and northerly shores of the lake. However, during the past three years record breaking inflow volumes and lower than normal evaporation rates have caused an unprecedented rate of rise in the elevation of the lake surface. The rising waters already have caused extensive damages to both public and private properties, including roads, highways, railroads, hunting club facilities, mineral extraction facilities, waterfowl areas, homes, water treatment facilities, and agricultural lands. For example, the Southern Pacific Railroad Company has spent many millions of dollars raising the level of the causeway which crosses the lake between Promontory Point and Lakeside on the western shore, and a causeway which was constructed by the State to provide access to a State park on the northern tip of Antelope Island now stands under approximately three feet of water. Continued increases in the lake level would create further damage to homes, transportation links (including the Salt Lake City International Airport), lakeside industries, and recreation facilities.

In order to reduce future damages from the rising waters of the lake, various diking options, among other alternative flood control possibilities, are being considered by the State. Some of the diking options were addressed in a recent feasibility-level engineering study completed by James M. Montgomery, Consulting Engineering, Inc., and a team of sub-consultants (Montgomery 1984). The study evaluates several on-shore (or perimeter) diking alternatives to protect specific facilities, such as waste-water treatment plants. In addition, the study looks at some in-lake diking alternatives which provide certain management options by compartmentalizing the lake.

The in-lake diking options presented by the Montgomery study include various configurations between points on the east shore of the lake and the Antelope and Fremont Islands. As might be expected, the Montgomery study shows that the in-lake dikes, although more comprehensive (less selective) in the protection provided, are considerably more costly both to construct and to maintain than perimeter dikes for the same area. Various possible perimeter dike configurations to protect properties on the east shore are discussed by the Montgomery report. The costs of these structures are compared with the much higher costs for in-lake dikes needed to protect the same properties. However, the report, by design, addresses the in-lake dikes purely from a flood protection point of view and does not consider other possible advantages of in-lake diking, including:

1. Possible freshening of the waters in areas enclosed by dikes along the east shoreline to enhance boating and swimming and to enable these waters to be used for irrigation, municipal, and industrial purposes.

2. Capabilities to manage the levels of the water adjacent to the east shoreline in order to optimize conditions for waterfowl sanctuaries.

3. Providing road access to the Antelope Island State Park, and even the possibility of an additional north-south transportation route by-passing Salt Lake City.

Each of these three issues needs careful study to evaluate the potential physical and economic impacts. For example, a study of items (1) and (2) should address questions such as: (a) Can water in the impounded areas be freshened sufficiently to permit its use for boating and swimming, irrigation, and/or municipal and industrial purposes? (b) To what extent will freshening create odors (anaerobic conditions), promote algae growth, and cause other water quality problems within the impounded areas? (c) Will regulation to maintain water and salinity levels suitable for waterfowl habitat preclude other uses such as boating and swimming, irrigation, and/or municipal and industrial?

Objectives

The primary objective of this study is to evaluate management alternatives for the easterly portion of the Great Salt Lake in terms of water quantity (impounded water levels which can be maintained) and water quality. Impounded water surface levels affect use of the stored water. For example, in the case of Farmington Bay, personnel from the Division of Wildlife Resources suggest that the optimum levels for the waterfowl sanctuaries lie between 4195 and 4200 feet above mean sea level (msl), whereas to provide adequate depth for boating and swimming, water levels should not be less than 4202 feet msl. With respect to water quality, only the salinity component is included in the computer model used for the study. Salinity is a critical quality parameter for irrigation, industrial, and municipal uses. In addition, biological activity is strongly linked to water salinity levels. The waters and sediments of Farmington Bay in particular contain high nutrient levels, so that reduced salinity levels will promote algae growth and create anaerobic conditions. In January 1985, the Utah Water Research Laboratory (UWRL) completed a preliminary study (funded by the State Division of Water Resources) (Israelsen et al. 1985) to evaluate the odor potential associated with freshening of the Farmington Bay waters. This work was extended as part of the current study and utilized in interpreting the likely effects of freshening within both the Farmington and East Bay areas of the lake. However, the biological quality component was not directly incorporated into the hydro-salinity model used for the study.

In the conduct of the study, two possible in-lake diking configurations were assumed (see Figure 1), namely:

1. Farmington Bay. Enclosure of the Farmington Bay area by a dike extending southward from the southern tip of Antelope Island and a second dike following the route of the now submerged Syracuse Causeway. It was assumed that the dikes would be constructed to a sufficient height to prevent overtopping from the main body of the lake.

2. East Bay. Enclosure of the entire easterly portion of the lake by three in-lake dikes, with the first extending southward from Antelope Island as in the first configuration, the second connecting Antelope and Fremont Islands, and the third extending northward from Fremont Island to Promontory Point. Under this configuration all flows from the Bear, Weber, and Jordan Rivers (except for diversions from the Jordan River through the Surplus Canal to the Goggin Drain) would enter the impounded area.

The potential for freshening the waters enclosed by the two preceding diking configurations was investigated by application of a computer simulation model. Under an earlier study at the UWRL, Chadwick and others (1983) developed a hydro-salinity model for Farmington Bay. For the current study, needed changes were made in the model structure.

The model was applied with sequences generated to represent flow probabilities based on a specific period of historic record. The model simulates monthly inflows to the impoundment areas (surface and groundwater flows and precipitation quantities) and evaporation and flows to the main lake from these areas over a particular period of time. In the case of this study, these quantities were generated for a period of 50 years. By generating a series of possible time sequences (for this study 50 sequences were generated) for a particular set of management conditions, it was possible to develop estimates of (1) the most likely water and salinity levels in the impounded areas, and (2) the variations in these parameters which are likely to occur under a given set of management conditions.

Management Variables

Salinity concentrations and surface elevations of the impounded waters are governed by the rate of evaporation from the impounded waters, the rate of inflow to the impoundments, the quality (salinity) of the inflowing streams, the rate of outflow from the impoundment, and the levels at which the surface of the impounded waters are maintained (either by pumping or by means of an overflow weir). Some degree of management control of each of these variables is possible except for the rate of evaporation from the surface of the impounded waters. For a

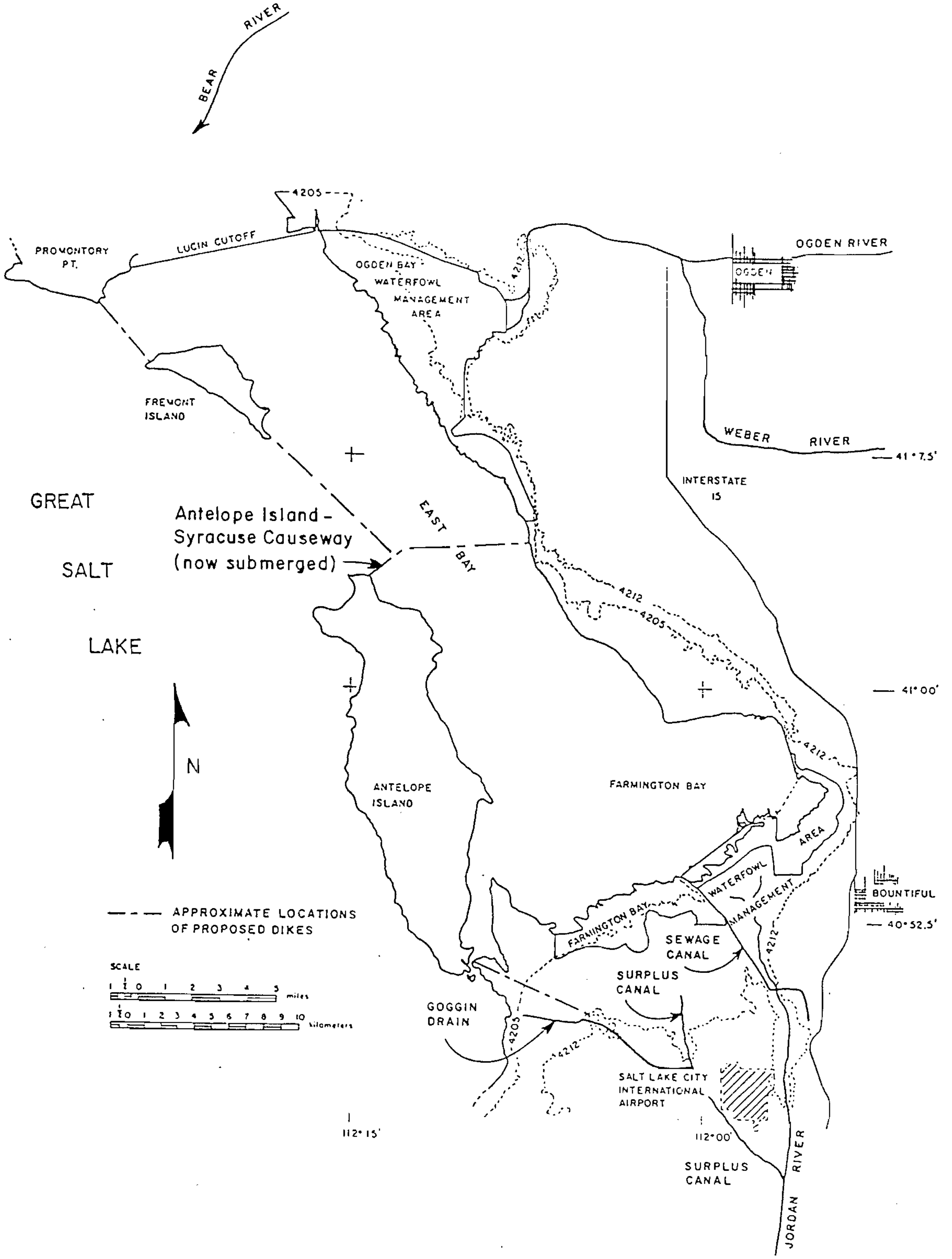

Figure 1. The east shoreline of the Great Salt Lake at a water level of 4200 feet above mean sea level and showing the proposed Farmington Bay and East Bay impoundment areas.

particular operating level (storage volume), decreases in the salinity levels of the impounded waters result for 1) increases in the rate of throughput (inflows and outflows) and 2) reductions in the salinities of the inflowing waters. For a given rate of throughput and a specific salinity level in the inflowing stream, impoundment salinities also are reduced by decreasing the stored volume. This effect occurs because the reservoir surface area is decreased and evaporation losses are correspondingly less. It is noted also that a reduced storage volume for a given rate of throughput results in increased flushing, and thus less time is required to produce a lowered equilibrium salinity level.

Farmington Bay

The surface water inputs to Farmington Bay include several small streams which flow from the Wasatch Range and the Jordan River which flows north from Utah Lake. In addition, the Salt Lake City Sewage Canal conveys treated sewage effluent to the bay. Rates of Jordan River inflow to Farmington Bay can be moderated by diversions from the river through the Surplus Canal and thence to the Goggin Drain (Figure 1) which discharges into the main lake west of Farmington Bay. The maximum diversion rate to the main lake is limited by the capacity of the Goggin Drain which was assumed to be 1,000 cfs for this study. The two primary reasons for diverting flows of the Jordan River directly to the main lake are to reduce 1) costs of pumping water from the bay in order to maintain a specific water surface elevation and 2) inflows from this source during periods (if any) when salinity levels in the lower Jordan River might be higher than those in the bay. In order to satisfy water right constraints in the Farmington Bay area, a minimum flow of 500 cfs was assumed to be required in the lower Jordan River system. Thus, diversions to the main lake through the Goggin Drain could occur only when flow rates in the lower Jordan exceeded 500 cfs.

The study also assumed that water could be imported to the Farmington Bay by diversion from the Weber River in the vicinity of Plain City. Conveyance works associated with this diversion are not addressed by the study, but a canal capacity of 300 cfs was assumed. A further constraint on this diversion is that the rate cannot exceed 75 percent of the flow available in the river at the Plain City gage.

It was assumed that impoundment levels within the Farmington Bay were independent of main lake levels. During periods when water surface elevations in the main lake exceed those of the bay, a pumping facility would be required to maintain a specific level within the bay. During periods when water surface levels of the bay exceed those of the main lake, a siphon (perhaps in conjunction with the pumping facility) or spillway structure would be adequate. A pumping capacity of 1000 cfs was assumed.

East Bay

The surface water inputs to this impoundment include those of Farmington Bay, several additional small streams and drains, and the Weber and Bear Rivers. Although the Goggin Drain is available for diversions from the Jordan River (the same constraints were applied as for the Farmington Bay impoundment), there is relatively little management control possible over inflows to the East Bay impoundment. Like Farmington Bay, it was assumed that water levels within the impoundment could be managed independently of main lake surface elevations through the use of a combination of pumps and gravity drainage facilities. A pumping capacity of 8,000 cfs was assumed.

Procedures

This study was divided into two basic components as follows:

1. Modification and application of a hydrologic-salinity computer model to predict salinity levels within the impounded waters as a function of time.

2. Field sampling and laboratory studies to examine the salt and heavy metal content of the sediments of the proposed impoundment areas with emphasis on Farmington Bay. In addition, the nutrient (phosphorus) loadings of the impoundments were approximated to provide estimates of the algae producing potential of these waters under fresh water conditions. The salt release characteristics of the bay sediments as a function of salinity in the overlying bay waters were incorporated into the model.

The procedures followed in conducting each of these components of the study are summarized briefly in the following paragraphs.

The hydro-salinity model

A hydro-salinity computer model of the Farmington Bay area was develolped under an earlier study (Chadwick et al. 1983). The model, which was somewhat altered and refined for this study, utilizes a monthly time increment and is based on a mass balance of salt and water of the form:

$$I - O = \Delta S \quad \ldots\ldots\ldots\ldots \quad (1)$$

in which

I = total inflow (water volume or salt mass) to the impoundment area per month.

O = total bay outflow (water volume or salt mass) from the impoundment area per month.

ΔS = change in storage (water volume or salt mass) within the impoundment area per month.

Inflows to the impoundment areas are grouped into three main categories, namely, surface streams, precipitation, and groundwater. Of these three, only the rate of input by surface streams is subject to management control. Outflows occur as evaporation from the impounded waters and discharges into the main lake. Rates of discharge to the lake, whether by pumping or by gravity (overflow weir and/or siphon), are subject to management requirements, and for a given rate of inflow, are dependent upon the selected control elevation.

A mass balance representation for the impounded areas ideally should include seepage flows between the impounded waters and the main lake. However, for the three reasons given below these flows were not included in the model.

1. It is understood that the proposed dike design includes a clay core so that seepage rates are expected to be low (see Montgomery report 1984).

2. Seepage rates depend directly on the head differential across the dikes. Thus a realistic estimation of seepage quantities would require that water surface levels in the main lake be simulated in conjunction with those within the impoundment areas. In the case of this study, the main lake levels were not simulated.

3. Seepage from the impoundment area to the main lake would not significantly affect salinity levels of the impounded waters. On the other hand, seepage from the main lake to the impounded waters (because of the normally higher salinity levels in the lake than in the bay) would tend to somewhat increase salinity levels in the impounded water. Thus, under these conditions actual salinity values would likely be slightly higher than those predicted by the present version of the model. In other words, the actual degree of freshening within the impoundment would be somewhat less than that indicated by the model results.

The model was calibrated by using either measured or estimated values of the parameters in the preceding mass balance equation. During the period October 1980 through December 1982 an extensive data gathering program was conducted for Farmington Bay. Flow rate and quality measurements were made at regular intervals for the inflowing surface streams, and quality samples were taken at various locations within the bay. The Farmington Bay model was calibrated using data and estimated values for this period.

Evaporation rates from the impoundment areas were estimated by taking into account the effects of salinity on evaporation. In this connection, within Farmington Bay, marsh and mud flat areas become increasingly significant as water levels fall below an elevation of 4203 feet above mean sea level (msl). Thus, evaporation rates from the exposed marshes and mud flats below 4203 feet are estimated differently than in the case of open water surfaces.

After verifying that the water and salt balance submodels for both the Farmington Bay and the East Bay were functioning satisfactorily, a stochastic component was added to complete the hydrologic-salinity model. Thus, beginning with known or assumed initial conditions, possible traces of water surface levels and salinity concentrations can be generated for any specified time period and for a particular set of management conditions. The initial conditions used for this study were estimated values for October 1, 1985 (the beginning of the 1986 water year). A listing of the hydrologic-salinity model, together with user instructions and sample input and output files, is contained in Appendix A.

Field sampling and laboratory studies

Four sediment samples were collected from Farmington Bay on April 1 and 3, 1985, for evaluation of odor production potential under fresh water conditions. For each sediment type, four replicate quantities of sediment were placed in 20 liter glass microcosms. Two replicate microcosms were filled with water from the Great Salt Lake and two with water from the Logan River. After incubation in the dark at 25°C and with gentle mixing three times a week, sample dilution series were prepared for evaluation by an odor panal on May 22 and 23. The point where 50 percent of the panelists could detect an odor was designated as the Threshold Odor Number (TON_{50}) for that odor microcosm.

Sediment core samples were collected from six sites in Farmington Bay and the East Bay on April 1 and 3, 1985. Overlying Great Salt Lake water was replaced with Weber River water. Salinity and nutrient dynamics were studied in three replicates of each sediment type under both oxic and anoxic conditions by sampling the water column every 3 to 5 days from April 9 to May 14, 1985. Two of these sediment cores from the south Farmington Bay were examined for heavy metal contamination.

Water samples were analyzed for ortho-phosphorus, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, total phosphorus, total nitrogen, total dissolved solids and specific conductance by EPA - approved methods. Five additional water samples were collected from Farmington Bay on May 22, 1985, for odor evaluation, analysis of chlorophyll *a*, and identification of dominant algal species.

Using estimates of total phosphorus loading to the impoundments, and an empirical model of the eutrophication potential in freshwater lakes and reservoirs (Jones and Lee 1982), predictions of the eutrophication potential of Farmington Bay and the East Bay were made. Further information on the field sampling and laboratory studies involving the bottom sediments of the bays is contained in Appendix B.

The Study Area

Farmington Bay hydrology

Inflows to Farmington Bay are grouped into four main categories, namely surface streams, precipitation, groundwater, and in some cases imported flows from the Weber River. Outflows from the bay occur as evaporation from the water surface, mud flats, and plant surfaces and (for this study) either pumped or gravity flows to the main lake. For the reasons given in the previous section, seepage flows through the dikes separating the bay from the main lake were assumed to be negligible.

Surface streams. Major inflows to Farmington Bay come from the Jordan River and the Surplus Canal (Figure 1). The average annual flow of the Jordan River below the Surplus Canal diversion was approximately 103,000 acre-feet for the period from 1944 through 1982. The Surplus Canal diverts water from the Jordan River, and carried an average annual flow for the same period of about 183,000 acre-feet. Of the flow in the

Surplus Canal, an annual average of about 100,000 acre-feet were diverted into the Goggin Drain and did not enter Farmington Bay (Waddell and Barton 1980). Other significant, though much smaller, tributaries of Farmington Bay include Kays, Holmes, Farmington, Stone, and Bear Creeks. Effluent flows from the North Davis, Central Davis, and South Davis South waste water treatment plants also enter the bay. Other smaller, unnamed tributaries also flow into the Farmington Bay. An extensive data gathering program to monitor surface inflows to the bay was conducted during the period of October 1980 through December 1982.

Flows of the Jordan River for the period 1943 to 1976 were estimated by summing measurements of the river flow at a point below Cudahy Lane (Waddell and Barton 1980) and measurements of Surplus Canal flows at Salt Lake City (2100 South). For the period 1976 to 1984 measurements of the Jordan River flow were made at 500 North and these records were used in place of the Cudahy Lane flows. The estimated river flows throughout the 1943 to 1984 time period were adjusted to present conditions and are termed "present modified flows".

The present modified flows in the Jordan River as estimated by the procedure outlined in the preceding paragraph include flows diverted into the Surplus Canal (Figure 1). However, a portion of the flows diverted by the canal enter the main lake through the Goggin Drain which diverts from the canal at a point west of the Salt Lake City International Airport (Figure 1). Thus, to estimate the Jordan River flows which enter Farmington Bay, it is necessary to subtract the Goggin Drain discharge from the estimated total Jordan River flows. For this reason, a relationship was developed to estimate the annual discharge from the Goggin Drain as a function of the present modified flows in the Jordan River. The relationship was based on flow data for the Goggin Drain taken from Waddell and Barton (1980) for the period 1943-1976, and from Water Resources Data for Utah (individual years) for the period 1977-1984.

$$Q_{gd} = 0.54231\,(Q_{JR}) - 83{,}167 \ldots\ldots\ldots\ldots \qquad (2)$$

in which

Q_{gd} = the estimated annual discharge from the Goggin Drain in acre-feet

Q_{JR} = the present modified annual discharge in the Jordan River (as estimated above) in acre-feet.

Ungaged surface inflows to the bay consist of the following streams:

1. Farmington Creek at Unit 1 dike.
2. A total of 9 different drains.
3. The Sewage Canal at its outfall to the bay.
4. A concrete canal on 800 West.
5. Stone Creek.
6. A ditch adjacent to the North Davis waste water treatment plant.
7. Kays Creek.
8. Holmes Creek.
9. Bear Creek.

10. Flows from the North Davis and Central Davis waste water treatment plants.

Flows from the North and Central Davis treatment plants average 25.16 cfs and vary little. Thus, a constant flow rate of 25 cfs was assumed to come from these sources. The total flow rate from the remaining 9 sources was estimated by the following regression equation:

$$Q_{ug} = 5.7 + 0.32288\ Q_g \quad \ldots\ldots\ldots\ldots \quad (3)$$

in which

Q_g = flow in cfs of the Jordan River at 500 North plus flow of the Surplus Canal at Salt Lake City.

Q_{ug} = estimated total surface inflow in cfs from all ungaged sources (except the North and Central Davis waste water treatment plants).

The ungaged sources included in Equation 3 were gaged during the 1980 to 1982 study, and the resulting data form the basis of the regression relationship. The r^2 for this relationship is 0.564 and the standard error is 99.31 cfs.

As indicated in the section titled "Management Variables," studies were conducted to evaluate the effects of imported flows from the Weber River on the degree of freshening in Farmington Bay. The maximum rate of this diversion was limited by an assumed canal capacity of 300 cfs, and the constraint that the rate could not exceed 75 percent of the flow available in the Weber River at the Plain City gage. This constraint necessitated estimating the river flows at this point and the following relationship was developed:

$$Q_w = -\ 110784 + 19262\ (P_{FB}) + 0.615\ (Q_{JR}) \ldots\ldots\ldots\ldots \quad (4)$$

in which

Q_w = annual discharge in acre-feet of the Weber River at the Plain City gage.

P_{FB} = the estimated annual precipitation in inches on the Farmington Bay.

Q_{JR} = the annual discharge (present modified) in acre-feet of the Jordan River at 2100 South.

Precipitation. Precipitation estimates for Farmington Bay were derived using a slightly modified approach to the Thiessen polygon method (Linsley et al. 1982). Three nearby gages were chosen for use in estimating precipitation on the bay, namely the Farmington USU, Salt Lake Airport, and Ogden Sugar Factory gages. Based on the location of these gages relative to the position of the bay, Thiessen weighting polygons were constructed from which weighting coefficients were determined for each of the three gages. These weighting coefficients were 0.724, 0.181, and 0.095 for the Farmington USU, Salt Lake Airport, and Ogden Sugar Factory gages, respectively. Since each of these three gages has an average annual precipitation value significantly higher than that of Farmington Bay, a correction factor for each gage was computed as the ratio of the average annual precipitation for Farmington Bay to the average annual precipitation measured at the respective gage. From the Hydrologic Atlas of Utah (Jeppson et al. 1964) the 1931-1960 normal annual precipitation on Farmington Bay was estimated as being 14 inches. Corresponding quantities for the three precipitation stations used are Farmington USU - 19.22 inches, Salt Lake Airport - 14.32 inches, and Ogden Sugar Factor - 14.10 inches. The Ogden Sugar Factory record for the period 1931-1952 was corrected by a factor of 0.87. This correction factor was determined from a double-mass analysis which is reported by Chadwick (1985). Thus, the following equation provides an estimate of the monthly precipitation quantities on Farmington Bay:

$$P_{FB} = \frac{14}{19.22}(0.724)\,P_1 + \frac{14}{14.32}(0.181)\,P_2 + \frac{14}{14.10}(0.095)\,P_3 \quad \ldots\ldots \quad (5)$$

in which

P_{FB} = monthly precipitation on Farmington Bay (inches)
P_1 = monthly precipitation at the Farmington USU gage (inches)
P_2 = monthly precipitation at the Salt Lake Airport gage (inches)
P_3 = monthly precipitation at the Ogden Sugar Factory gage (inches)

<u>Groundwater.</u> Investigators of Great Salt Lake and its surrounding watersheds have reached varying conclusions as to the amount of groundwater inflow to the lake. Some of the differences are a result of varying definitions of groundwater inflow. For example, some reports refer to all lake inflows (except precipitation) that are not measured at stream gages as groundwater inflow, while others refer to groundwater as being only that which enters the bay beneath the water surface. In any case, these estimates are only approximate at best because of the difficulties associated with accurately estimating diffuse groundwater sources. Waddell and Fields (1977) estimate that groundwater inflows to Farmington Bay and the entire Great Salt Lake average about 27,600 acre-feet per year and about 75,000 acre-feet per year, respectively.

Bowles et al. (1985) propose the following relationship for estimating annual groundwater flows, Q_{gw}, to the Great Salt Lake.

$$Q_{gw} = 0.015\,[(Q_t) + (Q_{t-1}) + (Q_{t-2})] \quad \ldots\ldots \quad (6)$$

in which

Q_t = the sum of the present modified inflows of the Bear, Weber, and Jordan Rivers for the year t.

The average annual present modified inflows for the 1944 to 1982 period are as follows:

Sum of the Bear, Weber, and Jordan River = 1,746,461 acre-feet
Jordan River only = 294,114 acre-feet

On the basis of these figures and the corresponding estimated groundwater inflows given by Waddell and Fields (1977), the coefficient of Equation 6 was adjusted to provide estimates of groundwater inflow to Farmington Bay on the basis of Jordan River flows as follows:

$$\text{Farmington Bay coefficient} = 0.015 \left(\frac{27,600}{75,000}\right) \left(\frac{1,746,461}{294,114}\right)$$
$$= 0.0328$$

Thus, annual groundwater inflows to Farmington Bay in acre-feet were estimated by the following relationship:

$$Q_{gw}\ (FB) = 0.0328\ [(Q_t\ (JR) + (Q_{t-1}\ (JR) + (Q_{t-2}\ (JR)] \ldots \quad (7)$$

in which

Q_{gw} (FB) = the estimated annual groundwater inflow to Farmington Bay in acre-feet for year t.

Q_t (JR) = the present modified flow of the Jordan River at 2100 South in acre-feet for year t.

Evaporation. Evaporation from Farmington Bay was estimated by first assuming a freshwater surface and then reducing the estimate by a factor depending upon the salinity of the water surface to account for the reduced evaporation from brines. From Figure 9 of Hughes et al. (1974) the average annual "freshwater" evaporation from Farmington Bay is estimated to be approximately 48.5 inches. The estimated average annual evaporation from the Class A pan at the Bear River Bird Refuge for the 1943 to 1982 period is 60.4 inches. On this basis, the monthly evaporation from Farmington Bay is estimated from the relationship.

$$FBE_i = \frac{48.5}{60.4}\ (BRRPE)\ C_i \ldots\ldots\ldots\ldots \quad (8)$$

in which

FBE_i = estimated evaporation in inches from the Farmington Bay (assuming a freshwater surface) for month i.

BRRPE = the stochastically generated annual pan evaporation in inches at the Bear River Bird Refuge for the year containing month i.

C_i = a disaggregation coefficient for month i (discussed in a later section of this report)

To correct the monthly evaporation estimate of Equation 8 for the effects of water salinity, a relationship proposed by Waddell and Bolke (1973) was used:

$$K_i = 1.0 - 0.000778\ c/p \ldots\ldots\ldots\ldots \quad (9)$$

in which

K_i = salinity correction factor (no units) for month i

c = salinity of the water surface (g/l)

p = 1.0 + 0.00063(c) = brine density (g/l)

Thus, monthly estimates of the evaporation from the surface of Farmington Bay were obtained by multiplying the results of Equation 8 by estimated corresponding monthly values of K_i from Equation 9.

It is assumed in this study that in managing the levels of the Farmington Bay the Farmington Bay Waterfowl Management Area situated on the south edge of the bay would be protected from inundation by the waters of the bay. In this event, approximately 9,900 acres of marshes within the Management Area plus an additional 7,000 acres of marshes situated south of the Management Area at the mouth of the Jordan River would be protected from flooding. This total area of 16,900 acres was assumed to consist of 50 percent open freshwater and 50 percent marshland vegetation. Evaporation rates from the vegetated areas (evapotranspiration) was assumed to be 130 percent of that from open freshwater.

When water surface levels in Farmington Bay are less than 4203 feet (msl), areas of mud flats surround the bay. These areas also evaporate water. It was assumed that water rises by capillary action in soils surrounding the bay, so that open water evaporation rates are maintained when mud flats are 1.25 feet or less above the water surface of the bay. It was further assumed that this evaporation rate reduces linearly to zero as the elevation of the water surface in the bay falls to 3.0 feet below the mud flats. These assumptions are consistent with observations of evaporation from the surface of the mud flats surrounding the bay. When water suface levels in the bay are equal to or exceed an elevation of 4203 feet (msl), no mud flats are exposed and they are, therefore, not considered in evaporation estimates from the bay.

Approximately 5,600 acres of marshlands exist in the Kaysville area and near the Jordan River estuary which are flooded at high water levels. To avoid the necessity of distinguishing between this area and the mud flats in the evaporation computations, these marshlands were assumed to behave like mud flats. This simplifying assumption was justified on the basis that at a water level of 4200 feet in the bay most of the marshlands are within 1.25 feet of the bay surface. Thus, the results are affected very little by whether this area of 5,600 acres is treated as a marshland (as in the case of the Waterfowl Management Area) or as a mud flat.

East Bay hydrology

Inflows to the East Bay are grouped into the three categories of surface streams (gaged and ungaged), precipitation, and groundwater. Like the Farmington Bay, outflows occur as evaporation from the water surface of the bay, mud flats, and vegetated areas, and flows by either pumping or gravity to the main lake. Also, as is the case for Farmington Bay, seepage flows through the dikes separating the East Bay from the main lake were assumed to be negligible.

Surface streams. The measured inflows to the East Bay area consist primarily of the Jordan River flow (less the Goggin Drain discharge), the Weber River flow near Plain City, the Bear River discharge at Corinne, and releases from the Willard Bay reservoir. These releases are estimated by Chadwick (1985). All flows are adjusted to represent "present" conditions, so that all flows before 1966 are changed in accordance with the procedure given by James et al. (1979). For the

East Bay studies these records were summed on an annual basis, and the resulting records for the 1938-1982 period were used to develop the statistics required by the stochastic component of the model.

Ungaged surface flows to the East Bay area are estimated by a relationship which was developed from an expression for ungaged surface flows to the entire lake proposed by the Utah Division of Water Resources and published in James et al. (1981).

$$Q_{ug} = 7951\ (P_{EB}) - 746.8\ (E_{BR}) \qquad (10)$$

in which

Q_{ug} = the estimated annual ungaged surface flow in acre-feet to the East Bay area

P_{EP} = the estimated annual precipitation in inches over the East Bay area

E_{BR} = the annual pan evaporation quantity in inches at the Bear River Bird Refuge station.

From this relationship, the estimated average annual ungaged inflow for the 1938 to 1984 period is 70,036 acre-feet.

Precipitation. As for Farmington Bay, Thiessen weighting polygons were developed for the East Bay using the four precipitation stations of Farmington USU, Salt Lake Airport, Ogden Sugar Factory, and Corinne. As before, a double-mass analysis correction factor of 0.87 was applied to the Ogden Sugar Factory records for the 1931 to 1952 period. From the Hydrologic Atlas of Utah (Jeppson et al. 1964), the normal annual precipitation in the East Bay area for the 1931-1960 period was estimated to be 13 inches. For this same period the normal annual precipitation quantities for the four precipitation stations used in the analysis are Farmington USU - 19.22 inches, Salt Lake Airport - 14.32 inches, Ogden Sugar Factory (adjusted) - 14.10 inches, and Corinne - 15.08 inches. On the basis of these numbers, the following equation provides an estimate of the precipitation quantities on the East Bay.

$$P_{EB} = \frac{13}{19.22}(0.295)\ P_1 + \frac{13}{14.32}(0.074)\ P_2 + \frac{13}{14.10}(0.471)\ P_3 + \frac{13}{15.08}(0.295)\ P_4 \qquad (11)$$

in which

P_{EB} = monthly (or annual) precipitation in inches on the East Bay.

P_1 = monthly (or annual) precipitation in inches at the Farmington USU gage.

P_2 = monthly (or annual) precipitation in inches at the Salt Lake Airport gage.

P_3 = monthly (or annual) precipitation in inches at the Ogden Sugar Factory gage.

P_4 = monthly (or annual) precipitation in inches at the Corinne gage.

Groundwater. Waddell and Fields (1977) estimate the average annual groundwater inflow to the East Bay area as being 48,000 acre-feet, and the average groundwater inflow to the entire lake as being about 75,000 acre-feet per year. Equation 6 is used to estimate the annual groundwater inflow to East Bay, with the value of the coefficient being replaced with the following:

$$\text{coefficient} = 0.015\ (\frac{48{,}000}{75{,}000}) = 0.0096$$

Evaporation. From Figure 9 of Hughes et al. (1974), the average annual "freshwater" evaporation from the East Bay is estimated as being 47.5 inches. The estimated annual evaporation from the pan at the Bear River Bird Refuge for the 1938 to 1982 period is 61.1 inches. Thus, Equation 8 is modified as follows:

$$EBE_i = \frac{47.5}{61.1}\ (BRRPE)\ C_i \ \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

in which

EBE_i = estimated evaporation in inches from the East Bay (assuming a freshwater surface) for month i.

The remaining two variables are defined by Equation 8.

Evaporation losses from brine surfaces, mud flats, and marshlands are treated in the same manner as for Farmington Bay.

Monthly disaggregation of annual flows

Monthly values (or estimates) of the various physical parameters discussed above for the Farmington and East Bays are obtained from the average monthly distribution for each of the parameters for the 1943 to 1984 period of record. These results are tabulated in Table 1.

Table 1. Monthly disaggregation percentages for various hydrologic parameters.

Parameter	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Farmington Bay												
Precipitation	8.44	8.50	9.38	8.93	8.33	10.68	12.90	10.74	7.50	3.18	5.38	6.05
Streamflow (gaged and ungaged)	6.45	6.75	7.44	8.15	7.30	10.79	12.86	15.30	12.05	4.48	3.56	4.85
Weber River at Plain City	4.63	4.91	5.80	5.82	5.61	10.76	17.34	22.99	14.71	2.41	1.59	3.42
Goggin Drain	3.86	4.13	4.21	5.51	6.41	11.81	12.67	15.13	16.60	7.62	6.31	5.75
Pan evaporation[1]	6.70	2.68	1.61	1.34	1.61	3.49	6.70	10.99	15.01	20.38	17.96	11.53
East Bay												
Precipitation	8.98	8.55	9.56	9.05	8.06	10.12	12.35	10.54	8.08	3.28	4.67	6.76
Streamflow (gaged and ungaged)	6.45	6.75	7.44	8.15	7.30	10.79	12.86	15.30	12.05	4.48	3.56	4.85
Pan evaporation[1]	same as Farmington Bay											

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[1] The distribution is estimated from the modified Blaney-Criddle equation using data from the Farmington USU weather station.

The monthly value of a given parameter for a particular month is estimated from the annual value (for example, the estimate provided by Equation 7) by multiplying it by the appropriate percentage for the particular month from Table 1.

Salinity values

Salinity values in each of the streams is estimated by correlating salinity with flow in cfs using available data. These values are needed in order to represent salt movement through the systems being modeled. The relationships developed for the Farmington and East Bay systems are given as follows. Unless otherwise specified, salt flow is given in tons per day and water flow, Q, is in cfs. These are average quantities for the particular month under consideration.

Farmington Bay.

1. All gaged surface flows (including the Goggin Drain exports):

   $$\text{Salt} = 7.542\ (Q)^{0.8148},\ r^2 = 0.87 \quad (13)$$

2. Ungaged surface flows:

   $$\text{Salt} = 49.4(Q)^{0.4694},\ r^2 = 0.38 \quad (14)$$

3. Groundwater - A salinity level of 1500 milligrams per liter (mg/l) was assumed as being the average concentration of the inflowing groundwater. This estimate is based on information obtained from groundwater quality samples collected from wells adjacent to the east shore of the Great Salt lake. Since groundwater flows contribute a minor portion of the total inflows of both water and salt to the bay, fairly large errors in the estimated quantity and quality of groundwater inflows have only small effects on the computed hydrologic and salt budgets of the bay.

4. Wastewater treatment plants - On the basis of sample analyses, the salinity was taken to be a constant 1000 mg/l.

5. Weber River at Plain City - Estimates of the salinity of this water are needed when river diversions to Farmington Bay are occurring in the model.

   $$\text{Salt} = 3.249(Q)^{0.7777},\ r^2 = 0.96 \quad (15)$$

6. Precipitation - The salinity of precipitation was assumed to be zero.

East Bay

1. Gaged surface flows:

   $$\text{Salt} = 74.76(Q)^{0.4965},\ r^2 = 0.88 \quad (16)$$

2. Ungaged surface flows - It was assumed that the salinity estimated for gaged surface flows in a particular month

(Equation 16) is also applicable to the ungaged surface inflows for the same month.

3. Groundwater - As for the Farmington Bay, the average salinity of groundwater inflows was assumed to be 1500 mg/l.

4. Precipitation - The salinity of precipitation was assumed to be zero.

5. Exports (Goggin Drain) - Estimates of the salinity of these waters are needed when exports to the main lake through the Goggin Drain flows are occurring. Because the Goggin Drain flows originate in the Jordan River, the relationship is based on Jordan River flows. In the case of the East Bay model, only the combined flows of the Bear, Weber, and Jordan Rivers are simulated. Thus, the Jordan flows are not directly available and are estimated by the relationship:

$$Q_{JR} = -91676 + 0.228\,Q_{BWJ} \qquad (17)$$

in which

Q_{JR} = the estimated annual flow in the Jordan River (500 North plus the Surplus Canal flows) in acre-feet

Q_{BWJ} = the annual total discharge from the Bear, Weber, and Jordan Rivers in acre-feet

The annual estimate of the Jordan River flow, Q_{JR}, as given by the above equation is disaggregated on a monthly basis using values developed for the Jordan River for the period 1943 to 1984 as listed in Table 1. The resulting monthly volume estimate is converted to cubic feet per second (cfs) and used in the following relationship to estimate salt flow (tons per day) in the Jordan River.

$$\text{Salt} = 7.542(Q)^{0.9148} \qquad (18)$$

in which

Salt = salt flow expressed as tons per day

Q = combined Jordan River flow in cfs

The following expression was used as needed to convert salt flow in tons per day (salt) to salinity (TDS) at a given rate of water flow, Q, in cfs.

$$\text{TDS} = 370.5627\left(\frac{\text{Salt}}{Q}\right) \qquad (19)$$

Sediment salt

The sediments at the bottom of reservoirs (in this case Farmington and East Bays) function as either a sink or a source for salt in the overlying waters. Thus, when significant changes in salinity concentration are apt to occur in either the sediment or the overlying water, the resulting changes in salt storage in the water and/or sediment must be considered. When salt concentrations in the overlying water are high, salt tends to accumulate on the sediment particles. As water salinity levels decrease, accumulated salts diffuse from the sediments and again become dissolved in the overlying water. The rate or flux of this salt transfer process is a function of the concentration gradient across the sediment/water interface. In differential form this concentration gradient is expressed as dc/dx, in which dc represents the change in concentration across a distance dx. In finite element form this gradient is expressed as $\Delta c/\Delta x$. Thus,

$$\text{Flux} = K\ \Delta c/\Delta x \quad \ldots\ldots \quad (20)$$

in which

Flux = mass transfer rate in units such as lbs/acre/day
$\Delta c/\Delta x$ = concentration gradient across the soil/water interface
K = a diffusion or flux coefficient

From laboratory tests on Farmington Bay sediments, Flux was measured for known values of Δc, and from these results it was possible to estimate $K/\Delta x$ at 9.59 lbs/day/1000 acres/mg/l. From known (or estimated) values of salinity (TDS) in the waters and in the underlying sediment, it is possible to estimate Δc as:

$$\Delta c = \text{TDS (water)} - \text{TDS (sediment)} \quad \ldots\ldots \quad (21)$$

and from this value Flux is estimated as:

$$\text{Flux} = 9.59\ \Delta c \quad \ldots\ldots \quad (22)$$

Initial estimates of the salt in the sediments of the Farmington and East Bays are based on the results of laboratory analyses and on the assumption that interchange with the overlying waters occurs to a sediment depth of 15 cm. Equation 22 is applied to estimate the total salt transferred either to or from the sediment during a particular month (the results of Equation 22 are multiplied by the number of days in the month under consideration and the area in acres inundated by the waters of the bay). When the salinity of the water is less than that of the sediment (which is usually the case when the stored water is freshening), the gradient causes the salt to move from the sediment to the water. In this situation the salt load transferred during the month is subtracted from the sediment salt at the beginning of the month to provide an estimate of the salt load remaining in the sediment at the end of the month. Obviously, when Δc is less than zero the gradient is in the opposite direction and the sediment acts as a sink rather than a source.

Farmington Bay water quality

Salinity levels in Farmington Bay have changed significantly in recent history. Salinity of the entire southern portion of Great Salt Lake decreased following the completion of the rock-fill railroad causeway in 1957, and the construction of the Antelope Island Syracuse causeway further isolated Farmington Bay from the rest of Great Salt Lake resulting in still further reductions in salinity. Great Salt Lake elevations decreased to 4191.6 feet above sea level in 1963 leaving most of Farmington Bay as a mud flat, while the current lake elevation of nearly 4210 feet has overtopped the Syracuse causeway and restored essentially unimpaired interaction of the Bay with the rest of the southern portion of Great Salt Lake. Within the bay, salinity levels are not homogeneous, but tend to be lowest in the southern portion where major freshwater inputs are located and tend to increase toward the north. For example, in November 1984 salinity near the south shore was 3.76 percent while salinity over the Syracuse causeway was 5.39 percent (Israelsen et al. 1985).

Many changes in the flora and fauna of Farmington Bay and the southern portion of Great Salt Lake have taken place as salinities have decreased from roughly 20 percent prior to the railroad causeway construction to current values of 5 percent or less (Gillespie and Stephens 1977, Felix and Rushforth 1979, Rushforth and Felix 1982). Bacterial indicators of fecal pollution (coliforms) and pathogenic bacteria were shown to survive up to seven weeks in Great Salt Lake water in the 1920's when salinity was probably about 20 percent (Frederick 1924), and the ability of coliforms to grow in diluted, enriched Great Salt Lake waters with salinities less than 5 percent suggests that there should be concern for the sanitary quality of Great Salt Lake water as salinities decrease. This is especially true at recreational areas where swimming might occur.

As salinities decrease and the osmotic stress on microorganisms is alleviated, the spectrum of active decomposer organisms is increased, biological nutrient cycling processes are accelerated, and dissolved oxygen consumption rates are increased. In Farmington Bay, increased decomposer activity in the water and sediment under oxygen depleted conditions has produced odorous compounds, such as hydrogen sulfide, resulting in an enhanced nuisance odor problem. This problem is long-term because of the high nutrient content of the Farmington Bay waters. Nutrients in the low salinity waters promote algae growth, which, in turn, contribute to the odor problems through the decomposition process under oxygen deficient conditions.

High production of algae in Farmington Bay probably has occurred in the past whenever high flows through the Bay have reduced salinity, and adequate nutrients have been available to allow rich algae growth. Figure 2 shows satellite imagery of Farmington Bay in the summer of 1976 following a high spring runoff. Areas of high algae concentration appear as white amorphous patches resembling land in the satellite image, indicating the high concentrations of biomass that were present at that time. The organic matter accumulated in the bay during periods of high productivity is eventually decomposed resulting in dissolved oxygen consumption and odor production.

A resident of the towns of Buttlerville and Sandy from 1894 through 1915 recalls annoying "sulfury" odors from Great Salt Lake (Eva Israelsen, personal communication, N. Logan, Utah 1985). Those years encompassed a period of rapid rise in Great Salt Lake from about 4197 to 4203 ft amsl, when exposed sediments were being inundated and high river flows tended to decrease the salinity in Farmington Bay.

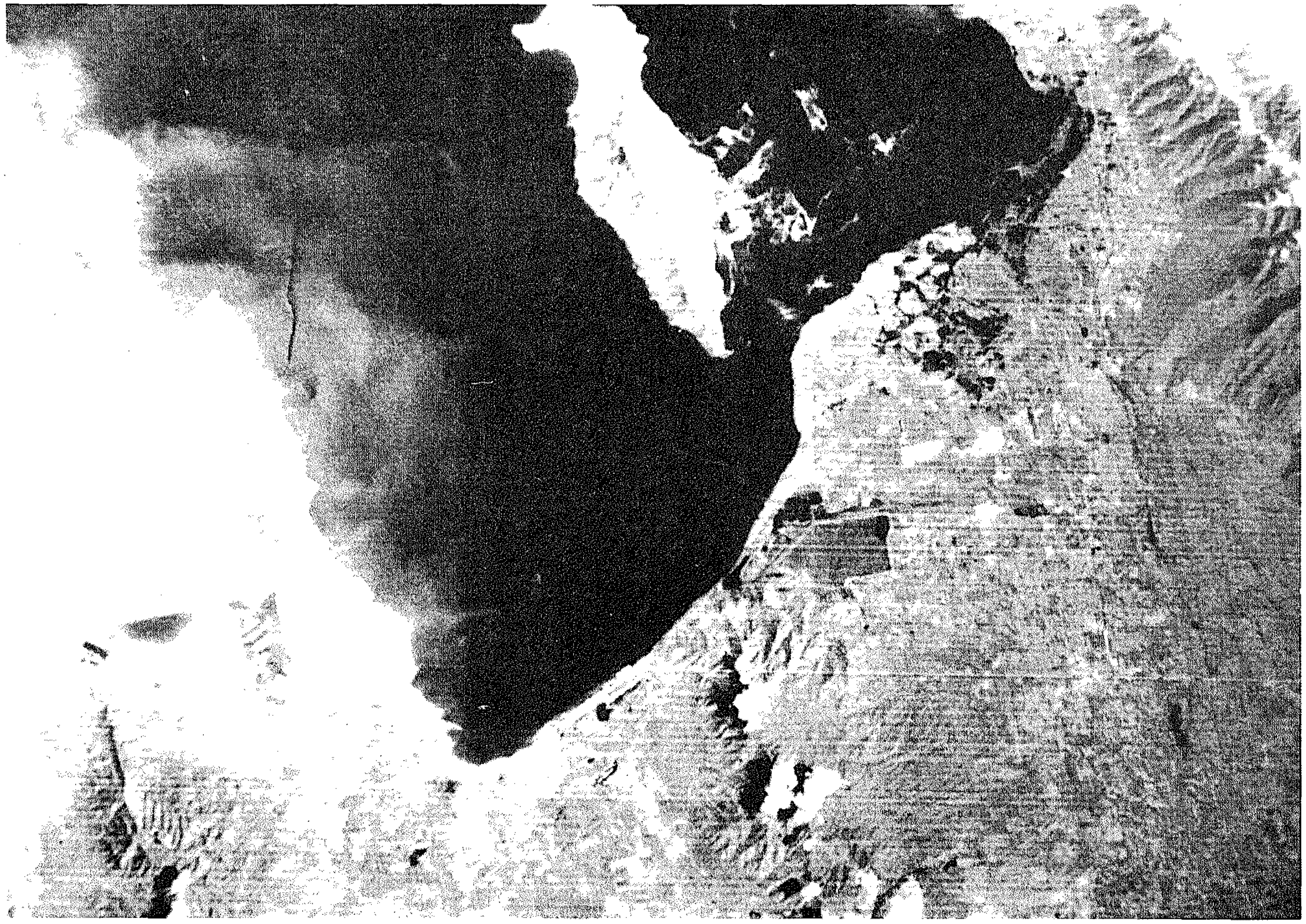


Figure 2. Landsat satellite image of Farmington Bay in the summer of 1976 showing high concentration of algae as white amorphous areas in the Bay. (Courtesy of Paul Sturm, Utah Geological and Mineral Survey).

East Bay water quality

Very little information is available on the water quality of the East Bay area of Great Salt Lake, forcing the assumption that the water quality is similar to the larger southern portion of Great Salt Lake and Farmington Bay. Since the East Bay north of Farmington Bay is influenced largely by the Bear River and Weber River inflows which are generally of lower nutrient content than the Jordan River, and because Great Salt Lake water freely circulates through the East Bay maintaining higher salinities, algae production problems probably have not been as severe as in Farmington Bay and have not been documented.

The Computer Model

As indicated in the "Procedures" section of this report, the computer model applied in the study consists of two components, one of which is based on the principle of mass balance, and the second is a probabilistic or stochastic component used to simulate various hydrologic time series for input to the mass balance component. In this way, it is possible to simulate various water surface elevations and salinity (TDS) levels in the bays under specific management options. The model also generates various probabilities associated with the occurrence of particular events, such as the occurrence of a particular salinity level within Farmington Bay under a specific management option. A listing of the model together with user instructions and sample input and output files are contained in Appendix A.

Mass balance model

As stated in the "Procedures" section of this report, the mass balance component of the computer model is based on the premise that the inflows minus the outflows are equal to the changes in storage during a particular time interval (see Equation 1). Equation 1 can be applied to water, or to any particular conservative constituent in the bay. All significant inflows and outflows must be accounted for to achieve acceptable results.

When water flow is modeled, each of the inflows are added together, each of the outflows are subtracted from the inflows, and the result is the net storage change in the bay during the month under consideration. Based on the change in storage, the elevation of the bay can be determined by the use of the stage-area-volume curves for the bay.

When a water quality parameter such as TDS is modeled, the concentration of the inflows and outflows are multiplied by the corresponding flows to yield a quantity corresponding to a mass of the constituent. At any time, the mass of the salt within the bay can be divided by the volume of water in the bay to yield an average TDS concentration for the bay. Because of the lack of spatial variation data for salinity (TDS) within the waters of the bays examined by this study, it was assumed that they are well mixed, or that average salinity conditions prevail throughout the bay being considered.

Stochastic model

A stochastic component was added to the water balance portion of the model for the purpose of examining bay salinity levels for various generated sequences of hydrologic imputs under specified management schemes. Multivariate ARMA(p,q) models of the type discussed by Salas et al. (1980) were considered for use in generating the required time series for simulating the water-budget sequences of Farmington Bay and the East Bay. The three annual time series generated include: 1) pan evaporation at the Bear River Bird Refuge, 2) precipitation depths over the Farmington Bay or East Bay as appropriate, and 3) gaged streamflow consisting of the sum of the Surplus Canal at Salt Lake City and the Jordan River near 500 North in the case of Farmington Bay simulations, and the sum of flows of the Bear River near Corinne, Weber River near Plain City (including Willard Bay spills), and Jordan River combined flows in the case of East Bay simulations. Other components of the total mass-budget equations were estimated from the generated values of these three generated annual time series.

In the case of gaged flows, previous studies have shown that historically gaged flows into the Great Salt Lake are not homogeneous. In other words, flow patterns have changed over time, due mainly to man's activities in the basin (increased storage and diversions). Consequently, to produce a homogeneous times series, adjustments were made to the historical inflow series. Adjustments to current conditions in this study were taken from James et al. (1979). The resulting flow series are estimates of the flows under current conditions of basin development and use regulation. Thus, flows generated by the models developed in this study, are representative of current levels of development. James et al. (1981) indicate that basin conditions have not appreciably changed since about 1965.

Time period utilized for parameter estimations. Because of the somewhat limited extent of many hydrologic data series, it is often necessary to use as much appropriate data as are available in order to obtain reasonably reliable estimates of model parameters. Such is the case with the models developed in this study. The most serious data limitation involved pan evaporation. An evaporation pan in the mouth of the Bear River estuary was established in 1937 (Figure 1). Flow stations near the mouths of the Bear and Weber Rivers were established before this time. Precipitation stations used to estimate rainfall input to the two bays also were established before 1938. Flow records at the Jordan River and Surplus Canal stations were not kept until the 1943 water year. Consequently, the calibration period for the Farmington Bay model begins in 1943. In the case of the East Bay model the calibration period begins in 1938. The 1938 year for the East Bay model was justified on the basis that the Jordan River flows compose a relatively small part of the total gaged inflows to the East Bay, and it was felt that the benefits from including information obtained from the 1938-42 period more than offset the disadvantages of using estimated Jordan River flows for this period.

Another important issue involved determining whether or not to include the data from the 1983-84 period in model calibration (parameter estimation). The statistical distribution of stochastically generated hydrologic time series should adequately reflect the true distribution of the actual time series. However, when only a single historical sample is available, assumptions or estimates must be made concerning the true distribution. One common and fairly versatile distribution used for annual flows is a three-parameter log-normal distribution. In fact, the annual flow series for the Farmington Bay model for the 1943-82 period is well represented by a three-parameter log-normal distribution. However, data for the 1943-84 period are not fit well by any common distribution. Deriving a new distribution to fit the unusual sample is not advisable as it would be attaching too much validity to two data points (1983 and 1984). Other hydrologic records in the area show that flows in these two years are very unusual indeed, and could very well be what might be termed "outliers", that is, they appear to be from a different population than that represented by the data for the 1943-82 period. Consequently, utilizing these two very unusual years would excert a strong influence on the estimated parameters (particularly the time-series variance). For some types of model applications, these two years contain valuable information. However, for the application discussed in this report, it was deemed important to fit the distribution exhibited during the 1943-82 period (or 1938-82 period in the case of the East Bay model) rather than unusual distribution resulting from inclusion of the 1983-84 data. The expected consequences of this decision are that the models likely provide very adequate estimates of typical variations of data series, but might not do as well in predicting extreme high values, such as those exhibited in 1983-84. For the purposes of this application, this decision was considered to result in an appropriate trade-off. For some other applications, a different approach to handling the 1983-84 data might be chosen. The final decision, therefore, was to use the 1943-82 data for estimating parameters for the Farmington Bay model, and the 1938-82 data for estimating the East Bay model parameters.

Model selection. Maximum likelihood estimates of the third parameter in the three-parameter log-normal distributions of the various annual time series were obtained. These estimated values are shown in Table 2. Because of the fact that long time series were not available for estimating model parameters, it was necessary to use a low-order ARMA(p,q) model. Individual analyses of the three annual series showed that an ARMA(1,0) model accounted for most of the time-dependence of each series. This result, plus the better parsimony of an ARMA (1,0) model compared to higher order models, strongly influenced the decision to use an ARMA(1,0) model. Statistically significant cross-correlation between the three annual time series (pan evaporation, precipitation, and gaged streamflow) made the use of multivariate generation techniques important. In summary, a multivariate ARMA(1,0) model was used to generate the three annual time series which in turn are used either directly or indirectly (as described elsewhere in this report) to drive the water and salt budget models. It is important to note that although the model generates annual values, monthly estimates were made on the basis of average distributions into monthly values (Table 1).

Table 2. Maximum likelihood estimates of the third parameter in three-parameter log-normal distributions of annual time series.

	Farmington Bay (1943-82 period)	East Bay (1938-82 period)
Pan evaporation	48 inches	45 inches
Bay precipitation	- 5 inches	3 inches
Gaged streamflow	- 50,000 acre-feet	-450,000 acre-feet

Testing the residuals of the ARMA(1,0) models for independence was performed as outlined in Salas et al. (1980). These test results, although not totally satisfactory, were considered acceptable. The alternative of using a more complex (and consequently less parsimonious) model than ARMA (1,0) was considered to be unacceptable. Longer than available historic data series would make such an alternative more viable and worth testing. However, with the existing data this alternative was considered not to be a viable option.

Quality Studies

Sediment odor microcosms

Four sediment samples were collected from Farmington Bay on April 1 and 3, 1985, for evaluation of odor production potential under fresh water conditions (Figure 3). Sediment samples were drained of overlying water and mixed thoroughly. The consistency of the sediments varied from very fluid with high liquid content to much stiffer sediments with low moisture levels. For each sediment type, 1500 ± 100 ml quantities of sediment were placed in each of four 20 liter glass carboys. On April 5 or 6, two replicate microcosms of each sediment type were filled with water from Farmington Bay and two with water from the Logan River. Logan River water is chemically similar to Weber River water, especially with respect to total dissolved solids and specific conductance. The microcosms were loosely covered with aluminum foil and placed in the dark at 25 ± 2^{o}C. Each microcosm was gently stirred three times a week to prevent the formation of salinity gradients. Samples for odor analysis of the microcosm waters were collected and analyzed on May 22 and 23, 1985.

Because of the complex nature of odor perception, and the lack of sensitive chemical procedures that can be consistently correlated with odor, the production of odors in the microcosms was evaluated using a panel of odor judges to determine odor thresholds (APHA 1981). A panel of 11 judges was selected for their sensitivity to Great Salt Lake sediment odors (Israelsen et al. 1985). On each analysis day panelists evaluated sets of sample dilutions with eight dilutions per set. Within

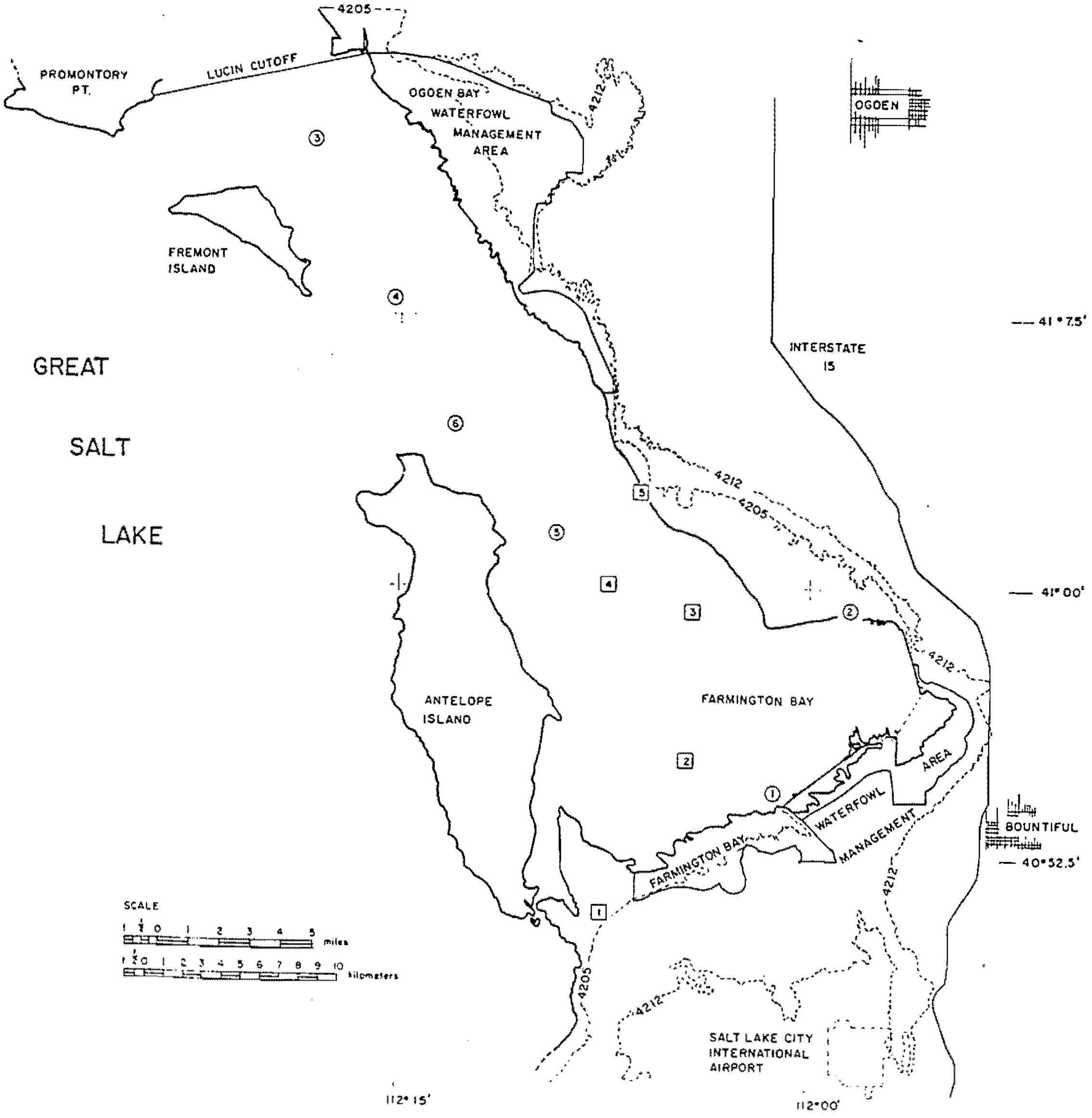


Figure 3. Map of sampling locations for sediments (O) and surface water (□).

each set, two of the flasks contained deionized water (blanks) while the remaining six flasks contained increasing concentrations of odorous water.

Threshold odor number (TON) was calculated as the reciprocal of the dilution of the sample at which odor could be detected. For example, if no dilution of the sample is made the TON is 1, but if a 1:10,000 dilution is made of the sample and the odor is first recognized at that dilution, the TON is 10,000. Six increasing dilutions of the sample surrounding the estimated odor threshold, along with two randomly positioned unidentified blanks and a known reference blank, were presented to the panelists in glass stoppered 500 ml flasks at room temperature. Panelists swirled each sample, removed the stopper, sniffed the vapors and then noted if the sample smelled like pure water or if it had any other detectable odor. Samples within each set were evaluated in order of increasing concentration. Ten or eleven sets of samples were evaluated during each panel session.

Individual threshold values were tabulated and the percentage was calculated of panelists who could correctly smell an off-odor at each concentration. The percent correct was plotted against the TON values for each concentration. The point where 50 percent of the panelists could detect an odor was considered the threshold for that sample and designated as the TON_{50}.

Odor of Farmington Bay

Five water samples were collected from Farmington Bay on May 22, 1985, for odor evaluation, analysis of chlorophyll a, and identification of dominant algal species (Figure 3). Odor analysis was done as described for the odor microcosms above. Chlorophyll a was analyzed by fluorometry (APHA 1981) in methanolic extracts of algae concentrated on glass fiber filters. Microscopic identification of algae followed the work of Felix and Rushforth (1979).

Sediment core salinity and nutrient release

Sediment core samples were collected by scuba divers from six sites in Farmington Bay on April 1 and 3, 1985, using acrylic tubes 1.5 inches (3.8 cm) by 18 inches (45.7 cm) in length (Figure 3). Sediment height and volume of the overlying water column were recorded. Overlying water was aspirated from each column and Weber River replacement water was added to within approximately 4 cm of the top of the acrylic tube.

Six replicate cores of each sediment type were set up on April 8, 1985, in a room controlled to 12 ± 2°C. Three replicate cores of each type were maintained aerobic ("oxic") by bubbling with water saturated air. Oil and particulates were removed from the air stream by filtering through granular activated charcoal. Flow of air was controlled by aquarium-type air valves connected to tygon tubing with pasteur pipets whose tips extended about halfway down the overlying column of Weber River water. The three remaining replicate cores for each sediment type were made anaerobic ("anoxic") and were stoppered and purged with high-purity, compressed nitrogen gas at set up and at each sample event. All cores were incubated in the dark.

Samples of water above the sediment cores were collected every three days beginning April 9 and continuing through April 24. Samples were then collected every five days through May 14, 1985. On each sample day, about 75 ml of water was collected from each core tube and replaced with an equivalent volume of Weber River water.

Water samples were analyzed for orthophosphorus, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, total dissolved solids, and specific conductance. All analytical procedures were in accordance with standard methods (APHA 1981) with the exception of total nitrogen which was analyzed by persulfate digestion with subsequent analysis of nitrate-nitrogen (Solorzano and Sharp 1980). Amendments to procedures were made to accommodate the small sample size. Most sample volumes used for analyses were 10 ml.

Salinity (TDS), mineral nitrogen, and phosphorus flux from or into the sediments were measured by calculating the change in mass for each constituent over time.

Sediment pollution

One sediment core from site 1 near the mouth of the Salt Lake Sewage Canal and one core from site 2 west of Farmington in Farmington Bay (see Figure 3) were divided into 1 cm sections. A portion of each section was extracted with deionized water for heavy metals analysis. This extraction was performed at a weight to volume ratio of 1:50. The slurried sediment was extracted on an orbital shaker at 200 rpm for 24 hours at room temperature. These extraction conditions simulate worst case conditions for the release of metals from the sediment under freshwater conditions. The sediment slurries were centrifuged at 600 g's for 10 minutes and the supernatant was analyzed for As, Cd, Cr, Cu, Pb, and Zn by atomic absorption or plasma emission spectroscopy.

Results

Salinity release from sediments

As salinity in the water decreases with inputs of freshwater to Farmington Bay or the East Bay, salinity stored in the sediments will diffuse into the overlying water, and add to the mass of salts that must be removed from the bays to accomplish freshening. The flux of salinity (TDS) from Farmington and East Bay sediment cores over time when exposed to fresh water is shown in Figure 4. Flux rates were high initially while the concentration gradient was highest, but decreased as expected, as the gradient decreased and the release of salinity from the sediments was limited by diffusion of the soluble salts from an increasing sediment depth. Based on a diffusion coefficient of 1.08 k/m^2/day estimated from data taken in the initial period of this study, the average soluble salt concentration in the sediments (56 kg/m^3), and an "active" sediment depth of 15 cm, the hydro-salinity model predicts that

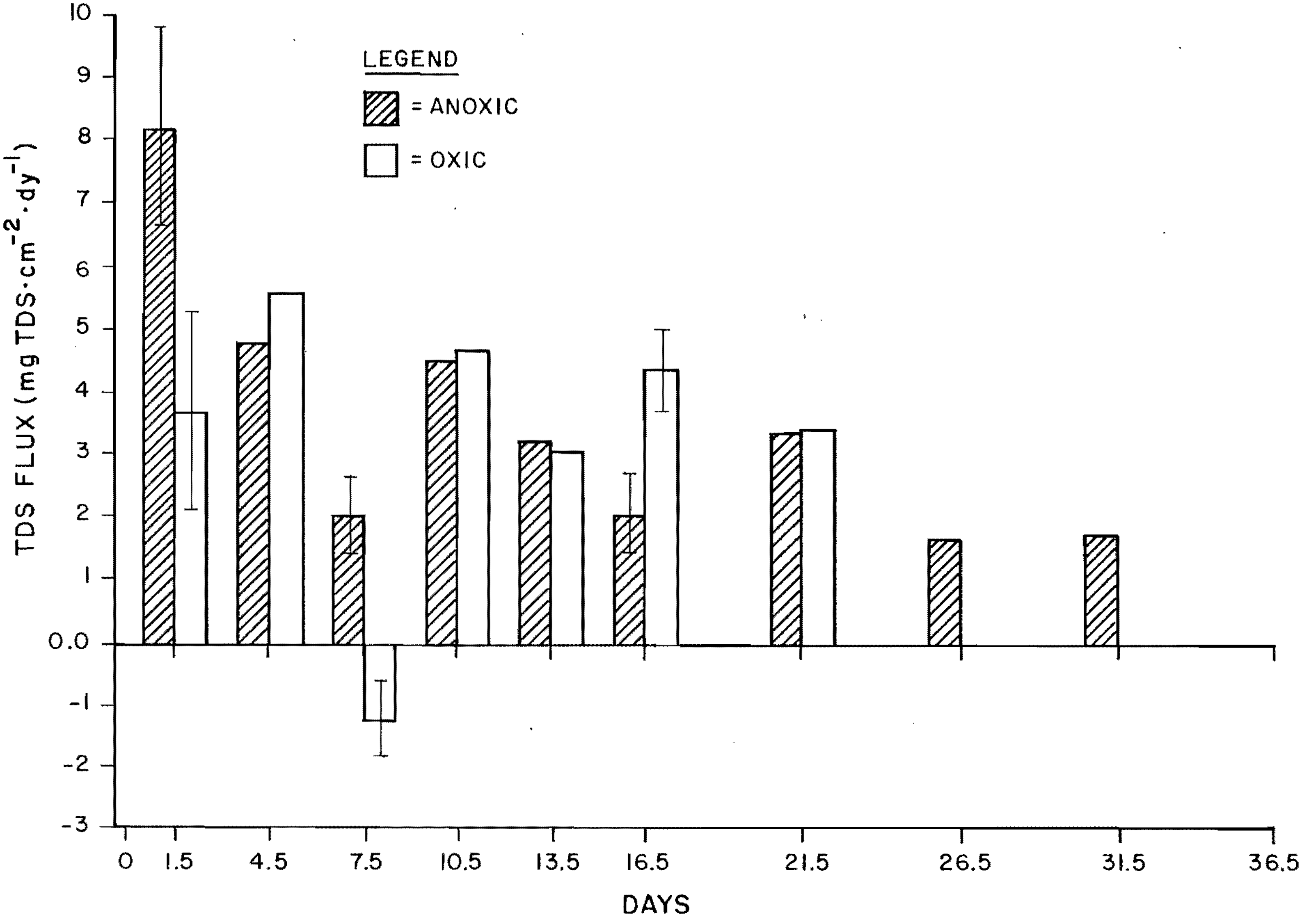


Figure 4. Salinity flux from Farmington Bay and East Bay sediments incubated under aerobic (oxic) and anaerobic (anoxic) conditions. Error bars are shown where significant differences occur and represent the least significant difference between treatments.

an appreciable influence of the sediment salinity release will extend only two or three years into the freshening process.

Sanitary quality

With the loss of access to Great Salt Lake State Park due to the inundation of the Syracuse-Antelope Island causeway, and increased use of Farmington Bay for recreation, Davis County Health Department personnel analyzed samples of Farmington Bay water for fecal pollution indicator bacteria in the summer of 1983. The results of their analyses are shown in Table 3. The apparent absence of fecal coliforms in most samples, with relatively lower number of fecal streptococci in others, suggests that the health hazard from fecal pollution in Farmington Bay is low. The presence of fecal streptococci in the absence of fecal coliforms could suggest that the source of the fecal streptococci is from animal life, such as waterfowl (APHA 1981). However, the number of organisms is too low and too little is known about the relative survival of fecal coliforms and fecal streptococci in Farmington Bay water to place much confidence in the use of the fecal coliform: fecal streptococci ratio (APHA 1981) as an indicator of the source of fecal pollution.

Sediment pollution

Earlier observations of the distribution of biological productivity in Farmington Bay have noted relatively low production in the vicinity of the Salt Lake Sewage Canal entrance to the bay (McDonald and Garifin 1965, and Bott and Shipman 1971). Israelsen et al. (1985) observed low algal production in sediment-water laboratory microcosms which contained sediment taken in the vicinity of the Sewage Canal. These results are surprising in light of the relatively high amounts of nutrients entering the bay through the Sewage Canal, and suggest that toxic factors may limit production in that area of the bay. A sediment core taken at about 4200 feet elevation in this area (Sediment 2, Figure 3) was examined for water soluble heavy metals and the results were compared to a sediment core taken west of Farmington (Sediment 1, Figure 3). The results of these analyses are shown in Table 4. Relative to the sediment core taken west of Farmington, the sediment taken near the Sewage Canal showed elevated concentrations of cadmium, chromium, copper, lead, and zinc at all depths examined. It is not clear that the observed toxicity is due to these soluble metals, but the toxicity of copper to algae, for example, is well known. It is not known what concentrations of these metals may result in the overlying water column in either salt water or fresh water conditions. The appearance and odor of the sediment core from near the Sewage Canal suggests that industrial organic wastes might also pollute these sediments. The time constraint of the current study did not allow investigation of this possibility.

Eutrophication and odor production

Samples taken throughout Farmington Bay on May 22, 1985, had cholorophyll a concentrations indicative of a mesotrophic condition (Tables 5 and 6) and were visibly green. Very little odor was associated with the water, indicating that odor problems are not

Table 3. Fecal pollution indicator bacteria concentrations in Farmington Bay surface water. (Data courtesy of Davis County Health Department.)

Date		Water Temp.	Fecal strep.	Fecal Coliforms
			#/100 ml	
8/3/83	FBR* Boat Launch	25°C	400	<1
	2 mi W. of Boat Launch	30°C	<1	<1
	4 mi W. of Boat Launch	30°C	<1	<1
	6 mi W. of Boat Launch	31°C	100	<1
	8 mi W. of Boat Launch	30°C	100	<1
	Bird Refuge Outflow	24°C	100	6
6/21/83	Near Antelope Island		-- <1	
	Mid Syracuse Causeway		-- <1	

*FBR = Farmington Bird Refuge

Table 4. Water soluble metals concentrations in Farmington Bay sediments.

Sediment	Depth(cm)	As	Cd	Cr	Cu	Pb	Zn
		--- µg/g ---					
1 (near Sewage Canal)	1	0.30	0.08	0.13	1.87	0.02	1.34
	2	0.39	0.07	<0.10	2.04	0.03	1.12
	3	0.34	0.11	0.12	1.62	0.01	1.58
	4	0.46	0.08	0.21	1.44	0.05	1.85
	5	0.70	0.09	0.26	1.33	0.11	2.12
	6	0.61	0.05	0.22	1.17	0.03	1.01
	7	0.90	0.08	0.20	1.84	0.12	1.30
	8	0.78	0.05	0.19	1.24	0.02	0.51
2 (W. of Farmington)	1	0.53	<0.04	<0.10	0.32	<0.01	0.24
	2	0.31	<0.04	<0.10	0.05	<0.01	<0.04
	3	0.26	<0.04	<0.10	<0.04	<0.01	<0.04
	4	0.34	<0.04	<0.10	0.08	<0.01	0.06
	5	0.32	<0.04	<0.10	0.04	<0.01	<0.04

Table 5. Limnological classification of trophic status of lakes and reservoirs (Jones and Lee 1982).

Classification	Average Planktonic Algal Chlorophyll ($\mu g\ l^{-1}$)	Average Secchi Depth (m)	Average in Lake Total Phosphorus ($\mu g\ l^{-1}$)
Oligotrophic	<2.0	>4.6	<7.9
Oligotrophic - mesotrophic	2.1-2.9	4.5-3.8	8-11
Mesotrophic	3.0-6.9	3.7-2.4	12-27
Mesotrophic - eutrophic	7.0-9.9	2.3-1.8	28-39
Eutrophic	≥10	≤1.7	≥40

Table 6. Chlorophyll *a* concentrations, dominant algae, and threshold odor numbers of (TON$_{50}$) Farmington Bay water collected May 22, 1985.

Sample Site	Chlorophyll *a* μg/ℓ	Dominant Algae	TON$_{50}$
1	4.1	*Oocystis parva* or *Carteria spp.*, *Nitzschia acicularis* *Dunaliella viridis* *Nitzschia palea*	12
2	6.0	*Dunaliella viridis* *Spermatozoopsis exultans* *Nitzschia acicularis*	7
3	4.1	*Dunaliella viridis* *Nitzschia acicularis* *Oocystis parva* or *Carteria spp*	3
4	5.0	*Spermatozoopsis exultans* *Dunaliella viridis* *Nitzschia acicularis*	14
5	1.9	*Dunaliella viridis* *Nitzschia acicularis* *Spermatozoopsis exultans* *Coccochloris elabens?*	30

produced by the algal flora and concentrations of algae observed. Algae concentrations in Farmington Bay increase significantly as the waters warm through the summer. It is noteworthy that the strongest odor level observed in the May 22 samples was associated with the sample taken from the recently inundated marshes near the shore (site 5).

Reduction of the osmotic potential of the water and sediments as the bays freshen will allow increased biological activity. Decompositon rates probably will increase as a broad spectrum of microorganisms become established in the sediments and water, and the potential for serious odor production will develop.

Israelsen et al. (1985) identified odorous compound production in anaerobic sediments taken from Farmington Bay near the Sewage Canal and from inundated marsh areas as potential sources of nuisance odors associated with Great Salt Lake. Objectionable odors also were associated with concentrated blue-green algae (Nodularia spumigena) production in laboratory sediment-water microcosms, and a review of the literature indicated that odor production from decay of brine flies and the products of their life cycle is probably important. Near the end of the laboratory experiments, there was some indication that more serious sediment odors developed where low salinity water was placed over the sediments (Israelsen et al. 1985). Odor production was evaluated from different sediments incubated under either Logan River water or Farmington Bay water. The results of this experiment after 7 weeks of incubation are shown in Table 7. Odor levels were lower than those reported by Israelsen et al. (1985), and show little difference in the intensity of odor produced between freshwater and Farmington Bay water. A notable exception is the consistently high odor threshold found for sediments collected near the Ogden Bay Waterfowl Management Area. Odor produced in this inundated marsh sediment averaged more than twice the intensity produced under Farmington Bay water when freshwater was placed over it. Apparently, sediments high in organic matter can produce more intense odors under freshwater conditions than under saline conditions, but the extent of these kinds of sediments might be somewhat limited, especially if the bays are controlled at elevations below the marsh areas.

As salinity is decreased in the bays, and osmotic stress is removed, algae production will be limited only by nutrient availability, light, and grazing. Algae rich, eutrophic water bodies are generally considered to be undesirable. Dissolved oxygen can be depleted during dark hours when the algae are respiring, and odor problems can develop either from the algae themselves or as they decompose. The appearance of algae laden water is objectionable, and treatment costs for producing water usable in municipal and industrial applications are increased.

Most predictions of eutrophication potential in lakes and reservoirs rely on total phosphorus loading to the water body since phosphorus often is the nutrient limiting algal growth. Total phosphorus loads to Farmington and East Bays were estimated using annual average total phosphorus concentration data collected by the Utah Department of Health, Bureau of Water Pollution Control, between 1980 and 1984 for both gaged and ungaged streams entering the bays, and

Table 7. Odor levels produced in eastern Great Salt Lake sediment microcosms containing river water or Farmington Bay water.

		TON_{50}*	
Sediment Source	Replicates	Logan River**	Farmington Bay **
Near Salt Lake Sewage Canal	a	$\geq$1600.	$\geq$800.
	b	250.	233.
West of Farmington	a	10.	9.
	b	13.	11.
West of North Davis WWTP	a	600.	879.
	b	500.	1120.
Near Ogden Bay Waterfowl Refuge	a	$\geq$1600.	69.
	b	1500.	745.

*TON_{50} - Threshold Odor Number: The water dilution at which 50 percent of the panelists could detect an odor, i.e. 1:1600 = 1600.

**Source of water over eastern Great Salt Lake sediment.

Table 8. Estimated phosphorus loading and predicted mean summer chlorophyll *a* concentrations in Farmington Bay and the East Bay.

Area	Elevation (ft.)	Areal Phosphorus Load (mg P m^{-2} yr^{-1})	Mean Chlorophyll *a* (µg/ℓ)
Farmington Bay	4200	3,240	100
	4206	300	35
East Bay	4200	2,000	80
	4206	1,400	60

average stream flows from historical data. Groundwater inputs were ignored. The estimated areal phosphorus loads for bay elevations of 4200 and 4206 ft are shown in Table 8. The empirical model (Jones and Lee 1982) which uses phosphorus load, water depth, and mean residence time information, predicts serious eutrophication problems for both bays at both elevations. The least serious problems are likely to develop in Farmington Bay when the water level is maintained at 4206 ft elevation, but the predicted chlorophyll a concentrations are still more than three times the commonly accepted eutrophic level.

In many lakes and reservoirs the release of nutrients from the sediments has an appreciable impact on the amount of algal production the water body will support. Large amounts of phosphorus can be released from some sediments under anaerobic or reducing conditions. The flux of nutrients from Farmington and East Bay sediments under aerobic and anaerobic incubation conditions is illustrated in Figures 5, 6, and 7. Generally, sediments removed orthophosphorus, ammonium, and nitrate nitrogen from the overlying water under both aerobic and anaerobic conditions. Occasionally there were significant differences between sediment samples in the fluxes of some nutrients between the water and the sediment, but no one sample was consistently significantly different from another. There appears to have been a tendency for nutrient uptake rates by sediments to decrease throughout the experiments, and anaerobic sediments were releasing ammonium nitrogen at the end of the experiment. This pattern suggests that nutrient uptake was due to nutrient immobilization as organic matter made available from disturbing the sediments or from changing the salinity was decomposed. If these experiments were continued, additional nutrient release from the sediments might be observed. The role of the sediments in impoundment nutrient dynamics and hence eutrophication potential is unclear, but there does not appear to be a potential for immediate release of nutrients from the sediments simply because of freshening the overlying water.

Eutrophication and odor production problems in the proposed impoundment areas appear to have become increasingly severe as southern Great Salt Lake waters have freshened (Gillespie and Stephens 1977, Rushforth and Felix 1982, Israelsen et al. 1985), and nutrient loading coupled with impoundment morphometry lead to the prediction that eutrophication problems are likely to be worse under freshwater conditions. In contrast, it seems reasonable to propose that these problems might be ameliorated by increasing the salinity of these waters and maintaining the salinity high enough to achieve a "pickling" effect which would limit the spectrum of organisms that could grow in these areas. It is not likely that the aesthetics and recreational value of a pristine freshwater environment could be achieved in such a nutrient and organic matter rich water body, but a more aesthetically acceptable resource is likely to develop in a hypersaline environment. To achieve the desired effect, salinity concentrations in excess of 10 percent would need to be maintained, since algal production is apparently limited to *Dunaliella viridis* and *D. salina* above this concentration (Gillespie and Stephens 1977, Post 1980). Blooms of these eucaryotic flagellated algae apparently have not been associated with nuisance odor problems, but they do color the water and serve as food for brine shrimp

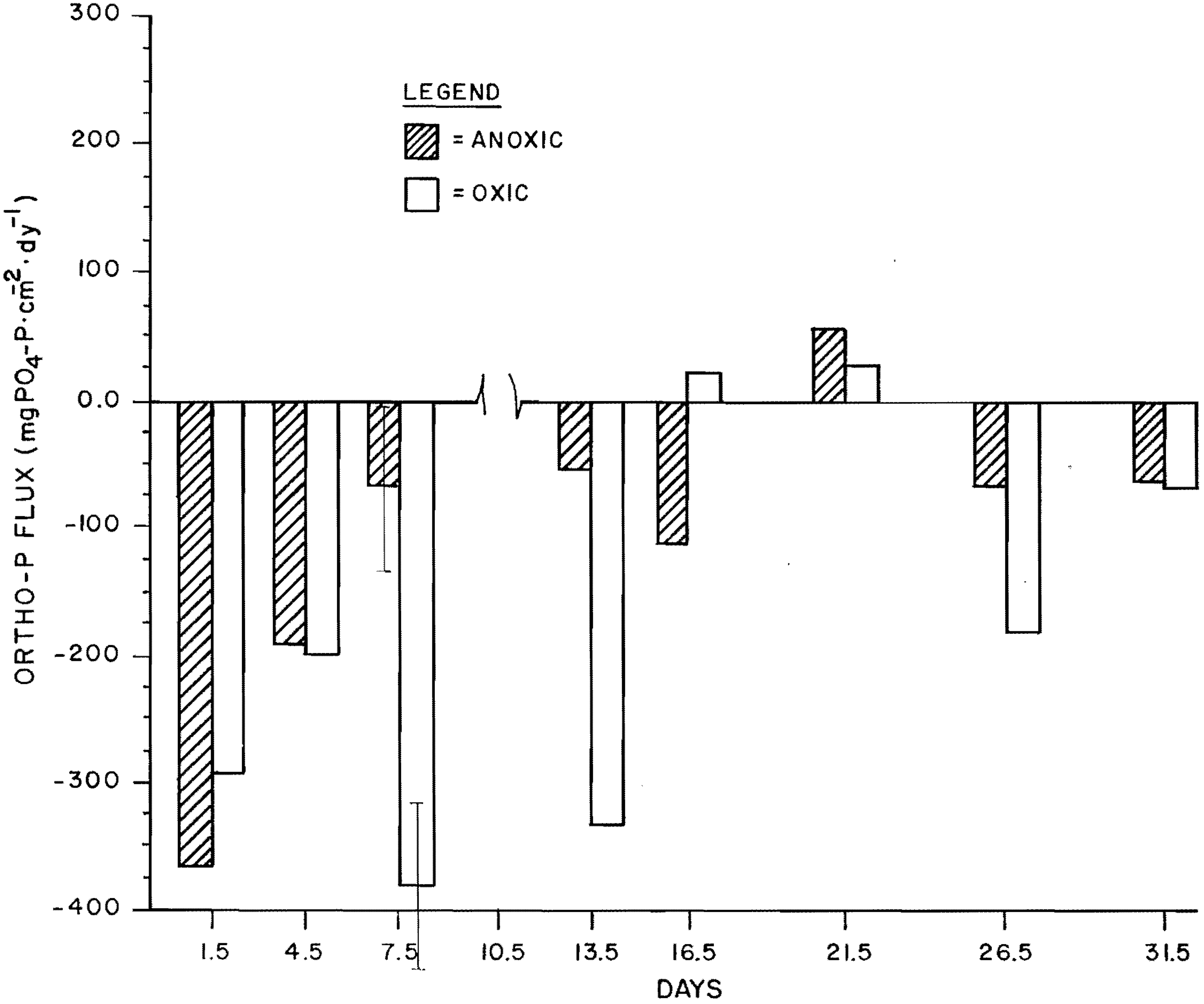


Figure 5. Orthophosphorus flux from Farmington and East Bay sediments under aerobic (oxic) and anaerobic (anoxic) conditions. Error bars are shown where significant differences occur and represent the least significant difference between treatments.

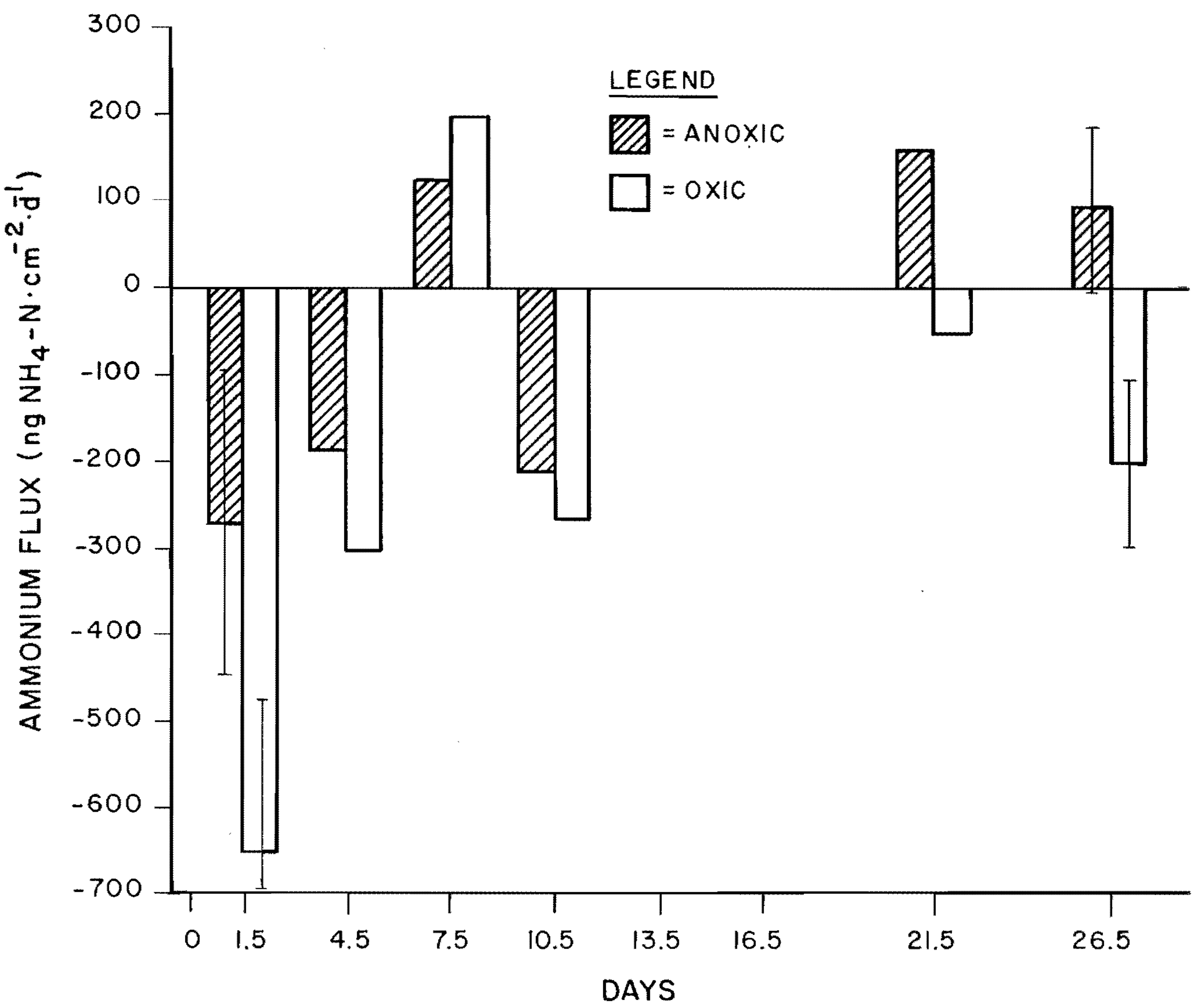


Figure 6. Ammonium flux from Farmington and East Bay sediments under aerobic (oxic) and anaerobic (anoxic) conditions. Error bars indicate the least significant difference between treatments, and are shown only where a significant difference occurs.

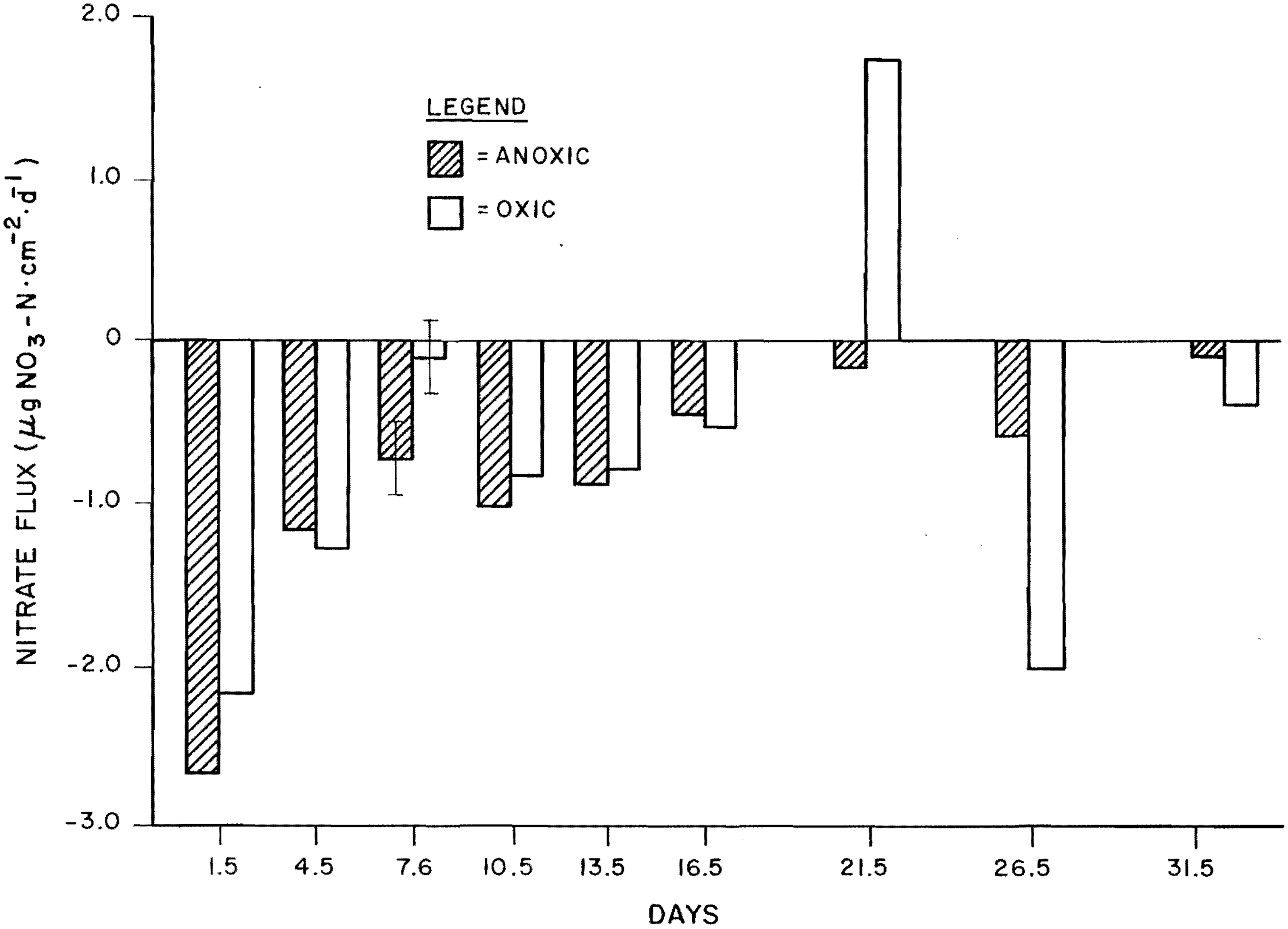


Figure 7. Nitrate flux from Farmington and East Bay sediments under aerobic (oxic) and anaerobic (anoxic) conditions. Error bars are shown where significant differences occur and represent the least significant difference between treatments.

and brine flies. In general, much more information is needed to predict with confidence the quality of the water resource that could be developed in the proposed impoundments.

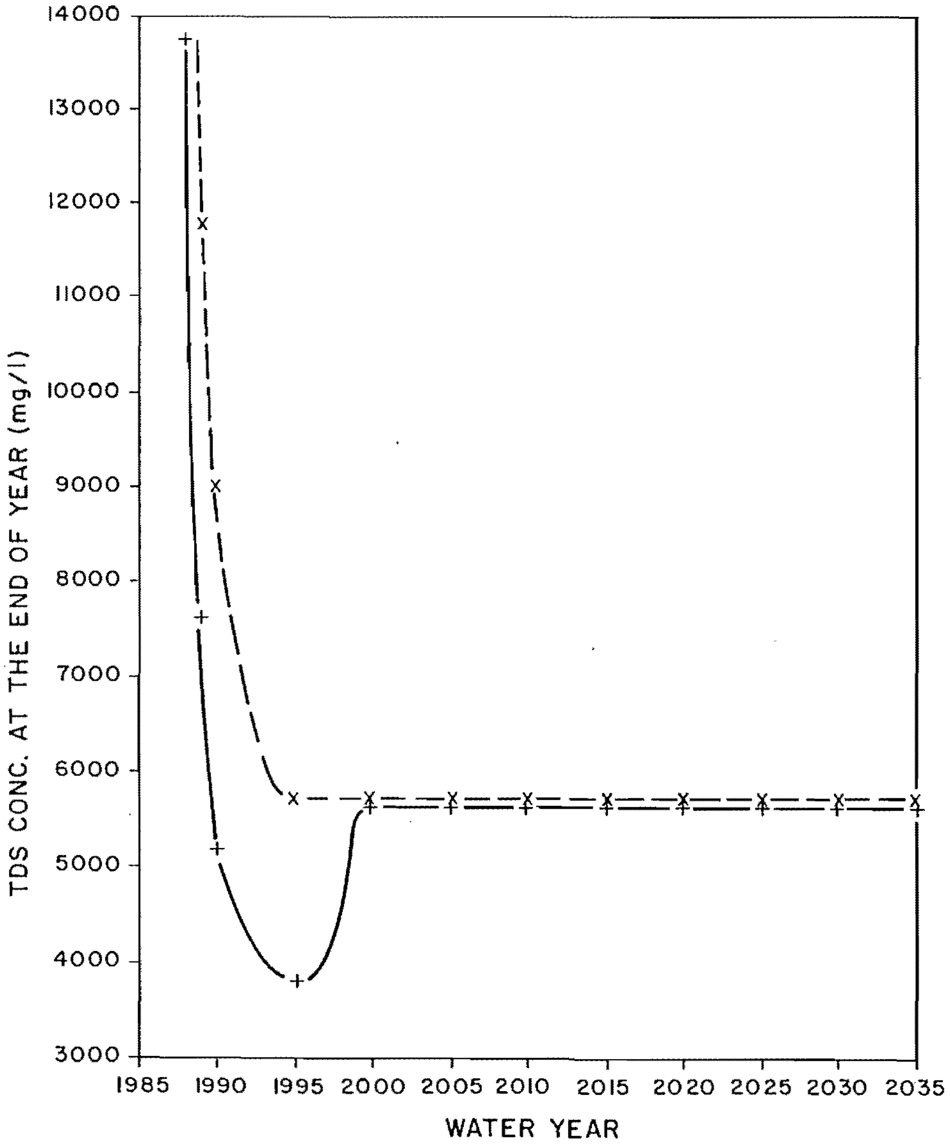
The hydro-salinity model

The computer model was used to determine the expected water surface elevations and salinity levels for various management alternatives. For the Farmington Bay impoundment, it was assumed that water could be imported from the Weber River, and that a portion of the Jordan River flows could be excluded from the system if desired by diversions through the Surplus Canal into the Goggin Drain which discharges directly into the main lake (Figure 1). These diversions are limited by two constraints, namely: (1) the Goggin Drain capacity (assumed to be 1000 cfs for this study), and (2) a minimum discharge of 500 cfs from the Lower Jordan River system to the Farmington Bay area as required by existing water rights. This latter condition cannot, of course, be met when Jordan River flows are less than 500 cfs. During periods when the surface level of the impounded water is less than that of the main lake, pumping from the impoundment is necessary and exports reduce the pumping costs. For some computer trials, a third export constraint was added, namely, that diversions through the Goggin Drain occur only when the salinity of the Jordan River is higher than that of the impounded waters. In actual fact, this constraint was rarely met, so that exports under this mode of operation were negligible. Flushing through the impoundment is, of course, somewhat increased, but so are pumping costs during those periods when pumping is needed.

Discharge volumes from the impoundment areas to the main lake are a function of pump capacity (or weir crest length) and the elevation of the water control level within the impoundment. Computer runs were made for both the pump and weir forms of level control. As might be expected, the only difference between the two sets of results is that fluctuations of the impounded water surface elevations are somewhat less for pumping than for weir control. Thus, only the results for pumping are included in this report. In actual practice both forms of control (that is, pumping and a gravity flow device, such as a weir or siphon) would be installed to accommodate the differences in the relative water surface elevations which would occur across the dike during the life of the project.

Farmington Bay. Figure 8 shows time traces of average annual salinity values within the bay at exceedence probabilities of 50 percent (median values) and for control elevations of 4200.5 feet and 4205.0 feet msl. In each case, the assumed discharge pumping capacity is 1000 cfs. For both traces, exports from the Jordan River through the Goggin Drain occurred when the surface level of the impounded waters exceeded the control elevation, provided, of course, the river flow rate exceeded 500 cfs. There were no imports of water from the Weber River for either of the two cases illustrated.

Because a greater degree of flushing occurs for the low control elevation (4200.5 feet) than for the high control elevation (4205 feet), freshening is more rapid for the low control than for the high



Legend

\+ Control elevation = 4200.5 feet amsl

x Control elevation = 4205.0 feet amsl

Notes

1) Pump capacity for discharge to the main lake = 1000 cfs.

2) Minimum discharge rate from the Jordan River to Farmington Bay as limited by water rights requirements = 500 cfs.

3) Capacity of the Goggin Drain = 1000 cfs.

4) Exports from the Jordan River through the Goggin Drain occur when the impounded water surface level exceeds the control elevation. Export rates are limited by the constraints of items (2) and (3).

5) No imports from the Weber River are assumed to occur.

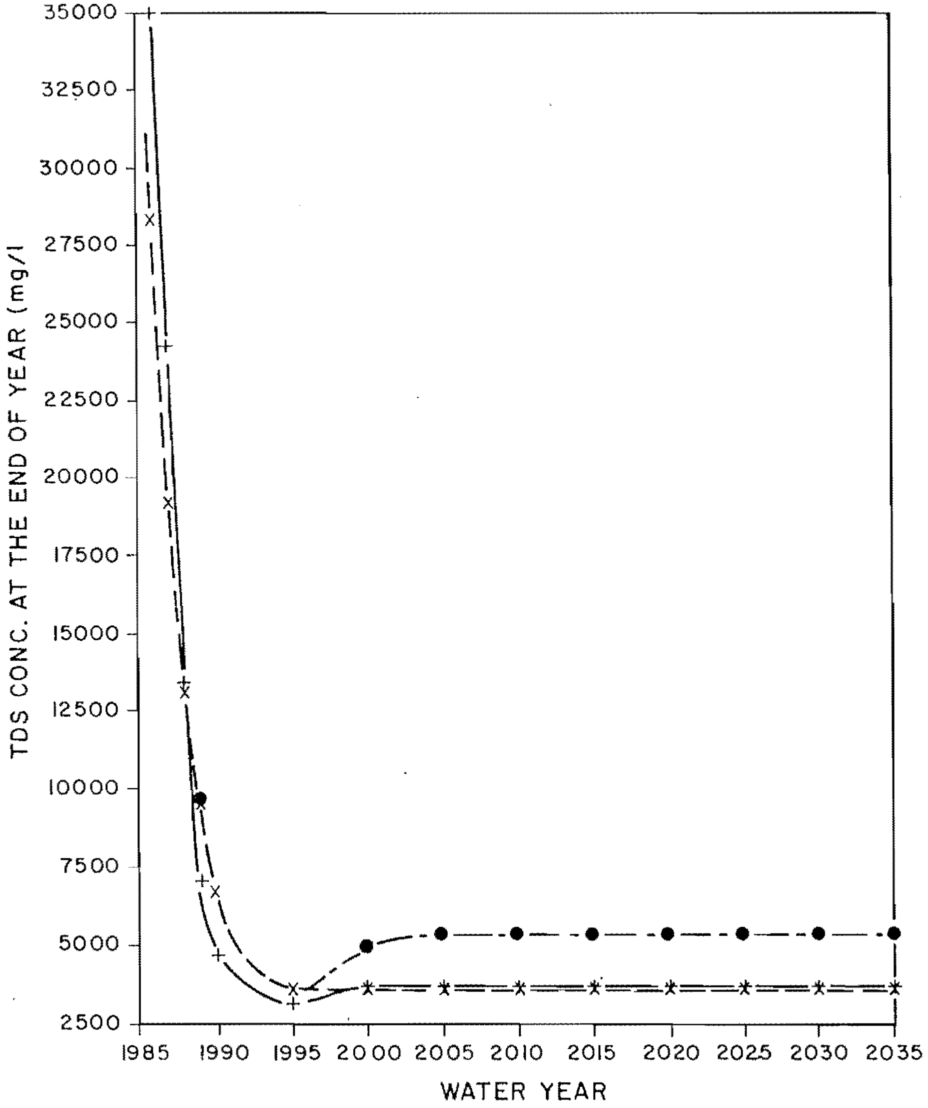
Figure 8. Projected most likely end of water year salinity concentrations in Farmington Bay.

control. In both cases flushing of the salt accumulations within the bottom sediments occurs during the first two or three years of the project operation. For the low control case, the significant dip in the curve between the water years 1990 and 2000 results from higher than average water supply years during the initial stages of the project. This situation reflects the effects on the model results of the high initial conditions represented by those projected for October 1, 1985. As might be expected, the equilibrium or long-term position for the low control trace is somewhat less than that of the high control trace, but the difference between the two is not significant. For each case, the average equilibrium salinity of the bay is estimated to be approximately 5600 mg/l.

Figure 9 shows three salinity traces for a control level of 4200.5 feet amsl. In each case long-term salinity equilibrium was reached after a period of about 20 years from the beginning of the project. The highest equilibrium salinity (about 5300 mg/l) represents management conditions of "no imports" and exports through the Goggin Drain subject to the three constraints outlined above. It is interesting to compare the equilibrium level of this curve (5300 mg/l) with that for the 4200.5 feet control elevation of Figure 2 (about 5600 mg/l). The results shown by this plot were not subject to the quality constraint for exports through the Goggin Drain. The slightly improved quality indicated by the corresponding plot of Figure 10 results from the additional flushing of the system under the three export constraints.

The two lower curves of Figure 9 include the effects of imports to the bay from the Weber River at Plain City. These imports are subject to two constraints, namely: (1) an assumed conveyance canal capacity of 300 cfs, and (2) a maximum diversion of 75 percent of the flow in the Weber River at Plain City. The remaining flow was left in the main channel to meet water requirements in the Ogden Bay Waterfowl Management Area. The only management difference represented by these two plots is that in the one case the three export constraints were applied for the Goggin Drain, while in the other the quality constraint (number 3) was not used. Although the differences of approximately 200 mg/l in the equilibrium salinity levels for the two traces is not significant, the lower curve at about 3500 mg/l does represent the conditions of increased flushing resulting from the application of the three export constraints to the Goggin Drain. The equilibrium salinity levels shown by both of these curves reflect the freshening effects of importing high quality water to the bay from the Weber River system.

Figure 10 shows two salinity traces for a control level of 4205.0 feet msl. For both cases, there were no imported flows from the Weber River and the three constraints applied to exports through the Goggin Drain. The only difference between the two results is the calibration periods used in the model (1943 to 1982 and 1938 to 1984), with the lower curve reflecting the results of including the recent wet years in the calibration (1983 and 1984). The equilibrium salinity levels for the two plots closely agree, and are approximately the same as that for the highest curve of Figure 9 (approximately 5300 mg/l).



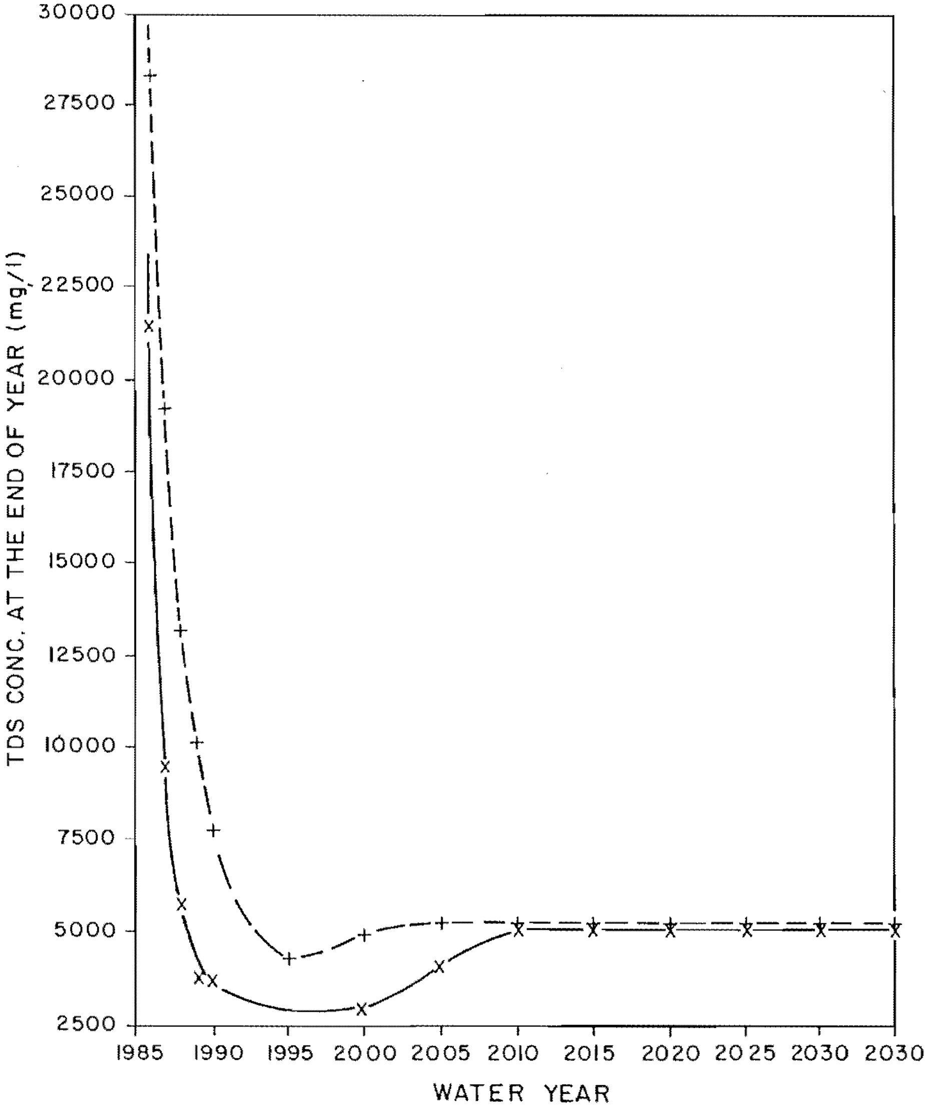
Legend

- 0 salinity constrained exports, no imports.
- X imports from Weber River, salinity constrained exports.
- \+ imports from Weber River, exports not constrained by water salinities.

Notes

1. Pump capacity for discharge to the main lake = 1000 cfs.
2. Control elevation = 4200.5 feet msl.
3. Minimum discharge rate from the Jordan River to Farmington Bay as limited by water rights requirements = 400 cfs.
4. Capacity of the Goggin Drain = 1000 cfs.
5. Water is exported from the Jordan River through the Goggin Drain only when the salinity of the river higher than that of the impounded waters.
6. Exports from the Jordan River occur through the Goggin Drain when the impounded water surface level exceed the control elevation, subject to the constraints (2), (4), and (5) above and as specified by the Legend.
7. For imports from the Weber River, a canal capacity of 300 cfs was assumed. A further constraint on Weber River diversions is a maximum of 75 percent of the flow available in the river at Plain City, Utah.

Figure 9. Projected most likely end of water year salinity concentrations in the Farmington Bay.



Legend

+ calibration period 1943 to 1982

X calibration period 1938 to 1984

Notes

1. Pump capacity for discharge to the main lake = 1000 cfs.
2. Control elevation = 4205.0 feet msl
3. Minimum discharge rate from the Jordan River to Farmington Bay as limited by water rights requirements = 500 cfs.
4. Capacity of the Goggin Drain = 1000 cfs.
5. Water is exported from the Jordan River through the Goggin Drain only when the salinity of the river is higher than that of the impounded waters.
6. Exports from the Jordan River through the Goggin Drain occur when the impounded water surface level exceeds the control elevation, subject to the constraints of items (2), (3), and (4) given above.

Figure 10. Projected most likely end of the water year salinity concentrations in the Farmington Bay.

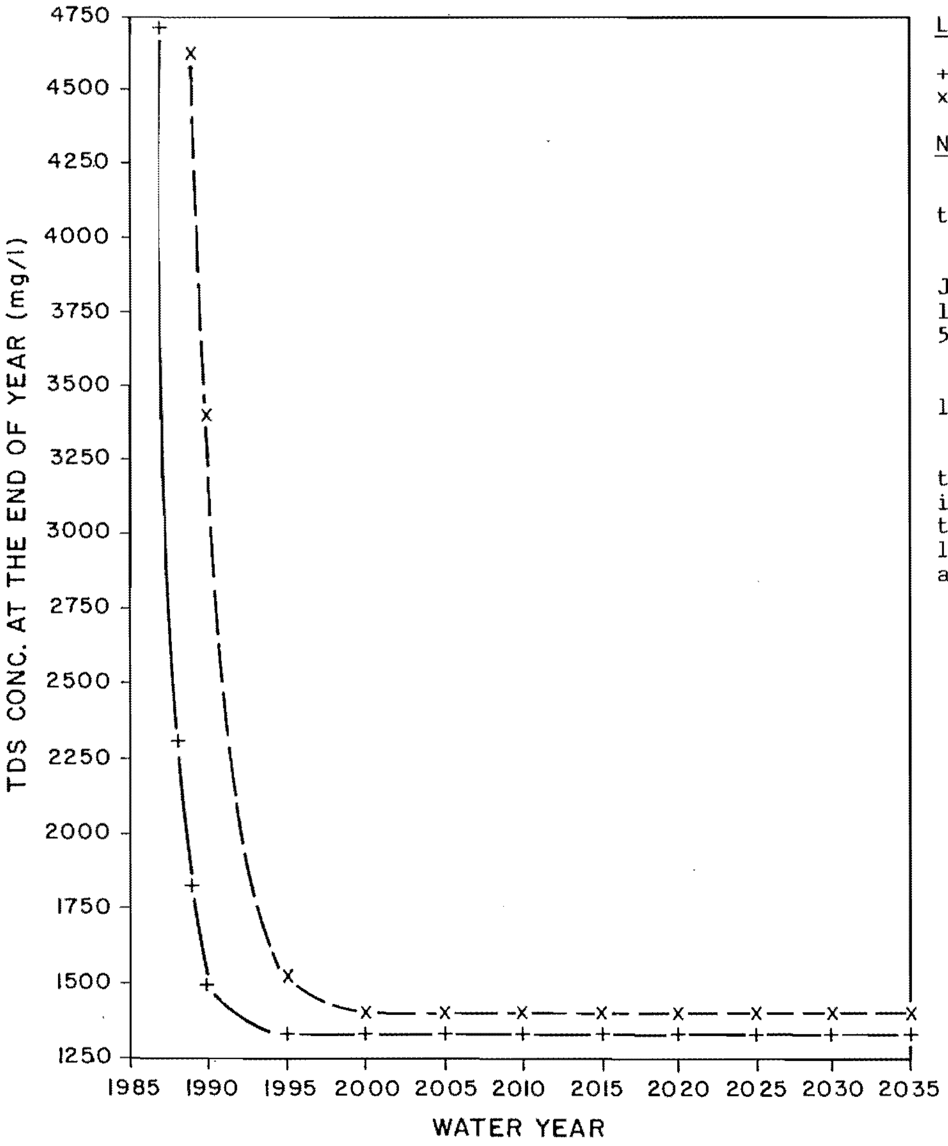
East Bay. Figure 11 shows for the East Bay impoundment the same time traces as Figure 8, namely, average end of water year salinity values within the bay at exceedence probabilities of 50 percent (median values) for control elevations of 4200.5 feet and 4205.0 feet msl. The pumping capacity for discharge from the bay to the main lake was assumed to be 8000 cfs. Exports through the Goggin Drain were assumed to be constrained in the same manner as those for Farmington Bay. Again, because of the increased flushing, the trace for the low control elevation shows consistently lower salinity levels than that for the high control elevation. Because of the large inflow volumes from the Bear, Weber, and Jordan Rivers, flushing occurs rapidly in both cases, so that there is no sign of the dip which occurred in the low control level trace for Farmington Bay (Figure 8). The long-term or equilibrium salinity value for the low control level is about 1350 mg/l and for the high control the value is approximately 1400 mg/l. While these values are suitable for waters used for recreation and irrigation of some salt tolerant crops, they are too high for municipal and many industrial uses without either costly treatment or mixing with higher quality water.

Figure 12 shows four salinity traces, two of which are for a control level of 4200.5 feet msl and the remaining two are for a control elevation of 4205.0 feet. The only management difference between the two sets of plots at each control elevation is that for one curve at each elevation only the two quantity constraints were used to govern exports from the Jordan River through the Goggin Drain, whereas for the other curve the additional quality constraint also was applied. Under this constraint water is exported only when the salinity of the Jordan River waters exceeds that of the East Bay. As might be expected, this constraint is met somewhat infrequently but more often than for the Farmington Bay impoundment. In the case of Farmington Bay, the difference between the equilibrium salinity levels for the two plots (see Figures 8 and 9) is about 300 mg/l, with the lower of the two curves (Figure 9) reflecting the effects of the increased flushing resulting from the application of the quality export constraint. For the East Bay, the effects of the additional Jordan River flushing under this constraint are essentially negligible because of the large volumes of low salinity inflows from the Bear and Weber Rivers. In fact, for the 4205.0 feet control elevation the two curves are essentially coincident in the equilibrium salinity range. At this control elevation flushing is somewhat less so that the time required to reach the equilibrium salinity condition is somewhat longer for the higher than for the lower control elevation.

Summary

Farmington Bay

Based on the results of the studies reported herein, it appears that Farmington Bay cannot be turned into a freshwater lake by merely stopping the flow of brines from the Great Salt Lake into the bay. The effect of natural concentration due to evaporation from the normally large surface area of the bay is sufficient to keep the bay at salinity levels generally not considered suitable for freshwater use. For the management alternatives examined, it was found that the bay could be



Legend

+ Control elevation = 4200.5 feet amsl
x Control elevation = 4205.0 feet amsl

Notes

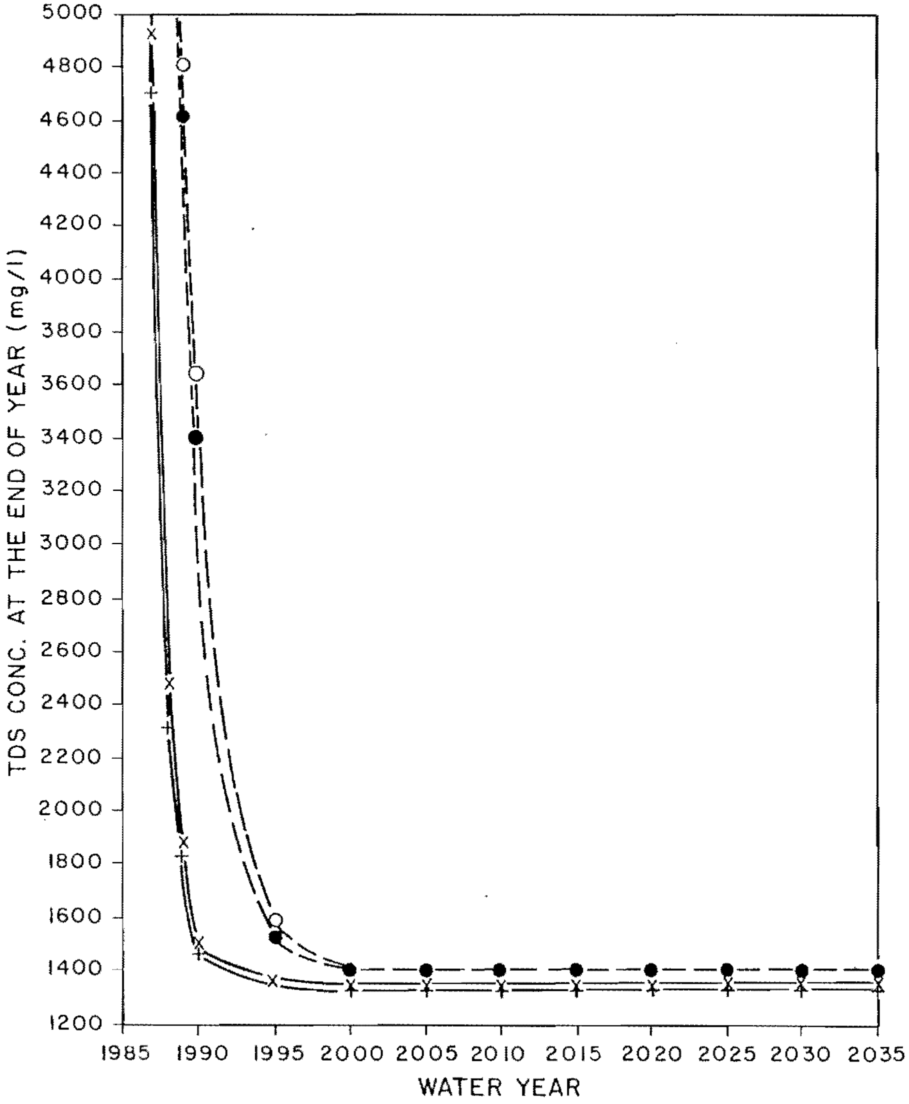
1) Pump capacity for discharge to the main lake = 8000 cfs.

2) Minimum discharge rate from the Jordan River to Farmington Bay as limited by water rights requirements = 500 cfs.

3) Capacity of the Goggin Drain = 1000 cfs.

4) Exports from the Jordan River through the Goggin Drain occur when the impounded water surface level exceeds the control elevation. Export rates are limited by the constraints of items (2) and (3).

Figure 11. Projected most likely end of water year salinity concentrations in the East Bay.



Legend

+ control elevation = 4200.5 feet msl and quality constraint applied to exports

X control elevation = 4200.5 feet msl and quality constraint not applied to exports

● control elevation = 4205.0 feet msl and quality constraint applied to exports

O control elevation = 4205.0 feet msl and quality constraint not applied to exports

Notes

1. Pump capacity for discharge to the main lake = 8000 cfs.
2. Minimum discharge rate from the Jordan River to Farmington Bay as limited by water rights requirements = 500 cfs.
3. Capacity of the Goggin Drain = 1000 cfs.
4. The quality export constraint requires that water be exported from the Jordan River through the Goggin Drain only when the salinity of the river is higher than that of the impounded waters.
5. Exports from the Jordan River through the Goggin Drain occur when the impounded water surface level exceeds the control elevation, subject to the constraints of of items (2), (3), and sometimes (4) as given above in the Legend.

Figure 12. Projected most likely end of water year salinity concentrations in the East Bay.

freshened to salinity levels approaching that normally considered suitable for freshwater recreation only by importing very large quantities of fresh water from the Weber River system. However, even under this management scenario the simulated equilibrium salinity level of the bay exceeded 3000 mg/l, which is too high for most agricultural, municipal, and industrial uses.

As a cautionary note, attempts to lower the salinity concentrations of Farmington Bay could have some adverse impacts. For more than a hundred years Farmington Bay has been the eventual repository of wastes from several population centers along the Jordan River and other communities adjacent to the bay, and natural inputs of nutrients and organic matter has occurred over geologic time. The high salinity levels of Farmington Bay have greatly inhibited the adverse effects normally resulting from high nutrient loadings in a body of water. If the salinity of the bay is lowered to levels that do not inhibit biological activity, consequences might be dramatic. Thus, an alternative management option which might be considered for Farmington Bay is to attempt to maintain high salinity levels within the impoundment (in excess of 100,000 mg/l) so as to inhibit biological activity.

East Bay

Because of the large volumes of freshwater inflows from the three major surface tributaries of the Great Salt Lake, equilibrium salinity levels in the East Bay impoundment are less than those of the Farmington Bay. However, even for the East Bay the equilibrium salinity levels are 1200 to 1500 mg/l.

By way of comparison, average year-end salinity values for the existing Willard Bay Reservoir are in the neighborhood of 500 mg/l. This value is consistent with the average volume-weighted quality of the waters which enter the Willard Bay impoundment from the Weber River of about 250 mg/l. The Weber River water salinity is the lowest of the three major tributaries.

This study indicates that non-selective mixing of the three streams, coupled with the concentrating effects of evaporation losses, results in water salinity levels which normally are too high for municipal and industrial purposes.

Conclusions

The principal conclusions of the study from the point of view of water salinity are summarized by the following table.

Table 9. Sumary of equilibrium salinity levels for Farmington and East Bays.

Impoundment	Most Likely Equilibrium Salinity (mg/l)	Acceptable for Agric.	Fresh Water Rec.	Muni.	Ind.
Farmington Bay					
- No imports	5500	No	Marginal	No	No
- Imports from Weber River	3500	No	Yes	No	No
East Bay	1400	Marginal	Yes	No	Some

With respect to organic decomposition activity and the associated odor production, numerous problems would result from freshening the waters along the east shore of the Great Salt Lake, particularly in the Farmington Bay area. If this management option were pursued, as opposed to maintaining high salinity levels, many additional water quality studies would be needed in order to identify the problems and their possible solutions.

Literature Cited

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Appendix A

The Hydrologic-Salinity Model, User Instructions, and Sample Input and Output Files

The Input Program

The input program entitled GSLBAYS is written in FORTRAN 77 for use on a VAX-11 computer. The program reads from two files. One must be named 'CAP.DAT' and contains elevation-area-volume tables for both Farmington Bay and the East Bay. The second input file contains instructions for the computer model. This instruction file can have any acceptable file name. All output is written to a file specified by the user. A description of the input file is contained in Table A-1.

Table A-1. Input data for the GSLBAYS water balance model.

1. TITLE - Format Character 100

1-100		Title of run

2. IYR,LYR,NTRC,NP,IER,IECHO1,IECHO2,IDBG1,IDBG2,IDBG3 - Format (15I5)

1-5	IYR	First water year to be simulated (e.g. 1986).
6-10	LYR	Last water year to be simulated (LYR-IYR+1 must not exceed 60).
11-15	NTRC	Number of stochastic traces to be generated (maximum of 100).
16-20	NP	Number of elevations contained in the elevation-area-volume table contained in file 'CAP.DAT'.
21-25	IER	If IER=1, generated random numbers are written to output file.
26-30	IECHO1	If IECHO1=1, input file data are echoed to output file.
31-35	IECHO2	If IECHO2=1, elevation-area-volume table from file 'CAP.DAT' is written to output file.
36-40	IPDG1	If IDBG1=1, debugging information from subroutine MVGEN is written to output file.
41-45	IDBG2	If IDBG2=1, debugging information from the main program is written to output file.
46-50	IDBG3	If IDBG3=1, debugging information from subroutines WEIR1, WEIR2, and WEIR3 is written to output file.

3. ISEED,IP1,IP2,IP3,IP4,IP5,IW,IW1 - Format (I10,10I5)

1-10	ISEED	Seed number for random number generator. Use a large odd integer.
11-15	IP1	If IP1=1, Farmington Bay is simulated. If IP1=2, The East Bay is simulated.
16-20	IP2	If IP2=1, precipitation and evaporation on mudflats and marshes are ignored. Use IP2=1 when modeling the East Bay (i.e. when IP1=2). If IP2=2, precipitation and evaporation on 16,900 acres of marshes is considered. Mudflat precipitation and evaporation are ignored. If IP2=3, precipitation and evaporation on 16,900 acres of marshes is considered. Precipitation and evaporation on mudflats up to elevations as high as three feet above the bay water level (but no higher than 4203 feet above msl) are considered. For modeling Farmington Bay, IP2=3 is considered to be most realistic.
21-25	IP3	If IP3=1, Weber River imports are allowed. Do not use IP3=1 when modeling the East Bay (i.e. when IP1=2).

Table A-1. Continued.

26-30	IP4	If IP4=0, exports through the Goggin Drain are not allowed. If IP4=1, exports through the Goggin Drain are allowed when the beginning of the month bay elevation is not below the control elevation ('CONELV' described below) and the river inflow is greater than the downstream water right requirements ('JREQ' described below). If IP4=2, exports are computed as when IP4=1 except that exports are not allowed when the beginning of the month TDS in the bay is greater than the TDS of the Jordan River for the month. If IP4=3, exports are based on the historical statistical relationship between Goggin Drain flows river flows.
31-35	IP5	If IP5=1, pumped bay-outflow is simulated. If IP5=2, weir outflow from the bay is simulated.
36-40	IW	If IW=1, annual summaries of specified traces are written to output file. If IW=2, probability levels of various results are calculated and written to output file. If IW=3, both outputs from IW=1 and IW=2 are written to output file.
41-45	IW1	If IW1=1, monthly elevations and bay TDS of specified traces are written to output file.

4. CONELV,ELEVIC,WIMMAX,WRP,LEN,SCOEF,APE - Format (12F10.2)

1-10	CONELV	Control elevation in feet above msl (corresponds to pump turn-on elevation when IP5=1, or weir-crest elevation if IP5=2.
11-20	ELEVIC	Bay elevation initial condition.
21-30	WIMMAX	Maximum allowable inport from the Weber River in cfs.
31-40	WRP	Maximum allowable portion of monthly Weber River flow allowed to be imported (e.g. WRP=.75 indicates only 75 percent of the Weber River flow may be diverted for import.
41-50	LEN	Length of weir-crest in feet (not used when IP5=2).
51-60	SCOEF	Coefficient in sediment salt release equation (lbs/acre/day per mg/l difference between bay TDS and sediment TDS).
61-70	APE	Average pan evaporation at Bear River Refuge (inches/year).

Table A-1. Continued.

5. GOGMAX,JREQ,SEDVOL,SSEPIC,TDSIC,PUMPR - Format (12F10.0)

1-10	GOGMAX	Capacity (cfs) of Goggin Drain.
11-20	JREQ	Flow in lower Jordan River unavailable for export (cfs).
21-30	SEDVOL	Volume (AF) of sediment contributing to salt release.
31-40	SSEDIC	Initial condition of tons of salt in 'SEDVOL' acre-feet of sediment.
41-50	TDSIC	Initial condition of TDS (mg/l) of bay.
51-60	PUMPR	Pumping rate (cfs) if using IP5=1.

6. QIN(3,-1),QIN(3,0) - Format (12F10.0)

1-10	QIN(3,-1)	Annual gaged river flow (AF) two years prior to IYR.
11-20	QIN(3,0)	Annual gaged river flow (AF) in year prior to IYR.

7. NA,(LA(J),J=1,NA) - Format (15I5)

1-5	NA	Number of traces for which annual summaries are written to output file (maximum of 10).
6-10 etc.	LA(J)	Trace number for which annual summaries are written to output file.

8. NS,(LS(J),J=1,NS) - Format (15I5)

1-5	NS	Number of years for which probability levels of various results are written to output file (maximum of 15).
6-10 etc.	LS(J)	Year for which probability levels of various results are written to outut file (e.g. if IYR = 1986, LS(J)=1 would correspond to 1986 and LS(J)=5 would correspond to 1990).

9. NM,(LM(J),J=1,NM) - Format 15I5)

1-5	NM	Number of traces for which monthly summaries of elevation and TDS results are written to output file (maximum of 5).
6-10 etc.	LM(J)	Trace number for which monthly summaries of elevation and TDS results are written to output file.

10. NPROB,(PROB(J),J=1,NPROB) - Format (I5,15F5.2)

1-5	NPROB	Number of probability levels examined for various results (maximum of 7).
6-10 etc.	PROB(J)	Exceedence probability level determined for various results.

11-13. ((AM(I,J),J=1,3)I=1,3) - Format (3F10.5)

1-10 etc.	AM(I,J)	A matrix for stochastic, multivariate generation.

Table A-1. Continued.

14-16. ((BM(I,J),J=1,3),I=1,3) - Format (3F10.5)

1-10 etc.	BM(I,J)	Matrix for stochastic, multivariate generation.

17. (MU(J),J=1,3) - Format (3F10.5)

1-10 etc.	MU(J)	Mean of transformed data of series J.

18. (SIG(J),J=1,3) - Format (3F10.5)

1-10 etc.	SIG(J)	Standard deviation of transformed data of series J.

19. (BETA(J),J=1,3) - Format (12F10.2)

1-10 etc.	BETA(J)	Third parameter of three parameter log-normal distribution of series J.

20. (XIC(J),J=1,3) - Format (2F10.2,F10.0)

1-10 etc.	XIC(J)	Initial condition of series J (i.e. actual value of series J for year IYR-1).

21. (IV(J),J=1,3) - Format (15I5)

1-5 etc.	IV(J)	Transformation index for series J. If IV(J) = -1, data series J is assumed to be from a three-parameter log-normal distribution. If IV(J) ≠ -1, data series J is assumed to be normally distributed.

```
C**********************************************************************
C
C          FARMINGTON BAY AND EAST BAY WATER AND SALT BUDGET MODEL
C
C      THIS PROGRAM WAS WRITTEN BY D. GEORGE CHADWICK JR. AT UTAH STATE
C  UNIVERSITY FOR USE ON A VAX-11 COMPUTER USING FORTRAN 77.  THE MODEL
C  STOCHASTICALLY GENERATES MONTHLY WATER AND SALT BUDGET TRACES. INPUT
C  IS READ FROM A USER-SPECIFIED INPUT FILE AS WELL AS A FILE NAMED
C  'CAP.DAT' CONTAINING AN ELEV-AREA-VOLUME TABLE.  OUTPUT IS WRITTEN
C  TO A USER-SPECIFIED OUTPUT FILE.
C
C**********************************************************************
C                          DESCRIPTION OF INPUT DATA
C
C  TITLE -A USER SPECIFIED RUN TITLE OF UP TO 100 CHARACTERS IN LENGTH
C  IYR   -THE FIRST YEAR TO BE SIMULATED
C  LYR   -THE LAST YEAR TO BE SIMULATED (LYR-IYR+1 MUST BE < 61)
C  NTRC  -THE NUMBER OF STOCHASTIC TRACES TO BE GENERATED (100 MAXIMUM)
C  NP    -# OF ENTRIES IN THE ELEV-AREA-VOLUME TABLE IN FILE 'CAP.DAT'
C  IER   -IF=1, GENERATED RANDOM NUMBERS ARE WRITTEN TO OUTPUT FILE
C  IECHO1-IF=1, ECHOES DATA IN THE INPUT FILE
C  IECHO2-IF=1, ECHOES ELEV-AREA-VOLUME TABLE IN FILE 'CAP.DAT'
C  IDBG1 -IF=1, DEBUG INFO OF SUBROUTINE MVGEN WRITTEN TO OUTPUT FILE
C  IDBG2 -IF=1, DEBUG INFO OF MAIN PROGRAM WRITTEN TO OUTPUT FILE
C  IDBG3 -IF=1, DEBUG INFO FROM WEIR SUBROUTINES WRITTEN TO OUTPUT FILE
C  ISEED -LARGE, ODD, POSITIVE INTEGER FOR RANDOM NUMBER GENERATOR SEED
C  IP1   -IF=1, SIMULATES FARMINGTON BAY; IF=2, SIMULATES THE EAST BAY
C  IP2   -IF=1 PREC AND EVAP ON MUDFLATS AND MARSHES IGNORED
C         IF=2 PREC AND EVAP ON 16900 ACRES OF PROTECTED MARSHES
C         IF=3 PREC AND EVAP ON 16900 ACRES OF PROTECTED MARSHES PLUS
C         MUDFLATS UP TO THE GREATER OF 3 FT ABOVE BAY OR 4203.
C  IP3   -IF=1, ALLOWS WEBER RIVER IMPORTS TO BAY, OTHERWISE DOES NOT
C  IP4   -IF=1, ALLOWS GOGGIN DRAIN EXPORTS; IF=2, ALLOWS GOGGIN DRAIN
C         EXPORTS WHEN JORDAN RIVER TDS > BAY TDS; IF=0 NO EXPORTS
C         IF=3, EXPORTS BASED ON RIVER FLOW VS EXPORT REGRESSION
C  IP5   -IF=1, SIMULATES PUMPING BAY OUTFLOW; IF=2, SIMULATES A WEIR
C  IW   -IF=1 WRITES ANNUAL SUMMARY FOR SPECIFIED TRACES
C        IF=2 WRITES SUMMARY OF PROBABILITIES FROM STOCHASTIC ANALYSES
C        IF=3 SAME AS IW=1 PLUS IW=2
C  IW1  -IF=1, WRITES MONTHLY ELEV AND TDS SUMMARY FOR SELECTED TRACES
C  CONELV-PUMP TURN-ON ELEV IF IP5=1, OR WEIR CREST ELEV IF IP5=2
C  ELEVIC-BAY ELEVATION INITIAL CONDITION
C  WIMMAX-WEBER RIVER IMPORT CANAL CAPACITY (CFS); USED ONLY IF IP3=1
C  WRP   -PORTION OF WEBER RIVER AVAIL FOR IMPORT; USED ONLY IF IP3=1
C  LEN   -LENGTH OF WEIR CREST; USED ONLY IF IP5=2P^
C  SCOEF -SEDIMENT SALT RELEASE RATE IN LBS/ACRE/DAY PER MG/L GRADIENT
C  APE   -ANNUAL AVERAGE PAN EVAPORATION AT BEAR RIVER REFUGE (INCHES)
C  GOGMAX-MAXIMUM FLOW (CFS) POSSIBLY EXPORTED BY GOGGIN DRAIN; USED
C         ONLY IF IP4=1 OR 2
C  JREQ  -FLOW (CFS) IN LOWER JORDAN RIVER UNAVAILABLE FOR EXPORT
C  SEDVOL-VOLUME (AF) OF SEDIMENT CONTRIBUTING TO SALT RELEASE
C  SSEDIC-AVAILABLE SALT (TONS) IN SEDIMENT AT INITIAL CONDITIONS
C  TDSIC -BAY TDS (MG/L) INITIAL CONDITION
C  PUMPR -PUMPING RATE (CFS); USED ONLY IF IP5=1
C  QIN(3,-1)-ANNUAL GAGED FLOW (AF) TWO YEARS BEFORE 'IYR'
C  QIN(3,0) -ANNUAL GAGED FLOW (AF) 1 YEAR BEFORE 'IYR'
C  NA    -# OF TRACES FOR WHICH ANNUAL SUMMARIES ARE WRITTEN TO OUTPUT
C         FILE (MAXIMUM OF 10)
C  LA(J) -TRACE #'S FOR WHICH ANNUAL SUMMARIES ARE WRITTEN TO OUTPUT
C  NS    -# OF YEARS FOR WHICH STOCHASTIC PROBABILITIES ARE WRITTEN
```

```
C          TO OUTPUT FILE(MAXIMUM OF 15)
C  LS(J) -YEAR #'S FOR WHICH STOCHATIC PROBABILITIES ARE WRITTEN (E.G.
C          IF IYR=1986, LS(J)=1 IS 1986, LS(J)=2 IS 1987, ETC)
C  NM    -# OF TRACES FOR WHICH MONTHLY SUMMARIES ARE WRITTEN TO OUTPUT
C          FILE (MAXIMUM OF 5)
C  LM(J) -TRACE # FOR WHICH MONTHLY SUMMARIES ARE WRITTEN TO OUTPUT
C  NPROB -# OF PROBABILITY LEVELS EXAMINED FOR STOCHASTIC PROB SUMMARY
C          (MAXIMUM OF 7)
C  PROB(J)-PROBABILITY LEVEL EXAMINED FOR STOCHATIC PROBABILITY SUMMARY
C  AM(I,J)-'A' MATRIX FOR MULTIVARIATE GENERATION
C  BM(I,J)-'B' MATRIX FOR MULTIVARIATE GENERATION
C  MU(J)  -MEANS OF TRANSFORMED DATA SERIES
C  SIG(J) -STANDARD DEVIATION OF TRANSFORMED DATA SERIES
C  BETA(J)-THIRD PARAMETER IN 3PLN TRANSFORMATION OF DATA SERIES
C  SIC(J) -INITIAL CONDITION OF DATA SERIES
C  IV(J)  -IF=-1, DATA ARE CONSIDERED TO BE 3PLN DISTRIBUTED
C**********************************************************************

      CHARACTER TITLE*100,NAME1*30,NAME2*10,NAME3*20
      COMMON/C1/AM(3,3),BM(3,3),MU(3),SIG(3),BETA(3),IV(3),XIC(3)
      COMMON/C2/E(40),A(40),V(40),NP
      COMMON/C3/EXPORT(12),EXPMAX(12),WIMP(12),WIMPMAX(12),TDSEXP(12),
     *QPMAX(12),SIMP(12),TDSWEB(12),SEXP(12),QOUT(12),SQO(12),SGW(12),
     *ELBAY(12,60,100),SSED(12),QGW(12),QRIV(12),QTRIB(12),SRIV(12),
     *STRIB(12),TDSBAY(12,60,100),IP1,IP2,IP3,IP4,AREA
      COMMON/C4/DAY(12),SEDVOL,SSEDTONS,SCOEF
      COMMON/C5/PREC(12),PRE(12),PEVAP(12),FWEV(2),KC(12),EV(12),APE
      COMMON/C6/CONELV,CONVOL,Q,INFLO,IDBG3
      REAL FCBWJ(12),FCJRC(12),FCWPC(12),EC(12),PCFB(12),PCEB(12),
     *TEM1(100),TEM2(100),TEM3(100),TEM4(100),TEM5(100),TEM6(100),
     *TEM7(100),TEM8(100),TEM9(100),TEM10(100),X8(7,15),X9(7,15),
     *X1(7,15),X2(7,15),X3(7,15),X4(7,15),X5(7,15),X6(7,15),X7(7,15),
     *X10(7,15),EMIN(60,100),GWT(60),TRIBT(60),WIMPT(60,100),GC(12),
     *EVT(60),QOUTT(60,100),SRIVT(60),TDSMAX(60,100),QIN(3,-1:100),
     *TDSMIN(60,100),PRET(60),ELEOY(60,100),SGWT(60),SSEDT(60),PROB(7),
     *STRIBT(60),SQOT(60),TDSEOY(60,100),SIMPT(60),SEXPT(60),
     *EMAX(60,100),EXPT(60,100),QTT(60,100),MU,JREQ,KC,INFLO,LEN
      INTEGER IDX1(100),IDX2(100),IDX3(100),IDX4(100),IDX5(100),
     *IDX6(100),IDX7(100),IDX8(100),IDX9(100),IDX10(100),LS(15),LA(10),
     *LM(5),MEMAX(60),MEMIN(60),MTDSMAX(60),MTDSMIN(60)
      DATA DAY/31,30,31,31,28,31,30,31,30,31,31,30/
      DATA FWEV/48.5,47.5/
      DATA PCEB/.0898,.0855,.0956,.0905,.0806,.1012,.1235,.1054,.0808,
     *.0328,.0467,.0676/
      DATA PCFB/.0844,.0850,.0938,.0893,.0833,.1068,.1290,.1074,.0750,
     *.0318,.0538,.0605/
      DATA FCWPC/.0463,.0491,.0580,.0582,.0561,.1076,.1734,.2299,.1471,
     *.0241,.0159,.0342/
      DATA FCJRC/.0664,.0602,.0669,.0703,.0733,.0896,.0970,.1242,.1295,
     *.0812,.0699,.0715/
      DATA FCBWJ/.0645,.0675,.0744,.0815,.0730,.1079,.1286,.1530,.1205,
     *.0448,.0356,.0485/
      DATA EC/.0670,.0268,.0161,.0134,.0161,.0349,.0670,.1099,.1501,
     *.2038,.1796,.1153/
      DATA GC/.0386,.0413,.0421,.0551,.0641,.1181,.1267,.1513,.1660,
     *.0762,.0631,.0575/
      DATA KC/1.15,1.0,1.0,1.0,1.0,1.0,1.15,1.2,1.2,1.2,1.2,1.2/
      GWTDS=1500.

      PRINT*, 'ENTER NAME OF INPUT FILE'
```

```
      ACCEPT '(A)',NAME1
      OPEN(10,FILE=NAME1,STATUS='OLD')
      OPEN(11,FILE='CAP.DAT',STATUS='OLD')
      PRINT*, 'ENTER NAME OF OUTPUT FILE'
      ACCEPT '(A)',NAME1
      OPEN(15,FILE=NAME1,STATUS='NEW')

C**  READ DATA AND ECHO BASED ON IECHO1 AND IECHO2
      READ(10,'(A)')TITLE
      READ(10,900)IYR,LYR,NTRC,NP,IER,IECHO1,IECHO2,IDBG1,IDBG2,IDBG3
      READ(10,911)ISEED,IP1,IP2,IP3,IP4,IP5,IW,IW1
      READ(10,901)CONELV,ELEVIC,WIMMAX,WRP,LEN,SCOEF,APE
      READ(10,908)GOGMAX,JREQ,SEDVOL,SSEDIC,TDSIC,PUMPR
      READ(10,908)QIN(3,-1),QIN(3,0)
      READ(10,900)NA,(LA(J),J=1,NA)
      READ(10,900)NS,(LS(J),J=1,NS)
      READ(10,900)NM,(LM(J),J=1,NM)
      READ(10,906)NPROB,(PROB(J),J=1,NPROB)

C*  READ ELEVATION-VOLUME-AREA TABLE
      IF(IP1.NE.1) GO TO 105
      READ(11,'(A)')NAME1
      READ(11,'(2A)')NAME2,NAME3
      DO 100 I=1,NP
100   READ(11,902)E(I),A(I),V(I)
      GO TO 110
 105  READ(11,'(30X,A)')NAME1
      READ(11,'(A,20X,A)')NAME2,NAME3
      DO 101 I=1,NP
101   READ(11,903)E(I),A(I),V(I)

C*  READ DATA FOR MULTIVARIATE GENERATION OF FLOW, PREC, AND PAN EVAP
 110  DO 130 I=1,3
130   READ(10,904)(AM(I,J),J=1,3)
      DO 131 I=1,3
131   READ(10,904)(BM(I,J),J=1,3)
      READ(10,904)(MU(J),J=1,3)
      READ(10,904)(SIG(J),J=1,3)
      READ(10,902)(BETA(J),J=1,3)
      READ(10,901)(XIC(J),J=1,3)
      READ(10,900)(IV(J),J=1,3)

C*  ECHO DATA INPUT
      IF(IECHO1.NE.1) GO TO 150
      WRITE(15,'(A)')TITLE
      WRITE(15,900)IYR,LYR,NTRC,NP,IER,IECHO1,IECHO2,IDBG1,IDBG2,IDBG3
      WRITE(15,911)ISEED,IP1,IP2,IP3,IP4,IP5,IW,IW1
      WRITE(15,901)CONELV,ELEVIC,WIMMAX,WRP,LEN,SCOEF,APE
      WRITE(15,908)GOGMAX,JREQ,SEDVOL,SSEDIC,TDSIC,PUMPR
      WRITE(15,908)QIN(3,-1),QIN(3,0)
      WRITE(15,900)NA,(LA(J),J=1,NA)
      WRITE(15,900)NS,(LS(J),J=1,NS)
      WRITE(15,900)NM,(LM(J),J=1,NM)
      WRITE(15,906)NPROB,(PROB(J),J=1,NPROB)

C*  ECHO ELEVATION-VOLUME-AREA TABLE
 150  IF(IECHO2.NE.1) GO TO 151
      WRITE(15,'(A)')NAME1
      WRITE(15,'(2A)')NAME2,NAME3
      DO 189 I=1,NP
```

```
189   WRITE(15,902)E(I),A(I),V(I)

C*  ECHO DATA FOR MULTIVARIATE GENERATION OF FLOW, PREC, AND PAN EVAP
 151  DO 132 I=1,3
132   WRITE(15,904)(AM(I,J),J=1,3)
      DO 133 I=1,3
133   WRITE(15,904)(BM(I,J),J=1,3)
      WRITE(15,904)(MU(J),J=1,3)
      WRITE(15,904)(SIG(J),J=1,3)
      WRITE(15,901)(BETA(J),J=1,3)
      WRITE(15,905)(XIC(J),J=1,3)
      WRITE(15,900)(IV(J),J=1,3)

      NYR=LYR-IYR+1
      CALL INTERP(ARIC,A,ELEVIC,E,NP)
      CALL INTERP(VIC,V,ELEVIC,E,NP)
      CALL INTERP(CONVOL,V,CONELV,E,NP)

C* SET MAXIMUM MONTHLY PUMPING VOLUMES
      IF(IP5.NE.1) GO TO 135
      DO 134 K=1,12
 134  QPMAX(K)=PUMPR*1.983*DAY(K)
      IF(IDBG2.EQ.1) WRITE(15,908)(QPMAX(K),K=1,12)

C**** BEGIN TRACE LOOP

135   DO 500 NT=1,NTRC
      CALL MVGEN(QIN,ISEED,NYR,IER,IDBG1)
      DO 129 L=1,NYR
129    QTT(L,NT)=QIN(3,L)
      IF(IDBG2.NE.1) GO TO 136
      DO 128 L=1,NYR
128    WRITE(15,905)(QIN(NN,L),NN=1,3)
136   AREA=ARIC
      ELEV=ELEVIC
      TDS=TDSIC
      VOL=VIC
      SALT=TDS*VOL/735.
      SSEDTONS=SSEDIC

C***  BEGIN ANNUAL LOOP
      DO 501 L=1,NYR

C*  DIVIDE ANNUAL SERIES TO MONTHLY SERIES
      DO 160 K=1,12
       IF(IP1.EQ.2) GO TO 158
       QRIV(K)=FCJRC(K)*QIN(3,L)
       PREC(K)=PCFB(K)*QIN(2,L)
       GO TO 159
 158   QRIV(K)=FCBWJ(K)*QIN(3,L)
       PREC(K)=PCEB(K)*QIN(2,L)
 159   PEVAP(K)=EC(K)*QIN(1,L)
160   CONTINUE
      IF(IDBG2.EQ.1) WRITE(15,908)(QRIV(K),K=1,12)
      IF(IDBG2.EQ.1) WRITE(15,901)(PREC(K),K=1,12)
      IF(IDBG2.EQ.1) WRITE(15,901)(PEVAP(K),K=1,12)

C*  CALCULATE WEBER RIVER IMPORT AND TDS IF REQUIRED
      IF(IP3.NE.1.OR.IP1.NE.1) GO TO 162
      QWEB=-110784+19262*QIN(2,L)+0.615*QIN(3,L)
```

```
      IF(QWEB.LT.30000.) QWEB=30000.
      DO 161 K=1,12
       TEMP=FCWPC(K)*QWEB/DAY(K)/1.983
       TEMP1=TEMP*WRP
       IF(TEMP1.GT.WIMMAX) TEMP1=WIMMAX
       WIMPMAX(K)=TEMP1*DAY(K)*1.983
      STEMP=3.249*TEMP**.7777
161   TDSWEB(K)=STEMP/TEMP/0.0026957
      IF(IDBG2.EQ.1) WRITE(15,908)(WIMPMAX(K),K=1,12)
      IF(IDBG2.EQ.1) WRITE(15,908)(TDSWEB(K),K=1,12)

C*  DETERMINE EXPORTED WATER AND SALT IF REQUIRED
 162  IF(IP4.EQ.0) GO TO 163
      DO 164 K=1,12
      IF(IP1.EQ.1) GO TO 168
      QJR=-91676+0.228*QIN(3,L)
      IF(QJR.LT.66000.) QJR=66000.
      TEMP=FCJRC(K)*QJR/DAY(K)/1.983
      GO TO 169
 168  TEMP=QRIV(K)/DAY(K)/1.983
 169  STEMP=7.542*TEMP**.8148
      TEMP1=TEMP-JREQ
      IF(TEMP1.LT.0.) TEMP1=0.
      IF(TEMP1.GT.GOGMAX) TEMP1=GOGMAX
      EXPMAX(K)=TEMP1*DAY(K)*1.983
      TDSEXP(K)=STEMP/TEMP/0.0026957
 164  CONTINUE
      IF(IDBG2.EQ.1) WRITE(15,908)(EXPMAX(K),K=1,12)
      IF(IDBG2.EQ.1) WRITE(15,908)(TDSEXP(K),K=1,12)

C*  DETERMINE UNGAGED FLOWS (INCLUDING WWTP FLOWS OF 25 CFS)
 163  IF(IP1.NE.1) GO TO 166
      TOT=0.
      DO 165 K=1,12
      TEMP=QRIV(K)/DAY(K)/1.983
      TEMP=5.7+0.32288*TEMP+25.
      QTRIB(K)=TEMP*1.983*DAY(K)
      TOT=TOT+QTRIB(K)
 165  CONTINUE
      IF(TOT.LE.220000.) GO TO 198
       FACT=220000./TOT
       DO 152 K=1,12
152    QTRIB(K)=QTRIB(K)*FACT
198   IF(TOT.GT.90000.) GO TO 173
      FACT=90000./TOT
      DO 199 K=1,12
199    QTRIB(K)=QTRIB(K)*FACT
 166  IF(IP1.NE.2) GO TO 173
      QTR=7951.*QIN(2,L)-746.8*QIN(1,L)
      DO 167 K=1,12
167   QTRIB(K)=FCBWJ(K)*QTR
173   IF(IDBG2.EQ.1) WRITE(15,908)(QTRIB(K),K=1,12)

C*  CALCULATE GROUNDWATER FLOWS
      IF(IP1.NE.1) GO TO 174
      DO 172 K=1,12
172   QGW(K)=.0328*(QIN(3,L-2)+QIN(3,L-1)+QIN(3,L))*DAY(K)/365.
      GO TO 170
174   DO 171 K=1,12
 171  QGW(K)=0.0096*(QIN(3,L-2)+QIN(3,L-1)+QIN(3,L))*DAY(K)/365.
```

```
170   IF(IDBG2.EQ.1) WRITE(15,908)(QGW(K),K=1,12)

C* CALCULATE SALT OF GAGED & UNGAGED FLOWS IF MODELING FARMINGTON BAY
      IF(IP1.NE.1) GO TO 175
      DO 176 K=1,12
       TEMP=QRIV(K)/DAY(K)/1.983
       TEMP1=QTRIB(K)/DAY(K)/1.983-25.
       SRIV(K)=DAY(K)*7.542*TEMP**.8148
       STRIB(K)=DAY(K)*(49.4*TEMP1**.4694+25.*1.983*1000./735.)
 176  CONTINUE
      IF(IDBG2.EQ.1) WRITE(15,908)(SRIV(K),K=1,12)
      IF(IDBG2.EQ.1) WRITE(15,908)(STRIB(K),K=1,12)

C   CALCULATE SALT FROM GAGED AND UNGAGED FLOWS IF MODELING EAST BAY
 175  IF(IP1.NE.2) GO TO 177
      DO 183 K=1,12
       TEMP=QRIV(K)/DAY(K)/1.983
       SRIV(K)=DAY(K)*56.21*TEMP**0.5581
       STRIB(K)=SRIV(K)*QTRIB(K)/QRIV(K)
 183  CONTINUE
      IF(IDBG2.EQ.1) WRITE(15,908)(SRIV(K),K=1,12)
      IF(IDBG2.EQ.1) WRITE(15,908)(STRIB(K),K=1,12)

C*  CALCULATE GROUNDWATER SALT
177   DO 179 K=1,12
179   SGW(K)=QGW(K)*GWTDS/735.
      IF(IDBG2.EQ.1) WRITE(15,908)(SGW(K),K=1,12)

C*  CALCULATE EXPORT IF USING HISTORICAL RELATIONSHIPS
      IF(IP4.NE.3) GO TO 178
      IF(IP1.EQ.1) QEXP=0.54231*QIN(3,L)-83167.
      IF(IP1.EQ.2) QEXP=0.12676*QIN(3,L)-140987.
      IF(QEXP.LT.5000.) QEXP=5000.
      DO 182 K=1,12
182    EXPORT(K)=GC(K)*QEXP

C** WATER BALANCE MONTHLY LOOP

178   IF(IP5.NE.1) GO TO 400
C*       PUMP OPTIONS
      CALL PUMP(VOL,CONVOL,ELEV,SALT,TDS,NT,L)
      GO TO 600

C*       WEIR OPTIONS
400   IF(IP5.NE.2) GO TO 600
      CALL WEIR(VOL,NT,L,TDS,ELEV,SALT,LEN)

600   IF(IDBG2.NE.1) GO TO 610
      WRITE(15,908)(EXPORT(K),K=1,12)
      WRITE(15,908)(EV(K),K=1,12)
      WRITE(15,908)(PRE(K),K=1,12)
      WRITE(15,908)(WIMP(K),K=1,12)
      WRITE(15,908)(QOUT(K),K=1,12)
      WRITE(15,901)(ELBAY(K,L,NT),K=1,12)
      WRITE(15,908)(TDSBAY(K,L,NT),K=1,12)
      WRITE(15,908)(SSED(K),K=1,12)
      WRITE(15,908)(SIMP(K),K=1,12)
      WRITE(15,908)(SEXP(K),K=1,12)
      WRITE(15,908)(SQO(K),K=1,12)
```

```
C*  PREPARE ANNUAL OUTPUT
C      WATER BALANCE OUTPUT PREPARATION
610    EMAX(L,NT)=ELBAY(1,L,NT)
       EMIN(L,NT)=EMAX(L,NT)
       MEMAX(L)=1
       MEMIN(L)=1
       GWT(L)=0.
       TRIBT(L)=0.
       WIMPT(L,NT)=0.
       EXPT(L,NT)=0.
       PRET(L)=0.
       EVT(L)=0.
       QOUTT(L,NT)=0.
       ELEOY(L,NT)=ELBAY(12,L,NT)

       DO 627 K=1,12
        IF(ELBAY(K,L,NT).LT.EMIN(L,NT)) MEMIN(L)=K
        IF(ELBAY(K,L,NT).LT.EMIN(L,NT)) EMIN(L,NT)=ELBAY(K,L,NT)
        IF(ELBAY(K,L,NT).GT.EMAX(L,NT)) MEMAX(L)=K
        IF(ELBAY(K,L,NT).GT.EMAX(L,NT)) EMAX(L,NT)=ELBAY(K,L,NT)
        GWT(L)=GWT(L)+QGW(K)
        TRIBT(L)=TRIBT(L)+QTRIB(K)
        WIMPT(L,NT)=WIMPT(L,NT)+WIMP(K)
        EXPT(L,NT)=EXPT(L,NT)+EXPORT(K)
        PRET(L)=PRET(L)+PRE(K)
        EVT(L)=EVT(L)+EV(K)
        QOUTT(L,NT)=QOUTT(L,NT)+QOUT(K)
627    CONTINUE

C   SALT BALANCE OUTPUT PREPARATION
       TDSMAX(L,NT)=TDSBAY(1,L,NT)
       TDSMIN(L,NT)=TDSMAX(L,NT)
       MTDSMIN(L)=1
       MTDSMAX(L)=1
       SRIVT(L)=0.
       SGWT(L)=0.
       SSEDT(L)=0.
       STRIBT(L)=0.
       SIMPT(L)=0.
       SEXPT(L)=0.
       SQOT(L)=0.
       TDSEOY(L,NT)=TDSBAY(12,L,NT)
       DO 661 K=1,12
        IF(TDSBAY(K,L,NT).LT.TDSMIN(L,NT)) MTDSMIN(L)=K
        IF(TDSBAY(K,L,NT).LT.TDSMIN(L,NT)) TDSMIN(L,NT)=TDSBAY(K,L,NT)
        IF(TDSBAY(K,L,NT).GT.TDSMAX(L,NT)) MTDSMAX(L)=K
        IF(TDSBAY(K,L,NT).GT.TDSMAX(L,NT)) TDSMAX(L,NT)=TDSBAY(K,L,NT)
        SRIVT(L)=SRIVT(L)+SRIV(K)
        SGWT(L)=SGWT(L)+SGW(K)
        SSEDT(L)=SSEDT(L)+SSED(K)
        STRIBT(L)=STRIBT(L)+STRIB(K)
        SIMPT(L)=SIMPT(L)+SIMP(K)
        SEXPT(L)=SEXPT(L)+SEXP(K)
        SQOT(L)=SQOT(L)+SQO(K)
661    CONTINUE
501    CONTINUE

C** WRITE ANNUAL OUTPUT
       IF(IW.EQ.2) GO TO 500
C*  WATER BALANCE OUTPUT
```

```
      DO 626 J=1,NA
       IF(LA(J).EQ.NT) GO TO 628
626   CONTINUE
      GO TO 500
628   WRITE(15,'(1H1)')
      IF(J.EQ.1) WRITE(15,'(A)') TITLE
      WRITE(15,920)LA(J)
      WRITE(15,921)
      WRITE(15,922)
      DO 624 L=1,NYR
       LL=IYR+L-1
624    WRITE(15,923)LL,ELEOY(L,LA(J)),EMAX(L,LA(J)),MEMAX(L),
     *EMIN(L,LA(J)),MEMIN(L),QIN(3,L),GWT(L),TRIBT(L),
     *WIMPT(L,LA(J)),EXPT(L,LA(J)),PRET(L),EVT(L),QOUTT(L,LA(J))

C*  SALT BALANCE OUTPUT
      WRITE(15,'(1H1)')
      WRITE(15,920)LA(J)
      WRITE(15,924)
      WRITE(15,925)
      DO 625 L=1,NYR
       LL=IYR+L-1
625    WRITE(15,926)LL,TDSEOY(L,LA(J)),TDSMAX(L,LA(J)),MTDSMAX(L),
     *TDSMIN(L,LA(J)),MTDSMIN(L),SRIVT(L),STRIBT(L),SGWT(L),SSEDT(L),
     *SEXPT(L),SIMPT(L),SQOT(L)
500   CONTINUE

C*  SORT STATISTICS
      IF(IW.EQ.1) GO TO 800
      DO 681 J=1,NS
       DO 680 NT=1,NTRC
        IDX1(NT)=NT
        IDX2(NT)=NT
        IDX3(NT)=NT
        IDX4(NT)=NT
        IDX5(NT)=NT
        IDX6(NT)=NT
        IDX7(NT)=NT
        IDX10(NT)=NT
        IF(IP4.EQ.0) GO TO 727
        IDX8(NT)=NT
727     IF(IP3.NE.1) GO TO 728
        IDX9(NT)=NT
728     TEM1(NT)=TDSEOY(LS(J),NT)
        TEM2(NT)=TDSMAX(LS(J),NT)
        TEM3(NT)=TDSMIN(LS(J),NT)
        TEM4(NT)=ELEOY(LS(J),NT)
        TEM5(NT)=EMAX(LS(J),NT)
        TEM6(NT)=EMIN(LS(J),NT)
        TEM7(NT)=QOUTT(LS(J),NT)
        TEM10(NT)=QTT(LS(J),NT)
        IF(IP4.EQ.0) GO TO 723
        TEM8(NT)=EXPT(LS(J),NT)
723     IF(IP3.NE.1) GO TO 680
        TEM9(NT)=WIMPT(LS(J),NT)
680    CONTINUE
       CALL QKSRT2(TEM1,IDX1,NTRC)
       CALL QKSRT2(TEM2,IDX2,NTRC)
       CALL QKSRT2(TEM3,IDX3,NTRC)
       CALL QKSRT2(TEM4,IDX4,NTRC)
```

```
       CALL QKSRT2(TEM5,IDX5,NTRC)
       CALL QKSRT2(TEM6,IDX6,NTRC)
       CALL QKSRT2(TEM7,IDX7,NTRC)
       CALL QKSRT2(TEM10,IDX10,NTRC)
       IF(IP4.EQ.0) GO TO 731
       CALL QKSRT2(TEM8,IDX8,NTRC)
 731   IF(IP3.NE.1) GO TO 732
       CALL QKSRT2(TEM9,IDX9,NTRC)
 732   DO 682 MM=1,NPROB
        II=(1.-PROB(MM))*FLOAT(NTRC+1)+.5
        X1(MM,J)=TEM1(II)
        X2(MM,J)=TEM2(II)
        X3(MM,J)=TEM3(II)
        X4(MM,J)=TEM4(II)
        X5(MM,J)=TEM5(II)
        X6(MM,J)=TEM6(II)
        X7(MM,J)=TEM7(II)
        X10(MM,J)=TEM10(II)
        IF(IP4.EQ.0) GO TO 734
        X8(MM,J)=TEM8(II)
 734    IF(IP3.NE.1) GO TO 682
        X9(MM,J)=TEM9(II)
 682   CONTINUE
 681  CONTINUE
      WRITE(15,'(1H1)')
      WRITE(15,931)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 701 JJ=1,NS
       LL=IYR+LS(JJ)-1
 701   WRITE(15,909)LL,(X1(II,JJ),II=1,NPROB)
      WRITE(15,932)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 702 JJ=1,NS
       LL=IYR+LS(JJ)-1
 702   WRITE(15,909)LL,(X2(II,JJ),II=1,NPROB)
      WRITE(15,933)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 703 JJ=1,NS
       LL=IYR+LS(JJ)-1
 703   WRITE(15,909)LL,(X3(II,JJ),II=1,NPROB)
      WRITE(15,934)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 704 JJ=1,NS
       LL=IYR+LS(JJ)-1
 704   WRITE(15,910)LL,(X4(II,JJ),II=1,NPROB)
      WRITE(15,935)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 705 JJ=1,NS
       LL=IYR+LS(JJ)-1
 705   WRITE(15,910)LL,(X5(II,JJ),II=1,NPROB)
      WRITE(15,936)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 706 JJ=1,NS
       LL=IYR+LS(JJ)-1
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706    WRITE(15,910)LL,(X6(II,JJ),II=1,NPROB)
      WRITE(15,937)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 707 JJ=1,NS
       LL=IYR+LS(JJ)-1
707    WRITE(15,909)LL,(X7(II,JJ),II=1,NPROB)
      WRITE(15,929)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 710 JJ=1,NS
       LL=IYR+LS(JJ)-1
710    WRITE(15,909)LL,(X10(II,JJ),II=1,NPROB)
      IF(IP4.EQ.0) GO TO 741
      WRITE(15,938)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 708 JJ=1,NS
       LL=IYR+LS(JJ)-1
708    WRITE(15,909)LL,(X8(II,JJ),II=1,NPROB)
741   IF(IP3.NE.1) GO TO 800
      WRITE(15,939)
      WRITE(15,930)
      WRITE(15,907)(PROB(J),J=1,NPROB)
      DO 709 JJ=1,NS
       LL=IYR+LS(JJ)-1
709    WRITE(15,909)LL,(X9(II,JJ),II=1,NPROB)

800   IF(IW1.NE.1) GO TO 1000
      DO 850 M=1,NM
       WRITE(15,'(1H1)')
       WRITE(15,940)LM(M)
       WRITE(15,941)
       DO 820 L=1,NYR
        LL=IYR+L-1
820     WRITE(15,947)LL,(ELBAY(K,L,LM(M)),K=1,12)
       WRITE(15,'(1H1)')
       WRITE(15,945)LM(M)
       WRITE(15,941)
       DO 830 L=1,NYR
        LL=IYR+L-1
830     WRITE(15,946)LL,(TDSBAY(K,L,LM(M)),K=1,12)
850   CONTINUE

 900  FORMAT(15I5)
 901  FORMAT(12F10.2)
 902  FORMAT(F10.2,2F10.0)
 903  FORMAT(F10.2,20X,2F10.0)
 904  FORMAT(3F10.5)
905   FORMAT(2F10.2,F10.0)
906   FORMAT(I5,15F5.2)
907   FORMAT('  YEAR',F8.2,14F9.2)
908   FORMAT(12F10.0)
909   FORMAT(I6,13F9.0)
910   FORMAT(I6,13F9.1)
911   FORMAT(I10,10I5)
920   FORMAT(/,40X,' ANNUAL SUMMARY FOR TRACE #',I3,/)
921   FORMAT(' WATER   YR END',13X,'ELEVATION',16X,'RIVER',5X,'GW',6X,
     *'TRIB    IMPORT    EXPORT  PRECIP    EVAP   OUTFLOW')
922   FORMAT('  YEAR    ELEV',9X,'MAX   MON   MIN   MON',8X,'INFLOW   I
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     *NFLOW   INFLOW   INFLOW   OUTFLOW   (AF)     (AF)     (AF)')
923   FORMAT(I6,F9.1,5X,2(F8.1,I4),F15.0,7F9.0)
924   FORMAT(' WATER     TOTAL DISSOLVED SOLIDS (MG/L)',18X,'SALT  IN
     *PUT  OR  OUTPUT  IN  TONS  PER  YEAR')
925   FORMAT('  YEAR     YR END   MAX    MON    MIN   MON',10X,'GAG STR
     *   UNG STR    GR WAT   SED REL    EXPORT    IMPORT   OUTFLOW')
926   FORMAT(I6,F11.0,2(F8.0,I4),F18.0,6F10.0)
929   FORMAT(///,6X,' RIVER INFLOW (AF)',/)
930   FORMAT(' WATER',8X,'PROBABILITY LEVEL')
931   FORMAT(///,6X,' END OF YEAR TDS IN MG/L',/)
932   FORMAT(///,6X,' MAXIMUM TDS IN MG/L',/)
933   FORMAT(///,6X,' MINIMUM TDS IN MG/L',/)
934   FORMAT(///,6X,' END OF YEAR ELEVATION',/)
935   FORMAT(///,6X,' MAXIMUM ELEVATION',/)
936   FORMAT(///,6X,' MINIMUM ELEVATION',/)
937   FORMAT(///,6X,' ANNUAL OUTFLOW WATER (AF)',/)
938   FORMAT(///,6X,' ANNUAL EXPORTED WATER (AF)',/)
939   FORMAT(///,6X,' ANNUAL IMPORTED WATER (AF)',/)
940   FORMAT(//,24X,'MONTHLY SUMMARY FOR END OF THE MONTH ELEVATIONS
     * FOR TRACE #',I3//)
941   FORMAT(' YEAR       OCT        NOV        DEC        JAN        FEB
     *       MAR        APR        MAY        JUN        JUL        AUG
     *       SEP')
945   FORMAT(//,17X,'MONTHLY SUMMARY FOR END OF THE MONTH BAY TDS IN
     * MILLIGRAMS PER LITER FOR TRACE #',I3,//)
946   FORMAT(I5,12F10.0)
947   FORMAT(I5,12F10.2)
1000  STOP
      END




      SUBROUTINE EVAPRE(PE,TDS,ELEV,AREA,AEP,IP1,IP2,APE,KC,EVAP,PR,P)

C*  THIS SUBROUTINE CALCULATES EVAPORATION (EVAP) BASED ON PAN EVAP (
C    I.E. PE), SALINITY (I.E. TDS), AND OTHER INFO SUCH AS PLANT AND
C    WATER AREAS, ETC. AS WELL AS CALCULATES PRECIPITATION.
C    IF IP2=1, NO MUDFLAT OR MARSH AREAS CONSIDERED
C    IF IP2=2, DIKED MARSHES (16900 AC) CONSIDERED
C    IF IP2=3, SAME AS =2 PLUS MUDFLATS (BELOW 4203 OR 3' ABOVE BAY)
      COMMON/C2/E(40),A(40),V(40),NP
      REAL KC

      EE=AEP/APE*PE/12.
      EEVA=(1.-.000000778*TDS/(1.+.00000063*TDS))*EE
      IF(IP1.EQ.2.OR.IP2.NE.3) GO TO 30
      CONST=ELEV
      IF(CONST.LT.4203.) CONST=4203.
      ALT1=ELEV+1.25
      ALT2=ELEV+1.69
      ALT3=ELEV+2.12
      ALT4=ELEV+2.56
      ALT5=ELEV+3.00
      IF(ALT1.GT.CONST) ALT1=CONST
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      IF(ALT2.GT.CONST) ALT2=CONST
      IF(ALT3.GT.CONST) ALT3=CONST
      IF(ALT4.GT.CONST) ALT4=CONST
      IF(ALT5.GT.CONST) ALT5=CONST
      CALL INTERP(AREA1,A,ALT1,E,NP)
      CALL INTERP(AREA2,A,ALT2,E,NP)
      CALL INTERP(AREA3,A,ALT3,E,NP)
      CALL INTERP(AREA4,A,ALT4,E,NP)
      CALL INTERP(AREA5,A,ALT5,E,NP)
C*  EVAP & PREC FOR OPEN WATER, FBWMA AND J.R. MARSHES, AND MUDFLATS
      EEVA=EEVA*(0.125*AREA1+0.25*(AREA2+AREA3+AREA4)+0.125*AREA5)
      ET=KC*EE*8450.
      FWE=EE*8450.
      EVAP=EEVA+ET+FWE
      P=PR/12.*(0.125*AREA1+0.25*(AREA2+AREA3+AREA4)+0.125*AREA5+
     *16900.)
      GO TO 40
 30   IF(IP1.NE.2.OR.IP2.NE.2) GO TO 20
      EVAP=EEVA*AREA+8450.*EE*(1.+KC)
      P=PR/12.*(AREA+16900.)
      GO TO 40
 20   EVAP=EEVA*AREA
      P=PR/12.*AREA
  40  RETURN
      END



      SUBROUTINE SEDSALT(SSR,K,AREAOLD,TDS)

C*  CALCULATES SEDIMENT RELEASED SALT IN TONS FOR MONTH K BASED ON THE
C   FORMULA: SALT(TONS)=C1*(TDS(SEDIMENT)-TDS(BAY))   TDS'S ARE IN MG/L
C   AND C1 IS IN LBS/1000 ACRES/DAY PER MG/L DIFFERENCE
      COMMON/C4/DAY(12),SEDVOL,SSEDTONS,SCOEF

      TDSSED=SSEDTONS*735./SEDVOL
      DC=TDSSED-TDS
      FLUX=SCOEF*DC
      SSR=FLUX*DAY(K)*AREAOLD/2000000.
      SSEDTONS=SSEDTONS-SSR
      RETURN
      END



      SUBROUTINE INTERP(A,AA,B,BB,NTAB)

C*  This subroutine interprets A corresponding to B in a table of AA
C    vs BB having NTAB values.  If B is less than BB(1), then A is set
C    to AA(1).  If B is greater than BB(NTAB) then A is set at AA(NTAB)
      DIMENSION AA(1),BB(1)

      IF(B.GT.BB(1)) GO TO 40
      A=AA(1)
      GO TO 90
 40   J=0
      DO 50 I=1,NTAB
      IF(B.GT.BB(I)) GO TO 50
      J=I
      GO TO 70
```

```
 50   CONTINUE
      A=AA(NTAB)
      GO TO 90
 70   A=AA(J-1)+(AA(J)-AA(J-1))*(B-BB(J-1))/(BB(J)-BB(J-1))
 90   RETURN
      END



      SUBROUTINE MADSUB(A,B,C,N1,N2,D,N3,N4,N5,N6,N7,N8)

C** This subroutine adds or subtracts matrices.  If D<0, then B is
C    subtracted from A and returned as C.  If D>0, then B is added to A
C    and returned as C.  N1 and N2 are the actual sizes of the matrices
C    to be manipulated.  N3, N4, N5, N6, N7, and N8 must be the actual
C    dimensioned size in the calling program.
      INTEGER D
      DIMENSION A(N3,N4),B(N5,N6),C(N7,N8)

      DO 10 I=1,N1
      DO 10 J=1,N2
      IF(D.LT.0)GOTO 5
       C(I,J)=A(I,J)+B(I,J)
      GOTO 10
 5     C(I,J)=A(I,J)-B(I,J)
 10   CONTINUE

      RETURN
      END



      SUBROUTINE MMULT(A,B,C,N1,N2,N3,N4,N5,N6,N7,N8,N9)

C** This subroutine multiplies matrix A by matrix B and returns as
C    matrix C.  Matrix A is of size (N1,N3), B is (N3,N2), and C is
C    (N1,N2).  N4, N5, N6, N7, N8, and N9, are the actual dimensioned
C    sizes of matrices A, B, and C respectively in the calling program.
      DIMENSION A(N4,N5),B(N6,N7),C(N8,N9)

      DO 1 I=1,N1
      DO 1 J=1,N2
      C(I,J)=0.
      DO 1 K=1,N3
    1 C(I,J)=C(I,J)+A(I,K)*B(K,J)

      RETURN
      END



      SUBROUTINE MVGEN(XX,IISEED,NYR,IER,IDBUG1)

C     MULTIVARIATE GENERATION SUBROUTINE
      REAL MU
      COMMON/C1/A(3,3),B(3,3),MU(3),SIG(3),BETA(3),IV(3),XIC(3)
      DIMENSION Z1(3,1),XX(3,-1:100),E(3,1),DUM1(3,1),DUM2(3,1),Z(3,1)

      DO 125 I=1,3
      Z1(I,1)=XIC(I)-MU(I)
```

```
      IF(IV(I).EQ.-1)Z1(I,1)=ALOG(XIC(I)-BETA(I))-MU(I)
      Z1(I,1)=Z1(I,1)/SIG(I)
  125 CONTINUE
      DO 250 J=1,NYR
      DO 150 I=1,3
      E(I,1)=RNMR(IISEED)
  150 CONTINUE
      IF(IER.EQ.1) WRITE(15,9000)(E(I,1),I=1,3)
      CALL MMULT(A,Z1,DUM1,3,1,3,3,3,3,1,3,1)
      IF(IDBUG1.EQ.1)WRITE(15,9000)(DUM1(I,1),I=1,3)
      CALL MMULT(B,E,DUM2,3,1,3,3,3,3,1,3,1)
      IF(IDBUG1.EQ.1)WRITE(15,9000)(DUM2(I,1),I=1,3)
      CALL MADSUB(DUM1,DUM2,DUM1,3,1,1,3,1,3,1,3,1)
      IF(IDBUG1.EQ.1)WRITE(15,9000)(DUM1(I,1),I=1,3)
      DO 185 I=1,3
      Z(I,1)=DUM1(I,1)
  185 CONTINUE
      DO 200 I=1,3
      Z1(I,1)=Z(I,1)
      XX1=(Z(I,1)*SIG(I))+MU(I)
      IF(IV(I).EQ.-1)XX1=BETA(I)+EXP(XX1)
      IF(XX1.LT.0.)XX1=0.
      XX(I,J)=XX1
  200 CONTINUE
  250 CONTINUE
      DO 260 I=1,3
      IF(IDBUG1.EQ.1)WRITE(15,9001)(XX(I,J),J=1,NYR)
  260 CONTINUE
 9000 FORMAT(3F15.5)
 9001 FORMAT(10F13.2)
      RETURN
      END



      REAL FUNCTION RNMR(ISEED)

C*  Generates random numbers with a 0 mean and variance 1.  Uses a
C   machine function (RAN) which generates random #'s uniformly dis-
C   tributed from 0. to 1.  ISEED should be a large, odd integer.
      DATA ISW/0/

      IF(ISW.EQ.0) GO TO 5
      RNMR=TEMP
      ISW=0
      GO TO 8
 5    XR=2.0*RAN(ISEED)-1.0
      YR=2.0*RAN(ISEED)-1.0
      SR=XR*XR+YR*YR
      IF(SR.GT.1.0) GO TO 5
      SR=SQRT(-2.0*ALOG(SR)/SR)
      RNMR=XR*SR
      TEMP=YR*SR
      ISW=1
 8    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PUMP(VOL,CONVOL,ELEV,SALT,TDS,NT,L)

C* PUMPING OPTION---DETERMINES MAXIMUM EXPORTS WHEN WITH IMPORTS (IF
C  ANY), THE END OF MONTH WATER LEVEL DOESN'T DROP BELOW 'CONELV'.
C  IMPORTS ARE MAXIMIZED AS LONG AS MONTHLY PUMPING ISN'T INCREASED.
C  IF IP3=1, ALLOWS IMPORTS; IF IP4=1, ALLOWS EXPORTS; IF IP4=2, NO
C  EXPORTS ALLOWED WHEN TDS OF EXPORTS < TDS OF BAY; IF IP4=3,
C  EXPORTS ARE UNCHANGED BY THIS SUBROUTINE.
      COMMON/C2/E(40),A(40),V(40),NP
      COMMON/C3/EXPORT(12),EXPMAX(12),WIMP(12),WIMPMAX(12),TDSEXP(12),
     *QPMAX(12),SIMP(12),TDSWEB(12),SEXP(12),QPUMP(12),SQP(12),SGW(12),
     *ELBAY(12,60,100),SSED(12),QGW(12),QRIV(12),QTRIB(12),SRIV(12),
     *STRIB(12),TDSBAY(12,60,100),IP1,IP2,IP3,IP4,AREA
      COMMON/C4/DAY(12),SEDVOL,SSEDTONS,SCOEF
      COMMON/C5/PREC(12),PRE(12),PEVAP(12),FWEV(2),KC(12),EV(12),APE
      REAL KC

      DO 60 K=1,12
       AREAOLD=AREA
       CALL EVAPRE(PEVAP(K),TDS,ELEV,AREA,FWEV(IP1),IP1,IP2,APE,KC(K),
     *EV(K),PREC(K),PRE(K))
       VOL=VOL+QRIV(K)+QTRIB(K)+PRE(K)-EV(K)+QGW(K)
      IF(IP3.NE.1.OR.IP4.EQ.0.OR.IP4.EQ.3) GO TO 10
      EXPORT(K)=VOL-CONVOL+WIMPMAX(K)
      IF(EXPORT(K).LE.0.) EXPORT(K)=0.
      IF(EXPORT(K).GT.EXPMAX(K)) EXPORT(K)=EXPMAX(K)
      IF(IP4.EQ.2.AND.TDSEXP(K).LT.TDS) EXPORT(K)=0.
      WIMP(K)=EXPORT(K)-VOL+CONVOL
      IF(WIMP(K).GT.WIMPMAX(K)) WIMP(K)=WIMPMAX(K)
      IF(WIMP(K).LT.0.) WIMP(K)=0.
      GO TO 50
10    IF(IP3.NE.1) GO TO 20
       WIMP(K)=CONVOL-VOL
       IF(WIMP(K).LT.0) WIMP(K)=0.
       IF(WIMP(K).GT.WIMPMAX(K)) WIMP(K)=WIMPMAX(K)
       GO TO 50
20    IF(IP4.EQ.3) GO TO 40
      IF(IP4.EQ.0) GO TO 30
      IF(IP4.EQ.2.AND.TDSEXP(K).LT.TDS) GO TO 30
       EXPORT(K)=VOL-CONVOL
       IF(EXPORT(K).LE.0) EXPORT(K)=0.
       IF(EXPORT(K).GT.EXPMAX(K)) EXPORT(K)=EXPMAX(K)
       GO TO 50
30     EXPORT(K)=0.
40     WIMP(K)=0.
50    QPUMP(K)=VOL+WIMP(K)-EXPORT(K)-CONVOL
      IF(QPUMP(K).LT.0.) QPUMP(K)=0.
      IF(QPUMP(K).GT.QPMAX(K)) QPUMP(K)=QPMAX(K)
      VOL=VOL+WIMP(K)-EXPORT(K)-QPUMP(K)
      CALL INTERP(ELEV,E,VOL,V,NP)
      ELBAY(K,L,NT)=ELEV
      CALL INTERP(AREA,A,VOL,V,NP)
C*  CALCULATE SALT BALANCE
      SQP(K)=TDS*QPUMP(K)/735.
      CALL SEDSALT(SSED(K),K,AREAOLD,TDS)
      SIMP(K)=TDSWEB(K)*WIMP(K)/735.
      SEXP(K)=TDSEXP(K)*EXPORT(K)/735.
      SALT=SALT+SRIV(K)+STRIB(K)+SGW(K)+SIMP(K)-SEXP(K)+SSED(K)-SQP(K)
      TDS=SALT*735./VOL
      TDSBAY(K,L,NT)=TDS
```

```
60    CONTINUE
      RETURN
      END



      SUBROUTINE QKSRT2(X,IDX,N)

C*  This subroutine sorts the X(N) array.  When through X(L) will
C    correspond to the Lth smallest element of the X(N) array.
      INTEGER P,UV(16),UP,IDX(1)
      DIMENSION X(1),LV(16)

      LV(1)=1
      UV(1)=N
      P=1
    5 IF(P.LT.1) RETURN
    7 IF((UV(P)-LV(P)).GE.1) GO TO 9
      P=P-1
      GO TO 5
    9 LP=LV(P)-1
      UP=UV(P)
      Y=X(UP)
      IY=IDX(UP)
   11 IF((UP-LP).LT.2) GO TO 17
      LP=LP+1
      IF(X(LP).LE.Y) GO TO 11
      X(UP)=X(LP)
      IDX(UP)=IDX(LP)
   13 IF((UP-LP).LT.2) GO TO 15
      UP=UP-1
      IF(X(UP).GE.Y) GO TO 13
      X(LP)=X(UP)
      IDX(LP)=IDX(UP)
      GO TO 11
   15 UP=UP-1
   17 X(UP)=Y
      IDX(UP)=IY
      IF((UP-LV(P)).LT.(UV(P)-UP)) GO TO 19
      LV(P+1)=UP+1
      UV(P+1)=UV(P)
      UV(P)=UP-1
      P=P+1
      GO TO 7
   19 LV(P+1)=LV(P)
      UV(P+1)=UP-1
      LV(P)=UP+1
      P=P+1
      GO TO 7
      END



      SUBROUTINE WEIR(VOL,NT,L,TDS,ELEV,SALT,LEN)

      COMMON/C2/E(40),A(40),V(40),NP
      COMMON/C3/EXPORT(12),EXPMAX(12),WIMP(12),WIMPMAX(12),TDSEXP(12),
     *QPMAX(12),SIMP(12),TDSWEB(12),SEXP(12),QOUT(12),SQO(12),SGW(12),
     *ELBAY(12,60,100),SSED(12),QGW(12),QRIV(12),QTRIB(12),SRIV(12),
     *STRIB(12),TDSBAY(12,60,100),IP1,IP2,IP3,IP4,AREA
```

```
      COMMON/C4/DAY(12),SEDVOL,SSEDTONS,SCOEF
      COMMON/C5/PREC(12),PRE(12),PEVAP(12),FWEV(2),KC(12),EV(12),APE
      COMMON/C6/CONELV,CONVOL,Q,INFLO,IDBG3
      REAL INFLO,KC,LEN

      DO 60 K=1,12
       IF(IP3.NE.1) WIMP(K)=0.
       IF(IP3.EQ.1) WIMP(K)=WIMPMAX(K)
       SIMP(K)=TDSWEB(K)*WIMP(K)/735.
       IF(IP4.EQ.3) GO TO 20
       IF(IP4.NE.0) EXPORT(K)=EXPMAX(K)
       IF(IP4.EQ.0.OR.ELEV.LT.CONELV) EXPORT(K)=0.
       IF(IP4.EQ.2.AND.TDSEXP(K).LT.TDS) EXPORT(K)=0.
20     SEXP(K)=TDSEXP(K)*EXPORT(K)/735.
       INFLO=QRIV(K)+QTRIB(K)+QGW(K)+WIMP(K)-EXPORT(K)
       TDSINF=735.*(SRIV(K)+STRIB(K)+SGW(K)+SIMP(K)-SEXP(K))/INFLO
       CALL SEDSALT(SSED(K),K,AREA,TDS)
       CALL EVAPRE(PEVAP(K),TDS,ELEV,AREA,FWEV(IP1),IP1,IP2,APE,KC(K),
     *EV(K),PREC(K),PRE(K))

C* TEST TO SEE WHICH SUBROUTINE TO CALL
      IF(ELEV.LT.CONELV) GO TO 875
C* CALCULATE OUTFLOW (QMAX) IF BAY DROPS EXACTLY TO WEIR ELEVATION
      QMAX=1.983*DAY(K)*LEN*3.37*((ELEV-CONELV)/2.)**1.5

C*  TEST TO SEE IF BAY ELEV GOES FROM ABOVE TO BELOW THE WEIR
      TEST=VOL-CONVOL+INFLO+PRE(K)-EV(K)-QMAX
875   IF(ELEV.LT.CONELV) THEN
       CALL WEIR1(ELEV,DAY(K),EV(K),PRE(K),VOL,FLAG,FALT,FVOL,LEN)
       ELSE IF(TEST.LT.0.) THEN
         Q=QMAX
        CALL WEIR2(ELEV,DAY(K),EV(K),PRE(K),VOL,FLAG,FALT,FVOL)
       ELSE
        CALL WEIR3(ELEV,DAY(K),EV(K),PRE(K),VOL,FLAG,FALT,FVOL,LEN)
      END IF
      IF(FLAG.EQ.1.) GO TO 500
      CALL INTERP(AREA,A,FVOL,V,NP)
      QOUT(K)=Q
      ELBAY(K,L,NT)=FALT
      ELEV=FALT
      VOL=FVOL

C  CALCULATE SALT INFORMATION
      SQO(K)=TDS*QOUT(K)/735.
      SALT=SALT+SRIV(K)+STRIB(K)+SGW(K)+SIMP(K)-SEXP(K)-SSED(K)-SQO(K)
      TDS=SALT*735./VOL
      TDSBAY(K,L,NT)=TDS

60    CONTINUE
      RETURN
500   STOP
      END



      SUBROUTINE WEIR1(ALT,DY,EVAP,PREC,VOL,FLAG,FALT,FVOL,LEN)

C*  THIS SUBROUTINE CALCULATES THE REQUIRED PARAMETERS IF THE WATER IS
C   BELOW THE CONTROL ELEVATION
      COMMON/C2/E(40),A(40),V(40),NP
```

```
      COMMON/C6/WE,WEVOL,Q,INFLO,IDBG3
      REAL XX(20),GUESS(25),INFLO,LEN

       IF(IDBG3.EQ.1) WRITE(15,10)ALT,DY,INFLO,WE,WEVOL,VOL,EVAP,PREC
10    FORMAT(' WEIR1',10F12.2)
      DIFF=1.0
      FALT=ALT
      N=1
      XX(1)=1.0
      XX(2)=1.0

C  CONVERGE ON FRACTION (XX) OF MONTH TO REACH WEIR ELEVATION
      DO WHILE (DIFF.GT.0.02)
         XX(N+1)=(XX(N+1)+XX(N))/2.
100      N=N+1
         AVGE=(ALT+FALT)/2.
         FVOL=VOL+(PREC+INFLO-EVAP)*XX(N)
         CALL INTERP(FALT,E,FVOL,V,NP)
         IF(IDBG3.EQ.1) WRITE(15,20)N,DIFF,AVGE,FVOL,FALT
         IF(FALT.LE.WE) THEN
           IF(N.GE.3) THEN
              Q=0.
              FLAG=0.
              RETURN  !AFTER 3 TRIALS IF BELOW 'WE' RETURN
           END IF
           XX(N+1)=1.0
           GO TO 100
         END IF
         XX(N+1)=(WEVOL-VOL)/(FVOL-VOL)
         DIFF=ABS(XX(N+1)-XX(N))
         FALT=WE
      END DO

C  KNOWING XX, STORE MID-MONTH VALUES
      PREC1=PREC*XX(N+1)
      EV1=EVAP*XX(N+1)
      ZZ=1.-XX(N+1)
      IF(ZZ.LT.0.02) THEN
        FALT=WE
        Q=0.
        GO TO 300
      END IF
      DAYS=DY*ZZ     ! DAYS IN REMAINDER OF MONTH

      GUESS(1)=WE
      DIFF=1.0
      N=0
C  CONVERGE ON MONTH-END ELEVATION USING NEWTON METHOD
C  --ANALYTICAL DERIVITIVE=dF=(F(X+.001)-F(X))/.001
      DO WHILE (DIFF.GT.0.001)
         N=N+1
         AVGE=(WE+GUESS(N))/2.
         AVGH=AVGE-WE
         CALL INTERP(FVOL,V,GUESS(N),E,NP)
        Q1=WEVOL-FVOL+(INFLO+PREC-EVAP)*ZZ-DAYS*1.983*3.37*LEN*AVGH**1.5
         GUESS2=GUESS(N)+.001
         AVGE=(WE+GUESS2)/2.
         AVGH=AVGE-WE
         CALL INTERP(FVOL,V,GUESS2,E,NP)
        Q2=WEVOL-FVOL+(INFLO+PREC-EVAP)*ZZ-DAYS*1.983*3.37*LEN*AVGH**1.5
```

```
         GUESS(N+1)=GUESS(N)-(Q1*0.001)/(Q2-Q1)
C  H**1.5 IS UNDEFINED IF H < 0
         IF(GUESS(N+1).LT.WE)GUESS(N+1)=WE+.0001
         DIFF=ABS(GUESS(N+1)-GUESS(N))
         IF(IDBG3.EQ.1) WRITE(15,20)N,DIFF,AVGE,GUESS(N+1),Q1,Q2,ZZ
20    FORMAT(I5,F10.5,9F12.2)
         IF(N.GE.25) THEN
           FLAG=1.0
           WRITE(15,900)
900   FORMAT(' WEIR1--HEAD CONVERGENCE ERROR')
           RETURN
         END IF
      END DO
      FALT=GUESS(N+1)
      Q=DAYS*1.983*3.37*LEN*AVGH**1.5
300   FVOL=VOL+INFLO+PREC+EVAP-Q
      CALL INTERP(FALT,E,FVOL,V,NP)
      FLAG=0.0
      RETURN
      END



      SUBROUTINE WEIR2(ALT,DY,EVAP,PREC,VOL,FLAG,FALT,FVOL)

C*  CALCULATES WEIR OVERFLOW AND MONTH-END WATER LEVEL IF THE WATER
C    LEVEL FALLS FROM ABOVE TO BELOW THE WEIR CREST DURING THE MONTH
      COMMON/C2/E(40),A(40),V(40),NP
      COMMON/C6/WE,WEVOL,Q,INFLO,IDBG3
      REAL ALT2(20),INFLO

      IF(IDBG3.EQ.1) WRITE(15,10)ALT,DY,INFLO,WE,WEVOL,VOL,EVAP,PREC
10    FORMAT(' WEIR2',10F12.2)
C  CALCULATE FRACTION (YY) OF MONTH TO DROP TO WEIR ELEVATION
      YY=(WEVOL-VOL)/(INFLO+PREC-EVAP-Q)
      ZZ=1-YY
      FVOL=WEVOL+(INFLO+PREC-EVAP)*ZZ
      CALL INTERP(ALT2(1),E,FVOL,V,NP)
      DIFF=1.0
      N=0

C*  CONVERGE ON FINAL ELEVATION
      DO WHILE (DIFF.GT.0.02)
         N=N+1
         AVGE=(ALT+ALT2(N))/2.
         YY=(WEVOL-VOL)/(INFLO+PREC-EVAP-Q)
         ZZ=1-YY
         FVOL=WEVOL+(INFLO+PREC-EVAP)*ZZ
         CALL INTERP(ALT2(N+1),E,FVOL,V,NP)
         FALT=ALT2(N+1)
         DIFF=ABS(ALT2(N+1)-ALT2(N))
      IF(IDBG3.EQ.1) WRITE(15,20)N,DIFF,AVGE,FVOL,FALT,ZZ
20    FORMAT(I5,F10.5,9F12.2)
         IF(N.GE.20)THEN
           FLAG=1.0
           WRITE(15,900)
900   FORMAT(' WEIR2--ELEVATION CONVERGENCE ERROR')
           RETURN
         END IF
         Q=YY*Q
```

```
      END DO
      FALT=ALT2(N+1)
      FLAG=0.0

      RETURN
      END


      SUBROUTINE WEIR3(ALT,DY,EVAP,PREC,VOL,FLAG,FALT,FVOL,LEN)

C*  CALCULATES WEIR OVERFLOW AND MONTH-END WATER ELEVATION WHEN WATER
C    LEVEL STAYS ABOVE WEIR CREST ELEVATION DURING ENTIRE MONTH
      COMMON/C2/E(40),A(40),V(40),NP
      COMMON/C6/WE,WEVOL,Q,INFLO,IDBG3
      REAL GUESS(25),INFLO,LEN

      IF(IDBG3.EQ.1) WRITE(15,10)ALT,DY,INFLO,WE,WEVOL,VOL,EVAP,PREC
10    FORMAT(' WEIR3',10F12.2)
      GUESS(1)=ALT
      DIFF=1.0
      N=0
C  CONVERGE ON MONTH END ELEVATION USING THE NEWTON METHOD
      DO WHILE (DIFF.GT.0.001)
         N=N+1
         AVGE=(ALT+GUESS(N))/2.
         AVGH=AVGE-WE
         CALL INTERP(FVOL,V,GUESS(N),E,NP)
         Q1=VOL-FVOL+INFLO+PREC-EVAP-DY*1.983*3.37*LEN*AVGH**1.5
         GUESS2=GUESS(N)+0.001
         AVGE=(ALT+GUESS2)/2.
         AVGH=AVGE-WE
         CALL INTERP(FVOL,V,GUESS2,E,NP)
         Q2=VOL-FVOL+INFLO+PREC-EVAP-DY*1.983*3.37*LEN*AVGH**1.5
         GUESS(N+1)=GUESS(N)-(Q1*0.001)/(Q2-Q1)
         IF(GUESS(N+1).LT.WE)GUESS(N+1)=WE+.0001
         DIFF=ABS(GUESS(N+1)-GUESS(N))
         IF(IDBG3.EQ.1) WRITE(15,20)N,DIFF,AVGE,GUESS(N+1),Q1,Q2
20    FORMAT(I5,F10.5,9F12.2)
         IF(N.GE.25) THEN
           FLAG=1.0
           WRITE(15,900)
900   FORMAT(' WEIR3--HEAD CONVERGENCE PROBLEM')
           RETURN
         END IF
      END DO
      AVGH=(GUESS(N+1)+ALT)/2.-WE
      Q=DY*1.983*3.37*LEN*AVGH**1.5
      FVOL=VOL+INFLO+PREC-EVAP-Q
      CALL INTERP(FALT,E,FVOL,V,NP)
      FLAG=0.0
      RETURN
      END
```

Sample Input

```
FARM 3A(-WEIR 100).NOIMPORT.CONDEXPORT(1000),NOMUD%NOMAR,1983 I.C.--4200.5--1943-82 CAL
1986 2035   50   27    0    1    0    0    0    0
3333333.3    1    2    0    2    2    1    3    1
  4200.50   4209.00  50000.00   1000.00    300.00       0.75     100.00        9.59       60.44
   1000.        500.    51000.  3860000.
 1322750.   1641510.
    1    1
   14    1    2    3    4    5   10   15   20   25   30   35   40   45   50
    1    1
    3 0.20 0.50 0.60
  0.47961    0.63976   -0.35161
  0.00576   -0.52537    0.53871
 -0.05631    0.06296    0.72561
  0.34223    0.00000    0.00000
 -0.46612    0.69489    0.00000
 -0.20561    0.28117    0.52101
  2.46000    2.98619   12.70802
  0.22563    0.15665    0.27667
    48.00      -5.00  -50000.00
    60.44      15.05   1000000.
   -1   -1   -1
```

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FARM BAY-WEIR(100),NOIMPORT,CONDEXPORT(1000),NOMUD&NOMAR,1983 I.C.--4200.5--1943-82 CAL

                                   ANNUAI  SUMMARY FOR TRACE #  1

WATER  YR END          ELEVATION                    RIVER     GW       TRIB    IMPORT    EXPORT   PRECIP    EVAP    OUTFLOW
YEAR    ELEV       MAX   MON    MIN   MON          INFLOW   INFLOW   INFLOW   INFLOW   OUTFLOW    (AF)     (AF)     (AF)
1986   4202.6    4206.2   1   4202.6  11          855006.  125305.  220000.      0.        0.   204346.  348219. 1716545.
1987   4202.4    4203.6   8   4202.4  11          843612.  109556.  220000.      0.        0.   157091.  349642.  992047.
1988   4202.0    4203.1   8   4202.0  11          620486.   76067.  220000.      0.        0.   139356.  329203.  763752.
1989   4201.5    4202.5   7   4201.4  11          424111.   61933.  159157.      0.        0.   137519.  314416.  512392.
1990   4201.1    4202.2   7   4201.1  11          400578.   47402.  151559.      0.        0.   104304.  357319.  376809.
1991   4200.9    4202.0   7   4200.9  12          323856.   37672.  126787.      0.        0.    97957.  327510.  274941.
1992   4200.6    4201.8   6   4200.6  12          270056.   32619.  109416.      0.        0.    83572.  328107.  192117.
1993   4201.0    4202.0   7   4200.8   1          330850.   30332.  129045.      0.        0.   103356.  316765.  247152.
1994   4200.9    4202.0   7   4200.9  12          329049.   30503.  128464.      0.        0.    92554.  330523.  257666.
1995   4201.1    4202.2   7   4201.1   1          368119.   33719.  141079.      0.        0.   114694.  317014.  318377.
1996   4200.9    4202.0   7   4200.9  12          296398.   32569.  117921.      0.        0.   126488.  313398.  278768.
1997   4201.0    4202.1   7   4201.0  11          354933.   33438.  136821.      0.        0.   119130.  330105.  303661.
1998   4201.1    4202.2   7   4201.1  11          400088.   34487.  151401.      0.        0.    99192.  335279.  341341.
1999   4201.0    4202.1   7   4201.0  11          323565.   35378.  126693.      0.        0.   123282.  313402.  303949.
2000   4200.9    4202.0   7   4200.9  12          338131.   34827.  131396.      0.        0.   108255.  330908.  286964.
2001   4200.4    4201.7   6   4200.4  12          251810.   29963.  103525.      0.        0.    86153.  344119.  173602.
2002   4200.3    4201.6   7   4200.3  12          213665.   26398.   91209.      0.        0.    99143.  318880.  131160.
2003   4200.2    4201.5   6   4200.2  12          213722.   22278.   91227.      0.        0.    75281.  319752.  109623.
2004   4200.2    4201.5   7   4200.2  12          210627.   20927.   90228.      0.        0.    96574.  320151.  110996.
2005   4200.4    4201.6   7   4200.4  12          239018.   21758.   99395.      0.        0.    82587.  321945.  127235.
2006   4200.7    4201.9   7   4200.7  12          283503.   24047.  113758.      0.        0.   106840.  326090.  218348.
2007   4200.0    4201.5   6   4200.0  12          225563.   24537.   95050.      0.        0.    71608.  354138.  117349.
2008   4200.0    4201.5   7   4200.0  12          237771.   24496.   98992.      0.        0.    80795.  366747.   88354.
2009   4200.0    4201.5   7   4200.0  12          225851.   22605.   95143.      0.        0.    99056.  357356.   91742.
2010   4200.4    4201.7   7   4200.2   1          270253.   24071.  109480.      0.        0.    98790.  356169.  138320.
2011   4200.9    4202.0   7   4200.9  12          348953.   27718.  134890.      0.        0.    96147.  334234.  272858.
2012   4200.8    4201.9   7   4200.8  12          298240.   30092.  118516.      0.        0.   105874.  315898.  243568.
2013   4200.4    4201.7   6   4200.4  12          285283.   30585.  114333.      0.        0.    71798.  354857.  178609.
2014   4200.5    4201.8   6   4200.5  12          253157.   27443.  103960.      0.        0.   101555.  328557.  193006.
2015   4200.1    4201.5   6   4200.1  12          239688.   25523.   99611.      0.        0.    74920.  353384.  118414.
2016   4200.5    4201.7   7   4200.3   1          259932.   24691.  106148.      0.        0.   111696.  333133.  153852.
2017   4200.3    4201.6   7   4200.3  12          225301.   23777.   94966.      0.        0.    85962.  326899.  124527.
2018   4200.8    4201.9   7   4200.8  12          304747.   25911.  120617.      0.        0.   110155.  328205.  233956.
2019   4200.8    4201.9   7   4200.8  12          297484.   27143.  118272.      0.        0.   100251.  320274.  223635.
2020   4200.3    4201.6   6   4200.3  12          210323.   26652.   90130.      0.        0.    95496.  312974.  144408.
2021   4200.8    4201.9   7   4200.8  12          289890.   26164.  115820.      0.        0.   118994.  315275.  237908.
2022   4200.5    4201.7   6   4200.5  12          285153.   25760.  114291.      0.        0.    77184.  348025.  181097.
2023   4200.9    4202.1   7   4200.9  12          322074.   29425.  126212.      0.        0.   137694.  331623.  290742.
2024   4200.4    4201.6   6   4200.4  12          285569.   29284.  114425.      0.        0.    78756.  364378.  186195.
2025   4200.0    4201.5   6   4200.0  12          180431.   25850.   90000.      0.        0.   106833.  340356.  112022.
2026   4200.2    4201.5   7   4200.1   1          223798.   22627.   94481.      0.        0.    95745.  339194.   94716.
2027   4199.6    4201.3   6   4199.6  12          152168.   18251.   90000.      0.        0.    87525.  336125.   60195.
2028   4199.9    4201.2   7   4199.7   1          179178.   18209.   90000.      0.        0.    83757.  314228.   44396.
2029   4199.7    4201.2   7   4199.7  12          179037.   16741.   90000.      0.        0.    68278.  330189.   47101.
2030   4200.6    4201.7   7   4200.0   1          270902.   20635.  109689.      0.        0.   124381.  331611.  138336.
2031   4200.6    4201.8   7   4200.6  12          312303.   25002.  123057.      0.        0.    93477.  361565.  193734.
2032   4200.8    4202.0   7   4200.8   1          311655.   29351.  122848.      0.        0.   138063.  336920.  243598.
2033   4199.9    4201.5   6   4199.9  12          198158.   26965.   90000.      0.        0.    70527.  345082.  115168.
2034   4199.7    4201.2   7   4199.7  12          185663.   22812.   90000.      0.        0.    74460.  347629.   49845.
2035   4200.1    4201.3   7   4199.8   1          192084.   18890.   90000.      0.        0.    82361.  308273.   53684.
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Sample Output

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                                         ANNUAL SUMMARY FOR TRACE #  1

WATER     TOTAL DISSOLVED SOLIDS (MG/L)                      SALT  INPUT  OR  OUTPUT  IN  TONS  PER  YEAR
 YEAR     YR END     MAX  MON    MIN  MON          GAG STR   UNG STR   GR WAT   SED REL    EXPORT     IMPORT    OUTFLOW
 1986      6887.   45637.   1   6887.  12          873079.   276112.  255724.  2520664.        0.         0.  73610360.
 1987      1405.    5865.   1   1405.  12          863586.   276116.  223584.  1078563.        0.         0.   4032962.
 1988      1198.    1333.   1    942.   8          672361.   276216.  155238.   169287.        0.         0.   1134618.
 1989      1429.    1429.  12   1053.   7          493122.   237270.  126394.     8851.        0.         0.    769217.
 1990      1780.    1780.  12   1251.   7          470711.   231819.   96738.   -14291.        0.         0.    682292.
 1991      2058.    2059.  12   1499.   7          395840.   212802.   76882.   -18029.        0.         0.    603222.
 1992      2497.    2497.  12   1761.   7          341376.   198050.   66570.   -21090.        0.         0.    497574.
 1993      2317.    2463.   1   1821.   8          402791.   214625.   61902.    -5579.        0.         0.    675789.
 1994      2343.    2343.  12   1778.   8          401004.   214158.   62250.     2470.        0.         0.    686181.
 1995      2056.    2296.   1   1646.   8          439392.   224024.   68814.     9207.        0.         0.    804274.
 1996      2097.    2097.  12   1593.   8          368272.   205443.   66508.     5107.        0.         0.    666615.
 1997      2034.    2073.   1   1561.   8          426325.   220757.   68241.     2275.        0.         0.    715726.
 1998      1960.    2011.   1   1512.   8          470242.   231704.   70381.     3622.        0.         0.    784169.
 1999      1980.    1980.  12   1518.   8          395550.   212726.   72199.      717.        0.         0.    697232.
 2000      2078.    2078.  12   1559.   8          410000.   216502.   71075.    -3053.        0.         0.    665243.
 2001      2696.    2696.  12   1808.   7          322462.   192713.   61149.   -20480.        0.         0.    452454.
 2002      3035.    3035.  12   2134.   7          282066.   180885.   53792.   -24267.        0.         0.    402654.
 2003      3486.    3486.  12   2431.   7          282128.   180904.   45465.   -23522.        0.         0.    381242.
 2004      3666.    3666.  12   2635.   7          278794.   179899.   42708.   -16572.        0.         0.    421861.
 2005      3658.    3658.  12   2705.   8          309051.   188854.   44405.    -5915.        0.         0.    500716.
 2006      2990.    3204.   1   2316.   8          355164.   201868.   49076.    25835.        0.         0.    774957.
 2007      3827.    3827.  12   2517.   7          294800.   184681.   50076.   -14221.        0.         0.    426412.
 2008      4364.    4364.  12   2921.   7          307736.   188472.   49992.   -31352.        0.         0.    368038.
 2009      4605.    4605.  12   3196.   7          295107.   184772.   46133.   -21943.        0.         0.    420698.
 2010      4128.    4541.   1   3055.   8          341579.   198107.   49125.     7962.        0.         0.    628448.
 2011      2903.    3565.   1   2369.   8          420660.   219255.   56567.    51329.        0.         0.   1022771.
 2012      2624.    2854.   1   2065.   8          370136.   205947.   61413.    28922.        0.         0.    773532.
 2013      3022.    3022.  12   2124.   7          356980.   202366.   62419.    -2282.        0.         0.    550678.
 2014      2890.    2890.  12   2116.   7          323867.   193113.   56006.     1060.        0.         0.    604656.
 2015      3583.    3583.  12   2404.   7          309756.   189058.   52087.   -22743.        0.         0.    409271.
 2016      3285.    3540.   1   2467.   8          330912.   195112.   50390.    -5613.        0.         0.    561218.
 2017      3642.    3642.  12   2616.   7          294521.   184598.   48525.    -9703.        0.         0.    473041.
 2018      2838.    3169.   1   2231.   8          376703.   207716.   52880.    25023.        0.         0.    807405.
 2019      2668.    2801.   1   2070.   8          369371.   205741.   55394.    15678.        0.         0.    701405.
 2020      3084.    3084.  12   2199.   7          278467.   179801.   54391.    -7975.        0.         0.    462496.
 2021      2535.    2710.   1   1978.   8          361670.   203649.   53397.    14488.        0.         0.    775787.
 2022      2893.    2893.  12   2052.   7          356848.   202330.   52571.    -3895.        0.         0.    543990.
 2023      2306.    2527.   1   1794.   8          394065.   212335.   60052.    17131.        0.         0.    807499.
 2024      2839.    2839.  12   1923.   7          357271.   202446.   59763.    -8160.        0.         0.    521910.
 2025      3482.    3482.  12   2279.   7          245825.   179749.   52756.   -28114.        0.         0.    366397.
 2026      3786.    3786.  12   2651.   7          292919.   184124.   46178.   -27303.        0.         0.    352188.
 2027      4860.    4860.  12   3107.   7          213916.   179841.   37248.   -39214.        0.         0.    254250.
 2028      5176.    5176.  12   3690.   7          244378.   179753.   37161.   -40647.        0.         0.    227607.
 2029      6048.    6048.  12   4094.   7          244221.   179753.   34164.   -35707.        0.         0.    271043.
 2030      4477.    5851.   1   3603.   8          342247.   198293.   42112.    29851.        0.         0.    750750.
 2031      3862.    4385.   1   2973.   8          384296.   209746.   51024.    50033.        0.         0.    892264.
 2032      2993.    3742.   1   2417.   8          383645.   209573.   59901.    45019.        0.         0.    923471.
 2033      3960.    3960.  12   2569.   7          265271.   179699.   55031.    -7284.        0.         0.    427436.
 2034      4984.    4984.  12   3204.   7          251560.   179734.   46554.   -48073.        0.         0.    227684.
 2035      5058.    5058.  12   3712.   8          256627.   179716.   38550.   -34604.        0.         0.    250645.
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END OF YEAR TDS IN MG/L

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	11250.	9345.	7143.
1987	3349.	2348.	1802.
1988	2263.	1571.	1250.
1989	2195.	1623.	1403.
1990	2388.	1751.	1487.
1995	3347.	2365.	1803.
2000	3726.	2629.	1875.
2005	4320.	2961.	1914.
2010	4602.	2901.	2157.
2015	4047.	2737.	2080.
2020	3920.	2517.	1803.
2025	3613.	2845.	2000.
2030	3867.	2731.	1793.
2035	3794.	2919.	1860.

MAXIMUM TDS IN MG/L

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	46845.	46372.	45739.
1987	9949.	8183.	6152.
1988	3249.	2241.	1664.
1989	2256.	1729.	1429.
1990	2662.	1780.	1489.
1995	3406.	2420.	1890.
2000	3725.	2896.	2037.
2005	4339.	2983.	1974.
2010	4602.	3092.	2167.
2015	4196.	2901.	2171.
2020	4539.	3000.	1938.
2025	4026.	2906.	2046.
2030	4210.	2805.	1963.
2035	4348.	2919.	1916.

MINIMUM TDS IN MG/L

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	11250.	9345.	7143.
1987	3294.	2348.	1602.
1988	1824.	1333.	1048.
1989	1503.	1231.	1063.
1990	1828.	1295.	1126.
1995	2332.	1746.	1355.
2000	2407.	2064.	1443.
2005	3155.	2097.	1454.
2010	3146.	2198.	1593.
2015	2955.	2029.	1611.
2020	2959.	1994.	1408.
2025	2471.	2102.	1568.
2030	2985.	1982.	1386.
2035	2847.	2036.	1400.

END OF YEAR ELEVATION

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	4202.6	4202.3	4202.1
1987	4202.2	4201.9	4201.5
1988	4202.0	4201.6	4201.0
1989	4201.7	4201.4	4200.8
1990	4201.5	4201.2	4200.7
1995	4201.2	4200.8	4200.2
2000	4201.1	4200.7	4200.1
2005	4201.2	4200.6	4200.1
2010	4201.0	4200.6	4200.1
2015	4201.1	4200.7	4200.2
2020	4201.3	4200.7	4200.1
2025	4201.1	4200.6	4200.0
2030	4201.3	4200.7	4200.2
2035	4201.1	4200.6	4200.2

MAXIMUM ELEVATION

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	4206.2	4206.2	4206.1
1987	4203.3	4202.9	4202.6
1988	4203.1	4202.7	4202.1
1989	4202.8	4202.4	4202.0
1990	4202.6	4202.2	4201.8
1995	4202.2	4201.9	4201.5
2000	4202.2	4201.9	4201.5
2005	4202.3	4201.8	4201.4
2010	4202.0	4201.8	4201.5
2015	4202.2	4201.9	4201.5
2020	4202.3	4201.8	4201.5
2025	4202.1	4201.8	4201.5
2030	4202.3	4201.8	4201.5
2035	4202.2	4201.8	4201.5

MINIMUM ELEVATION

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	4202.6	4202.3	4202.1
1987	4202.2	4201.9	4201.5
1988	4202.0	4201.6	4201.0
1989	4201.7	4201.4	4200.8
1990	4201.5	4201.2	4200.7
1995	4201.2	4200.8	4200.1
2000	4201.1	4200.6	4200.0
2005	4201.1	4200.5	4200.0
2010	4201.0	4200.5	4200.1
2015	4201.1	4200.7	4200.2
2020	4201.2	4200.6	4200.0
2025	4201.0	4200.6	4200.0
2030	4201.2	4200.7	4200.0
2035	4201.1	4200.6	4200.1

ANNUAL OUTFLOW WATER (AF)

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	1691864.	1565781.	1461537.
1987	843020.	709443.	557291.
1988	737432.	589143.	365968.
1989	615418.	468498.	288364.
1990	537674.	379327.	209321.
1995	366811.	241721.	127741.
2000	341228.	219435.	91628.
2005	374535.	185205.	88915.
2010	291895.	182924.	94783.
2015	329889.	206990.	104984.
2020	372729.	209838.	103853.
2025	296769.	186150.	99469.
2030	390736.	214557.	118801.
2035	364971.	208444.	114736.

RIVER INFLOW (AF)

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	822697.	706683.	620005.
1987	728784.	574773.	479370.
1988	613669.	508051.	350395.
1989	538436.	442170.	325858.
1990	485991.	393692.	278804.
1995	394364.	311100.	218490.
2000	382893.	285330.	207025.
2005	406189.	278012.	211380.
2010	344215.	264220.	206734.
2015	380551.	293789.	213000.
2020	413319.	284295.	210323.
2025	349711.	268259.	191915.
2030	405280.	285051.	228219.
2035	384437.	278052.	218415.

ANNUAL EXPORTED WATER (AF)

WATER YEAR	PROBABILITY LEVEL 0.20	0.50	0.80
1986	0.	0.	0.
1987	0.	0.	0.
1988	0.	0.	0.
1989	0.	0.	0.

1990	0.	0.	0.
1995	0.	0.	0.
2000	0.	0.	0.
2005	0.	0.	0.
2010	0.	0.	0.
2015	0.	0.	0.
2020	0.	0.	0.
2025	0.	0.	0.
2030	0.	0.	0.
2035	0.	0.	0.

MONTHLY SUMMARY FOR END OF THE MONTH ELEVATIONS FOR TRACE # 1

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1986	4206.24	4204.82	4204.10	4203.74	4203.65	4203.65	4203.69	4203.77	4203.71	4202.97	4202.57	4202.38
1987	4202.66	4202.79	4202.95	4203.08	4203.23	4203.37	4203.47	4203.58	4203.55	4202.82	4202.42	4202.44
1988	4202.41	4202.48	4202.60	4202.70	4202.82	4202.93	4203.00	4203.06	4202.99	4202.34	4201.99	4202.00
1989	4201.97	4202.05	4202.17	4202.27	4202.36	4202.44	4202.48	4202.47	4202.34	4201.77	4201.45	4201.46
1990	4201.53	4201.69	4201.88	4202.02	4202.14	4202.22	4202.23	4202.19	4202.04	4201.43	4201.08	4201.09
1991	4201.20	4201.40	4201.61	4201.76	4201.89	4201.98	4201.99	4201.94	4201.77	4201.22	4200.89	4200.89
1992	4200.99	4201.18	4201.38	4201.54	4201.67	4201.75	4201.75	4201.67	4201.48	4200.95	4200.60	4200.57
1993	4200.82	4201.13	4201.43	4201.65	4201.82	4201.94	4201.98	4201.96	4201.81	4201.27	4200.95	4200.95
1994	4201.10	4201.31	4201.54	4201.71	4201.85	4201.94	4201.96	4201.91	4201.75	4201.20	4200.86	4200.85
1995	4201.10	4201.37	4201.64	4201.84	4202.00	4202.11	4202.15	4202.14	4202.00	4201.45	4201.13	4201.13
1996	4201.24	4201.43	4201.62	4201.77	4201.89	4201.98	4201.99	4201.94	4201.76	4201.22	4200.90	4200.90
1997	4201.11	4201.37	4201.63	4201.82	4201.98	4202.08	4202.11	4202.08	4201.93	4201.36	4201.03	4201.03
1998	4201.23	4201.48	4201.72	4201.91	4202.06	4202.16	4202.19	4202.18	4202.04	4201.47	4201.13	4201.14
1999	4201.27	4201.47	4201.68	4201.83	4201.96	4202.05	4202.07	4202.03	4201.87	4201.32	4201.01	4201.01
2000	4201.16	4201.39	4201.62	4201.79	4201.93	4202.02	4202.04	4202.00	4201.84	4201.27	4200.94	4200.94
2001	4201.00	4201.16	4201.35	4201.51	4201.62	4201.69	4201.67	4201.57	4201.36	4200.79	4200.42	4200.35
2002	4200.48	4200.96	4201.18	4201.36	4201.49	4201.58	4201.58	4201.49	4201.28	4200.74	4200.38	4200.31
2003	4200.41	4200.86	4201.09	4201.27	4201.40	4201.49	4201.48	4201.39	4201.18	4200.65	4200.27	4200.18
2004	4200.30	4200.77	4201.04	4201.24	4201.40	4201.50	4201.52	4201.43	4201.22	4200.68	4200.31	4200.23
2005	4200.37	4200.83	4201.11	4201.31	4201.47	4201.57	4201.58	4201.50	4201.31	4200.78	4200.42	4200.36
2006	4201.10	4201.29	4201.49	4201.64	4201.77	4201.85	4201.85	4201.78	4201.60	4201.05	4200.70	4200.69
2007	4200.74	4200.93	4201.14	4201.31	4201.44	4201.51	4201.48	4201.37	4201.13	4200.54	4200.11	4199.98
2008	4200.09	4200.34	4200.83	4201.10	4201.31	4201.44	4201.46	4201.37	4201.14	4200.53	4200.09	4199.96
2009	4200.08	4200.34	4200.83	4201.11	4201.32	4201.46	4201.48	4201.39	4201.16	4200.57	4200.14	4200.03
2010	4200.19	4200.74	4201.07	4201.33	4201.52	4201.65	4201.67	4201.60	4201.39	4200.81	4200.42	4200.36
2011	4201.17	4201.39	4201.61	4201.78	4201.91	4202.01	4202.02	4201.98	4201.82	4201.26	4200.92	4200.92
2012	4201.06	4201.28	4201.50	4201.67	4201.81	4201.90	4201.92	4201.86	4201.70	4201.16	4200.84	4200.83
2013	4200.92	4201.12	4201.34	4201.52	4201.65	4201.73	4201.72	4201.63	4201.43	4200.86	4200.48	4200.43
2014	4201.14	4201.28	4201.46	4201.59	4201.70	4201.76	4201.75	4201.66	4201.46	4200.91	4200.55	4200.52
2015	4200.62	4200.84	4201.09	4201.29	4201.44	4201.54	4201.53	4201.43	4201.21	4200.63	4200.21	4200.10
2016	4200.29	4200.83	4201.15	4201.39	4201.57	4201.69	4201.72	4201.66	4201.46	4200.91	4200.55	4200.52
2017	4200.64	4200.87	4201.11	4201.31	4201.45	4201.55	4201.55	4201.46	4201.26	4200.71	4200.34	4200.26
2018	4201.04	4201.26	4201.49	4201.67	4201.81	4201.91	4201.92	4201.87	4201.69	4201.13	4200.80	4200.79
2019	4200.95	4201.19	4201.43	4201.61	4201.76	4201.86	4201.88	4201.82	4201.65	4201.12	4200.77	4200.78
2020	4200.86	4201.04	4201.24	4201.39	4201.51	4201.59	4201.58	4201.49	4201.28	4200.75	4200.40	4200.33
2021	4201.09	4201.30	4201.52	4201.68	4201.81	4201.90	4201.92	4201.87	4201.69	4201.15	4200.82	4200.82
2022	4200.92	4201.12	4201.34	4201.52	4201.65	4201.74	4201.73	4201.65	4201.45	4200.89	4200.52	4200.47
2023	4201.29	4201.48	4201.69	4201.85	4201.97	4202.05	4202.08	4202.02	4201.84	4201.26	4200.93	4200.93
2024	4201.00	4201.18	4201.38	4201.55	4201.68	4201.75	4201.73	4201.64	4201.42	4200.83	4200.44	4200.38
2025	4200.47	4200.94	4201.15	4201.32	4201.44	4201.51	4201.49	4201.37	4201.11	4200.53	4200.10	4199.90
2026	4200.10	4200.37	4200.85	4201.12	4201.32	4201.46	4201.49	4201.41	4201.20	4200.64	4200.24	4200.15
2027	4200.19	4200.39	4200.79	4201.01	4201.17	4201.27	4201.26	4201.14	4200.88	4200.29	4199.81	4199.64
2028	4199.74	4199.97	4200.27	4200.68	4200.94	4201.13	4201.20	4201.16	4200.97	4200.44	4200.05	4199.93
2029	4199.98	4200.18	4200.45	4200.84	4201.05	4201.18	4201.21	4201.12	4200.90	4200.33	4199.87	4199.73
2030	4199.96	4200.31	4200.87	4201.21	4201.46	4201.65	4201.72	4201.69	4201.51	4200.96	4200.61	4200.59
2031	4200.77	4201.05	4201.33	4201.55	4201.71	4201.82	4201.83	4201.76	4201.57	4200.98	4200.60	4200.57
2032	4200.82	4201.14	4201.44	4201.67	4201.84	4201.96	4202.00	4201.95	4201.77	4201.19	4200.83	4200.85
2033	4200.85	4201.00	4201.17	4201.31	4201.41	4201.47	4201.43	4201.30	4201.05	4200.47	4200.03	4199.88
2034	4199.94	4200.16	4200.44	4200.86	4201.07	4201.21	4201.23	4201.14	4200.90	4200.31	4199.84	4199.67
2035	4199.78	4200.03	4200.33	4200.76	4201.01	4201.19	4201.27	4201.23	4201.05	4200.54	4200.17	4200.07

MONTHLY SUMMARY FOR END OF THE MONTH BAY TDS IN MILLIGRAMS PER LITER FOR TRACE # 1

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1986	45637.	40164.	34046.	28359.	23541.	18837.	15037.	11767.	9468.	8690.	7923.	6887
1987	5863.	4942.	4083.	3372.	2821.	2318.	1941.	1643.	1461.	1464.	1464.	1405.
1988	1333.	1248.	1161.	1088.	1030.	980.	950.	942.	964.	1069.	1163.	1198.
1989	1206.	1184.	1150.	1117.	1089.	1064.	1053.	1066.	1112.	1249.	1374.	1425.
1990	1448.	1422.	1379.	1335.	1296.	1263.	1251.	1270.	1332.	1519.	1693.	1780.
1991	1792.	1751.	1690.	1628.	1572.	1523.	1499.	1510.	1572.	1775.	1969.	2058.
1992	2080.	2037.	1968.	1899.	1837.	1783.	1761.	1783.	1867.	2122.	2375.	2497.
1993	2463.	2364.	2239.	2120.	2014.	1915.	1848.	1821.	1855.	2057.	2247.	2317.
1994	2302.	2223.	2118.	2015.	1924.	1840.	1789.	1778.	1827.	2046.	2256.	2343.
1995	2276.	2193.	2069.	1951.	1847.	1749.	1680.	1646.	1669.	1842.	2001.	2056.
1996	2041.	1972.	1881.	1794.	1717.	1645.	1599.	1593.	1643.	1838.	2021.	2097.
1997	2073.	1993.	1891.	1794.	1708.	1628.	1576.	1561.	1602.	1790.	1966.	2034.
1998	2011.	1934.	1837.	1743.	1660.	1583.	1535.	1518.	1552.	1729.	1897.	1960.
1999	1946.	1880.	1794.	1711.	1638.	1569.	1525.	1518.	1562.	1743.	1911.	1980.
2000	1973.	1910.	1824.	1742.	1669.	1601.	1562.	1559.	1610.	1809.	1998.	2078.
2001	2109.	2069.	2003.	1935.	1874.	1823.	1808.	1843.	1948.	2243.	2542.	2696.
2002	2713.	2524.	2428.	2332.	2247.	2171.	2134.	2155.	2259.	2571.	2881.	3035.
2003	3062.	2851.	2747.	2642.	2547.	2466.	2431.	2459.	2577.	2936.	3300.	3486.
2004	3489.	3219.	3076.	2935.	2810.	2698.	2635.	2642.	2752.	3121.	3490.	3666.
2005	3654.	3365.	3207.	3052.	2913.	2787.	2714.	2705.	2796.	3149.	3500.	3658.
2006	3204.	3068.	2897.	2732.	2586.	2448.	2354.	2316.	2362.	2632.	2891.	2990.
2007	3026.	2955.	2844.	2731.	2630.	2546.	2517.	2559.	2706.	3135.	3587.	3827.
2008	3850.	3720.	3425.	3257.	3109.	2981.	2921.	2945.	3094.	3587.	4104.	4364.
2009	4360.	4188.	3838.	3630.	3449.	3287.	3196.	3198.	3338.	3841.	4357.	4605.
2010	4541.	4101.	3854.	3617.	3411.	3220.	3097.	3055.	3136.	3549.	3960.	4128.
2011	3565.	3378.	3155.	2943.	2756.	2576.	2448.	2369.	2375.	2612.	2837.	2903.
2012	2854.	2731.	2580.	2435.	2307.	2185.	2102.	2066.	2103.	2330.	2543.	2624.
2013	2635.	2560.	2452.	2344.	2247.	2163.	2124.	2137.	2230.	2548.	2870.	3022.
2014	2682.	2597.	2481.	2366.	2264.	2170.	2116.	2117.	2196.	2482.	2763.	2890.
2015	2921.	2848.	2736.	2623.	2523.	2438.	2404.	2436.	2566.	2962.	3372.	3583.
2016	3540.	3225.	3046.	2875.	2725.	2585.	2494.	2467.	2535.	2852.	3159.	3285.
2017	3290.	3189.	3049.	2910.	2786.	2676.	2616.	2623.	2730.	3098.	3466.	3642.
2018	3169.	3023.	2844.	2673.	2522.	2378.	2278.	2231.	2266.	2516.	2753.	2838.
2019	2801.	2689.	2546.	2409.	2287.	2173.	2098.	2070.	2114.	2352.	2579.	2668.
2020	2679.	2610.	2509.	2408.	2319.	2239.	2199.	2217.	2318.	2627.	2933.	3084.
2021	2710.	2597.	2455.	2320.	2201.	2087.	2009.	1978.	2020.	2244.	2455.	2535.
2022	2545.	2472.	2369.	2265.	2172.	2091.	2052.	2063.	2150.	2450.	2751.	2693.
2023	2527.	2412.	2270.	2136.	2018.	1906.	1827.	1794.	1830.	2040.	2235.	2306.
2024	2327.	2270.	2182.	2094.	2015.	1948.	1923.	1948.	2049.	2362.	2681.	2839.
2025	2873.	2668.	2569.	2470.	2383.	2308.	2279.	2321.	2465.	2859.	3264.	3482.
2026	3490.	3370.	3113.	2963.	2831.	2714.	2651.	2652.	2782.	3183.	3589.	3785.
2027	3842.	3750.	3500.	3362.	3242.	3142.	3107.	3172.	3377.	3935.	4530.	4860.
2028	4866.	4695.	4461.	4135.	3947.	3760.	3690.	3701.	3856.	4389.	4930.	5196.
2029	5238.	5083.	4855.	4520.	4330.	4167.	4094.	4135.	4344.	4997.	5683.	6049.
2030	5851.	5482.	4921.	4557.	4244.	3946.	3727.	3603.	3621.	4007.	4369.	4477.
2031	4385.	4162.	3890.	3631.	3403.	3190.	3046.	2973.	3016.	3378.	3735.	3862
2032	3742.	3525.	3274.	3041.	2838.	2643.	2498.	2417.	2431.	2688.	2924.	2993.
2033	3033.	2969.	2866.	2761.	2667.	2590.	2569.	2622.	2784.	3230.	3701.	3960.
2034	4017.	3910.	3746.	3492.	3356.	3243.	3204.	3261.	3461.	4036.	4651.	4984.
2035	4971.	4785.	4537.	4202.	4003.	3824.	3721.	3712.	3843.	4335.	4828.	5058.

Appendix B

Field Sampling and Laboratory Studies of the Bottom Sediments

Materials and Methods

Odor microcosms

Location of sample sites. Sediment samples were drained by standing water and mixed thoroughly. Consistency differences in the sediments were noted and varied from oozy sediments with high liquid content to much stiffer sediments lower in moisture.

Glass carboys with volumes of 20 ℓ (about 5 gallons) were used as the odor microcosms. The containers were scrubbed with a non-phorphorus detergent and rinsed with dilute acid (10 percent HCl) and deionized water. Four 1500 ± 100 ml replicates of each sediment type were placed in microcosms and distributed evenly.

Microcosms were then filled with water to the 20 liter mark on April 5-6, 1985. For each sediment type, two replicate microcosms were filled with Great Salt Lake water and two replicates were filled with Logan River water. Logan River water was chosen because it is chemically similar to Weber River water, especially with respect to total dissolved solids and specific conductance.

The microcosms were loosely covered and placed in the dark at 25 ± 2°C. Each microcosms was gently stirred three times a week to prevent the formation of haloclines or unusually anaerobic conditions.

Odor analysis

Samples for odor evaluations were collected and analyzed on May 22 and 23, 1985. These samples included water from the sixteen odor microcosms and water from five sites in Farmington Bay collected on May 22, 1985.

Because of the complex nature of odor perception, and the lack of sensitive chemical procedures that can be correlated with odor, the production of odors in the microcosms was evaluated using a panel of odor judges to determine odor thresholds (APHA 1981). A panel of 11 judges was selected for their sensitivity to odor. On each analysis day panelists evaluated sets of sample dilutions with 8 dilutions/set. Within each set, 2 of the flasks contained deionized water (blanks) while the remaining 6 flasks contained increasing concentrations of odorous water.

Threshold odor number (TON) was calculated as the reciprocal of the dilution of the sample at which odor could be detected. For example, if no dilution of the sample is made the TON is 1, but if a 1:10,000 dilution is made of the sample and the odor is first recognized at that dilution, the TON is 10,000. Six increasing dilutions of the sample surrounding the estimated odor threshold, along with two randomly positioned unidentified blanks and a known reference blank, were presented to the panelists in glass stoppered 500 ml flasks at room temperature. Panelists swirled each sample, removed the stopper, sniffed the vapors and then noted if the sample smelled like pure water (no) or if it had any other detectable odor (yes). Panelists were not made aware of the origins of the samples. Samples within each set were evaluated in order of increasing concentration. Ten and eleven sets of samples were evaluated during each panel session.

Individual threshold values were tabulated and the percentage of panelists who could correctly smell an off-odor at each concentration was calculated. The percent correct was plotted against the TON values for each concentration. The point where 50 percent of the panelists could detect an odor was considered the threshold for that sample and designated as the TON_{50}.

Sediment Core Column Study

Sediment core samples were collected from six sites in Farmington Bay on land April 3, 1985, using acrylic tubes of 1.5" diameter and length sufficient to accommodate up to 20 cm of sediment core depth. Sediment height and weight and volume of the overlying water column were recorded. Samples were vacuum drained to remove the overlying water and Weber River replacement water was added to each column to within approximately 4 cm of the top of the acrylic tube.

Six replicate cores of each sediment type were set up on April 8, 1985 in a room controlled to $12 \pm 1^{o}C$. Three replicate cores of each type were designated "oxic" and were bubbled with laboratory compressed air that had been filtered through granular activated charcoal, glass wool and water. Flow of air was controlled by aquarium-type air valves connected to typon tubing and pasteur pipets whose tips extended about halfway down the overlying column of Weber River water. The three remaining replicate cores for each sediment type were designated "anoxic" and were stoppered and bubbled with high-purity, compressed nitrogen gas. These cores were stored in the dark.

Sample and Analysis

Samples of overlying water above the sediment cores were collected every three days beginning April 9, 1985 and continuing through April 24, 1985. Samples were then collected every five days through May 14, 1985.

On each sample day, about 75 ml of overlying water was collected from each core tube and replaced with an equivalent volume of Weber River water.

Water samples were analyzed for orthophosphorus, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, total phosphorus, total nitrogen, total dissolved solids and specific conductance. All analytical procedures were in accordance with standard methods (APHA 1981) with the exception of total nitrogen which was analyzed by persulfate digestion with subsequent analysis of nitrate-nitrogen (Solorzano and Sharp 1980). Amendments to procedures were made to accommodate the small total sample size of 75 ml, most sample volumes used for analyses were 10 ml.

Farmington Bay samples collected on May 22, 1985, for odor analysis were also analyzed for chlorophyll a by spectro fluorometric methods (APHA 1981) and centrifuged to enumerate algal and diatom species by microscopic techniques.