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# SOME LAKE LEVEL CONTROL ALTERNATIVES FOR THE GREAT SALT LAKE

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Utah Water Research Laboratory
Utah State University
Logan, Utah

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# ABSTRACT

Fluctuations of the level of the Great Salt Lake cause large changes in both surface area and shoreline. Developments adjacent to the lake have been damaged by both high and low lake levels; and unless measures are implemented to regulate lake level fluctuations or otherwise to protect these developments, damages will continue. Various possible management alternatives for mitigating potential damages from lake level fluctuations need to be examined and evaluated.

In this study, three possible techniques are examined for reducing damages from fluctuating water levels at the lake, namely:

1. Consumptively using an increased proportion of the inflowing fresh waters on irrigated crop lands during periods of high lake inflow.

2. Protecting important properties and facilities around the lake through the construction of a system of dikes.

3. Removing lake water through pumping into the West Desert for evaporation.

The above three alternatives are evaluated only for economic feasibility, with physical, legal, and institutional constraints being neglected. The philosophy behind this approach was that if economic feasibility could be demonstrated, other investigations could follow. With reference to the first alternative, the additional irrigation is assumed to occur within the Bear River Basin. The Bear River, which contributes approximately 56 percent of the total inflow to the Great Salt Lake, drains the only tributary basin which contains significant areas of irrigable but not yet irrigated lands.

A reconnaissance level economic analysis of each of the above management alternatives is presented. Capital and annual costs are estimated and compared with estimates of the flood control benefits generated. The overall feasibility, the optimum design, and the optimum time of construction are thus determined for each alternative. From the results of the study, it is concluded that irrigation in the Bear River Basin, except perhaps as part of a multiple purpose project, and the West Desert pumping alternatives are not economically feasible. Particular configurations of the dike alternative are economically attractive if construction is commenced when lake levels rise to elevations exceeding 4202 feet.

## ACKNOWLEDGMENTS

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Thanks also are expressed to Messrs. Barry Saunders, Lloyd Austin, and Norman Stauffer of the Water Resources Division of the State Department of Natural Resources and Energy for their helpful comments and constructive suggestions. Members of the Great Salt Lake Technical Advisory Committee also provided helpful suggestions and information during the study.

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# CHAPTER I

# INTRODUCTION

## Background of Study

Fluctuations of the surface elevation of the Great Salt Lake mean large variations in surface area, shoreline, and salinity concentration. Seiches and oscillatory waves during windy periods add substantially to the areas subject to inundation during storm periods. Facilities and activities near the lake suffer damages or losses when levels either rise above or fall below an optimal range. Major losses can be expected periodically in the future unless measures are implemented to control lake level fluctuations or otherwise protect these developments. For this reason, there is a need to examine and evaluate various alternatives for either holding lake levels within tolerable limits or otherwise reducing damages from the lake fluctuations.

## The Great Salt Lake

The Great Salt Lake is all that remains of a large body of water known as Lake Bonneville which once covered much of the Great Basin region. It is the largest salt water lake in the United States and one of the most salty bodies of water in the world, being approximately 25 percent mineral by weight. The lake has a drainage basin of 21,540 square miles and is fed principally by the Bear, Weber, and Jordan Rivers (see Figure 1.1). Since the lake lies in the bottom of a closed basin, the only outflow is evaporation.

At a water surface elevation of 4200 feet, the Great Salt Lake is about 70 miles long, 40 miles wide, and very shallow, with an average depth of 14.2 feet and a maximum depth of 35 feet (Utah Division of Water Resources 1974). At the surface elevation of 4200 feet, the lake has a surface area of about 1,079,000 acres and a volume of 15,370,000 acre-feet. In 1959, Southern Pacific Railroad constructed a causeway which divided the lake into north and south arms. Because nearly all of the fresh water inflow occurs to the south arm (Figure 1.1), this body of water has stratified, with a diluted brine overlying a concentrated brine. The north arm has a more uniform concentrated brine (Jones et al. 1976).

## Development of lake resources

Industrial developments. Seven industrial firms are recovering minerals from the brines of the Great Salt Lake at this time. They are Great Salt Lake Minerals and Chemicals Corporation, Lake Crystal, AMAX Corporation, Solar Division of American Salt, Domtar Industries, Stauffer Chemical, and Morton Salt (Figure 1.2). In 1976, these industries (or their predecessor) had a total replacement value of $200 million and operated ponds enclosed by approximately 65 miles of dikes. It has been estimated that if the industries had been operated at capacity in 1976, the total annual value of the products (1976 dollars) would have been close to $90 million (Bradley 1978; Harza Engineering Company 1976).

Transport. Several railroads and highways are located close to the lake, and about 15 miles of dikes have been constructed for highway protection

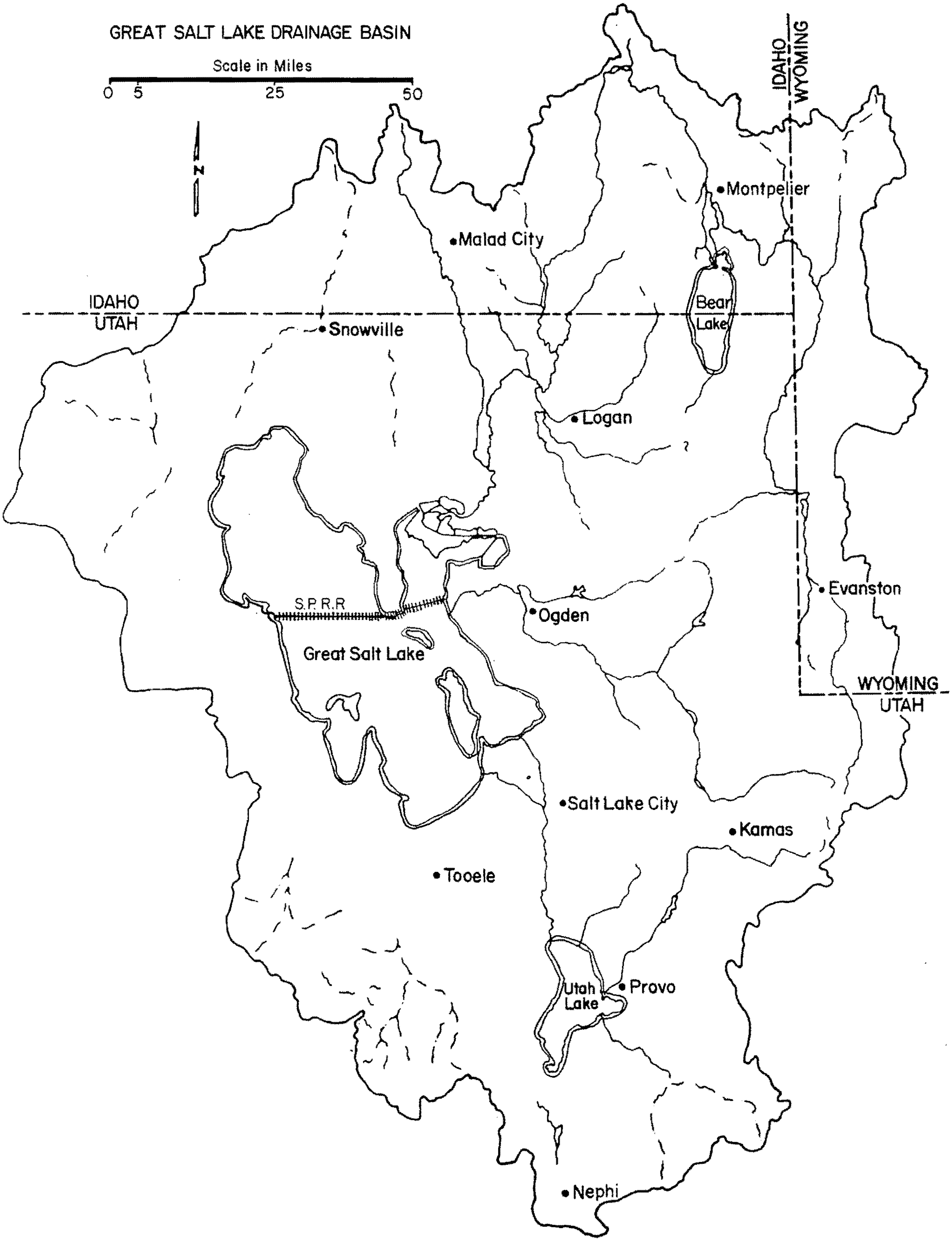


Figure 1.1. Great Salt Lake Basin (Utah Division of Water Resources 1974).

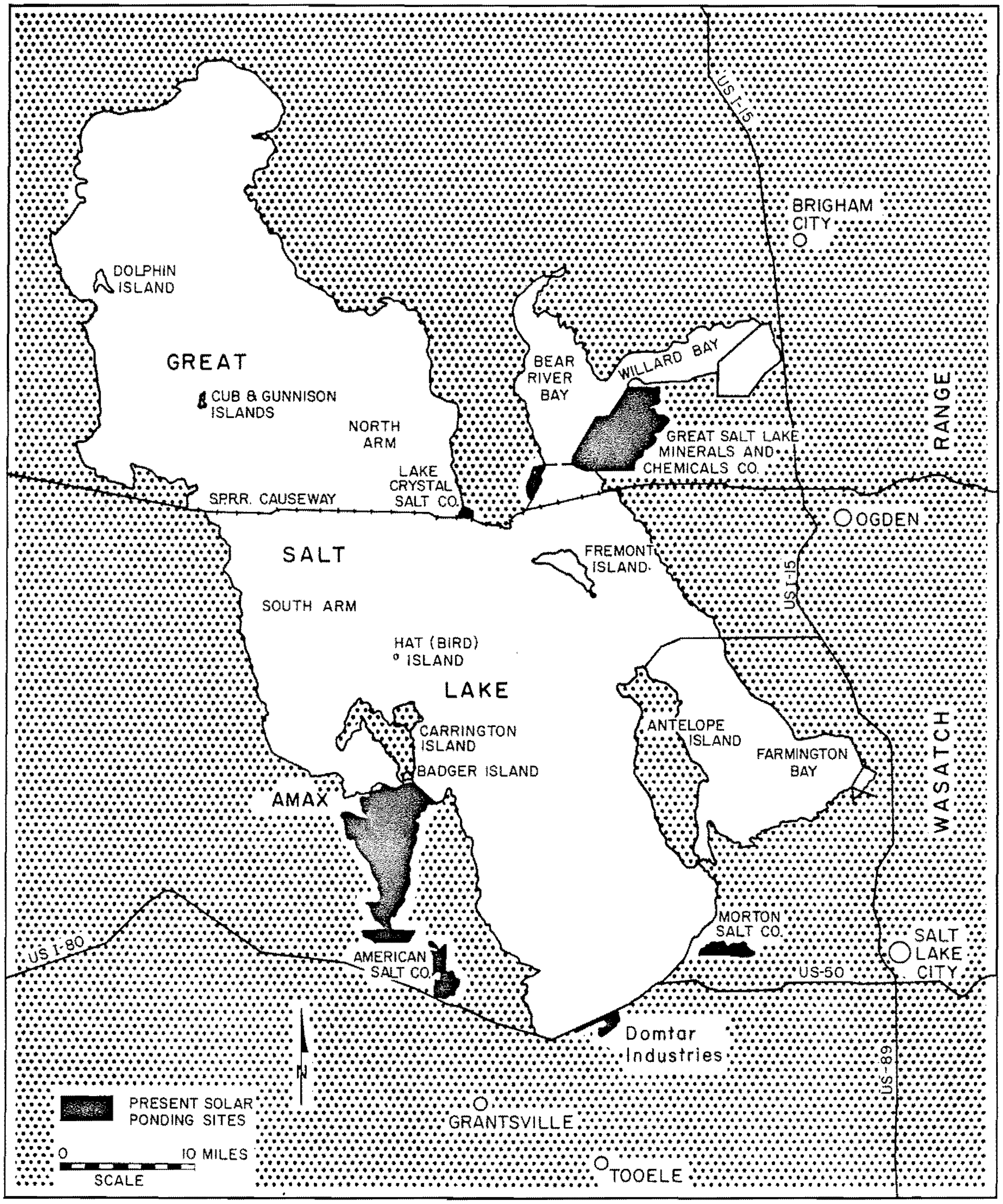


Figure 1.2. Map showing location of industries adjacent to Great Salt Lake.

(Harza Engineering Company 1976). Interstates 80 and 215, Western Pacific, and Union Pacific Railroads cross lands bordering on the south shore of the Great Salt Lake. Union Pacific and Denver-Rio Grande Railroads as well as Interstate 15 border on portions of the east shore. Southern Pacific Railroad has constructed a causeway across the lake, and the Utah Department of Highways has built a causeway to the state park on Antelope Island. A few other minor railroad lines and county roads are in the Great Salt Lake floodplain. The Salt Lake International Airport is located near the south end of the lake at an elevation of approximately 4218 feet and would be adversely affected by extremely high lake stages.

Waterfowl preserves. Marsh areas along the eastern shore of the Great Salt Lake historically have some of the largest waterfowl concentrations in North America, with nearly 200 different species having been identified. The marshes are located between the Pacific and Central Flyways and serve as some of the more important breeding grounds for waterfowl in the United States. They are especially important as nesting areas for the Canada Goose (Office of Legislative Research, State of Utah 1976). To protect these marshlands, a number of waterfowl management areas have been established. The federal government established the Bear River Migratory Bird Refuge located at the mouth of Bear River while the State of Utah has developed a total of eight waterfowl management areas. These include Timpie Springs, Farmington Bay, Howard Slough, Ogden Bay, Harold S. Crane, Public Shooting Grounds, Salt Creek, and Locomotive Springs (Figure 1.3). The federal bird refuge includes 36 miles of protective dikes, and the state bird refuges have a total of 44 miles of dikes (Harza Engineering Company 1976). Private hunting clubs are now located around the lake on most of the remaining marsh lands.

Recreational developments. A number of recreational facilities have been constructed on the shores of the Great Salt Lake in the past. Resorts have included Lake Park, Lake Point, Black Rock, Garfield Beach, Syracuse, and Saltair, all of which were constructed in the late 1800s. About 1890 lake levels began dropping and the receding shorelines caused all but Saltair to lose popularity and eventually cease operations. Saltair, built in 1893, included a large pavillion, an amusement park, and swimming facilities and was constructed on pilings over the water and situated several hundred feet from shore. This location enabled the resort to survive the low lake levels which occurred from 1900 to 1910, and it became nationally famous in the 1920s. Declining lake levels began again in the 1930s and became an important contributing factor in the eventual closing of Saltair (Office of Legislative Research, State of Utah 1976; Allen 1979).

Present recreational facilities on the lake are Great Salt Lake State Park on Antelope Island, and Saltair Beach State Park on the south shore of the lake. They provide primarily swimming, picnicking, camping, sightseeing, and boating facilities. Development of the park on Antelope Island required the construction of a 7-mile long causeway across the north end of Farmington Bay from Syracuse to the island.

## Lake stage damages

Most of the present developments around the Great Salt Lake would be damaged by high lake levels and some could sustain losses due to low lake levels. The concern in the late 1970s, which prompted this study, was the now rising level of the lake.

Fluctuating lake levels. The maximum recorded elevation for the Great Salt Lake was observed in 1873 at 4211.6 feet above sea level. After its lowest recorded level occurred in 1963 at 4191.5 feet above sea level, the Great Salt Lake rose at an average rate of

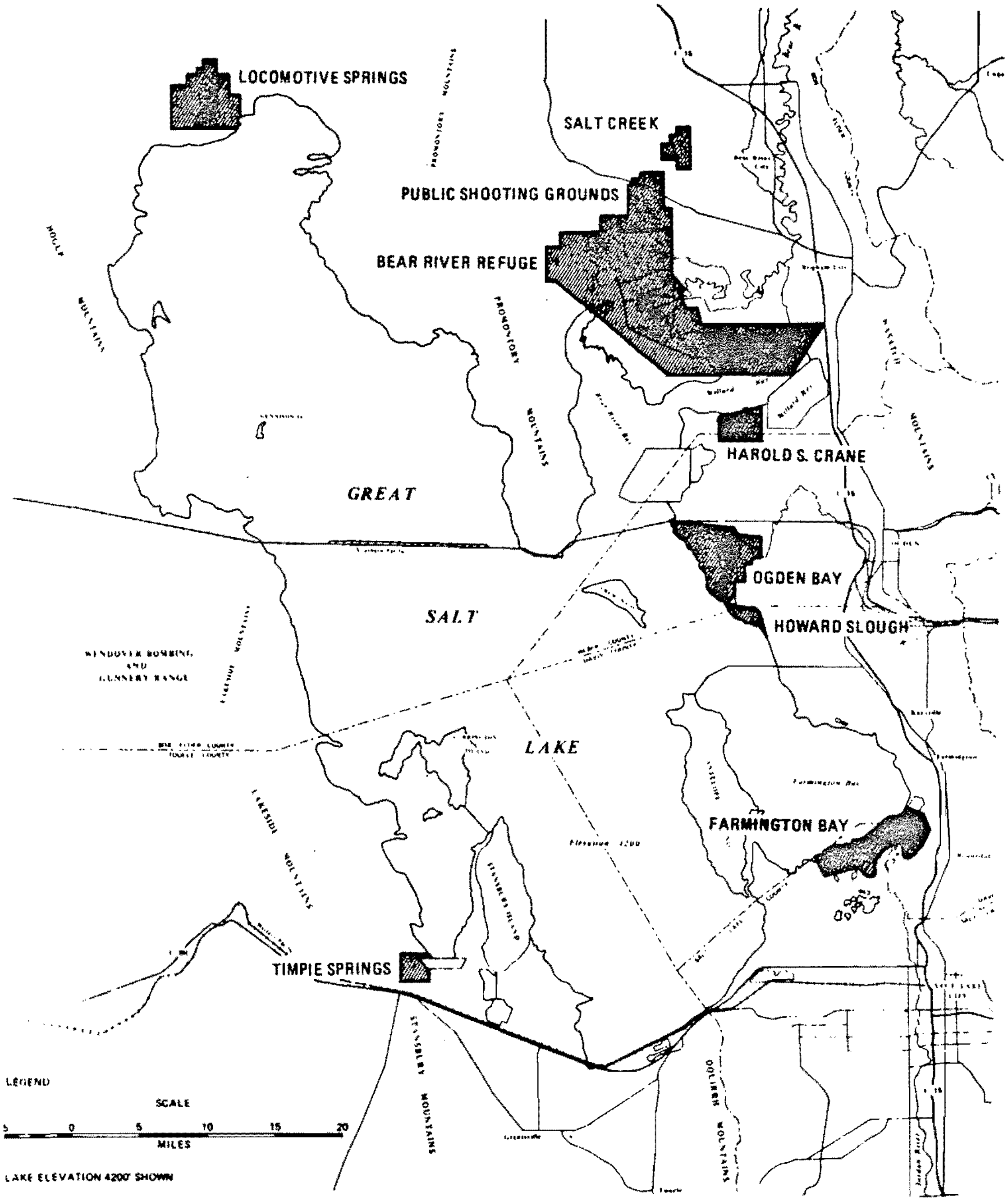


Figure 1.3. Locations of state and federal bird refuges at the Great Salt Lake (Office of Legislative Research, State of Utah 1976).

about 1 foot per year to a high of 4202.25 in 1976 (see Figure 1.4). From 1977 to 1982 maximum annual lake levels ranged from 4199.90 to 4200.85 feet elevation. As of January 1, 1983, the lake level had risen to 4201.65 and was threating to reach over 4203 by spring. This would be the highest peak since 1927.

As one can see from the stage-area-volume data on Table 1.1, the gentle slopes of the lake bed cause small fluctuations in lake level depth to produce drastic changes in surface area and shoreline. Fluctuations of just a few feet expose or flood several hundred square miles of land.

High lake level damages. A 1976 study estimated that a lake elevation of 4206 feet would cause capital damages of approximately $25 million to industries, $12 million to state owned facilities, and $5 million to other developments (Searle 1977). In 1976, the Great Salt Lake reached a level of 4202.25 feet above sea level and caused about $4 million worth of damage (James et al. 1979). At a lake elevation of 4207, another $57 million of damages would occur. The Great Salt Lake has not been at these levels since about 1885, but levels of this magnitude have about a 10 percent chance of occurring during the next 35 years even with the present water consumption and storage facilities upstream of the lake.

### Alternatives for controlling lake levels

The goal of protecting the developments adjacent to the Great Salt Lake against damages from rising levels, such as would occur should the trend of the past decade continue, has resulted in identification of various means of

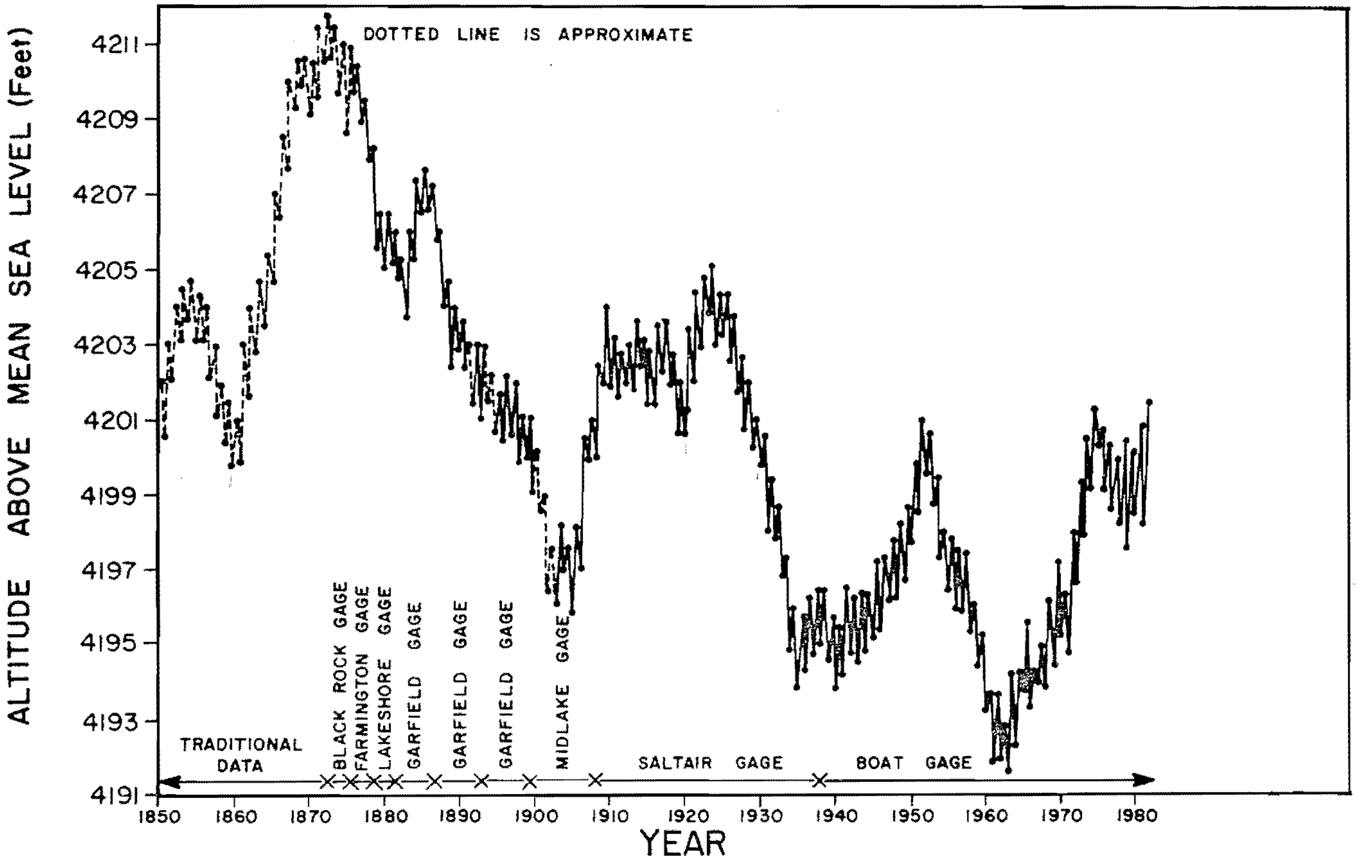


Figure 1.4 Historic surface elevation of Great Salt Lake (Jones et al. 1976).

protection against high water damages. Suggested alternatives include:

1. Increase the width of the openings in the Southern Pacific Railroad causeway across the lake.

2. Increase evaporation during high lake periods by pumping lake water into the desert west of the lake.

3. Construct dikes to protect various developments around the lake.

Table 1.1. Stage-area-volume-evaporation data for the Great Salt Lake.

| Water Surface Elevation (feet) | Surface Area 1000 Acres | Storage Volume 1000 Acre-feet | Water Loss 1000 AF/year |
|---|---|---|---|
| 4170 | 161 | 160 | 405 |
| 4180 | 407 | 2951 | 1023 |
| 4184 | 482 | 4733 | 1212 |
| 4186 | 509 | 5725 | 1280 |
| 4188 | 535 | 6769 | 1345 |
| 4189 | 550 | 7311 | 1383 |
| 4190 | 564 | 7868 | 1419 |
| 4191 | 580 | 8440 | 1458 |
| 4192 | 602 | 9031 | 1513 |
| 4193 | 633 | 9646 | 1591 |
| 4194 | 678 | 10301 | 1704 |
| 4195 | 720 | 11002 | 1810 |
| 4196 | 773 | 11750 | 1943 |
| 4197 | 840 | 12556 | 2111 |
| 4198 | 890 | 13422 | 2292 |
| 4199 | 970 | 14350 | 2557 |
| 4200 | 1079 | 15370 | 2908 |
| 4201 | 1140 | 16481 | 3133 |
| 4202 | 1175 | 17641 | 3288 |
| 4203 | 1201 | 18829 | 3413 |
| 4204 | 1223 | 20041 | 3524 |
| 4205 | 1251 | 21277 | 3648 |
| 4206 | 1330 | 22542 | 3923 |
| 4207 | 1375 | 23808 | 4100 |
| 4208 | 1410 | 25075 | 4240 |
| 4209 | 1450 | 26341 | 4397 |
| 4210 | 1490 | 27607 | 4550 |
| 4211 | 1530 | 29800 | 4722 |
| 4212 | 1570 | 30700 | 4862 |
| 4219 | 2000 | 43200 | 6431 |

4. Increase consumptive use of fresh waters through upstream irrigation to reduce inflow to the lake during periods of high lake levels.

5. Various combinations of the above alternatives.

6. A "do nothing" alternative.

## Past studies of high-water control alternatives

The causeway opening alternative. Harza Engineering Company (1976) recommends that implementation of any long-term measures be preceded by a study to evaluate the effects on lake elevations at the south shore of increasing the total width of the openings in the railroad causeway. The Utah Division of Water Resources and Utah Water Research Laboratory (1977) conducted a benefit-cost analysis of this alternative and pointed out that the greatest loss happens when a short period of high inflow occurs with the lake already at a relatively high level. They concluded that opening the railroad causeway would give only limited and short term relief from rising lake levels, and would not significantly reduce damages over the long term.

Studies of the West Desert pumping alternative. The Sacramento District, U.S. Army Corps of Engineers, performed a preliminary study of pumping lake water into the West Desert near Lakeside for evaporation (Utah Division of Water Resources 1976). Three alternative plans would result in average annual net evaporations of 310,000, 380,000, and 850,000 acre-feet of water, respectively.

Each of the three alternatives proposes to pump water from the south arm of the Great Salt Lake during high lake stages. The water would be impounded near the Newfoundland Mountain Range to produce a shallow lake for evaporation. A return canal would be constructed to convey concentrated brine back to the north arm of the lake in order to prevent precipitation and buildup of salts in the impoundment area. An alternative drainage canal to the south arm could be constructed, but at a significantly greater cost.

The first alternative (Figure 1.5), resulting in a net annual evaporation of 310,000 acre-feet, pumps up to 1,000 cfs through a canal from the lake to the holding area. The confinement would have an area of 96,000 acres and contain 137,000 acre-feet at elevation 4215. Two dikes would be required, one on the north to protect the Southern Pacific Railroad and one on the east to prevent flow back to the Great Salt Lake. A channel for a return flow of 600 cfs would be required. Over a 9-month pumping period, about 520,000 acre-feet could be removed from the lake, 210,000 acre-feet would be returned, and 310,000 acre-feet would be lost to evaporation.

The second alternative (Figure 1.6) is similar to the first with the exception that the containment area has a maximum surface elevation of 4216 feet, a surface area of 105,000 acres, and a volume of 240,000 acre-feet. The pump capacity is 1200 cfs, and the return canal has a capacity of 800 cfs. For a 10 month pumping period, about 690,000 acre-feet could be removed from the lake, approximately 310,000 acre-feet returned, with a possible net average annual evaporation of 380,000 acre-feet.

The third alternative inundates a much larger area both east and west of

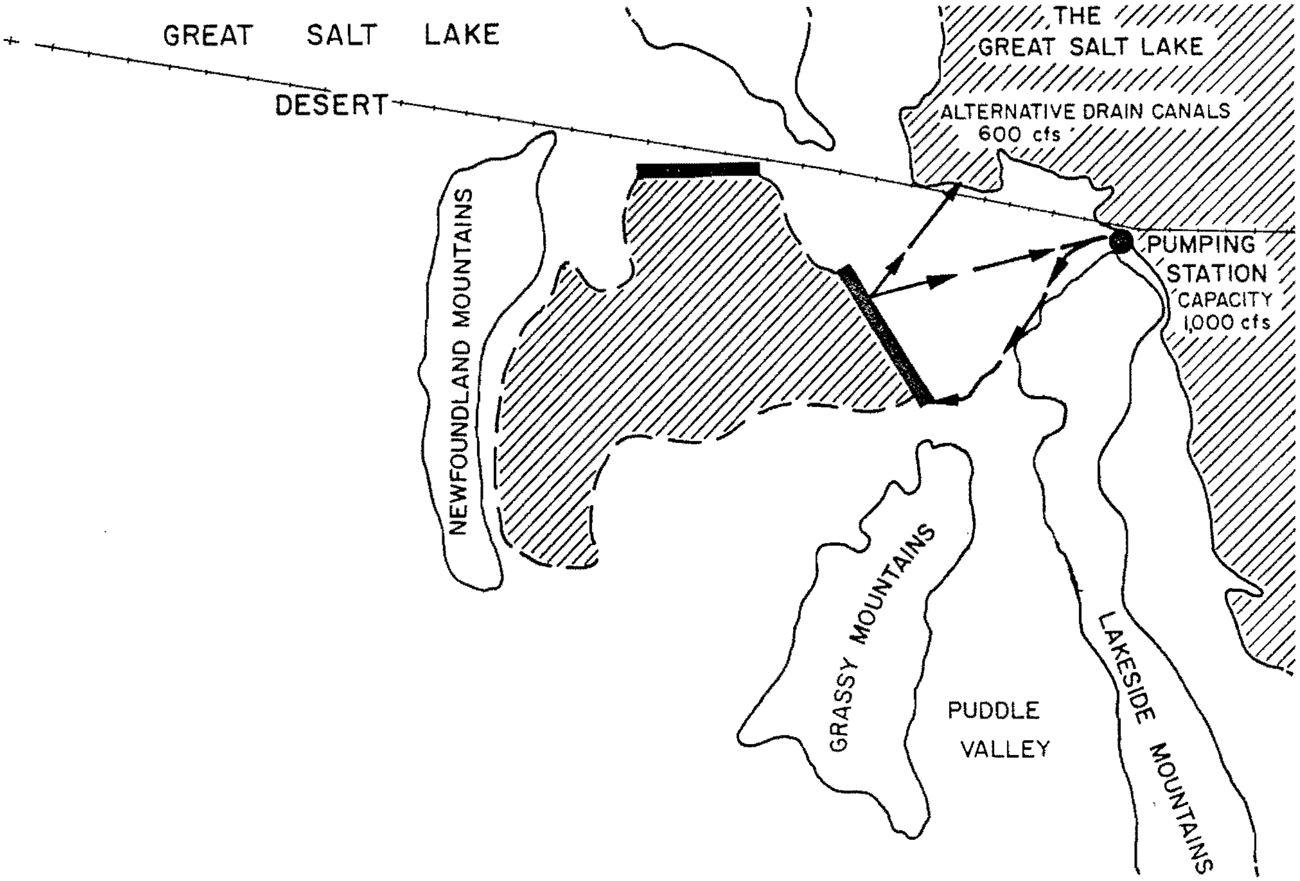


Figure 1.5. Map of pumping alternative #1.

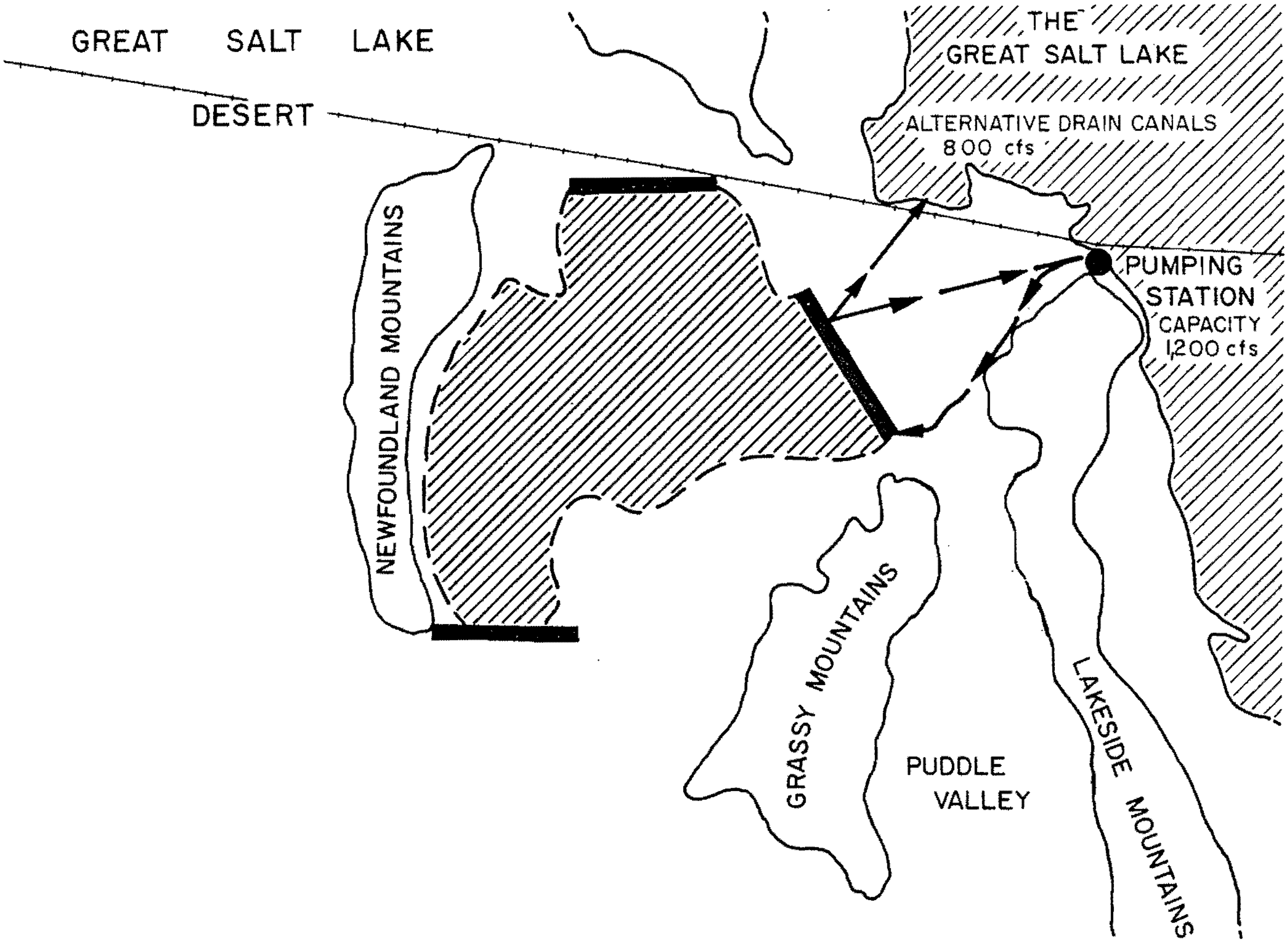


Figure 1.6. Map of pumping alternative #2.

the Newfoundland range (Figure 1.7). With a maximum surface elevation of 4216 for the east area, and 4215 for the west area, the impoundment has a surface area of 311,000 acres and a volume of 540,000 acre-feet. The pump capacity is 2500 cfs, and the return channel conveys a maximum of 1000 cfs from the east area. A net annual evaporation of 850,000 acre-feet could be expected. Without a return channel from the west area, a buildup of salts would reduce the holding capacity. A return channel for the west area could be constructed, but at considerable cost.

The Utah Division of Water Resources (1977) developed a computer simulation model for the Great Salt Lake and evaluated the effectiveness of pumping to the West Desert, along with several other alternatives for controlling the lake level. As input data to the model, the authors used the historical inflows to the lake for the period 1868 to 1969 as adjusted for present day consumptive use conditions. Pumping was initiated in the model when lake level passed an elevation of 4200, and was discontinued when levels dropped below this same elevation. They found that at present rates of upstream water use an average water volume of about 2,000,000 acre-feet would have needed to be pumped from the lake each year during periods of high lake inflow in order to prevent surface elevations from exceeding the 4202 foot level during the 1868

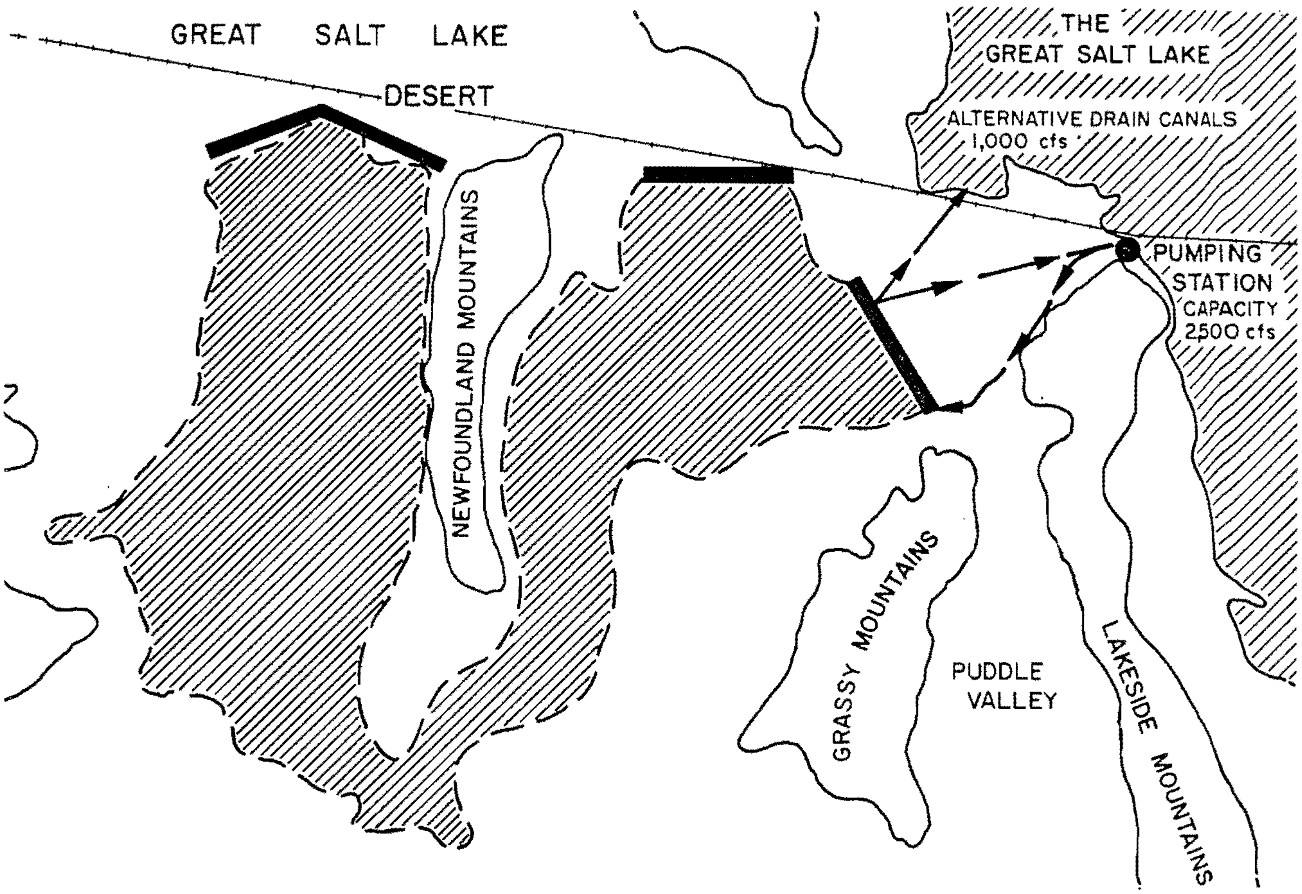


Figure 1.7. Map of pumping alternative #3.

to 1969 historical record. The authors concluded that a combination of pumping to the West Desert and increased upstream consumptive use likely would be the most suitable means of controlling lake levels, noting that pumping would be the most satisfactory method for handling short periods of very high inflow.

Later, the Utah Division of Water Resources coupled their computer simulation of the Great Salt Lake levels with a stage-damage model and estimated the reduction of damages that the West Desert pumping alternative would achieve. They simulated five pumping capacities with the results summarized in Table 1.2.

Study of the diking alternative. At the request of the Office of Legislative Research, State of Utah, Riley (1977) evaluated a proposal for a system of dikes or levees to protect various interests around the lake. A preliminary levee design was patterned after the Willard Bay diking system designed by the U.S. Bureau of Reclamation (Figure 1.8). The proposed embankment is covered by rip-rap for protection from wave action. Possible dike locations considered are shown on Figure 1.9 and the mutually exclusive combinations are shown by Table 1.3.

Dike 15 would protect the Ogden Bay bird refuge, and dike 19 would protect the Bear River bird refuge. Each would require a pumping plant to lift the flow of the Weber and Bear Rivers, respectively, into the Great Salt Lake. The required pump capacities were estimated by Riley to be about 10,000 cfs, and the cost for each pump was estimated at about $10 million (1975 dollars).

Table 1.2. Average annual reduction in damages at the Great Salt Lake from pumping to the West Desert.[a]

| Pumping Depletion[b] (1000 acre-feet) | Average Annual Reduction in Total Damages[c] (1000 Dollars) |
|---|---|
| 250 | 253 |
| 500 | 650 |
| 750 | 1203 |
| 1000 | 1716 |
| 1250 | 1829 |

[a] From Utah Water Research Laboratory and the Utah Division of Water Resources 1977.

[b] Pumping was initiated when lake levels reached an elevation of 4200 feet and was discontinued when levels fell to this elevation.

[c] Based on 1976 dollars and 1850 to 1975 historical inflows to the Great Salt Lake adjusted for current consumptive use rates.

Table 1.3. Alternative diking combinations.[a]

| If the Following Dikes are Used (Figure 1.9) | Then the Following Dikes are Not Necessary (Figure 1.9) |
|---|---|
| 4 | 4.5 |
| 7, 8, 9, 10, 11 | 12, 13, 14 |
| 19 | 18, 18.5 |

[a] From Utah Water Research Laboratory (1977).

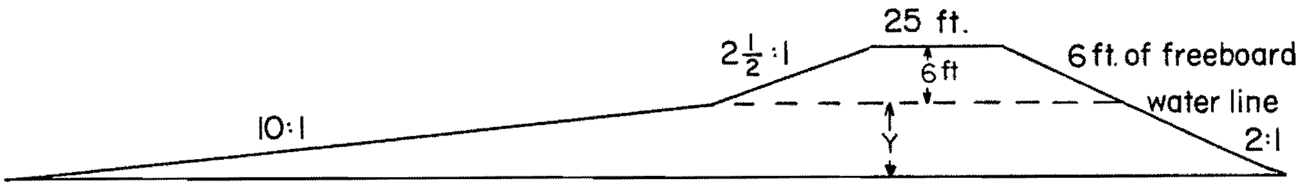


Figure 1.8. Typical dike cross-section assumed for protection at the Great Salt Lake (from Utah Water Research Laboratory 1977).

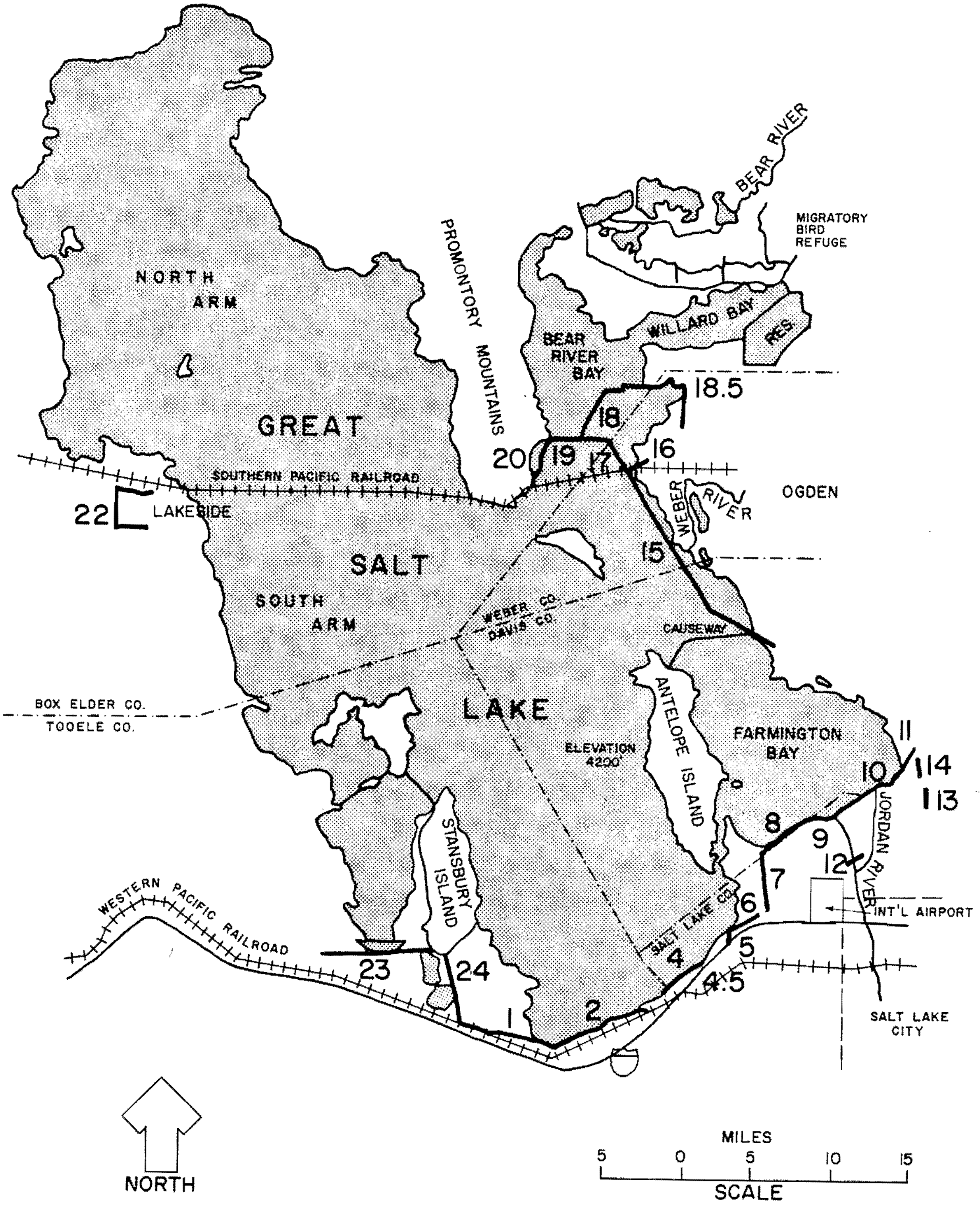


Figure 1.9. Alternative dike layout configurations indicating dike section numbers (from James et al. 1979).

Protection of all bird refuges, highways, railroads, and mineral companies would require construction of dikes 1, 2, 4.5, 5, 6, 7, 8, 9, 10, 11, 15, 17, 19, 20, 21, 22, 23, and 24.

Cost estimates for the dikes using the above levee design should be regarded as preliminary since no on-site investigations were made to determine foundation conditions, availability of materials, and other information needs. Two estimates were obtained on the unit costs of the dikes. An estimate of $1.25 per cubic yard in place (1975 dollars) was obtained from a local contractor, who assumed the borrow pits would be near the dike location. An estimate of $2.08 per cubic yard in place was obtained from actual cost figures for the Willard Bay project updated to 1975 dollars.

The estimate based on the Willard Bay project costs was considered more realistic and was used to estimate the cost of each dike from the average cross-sectional area and the length of dike section. The volume thus determined was increased by 30 percent to allow for settlement and consolidation of the foundation. Diking has intangible advantages due to its flexibility as to area protected, and for building and raising dikes as needed and its potential lack of interference with other uses of the lake.

Study of upstream consumptive use alternative. The possibility of consumptively using more fresh water before it becomes mixed with the briney waters of the Great Salt Lake is appealing because it offers fresh water to agricultural lands which are not presently irrigated. The Bear River contributes approximately 56 percent of the inflow to the Great Salt Lake and drains the only basin tributary to the lake containing significant areas of irrigable but not yet irrigated lands.

The U.S. Bureau of Reclamation (USBR) has identified approximately one million acres of arable land in the Bear River Basin, of which approximately 500,000 acres are being irrigated by existing projects (Figure 1.10). However, some of these lands are presently receiving only supplemental irrigation. The USBR (1970) also has conducted preliminary investigations for proposed projects which would irrigate up to 300,000 acres of arable land, which includes bringing to full service some lands presently receiving supplemental irrigation.

Riley (1978) in a progress report evaluating this alternative for Reed T. Searle, then Research Analyst for the State of Utah, suggests the need to examine the feasibility of consumptively using an increased proportion of fresh waters of the Bear River as a means for controlling levels of the Great Salt Lake.

A possible water use strategy would be to:

1. Irrigate on a continuous basis all of those lands in which the benefit/cost (B/C) ratios are greater than one.

2. During rising lake stages, additional lands would be brought under irrigation as needed, beginning at a particular lake stage, 4202 feet for example. Under falling lake levels these lands would not be irrigated.

3. Those projects not used continuously (B/C ratios less than one) would be subsidized as needed for economic feasibility by flood control benefits.

Riley proposed that determination of the acreages to be irrigated and comprehensive evaluation of the above strategy would require a water accounting model of the Bear River Basin, including reservoir and water rights constraints; a stochastic input model giving quantities of water available at various locations along the length of

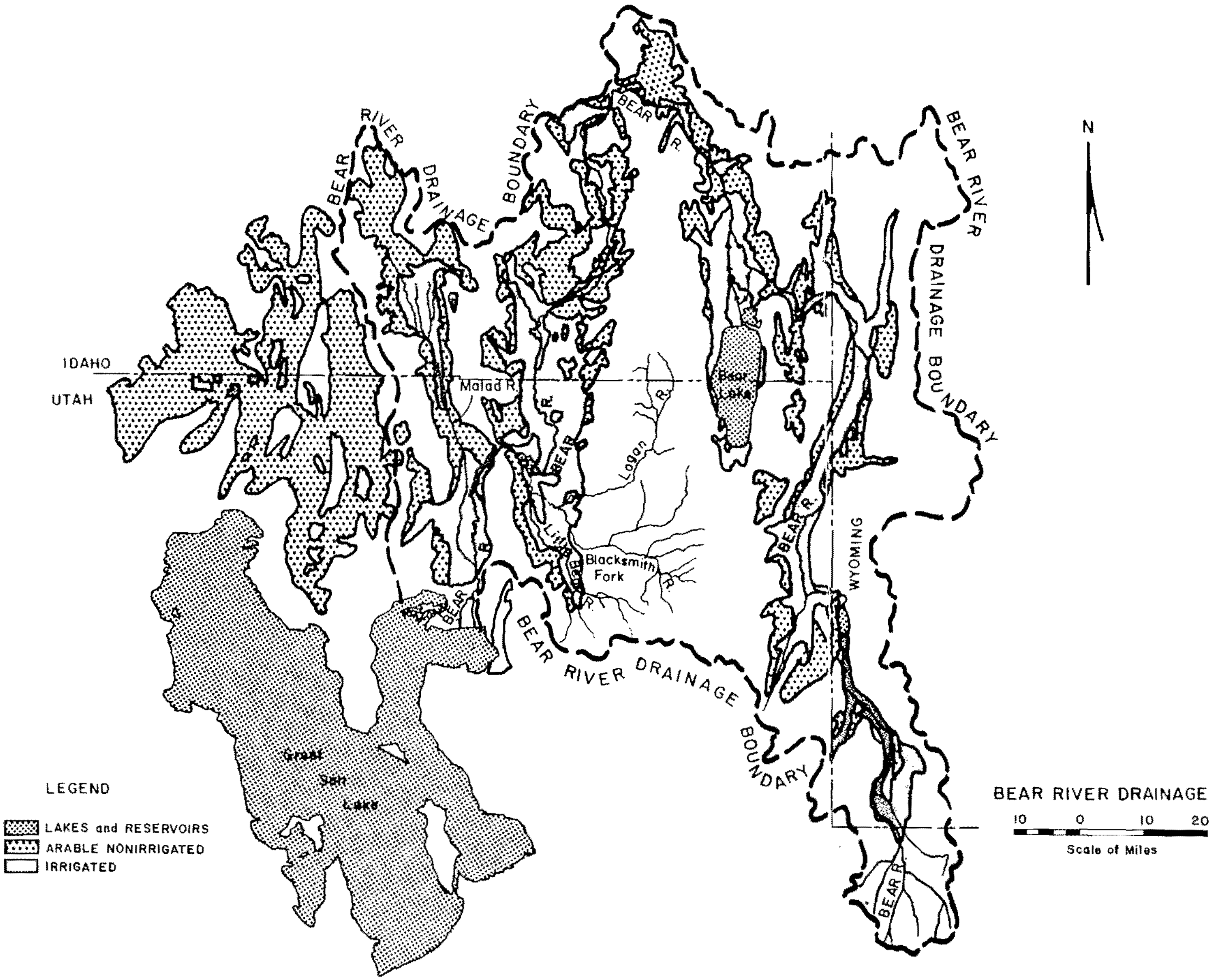


Figure 1.10. Arable non-irrigated and irrigated land within the Bear River Basin (taken from USBR 1970).

the river; a stage-damage simulation model for the Great Salt Lake, which is now completed; and an evaluation of B/C ratios for various upstream water developments.

Under the study reported herein preliminary investigations were conducted for projects that would supply water to nearly all of the remaining irrigable lands within the Bear River Basin. These investigations, based primarily on projections from USBR studies, provided benefit/cost analyses for projects to supply water to lands lying outside the boundaries of the proposed USBR projects.

In his progress report to Searle (1978), Riley proposed an initial simplified approach to examining the feasibility of consumptively using water upstream in the Bear River Basin for controlling lake levels. This approach uses the models mentioned above to evaluate the economic feasibility of this strategy for controlling lake levels. This simplified approach neglects the physical, institutional, and social constraints, such as the multi-stage nature of the basin, water rights, and water distribution within the basin. The rationale is that if the simplified study indicated that lake level control through upstream consumptive use was economically feasible, more detailed investigations could follow. However, if the test failed, additional investigations would likely be unnecessary, at least at this time.

The Utah Division of Water Resources developed a hydrologic simulation model that was coupled with a stage damage simulation model for the Great Salt Lake (Utah Division of Water Resources and the Utah Water Research Laboratory 1977). This model predicts peak and low lake elevations associated with various management alternatives and the resulting flood damage reductions. For example, an average annual upstream depletion of 500,000 acre-feet would reduce annual damages by $1,448,000 (1976 dollars) with a pumping control elevation of 4200 feet. The economic, physical, social, or institutional constraints to additional upstream use would also have to be considered before selecting a lake management alternative. However, the information here provides a preliminary trade off analysis that reduces the number of management alternatives that need to be considered in detail later.

## Study Objectives

The objective of this study is to apply the tools mentioned above in the evaluation of alternatives for lake level control. The three alternatives which are examined are:

1. Upstream consumptive use in the Bear River Basin.

2. Selected diking at the lake.

3. Pumping brines form the lake into an evaporation area located west of the lake, with pumping occurring during only high water periods in the lake.

The following three chapters are devoted to these three alternatives. Two other alternatives, combinations of basic three and a "do nothing" strategy, are considered with the others at the end of this report.

## Assumptions

The assumptions used in making the benefit-cost analyses and comparisons were:

1. All calculations of costs and benefits for the proposed flood control methods are in October 1978 dollars and assume that costs and benefits will rise equally with the general inflation rate.

2. Any future development around the Great Salt Lake would adequately protect its facilities so as to prevent flood damages.

3. The total reservoir storage required to serve upstream water users is constructed at the beginning of the study period and, therefore, available as needed by the various irrigation projects. This, of course, is not a realistic assumption, but matches the conservative stance taken by this preliminary study.

4. The economic analysis includes only the cost of implementing the upstream projects and not the cost of obtaining water rights.

5. The managers of each facility at the lake have indicated that lake surface elevation above which it would no longer be economical to continue operation due to high maintenance costs, the need to raise existing dikes, or the need to construct new dikes. During simulation, if a proposed project dike were breached at an elevation lower than the indicated wipeout elevation, it was assumed that an entity could continue its operations until its indicated wipeout elevation was reached.

6. All capital investment costs, which are needed for an entity to resume operations after wipeout of the protecting dike, are incurred at the time the protecting dike is breached. An exception was made for state bird refuges where it was assumed that when the protecting dike was washed out, no further effort would be made to protect the bird refuge until the lake level had fallen below the effective level of the dike.

## Definitions

1. Institutional constraints: constraints to employment of lake level control methods resulting from resistance by an institution, such as a municipality or water improvement district.

2. Economic constraints: constraints to economic justification such as the cost of building the upstream projects.

3. Physical constraints: constraints caused by the physical nature of the system, such as land surface topography and the spatial distribution of water supplies within a basin.

4. Social constraints: constraints resulting from limitations to efficient popular use of the facilities, such as irregular and uncertain irrigation water deliveries.

5. Net potential consumptive use: consumptive use from irrigated crops and lake water surfaces minus growing season precipitation.

6. Present modified historical flows: refers to the historical records of streamflow into the Great Salt Lake modified to reflect present development and use of water resources, including exports from the basin.

7. Net evaporative capacity: the maximum amount of water which can be evaporated from a water surface under particular conditions and during a specified period of time.

8. Design protection elevation: the maximum water surface elevation for which a dike is designed to eliminate flood damages to entities protected (including wave action damages).

# CHAPTER II

# THE UPSTREAM CONSUMPTIVE USE ALTERNATIVE

## Objectives and Tasks

This chapter describes the procedures applied to examining the feasibility of controlling the water levels in the Great Salt Lake by adding to consumptive use in the Bear River Basin. The study is based upon a "simplified approach" (Riley 1978) in which only economic constraints are examined.

The specific objectives of the study and the tasks used to accomplish them were:

Objective 1: With assumed operating rules for implementing and discontinuing projects, to estimate the withdrawals (consumptive use) from the Bear River required in order to maintain given lake levels.

Task 1: Assume operating rules for implementing and discontinuing irrigation projects. For example, one operating rule might be to operate continuously all projects with B/C ratios of one or greater, and to bring additional projects on line (projects having B/C ratios less than one) as a rising lake stage reaches 4202 feet. Those projects with the largest B/C ratios less than one would be brought on line first, and additional projects would be added as needed to achieve the desired lake level regulation. Under falling lake stages, those projects with the lowest B/C ratios would be dropped first. Therefore, projects having higher B/C ratios would be used more frequently, and those with lower B/C ratios less frequently.

Task 2: Couple stochastic flow generation with the lake level water balance model to estimate the withdrawals (annual amounts over the period of analysis) from the Bear River required to maintain lake levels when using the assumed operating rule.

Objective 2: To identify irrigation projects (without regard to water rights or the distribution of water supplies in the Bear River Basin) which could be used to provide the needed consumptive use.

Task 1: Identify reasonable irrigation projects for the Bear River Basin and classify them between projects with B/C ratios greater than 1 and projects with B/C ratios less than 1 subclassified into ranges as needed.

Task 2: Assume those projects with B/C ratios greater than 1 will deliver their full design consumptive use every year. Operate those with B/C ratios less than 1 as needed for controlling lake levels according to the assumed operating rule.

Task 3: From tasks 1 and 2, identify those projects which would be used over the historical flow sequence to provide the specified lake level regulation.

Objective 3: To evaluate the sufficiency of benefits generated at the lake in the form of damages prevented to offset the uncovered costs for those upstream projects with B/C ratios less than unity, but which are required to provide specific degrees of lake level regulation.

Task 1: Use the damage simulation model to estimate the flood control benefits at the lake resulting from the upstream irrigation projects.

Task 2: Compute the benefits required to bring to unity the B/C ratios of those upstream projects having ratios less than 1 but which were needed to achieve the desired regulation of lake levels.

Task 3: From tasks 1 and 2, determine if flood control benefits generated at the lake are sufficient when added to upstream irrigation benefits for overall project justification.

## Model Development

The procedure employed in this study was to develop a model for estimating 1) the effects of additional crop consumptive use within the Bear River Basin on water stages at the Great Salt Lake, and 2) the resulting damages prevented (and thus the benefits at the lake). The model thus needs to represent inflows to the lake, with and without the modifications to the Bear River flows resulting from the proposed irrigation projects, and also be capable of estimating damages prevented.

James et al. (1979) proposed a stochastic lake level model, and this model, with some adaptions, was used in this study. Alterations were necessary in order to provide for the effects of changing the consumptive use in the Bear River Basin by increasing the area of irrigated agricultural land. For this reason, a crop consumptive use submodel was developed and used to modify the stochastically generated flows for the Bear River. The damage simulation component is taken directly from James et al. (1979). The basinwide crop consumptive use submodel, the stochastic lake level water balance submodel, and the damage simulation submodel are discussed in this order in the following sections of this chapter.

### Irrigated crop consumptive use

Relationship between basin consumptive use and Bear River flows. The basin-wide irrigated crop consumptive use submodel was developed to estimate the historical annual net consumptive use of water by irrigated crops within the Bear River Basin. Estimates are based on historical records of surface air temperature, precipitation, area of irrigated land, and crop distribution. If a correlation exists between these annual crop consumptive use estimates and the Bear River annual discharge given by the stochastic lake level water balance submodel, crop consumptive use could not be estimated independently from the annual Bear River discharge quantity. Therefore, the relationship between these two quantities was investigated.

Annual Bear River discharge records are available from the USGS "Surface Water Records" for stations at Corinne and Collinston, Utah. However, because only 22 years of records are available at Corinne, a regression was performed of annual discharge at Corinne on annual discharge at Collinston. The coefficient of determination, $r^2$, was equal to 0.995, and the resulting equation was:

$$QCOR = 1.051\ QCOL + 78{,}035.0 \qquad \ldots\ldots (2.1)$$

where

QCOR = Annual discharge at Corinne (ac-ft)
QCOL = Annual discharge at Collinston (ac-ft)

A second regression was used to test the correlation between Bear River annual discharge and estimated annual crop consumptive use within the basin. The $r^2$ value of 0.0003 suggests no linear correlation. Figure 2.1 illustrates that there is no correlation whatsoever between Bear River discharge and basin consumptive use, and the annual consumptive use amounts were thus synthesized by taking values at random from the estimated historical values.

<u>Data collection.</u> The Bear River Basin was divided into ten subunits (Figure 2.2) and representative climatological stations were selected in each subunit. Temperature and precipitation data were obtained from the National Oceanic and Atmospheric Administration's "Climatological Data" for the years from 1939 to 1974. Fifteen stations were selected such that most of the subunits were represented by at least two separate climatological stations. For periods of missing data, regression analyses were performed, correlating temperatures or precipitation with nearby climatological stations. Many nearby stations were checked to obtain the best correlations. The results of the best regression analysis for each station are presented in Table 2.1.

Data on areas of irrigated land were obtained from the U.S. Census of Agriculture. County data from this source are published every fifth year (Table 2.2). Five counties, namely, Box Elder, Bannock, Caribou, Lincoln and Uinta, lie only partially within the Bear River Basin. Ratios for converting county data to basin data were taken from Haws and Hughes (1972) as listed in Table 2.3. Ratios for converting the county data to subarea data were also developed from Haws and Hughes (1972) and are presented in Table 2.4. Table 2.5 contains data of the total irrigated land by subunit in the Bear River Basin for every fifth year since 1929. Linear interpolation was incorporated in the model to generate irrigated area by subunit for years basis between the years of record.

Acreages by crop by county were also obtained from the U.S. Census of Agriculture. A crop distribution for each county was determined by averaging the crop distribution data of 1959, 1964, and 1969. To determine the crop distribution by subarea, a weighted average was calculated based upon the contribution of irrigated land from

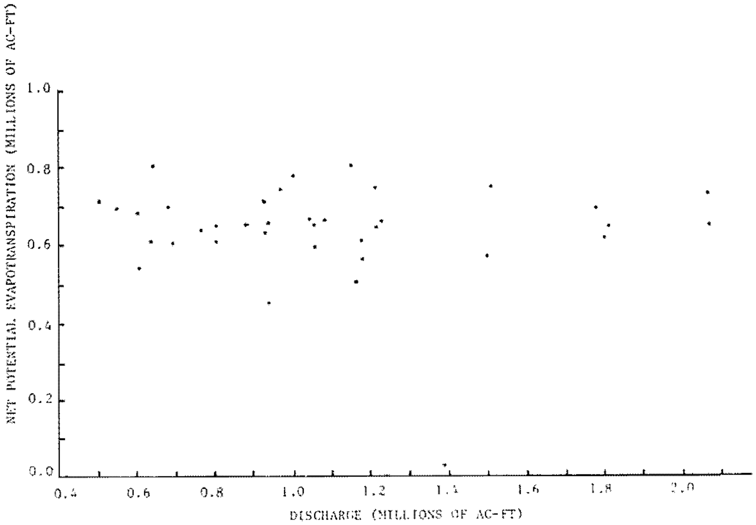


Figure 2.1. Net potential evapotranspiration from irrigated crops in the Bear River Basin versus Bear River discharge.

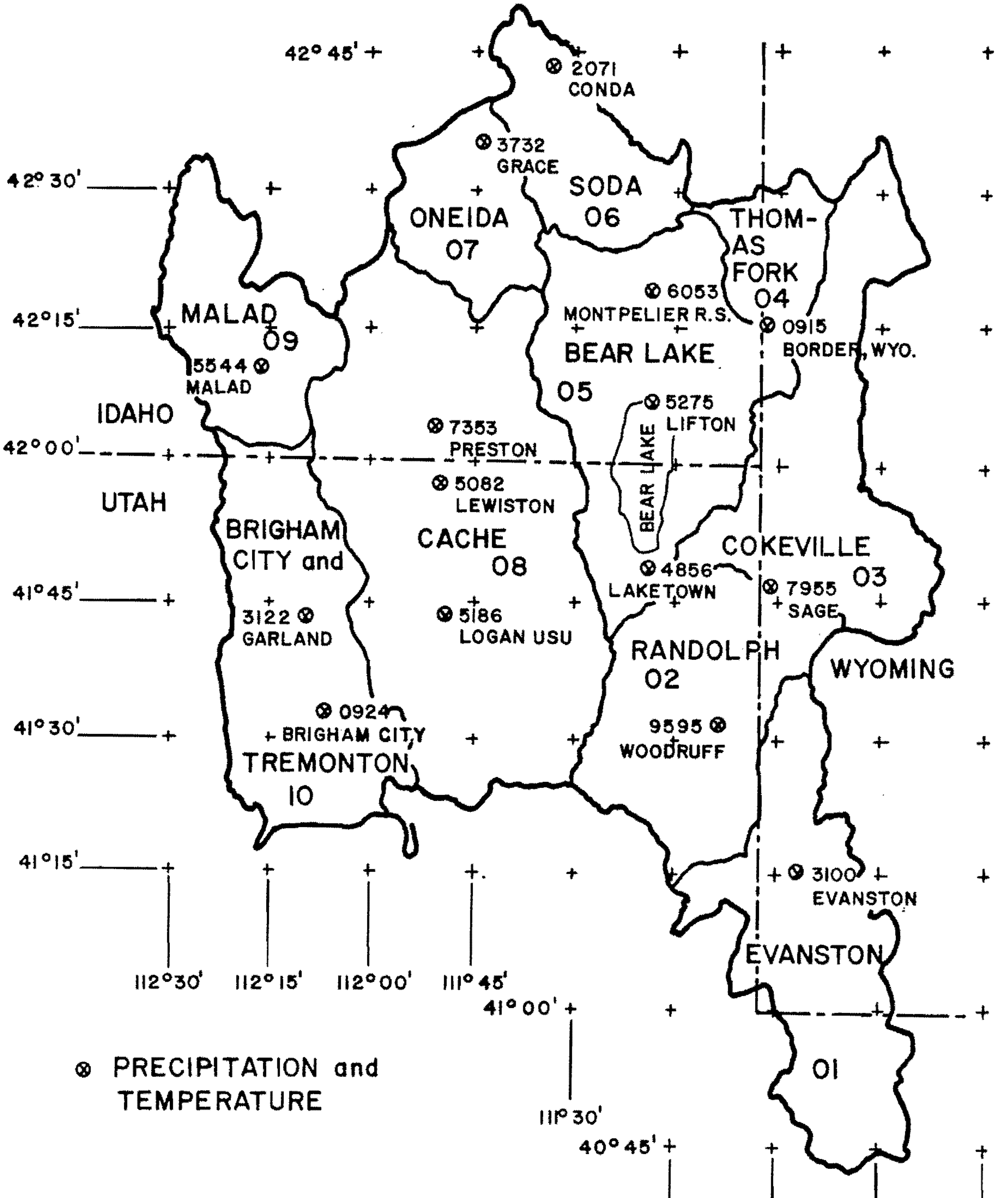


Figure 2.2. Hydrologic subunits and climatological stations in the Bear River Basin used to determine consumptive use (taken from Haws and Hughes 1973).

Table 2.1. Correlations used to provide estimates of missing temperature and precipitation data.

| Station Estimated | From Station | Data Estimated | Equation | $r^2$ |
|---|---|---|---|---|
| Garland | Brigham | Temp. | TE = 0.81T + 9.91 | 0.68 |
| Garland | Corinne | Prec. | PE = 1.10P - 0.05 | 0.75 |
| Lewiston | Logan | Prec. | PE = 0.93P + 0.86 | 0.86 |
| Brigham | Garland | Prec. | PE = 0.92P + 1.18 | 0.64 |
| Preston | Lewiston | Temp. | TE = 1.02T - 0.75 | 0.73 |
| Preston | Lewiston | Prec. | PE = 0.86P + 0.77 | 0.82 |
| Sage | Border | Prec. | PE = 0.72P + 0.73 | 0.64 |
| Sage | Woodruff | Temp. | TE = 0.76T + 13.72 | 0.51 |
| Evanston | Woodruff | Prec. | PE = 0.81P + 1.04 | 0.54 |
| Conda | Grace | Prec. | PE = 0.91P + 1.22 | 0.69 |
| Conda | Grace | Temp. | TE = 0.90T + 3.88 | 0.61 |

TE = Estimated temperature $^{o}$F.
T = Temperature used to make the estimation $^{o}$F.
PE = Estimated precipitation (inches).
P = Precipitation used to make the estimation (inches).

each county to the total irrigated land within the subarea. Table 2.6 summarizes the irrigated land use as estimated by subarea for the Bear River Basin. Land use by crop was assumed to remain unchanged throughout the period of the study.

Estimating the potential crop consumptive use for the basin. Thiessen weighting is used in the model to determine the average precipitation and temperature for the agricultural areas in each subunit (Linsley et al. 1975). The net potential consumptive use for each subarea is determined by the Blaney-Criddle formula (Dunne and Leopold 1978) of the form:

$$\text{NETPOT (inches)} = KTd - P \quad . \; . \; (2.2)$$

where

K = weighted seasonal crop coefficient
T = average subarea seasonal temperature in °F
d = seasonal fraction of annual hours of daylight
P = subarea seasonal precipitation in inches
NETPOT = seasonal net potential subarea consumptive use (inches)

Seasonal crop coefficients for each subunit were determined by weighting the seasonal crop coefficients for those crops listed in Table 2.6 by their respective percentage in the total crop distribution. Seasonal net crop consumptive use for the Bear River Basin is determined in the model by summing the seasonal consumptive use over the subunits. Estimates of the annual basinwide use were made for the period 1929 to 1974.

The statistical distribution of the net annual crop consumptive use for the basin. An autocorrelation analysis was performed on the estimated historical annual consumptive use for the Bear River Basin. Figure 2.3 graphs the autocorrelation coefficient versus lag. At the 95 percent confidence level,

Table 2.2. Total irrigated land in acres by county and state since 1919.

| County | 1919 | 1929 | 1935 | 1939 | 1944 | 1949 | 1954 | 1959 | 1964 | 1969 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cache | 94,705 | 94,952 | 59,030 | 82,160 | 81,325 | 74,861 | 79,771 | 84,244 | 85,555 | 80,591 | 75,527 |
| Box Elder | 86,734 | 76,324 | 60,290 | 73,406 | 87,340 | 87,542 | 79,485 | 90,819 | 94,021 | 94,618 | 94,814 |
| Rich | 42,913 | 54,825 | 19,815 | 43,995 | 52,278 | 59,178 | 50,756 | 53,433 | 55,556 | 47,168 | 47,728 |
| Bannock | 137,266 | 97,726 | 50,245 | 81,344 | 71,038 | 36,905 | 39,450 | 42,193 | 43,896 | 48,831 | 50,645 |
| Bear Lake | 67,202 | 54,625 | 22,655 | 54,143 | 68,731 | 48,315 | 56,820 | 59,212 | 56,849 | 55,375 | 49,330 |
| Caribou | 23,825 | 14,692 | 7,331 | 12,407 | 7,866 | 41,360 | 51,451 | 51,882 | 64,322 | 64,456 | 64,616 |
| Franklin | 37,460 | 52,738 | 24,602 | 54,062 | 38,479 | 37,831 | 41,417 | 43,423 | 47,276 | 41,985 | 44,508 |
| Oneida | 20,314 | 13,450 | 9,283 | 17,177 | 18,710 | 19,212 | 19,915 | 21,906 | 23,398 | 25,613 | 25,281 |
| Lincoln | 168,428 | 73,650 | 49,582 | 100,135 | 86,951 | 84,618 | 78,142 | 82,142 | 82,149 | 96,033 | 85,444 |
| Uinta | 102,695 | 86,122 | 23,732 | 91,192 | 89,853 | 102,538 | 80,596 | 107,038 | 119,396 | 95,653 | 87,004 |

Table 2.3. Ratios for converting total county irrigated land data to county data within the Bear River Basin (Haws and Hughes 1972).

| County | Box Elder (Utah) | Bannock (Idaho) | Caribou (Idaho) | Lincoln (Wyoming) | Uinta (Wyoming) |
|---|---|---|---|---|---|
| Ratio | 0.96 | 0.03 | 0.60 | 0.36 | 0.30 |

Table 2.4. Ratios for converting within basin county irrigated land data to subarea irrigated land data (Haws and Hughes 1973).

| Subarea | Counties<br>Box Elder (Utah) | Cache (Utah) | Rich (Utah) | Bear Lake (Idaho) | Bannock (Idaho) | Franklin (Idaho) | Oneida (Idaho) | Caribou (Idaho) | Lincoln (Wyom.) | Uinta (Wyom. |
|---|---|---|---|---|---|---|---|---|---|---|
| Evanston 01 | | | .002 | | | | | | | .992 |
| Randolph 02 | | | .803 | | | | | | | .008 |
| Cokeville 03 | | | .053 | | | | | | .854 | |
| Thomas Fork 04 | | | | .239 | | | | | .146 | |
| Bear Lake 05 | | | .142 | .612 | | | | | | |
| Soda 06 | | | | .149 | | | | .134 | | |
| Oneida 07 | | | | | | .042 | | .866 | | |
| Cache Valley 08 | | 1.00 | | | 1.00 | .958 | | | | |
| Malad 09 | | | | | | | 1.00 | | | |
| Brigham & Tremonton 10 | 1.00 | | | | | | | | | |

Table 2.5. Total irrigated land by subunit from 1929-1974 for the Bear River Basin.

| Subarea | 1929 | 1934 | 1939 | 1944 | 1949 | 1954 | 1959 | 1964 | 1969 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|
| Evanston 01 | 25,740 | 7,102 | 27,227 | 26,845 | 30,634 | 24,087 | 31,961 | 35,643 | 28,560 | 25,988 |
| Randolph 02 | 44,231 | 15,968 | 35,547 | 42,195 | 47,766 | 40,950 | 43,165 | 44,898 | 38,105 | 38,534 |
| Cokeville 03 | 25,549 | 16,294 | 33,117 | 29,503 | 29,151 | 26,714 | 28,086 | 28,200 | 32,024 | 28,798 |
| Thomas Fork 04 | 16,926 | 8,021 | 18,203 | 20,997 | 15,995 | 17,687 | 18,469 | 17,905 | 18,282 | 16,281 |
| Bear Lake 05 | 41,216 | 16,679 | 39,383 | 49,487 | 37,972 | 41,981 | 43,825 | 42,681 | 40,587 | 36,967 |
| Soda 06 | 9,320 | 3,965 | 9,065 | 10,873 | 10,524 | 12,603 | 12,994 | 13,642 | 13,433 | 12,545 |
| Oneida 07 | 9,849 | 4,842 | 8,717 | 5,703 | 23,080 | 28,473 | 28,782 | 35,407 | 35,255 | 35,444 |
| Cache 08 | 148,407 | 83,589 | 136,392 | 120,319 | 112,210 | 120,632 | 127,109 | 132,162 | 122,278 | 119,685 |
| Malad 09 | 13,450 | 9,283 | 17,177 | 18,710 | 19,212 | 19,915 | 21,906 | 23,398 | 25,613 | 25,281 |
| Brigham & Tremonton 10 | 73,271 | 57,878 | 70,470 | 83,846 | 84,040 | 76,306 | 87,186 | 90,260 | 90,833 | 91,021 |

Table 2.6. Summary by subarea of the irrigated land use in the Bear River Basin (all units are in percent).

| Crop | Evanston 01 | Randolph 02 | Cokeville 03 | Thomas Fork 04 | Bear Lake 05 | Soda 06 | Oneida 07 | Cache Valley 08 | Malad 09 | Brigham & Tremonton 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa | 4.7 | 12.4 | 30.4 | 25.3 | 21.6 | 25.5 | 30.1 | 34.0 | 40.7 | 27.6 |
| Pasture | 51.3 | 21.3 | 20.0 | 17.4 | 17.5 | 15.9 | 14.0 | 14.6 | 10.3 | 17.8 |
| Other Hay | 43.2 | 61.4 | 40.1 | 46.3 | 50.7 | 36.1 | 11.5 | 4.5 | 14.3 | 5.1 |
| Small Grains | 0.7 | 4.8 | 9.5 | 10.9 | 10.1 | 19.4 | 35.8 | 30.3 | 29.2 | 26.3 |
| Corn | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 4.9 | 2.6 | 6.5 |
| Sugar Beets | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 3.9 | 5.6 | 1.5 | 10.8 |
| Potatoes | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 3.6 | 0.7 | 0.9 | 0.3 |
| Orchard | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 2.0 |
| Peas | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.3 | 0.6 | 0.0 | 0.6 |
| Tomatoes | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 |
| Small Truck | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.5 | 0.4 | 4.0 | 0.5 | 1.8 |
| Beans | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.7 | 0.0 | 0.3 |

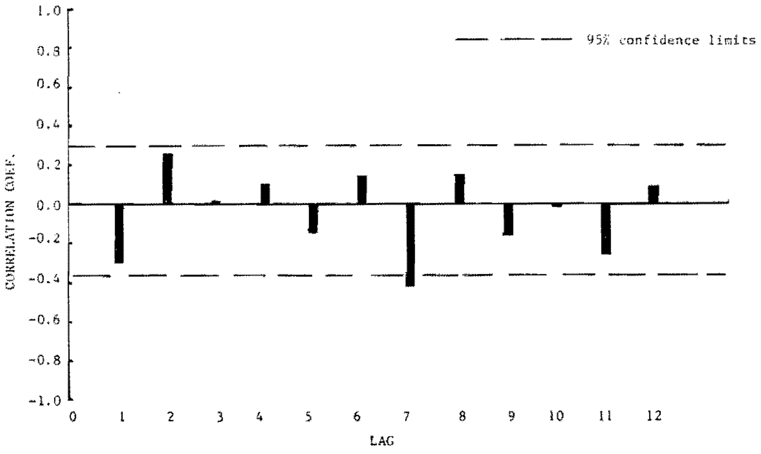


Figure 2.3. Correlogram of the net potential evaporation for the Bear River Basin.

under the hypothesis that the autocorrelation coefficient is zero, there are no significant autocorrelation coefficients within the first six lags and at the seventh lag the coefficient barely exceeds the confidence interval. This result strongly suggests that the evapotranspiration process has no memory and is adequately synthesized by random sampling from the historical distribution. The appropriate distribution was determined by plotting the historical data on both normal and log-normal probability paper. As can be seen from Figure 2.4, the occurrence of annual evapotranspiration quantity from irrigated lands in the Bear River Basin can be characterized as a normal statistical distribution. Therefore, Bear River Basin consumptive use is synthesized in the model by random sampling from a normal distribution.

### Stochastic lake level water balance submodel

The stochastic lake level water balance submodel synthesizes time series of streamflow, lake precipitation, and lake evaporation, and combines these series in a water balance model of the Great Salt Lake. The stochastic generation component of the model was developed at Utah State University. The lake water balance component of the model developed by the Utah Division of Water Resources (1974) was adapted for use in this study, as described below.

Stochastic data generation component. The stochastic model used in generating streamflow, precipitation, and evaporation for the lake is the ARMA (1,0) autoregressive lag one multivariate model. The model takes the form (James et al. 1979):

$$\underline{X}(t) = A\underline{X}(t-1) + B\underline{\varepsilon}(t) \quad . \quad . \quad (2.3)$$

$\underline{X}(t)$ = vector at time t of synthetic values of hydrologic sequences at m stations, each value expressed in standardized normal form $(X_i(t) - \mu_i/\sigma_i)$.

$\underline{\varepsilon}(t)$ = vector at time t of m normally and independently distributed random variables with zero mean and unit variance. Elements of $\underline{\varepsilon}(t)$ are independent of elements of $\underline{X}(t)$.

A = m by m coefficient matrix calculated as

$$A = M_1 M_o^{-1} \quad . \quad . \quad . \quad (2.4)$$

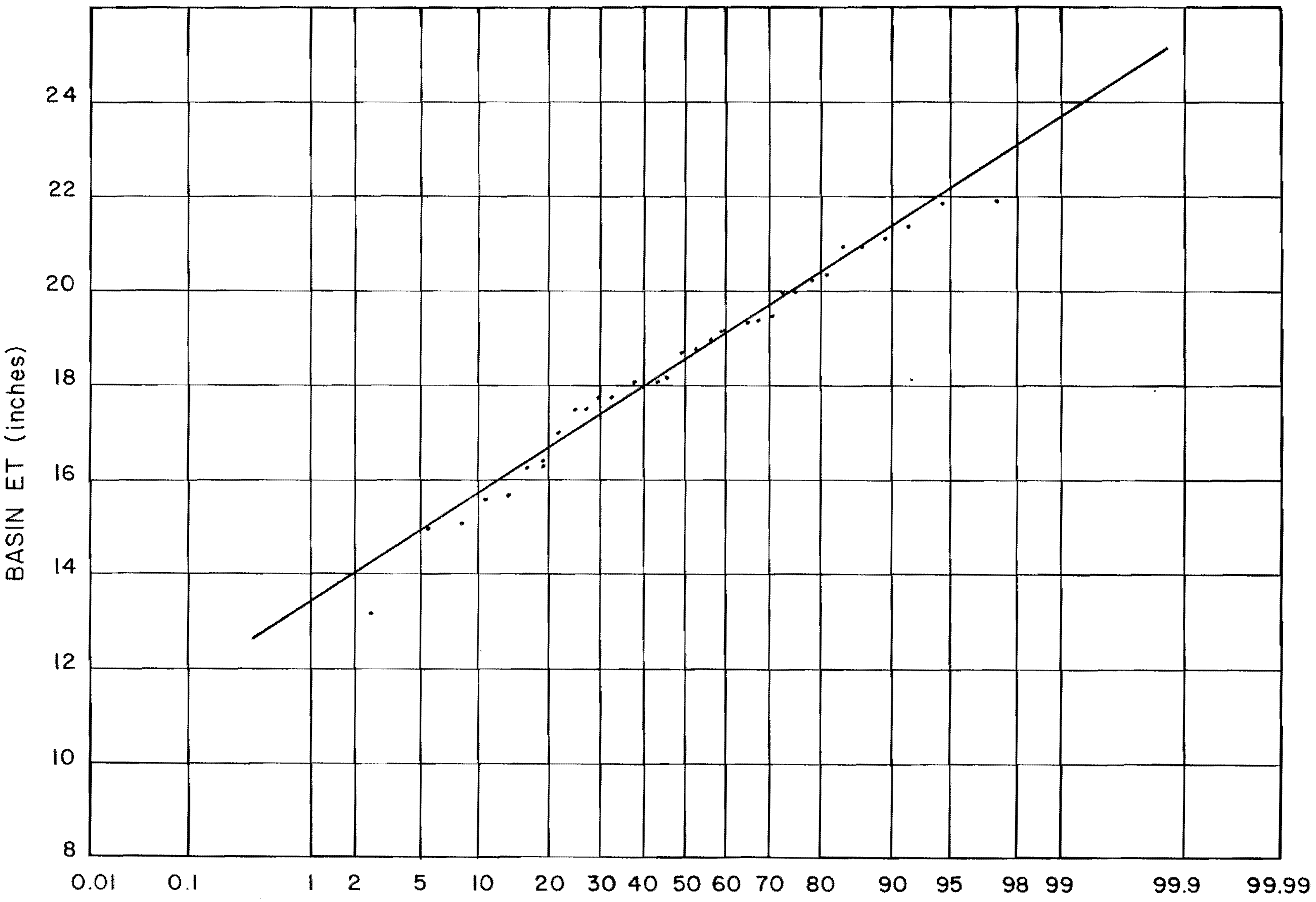


Figure 2.4. Normal probability plot of historical annual consumptive use by irrigated crops within the Bear River Basin (based on the period 1929 to 1974).

$B$ = m by m coefficient matrix derived from

$$BB^T = M_0 - M_1 M_0^{-1} M_1^T \quad . \ . \ . \ . \ . \ (2.5)$$

$M_0$ = the lag zero cross correlation matrix.

$M_1$ = the lag one cross correlation matrix.

The model has the capability of synthesizing either the natural flow sequences of the Bear, Weber, and Jordan Rivers, or flow sequences which reflect present reservoir storage and basin consumptive uses.

Water balance component. The lake water balance component utilizes the stochastically synthesized streamflow, precipitation, and evaporation sequences to synthesize corresponding lake stages. The general water balance equation is (James et al. 1979):

$$V_t = V_{t-1} + Q_{B,t} + Q_{W,t} + Q_{J,t} + S_t + G_t + (p_t - e_t)A_{t-1} \quad . \ . \ . \ . \ . \ (2.6)$$

in which

$V_t$ = volume of the lake at the end of the tth water year (ac-ft)

$Q_{B,t}$ = Bear River surface inflow in the tth water year (ac-ft)

$Q_{W,t}$ = Weber River surface inflow in the tth water year (ac-ft)

$Q_{J,t}$ = Jordan River surface inflow in the tth water year (ac-ft)

$S_t$ = ungaged surface inflow from small streams in the tth water year (ac-ft)

$G_t$ = subsurface inflow in the tth water year (ac-ft)

$P_t$ = precipitation on the lake in the tth water year (ft)

$e_t$ = evaporation rate from the lake surface in the tth water year (ft)

$A_t$ = surface area of the lake at the beginning of the tth year (ac)

Project effects on the water balance component. The model applies a given rule for adding projects so as to provide a specified lake level control and a basis for estimating system cost and the resulting irrigation and lake-level-control benefits. The model and computations:

1. Provide a capability for simultaneously operating projects that supply irrigation water continuously and projects that are only used for irrigation as needed for lake level control.

2. Recognize projects of the second sort as either operational or inactive by following the given rule year by year over the simulation period.

3. Represent the natural year-by-year variability in consumptive use with weather conditions.

4. Estimate the benefits and costs of the irrigation projects.

The flow diagram of Figure 2.5 outlines the logic used in adding or deleting the intermittent projects used in this study. To simplify representation of the reservoir storage requirements for these two types of projects, the model assumes that the water is contained within two separate reservoirs.

Reservoir accounting procedure. Carry over irrigation storage from one year to the next is accounted for in the operation of continuous and intermittent reservoirs by use of the continuity equation:

$$I - O = \Delta S \quad . \ . \ . \ . \ . \ . \ . \ (2.7)$$

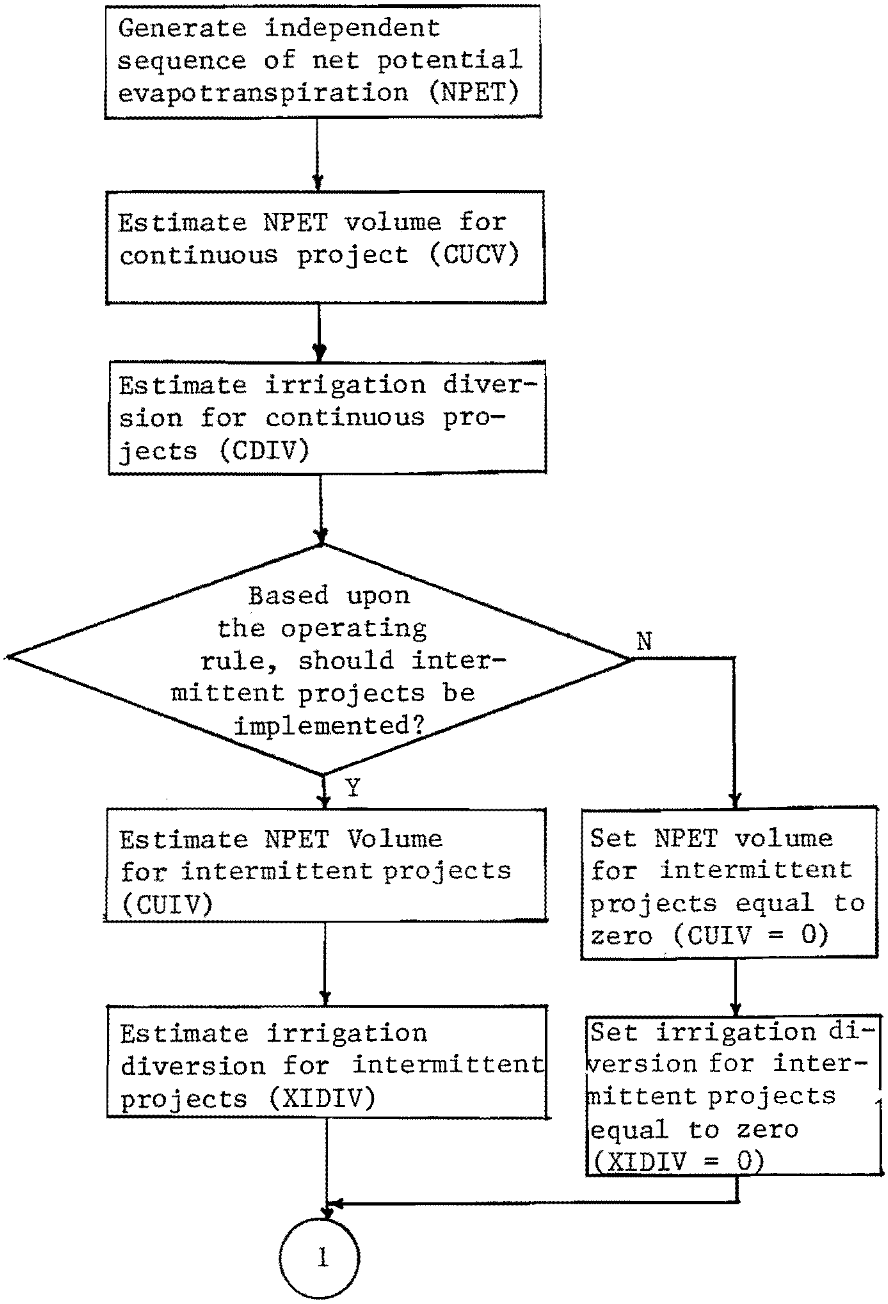
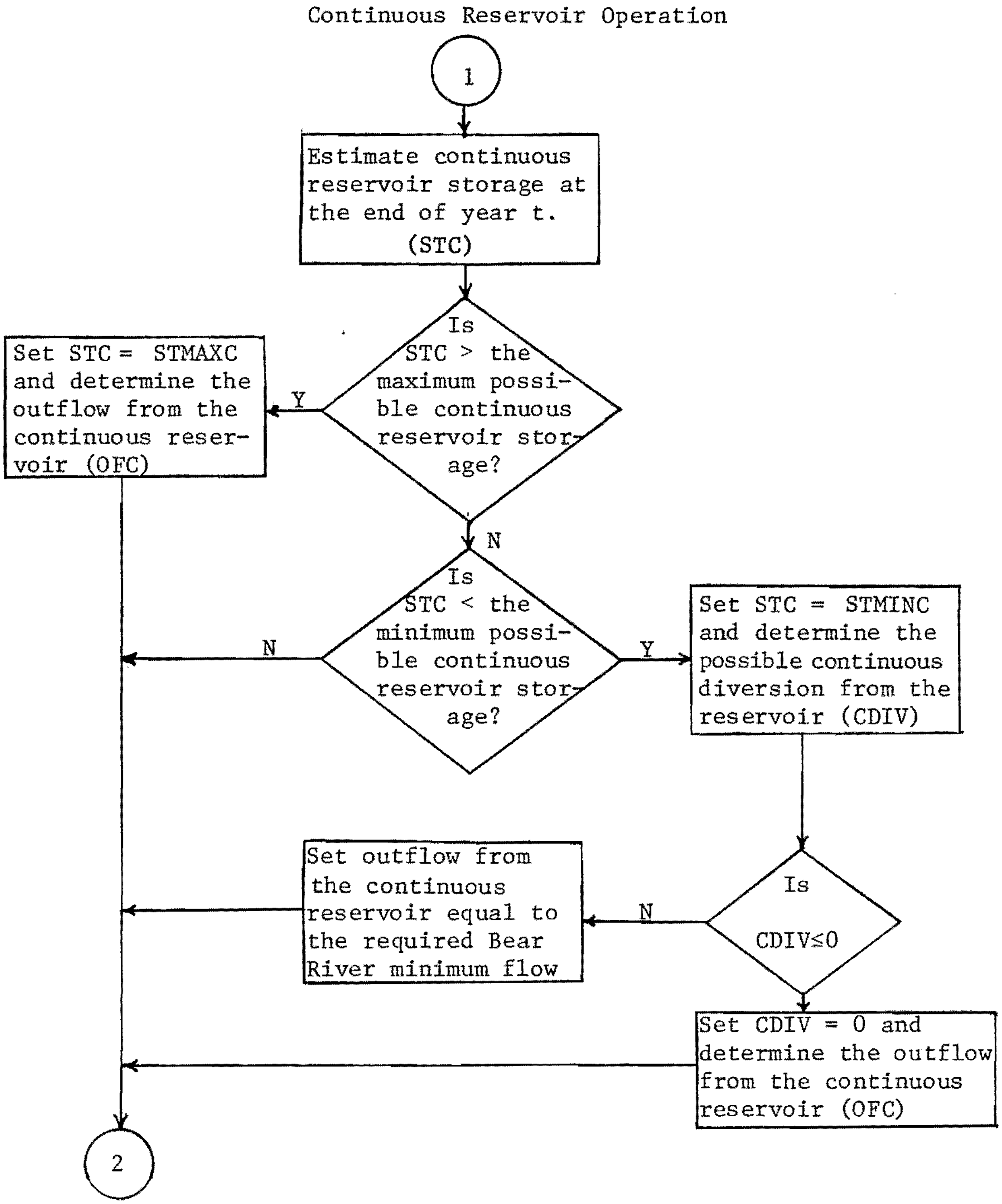


Figure 2.5. Flow diagram for the additions to the water balance component made for this study.



Continuous Reservoir Operation

Figure 2.5. Continued.

Intermittent Reservoir Operation

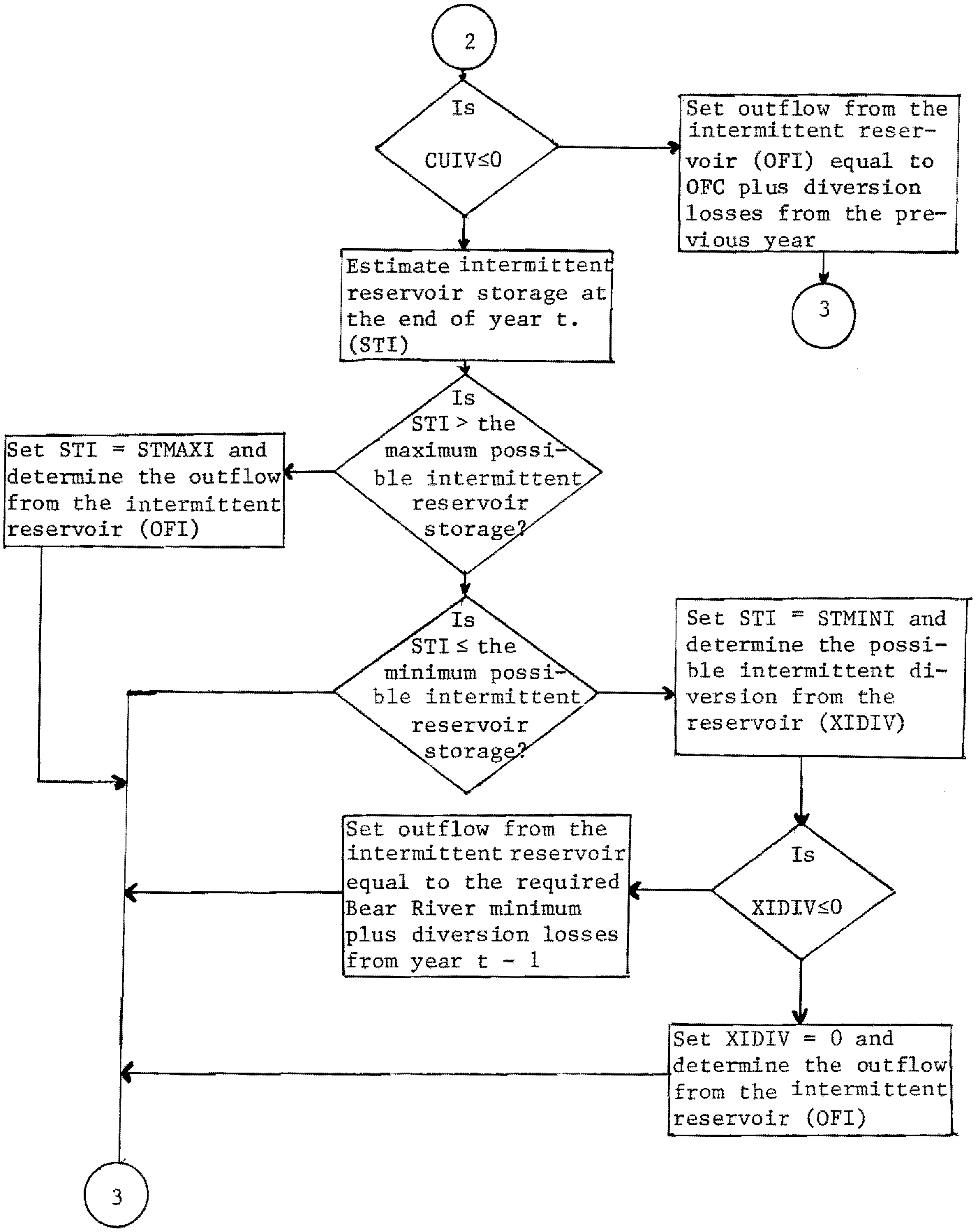


Figure 2.5. Continued.

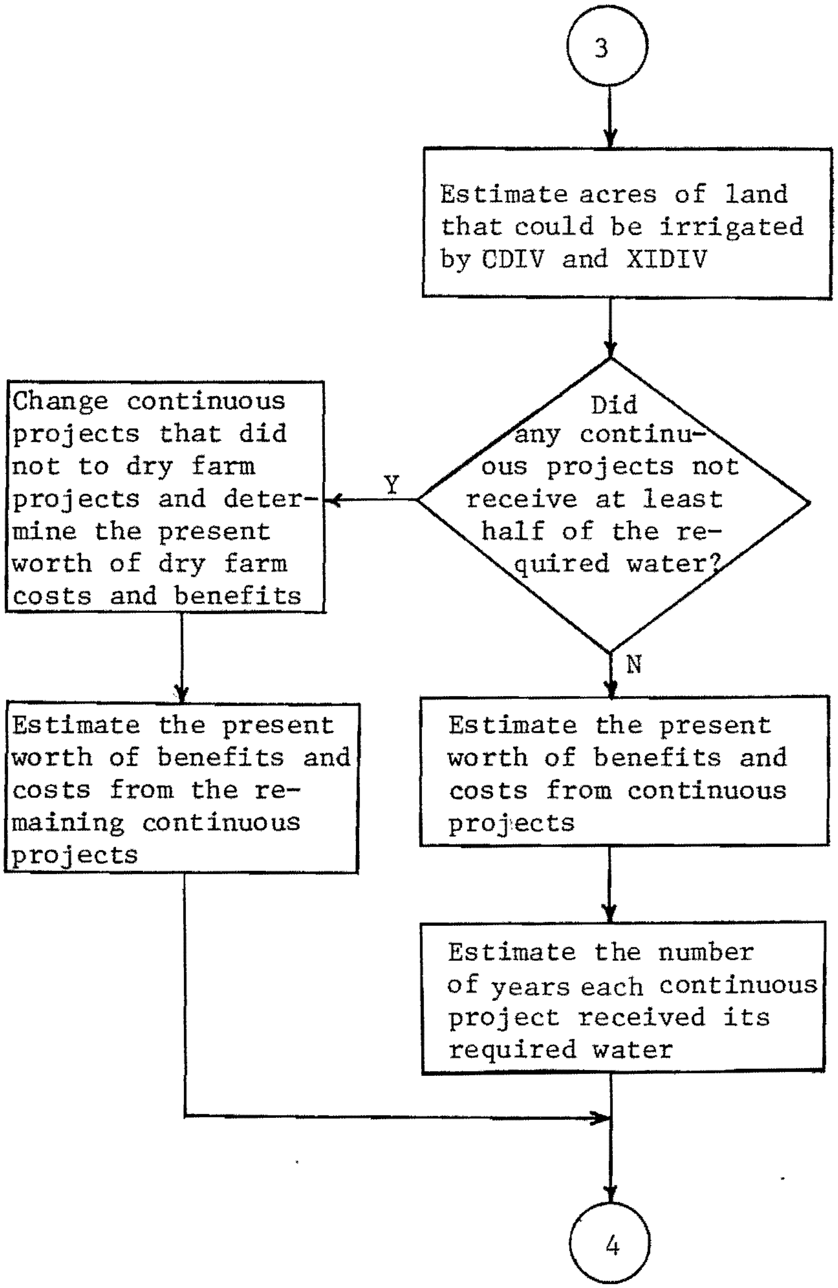


Figure 2.5. Continued.

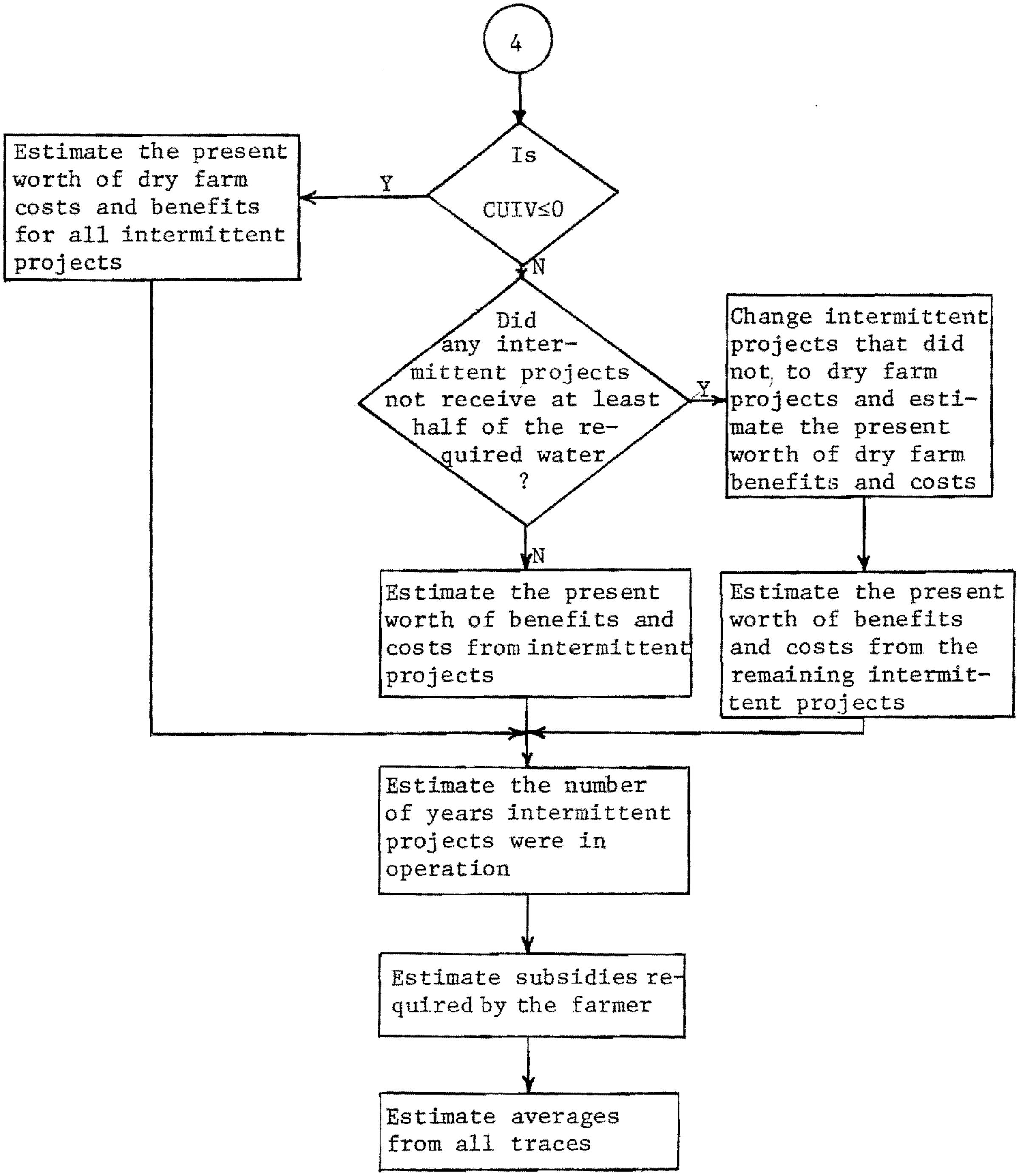


Figure 2.5. Continued.

in which

I = inflow into the reservoir in ac-ft/year
O = outflow from the reservoir to satisfy irrigation demand in ac-ft/year
$\Delta S$ = change in storage in acre-ft

Water allocations are made first to continuous projects and then to intermittent projects. Specifically, the Bear River is routed first through the continuous reservoir, from which releases satisfy the full consumptive use of the continuously irrigated project lands. Any additional diversions needed to maintain the levels of the Great Salt Lake within specified limits are routed to the intermittent reservoir, from which releases irrigate intermittent project lands. The inflow to the Great Salt Lake from the Bear River is the flow remaining in the river after these diversions plus irrigation losses to groundwater from the previous year. These are assumed to return to the Bear River system after October 1, which is the beginning of a new water year (Hill et al. 1973).

Irrigation benefit and cost analysis. The present worth of irrigation benefits and costs are estimated in the submodel for both continuous and intermittent project lands. Intermittent project benefits and costs include irrigation costs and benefits for those years in which the intermittent projects are operated and include dry farm costs and benefits and irrigation equipment costs for those years in which intermittent projects are not in operation.

### Damage simulation model

The input data to the model simulating damages from lake level fluctuations are the time series of annual lake peak stages and annual end of the year stages from the lake water balance model. The damage simulation model was used to estimate the reduction in damages at the lake resulting from increased water consumptive use in the Bear River Basin.

Lake stage damages. Economic losses are estimated by the model for both high and low lake stages. Losses resulting from high lake stages occur to transportation systems (railroads, highways, and the Antelope Island causeway), to the federal and state bird refuges (including their protective dikes) to private marshlands, to beach and marine areas and to the mineral industries at the lake.

Economic loss groups. Economic losses are estimated from a national viewpoint and classified into the following groups (James et al. 1979):

1. Capital investment in damage mitigation measures or in reinstating facilities temporarily abandoned because of high water.

2. Annual operation, maintenance, and repair costs caused by the effects of either high or low water including costs associated with mitigation measures.

3. Losses that accrue to producers (such as mineral industries) or consumers (such as recreationists) when facility use has to be curtailed because of extreme lake levels.

Output from the submodel may be obtained as either a uniform cost series or a present worth for 50-year traces for each group and for the total of the three. The submodel also estimates the average and standard deviation of the year by year damages in all four traces.

## Model Application

The procedures used to estimate crop consumptive use within the Bear River Basin, to establish project operating rules, to identify irrigation projects for use in the study, and to assess the project benefits and costs are discussed in this section.

### Project operating rule

The operating rule for implementing and discontinuing intermittent irrigation projects in the Bear River Basin was based upon the following criteria. If the lake stage in year t-1 is greater than or equal to 4201 feet, and if the lake stage has risen more than one-half foot between years t-1 and t-2, then intermittent projects are implemented. If, however, the lake has not risen more than one-half foot between the previous two years but continues to rise until it reaches 4202 feet at time t-1, then intermittent projects are automatically implemented. The intermittent projects are not discontinued until the lake stage has fallen to 4200 feet at time t-1 or until the intermittent reservoir is emptied.

### Estimation of the required withdrawals

Estimates of the volume of water that would have to be removed to hold the peak stage of the Great Salt Lake to 4202 feet were made by use of the lake water balance model. One option of the model computes the excess volume of water, from lake stage volume relationships, that needs to be removed to control the lake at a specified stage. This option was used to determine the volumes of water that need to be removed year by year in order to achieve lake level control at 4202 feet.

### Identification of irrigation projects

Irrigation project development. As illustrated in Figure 2.2, the U.S. Bureau of Reclamation (USBR) has identified approximately 1,000,000 acres of arable land in the Bear River Basin, of which approximately 500,000 acres are currently receiving either partial or full irrigation. The USBR has conducted preliminary investigations on proposed projects, including storage reservoirs, that would supply irrigation water to approximately 300,000 additional acres of land, some of which is currently receiving partial irrigation. Other potential reservoir sites are identified in a study made by the U.S. Department of Agriculture et al. (February 1976).

To supplement the projects examined by the USBR, additional irrigation projects were considered in this study from potential reservoir sites suggested by the USDA and to serve other agricultural lands in the basin which are not now irrigated. An additional 160,000 acres of land were proposed for full irrigation from the potential reservoir projects identified by the USDA. The development of these lands and the reservoir, diversion, and water conveyance and distribution facilities for each identified project were outlined, and a prelininary benefit-cost analysis was performed. Table 2.7 contains a list and description of the potential projects (identified as reservoir sites), and their locations are shown in Figure 2.6. Table 2.8 contains estimates for each project for water use, irrigation efficiencies, irrigation service area, and Bear River depletions. An average conveyance efficiency of 65 percent was used (U.S. Department of Agriculture et al. April 1976) along with an average irrigation application efficiency for sprinkling systems of 70 percent (Israelsen and Hansen 1962).

The service area requiring supplemental irrigation was converted to an equivalent full service area by using water requirement data for the supplemental irrigation lands presented in the project feasibility study of the USBR (1970). A ratio of full service lands equivalent to supplemental lands was estimated for each project as equal to one minus the current irrigation supply divided by the annual irrigation diversion requirement. This ratio was applied to project areas that could be irrigated from potential reservoirs proposed by the USDA which were located

Table 2.7. Information on potential reservoir sites in the Bear River Basin.

| Name of Site | Source of Information | County | Water Source | Reservoir Capacity ac/ft | Dam Dimensions | | Dam embankment per acre-foot of reservoir capacity $yd^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | Height ft. | Crest Length ft. | |
| | | | UTAH | | | | |
| Big Creek | USDA | Rich | Big Creek | 6,800 | | | |
| Card Canyon | USDA | Cache | Logan River | 35,000 | 310 | 900 | |
| Cutler Enl. | USDA | Box Elder | Bear River | 200,000 | 126 | 600 | |
| Hyrum Enl. | USDA | Cache | Little Bear River | 33,700 | 116 | 3,140 | 13.5 |
| Neponset | USDA | Rich | Dry Creek | 30,275 | 44 | 10,050 | |
| Otter Creek | USDA | Rich | Otter Creek | 12,100 | 80 | | |
| Smithfield | USBR | Cache | Bear River | 70,000 | 53 | 17,220 | 25.5 |
| Twin Creek | USDA | Cache | Logan River | 48,000 | | | |
| Woodruff Creek | USDA | Rich | Woodruff Creek | 10,292 | 150 | | |
| Wyuta | USDA | Summit | Yellow Creek & Bear | 146,000 | 170 | 1,850 | 16.6 |
| Avon | USDA | Cache | Little Bear River | 30,000 | 200 | 1,660 | 135.30 |
| | | | IDAHO | | | | |
| Bloomington | USDA | Bear Lake | Bloomington Creek | 11,800 | | | |
| Caribou | USBR | Caribou | Bear River | 40,000 | 76 | 3,680 | 10.5 |
| Grimley Hollow | USDA | Oneida | Devil Creek | 1,600 | | | |
| Liberty Dell | USDA | Bear Lake | Liberty Creek | 7,262 | 108 | 4,050 | |
| Montpelier | USDA | Bear Lake | Montpelier Creek | 12,000 | 87.5 | 820 | |
| Oneida Narrows | USBR | Franklin | Bear River | 435,000 | 314 | 1,245 | 12.4 |
| Sand Ridge | USDA | Oneida | Little Malad River | 16,200 | 138 | 3,800 | 139.0 |
| Sharon | USDA | Bear Lake | Emigration Creek | 3,000 | 92 | 775 | |
| Sleight Canyon | USDA | Bear Lake | Slights Canyon | 8,200 | | | |
| Willow Flat | USDA | Franklin | Cub River | 3,750 | 88 | 830 | 60.4 |
| | | | WYOMING | | | | |
| Thomas Fork | USBR | Lincoln | Thomas Fork | 11,500 | 117 | 710 | 51.9 |
| Ashby | USBR | Lincoln | Smiths Fork | 21,000 | 125 | 1,090 | 47.6 |
| Myers | USDA | Uinta | Bear River | 15,000 | 86 | 1,310 | 70,7 |
| Poker Hollow | USDA | Lincoln | Smiths Fork | 6,000 | 98 | 690 | 88.7 |

Table 2.8. Table of project summary data.

| | Reservoir Storage (ac-ft) | | | Water Supply at Diversion Point (ac-ft) | | Efficiencies | | | Possible Irrigation Service Area (acres) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dead | Active | Total | Irrigation | Total | Conveyance | Application | Total | Full Service | Supplemental in Equivalent Full Service Area | Total | Possible Bear River Depletion (ac-ft) |
| Thomas Fork | 2,000 | 9,500 | 11,500 | 9,500 | 9,500 | 0.65 | 0.70 | 0.46 | -- | 2,841 | 2,841 | 4,370 |
| Ashby | 4,200 | 16,800 | 21,000 | 16,800 | 16,800 | 0.65 | 0.70 | 0.46 | -- | 5,023 | 5,023 | 7,728 |
| Myers | 3,000 | 12,000 | 15,000 | 12,000 | 12,000 | 0.65 | 0.70 | 0.46 | -- | 3,588 | 3,588 | 5,520 |
| Poker Hollow | 1,200 | 4,800 | 6,000 | 4,800 | 4,800 | 0.65 | 0.70 | 0.46 | -- | 1,435 | 1,435 | 2,208 |
| Bennington | | | | 16,400 | 16,400 | 0.65 | 0.70 | 0.46 | 4,898 | -- | 4,898 | 7,544 |
| Bloomington | 2,300 | 9,440 | 11,800 | 9,440 | 9,440 | 0.65 | 0.70 | 0.46 | 2,822 | -- | 2,822 | 4,342 |
| Caribou | 5,000 | 35,000 | 40,000 | 35,000 | 35,000 | 0.65 | 0.70 | 0.46 | 10,465 | -- | 10,465 | 16,100 |
| Grimley Hollow | 320 | 1,280 | 1,600 | 1,280 | 1,280 | 0.65 | 0.70 | 0.46 | -- | 383 | 383 | 589 |
| Liberty Dell | 1,450 | 5,812 | 7,262 | 5,812 | 5,812 | 0.65 | 0.70 | 0.46 | -- | 1,738 | 1,738 | 2,675 |
| Montpelier | 2,400 | 9,600 | 12,000 | 9,600 | 9,600 | 0.65 | 0.70 | 0.46 | 2,870 | -- | 2,870 | 4,416 |
| Oneida Narrows | 140,000 | 295,000 | 435,000 | 295,000 | 295,000 | 0.65 | 0.70 | 0.46 | 59,900 | 28,200 | 88,100 | 135,700 |
| Sand Ridge | 3,240 | 12,960 | 16,200 | 12,960 | 12,900 | 0.65 | 0.70 | 0.46 | -- | 3,875 | 3,875 | 5,962 |
| Sharon | 600 | 2,400 | 3,000 | 2,400 | 2,400 | 0.65 | 0.70 | 0.46 | 718 | -- | 718 | 1,104 |
| Sleight Canyon | 1,640 | 6,560 | 8,200 | 6,560 | 6,560 | 0.65 | 0.70 | 0.46 | 2,859 | -- | 2,859 | 4,398 |
| Willow Flat | 700 | 3,000 | 3,700 | 3,000 | 3,000 | 0.65 | 0.70 | 0.46 | 897 | -- | 897 | 1,380 |
| Big Creek | 1,360 | 5,440 | 6,800 | 5,440 | 5,440 | 0.65 | 0.70 | 0.46 | -- | 1,626 | 1,626 | 2,502 |
| Card Canyon | 7,000 | 28,000 | 35,000 | 28,000 | 28,000 | 0.65 | 0.70 | 0.46 | -- | 8,372 | 8,372 | 12,880 |
| Cutler Enlargement | 60,000 | 140,000 | 200,000 | 140,000 | 140,000 | 0.65 | 0.70 | 0.46 | 36,538 | 5,262 | 41,800 | 64,400 |
| Hyrum Enlargement | 18,800 | 14,900 | 33,700 | 14,900 | 14,900 | 0.65 | 0.70 | 0.46 | 2,811 | 1,644 | 4,455 | 6,854 |
| Neponset | 6,055 | 24,220 | 30,275 | 24,220 | 24,220 | 0.65 | 0.70 | 0.46 | 7,242 | -- | 7,242 | 11,141 |
| Otter Creek | 2,420 | 9,680 | 12,100 | 9,680 | 9,680 | 0.65 | 0.70 | 0.46 | 2,895 | -- | 2,895 | 4,453 |
| Smithfield | 14,000 | 56,000 | 70,000 | 56,000 | 56,000 | 0.65 | 0.70 | 0.46 | -- | 16,744 | 16,744 | 25,760 |
| Twin Creek | 9,600 | 38,400 | 48,000 | 38,400 | 38,400 | 0.65 | 0.70 | 0.46 | 1,907 | 9,575 | 11,482 | 17,664 |
| Woodruff Creek No. 2 | 2,058 | 8,234 | 10,292 | 8,234 | 8,234 | 0.65 | 0.70 | 0.46 | 2,462 | -- | 2,462 | 3,788 |
| Wyuta | 29,200 | 116,800 | 146,000 | 116,800 | 116,800 | 0.65 | 0.70 | 0.46 | 13,250 | 21,674 | 34,924 | 53,728 |
| Avon | 10,000 | 20,000 | 30,000 | 20,000 | 20,000 | 0.65 | 0.70 | 0.46 | 5,980 | -- | 5,980 | 9,200 |

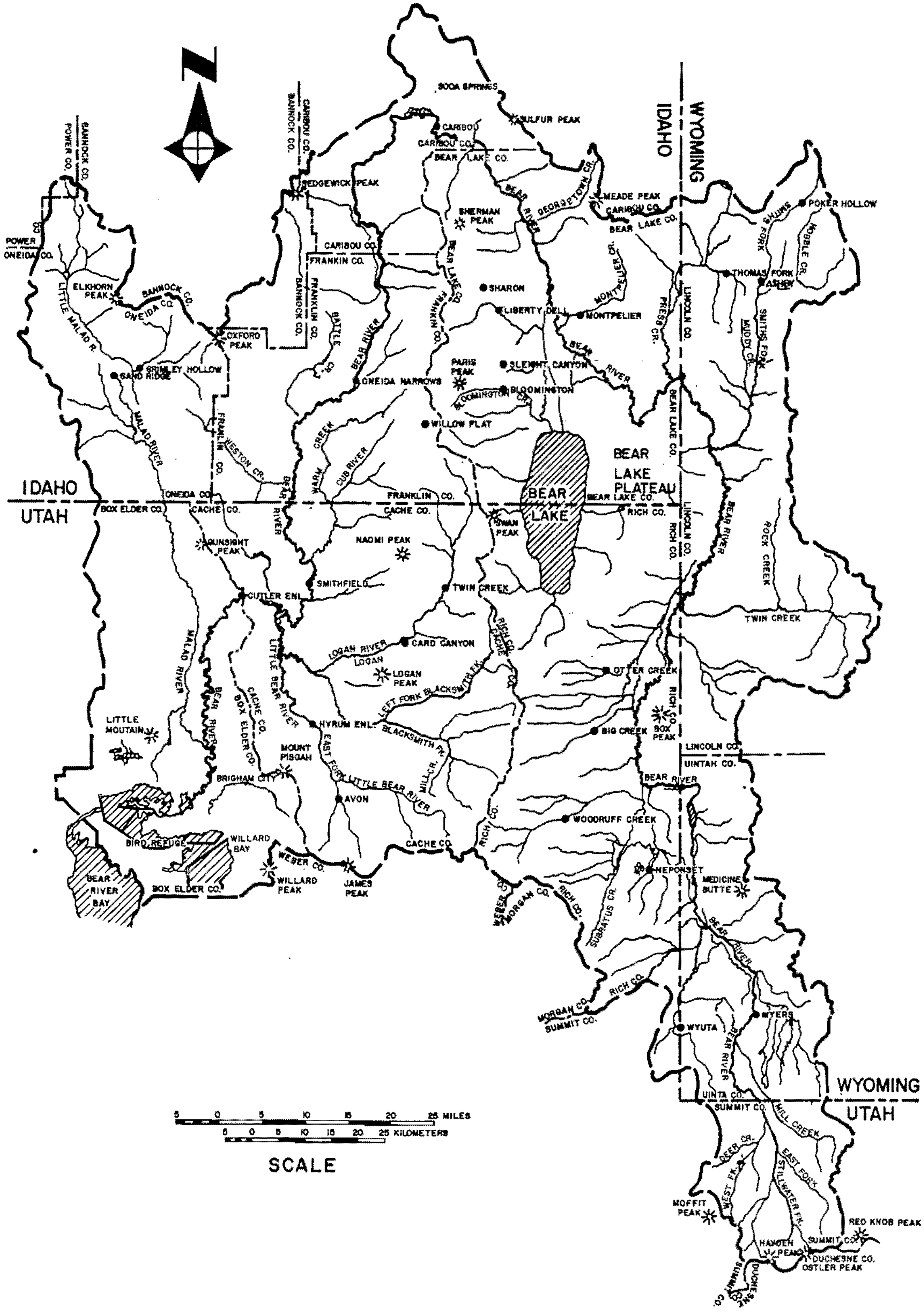


Figure 2.6. Potential reservoirs in the Bear River Basin used in this study (taken from USDA et al., February 1976).

in the near vicinity of the USBR projects. Possible Bear River depletion was estimated by applying the total irrigation efficiency to the water supply available for irrigation.

Criteria for classification of irrigation projects as continuous or intermittent. Continuous irrigation projects were to be operated continuously without regard to the stage of Great Salt Lake. Two basic criteria were set forth in the selection of continuous projects. First, the benefit-cost ratio had to be greater than one. Second, continuous projects could be served only up to the additional water allocations allowed by the amended Bear River Compact. Any project that could not be classified as continuous was classifed as intermittent.

The amended Bear River Compact allows the following changes to the 1958 compact (Utah Division of Water Resources 1979):

1. Lower Division below Stewart Dam (Bear Lake).

a. The 1958 Compact does not allocate water below Stewart Dam, but states that water delivery will be based on priority of rights without regard to state boundary lines. The Amended Bear River Compact protects all of these rights applied to beneficial use prior to January 1, 1976.

b. The remaining water is allocated between Utah and Idaho as shown below.

i) Idaho is granted the first right to develop and use 125,000 acre-feet of depletion including groundwater in the Lower Division.

ii) Utah is granted the right to develop and use 275,000 acre-feet of depletion including groundwater in the Lower Division.

iii) The next 150,000 acre-feet of depletion including groundwater will be divided equally between Utah and Idaho.

iv) All water in excess of the above allocations will be split between Utah and Idaho, with Idaho receiving 30 percent and Utah 70 percent.

2. Central and Upper Divisions (above Stewart Dam).

a. All present rights remain in force as stated in the 1958 Compact.

b. Additional storage granted above Bear Lake totals 74,500 acre-feet, divided 4500 acre-feet to Idaho and 35,000 acre-feet each to Utah and Wyoming. This storage, including groundwater development, is subject to an annual depletion limit of 28,000 acre-feet--of which Idaho is allocated 2000 acre-feet, and Utah and Wyoming 13,000 acre-feet each. This additional storage will not be allowed when Bear Lake is below elevation 5911 feet (Utah Power and Light Company Datum).

c. In addition, when Bear Lake is full and overflowing, additional water can be stored in the Upper and Central Divisions. The Bear Lake spills are allocated as 6 percent to Idaho and 47 percent each to Utah and Wyoming.

### Cost analyses for irrigation projects

Cost analyses performed for each project were preliminary in nature; included construction costs for reservoirs, main line canals, and recreational facilities as well as operation, maintenance and replacement costs; and were developed from the benefit/cost analyses performed by the U.S. Bureau of Reclamation (1970).

Construction costs. Construction costs included the cost of the reservoir, canals and recreational facilities. Regression analyses were performed to estimate reservoir costs from the volume of dam embankment. Data for the regression analysis were obtained from cost estimates for five reservoirs proposed by the USBR. The USBR cost analysis was in 1969 dollars; therefore, costs were updated to 1979 dollars by use of the USBR cost index (USBR 1979). The correlation was excellent with an $r^2$ at 0.97. The resulting regression equation is:

$$C = (5.37E + 3{,}081{,}450)\ CI \qquad \ldots\ldots (2.8)$$

in which

C = cost of the reservoir in 1979 dollars
E = volume of dam embankment ($yd^3$)
CI = USBR cost index (USBR 1979)

For many of the potential reservoirs investigated in this study, the only descriptive data available on the dam embankment were the dam height and crest length. Multiple regression was used to estimate the volume of dam embankment from the crest length and dam height. Data for 23 dams were obtained from the USDA (1976). The multiple coefficient of determination, $r^2$, was equal to 0.86. The resulting multiple regression equation from which the volume of dam embankment was estimated is:

$$V = 1{,}703{,}349 + 242.53\ L + 20{,}789.71\ H \qquad \ldots\ldots (2.9)$$

in which

V = volume of dam embankment ($yd^3$)
L = crest length (ft)
H = dam height (ft)

Another regression analysis was performed to estimate the construction costs per unit length of canals from their required capacity. Data for the analysis were obtained from nine construction cost estimates prepared by the USBR (1970). The USBR data were in 1969 dollars, therefore, the USBR cost index again was used to update their costs to 1979 dollars. The capacity of each canal was determined from the volume of water to be conveyed by the canal, assuming a 150 day growing season. The resulting coefficient of determination, $r^2$, was 0.78 for the regression:

$$CF = (0.462\ Cap + 12.84)\ CI \qquad \ldots\ldots (2.10)$$

in which

CF = cost per foot of canal in dollars
Cap = capacity of the canal (cfs)
CI = USBR cost index (USBR 1979)

Construction costs for recreational facilities were estimated by obtaining data from existing reservoirs of similar size and located near the reservoir for which the estimate was being made (Liljegren 1979). Cost data from existing reservoirs in or near the Bear River Basin were obtained from the "Recreation and Wildlife Summary" (1977) published annually by the U.S. Bureau of Reclamation. The costs were in 1977 dollars and were updated to 1979 dollars by the USBR cost index.

Operation, maintenance, and replacement costs. Operation, maintenance, and replacement costs (OM&R) for the reservoirs were estimated as 0.03 percent of the construction cost. This percentage is averaged from the benefit/cost analyses made by the USBR for potential reservoirs in the Bear River Basin (1970). OM&R costs for canals were estimated as 0.3 percent of their construction costs as averaged from data for nine canal cost estimates made by the USBR (1970). The same procedure used to estimate construction costs for recreational facilities was employed to estimate their associated OM&R costs.

Subsidies to the farmers. Intermittent irrigation could be made more attractive to farmers by subsidizing the projects according to their lake level control benefits. Two possible limits to subsidizing the intermittent irrigators are as follows: 1) the farmer is subsidized to the extent of the net profit he would receive if he were able to irrigate on a continuous basis, and 2) during those periods when the irrigation system is not in use, the farmer is subsidized to the extent of the profit which he would receive under a continuous dry farming mode of operation. The latter form of subsidy would help the farmer to pay the irrigation system costs when the system was not in use. The second type of subsidy was assumed for this study to be the more acceptable of the two alternatives.

Annual costs. An interest rate of 6.875 percent, applicable to economic appraisal of federal projects in fiscal year 1979, and a project life of 50 years were used in estimating the annual equivalent costs and benefits.

### Benefit analysis

Net direct and indirect irrigation benefits and recreational benefits were estimated to determine total project benefits.

Net direct irrigation benefits. Annual net direct irrigation benefits are the net receipts to the farmer, equal to total receipts minus total costs. Net direct irrigation benefits were estimated from crop budgets presented in "Utah Agricultural Statistics" (Utah State Department of Agriculture 1978), which contains receipts and costs for irrigated alfalfa, barley, corn, sugar beets, and dry farm wheat. Annual incomes for each crop were estimated on the basis of the average price paid for the crop over the years (from 1975 to 1978). Costs were available for 1976 and 1977 only, and it was assumed that the 1977 costs represent average conditions.

The costs estimated for the project budget did not include irrigation system costs. Irrigation system costs were estimated by obtaining per acre estimates of the cost of installation of an irrigation sprinkling system from local businesses. The costs ranged from $250 per acre to $450 per acre for a complete system. The average, $350 per acre, when amortized at 6 7/8 percent interest over a project life of 50 years, is approximately $25 per acre per year. The annual operation and maintenance cost was estimated by the local businesses at 1 percent of the capital investment. The total annual cost for the sprinkling system was, therefore, estimated at $28.50 per acre.

Assuming that irrigation would not be used on pasture or wild hay, the four crops for which budgets were available represent 96.6 percent of the total crop acreage in the Bear River Basin. Weighting by the respective percentages in the basin crop distribution gave the cost estimates and the net direct irrigation benefits (Table 2.9).

Net indirect irrigation benefits. Net indirect irrigation benefits include increased profits from retail and wholesale trade, processing, and marketing of farm products that result from increased irrigation. Net indirect benefits were determined by use of a multiplier. Andersen (1979) suggests that a factor of 2.0 is appropriate for estimating total net irrigation benefits, including direct and indirect, for the Bear River Basin area. Therefore, indirect irrigation benefits were assumed to equal net direct irrigation benefits.

Table 2.9. Total receipts, total costs, and net direct irrigation benefits in the Bear River Basin.

| Total Annual Receipts $/acre | Total Annual Cost Excluding Irrigation System $/acre | Total Annual Cost With Irrigation System $/acre | Total Annual Net Benefit Without Irrigation System Costs $/acre | Total Annual Net Benefit With Irrigation System Costs $/acre |
|---|---|---|---|---|
| 244.09 | 158.95 | 187.41 | 85.14 | 56.68 |

Recreational benefits. The USBR "Recreation and Wildlife Summary" gives actual visitor days to existing reservoirs. Recreational benefits for the existing reservoirs were estimated by assuming a benefit of $2.50 per visitor day. This figure was obtained by using the consumer price index to update the figures published by the Water Resources Council in 1972 (Liljegren 1979).

### Project operation

The lake water balance model in conjunction with the damage simulation model was used to estimate the lake level control benefits from irrigation projects operating both continuously and intermittently.

Continuous project operation. The lake water balance model and damage simulation model were run to estimate incremental benefits for each project. Each time the models were run, an additional continuous project was added to determine the change in total benefits and costs from the addition. Projects were entered in the order of decreasing benefit/cost ratios, in which projects with higher B/C ratios were modeled first. It is noted that the combined capacities of the continuous project reservoirs being considered in any one computer run were represented in the model by a single continuous project reservoir. This simplification followed from the assumption made for this preliminary study that the spatial distribution of the water supply within the basin would not be considered.

Intermittent project operation. After the effects of the continuous projects on lake levels had been modeled, intermittent projects were selected in the order of declining benefit-cost ratios. The models were run to determine the change in total benefits and total costs with the addition of each new intermittent project. The intermittent project reservoir storages were treated in the model in the same manner as for the continuous projects.

Analysis of benefits and costs from project operation. The total benefits and costs as estimated for the addition of each new continuous and/or intermittent project were examined for the following two points:

1. The point where the change in benefits equals the change in costs ($\Delta B \simeq \Delta C$).

2. The point where the total benefits equal the total costs ($B = C$).

The total benefits and costs of the intermittent projects included irrigation costs and benefits during those years in which the intermittent projects were in use and included dry farm costs and benefits during those years in which they were not in use. The subsidies required by the farmer to operate on an intermittent basis included the cost of the irrigation system to the farmer during those years when irrigation water was not available. Thus, the intermittent project farmer has an opportunity to increase his income during those periods when he is able to irrigate; however, it was assumed that he would not risk irrigation farming if there was an additional cost to him during those periods when irrigation water was not available.

# CHAPTER III

# THE DIKING ALTERNATIVE

## Objectives and Tasks

This chapter describes the procedures which were applied in examining the economic feasibility of controlling flooding at the Great Salt Lake by constructing dikes to protect specific properties or facilities at selected locations adjacent to the lake.

The specific objectives of the analysis of diking and the tasks used to perform them were:

Objective 1. To estimate the benefits generated by the construction of various diking systems as a means of flood protection at the Great Salt Lake.

Task 1: Propose diking systems to protect various designated areas.

Task 2: Develop a rule as to how close the lake surface elevation must be to the top of the dike before it is considered to be washed out or breached.

Task 3: Determine the effects of the proposed diking systems upon the stage-volume relationship of the Great Salt Lake.

Task 4: Use the stochastic lake level water balance and stage-damage simulation models described in Chapter II to simulate the effects of various diking configurations on lake elevation and to estimate the benefits generated through a reduction of flood damages.

Objective 2. On the basis of reduced flood damage, perform benefit-cost analyses for the various diking configurations proposed.

Task 1: Make cost estimates for each diking configuration proposed.

Task 2: Estimate the annual maintenance and repair costs for each proposed diking system.

Task 3: Through a comparison of benefits versus costs, determine the feasibility of constructing various dikes for flood protection of important areas along the shores of the Great Salt Lake.

## Model Development

The procedure employed for this portion of the study was to develop a model capable of estimating the damages prevented (and thus the resulting benefits) by various diking configurations (locations and heights) at the lake. The model thus needs to represent water surface elevations at the lake and also to be capable of estimating damages prevented by diking systems under consideration. The stochastic lake level water balance model and the damage simulation model of James et al. (1979) were used to represent the lake levels. Additional modifications as described in the following section were made in order to adapt the models to the needs of the diking study.

### Additions to the stochastic lake level water balance model

The stochastic data generation component. A limitation of the multivariate stochastic generation component developed by James et al. (1979) is that in order to begin data generation it requires a knowledge of the initial conditions for all variables. This limitation is suitable for generation of future time series using present conditions for initialization. Beginning with the lake at any other level requires some assumption on evaporation, precipitation, and streamflow quantities for the previous year.

One possible procedure is to begin with an approximate set of initial conditions and to discard the first part of the generated synthetic sequence because the effects of the initial conditions become negligible after a period of a few years. Another alternative is to randomly initialize each time series sequence. The latter method is less expensive and was used in this study.

For multivariate random initialization Haan (1977) adopts the relationship:

$$\underline{X} = \underline{Z}\,\underline{A}^t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.1)$$

in which

$\underline{X}$ = m-vector of normally distributed standardized variables
$\underline{Z}$ = m-vector of components $Z_m$ with a mean of zero and a variance of $\lambda_m$
$\underline{A}_t$ = the transpose of an m x m orthogonal matrix of characteristic vectors for the cross-correlation matrix
$\lambda_m$ = the corresponding eigenvalue for the cross-correlation matrix

The m components of $\underline{X}$ are then transformed by:

$$Y_m = \sigma_m X_m + \quad {}_m \quad . \quad . \quad . \quad . \quad . \quad (3.2)$$

in which

$Y_m$ = desired random variable
$\sigma_m$ = corresponding standard deviation of desired random variable
$\mu_m$ = corresponding mean of desired random variable

resulting in $\underline{Y}'$, which is made up of m normally distributed random variables with the desired mean and standard deviations for each variable and the desired cross-correlation between variables. The vector $\underline{Y}'$ is then transformed into $\underline{Y}$, a log-normally distributed vector of m random variables. A flow diagram of the additions to the stochastic generation component is shown in Figure 3.1.

The water balance component. For the purposes of the diking study, no changes were made in this component of the lake level water balance model described in Chapter II.

### Additions to the damage simulation model

The damage simulation model was modified in order to simulate the reduction in damages which would occur if various dikes were built at the Great Salt Lake.

If a dike were constructed to protect a particular entity at the lake, it should eliminate all of the flood related expenses for operation, maintenance, and repair, and for capital investment up to the design protection elevation for the dike. For further lake level increases, the freeboard for the dike will prevent some damage to the entity, but not all. The damages may occur in three ways:

1. Increased operation, maintenance, and repair of damaged dikes.

2. Pumping costs to return lake water back over the dike after overtopping during a period of high wave action.

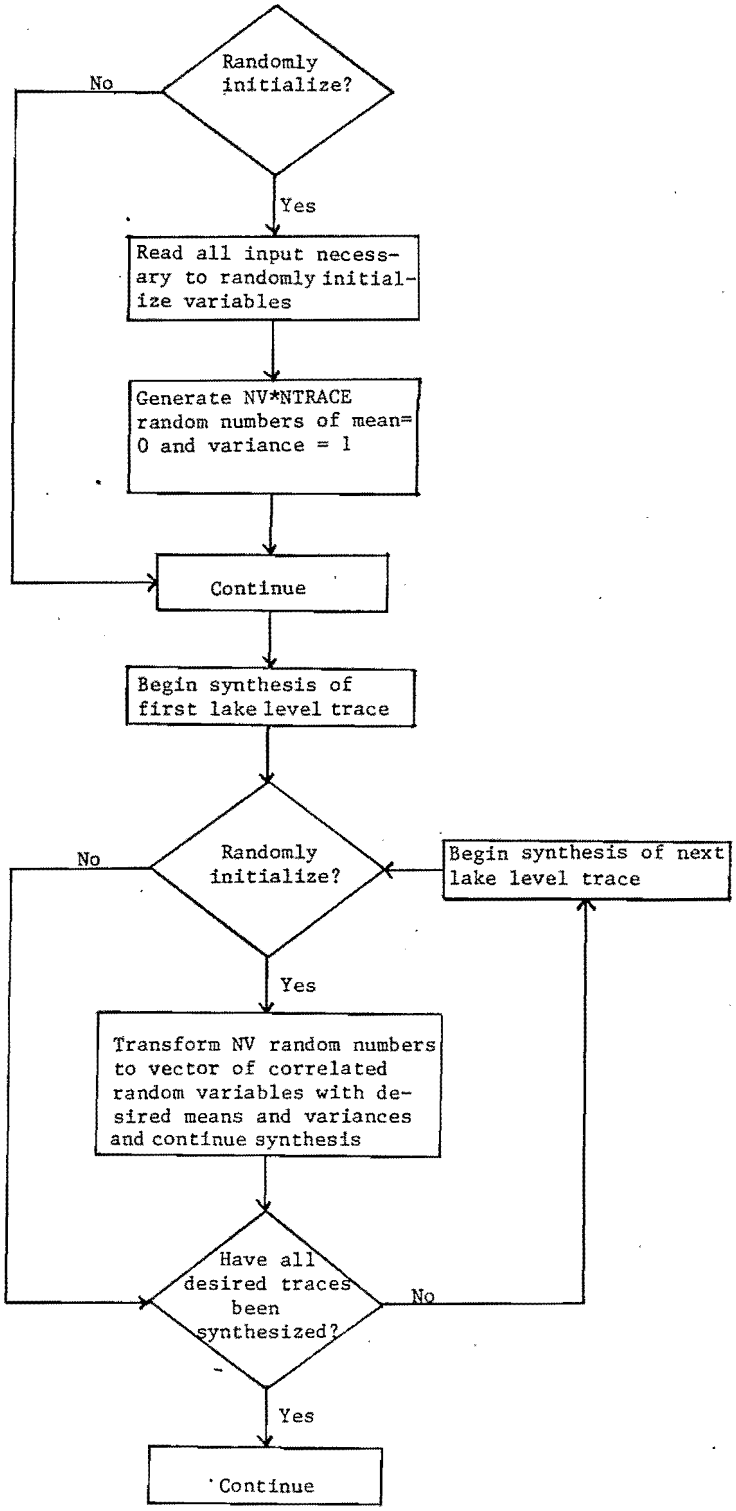


Figure 3.1. Flow diagram for additions to the stochastic generation component of the stochastic lake level water balance model.

3. Decreased profits for the mineral industries due to a decrease in salinity of their evaporation ponds caused by excess water from seepage through the dike or by waves splashing over the crest of the dike.

At some elevation before the rising lake level reaches the crest, wind blown waves can be expected to cause the dike to breach and no longer protect property and facilities behind it. This level is referred to as the "wipe out" elevation of the dike.

The approach used to simulate the ability of diking to reduce damages to the various entities around the lake is to modify the stage damage table read as input to the damage simulation model. The estimated damages at various lake levels for each protected entity are reduced or eliminated according to the design protection and wipeout elevation of the dike.

All damages for lake levels below the design protection elevation are set to zero. For lake levels between the design protection elevation and the wipeout elevation, only flood related damages associated with operation, maintenance, and repair are assessed. At each 1 foot increment between these two elevations, damages are computed as an increasing fraction of the pre-diking operation, maintenance, and repair costs estimated by the entity protected. At the wipeout elevation, the entity either goes out of business or the capital investment estimate provided by the entity to protect itself to that elevation is taken as a loss, depending on whether the dike wipeout elevation is above or below the elevation at which the entity has indicated it would cease operations. If the entity is wiped out, revenue loss is assessed; if not, original damages estimated by the entity for further rises in lake levels are assessed.

Another addition was made to the damage simulation model to allow the simulation of the effect of proposed dikes on damages to individual state bird refuges. The state bird refuges had previously been lumped together and treated as one entity. However, since the refuges are actually at different elevations, it is necessary in a diking study to treat the refuges on an individual basis. A flow diagram of all additions to the damage simulation model is shown in Figure 3.2.

## Annual dike cost simulation model

To estimate costs associated with maintaining and repairing the proposed dikes, an annual dike cost simulation model was developed. The model simulates a time series of dike costs in response to the annual lake level time series generated by the stochastic lake level water balance model.

Model description. The annual dike cost simulation model generates zero costs for years when the lake level is below the base of the dike. When the lake level reaches the base of the dike, a fixed annual cost is charged to operation, maintenance, and repair of the dike. When the lake level rises above the design protection level, operation, maintenance, and repair costs are increased until the level reaches the dike wipeout elevation. At the dike wipeout elevation all costs are set to zero until the lake level drops below the wipeout elevation for a specified period of time. The cost of rebuilding or repairing the dike is then assessed, and operation, maintenance, and repair costs are resumed. A flow diagram of the annual dike cost simulation model is given in Figure 3.3.

Model output. The annual dike cost simulation model estimates the present worth of the annual costs associated with a given diking scheme for each simulated lake level time series. It arranges the annual cost estimates thus calculated in ascending order and calculates the mean and standard deviation.

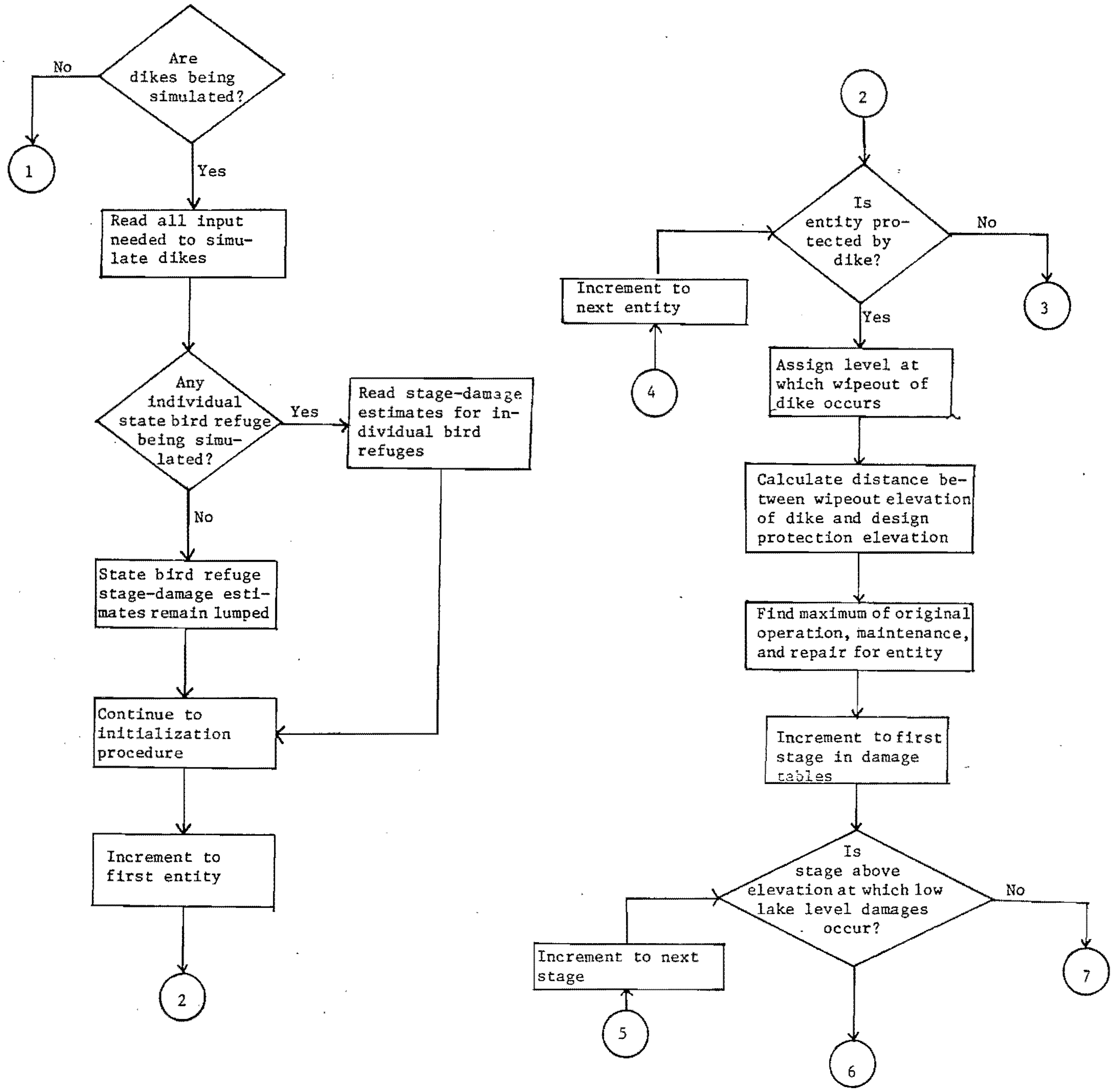


Figure 3.2. Flow diagram for additions to the damage simulation model made for this study.

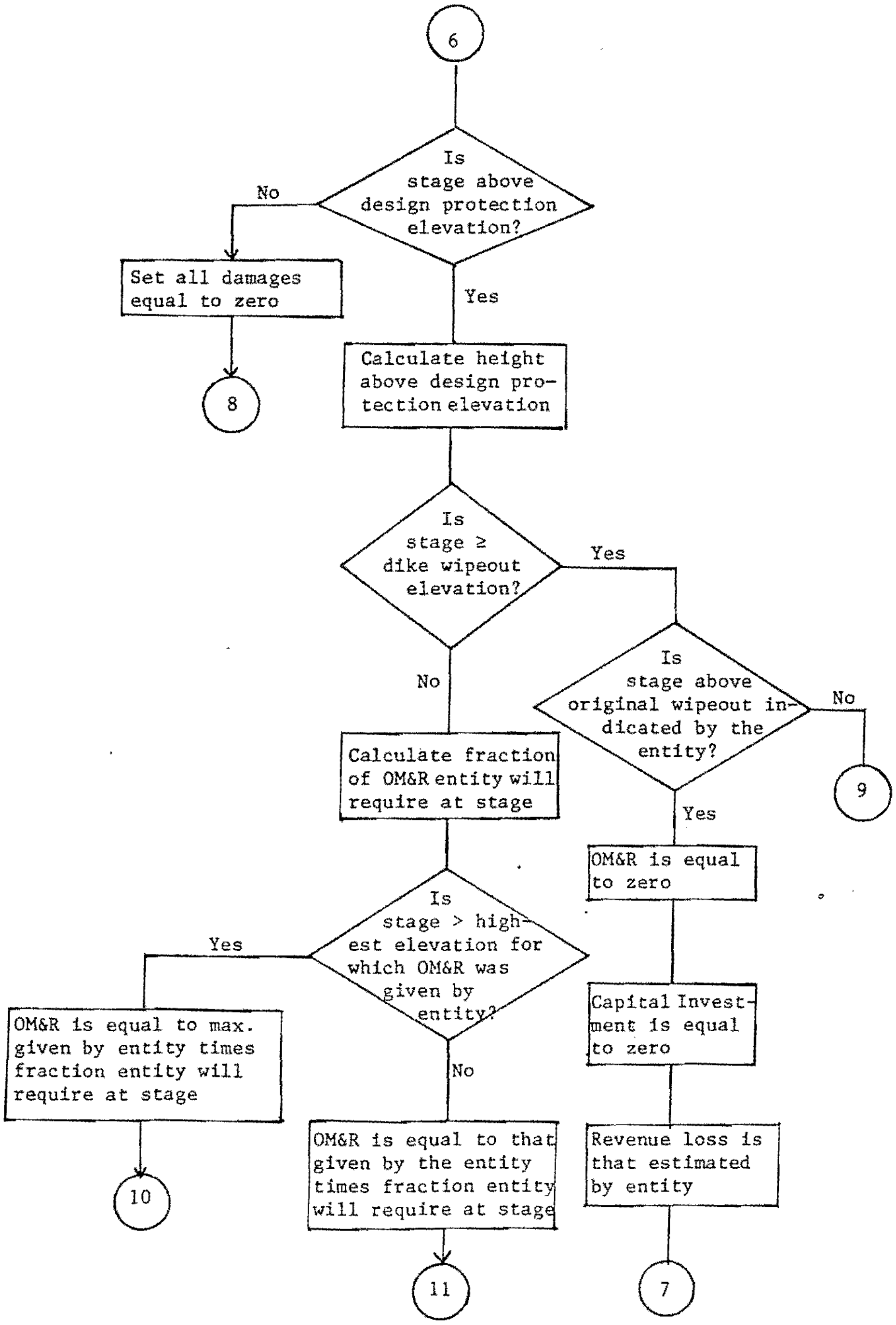


Figure 3.2. Continued.

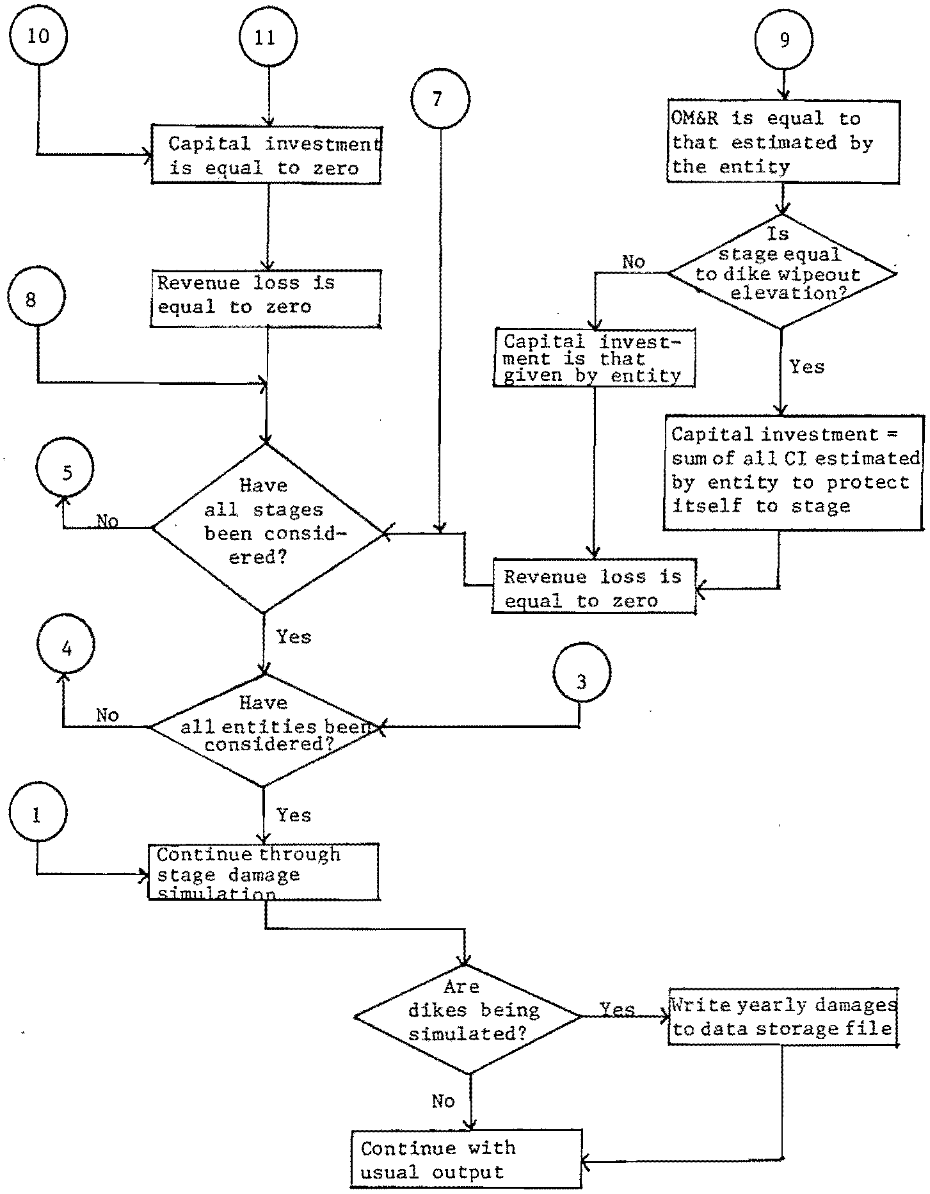


Figure 3.2. Continued.

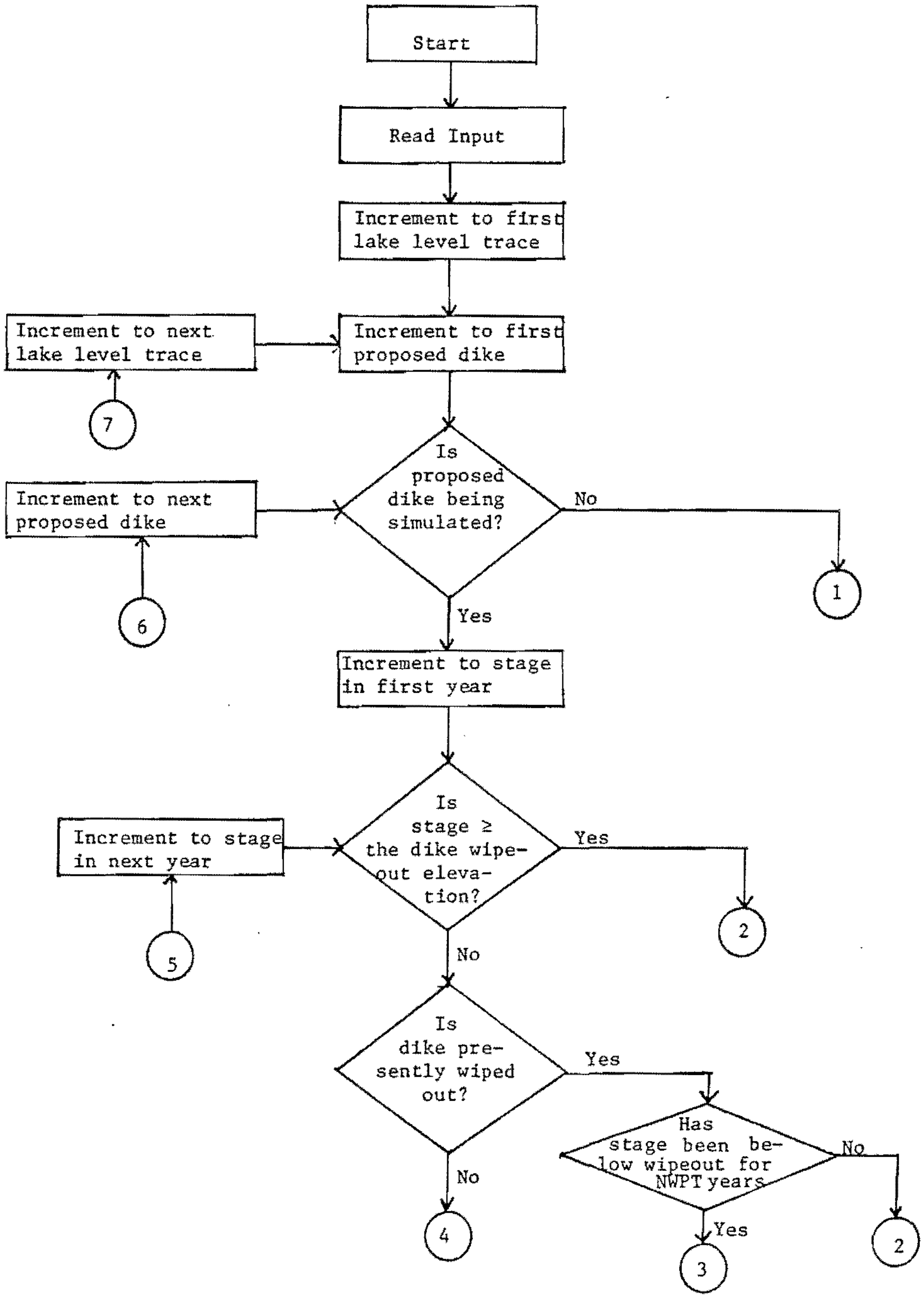


Figure 3.3. Flow diagram of the annual dike cost simulation model.

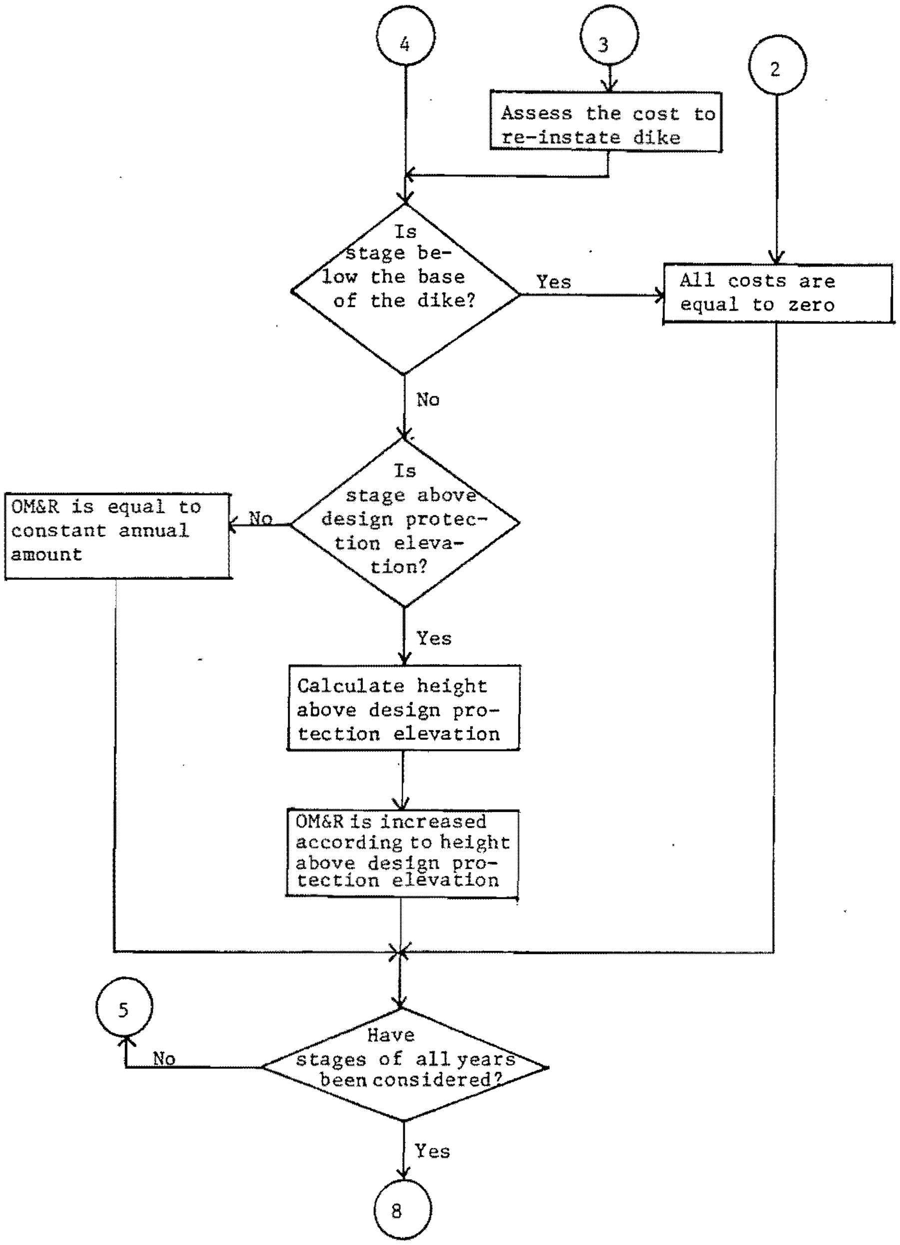


Figure 3.3. Continued.

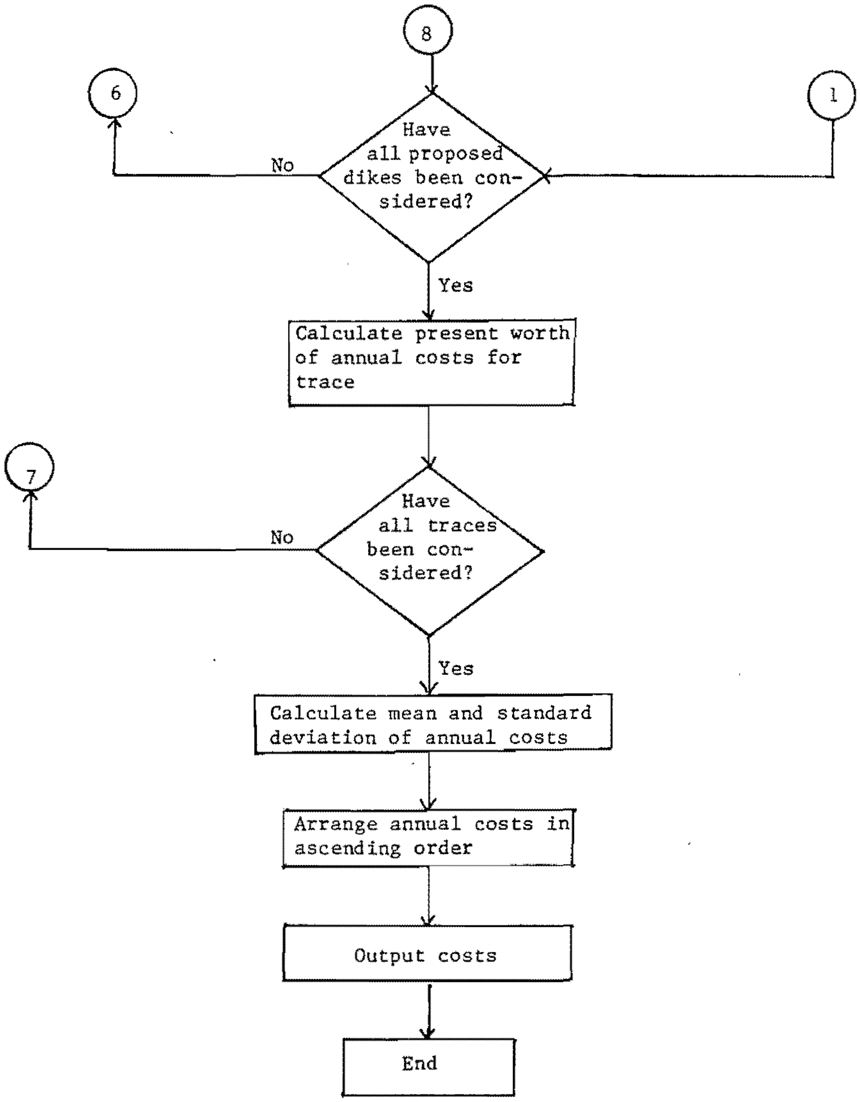


Figure 3.3. Continued.

## Model Application

### The diking system

The diking system proposed by Riley (Figure 1.9) was evaluated to ensure that all important areas were protected and that damages for all areas protected were estimated by the damage simulation model.

Several changes were necessary. Since Riley's diking proposal, Intermountain Mineral Industries near Lakeside has gone out of business making dike 22 no longer necessary. It was found that dike 23 did not protect and its alignment was relocated as shown on Figure 3.4. Also, dike 25 is now proposed to protect Lake Crystal which was not protected by the previous diking system. Table 3.1 shows the entities protected by each dike.

The costs of raising the railroad causway are included in the damage simulation model, but no consideration is given to evaluating the need for raising this structure.

Because of their high elevations, the damage simulation model does not assess damages to the Salt Lake International Airport, to Interstate Highway 215, or to any other interest which might be protected by dike 12. Also, no damages are assessed to Locomotive Springs Bird Refuge at the north end of the lake. For this reason, dikes 12 and 21 are not considered in this study.

### Simulation of dike protection

Dike wipeout elevation. At some point before the rising average lake level reaches the top of the dike, a phenomenon known as wind tides is likely to cause local lake levels to rise long enough to overtop and break the dike. Wind tides are a tilting of the lake surface during a long period of high winds. Lin (1976) studied wind tides or seiches on the Great Salt Lake and found that a rise of as much as 2 feet may occur at Silver Sands Beach. Lin also gave estimates of the wind tide amplitudes for various points around the south arm of the lake as a fraction of that at Silver Sands Beach.

For this study, the wipeout elevation was taken as being the crest height of the dike less the maximum wind tide height at each proposed dike. Wind tide height of 2 feet was assumed for all proposed dikes on the south and north shores of the lake and of 1 foot for the dikes on the west and east shores of the lake.

Lake levels between design protection and wipeout elevations. At lake levels between the design protection elevation and the wipeout elevation of a proposed dike (within the freeboard range), some damages will be caused by water splashing over a dike during periods of high wave action. These damages were estimated using wave height probabilities.

From Linsley and Franzini (1972), the equation for predicting seiche or wind tide on a fesh water lake is:

$$Z_s = \frac{V_w^2 F}{1400\ d} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.3)$$

in which

$Z_s$ = seiche height in feet
$V_w$ = wind speed in mph over water
$F$ = length of water surface over which high wind blows
$d$ = average depth of lake in feet

The equation for short wave height is:

$$Z_w = 0.034\ V_w\ 1.06\ F^{0.47} \quad . \quad . \quad (3.4)$$

in which

$Z_w$ = short wave height

The wind speed $V_w$ over water is approximately 1.31 times that over land (James et al. 1979).

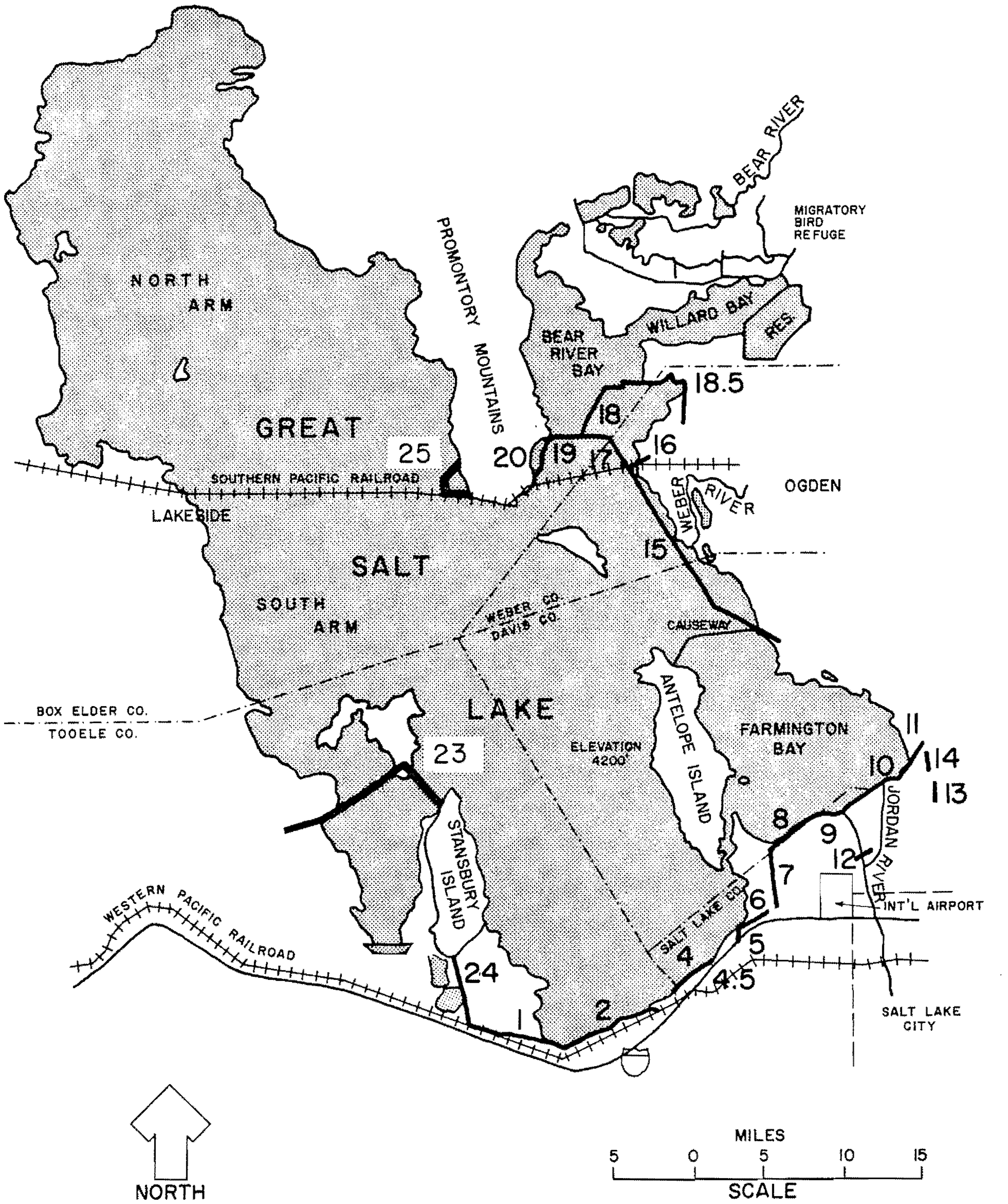


Figure 3.4. Revised alternative dike layout configurations indicating dike section numbers (adapted from James et al. 1979).

Table 3.1. Entities protected by each dike.

| Entities \ Dikes | 1 | 2 | 4 | 4.5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 18.5 | 19 | 20 | 21 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industries | | | | | | | | | | | | | | | | | | | | | | | | | |
| Great Salt Lake Minerals | | | | | | | | | | | | | | | | X | X | X | X | X | X | | | | |
| American Salt | | | | | | | | | | | | | | | | | | | | | | | X | X | |
| Morton Salt | | | X | X | X | X | | | | | | | | | | | | | | | | | | | |
| National Lead Industries | | | | | | | | | | | | | | | | | | | | | | | X | X | |
| Hardy | | X | | | | | | | | | | | | | | | | | | | | | | | |
| Lake Crystal | | | | | | | | | | | | | | | | | | | | | | | | | X |
| Stauffer Chemical | | | X | X | X | X | | | | | | | | | | | | | | | | | | | |
| Railroads | | | | | | | | | | | | | | | | | | | | | | | | | |
| Southern Pacific Causeway | | | | | | | | | | | | | | | | | | | | | | | | | |
| Western Pacific | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | | |
| Union Pacific | X | X | X | X | X | X | X | X | X | X | X | | X | X | | | | | | | | | | | |
| Little Mountain | | | | | | | | | | | | | | | | X | X | X | X | X | | | | | |
| Highways | | | | | | | | | | | | | | | | | | | | | | | | | |
| Interstate 80 | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | | |
| Antelope Island Causeway | | | | | | | | | | | | | | | | | | | | | | | | | |
| Interstate 15 | | | | | | | X | X | X | X | X | | X | X | | | | | | | | | | | |
| Marshlands | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bear River Mig. Bird Refuge | | | | | | | | | | | | | | | | X | X | | | X | | | | | |
| Ogden Bay Bird Refuge | | | | | | | | | | | | | | | X | X | | | | | | | | | |
| Howard Slough Bird Refuge | | | | | | | | | | | | | | | X | X | | | | | | | | | |
| Farmington Bay Bird Refuge | | | | | | | X | X | X | X | X | | | | | | | | | | | | | | |
| Other State Bird Refuges | | | | | | | | | | | | | | | | X | X | | | X | | X | | | |
| Private Marshlands | | | | | | | X | X | X | X | X | | | | X | X | X | | | X | | | | | |
| Recreation | | | | | | | | | | | | | | | | | | | | | | | | | |
| Saltair Beach State Park | | | X | | | | | | | | | | | | | | | | | | | | | | |
| Antelope Island State Park | | | | | | | | | | | | | | | | | | | | | | | | | |
| Willard Bay | | | | | | | | | | | | | | | | X | X | | | X | | | | | |

Wind frequency curves for maximum 3-hour daily wind speeds at the Salt Lake International Airport were prepared for the years 1976 through 1978 and averaged. The probabilities of exceedance for specific wave heights (heights include seiche) were calculated (Table 3.2). A value of F = 35 miles was used for the south and north shores of the lake and a value of F = 25 miles was used for the west and east shores.

It is recognized that in order for a seiche to develop on the Great Salt Lake, the wind must remain above 10 knots for at least 12 hours (Lin 1976). Thus, the use of 3-hour daily maximum wind speeds for wave frequency analysis will yield high values for wave heights. Also, the above equations are for freshwater lakes, and thus the estimated values are higher than might be expected for the Great Salt Lake with its high density brines. However, the values of wave height in Table 3.2 correspond closely with those predicted by Johnson (1956). A further compensating consideration is that the high density brines of the Great Salt Lake possess a greater damaging potential than does fresh water.

The damage simulation model computes damages between the design protection elevation and wipeout elevation of the dike for each 1 foot increment as an increasing fraction of the original operation, maintenance, and repair costs estimated by the entity protected. This fraction was taken as the probability of a wave of sufficient height to exceed the top of the dike as given in Table 3.2.

Table 3.2. Probabilities of exceedance for various wave heights.

| Wave Height ft | Probability of Exceedance | |
|---|---|---|
| | F = 35 Miles | F = 25 Miles |
| 1 | 1.00 | 1.00 |
| 2 | 0.86 | 0.74 |
| 3 | 0.60 | 0.48 |
| 4 | 0.39 | 0.28 |
| 5 | 0.24 | 0.14 |
| 6 | 0.13 | 0.00 |
| 7 | 0.00 | 0.00 |

Effects of the diking system on the lake stage-volume relationship. Each dike will alter the stage-volume relationship of the Great Salt Lake slightly, but for the proposed dikes, with the exception of dike 19, the effects are assumed negligible. Dike 19 would separate the Bear River Bay from the body of the south arm and would change significantly the stage-volume relationship of the lake. The stage-volume relationship of the Bear River Bay was determined from a contour map and the revised stage-volume relationship above elevation 4202 feet for the Great Salt Lake with dike 19 in position is shown in Table 3.3. It was assumed that the water level of the Bear River Bay would be held at 4202 feet or below. For lake levels in excess of 4201, pumping to the lake from Bear River Bay is assumed.

Protection of individual state bird refuges and mashlands. Since dikes 15 and 19 protect several state bird refuges and will require expensive pumping plants, it is desirable to analyze the benefits of each of the dikes separately. However, since the stage-damage table developed by James et al. (1979) for input into the damage simulation model treats all state bird refuges as a single lumped entity, it was first necessary to determine the proportion of the damages which would occur to each individual state bird refuge. Similarly, James et al. lumped all private marshlands as one entity and it, therefore, was necessary to determine the portion of damages to private marshlands prevented by each proposed dike. The proportions of land are used for these separations are

Table 3.3. Stage-volume and stage-area data for the Great Salt Lake above 4202 feet (msl).

| Water Surface Elev. ft (msl) | Without Dike 19 |  | With Dike 19 |  |
|---|---|---|---|---|
|  | Volume acre-ft | Area acres | Volume acre-ft | Area acres |
| 4202 | 17,640,700 | 1,175,000 | 17,640,700 | 1,175,000 |
| 4203 | 18,828,700 | 1,201,000 | 18,806,640 | 1,190,000 |
| 4204 | 20,040,700 | 1,223,000 | 19,927,100 | 1,202,500 |
| 4205 | 21,276,000 | 1,250,500 | 21,060,600 | 1,219,800 |
| 4206 | 22,542,000 | 1,330,000 | 22,214,600 | 1,289,100 |
| 4207 | 23,808,000 | 1,375,000 | 23,358,400 | 1,323,900 |
| 4208 | 25,075,000 | 1,410,000 | 24,493,000 | 1,348,700 |
| 4209 | 26,341,000 | 1,450,000 | 25,616,300 | 1,378,500 |
| 4210 | 27,607,000 | 1,490,000 | 26,729,400 | 1,408,200 |
| 4211 | 29,800,000 | 1,530,000 | 28,759,300 | 1,438,000 |
| 4212 | 30,700,000 | 1,570,000 | 29,486,000 | 1,467,800 |
| 4219 | 43,200,000 | 2,000,000 | 41,676,800 | 1,826,300 |

given in Table 3.4. The damage estimates developed by James et al. for private marshlands were based on land area.

## Diking alternatives studied

In this study, five combinations of the various proposed dikes are analyzed (see Table 3.5). In order to examine the sensitivity of the results to the dike height and initial lake elevation, each diking system is analyzed with the dike crests at elevations 4208, 4210, and 4212 feet above sea level, and with initial lake elevations at 4200, 4202, and 4204 feet. In each case, it was assumed that all entities had protected themselves at least to the initial lake elevation. In actual fact this assumption is true except for the 4204 feet elevation. Individual dikes are not evaluated separately for three reasons:

1. Much of the data in the stage-damage table used as input for the damage simulation model were provided by the entities involved with the understanding that it would not be generally distributed. Thus, considering the dikes on an individual basis could reveal some perhaps confidential information.

2. Political problems exist with using public monies for protection of some private industries and not others.

3. The limited funds available for this study made a consideration of individual dikes impractical.

## Benefit analysis

The stochastic lake level water balance model was used to generate 100 traces of lake level sequences of 50-year periods. The damages which would result from each trace, with and without proposed dikes, were estimated by the damage simulation model. Damages include economic losses to businesses during wipeout periods. Benefits were computed as the reduction in damages which resulted from implementation of a proposed diking scheme.

## Cost analysis

Dike capital cost. Riley (Utah Water Research Laboratory 1977) provided

Table 3.4. Proportions used to separate damages to individual state bird refuges and to private marshlands.

| Protecting Dikes | Bird Refuge | Proportion of Bird Refuge Damages | | Proportion of Private Marshlands Damages |
|---|---|---|---|---|
| | | Below 4212 | Above 4212 | |
| 7,8,9,10,11 | Farmington | 0.29 | 0.28 | 0.36 |
| 15 | Ogden | 0.64 | 0.37 | 0.03 |
| 19 | Other | 0.07 | 0.35 | 0.27 |
| Unprotected[a] | Timpie & Locomotive Springs | 0.00 | 0.00 | 0.34 |

[a] Because of the relatively high elevations of these small areas, it was not included in the stage-damage model of James et al. (1979). Thus, in order to be consistent, the costs of the relatively small dikes for these areas also were not included in this analysis.

Table 3.5. Diking schemes simulated.

| Diking Scheme | Dikes Included (see Figure 3.4) |
|---|---|
| Highways and Railroads | 1,2,4.5,5,6,13,14 |
| Industries and South Shore | 1,2,4,5,6,16,17,18,18.5,20,23,24,25 |
| Farmington Bay Bird Refuge | 7,8,9,10,11 |
| Ogden Bay and Howard Slough Bird Refuges | 15,16 |
| Bear River Migratory Bird Refuge | 16,17,19 |

cost estimates for his proposed dikes for top elevations from 4211 to 4216 feet above sea level (Chapter I). These cost estimates were updated to October 1978 dollars for the dike crest elevation of 4212 feet and used in this study. For the crest elevations of 4208 and 4210 feet, the average cross-sectional area and the length of the dike were determined. The cost was then obtained by using Riley's cost figure updated to October 1978 dollars after increasing the volume by 30 percent to allow for compaction and settlement.

The cost of dike 23 which protects AMAX was determined assuming that the company's present dikes can be raised. Cost estimates were modified to reflect the company's estimates of costs to raise its dike. The top of the present dike is at about elevation 4208 feet. The cost of construction for dike 25 which protects Lake Crystal was estimated in the same manner.

Pump capital costs. Dikes 15 and 19 each require a pump to convey the waters of the Weber and Bear Rivers respectively, over the dikes. Riley estimated the required capacity for each pump to be about 10,000 cfs and the cost of each pump to be about $10 million (1975 dollars). This cost estimate updated to October 1978 dollars would be approximately $12.5 million.

The pump capacities estimated by Riley may be greater than necessary and were re-examined. About 200,000 acre-feet of storage is available in Bear River Bay behind dike 19. This allows the use of a smaller pumping plant than would otherwise be necessary. For a 50-year flood, it is estimated that the pump capacity required is about 6000 cfs. A plot of the pumping capacity versus the capital cost of the pumping plants proposed for the West Desert pumping alternative indicates that the capital cost of a 6000 cfs capacity pumping plant is about $10.5 million in 1979 dollars.

Very little storage capacity exists behind dike 15; therefore, the pumping plant must be designed to handle the full flood flow over a relatively short time. For a 50-year flood, it is estimated that the pump capacity required is about 5200 cfs. If capital costs are estimated in the same manner as given above for the pump associated with dike 19, the capital cost is about $10 million in 1979 dollars.

Dike operation, maintenance, and repair costs. An annual dike cost simulation model was developed to estimate costs associated with maintaining and repairing the proposed dikes. For lake levels below the design protection level of the dike, a fixed annual operating, maintenance, and repair cost is assumed. This cost was calculated as being one percent of the initial cost of construction for each dike with the crest at elevation 4210.

As rising lake levels exceeded the design protection elevation, the operation, maintenance, and repair costs for each dike are increased in proportion to the wave height probabilities given in Table 3.2. To estimate costs of repairing a dike after it has been overtopped, it was assumed that only the top 3 feet of the dike would need to be reconstructed. Unit costs of reconstruction were taken as being 1.2 times the original cost of construction since repair unit costs generally are higher than original construction costs (James et al. 1979), neglecting inflation.

The annual operation, maintenance, and repair costs for the pumps required in conjunction with dikes 15 and 19 were also estimated from the data collected for the West Desert pumping alternative. It is estimated that these annual costs would be $900,000 for the pump associated with dike 15 and $950,000 for the pump associated with dike 19. It was assumed that pumping would be required only when the lake surface elevations rose above 4201 feet. Otherwise, the Bear and Weber Rivers could flow by gravity through gates in the dikes.

# CHAPTER IV

# THE PUMPING ALTERNATIVE

## Objectives and Tasks

This chapter describes the procedures applied in examining the economic feasibility of controlling flooding at the Great Salt Lake by pumping excess water into storage areas in the desert west of the lake for evaporation (Figures 1.5, 1.6, and 1.7).

The specific objectives in evaluating the pumping alternative and the tasks used to perform them were:

Objective 1. Estimate the benefits due to decreased flooding which would result from removing water from the Great Salt Lake by pumping to the West Desert area.

Task 1: Develop various operating rules for the pump. For example, one operating rule might be to pump water from the lake whenever the lake elevation exceeds 4200 feet.

Task 2: Use the stochastic lake level water balance and stage-damage simulation models (Chapter II) to simulate operation of the pump at various pumping capacities and operating rules and to estimate benefits generated.

Objective 2. Perform a benefit-cost analysis of pumping lake water into the West Desert area as a means of controlling high lake levels.

Task 1: Update cost estimates developed by the Corps of Engineers (Utah Division of Water Resources 1977) and use these estimates in predicting the cost of various pumping and holding area capacities as needed.

Task 2: Using a comparison of estimated costs and benefits, determine the most economical pump and holding area capacity, the most economical operating rule, and the overall feasibility of the project.

## Annual Pumping Cost Simulation Model

A pumping cost simulation model was developed to estimate annual operation, maintenance, and repair costs associated with pumping excess lake water into the West Desert for evaporation.

### Model description

The model uses the annual volume of water needing to be removed from the lake as calculated from the lake level time series provided by the stochastic lake level water balance model. For a given year of a lake level time series, the model calculates the evaporative capacity of the pond area in the West Desert. The operation, maintenance, and repair costs are then computed as the portion of the annual operation, maintenance, and repair costs which would occur if the project were operated at maximum capacity. For example, suppose the annual evaporative capacity of the West Desert holding area is 850,000 acre-feet and the actual amount evaporated from the holding area in a particular year is 425,000 acre-feet. If the annual operation, maintenance, and repair costs for the 850,000 acre-feet net evaporative capacity are $860,000, the value of the operation, maintenance, and repair cost computed by the model for that year is $430,000. A flow diagram of the annual pumping cost simulation model is given in Figure 4.1.

### Model output

The annual pumping cost simulation model estimates, for each lake level time series, the present worth of annual costs associated with the implementation of the West Desert area pumping alternative. The model arranges the annual cost estimates in ascending order and calculates the mean and standard deviation.

## Model Application

### Pump operating rule

In 1976, the level of the Great Salt Lake reached an elevation of 4202.3 feet above sea level, and some entities of the lake were forced to construct facilities to protect themselves to this level. It would seem desirable to prevent the lake level from exceeding this elevation in the future since damages become significant above this stage. The Utah Division of Water Resources (1977) explained how the pump control elevation must be below 4202 in order to ensure that the lake does not exceed this elevation. They suggest beginning pump operations when the rising lake level exceeds 4200 feet. The constraint to beginning pump operation too early is that it could cause significantly lower lake levels which may have adverse effects on lake related activities such as recreation.

For this study, two pump operating rules were simulated with initial lake levels at 4200, 4202, and 4204 feet above sea level. The pump control elevations investigated were at 4200 and 4202 feet. The pumps were started when rising lake levels reached these elevations.

### Pump capacities investigated

A study conducted by the Corps of Engineers (Utah Division of Water Resources 1977) provided cost estimates for annual pump and holding area capacities required to achieve net evaporative losses of 310,000, 380,000, and 850,000 acre-feet annually. These net evaporative capacities were used in this study together with an additional net evaporative capacity of 1,500,000 acre-feet per year estimated as the maximum evaporative capacity possible in the West Desert area (Utah Division of Water Resources 1976).

The above net evaporative capacities were treated as being the maximum amounts that could be removed from the lake in any one year. If in any one year the volume of lake water above the control elevation was less than the net evaporative capacity of the holding area, it was assumed that only the volume of water above the control elevation was pumped from the lake to the evaporation reservoirs.

### Benefit analysis

The stochastic lake level water balance model was used in conjunction with the damage simulation model to simulate pumping and to estimate the reduction in damages which each pumping strategy produced. The reduction in flood damages at the lake was considered to be the benefits of the pumping strategy.

For this study, 100 traces of 50-year lake level sequences were generated for each pumping strategy by the stochastic lake level water balance model. One hundred traces were found to be necessary in order to stabilize the expected values of the results, and the length of each trace corresponds to the assumed project life. The damages which would result from each trace were estimated by the damage simulation model. Reduction in damages was estimated for each trace by a comparison of damages

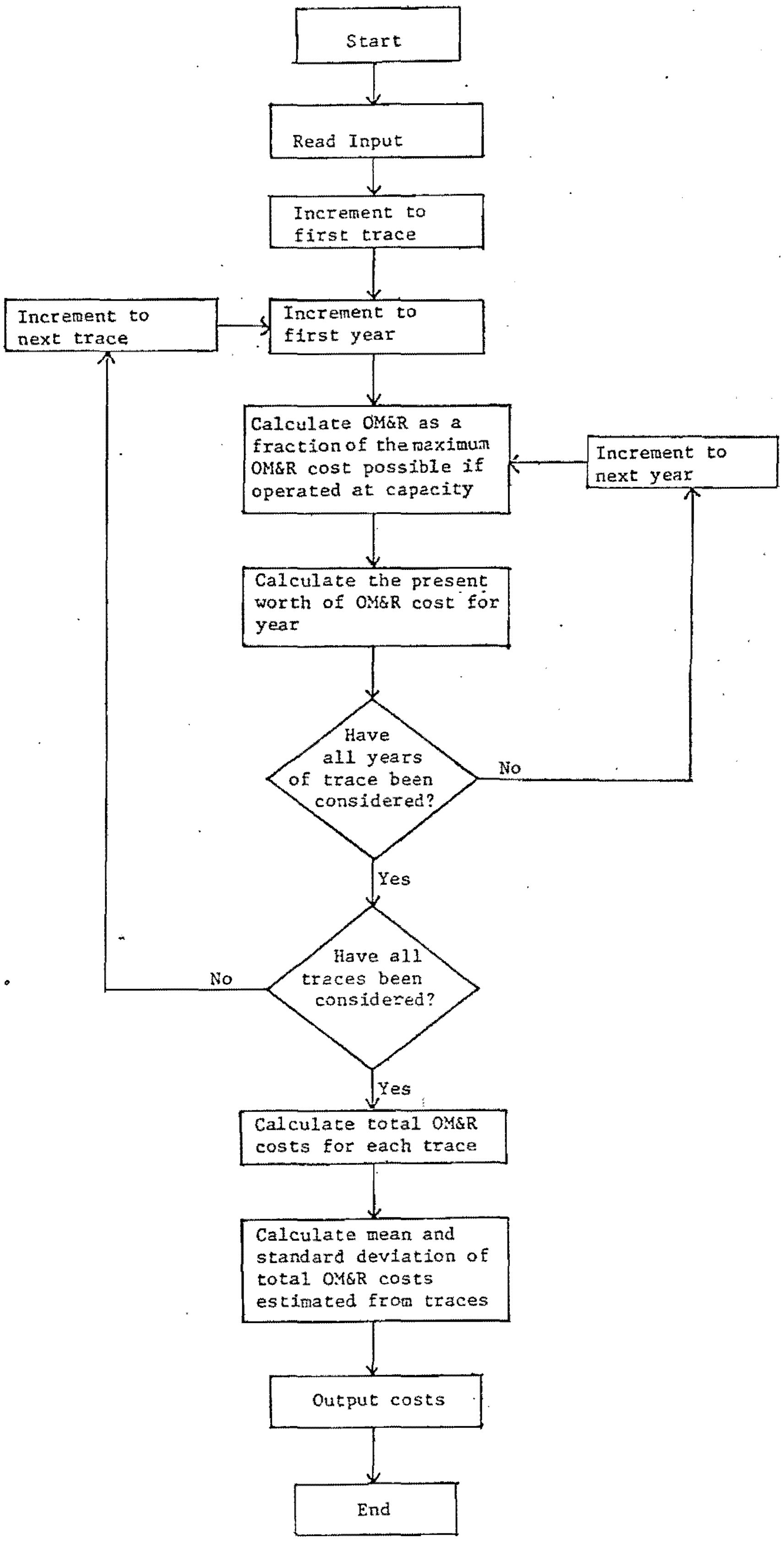


Figure 4.1. Flow diagram of the annual pumping cost simulation model.

which would occur with pump operation with those which would occur without pump operation.

### Cost analysis

Capital costs. The cost estimates provided by the Corps of Engineers (Utah Division of Water Resources 1977) for providing net annual evaporation capacities of 310,000, 380,000, and 850,000 acre-feet were updated through the use of a price index (USBR 1979) to October 1978 dollars. To estimate the cost of 1,500,000 acre-feet annual net evaporative capacity, the costs estimated by the Corps of Engineers were plotted versus net evaporative capacity on semilog paper. The cost of construction for a 1,500,000 acre-feet annual net evaporative capacity was then determined through extrapolation of a best-fit straight line.

It is emphasized that those costs must be regarded as preliminary. They are based on very limited data and no on-site surveys additional to those conducted for the Corps of Engineers study. For example, in many instances mapped topographic elevations for the area west of the Great Salt Lake are known to be approximate. In addition, the impact of the proposed reservoirs on the bombing range telemetry equipment and other facilities would need to be carefully evaluated if this lake management alternative were to be seriously considered.

Annual costs. The annual pumping cost simulation model was used in conjunction with the stochastic lake level water balance model to estimate the present worth of annual costs for operation, maintenance, and repair of proposed project facilities. The operation, maintenance, and repair costs for a given year for the four net annual evaporative capacities listed above were estimated in the same manner as the capital costs.

# CHAPTER V

# RESULTS AND DISCUSSION

This report provides a reconnaissance examination of the economic feasibility of three methods for reducing or eliminating flood damages at the Great Salt Lake:

1. Consumptively using an increased portion of the inflowing fresh water to irrigate crop lands during high periods of lake inflow.

2. Protecting important points around the lake through the construction of a system of dikes.

3. Pumping lake water into the West Desert area for evaporation.

The results are drawn together in this chapter. Benefits and costs of the projects were computed assuming a 50-year project life and a discount rate of 6.875 percent. All estimates were computed in fixed October 1978 dollars with the assumption that both cost and benefit streams are similarly affected by inflation.

## The Upstream Consumptive Use Alternative

### Amount of required withdrawals

In order to estimate the area of additional land which would have to be irrigated in order to provide lake level control, the required withdrawals from the Bear River were estimated for each year of simulated inflows in which the stage of the Great Salt Lake exceeded 4202 feet. A total of 100 traces showing lake stages year by year over a period of 50 years were synthesized. Of the 100 traces, 41 contained peak stages in excess of the control elevation (4202 feet). The maximum required annual withdrawal was 4,224,000 acre-feet, and the standard deviation of the trace maximums was 791,000 acre-feet. The average volume of water that would have to be withdrawn from the Bear River to provide lake level control at 4202 feet was estimated to be 847,600 acre-feet during each year in which the lake stage exceeds 4202 feet, and the average number of years in which lake levels exceeds 4202 feet during the 50-year simulation period was 3.24. Based on the average net consumptive use in irrigable areas of the Bear River Basin of 1.54 feet per year, and neglecting conveyance and field losses, 550,400 acres of additional lands would have to be irrigated to consumptively use 847,600 acre-feet of water and 2,743,000 acres would be required to consumptively use 4,224,000 acre-feet of water.

The search for lands where the water could be applied identified 300,000 acres of irrigable lands within suggested U.S. Bureau of Reclamation projects and 160,000 acres within suggested U.S. Department of Agriculture projects. The 300,000 acres from USBR projects includes some lands which currently receive partial irrigation but could use supplemental water. The additional water that would be required to provide full irrigation would be equivalent to that required to meet all the water needs of 100,000 acres. Thus, in full service equivalents, the total acreage is 260,000 consumptively using 400,000 acre-feet annually. Irrigation of additional areas to remove more of the required 847,600 acre-feet of water from the Bear River would require pumping to more remote locations.

Conveyance and field losses also need to be considered. These could easily add to water withdrawals by 30 to 50 percent. For a system seeking to use as much water as possible, there would be no incentive to go to extra expense to improve system efficiency. Irrigation 3 years out of 50 would not threaten to waterlog the soils and might in fact provide useful groundwater recharge. Consequently, irrigation systems designed to dissipate excess water would not have to be as costly as are conventional designs.

The relatively few years in which extra water would have to be evaporated (about 1 in 15) and the very large areas that would be required to evaporate the excess volumes during those few wet years, make lake level control difficult to justify economically. Both lake level control and irrigation benefits would need to be carefully evaluated. The amount of irrigation benefit could be substantially increased by reservoirs storing the water for irrigation over a period of several years or by groundwater recharge for long term use. The role conjunctive ground-surface water management could potentially play in lake level control deserves future consideration.

### Benefit-cost analysis of projects

Benefit-cost analyses were performed to determine which projects could be classified as continuous (B/C > 1) and which projects should be classified as intermittent (Table 5.1). Only two projects have B/C ratios greater than one, the Cutler Enlargement and Wyuta projects. Only the Cutler Enlargement has authorized Bear River depletions in the amended Bear River Compact. The Wyuta project thus fails the second criterion and was considered an intermittent project.

Data series preserving the statistics of the 1934-1977 record, the stochastic lake level water balance model, and the stage damage model were used in sequence to determine the benefits and costs of employing continuous and intermittent projects in accordance with an operating rule (Chapter II). Table 5.2 contains the results. The Cutler Enlargement, the only project classified as continuous, was analyzed first. The Wyuta project was then added as an intermittent project and operated in conjunction with the Cutler Enlargement. As can be seen in Table 5.2, the addition of the one intermittent project resulted in total costs exceeding total benefits and the change in costs exceeding the change in benefits. Since the Wyuta project may be economically justified when operated on a continuous basis, further study is needed to assess the feasibility of developing the project within an acceptable water allocation among the three Bear River Basin states, and possible control benefits.

The estimated costs in the B/C analyses are approximate and probably low. Except for the USBR projects and the Cutler Enlargement, they do not include cost estimates for canal laterals and drains. Construction costs do not reflect site-specific problems that could be encountered in actual reservoir construction. For example, it was assumed that larger reservoirs could be built downstream from existing reservoirs without incurring costs for removing or adapting existing structures. If indirect benefits had not been included in the B/C analysis and if the costs were estimated more carefully to reflect site conditions, all the B/C ratios could well have been less than one.

This expectation for single purpose projects, however, does not preclude economic justification of multiple purpose projects serving irrigation on a continuous basis. Recreation, municipal water supply, hydroelectric power, and

Table 5.1. Summary of the benefit/cost analysis for possible irrigation projects in the Bear River Basin.

| | Reservoir Volume (yd$^3$) | Construction Costs (Dollars) | | | | | Operation, Maintenance, & Replacement (Dollars Annually) | Annual Equivalent Cost at 6 7/8% | Benefits (Dollars Annually) | | | | B/C Ratio at $6\frac{7}{8}\%$ | Interest Rate Required for a B/C Ratio Equal to 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Reservoir | Canals | Recreation | Pumping Plant | Total | | | Net Direct Irrigation | Net Indirect Irrigation | Recreation | Total | | |
| Thomas Fork | 596,850 | 9,284,000 | -- | 97,100 | -- | 9,381,100 | 16,900 | 685,800 | 161,000 | 161,000 | 31,100 | 353,200 | 0.52 | 3.65% |
| Ashby | 999,600 | 17,828,000 | -- | 36,900 | -- | 17,925,100 | 19,400 | 1,297,500 | 284,700 | 284,700 | 50,200 | 619,600 | 0.48 | 3.329% |
| Myers | 1,060,500 | 18,518,000 | -- | 126,200 | -- | 18,644,200 | 17,000 | 1,346,300 | 203,400 | 203,400 | 40,600 | 447,400 | 0.33 | 1.722% |
| Poker Hollow | 532,200 | 12,532,000 | -- | 33,200 | -- | 12,565,200 | 5,200 | 901,100 | 81,300 | 81,300 | 10,400 | 173,000 | 0.19 | <0.01% |
| Bennington | | 3,101,700 | 4,030,100 | -- | 5,281,330 | 12,413,100 | 60,100 | 945,200 | 277,600 | 277,600 | -- | 555,200 | 0.59 | 4.286% |
| Bloomington | 802,400 | 15,594,000 | 286,900 | 158,300 | -- | 16,039,200 | 11,800 | 1,155,400 | 160,000 | 160,000 | 46,700 | 366,700 | 0.32 | 1.506% |
| Caribou | 420,000 | 19,201,000 | -- | 158,300 | -- | 19,359,300 | 16,000 | 1,398,300 | 593,200 | 593,200 | 51,900 | 1,238,300 | 0.89 | 6.523% |
| Grimley Hollow | 350,000 | 10,468,000 | -- | 21,000 | -- | 10,489,000 | 3,500 | 751,200 | 21,700 | 21,700 | 34,700 | 78,100 | 0.10 | <0.01% |
| Liberty Dell | 1,524,191 | 23,772,000 | -- | 40,200 | -- | 23,812,200 | 8,800 | 1,706,600 | 98,500 | 98,500 | 12,600 | 209,600 | 0.12 | <0.01% |
| Montpelier | 314,626 | 10,067,000 | 1,548,700 | 206,200 | -- | 11,821,900 | 36,600 | 879,500 | 162,700 | 162,700 | 262,000 | 587,400 | 0.67 | 4.625% |
| Oneida Narrows | 5,394,000 | 67,498,900 | 99,528,700 | 616,100 | -- | 167,643,700 | 390,400 | 12,360,200 | 4,993,500 | 4,993,500 | 391,700 | 10,378,700 | 0.84 | 6.223% |
| Sand Ridge | 2,251,800 | 32,016,000 | -- | 278,300 | -- | 32,294,300 | 48,600 | 2,351,200 | 219,600 | 219,600 | 353,700 | 792,900 | 0.34 | 1.339% |
| Sharon | 397,266 | 11,003,000 | 353,300 | 30,000 | -- | 11,386,300 | 4,800 | 816,700 | 40,700 | 40,700 | 48,900 | 130,300 | 0.16 | <0.01% |
| Sleight Canyon | 382,120 | 10,832,000 | 524,900 | 141,600 | -- | 11,498,500 | 7,100 | 826,900 | 162,000 | 162,000 | 61,500 | 385,500 | 0.47 | 3.165% |
| Willow Flat | 226,500 | 9,068,000 | 306,300 | 37,100 | -- | 9,411,400 | 4,200 | 675,200 | 50,800 | 50,800 | 61,000 | 162,700 | 0.24 | 0.17% |
| Big Creek | 1,048,560 | 18,383,000 | -- | 27,000 | -- | 18,412,000 | 6,700 | 1,319,500 | 92,200 | 92,200 | 9,100 | 193,500 | 0.15 | <0.01% |
| Card Canyon | 4,959,740 | 62,699,000 | 957,600 | 126,600 | -- | 63,783,200 | 36,500 | 4,584,200 | 474,500 | 474,500 | 38,900 | 987,900 | 0.22 | 0.098% |
| Cutler Enlargement | 1,062,000 | 18,535,000 | 22,251,200 | 300,000 | 5,224,800 | 46,311,000 | 150,600 | 3,452,600 | 2,369,800 | 2,369,800 | 200,000 | 4,939,600 | 1.43 | |
| Hyrum Enlargement | 454,950 | 11,657,000 | -- | -- | -- | 11,657,000 | 3,500 | 831,144 | 252,500 | 252,500 | -- | 505,000 | 0.61 | 4.561% |
| Neponset | 1,600,000 | 24,631,000 | 2,255,900 | 39,700 | -- | 26,926,600 | 29,400 | 1,949,300 | 410,500 | 410,500 | 54,000 | 875,000 | 0.45 | 3.06% |
| Otter Creek | 1,100,000 | 18,966,000 | 1,582,000 | 191,500 | -- | 20,739,500 | 18,000 | 1,496,700 | 164,100 | 164,100 | 56,500 | 384,700 | 0.26 | 0.624% |
| Smithfield | 1,785,000 | 50,788,000 | -- | 651,000 | -- | 51,439,000 | 74,900 | 3,742,500 | 949,000 | 949,000 | 413,900 | 2,311,900 | 0.62 | 4.489% |
| Twin Creek | 3,500,000 | 46,159,000 | 2,094,800 | 282,600 | -- | 48,536,400 | 63,000 | 3,523,700 | 650,800 | 650,800 | 332,000 | 1,633,600 | 0.46 | 3.061% |
| Woodruff Creek | 987,987 | 17,696,000 | 928,000 | 86,900 | -- | 18,710,900 | 16,000 | 1,350,100 | 139,500 | 139,500 | 27,800 | 305,800 | 0.23 | 0.211% |
| Wyuta | 2,423,600 | 33,963,000 | 6,997,300 | 106,900 | -- | 41,067,200 | 53,300 | 2,981,391 | 1,979,500 | 1,979,500 | 119,300 | 4,078,300 | 1.37 | 9.058% |
| Avon | 4,059,000 | 11,500,000 | 8,625,000 | -- | -- | 20,125,000 | 66,700 | 1,503,600 | 338,900 | 338,900 | 210,300 | 888,100 | 0.59 | 4.155% |

Table 5.2. Benefit/cost analysis for projects operated on a continuous or intermittent basis in accordance with the operating rule.[a]

| Project on Line | Cutler Enl. (Continuous) | Cutler Enl. (Continuous) & Wyuta (Intermittent) |
|---|---|---|
| Benefits (Present worth in dollars) | | |
| Net direct irrigation | 35,399,016 | 46,770,446 |
| Net indirect irrigation | 35,399,016 | 46,770,446 |
| Recreation | 2,805,049 | 2,805,049 |
| Reduction in damages at the Great Salt Lake | 1,342,680 | 1,691,971 |
| Total | 74,945,761 | 98,037,911 |
| Costs (Present worth in dollars) | | |
| Construction | 46,311,000 | 87,271,300 |
| Operation, maintenance & replacement | 2,112,200 | 2,859,747 |
| Subsidy to farmers | 0 | 12,560,272 |
| Total | 48,423,200 | 102,691,319 |

[a] Refer to the description of the project operating rule in Chapter II.

flood control (whether through lake level control or in the tributary basin) may add the needed benefits. A rough estimate of the benefits that could be added could be obtained from the percentage of the benefit total attributed to irrigation for typical reservoir projects matching Bear River Basin conditions.

The reconnaissance estimates showed the reduction in damages to properties at the lake achieved by upstream projects to be much too low to support projects on an intermittent basis. The total present worth of the reduction in damages from operation of the continuous project was $1,342,680 (less than 9 percent of the average annual damages estimated below). The introduction of one intermittent project reduced the damages by another $300,000, but the addition of that one intermittent project required a total present worth of subsidy to be paid to the farmers of $12,560,270. In fact, the addition of one intermittent project completely depleted the net present worth of benefits from the continuous project (Table 5.2). Benefits generated at the lake are thus much too low to support the operation of upstream irrigation projects on an intermittent basis.

## Model verification

Historical Great Salt Lake stages for three 50-year periods (1860 to 1909, 1890 to 1939, and 1926 to 1975) were input into the stage damage model to verify the damage estimates obtained with stochastically synthesized traces. The flows for the three 50-year historical periods of lake stage were adjusted to represent present modified (1965 evapotranspiration) conditions. The average present worth of damages from the 100 traces of stochastically synthesized lake stage was $15,395,102. The maximum present worth of damages was

$55,245,017. In an analysis made by Christensen (1979) from a different set of random numbers to synthesize traces of lake stage, a maximum present worth of damages from 100 traces of lake stage of $128,000,000 was obtained. The present worth of damages from the historical stages were $140,667,304; $28,544,388; and $12,831,827 for the periods 1860 to 1909, 1890 to 1939, and 1926 to 1975, respectively.

The above estimates seem reasonable in that the high inflows of the 1860s and 1870s likely exceeded the 100-year event (James and Wang 1982). The average present worth of damages of $15,395,102 of the 100 traces of stochastically synthesized lake stages corresponds to the present worth of $12,831,827 from the historical 1926-1975 period. These two figures should compare due to the fact that the parameter estimates for the multivariate stochastic model were determined from the historical period of 1934-1977; therefore, the synthesized stages reflect historical characteristics of this time period. The 1934-1977 period of record was used because the historical evaporation records began in 1934.

The parameter estimates for the multivariate stochastic model could be refined to reflect the entire period from which Great Salt Lake stage estimates are available (1847-1979). The Division of Water Resources has developed a trace of historic total inflow into the Great Salt Lake which reflects present modified conditions. Regression analysis could be used to correlate Bear, Weber, and Jordan River streamflow with the present modified total inflow to the lake, allowing separation of the total streamflow into its three separate river components. Precipitation and evaporation estimates for the earlier period would also be necessary. This would allow estimation of the multivariate stochastic model parameters to be based upon the entire historical period for which lake stage records are available and thus include the very wet periods in the 19th century.

## The Diking Alternative

The 100 traces of 50-year lake level sequences were generated by the stochastic lake level water balance model. Each of the five diking schemes was then analyzed through the use of the damage simulation model and the annual dike cost simulation model to determine the reduction in damages and the annual costs. In order to determine the optimum lake level for construction, each diking scheme was analyzed with initial lake level elevations at 4200, 4202, and 4204 feet above sea level.

### Cost estimates

The initial construction costs for each proposed dike are given for various dike crest elevations in Table 5.3. Dikes 15 and 19 would require pumps to convey the flows of the Weber and Bear Rivers, respectively, over the dikes. Costs of construction would be approximately $10.0 million for the pump associated with dike 15 and about $10.5 million for the pump associated with dike 19. It is estimated that annual operation, maintenance, and repair costs for the pumping plants would be $900,000 and $950,000, respectively. Actual present worths may turn out larger than those calculated should energy costs continue to rise faster than the general inflation rate over the 50-year planning period.

Five diking combinations were analyzed, and the capital costs of the schemes are summarized in Tables 5.4 through 5.8. No discounting was performed to compute the present worth of the construction cost based on an assumption that the process would take no more than one year. The annual maintenance and repair costs were estimated using the annual dike cost simulation model for 100 possible 50-year traces, and the present worth of annual costs for each diking scheme are summarized also in Tables 5.4 through 5.8. The average annual costs for operation, maintenance, and repair

Table 5.3. Dike cost estimates for various levels of protection, in thousand dollars.

| Dike Crest | 4208 | | | 4210 | | | 4212 | | |
|---|---|---|---|---|---|---|---|---|---|
| Dike | Length yards | Volume cu. yards | Capital Cost | Length yards | Volume cu. yards | Capital Cost | Length yards | Volume cu. yards | Capital Cost |
| 1 | 6,520 | 170,697 | 440 | 7,707 | 321,724 | 830 | 7,707 | 485,754 | 1,255 |
| 2 | 11,550 | 780,680 | 2,020 | 11,594 | 1,169,770 | 3,030 | 11,594 | 1,551,364 | 4,010 |
| 4 | 6,710 | 347,951 | 900 | 7,359 | 568,687 | 1,470 | 7,359 | 791,723 | 2,046 |
| 4.5 | 6,920 | 95,208 | 240 | 7,568 | 198,134 | 510 | 7,568 | 324,711 | 839 |
| 5 | 0 | 0 | 0 | 1,666 | 14,198 | 40 | 1,666 | 28,430 | 73 |
| 6 | 1,520 | 9,345 | 20 | 1,527 | 25,379 | 60 | 1,527 | 44,636 | 116 |
| 7 | 4,900 | 54,189 | 140 | 6,735 | 153,768 | 390 | 6,735 | 251,976 | 651 |
| 8 | 6,526 | 304,003 | 780 | 6,526 | 458,597 | 1,180 | 6,526 | 664,545 | 1,717 |
| 9 | 3,437 | 197,838 | 510 | 3,437 | 265,604 | 680 | 3,437 | 379,706 | 982 |
| 10 | 10,480 | 296,250 | 760 | 10,484 | 462,446 | 1,190 | 10,484 | 751,703 | 1,942 |
| 11 | 1,060 | 11,723 | 30 | 1,458 | 33,288 | 80 | 1,458 | 54,551 | 141 |
| 12 | 1,500 | 9,388 | 20 | 1,527 | 25,379 | 60 | 1,527 | 44,636 | 116 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 1,180 | 3,963 | 10 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 625 | 2,098 | 5 |
| 15 | 24,600 | 1,275,647 | 3,300 | 24,716 | 1,909,998 | 4,940 | 24,716 | 2,720,460 | 7,031 |
| 16 | 2,260 | 67,105 | 170 | 2,499 | 116,412 | 300 | 2,499 | 175,200 | 453 |
| 17 | 3,120 | 145,340 | 370 | 3,124 | 219,530 | 560 | 3,124 | 312,752 | 809 |
| 18 | 12,290 | 752,055 | 1,940 | 12,289 | 949,667 | 2,460 | 12,289 | 1,538,097 | 3,975 |
| 18.5 | 10,410 | 173,016 | 440 | 11,247 | 333,950 | 860 | 11,247 | 521,445 | 1,347 |
| 19 | 6,735 | 473,283 | 1,220 | 6,735 | 679,524 | 1,760 | 6,735 | 980,788 | 2,535 |
| 20 | 5,400 | 269,000 | 690 | 5,415 | 418,459 | 1,080 | 5,415 | 585,035 | 1,511 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 2,708 | 19,823 | 51 |
| 23 | 0 | 0 | 0 | 17,781 | 1,119,430 | 1,850 | 18,445 | 1,507,630 | 3,950 |
| 24 | 0 | 0 | 0 | 7,012 | 208,203 | 540 | 7,012 | 330,073 | 853 |
| 25 | 2,400 | 210,058 | 100 | 2,400 | 149,817 | 350 | 2,400 | 285,111 | 550 |

Table 5.4. Present worth of costs and benefits for industry and south shore diking scheme, in thousand dollars.

| Dike crest elevation - ft. | | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 |
|---|---|---|---|---|---|---|---|---|---|---|
| Initial lake elevation - ft. | | 4200 | 4200 | 4200 | 4202 | 4202 | 4202 | 4204 | 4204 | 4204 |
| Capital Cost | | 7,090 | 13,430 | 20,950 | 7,090 | 13,430 | 20,950 | 7,090 | 13,430 | 20,950 |
| Present Worth of OM&R Costs for 100 Traces | Average | 917 | 900 | 895 | 1,050 | 1,003 | 995 | 1,242 | 1,121 | 1,085 |
| | Std. Deviation | 380 | 361 | 355 | 382 | 357 | 343 | 411 | 341 | 324 |
| | Median | 856 | 855 | 855 | 967 | 932 | 923 | 1,170 | 1,060 | 1,029 |
| | Maximum | 1,893 | 1,766 | 1,738 | 2,042 | 1,822 | 1,788 | 2,531 | 1,918 | 1,844 |
| | Minimum | 235 | 235 | 235 | 354 | 348 | 348 | 468 | 432 | 425 |
| Present Worth of Benefits for 100 Traces | Average | 7,497 | 8,314 | 8,529 | 15,420 | 17,293 | 17,636 | 30,164 | 38,293 | 39,091 |
| | Std. Deviation | 6,975 | 8,579 | 9,049 | 9,068 | 12,873 | 13,432 | 7,595 | 14,623 | 15,222 |
| | Median | 4,751 | 5,050 | 5,050 | 12,488 | 12,958 | 13,105 | 31,194 | 36,126 | 36,672 |
| | Maximum | 32,608 | 44,779 | 46,065 | 48,477 | 87,545 | 90,027 | 47,263 | 93,444 | 94,485 |
| | Minimum | 983 | 983 | 983 | 2,054 | 2,152 | 2,152 | 3,527 | 3,833 | 3,979 |
| Probability that benefit-cost ratio will be ≥ 1.0 | | 0.31 | 0.13 | 0.05 | 0.95 | 0.37 | 0.17 | 0.95 | 0.95 | 0.95 |
| Expected value of the benefit-cost ratio | | 0.94 | 0.58 | 0.39 | 1.89 | 1.20 | 0.80 | 3.62 | 2.63 | 1.77 |

Table 5.5. Present worth of costs and benefits for highways and railroads diking scheme, in thousand dollars.

| Dike crest elevation - ft. | | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 |
|---|---|---|---|---|---|---|---|---|---|---|
| Initial lake elevation - ft. | | 4200 | 4200 | 4200 | 4202 | 4202 | 4202 | 4204 | 4204 | 4204 |
| Capital Cost | | 2,720 | 4,470 | 6,300 | 2,720 | 4,470 | 6,300 | 2,720 | 4,470 | 6,300 |
| Present Worth of OM&R Costs for 100 Traces | Average | 231 | 221 | 219 | 292 | 268 | 264 | 372 | 318 | 301 |
| | Std. Deviation | 134 | 121 | 118 | 139 | 121 | 117 | 167 | 122 | 114 |
| | Median | 199 | 199 | 199 | 265 | 240 | 225 | 329 | 300 | 284 |
| | Maximum | 640 | 558 | 542 | 733 | 604 | 591 | 987 | 650 | 612 |
| | Minimum | 34 | 34 | 34 | 73 | 67 | 67 | 108 | 97 | 91 |
| Present Worth of Benefits for 100 Traces | Average | 976 | 1,235 | 1,325 | 1,680 | 2,178 | 2,318 | 2,596 | 5,051 | 5,350 |
| | Std. Deviation | 607 | 1,121 | 1,340 | 711 | 1,558 | 1,794 | 893 | 2,280 | 2,476 |
| | Median | 756 | 817 | 817 | 1,519 | 1,663 | 1,710 | 3,104 | 3,835 | 3,971 |
| | Maximum | 4,144 | 6,757 | 7,340 | 4,339 | 9,847 | 10,740 | 3,694 | 10,344 | 11,201 |
| | Minimum | 112 | 112 | 112 | 205 | 233 | 233 | 276 | 371 | 433 |
| Probability that benefit-cost ratio will be ≥ 1.0 | | 0.01 | 0.03 | 0.02 | 0.06 | 0.08 | 0.05 | 0.44 | 0.42 | 0.41 |
| Expected value of the benefit-cost ratio | | 0.33 | 0.26 | 0.20 | 0.56 | 0.46 | 0.35 | 0.84 | 1.05 | 0.81 |

Table 5.6. Present worth of costs and benefits for Farmington Bay Bird Refuge diking scheme, in thousand dollars.

| Dike crest elevation - ft | | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 |
|---|---|---|---|---|---|---|---|---|---|---|
| Initial lake elevation - ft | | 4200 | 4200 | 4200 | 4202 | 4202 | 4202 | 4204 | 4204 | 4204 |
| Capital Cost | | 2,230 | 3,550 | 5,430 | 2,230 | 3,550 | 5,430 | 2,230 | 3,550 | 5,430 |
| Present Worth of OM&R Costs for 100 Traces | Average | 191 | 190 | 190 | 227 | 220 | 218 | 284 | 255 | 248 |
| | Std. Deviation | 117 | 121 | 125 | 114 | 117 | 113 | 127 | 110 | 107 |
| | Median | 170 | 167 | 167 | 207 | 201 | 201 | 272 | 250 | 240 |
| | Maximum | 532 | 770 | 861 | 501 | 813 | 768 | 756 | 692 | 727 |
| | Minimum | 32 | 32 | 32 | 54 | 54 | 54 | 88 | 83 | 83 |
| Present Worth of Benefits for 100 Traces | Average | 810 | 819 | 833 | 1,206 | 1,251 | 1,259 | 3,154 | 3,264 | 3,301 |
| | Std. Deviation | 386 | 401 | 474 | 601 | 668 | 683 | 478 | 499 | 540 |
| | Median | 682 | 682 | 682 | 1,109 | 1,162 | 1,165 | 3,142 | 3,227 | 3,234 |
| | Maximum | 2,824 | 2,869 | 3,775 | 3,795 | 3,858 | 3,916 | 3,739 | 4,351 | 5,056 |
| | Minimum | 637 | 637 | 637 | 648 | 648 | 648 | 1,153 | 1,165 | 1,165 |
| Probability that benefit-cost ratio will be ≥ 1.0 | | 0.03 | 0.00 | 0.00 | 0.07 | 0.02 | 0.00 | 0.93 | 0.05 | 0.00 |
| Expected value of the benefit-cost ratio | | 0.33 | 0.22 | 0.15 | 0.49 | 0.33 | 0.22 | 1.25 | 0.86 | 0.58 |

Table 5.7. Present worth of costs and benefits for Ogden Bay Bird Refuge diking scheme, in thousand dollars.

| Dike crest elevation - ft. | | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 |
|---|---|---|---|---|---|---|---|---|---|---|
| Initial lake elevations - ft. | | 4200 | 4200 | 4200 | 4202 | 4202 | 4202 | 4204 | 4204 | 4204 |
| Capital Cost | | 13,470 | 15,240 | 17,480 | 13,470 | 15,240 | 17,480 | 13,470 | 15,240 | 17,480 |
| Present Worth of OM&R Costs for 100 Traces | Average | 1,700 | 1,697 | 1,698 | 3,127 | 3.115 | 3,113 | 4,246 | 4,208 | 4,200 |
| | Std. Deviation | 1,986 | 1,984 | 1,988 | 2,080 | 2,075 | 2,071 | 2,210 | 2,186 | 2,181 |
| | Median | 1,125 | 1,125 | 1,125 | 2,464 | 2,460 | 2,464 | 3,687 | 3,654 | 3,653 |
| | Maximum | 9,363 | 9,475 | 9,592 | 10,055 | 10,205 | 10,159 | 12,124 | 11,965 | 12,012 |
| | Minimum | 45 | 45 | 45 | 982 | 982 | 982 | 1,030 | 1,016 | 1,016 |
| Present Worth of Benefits for 100 Traces | Average | 1,002 | 1,010 | 1,014 | 1,037 | 1,068 | 1,073 | 2,128 | 2,194 | 2,219 |
| | Std. Deviation | 284 | 295 | 328 | 334 | 363 | 374 | 456 | 492 | 527 |
| | Median | 887 | 900 | 900 | 934 | 946 | 947 | 1,971 | 2,014 | 2,022 |
| | Maximum | 3,057 | 3,075 | 3,500 | 3,496 | 3,493 | 3,489 | 4,977 | 4,940 | 4,940 |
| | Minimum | 840 | 841 | 841 | 856 | 856 | 856 | 1,391 | 1,406 | 1,406 |
| Probability that benefit-cost ratio will be ≥ 1.0 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Expected value of the benefit-cost ratio | | 0.07 | 0.06 | 0.05 | 0.06 | 0.06 | 0.05 | 0.12 | 0.11 | 0.10 |

Table 5.8. Present worth of costs and benefits for Bear River Bird Refuge diking scheme, in thousand dollars.

| Dike crest elevation - ft. | | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 | 4208 | 4210 | 4212 |
|---|---|---|---|---|---|---|---|---|---|---|
| Initial lake elevation - ft. | | 4200 | 4200 | 4200 | 4202 | 4202 | 4202 | 4204 | 4204 | 4204 |
| Capital Cost | | 12,270 | 13,130 | 14,290 | 12,270 | 13,130 | 14,290 | 12,270 | 13,130 | 14,290 |
| Present Worth of OM&R Costs for 100 Traces | Average | 1,759 | 1,757 | 1,755 | 3,188 | 3,180 | 3.179 | 4,294 | 4,273 | 4,267 |
| | Std. Deviation | 1,961 | 1,958 | 1,958 | 2,068 | 2,064 | 2,062 | 2,167 | 2,152 | 2,150 |
| | Median | 1,220 | 1,220 | 1,220 | 2,561 | 2,556 | 2,555 | 3,749 | 3,740 | 3,733 |
| | Maximum | 9,336 | 9,296 | 9,289 | 10,045 | 9,996 | 9,984 | 12,178 | 12,000 | 11,955 |
| | Minimum | 108 | 108 | 108 | 1,081 | 1,081 | 1,081 | 1,100 | 1,093 | 1,090 |
| Present Worth of Benefits for 100 Traces | Average | 4,529 | 4,850 | 4,872 | 7,071 | 8,429 | 8,472 | 11,578 | 16,814 | 17,053 |
| | Std. Deviation | 3,188 | 3,595 | 3,649 | 5,997 | 6,246 | 6,350 | 13,068 | 9,566 | 9,704 |
| | Median | 3,5o0 | 3,719 | 3,719 | 6,533 | 6,785 | 6,785 | 16,316 | 16,956 | 17,119 |
| | Maximum | 18,585 | 19,498 | 19,743 | 20,345 | 51.970 | 52,833 | 18,922 | 71,690 | 72,163 |
| | Minimum | -6,402 | -6,082 | -6,013 | -36,838 | -9,329 | -9,238 | -52,540 | -12,726 | -12,635 |
| Probability that benefit-cost ratio will be ≥ 1.0 | | 0.03 | 0.04 | 0.03 | 0.09 | 0.11 | 0.09 | 0.47 | 0.45 | 0.24 |
| Expected value of the benefit-cost ratio | | 0.32 | 0.33 | 0.30 | 0.46 | 0.52 | 0.48 | 0.70 | 0.97 | 0.92 |

are shown to decrease with increasing dike height. This is due mainly to the reduced repair costs because taller dikes are overtopped less often.

Cost estimates for the dikes assumed that the dikes would be protected from erosion due to wave action by rip-rap. Johnson (Utah Geological and Mineral Survey 1979) studied the feasibility of protecting dikes at the Great Salt Lake by a sand beach. He suggests that this method of protection is effective and that the cost is approximately one-half that of protection by rip-rap. If this design were adopted, the cost estimates used in this study perhaps could be reduced, thus increasing the benefit-cost ratios presented.

### Benefit estimates

The simulated reduction in damages which would occur if a particular diking scheme were implemented is shown in Tables 5.4 through 5.8 and Figures 5.1 through 5.5.

The median value for the benefits of each diking scheme is consistently lower than the average. This skew is attributed to the fact that many of the lake level traces needed minimal diking. Thus, the benefits would be relatively small. However, some lake level traces very definitely required dikes for protection of the entities at the lake.

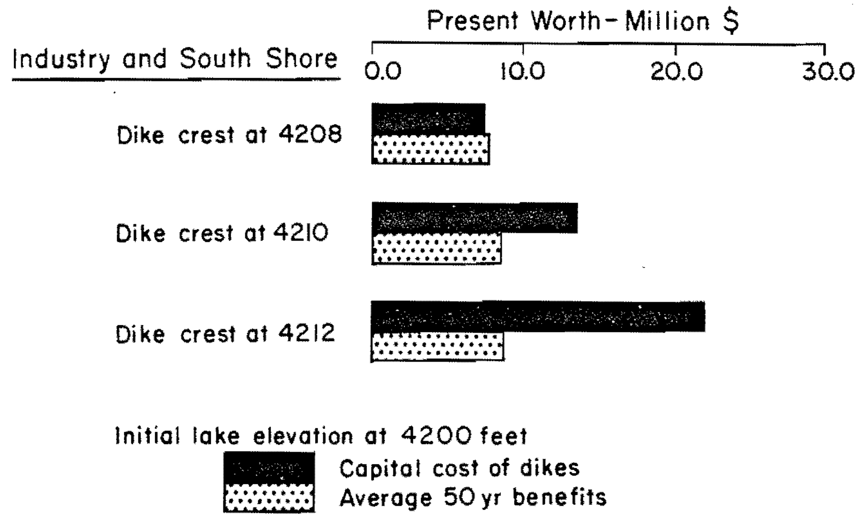
James and Bowles (1979) addressed the question of how the costs and benefits of lake level control of the Great Salt Lake could be estimated for the public sector. They developed methods to estimate the public costs and benefits associated with transportation, recreation, industry, and wildlife refuges. As it turns out, the apportionment of benefits between the public and private sectors is highly dependent upon lake level fluctuation. For lake levels below about 4204 feet above sea level, most of the direct damages which could be prevented by dikes accrue to private industry. At higher levels, significant damages begin to occur to wildlife refuge areas; and when the lake level rises above 4207 feet, public facilities would profit substantially from diking at the Great Salt Lake. Also, direct revenue losses to the state and local governments from lost taxation of private entities do not occur until lake levels rise high enough to close industrial plants.

### Benefit-cost analysis

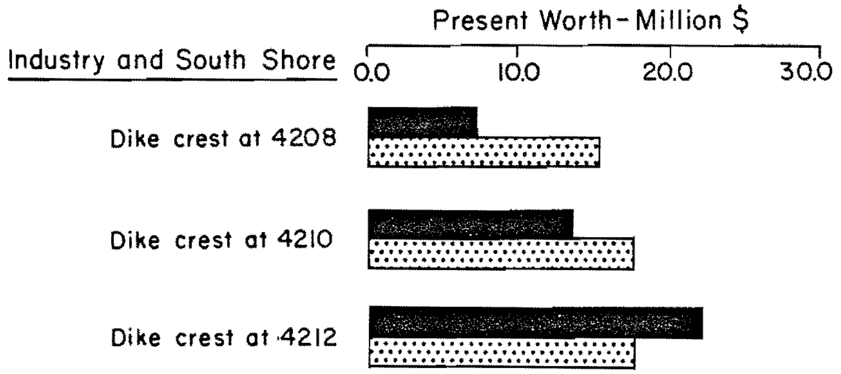
The expected benefit-cost ratios for each diking scheme, dike crest elevation, and initial lake level considered are given in Tables 5.4 through 5.8. From a strictly economic standpoint, only those dikes which have benefit-cost ratios greater than one should be given further consideration. The industry and south shore dikes are the only ones that produced a benefit-cost ratio exceeding one for more than one of the various conditions considered. Further analysis was used to determine the optimum dike height and the optimum time of construction.

To determine the optimum dike crest elevation, marginal cost and marginal benefit versus elevation are plotted in Figure 5.6. The optimum dike crest elevation is where marginal cost equals marginal benefit at about 4210 feet. However, construction would probably occur at the rising lake level where the benefit-cost ratio is first greater than one because an entity would be likely to protect itself as soon as it became profitable and not wait until net benefits became maximum. If this criterion were adopted, the preferred lake level for construction of the industry and south shore diking system would be at elevation 4202 feet. To determine optimum dike crest height at this lake elevation, marginal cost and marginal benefit versus dike height are plotted on Figure 5.7. The optimum dike crest elevation is at about 4209 feet.

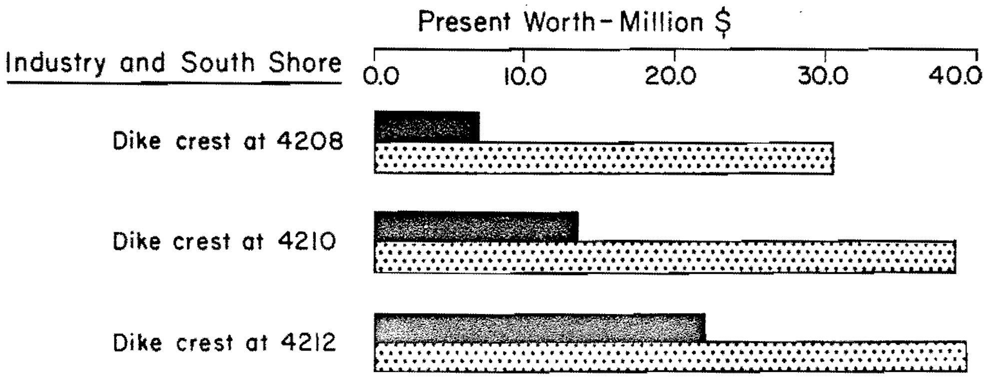
The optimum dike construction for the Farmington Bay Bird Refuge diking



Initial lake elevation at 4200 feet

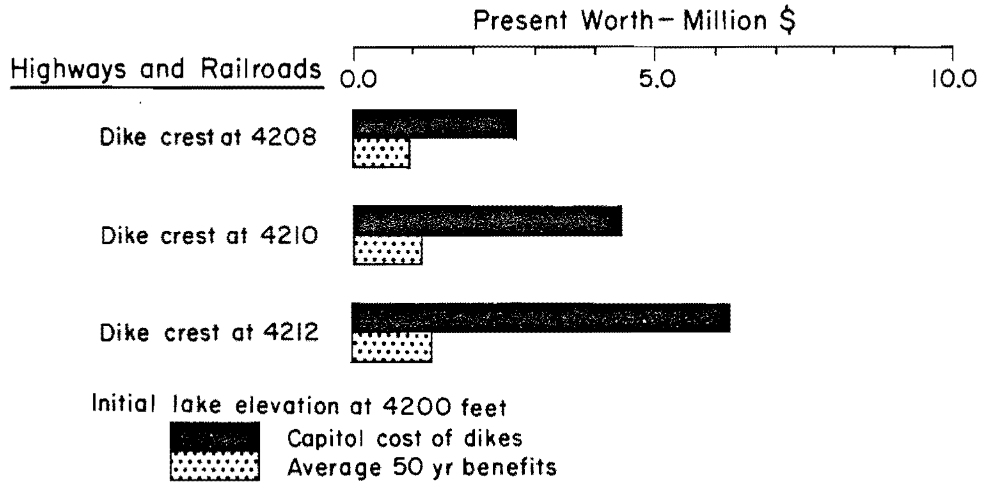


Initial lake elevation at 4202 feet

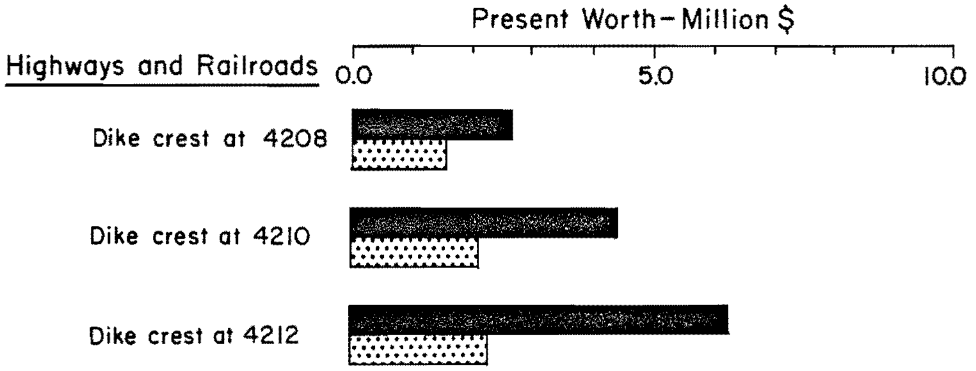


Initial lake elevation at 4204 feet

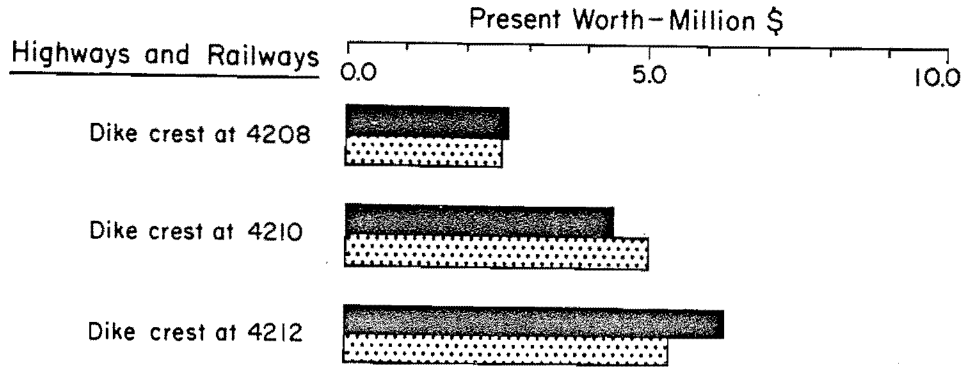
Figure 5.1. Capital costs versus average benefits for industry and south shore diking system.



Initial lake elevation at 4200 feet



Initial lake elevation at 4202 feet



Initial lake elevation at 4204 feet

Figure 5.2. Capital costs versus average benefits for highways and railroads diking system.

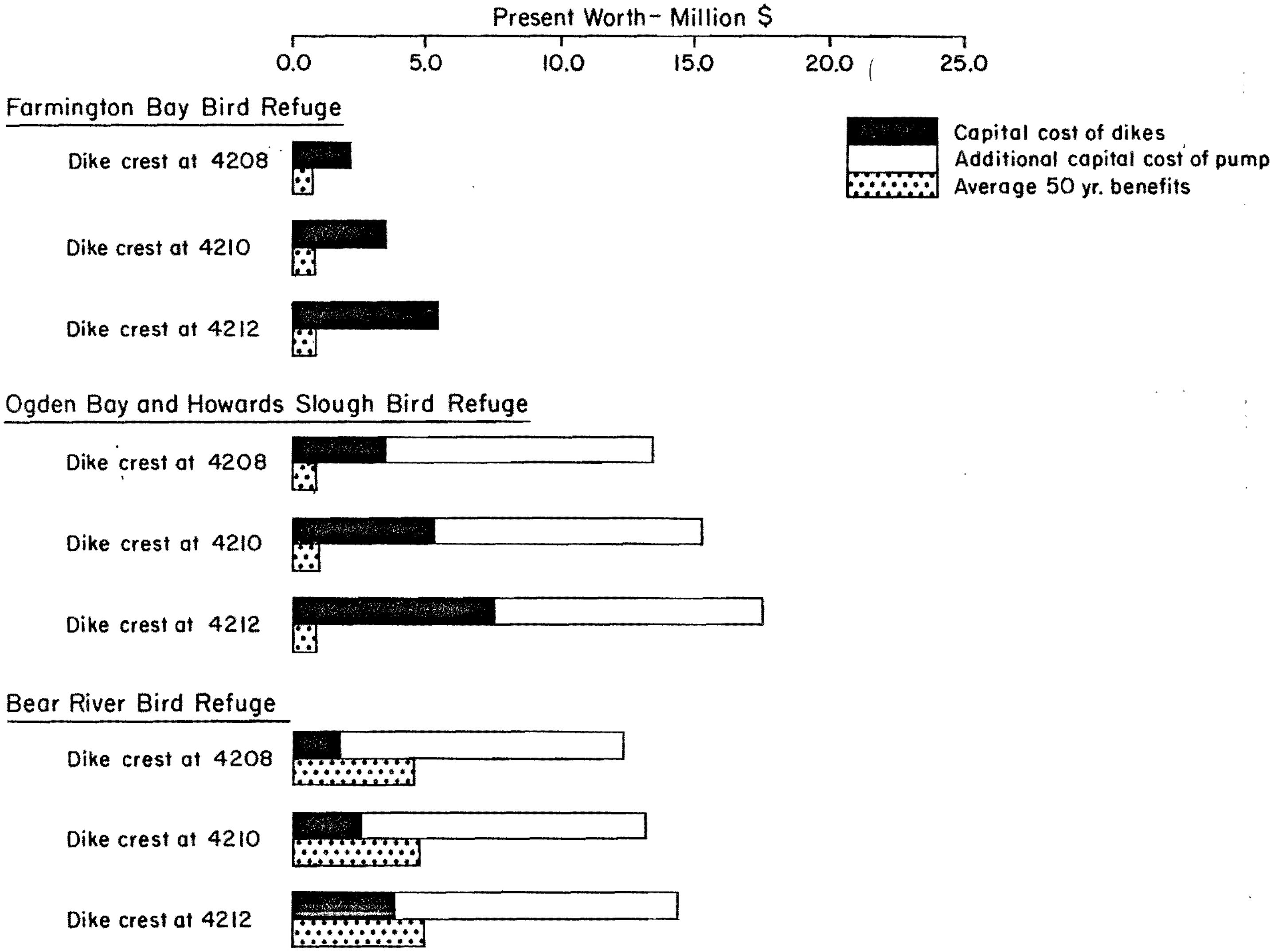


Figure 5.3. Capital costs versus average benefits for bird refuge diking systems--the initial lake elevation at 4200 feet.

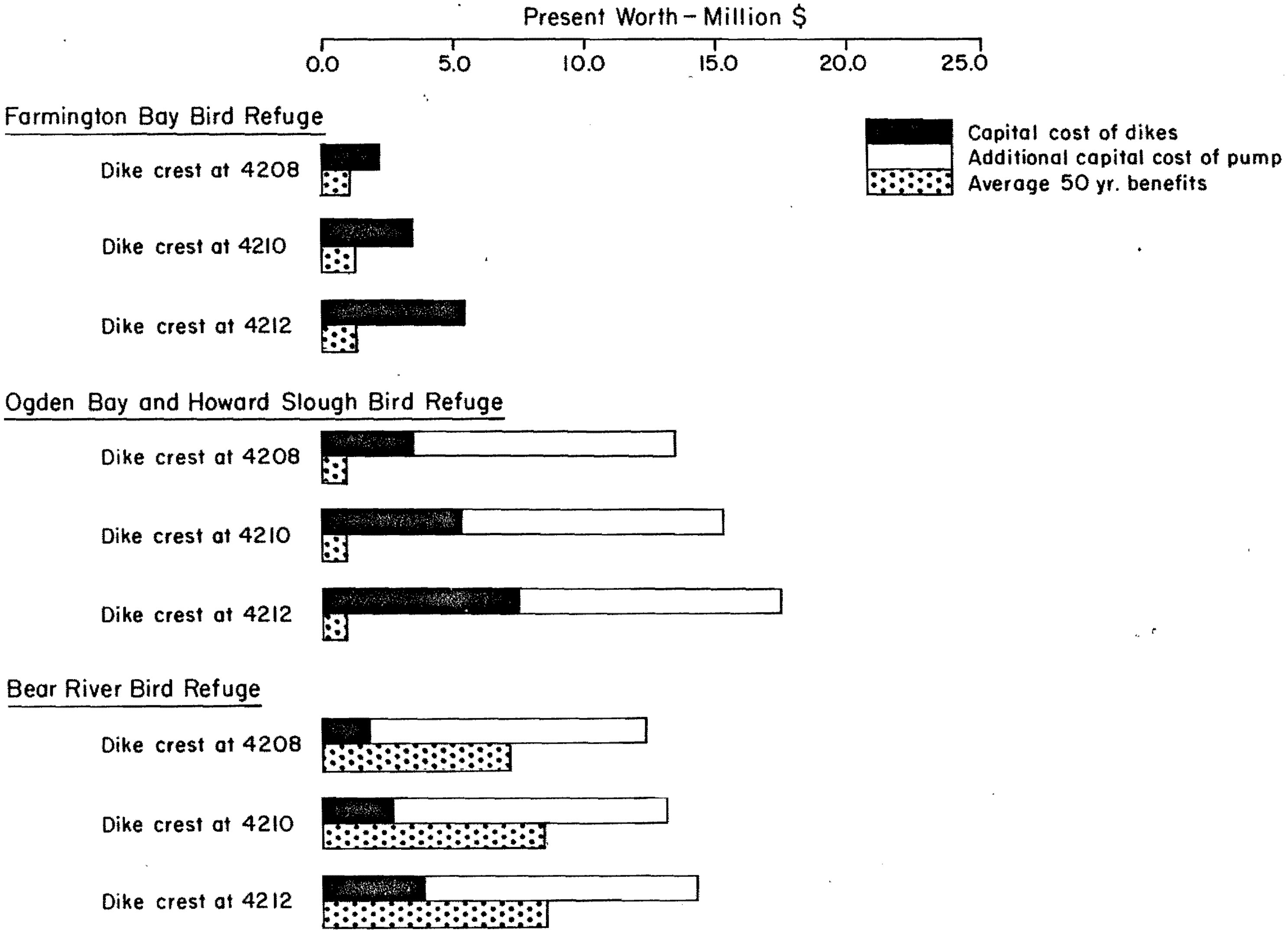


Figure 5.4. Capital costs versus average benefits for bird refuge diking systems--the initial lake elevation at 4202 feet.

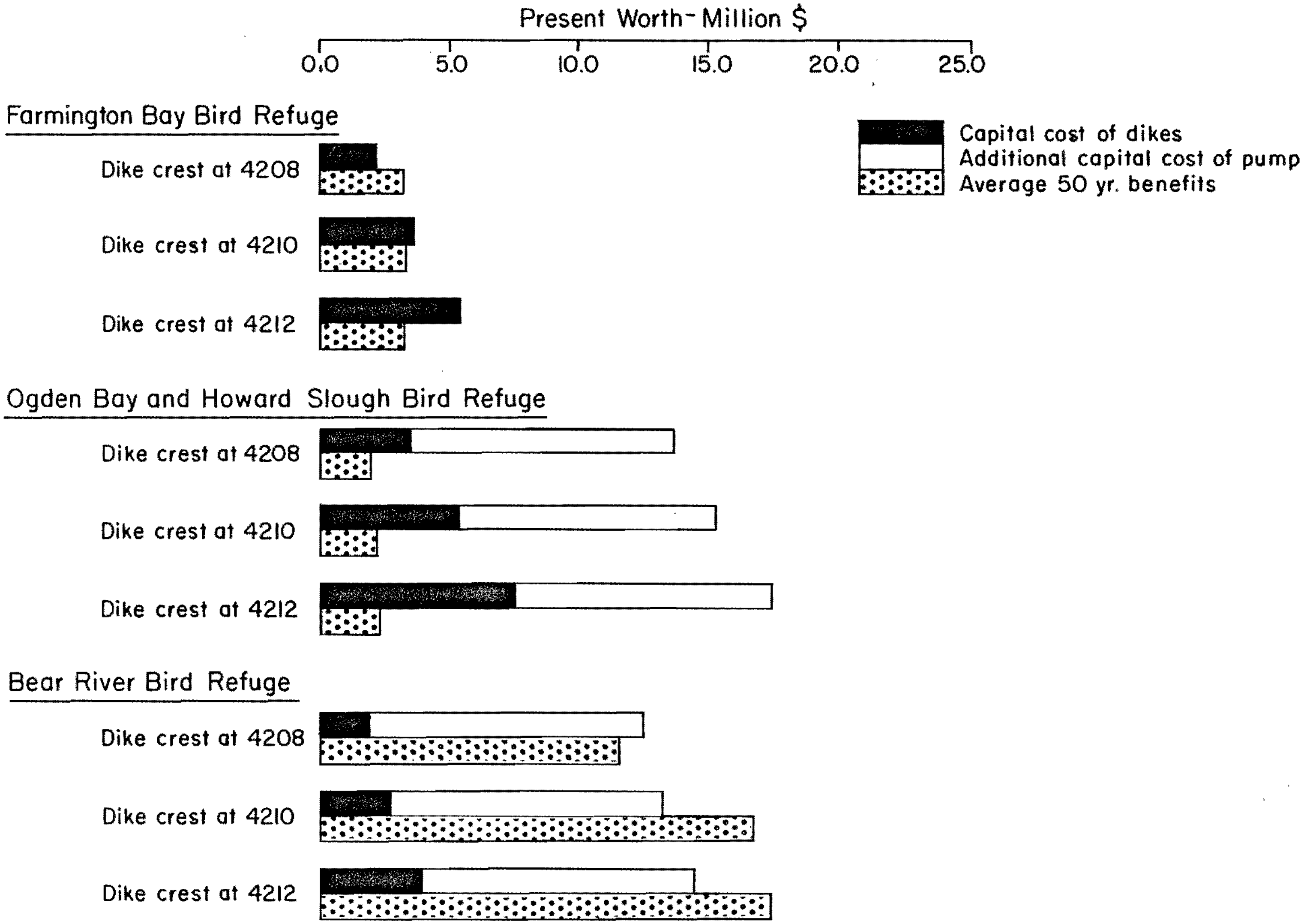


Figure 5.5. Capital costs versus average benefits for bird refuge diking systems--the initial lake elevation at 4204 feet.

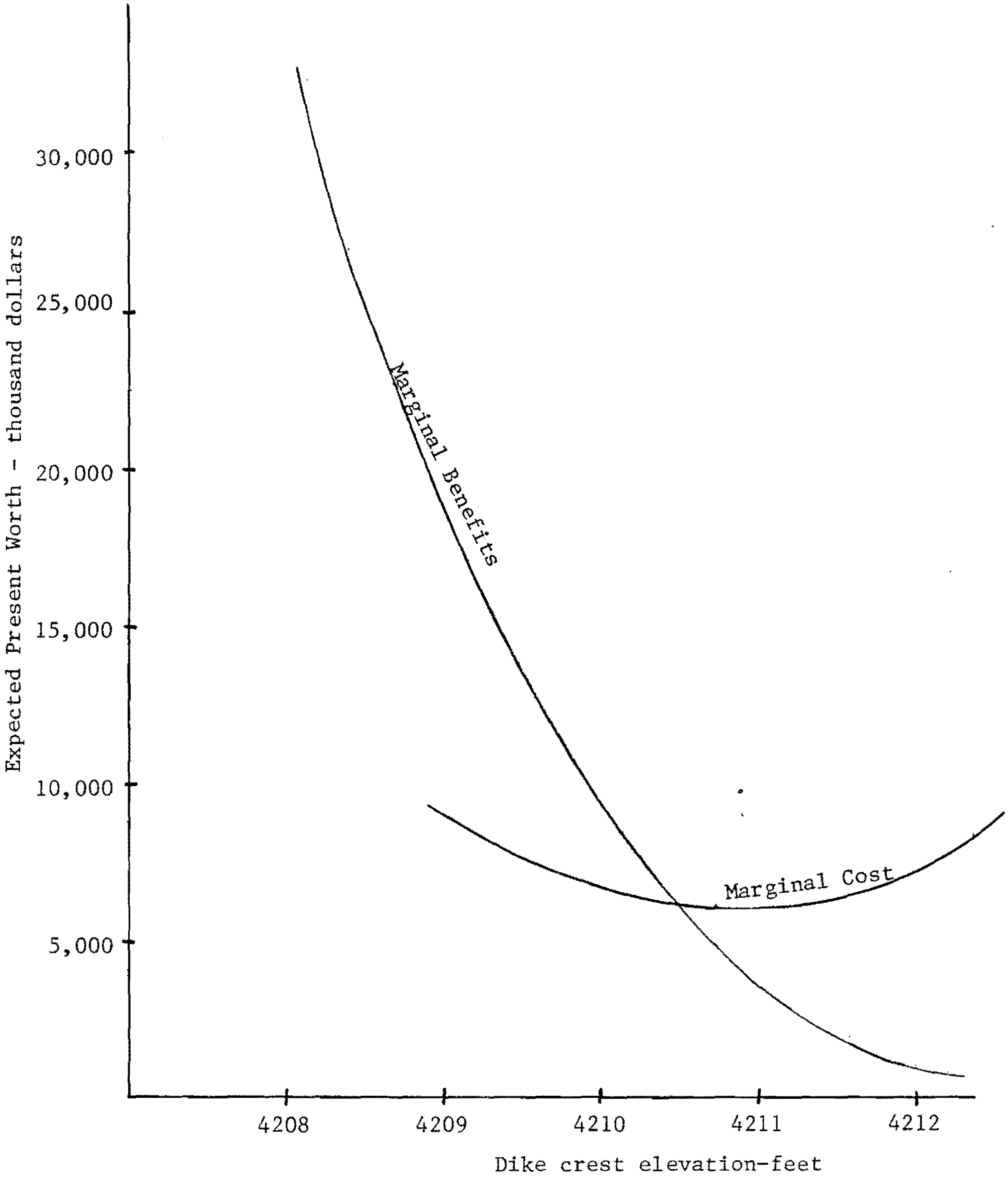


Figure 5.6. Expected value of marginal benefits versus expected value of marginal costs for the industry and south shore diking scheme with initial lake elevation at 4204 feet.

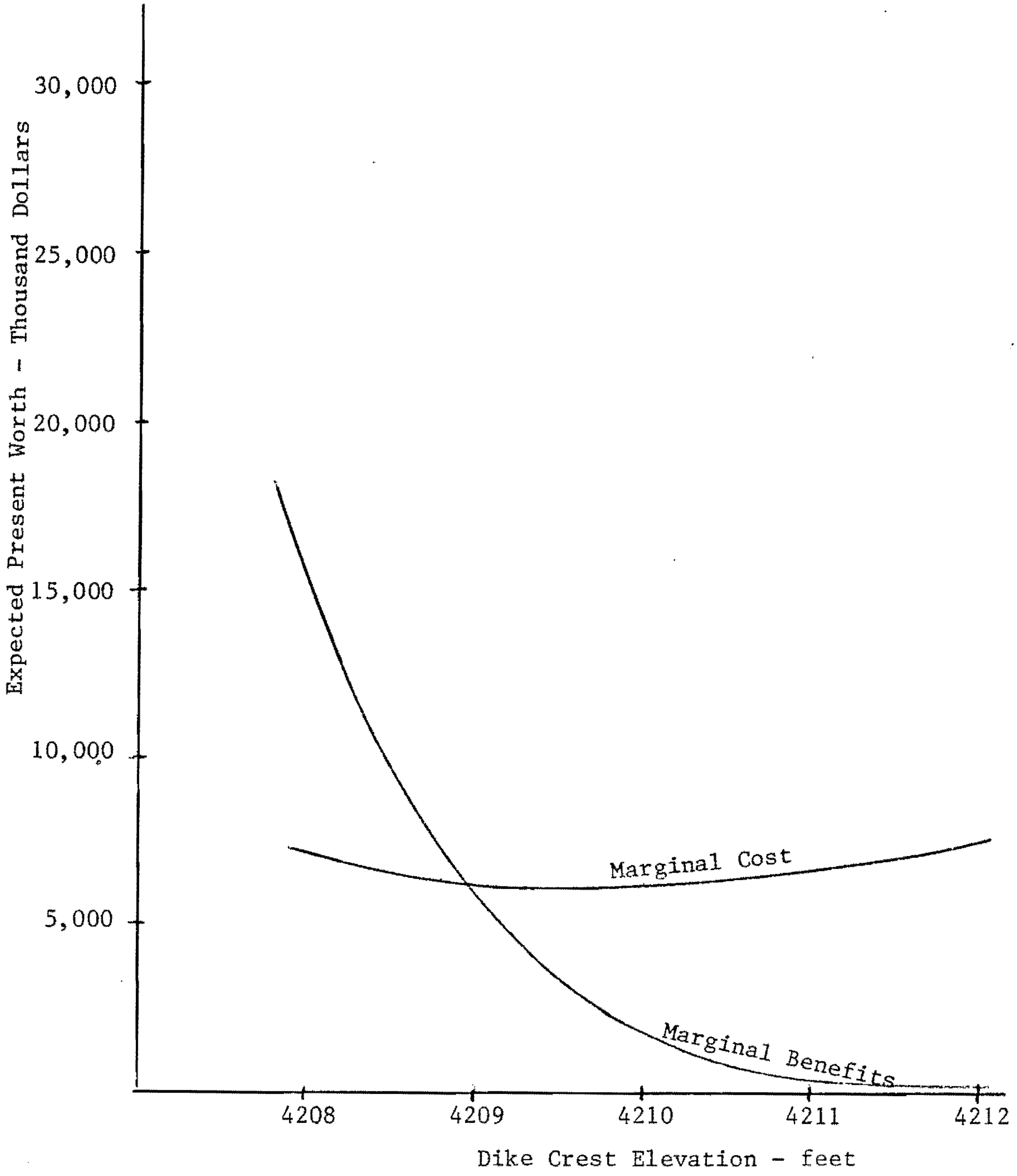


Figure 5.7. Expected value of marginal benefits versus expected value of marginal costs for the industry and south shore diking system with initial lake elevation at 4202 feet.

system is when the lake level rises to 4204 feet and to a crest about 4208 feet above sea level since no other dike crest elevation yielded an expected value of the benefit-cost ratio greater than one. The optimum dike construction for the highways and railroads diking system would also be at a lake level of 4204 feet but to a crest elevation of about 4210 feet. These dike crest elevations have a 93 percent probability for the Farmington diking system and a 42 percent probability for the highways and railroads diking systems that the benefit-cost ratios will be greater than one (Tables 5.5 and 5.6).

The industry and south shore diking system should thus be built when the lake level approaches 4202 feet above sea level, as it is in January 1983. This dike crest elevation has about a 70 percent chance (interpolating on Table 5.4) of having a benefit-cost ratio greater than one. The optimum lake elevation for construction of the individual dikes may be slightly higher or lower than 4202 feet.

The highways and railroads diking system and the Farmington Bay diking system protect areas along the south shore of the Great Salt Lake (Table 3.5 and Figure 3.5). The optimum lake level for construction of these diking systems is approximately 4204 feet. This suggests that for the average entity located on the south shore, the lake level at which the benefits begin to exceed costs is at about 4204 feet. For an individual dike, the optimum lake elevation for construction may be slightly higher or lower.

### Overview of diking results

The results on Tables 5.4 through 5.8 indicate that none of the diking schemes are economical until the lake level rises to at least 4202 feet above sea level. At this level, only the diking which would protect the mineral industries and the south shore have an expected benefit-cost ratio greater than one. At 4204 feet, the diking systems protecting the Farmington Bird Refuge and the highways and railroads become economical.

Also, the expected benefit-cost ratio for the diking system which protects the Bear River Migratory Bird Refuge is only slightly less than one. The negative values for the minimum benefits from the Bear River diking system (Table 5.8) indicate that these dikes could cause more damage than they prevent by increasing stages on the lake. However, the probability of producing negative benefits is very small.

The expected value of the benefit-cost ratio for the diking system which protects the Ogden Bay Bird Refuge is quite low for all initial lake elevations (Table 5.7). This is because the diking system would require expensive pumping to convey the waters of the Weber River over the dike.

### Comparison of the model predictions with the historical record

Historical Great Salt Lake stages for three 50-year periods (1860 to 1909, 1890 to 1939, and 1926 to 1975) were used in the stage damage model to compare the damage estimates with those for the stochastically synthesized 50-year traces. The average present worth of damages from the 100 traces of stochastically synthesized lake stage was equal to $16,877,701; the maximum present worth was $128,244,256. The present worth of damages from the three historical stage sequences were $140,667,304; $28,544,388; and $12,831,827, respectively. The maximum present worth of damages of $128,244,256 from the 100 synthezised traces corresponds closely to the present worth of damages for the period 1860-1909 ($140,677,304). Overall, these comparisons show that the stochastic lake level water balance model matches historical means and extremes.

The West Desert Pumping Alternative

Each pumping strategy investigated was applied to 100 traces of lake levels over a 50-year period in the stochastic lake level water balance model. The sequence for each pumping scheme was then analyzed to determine the annual cost of operation, the effect on lake level, and the reduction in damages. In order to determine the optimum lake level for triggering project implementation, the effects of the various pumping strategies were analyzed with initial lake level elevations at 4200, 4202, and 4204 feet above sea level. Project implementation was assumed to require 3 years. A crash program could probably be implemented in half that time.

Costs

For the annual net evaporative capacities of 310,000, 380,000, and 850,000 acre-feet, the cost estimates of the Corps of Engineers (Utah Division of Water Resources 1977) were updated to October 1978 dollars and are given in Tables 5.9, 5.10, and 5.11. To estimate the costs of construction and operation for a net annual evaporative capacity of 1,500,000 acre-feet, curves were developed relating costs to net evaporative capacity as shown in Figures 5.8 and 5.9. From these curves, capital cost estimates for a 1,500,000 acre-feet net evaporative capacity are $28.5 million if return drainage is to the south arm of the Great Salt Lake and $25.0 million if return drainage is to the north arm. The operation, maintenance, and repair costs for one year of operation are estimated at $1.1 million.

For each annual net evaporative capacity, the pumping cost simulation model was used to estimate the present worth of costs of annual operation, maintenance, and repair over the 50-year project life. The model computes the present worth of the annual pumping costs for each lake level time series generated. The results are summarized

Table 5.9. Updated cost estimates for a net evaporative capacity of 310,000 acre-feet annually.

| | Capital Costs | Annual Costs |
|---|---|---|
| Pumping Plant & Associated Facilities (1,000 cfs) | $ 4,815,000 | |
| OM&R | | $ 15,000 |
| Power Costs | | 335,000 |
| Pump Canal | 5,745,000 | |
| East Area Dikes | 630,000 | |
| OM&R | | 45,000 |
| Drain Canal | | |
| South Arm | 3,065,000 | |
| North Arm | (895,000) | |
| Total - Drain to South Arm | $14,255,000 | $395,000 |
| Total - Drain to North Arm | ($12,085,000) | |

Figures in parentheses are alternate costs with the less expensive drain to the North Arm.

Table 5.10. Updated cost estimates for a net evaporative capacity of 380,000 acre-feet annually.

| | Capital Costs | Annual Costs |
|---|---|---|
| Pumping Plant & Associated Facilities (1,200 cfs) | $ 5,215,000 | |
| OM&R | | $ 35,000 |
| Power Costs | | 430,000 |
| Pump Canal | 6,515,000 | |
| East Area Dikes | 1,005,000 | |
| OM&R | | 50,000 |
| Drain Canal | | |
| South Arm | 3,575,000 | |
| North Arm | (1,215,000) | |
| Total Cost - Drain to South Arm | $16,310,000 | $515,000 |
| Total Cost - Drain to North Arm | ($13,950,000) | |

Table 5.11. Updated cost estimates for a net evaporative capacity of 850,000 acre-feet annually.

| | Capital Costs | Annual Costs |
|---|---|---|
| Pumping Plant & Associated Facilities (2500 cfs) | $ 7,755,000 | |
| OM&R | | $ 50,000 |
| Power Costs | | 730,000 |
| Pump Canal | 10,470,000 | |
| East Area Dikes | 755,000 | |
| OM&R | | 45,000 |
| West Area Dikes | 250,000 | |
| OM&R | | 35,000 |
| Drain Canal | | |
| South Arm | 4,085,000 | |
| North Arm | (1,150,000) | |
| Total Cost - Drain to South Arm | $23,315,000 | $860,000 |
| Total Cost - Drain to North Arm | ($20,380,000) | |

in Table 5.12 and in Figures 5.10 and 5.11. The maximum and average number of years that pumps were operated for the 100 lake level traces generated are given in Figure 5.12.

## Benefits

*Effect on lake levels.* It was found that pumping lake water into the West Desert area had only a slight effect on low lake levels as long as the policy for beginning pumping did not drop significantly below the pump control elevation investigated. The low lake level from each trace for the most extreme pumping strategy averaged only about 0.20 feet below that which would occur without pumping. Thus, the pumping schemes investigated caused little or no additional damage due to lower lake levels.

None of the pumping schemes removed sufficient water to prevent the lake level elevation from passing 4202 feet

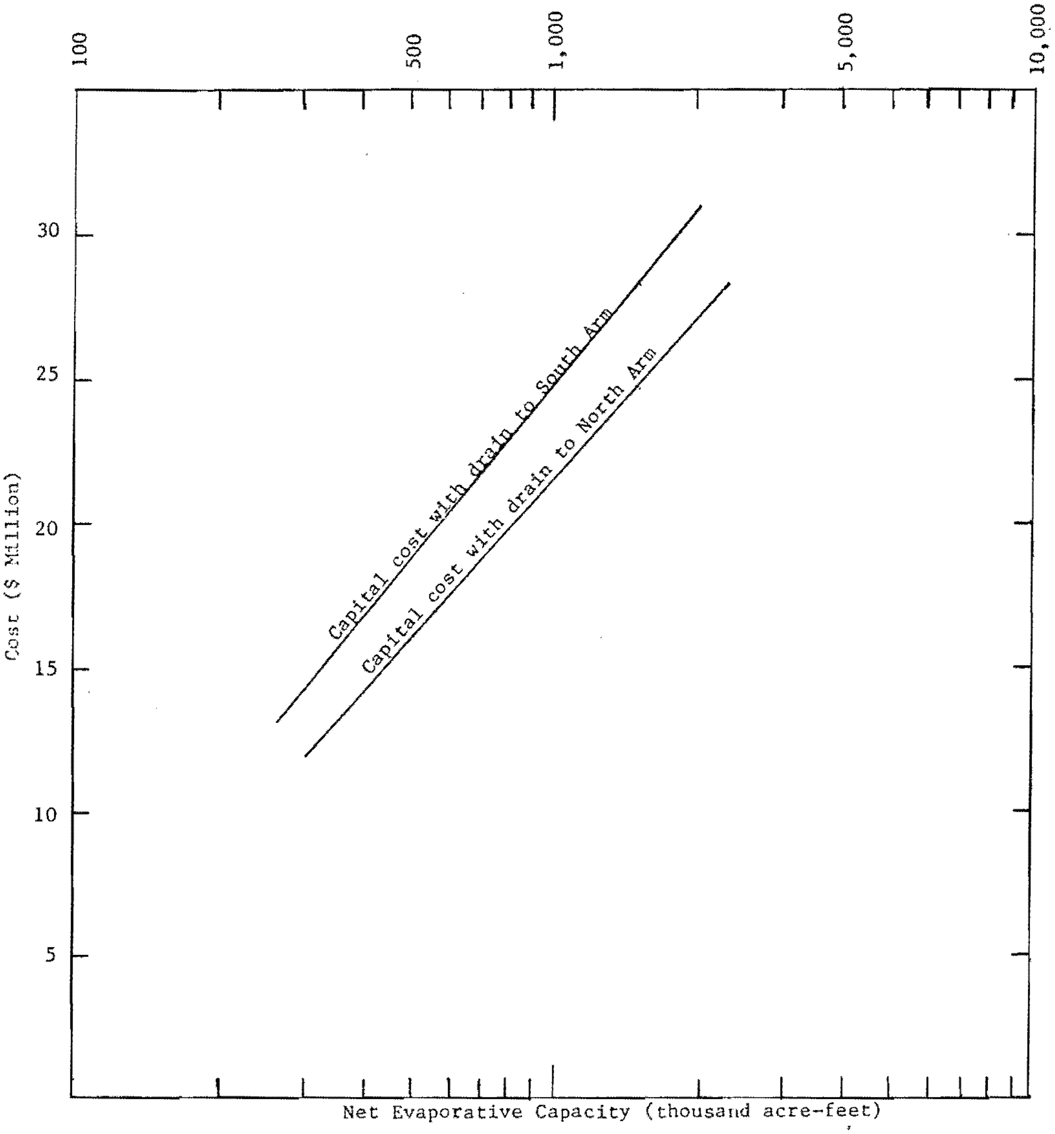


Figure 5.8. Capital costs versus net evaporative capacity.

above sea level for all traces. In fact, for the most extreme lake level trace investigated, the peak lake elevation could not be brought below 4207 feet, although this peak was reduced by 2.5 feet.

Effect on historical trace. An investigation was conducted to examine the effectiveness of the West Desert pumping plan in reducing damages at the Great Salt Lake if the present modified historical hydrologic record were to repeat itself. The historical record was divided into three 50-year periods, and pumping was simulated for 850,000 and 1,500,000 acre-feet net evaporative capacities. The control elevation for pump operation was at 4200 feet. The results are summarized in Figures 5.13 and 5.14.

### Benefit-cost analysis

Optimum timing of construction. The optimum time to construct a project should be chosen so as to maximize the net benefits derived. This study

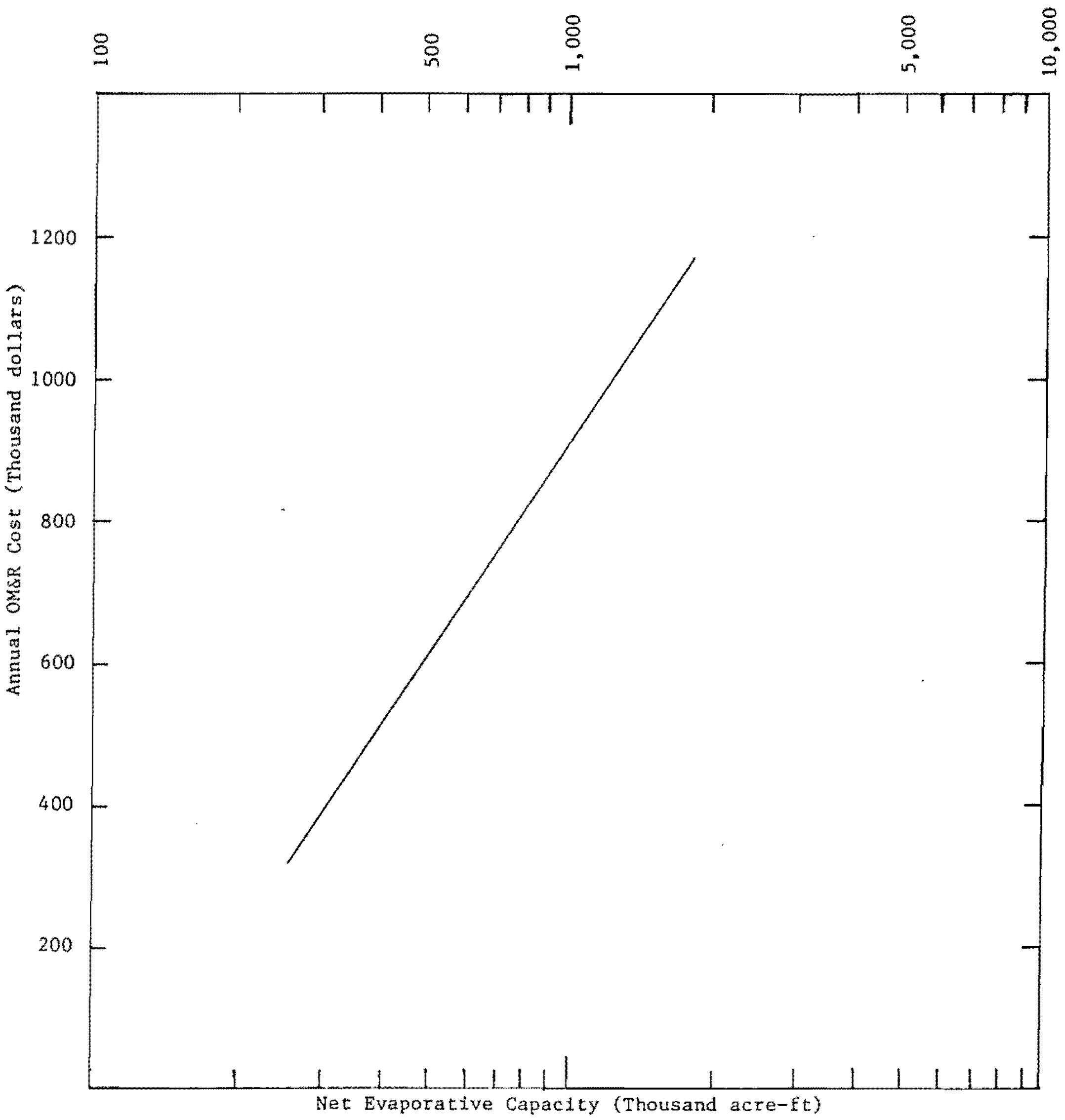


Figure 5.9. Operation, maintenance, and repair costs versus net evaporative capacity.

Table 5.12. Present worth[a] of benefits and costs of various West Desert pumping strategies in thousand dollars.

| Net Evaporative Cap. - ac. ft. | | 310,000 | 380,000 | 850,000 | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 |
|---|---|---|---|---|---|---|---|---|---|---|
| Initial Lake Elevation - ft. (msl) | | 4,200 | 4,200 | 4,200 | 4,200 | 4,200 | 4,202 | 4,202 | 4,204 | 4,204 |
| Control Elevation - ft. (msl) | | 4,200 | 4,200 | 4,200 | 4,200 | 4,202 | 4,200 | 4,202 | 4,200 | 4,202 |
| Present Worth of Capital Cost[b] | Drain to South Arm | 13,360 | 15,280 | 21,850 | 26,700 | 26,700 | 26,700 | 26,700 | 26,700 | 26,700 |
| | Drain to North Arm | 11,320 | 13,070 | 19,100 | 23,420 | 23,420 | 23,420 | 23,420 | 23,420 | 23,420 |
| Present Worth of OM&R Costs for 100 Traces | Average | 526 | 651 | 800 | 712 | 220 | 877 | 293 | 1,234 | 436 |
| | Std. Deviation | 685 | 851 | 1,086 | 1,000 | 460 | 1,116 | 600 | 1,214 | 778 |
| | Median | 254 | 321 | 313 | 266 | 0 | 383 | 0 | 893 | 2 |
| | Maximum | 3,137 | 3,784 | 4,838 | 4,443 | 2,310 | 4,862 | 3,160 | 5,348 | 3,725 |
| | Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Present Worth of Benefits for 100 Traces | Average | 1,938 | 2,143 | 3,710 | 4,311 | 2,650 | 4,580 | 3,326 | 4,276 | 2,854 |
| | Std. Deviation | 4,062 | 4,286 | 7,360 | 8,613 | 6,739 | 10,054 | 8,618 | 8,785 | 7,744 |
| | Median | 305 | 470 | 607 | 630 | 0 | 636 | 0 | 917 | 0 |
| | Maximum | 24,535 | 25,279 | 36,660 | 41,420 | 34,647 | 59,060 | 51,465 | 51,823 | 49,414 |
| | Minimum | 0 | 0 | 0 | 0 | 0 | -403 | 0 | -13 | 0 |
| Probability that Benefit-Cost Ratio will be $\geq$ 1.0[b] | | 0.02 | 0.02 | 0.05 | 0.05 | 0.04 | 0.07 | 0.06 | 0.04 | 0.04 |
| Expected Value of the Benefit-Cost Ratio[c] | | 0.16 | 0.16 | 0.19 | 0.18 | 0.11 | 0.19 | 0.14 | 0.17 | 0.12 |

[a] Discount rate is 6 7/8 percent.

[b] Discounted over three year construction period.

[c] Capital costs used in calculations were those for return drainage to the north arm of the Great Salt Lake.

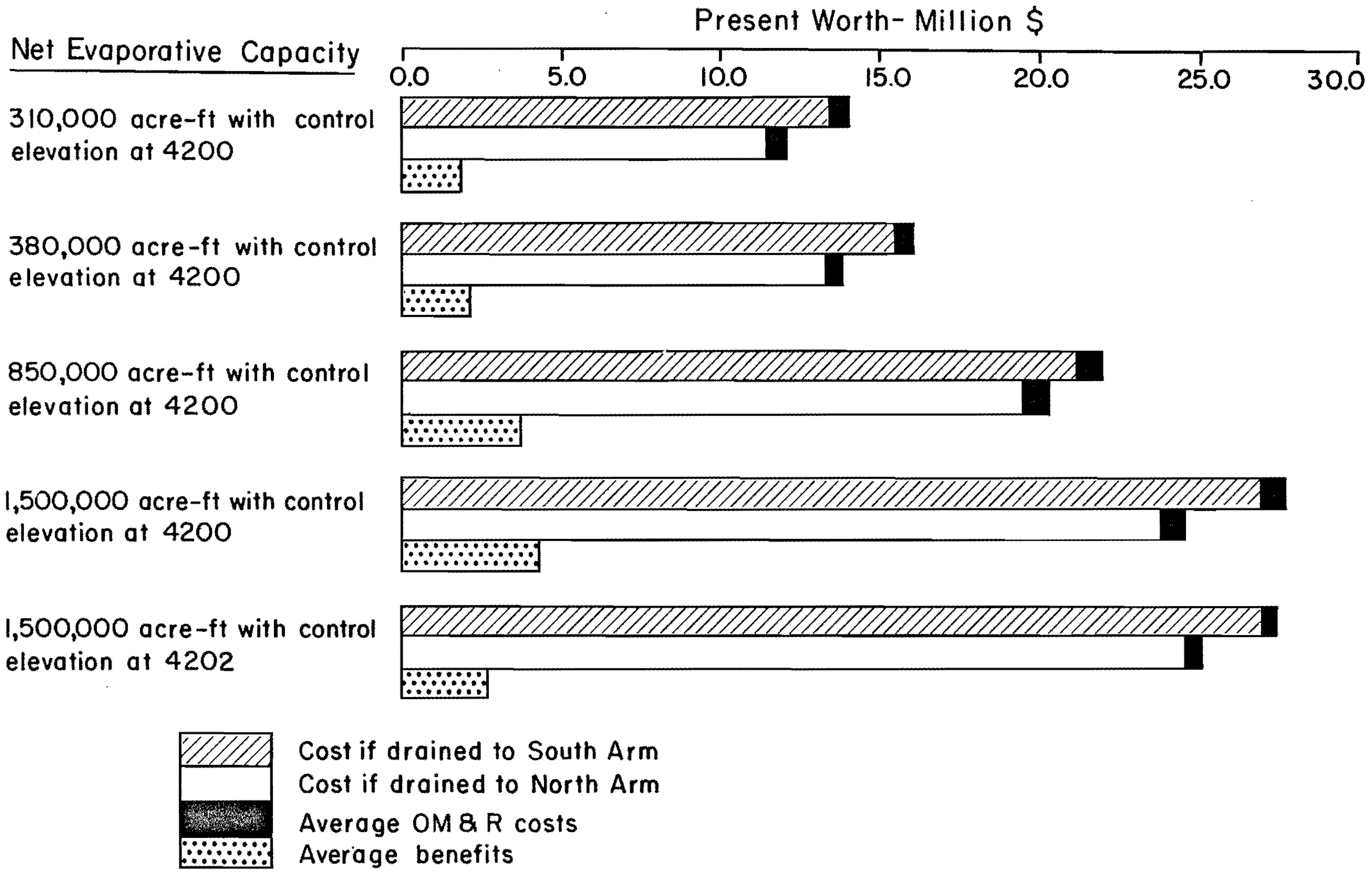


Figure 5.10. Average costs versus average benefits for various West Desert pumping strategies--initial lake elevation at 4200 feet.

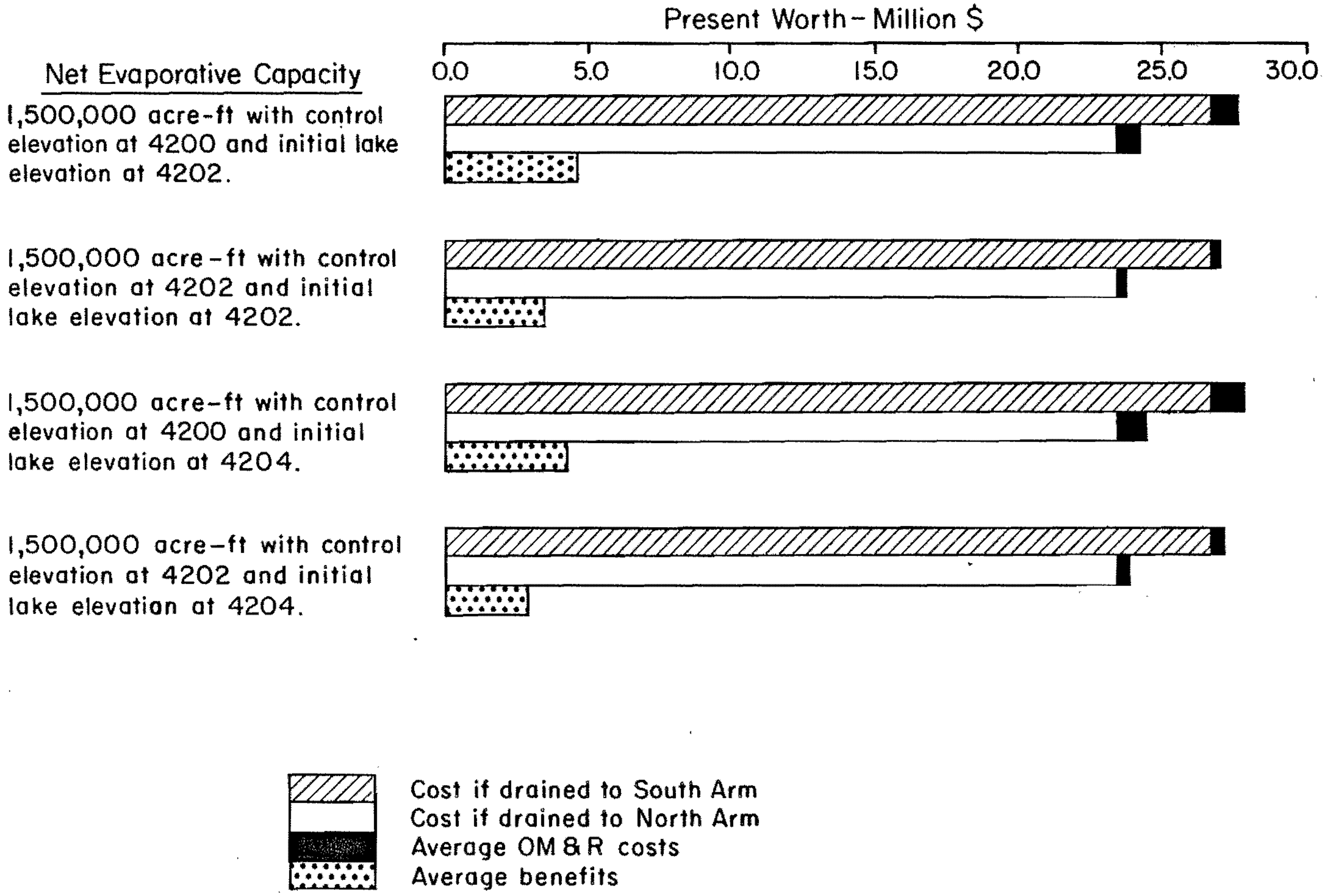


Figure 5.11. Average costs versus average benefits for various West Desert pumping strategies--initial lake elevation at 4202 and 4204 feet.

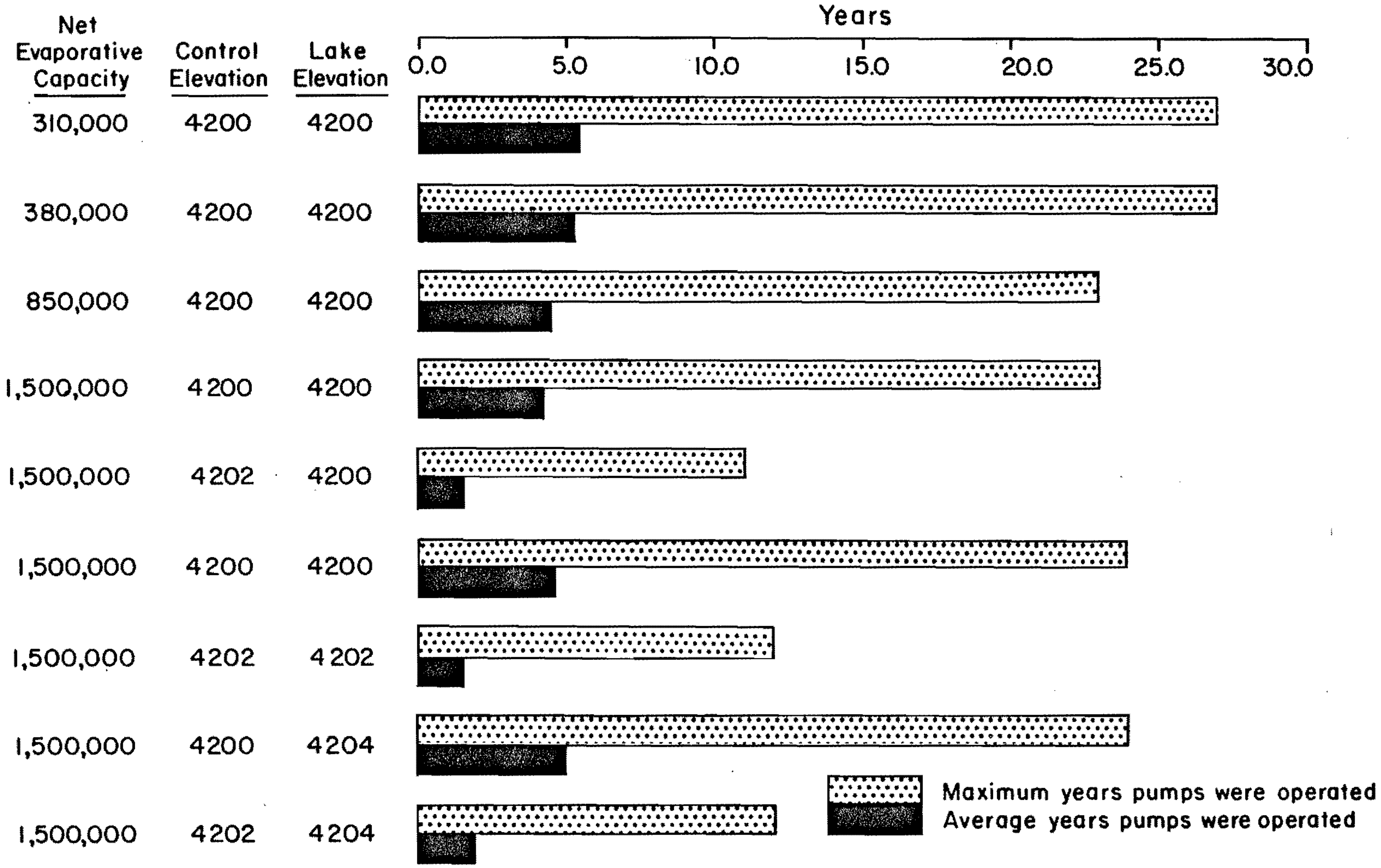


Figure 5.12. Number of years pumps were operated for various West Desert pumping strategies.

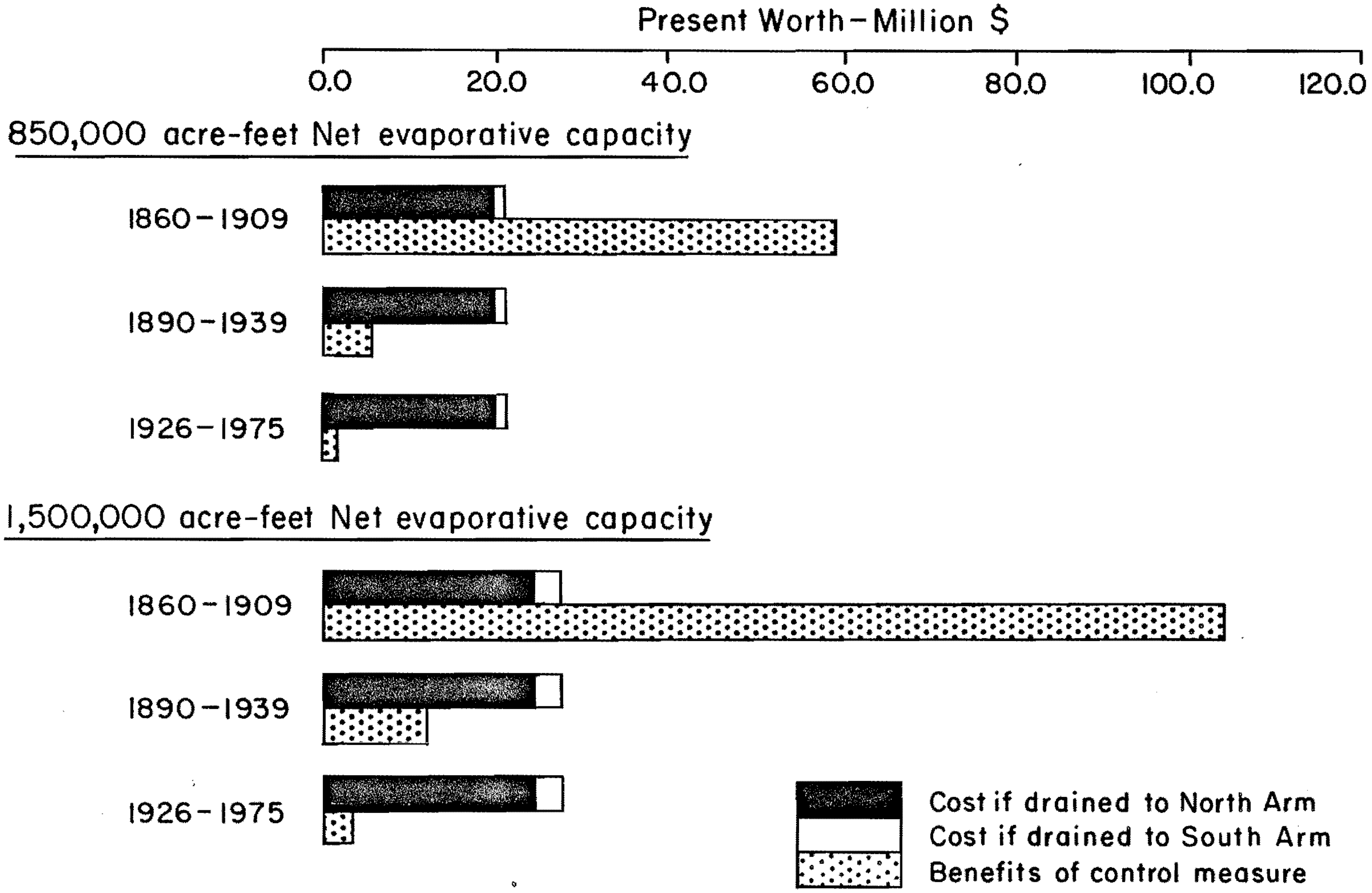


Figure 5.13. Present worth of cost vs. benefits of West Desert pumping plan for the present modified historical record.

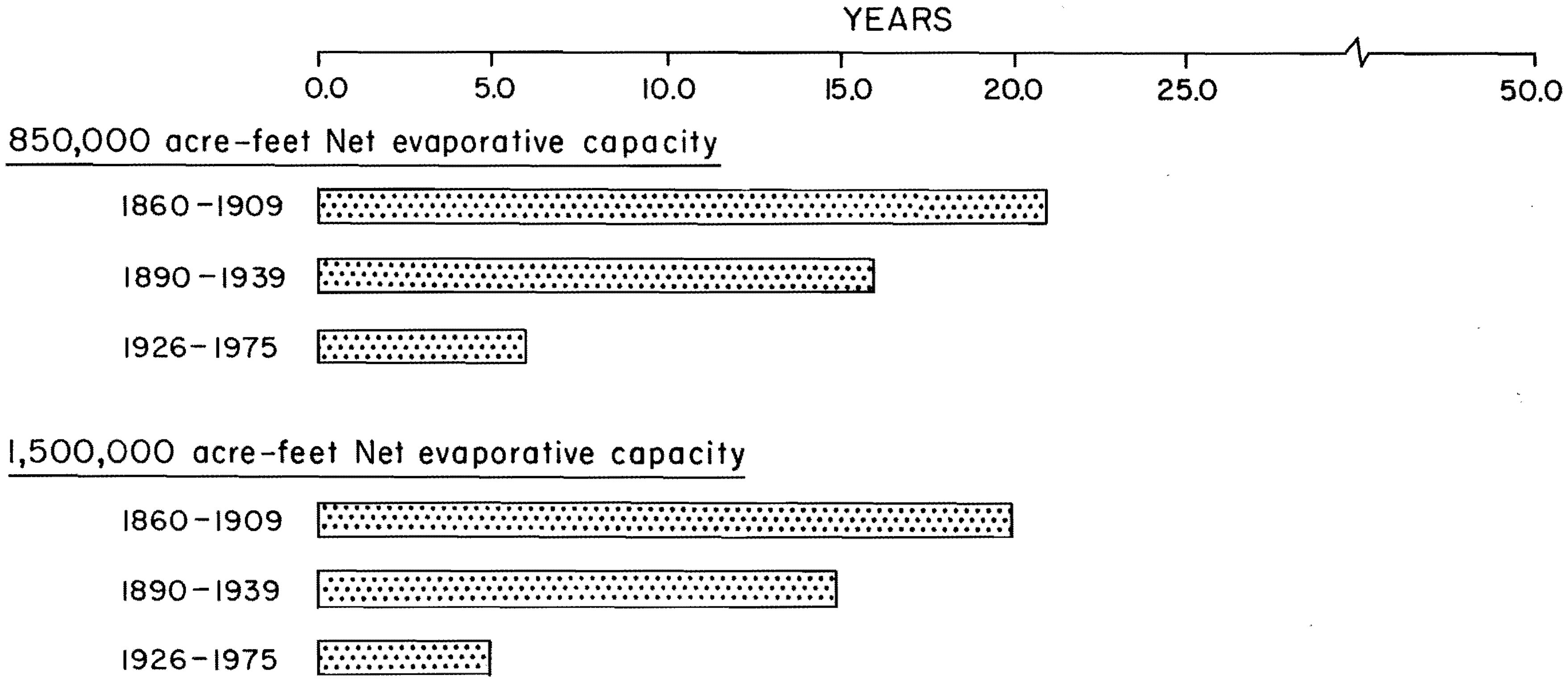


Figure 5.14. Number of years pumps were operated with control elevation at 4200 feet for the present modified historical record.

indicates that the optimum lake level (smallest net negative benefits) at which to begin construction of the West Desert pumping project is at about the 4202 feet above sea level (Table 5.12) which the lake is approaching in January 1983. Estimated benefits were lower with 4204 feet because considerable flooding damage would occur before the pumps came into operation. This effect is compounded in estimating present worth because the discount factor weights earlier damages more heavily than those which occur later.

Optimum project operation. From the results of the simulation, it is apparent that the better control elevation of the two investigated is 4200 feet above sea level. Under this policy, the pumps would be operated whenever the lake level rose above this elevation. The simulation using the 4200 foot control elevation consistently produced greater benefits than did that using 4202. Negative benefits occur if the pumps are operated too long and a long series of below average inflow follows, but the probability of this happening is about one in one hundred (Table 5.12). The optimum pump control elevation may be lower than 4200 feet, but further analysis was not made.

The analysis results. The results of the simulation of the West Desert pumping alternative indicate that the probability that benefits will exceed costs is very low (about 7 percent--Table 5.12). For the pumping schemes simulated, not one has an expected benefit-cost ratio greater than 0.20. For many of the 100 lake level traces synthesized, pumping was not needed at all or for only a short period. The average number of years the pumps were operated was about 6 out of 50, with a maximum pump operation of 27 years in 50 (Figure 5.12). For this extreme case, the benefit-cost ratio was found to be about 2.0 (Table 5.12).

Cost cutting possibilities in system design were not explored. One such would be for industry to capitalize on the West Desert pumping plan through extracting salts from the concentrated brines returned to the lake. Any commercial value for these brines would increase the benefits of the plan. Another possibility would be to use a less costly system for flow return or, in the extreme case, leave the brines in the desert. Some salts would be lost, but the value of that brine needs to be compared to the costs of returning it to the lake. Other possibilities are to stage pump installation to match needs, combine water withdrawals with solar ponds or pumped storage for electric power generation, and modify the design to reduce the cost of protecting the bombing range in the desert.

# CHAPTER VI

# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

From the reconnaissance review of the three alternatives addressed for regulating the level of the Great Salt Lake, the following conclusions are postulated.

### The upstream consumptive use alternative

1. Holding lake levels below 4202 feet above mean sea level requires removal of 847,000 acre-feet annually from the Bear River during occasional years (3 or 4 out of 50) when the lake would otherwise rise to higher peaks. According to estimates based on normal irrigation practices, this would require approximately twice the total irrigated area that is included in projects proposed by the U. S. Bureau of Reclamation and the U. S. Department of Agriculture. Additional irrigable lands available in the Bear River Basin cannot be economically irrigated either because they are too far from the water sources or because high pumping lifts are needed. Additional water would be used by designing new systems to be less efficient or by purposefully wasting water in existing systems.

2. Operation of irrigation projects on an intermittent basis is not an economically feasible alternative for controlling the rising levels of the Great Salt Lake. Subsidies required to construct and operate intermittent irrigation projects are much greater than the reduction in damages achieved at the lake.

3. From the viewpoint of economic feasibility, the development of new projects with additional consumptive use in the Bear River Basin was found to be an infeasible management strategy for controlling the rising levels of the Great Salt Lake.

4. While upstream irrigation cannot effectively control lake level rises that are caused by large amounts of excess flow in a few wet years, several irrigation opportunities in the Bear River Basin are close to economic feasibility on their own right and might become so if lake level control benefits were added to other benefits in a multiple purpose project. Such projects could significantly reduce damages at the lake, the costs of remedial measures, or both. Their development and use should be considered in a multiple means approach using the other alternatives outlined below.

5. Possibilities exist for using existing irrigation systems to distribute water for consumptive use on land not normally irrigated on an emergency basis during periods of rising lake levels. Much of this could be done in the late winter and spring before the normal irrigation users are using their canals to capacity. An inventory of disposal opportunities and an operating plan for such disposal should be formed and used to estimate the amount by which inflow to the lake could be reduced. If such an approach is technically feasible, incentives to the irrigators would need to be developed.

### The diking alternative

1. The dikes proposed to protect the Ogden Bay Bird Refuge and the Howard Slough Bird Refuge are not economically feasible. This is due mainly to the excessive costs of pumping Weber River flow over the dike (Table 5.7).

2. The economic feasibility of diking to protect the Bear River Bird Refuge is marginal (Table 5.8).

3. The diking systems proposed to protect the mineral industries, the highways and railroads, and the Farmington Bay Bird Refuge are economically feasible if construction is commenced when lake levels rise to sufficiently high elevations (Tables 5.4, 5.5, and 5.6). Such a lake level currently exists.

4. The optimum lake level for construction of dikes for protection of entities on the south shore of the Great Salt Lake is approximatley 4204 feet above mean sea level. The optimum lake level for construction of dikes for protection of entities on the other shores is approximately 4202 feet.

### The West Desert pumping alternative

1. The probability that this procedure for regulating the level of Great Salt Lake would be economically feasible is about 7 percent (Table 5.12) based on 1934-1977 hydrologic records and not considering lake rises in the last year or two. This percentage would likely increase if the high flows of the nineteenth century could be included in the period of record, or if the analysis began from current lake levels.

2. Cost cutting design modifications are possible and should be explored.

### Other alternatives

Two other lake level control alternatives which were not explicitly addressed by this study are various combinations of the three which were examined and a "do nothing" alternative. The "do nothing" alternative is being made increasingly unreasonable by rising lake levels. Combinations of accelerated development of feasible upstream irrigation and diking or pumping at the lake might be considered. At the present time, however, the economic feasibility of these alternatives is questionable.

## Recommendations

### Short term

The immediate problem is one of holding lake levels that are currently rising rapidly and to threatening levels below 4204.00 feet above mean sea level at which major damages begin. The situation is reasonably safe for the spring 1983 lake high, but damages are likely in following years. The approaches which should be considered for giving immediate relief are:

1. Promoting upstream consumptive use through incentives to canal companies or irrigators. Feasibility studies would be needed on amounts by which flows could be reduced and the possibility of establishing a fund amounting to some fraction of the damage reduction that could be achieved for use as an incentive. The entire water control system upstream of the lake should be evaluated for operational methods for reducing runoff to the lake during critical periods.

2. Accelerating construction of a pumping scheme without completing designs for return flows to the lake or for protection of military facilities. These features would not be needed immediately anyway.

3. Diking to protect critical facilities. This method is subject to failure should lake levels continue to rise. Once such a program is begun, the state may find itself locked into spending additional sums for the dike refurbishing or raising during subsequent wet periods, and this may create a financial problem. On the other hand, diking costs less than the other alternatives and has the advantage of having the least cost.

4. The above alternatives for promoting consumptive use and pumping into the desert are not to be regarded as being able to guarantee holding the lake to any given elevation but they can reduce rises and expected damage in the probabilistic sense.

Long term

The two basic approaches to damage reduction along the shores of the Great Salt Lake are diking and lake level control. The diking approach has a cost advantage but is generally regarded as less desirable for other reasons. Since the state is on the verge of being forced into choosing between these two fundamental approaches, they need to be carefully compared to determine the extra cost of lake control and to define the advantages purchased. From this information, a decision can be made as to whether the additional cost of control is justified and if money is available to finance it.

If the control option is selected, marginal analysis is needed to formulate an optimal overall design considering all the component alternatives and justifying each element. Elements include, for the pumping scheme, 1a) return flow channels, 1b) dikes to protect areas used by the military, 1c) a pumped storage system possibly utilizing solar ponds for generating power for pumping from the lake, 1d) scheduling the installation and removal of pump capacity, actual pumping, and return flows. Elements for augmenting upstream consumptive use include 2a) construction of new projects justified for multiple purpose use, 2b) project operation for lake level control, 2c) operation of existing irrigation systems for increased consumptive use, and 2d) incentives for increasing upstream consumptive use temporarily as needed during wet periods.

The benefits of lake level control need to be estimated for purposes of determining whether a control program is justified and what the state policy should be on charging beneficiaries. Conceivably, the answers to the above questions could be incorporated into a model optimizing an action plan over the next decade and state policy in the long run.

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# APPENDICES

The five appendices listed below contain listings and supplementary documentation on computer programs used in making the studies described in this report. These are available on request from the Utah Water Research Laboratory but are not published at the end of this report to reduce printing costs. The five models are:

A--Damage Simulation Model
B--Stochastic Lake Level Water Balance Model
C--Irrigated Crop Consumptive Use Model
D--Annual Dike Cost Simulation Model
E--Annual Pumping Cost Simulation Model