REPORT # 10

# SEGREGATION OF IRRIGATION AND POWER STORAGE IN BEAR LAKE RESERVOIR

By

W. V. IORNS

Open File Report

1959

GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

Prepared as part of Bear River Investigations
in cooperation with the States of
Idaho, Utah, and Wyoming

Logan, Utah

# SEGREGATION OF IRRIGATION AND POWER STORAGE IN BEAR LAKE RESERVOIR

A Thesis

Presented in partial fulfillment of the requirements for the

Degree of Professional Engineer

Major in Civil Engineering

in the

University of Idaho Graduate School

by

William Vaughn Iorns

1959

The thesis of William Vaughn Iorns, "Segregation of Irrigation and Power Storage in Bear Lake Reservoir", is hereby approved:

Major Professor ____________________ Date ____________________

Head of Department ____________________ Date ____________________

Dean of College ____________________ Date ____________________

Dean of Graduate School ____________________ Date ____________________

Approved by the Graduate Council:

Secretary of Graduate Countil ____________________ Date ____________________

## BIOGRAPHICAL SKETCH OF THE AUTHOR

William Vaughn Iorns was born in Hagerman, Idaho on June 27, 1906. He attended the Boise High School and received a diploma in 1924. In September 1925 he enrolled in the University of Idaho and received the degree of Bachelor of Science in 1929. In June 1929 he was appointed junior hydraulic engineer in the Water Resources Division, United States Geological Survey, and has served continuously with that organization as follows: junior hydraulic engineer, Surface Water Branch, Boise, Idaho, June 1929 to May 1931; assistant and associate hydraulic engineer, Surface Water Branch, and assistant to Water Master, District No. 36, Idaho Falls, Idaho, June 1931 to November 1942; office engineer, Surface Water Branch, Salt Lake City, Utah, December 1942 to June 1943; project engineer, Bear River Investigations, Surface Water Branch, and chairman, Engineering Committee, Bear River Compact Commission, Logan, Utah, July 1943 to February 1952; staff engineer, Technical Coordination Branch, and chairman, Subgroup on Hydrology, Arkansas-White-Red River Basins Inter-Agency Committee, Tulsa, Oklahoma, March 1952 to February 1955; hydraulic engineer and special representative of Delaware River Master, Milford, Pennsylvania, March 1955 to January 1958; and project hydrologist, Colorado River Hydrologic Study, Quality of Water Branch, Salt Lake City, Utah, February 1958 to date.

## ACKNOWLEDGMENT

The author wishes to acknowledge his appreciation to Wallace N. Jibson, hydraulic engineer, United States Geological Survey, Logan, Utah for his assistance in the initial computations upon which this thesis is based.

Gratitude is also expressed to associates and members of the United States Geological Survey for their kindness in reviewing this thesis and to Director Thomas N. Nolan for approving this thesis and its release to the open file.

Special thanks go to Afton Wright, Secretary, Upper Colorado River Hydrologic Study, who typed this thesis.

## TABLE OF CONTENTS

## ILLUSTRATIONS



## TABLES

Tables.--(Continued)

# SEGREGATION OF IRRIGATION AND POWER-STORAGE IN BEAR LAKE RESERVOIR

BY

WILLIAM VAUGHN IORNS

## INTRODUCTION

### PURPOSE OF STUDY

The Bear River Compact Commission, composed of representatives of the States of Idaho, Utah, and Wyoming, and a representative of the United States was charged with negotiating and preparing an interstate compact to divide the waters of Bear River between the States of Idaho, Utah, and Wyoming. Before the compact could be negotiated a number of complex hydrologic and engineering studies had to be made. One of these was a study of the historical stored-water operations of Bear Lake Reservoir.

From July 1943 to February 1952 the writer served as project engineer of Bear River Investigations for the U.S. Geological Survey. When the Bear River Compact Commission was organized the writer was made chairman of the Engineering Committee. A report by the chairman was subsequently used by the Engineering Committee as a basis for identifying the storage space in the Bear Lake Reservoir that should be reserved primarily for irrigation purposes.

This paper, which is substantially the same as the original report submitted to the Committee, describes the Bear Lake storage-segregation problem and its solution.

## LOCATION AND HISTORY

Bear Lake Reservoir is an interstate body of water in Bear Lake Valley near the southeastern corner of Idaho (Fig. 1). Approximately half of the surface area of the lake is in Idaho and half in Utah. The Bear Lake valley is a north-south depression formed by a block fault. The Bear River courses in a northwesterly direction across a broad alluvial plain in the northern end of the valley. At one time the lake occupied this area and the river was tributary to the lake. With the passage of time, sediment carried by the river filled the northern end of the ancient lake and the plain was formed.

Before Bear Lake was converted into the storage reservoir, a natural causeway, built up by wave action, extended along the northern shore line of the lake. On the northern side of this causeway, occupying depressions in the old Bear River delta, was a group of shallow interconnected lakes, called Mud Lake. A meandering outlet channel connected Bear Lake and Mud Lake and emptied into Bear River.

In the early 1900's the Telluride Power Company and the Utah Sugar Company began construction work to utilize the lake as an off-stream reservoir by diverting part of the waters of Bear River into Bear Lake. Their plan was to construct an inlet canal from Bear River

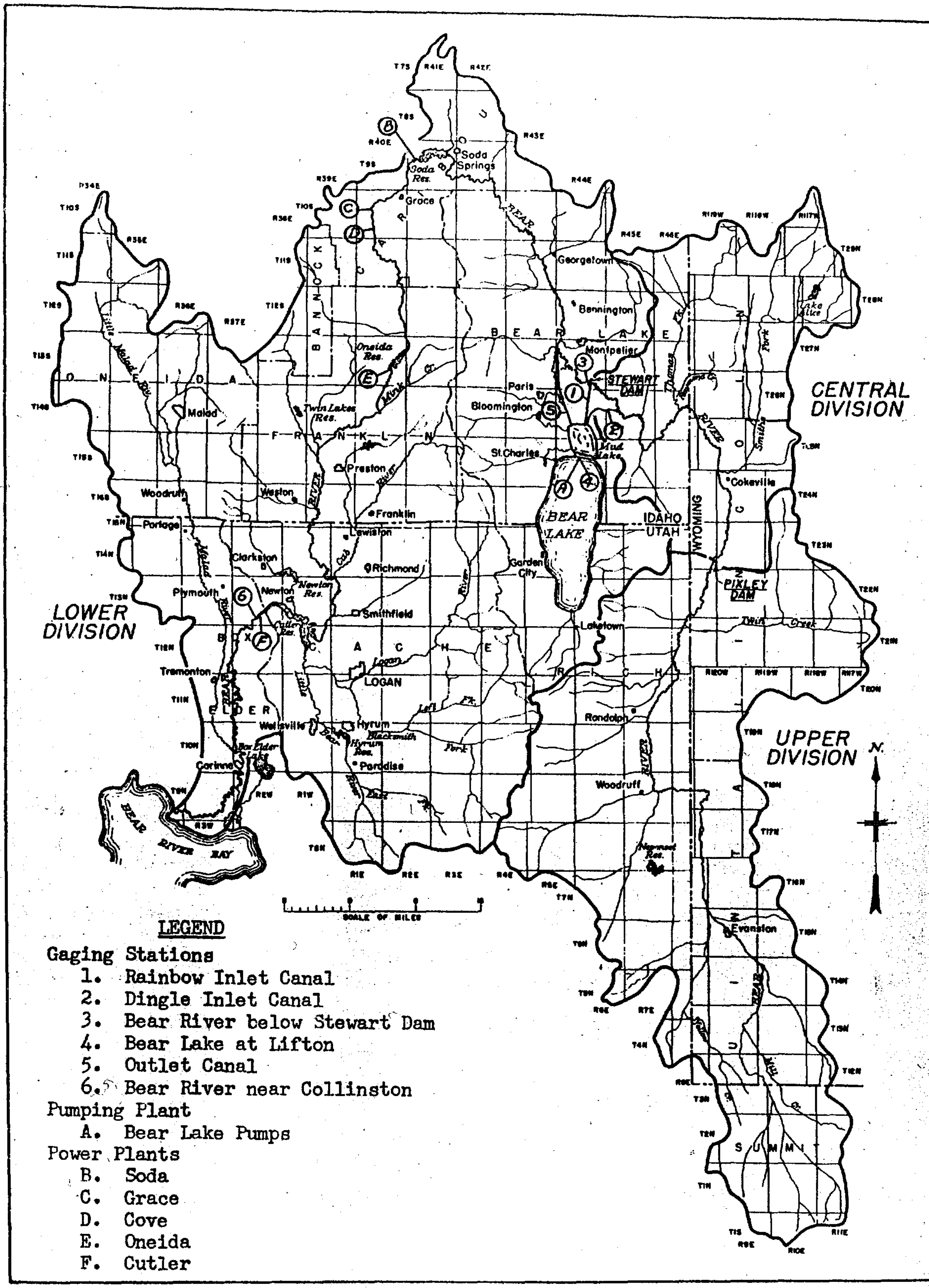


Figure 1.--Map of Bear River Basin.

where it entered the valley and an outlet canal from the lake to the river near its exit from the valley. Construction was sufficiently completed in 1911 to provide a small amount of storage. The Utah Power and Light Company, in 1912, acquired the storage development interests of the Telluride Power Company and the Utah Sugar Company. The Utah Power and Light Company constructed a pumping plant at the north end of Bear Lake, built dikes around Mud Lake, and constructed new inlet and outlet canals of large capacity.

## DESCRIPTION AND OPERATION OF BEAR LAKE STORAGE DEVELOPMENT

In converting Bear Lake into a storage reservoir the outlet channel from Bear Lake to Mud Lake was filled in approximately to the elevation of the natural causeway separating the two lakes. The causeway was also strengthened with additional fill material. This provided a substantial dike separating the two lakes. Gates were constructed in this dike to control interchange of water between the two lakes, and a pumping plant was constructed on the Bear Lake side of the dike to lift water from Bear Lake into Mud Lake. Mud Lake was enclosed by a second dike that was constructed across the valley along its northern shore line and an outlet canal was dredged through the west side of Mud Lake from the pumping plant to Bear River near the northwest end of the valley. Control gates were constructed in the channel of the outlet canal where it cut through the dike on the north side of Mud Lake. A diversion dam was constructed across Bear River near the east side of the valley and an inlet canal from the river to Mud Lake was constructed. A small inlet canal constructed in the early years of the development was continued in operation.

The control gates in the outlet canal at Mud Lake dike and the control gates in the causeway separating Mud and Bear lakes can be operated to vary the elevation of Mud Lake. Water can be diverted from Bear River into Mud Lake and returned to the river through the outlet canal, or be diverted into Bear Lake. Water can also be withdrawn from Bear Lake into Mud Lake and released to the river through the outlet canal. However, water can only be withdrawn by gravity from Bear Lake when the elevation of the reservoir is within its top four to five feet of capacity elevation. When the lake surface drops below this level the water in Bear Lake is lifted by the pumps from Bear Lake into Mud Lake and then released by gravity flow through the outlet canal, to Bear River. Through operation of the control gates and the pumps, controlled storage in Bear Lake has a range of 21.65 feet. The rated capacity for this range of stage is 1,421,000 acre-feet.

Mud Lake has a storage capacity of approximately 34,000 acre-feet in a range of stage of 4.65 feet between the bottom of the shallow lake and the top of the outlet control gate at the dike. This lake serves principally as a regulating reservoir. In normal operation, the lift pumps are operated only during "dump-power" periods. The pumped water is temporarily stored in Mud Lake and released as required.

## STORAGE RIGHTS

Storing of water in Bear Lake Reservoir and release of stored water down the natural channel of Bear River resulted in controversy between those having irrigation rights to natural-flow water and those having rights to stored water. The controversy culminated in litigation in the United States District Court of Idaho, Eastern Division. That court, in a decree dated July 13, 1920, defined the rights of the Utah Power and Light Company to store water in Bear Lake Reservoir and the rights of irrigation water users to natural-flow water in Idaho from Bear Lake downstream to the Idaho-Utah state line. In this decree the Utah Power and Light Company was awarded rights as follows:

"(a) Bear River and Bear Lake.

> The right to divert from the natural-flow waters in the main channel of Bear River to storage in Bear Lake Reservoir, 3,000 cubic-feet per second with a date of priority of March 1, 1911, and 2,500 cubic-feet per second with a date of priority of September 11, 1912. This water to be diverted through the Rainbow and Dingle Inlet Canals, stored in the lake, and withdrawn as needed or required for generating electrical power and for irrigation purposes.

"(b) Tributaries to Bear Lake.

> The right to store in Bear Lake Reservoir the natural flow of tributaries to Bear Lake, 300 cubic feet per second with a date of priority of September 1, 1912 and withdraw this stored water as needed or required for generating electrical power and for irrigation purposes.

"(c) From Mud Lake and tributaries to Mud Lake.

> The right to store in Bear Lake Reservoir the natural flow of tributaries to Mud Lake, 200 cubic-feet per second with a date of priority of September 1, 1912, and

withdraw this stored water as needed or required for generating electrical power and for irrigation purposes."

The decree did not place a limit on the maximum storage which might be created in Bear Lake, or differentiate between power and irrigation-storage water interests.

## USE OF BEAR LAKE STORED WATER

Stored water released from Bear Lake Reservoir is used for the production of electrical power and the irrigation of lands in Idaho and Utah. The Utah Power and Light Company has built five power plants along the main channel of Bear River between the reservoir and Great Salt Lake (Fig. 1). The approximate gross power head of each is as follows:

| Power plant | Approximate gross power head (feet) |
|---|---|
| Soda Plant at Alexander, Idaho . . . . . | 75 |
| Grace Plant near Grace, Idaho . . . . . | 524 |
| Cove Plant near Grace, Idaho. . . . . . | 98 |
| Oneida Plant near Preston, Idaho . . . . . | 146 |
| Cutler Plant near Collinston, Utah . . . . | 120 |
| Total. . . . . . . . . | 963 |

Regulating reservoirs were constructed above three of the power plants, as part of the power-head and diversion works. The usable storage capacities of these reservoirs, which bear the name of the power plant above which they are located are as follows:

| Reservoir | Usable storage capacity (acre-feet) |
|---|---|
| Soda . . . . . . | 11, 800 |
| Oneida . . . . . | 11, 500 |
| Cutler . . . . . | 15, 300 |

Major irrigation canals that receive stored water from Bear Lake Reservoir under agreements between the Utah Power and Light Company and the canal companies are the Last Chance Canal, the West Cache Canal, the Cub River Irrigation Pump Canal, the Hammond Canal, and the West Side Canal. The Last Chance Canal, which diverts water from the river between the Soda and Grace power plants, is entitled to receive annual deliveries of stored water as needed to supplement its natural-flow irrigation rights. The West Cache Canal, which diverts water from the river a few miles below the Oneida power plant is entitled to receive 12, 000 acre-feet of stored water annually. The Cub River Irrigation Pump Canal, which diverts water from the river a few miles above the Idaho-Utah state line, is entitled to receive 20, 000 acre feet of stored water annually. The Hammond and West Side Canals, which divert water from the river at the Cutler Dam, are entitled to receive a total delivery of up to 900 cubic-feet per second of stored water whenever this amount is required to supplement their natural-flow rights.

The Utah Power and Light Company also has agreements with a number of canal companies, whose diversion of water from the river are affected by fluctuations in the river level due to power plant operations, to supply some stored water as compensation. There are, in addition, a number of small canal companies that use electrical-powered pumps to divert water from the river. Most of the water pumped by these companies is stored water.

## THE PROBLEM

After the completion of Bear Lake Reservoir and prior to the drought period of the 1930's, runoff in the Bear River drainage basin was greater than normal. As water was plentiful, large quantities of natural-flow water and water released from storage in Bear Lake was used for the production of hydro-electric power, that is, not only passed through the Soda, Grace, Cove, and Oneida power plants but also through the Cutler power plant and discharged into Great Salt Lake. Not realizing that a severe drought was approaching, the Utah Power and Light Company continued using stored water for power production into the early years of the drought. This practice resulted in the reduction of hold-over storage in the reservoir to a quantity less than needed to meet irrigation commitments throughout the period of deficient runoff ending in 1935.

In the Bear River Compact negotiations, consideration was being given to an allowance of additional storage upstream from Bear Lake. Additional upstream storage would result in some depletion of storable supplies for Bear Lake. This would be adverse to the interests of water users dependent on Bear Lake for stored water. The downstream water users could be protected both from the possibility of over-draft on the reservoir for power purposes and upstream depletion by incorporating adequate provisions in the compact. To define what these provisions should be required a determination of the magnitude of storable water supply for Bear Lake Reservoir and a determination of the amount of stored water actually needed to fill the stored-water requirements of downstream irrigation water users.

A detailed stored-water and natural-flow segregation study of the reservoir and the reach of the river from Stewart Dam to Cutler Dam for a period of years that would be representative of long-term water supply conditions would be required to accurately determine these quantities. This kind of a segregation study would require intricate computations involving daily records of canal diversions, river discharges at control points, changes in reservoir contents, and contributions from tributaries. Evaporation losses, return flow from irrigation, time of transit of water down the river, and priority of water rights would also have to be taken into account. Some of this data, particularly that for tributary contributions and canal records, was non-existent or incomplete.

The temporary pondage of water in the regulating reservoirs and variations in time of transit of water through sections of the river, as a result of fluctuations in discharge caused by power-plant operations, would complicate computations in making a detailed segregation study. It was apparent that the estimates and assumptions which would have to be made in an approach of this type would tend to make the results inaccurate and possibly inconclusive; therefore, a different and less complicated procedure would have to be devised. In further analysis of the problem and information needed, four basic questions were set up:

1. If Bear Lake Reservoir was used entirely for irrigation purposes what would have been the maximum amount of water that could have been stored in Bear Lake annually? Of the total maximum quantity

    (a) How much water would have been derived from Bear River, and

    (b) How much from tributary inflow into Bear Lake?

2. How much of the stored water released from Bear Lake in each irrigation season has been used for irrigation?

3. How much of the maximum amount of storable water, determined in question 1 above, has been used for power production purposes, that is, passed down the river system through the Cutler Power Plant and discharged into Great Salt Lake?

4. What is the relationship between the maximum storable water in Bear Lake and the total irrigation requirement for stored water?

## ANALYSIS OF THE PROBLEM

### A SIMPLIFIED METHOD FOR SEGREGATION STUDY

A study of daily hydrographs of diversions from Bear River to Bear Lake, change in contents of Bear Lake, releases from Bear Lake, and streamflow passing the Cutler Dam led to a simplified method for solving the problem. This method consisted of treating the river system between Stewart Dam and Cutler Dam as a unit and considering primarily inflow into the upper end of the unit and outflow from the unit. Any stored water released into the upper end of the unit would either be consumed for irrigation purposes or accounted for as part of the outflow from the unit. By dividing the water year into storing and stored-water release periods the total quantity of storable water could be determined. From the relationship of daily hydrographs of storable supply from Bear River, quantities of water actually diverted to storage in Bear Lake, and outflow from the river unit, the portion of the inflow into the upper end of the unit needed to fill prior irrigation rights could be identified.

The inflow from Bear River into the upper end of the unit can be computed by combining the flows of the two inlet canals with the flow of Bear River below Stewart Dam. The outflow from the unit is the flow in Bear River near Collinston, Utah. The quantities of water diverted from Bear River to storage in Bear Lake and the quantities of stored water released from Bear Lake can be computed from the daily flows of water in the two inlet canals and the Bear Lake Outlet Canal. The contributation to the river unit from tributary inflow to Bear and Mud Lakes and losses due to evaporation from the surface of Bear Lake can be computed from data on the changes in contents of Bear Lake in combination with diversions from Bear River to Bear

Lake and releases from Bear Lake to Bear River.

Gaging stations recording the discharge in the two inlet canals, the outlet canal, and the discharge of the river below Stewart Dam were installed in January 1922. A gage recording the contents of Bear Lake was installed in January 1921. A gaging station on Bear River near Collinston, Utah was established in July 1889. Daily records for these gaging stations, for the period of time since the stations were established have been published in the Water Supply Papers of the U.S. Geological Survey or are available in the files of the U.S. Geological Survey in Salt Lake City, Utah. The names of the six gaging stations whose locations are shown on Figure 1 are as follows:

Rainbow Inlet Canal near Dingle, Idaho
Dingle Inlet Canal near Dingle, Idaho
Bear River below Stewart Dam, near Montpelier, Idaho
Bear Lake at Lifton near St. Charles, Idaho
Bear Lake Outlet Canal near Paris, Idaho
Bear River near Collinston, Utah

The Bear River Compact Commission had previously adopted the period October 1, 1923 to September 1948 as a base period representative of long-term water supply conditions in the Bear River Basin. The analysis of Bear Lake stored-water operations was therefore limited to this period.

Definitions and assumptions adopted in the segregation study in application of the simplified procedure are given in the following sections.

## DEFINITIONS

Water year is the twelve-month period beginning on October 1 of one year and ending September 30 of the following year. The year in which this period ends is used to designate any particular water year.

Cubic foot per second is the rate of discharge of a stream whose channel is one square foot in cross-sectional area and whose average velocity is one foot per second.

Acre-foot is the quantity of water required to cover an acre to the depth of one foot and is equivalent to 43,560 cubic feet. A cubic foot per second flowing for 24 hours is equivalent to 1.983471 acre-feet.

Natural-flow water is the water in Bear River exclusive of water released from storage in Bear Lake.

Prior-irrigation rights is the downstream irrigation water rights for natural-flow water having an earlier dated priority than the Bear Lake storage right.

Total streamflow of Bear River above Stewart Dam is the combined discharge of Bear River below Stewart Dam, Rainbow Inlet Canal and Dingle Inlet Canal.

Stewart Dam diversion loss is the leakage through Stewart Dam when all the streamflow in Bear River is being diverted into the Rainbow and Dingle Inlet Canals. It is equal to approximately 40 acre-feet per day.

By-passed water is the water released through the gates at Stewart Dam or routed back to the river through the inlet canals, Mud Lake, and the outlet canal.

Maximum storable water from Bear River is the total streamflow above Stewart Dam during the storing period less the Stewart Dam diversion loss and less the water by-passed to fill prior-irrigation rights. This water would be storable in Bear Lake.

Water diverted to Bear Lake is the water diverted from Bear River and actually stored in Bear Lake. It is equal to the total discharge of Rainbow and Dingle Inlet Canals minus the discharge in the Outlet Canal.

Release period is the period in the irrigation season that water is being released from Bear Lake and begins on the day that the discharge in the Outlet Canal exceeds the combined discharge in the Rainbow and Dingle Inlet Canals and ends on September 30.

Storing period is from October 1 to the day before the beginning of the release period. It is divided into a winter-storing period, beginning on October 1 and ending on March 31, and a high-water storing period, beginning on April 1 and ending on the day before the beginning of the release period.

Stored or storable water used for power production is stored water released from Bear Lake or by-passed storable water that is passed through the turbines at the Cutler power plant for the production of electrical power.

Apparent stored water used for irrigation is water released from Bear Lake during the release period and consumed in irrigation even though electrical power is produced as the water flows downstream to the last point of diversion for irrigation at Cutler Dam.

Irrigation stored-water requirement is the amount of stored water consumed by irrigation of lands, plus the stored water losses incurred in delivering stored water to the lands, plus the losses incurred in storing water in the Bear Lake Reservoir.

Storable water from Bear Lake tributary inflow is the water which would accumulate in Bear Lake under natural conditions during the storing period.

Bear Lake evaporation loss is the loss in Bear Lake contents under natural conditions during the release period.

Cutler diversion loss is the leakage through Cutler Dam when no water is passing the dam for power production. This leakage averages about 45 acre-feet daily.

## BASIC ASSUMPTIONS

### River System as a Unit

The river system between Stewart Dam and Cutler Dam can be treated as a unit if inflow into the upper end of the unit from Bear River and Bear Lake and outflow from the lower end of the unit, as measured at the Bear River near Collinston gaging station, are considered as the controlling factors. Any stored water released into the upper end of the unit would either be consumed for irrigation purposes or be an indentifiable part of the outflow from the unit. The portion of the natural-flow water entering the upper end of the unit needed for natural-flow irrigation rights within the unit could be identified.

<u>Effect of Regulating Reservoirs</u>

Mud Lake and the three downstream regulating reservoirs have a total capacity of 72,600 acre-feet. Under certain conditions of operation of the system, substantial quantities of water could be stored in these reservoirs during the storing period and released for power or irrigation during the release period. Another possibility is that water released from Bear Lake during the release period might be stored and released later. In treating the river as a unit between Bear Lake and Cutler Dam, either or both of these occurrences could introduce serious errors. If the reservoirs functioned only for re-regulation purposes, their effect would be negligible in comparison to the total amount of stored water involved. For this segregation study it was assumed that they were operated only as regulation reservoirs and their combined effect would be negligible. However, subsequent to this study, the operation of these reservoirs was investigated and it was found that their inclusion in the study would not have materially changed any of the findings.

<u>Return Flow and Natural Losses</u>

Between Bear Lake and Cutler Dam, a portion of the stored water that is applied to the lands is returned to the river and is available for re-use. Also, in this reach of the river there are evaporation losses and other natural losses. Part of these losses should be borne by natural-flow water and part by stored water. In this study, the assumption was made that the pro rata effect of these gains and losses, that should be added to or subtracted from stored waters, would be taken into account by treating the river system between Bear Lake and Cutler Dam as a unit.

## SEGREGATION STUDY COMPUTATIONS AND EXPLANATION OF METHOD

### General

Summary data and computations made in the simplified segregation study for the period October 1, 1923 to September 30, 1948 are shown in Table 1 (pocket). Column headings in the table conform to the definitions and footnotes to the table explain the source of data and computations. In the following, the segregation method is discussed and explained in detail using the 1947 water year as an example. Hydrographs of the daily quantities at gaging stations and combinations of gaging station for the 1947 water year are shown on Figure 2 (pocket).

### Bear Lake under Natural Conditions

If water were not withdrawn from Bear Lake and not diverted to the lake from Bear River, the water contained in the lake at any time would be the resultant of tributary inflow less evaporation loss. By algebraically subtracting monthly diversions from Bear River to Bear Lake and releases from Bear Lake (releases are given negative signs) from the monthly plus and minus changes in Bear Lake contents, the increase or decrease in Bear Lake under natural conditions can be computed. Computed monthly and annual change in contents of Bear Lake under natural conditions for the period 1924 to 1948 are shown in Table 2. This table is used in computing the maximum storable water in Bear Lake from tributary inflow during each storing period and the net loss in the reservoir, resulting from evaporation, during each release period. Monthly quantities are used except for the months in which storing of water ends and stored water release begins. For these months additional computations using daily quantities are required. The computed storable water from Bear Lake tributary inflow under natural conditions was 84, 100 acre-feet (col. 17, table 1) during the storing period in 1947. The computed Bear Lake evaporation loss under natural conditions was 25, 630 acre-feet (col. 27, table 1) during the release period in 1947.

Figure 3 shows a cumulative graph of the annual gains and losses for Bear Lake under natural conditions, beginning with zero on October 1, 1923. This graph indicates that over a long period of time, the gain in Bear Lake from tributary inflow only slightly exceeds the loss. If Bear Lake were entirely dependent on tributary inflow and did not overflow, the maximum change in contents during the twenty-five year period would have been about 250, 000 acre-feet.

Winter-Storing Period

The winter-storing period extends from October 1 to March 31.

This table is slightly in error prior to 1935 & in a few subsequent years — (old compilation on change in content used)

See 1950 compilation WSP 1314

| Water year | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1924 | +13,200 | +13,200 | +13,200 | +5,700 | +14,200 | +21,100 | +14,400 | +7,300 | -3,400 | -8,900 | -17,600 | -23,300 | +22,700 |
| 1925 | +1,400 | -21,900 | +12,500 | +12,800 | +13,500 | +27,400 | +18,900 | +25,400 | +7,700 | -8,700 | -20,600 | -8,300 | +60,100 |
| 1926 | -26,000 | -9,700 | -5,900 | +5,700 | +14,400 | +28,900 | +16,700 | +8,000 | -17,800 | -18,700 | -15,400 | -26,600 | -46,400 |
| 1927 | -14,500 | -9,900 | -18,400 | +17,300 | +18,800 | +34,400 | +18,000 | +20,600 | +14,100 | -21,900 | -30,200 | +800 | +29,100 |
| 1928 | -8,900 | +900 | -0 | -2,000 | +5,400 | +34,700 | +13,500 | +18,700 | +21,300 | -19,100 | -25,900 | -33,000 | +5,600 |
| 1929 | +10,400 | -6,400 | +7,700 | +11,400 | +13,700 | +26,800 | +35,200 | +17,200 | +11,500 | -16,300 | -14,700 | -6,500 | +90,000 |
| 1930 | -17,400 | -17,800 | -400 | +6,900 | +13,500 | +22,100 | +21,200 | +14,600 | -8,200 | -21,300 | +500 | -18,200 | -4,500 |
| 1931 | -6,200 | -15,200 | -5,500 | +7,400 | +7,400 | +15,100 | +12,500 | +2,100 | -19,900 | -35,000 | -26,000 | -24,500 | -87,800 |
| 1932 | -9,100 | -13,200 | +5,800 | +12,100 | +13,100 | +18,500 | +38,500 | +9,900 | +18,200 | -1,100 | -18,100 | -24,400 | +50,200 |
| 1933 | -14,500 | -7,300 | -5,500 | +7,800 | +11,700 | +6,600 | +27,300 | +23,100 | +6,600 | -22,500 | -34,400 | -25,600 | -26,700 |
| 1934 | -12,700 | -14,000 | +3,700 | +3,400 | +7,900 | +6,800 | -3,000 | -8,000 | -26,100 | -24,400 | -28,200 | -38,200 | -132,800 |
| 1935 | -13,400 | +1,700 | +500 | -1,500 | +14,500 | +12,700 | +25,000 | +2,500 | +8,900 | -23,400 | -27,800 | -33,300 | -33,600 |
| 1936 | -17,600 | -7,400 | -900 | +14,600 | +22,200 | +14,100 | +33,900 | +30,100 | +27,200 | -11,400 | -8,500 | -22,400 | +73,900 |
| 1937 | -2,800 | +4,700 | +2,300 | +4,200 | +11,300 | +17,500 | +27,800 | +32,000 | +10,100 | +1,400 | -32,800 | -24,300 | +51,400 |
| 1938 | -8,200 | -2,000 | -3,800 +3,800 | -200 | +5,100 | +23,900 | +25,400 | +27,400 | +7,700 | -9,300 | -23,500 | -14,400 | +35,700 |
| 1939 | -17,000 | -11,900 | -600 | +7,700 | +7,600 | +21,400 | +13,700 | +11,600 | -15,000 | -21,700 | -26,000 | -16,300 | -46,500 |
| 1940 | -16,500 | -13,000 | -2,300 | +3,200 | +7,400 | +14,100 | +2,600 | -7,900 | -22,000 | -26,900 | -34,000 | -6,100 | -101,400 |
| 1941 | -5,100 | -10,400 | +300 | +2,400 | +3,200 | +15,500 | +9,300 | +8,400 | -18,500 | +6,400 | -17,900 | -24,900 | -31,300 |
| 1942 | -3,400 | -6,700 | -300 | +1,700 | +13,100 | +19,000 | +18,900 | +15,100 | -3,700 | -29,400 | -19,100 | -15,500 | -10,300 |
| 1943 | -9,900 | -7,800 | -4,500 | +1,800 | +10,600 | +36,500 | +35,600 | +23,200 | +23,600 | -11,200 | -20,600 | -21,500 | +55,800 |
| 1944 | -12,800 | -6,500 | -3,800 | +4,400 | +11,900 | +19,800 | +32,600 | +15,200 | +12,600 | -26,700 | -36,100 | -23,200 | -12,600 |
| 1945 | -14,100 | -2,200 | -4,300 | +2,100 | +7,900 | +10,700 | +15,400 | +20,400 | +18,400 | -7,000 | -20,900 | -20,000 | +6,400 |
| 1946 | -8,600 | +11,100 | +4,800 | +9,200 | +7,800 | +26,800 | +40,400 | +35,300 | +4,600 | -18,400 | -9,600 | -23,200 | +80,200 |
| 1947 | -9,300 | -2,900 | +14,100 | -400 | +18,900 | +20,000 | +4,500 | +24,000 | +16,100 | -5,200 | -8,400 | -13,000 | +58,400 |
| 1948 | -17,800 | -9,600 | -1,600 | +7,900 | +11,200 | +11,600 | +12,300 | +19,900 | +18,600 | -10,700 | -25,900 | -20,500 | -4,600 |

Table 2.--Monthly and water year change in contents, in acre-feet, of Bear Lake under natural conditions.

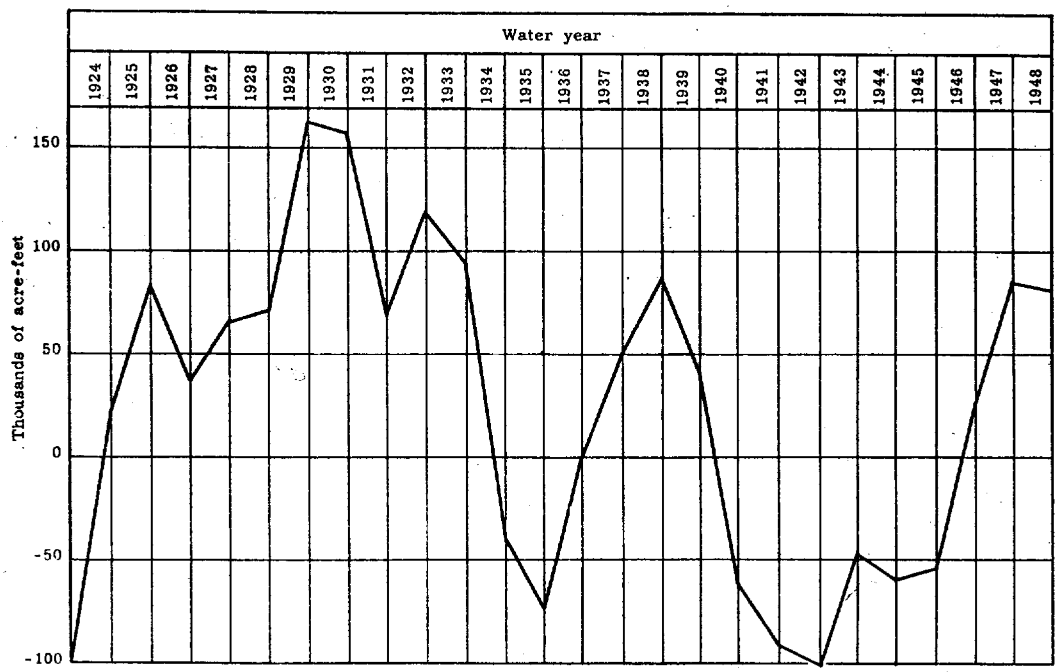


Figure 3.--Cumulative gains and losses in Bear Lake under natural conditions.

The total streamflow above Stewart Dam is indicated by the dash-dot line on Figure 2. The combined total for the winter storing period in 1947 was 120,400 acre-feet (col. 3, table 1). The shaded area below the dash-dot line indicates the maximum amount of Bear River water which could have been diverted to storage in Bear Lake during this period. The quantity of storable water represented by the shaded area is 113,000 acre-feet (col. 5, table 1). This is computed by deducting from the total streamflow above Stewart Dam the Stewart Dam diversion loss of 40 acre-feet daily, or 7,200 acre-feet (col. 4, table 1). The dotted hydrograph shows the daily quantity of water that was actually diverted and stored in Bear Lake. These daily quantities were computed by subtracting the discharge in the Outlet Canal from the combined discharges of the Rainbow and Dingle Inlet Canals when the differences were greater than zero. The area under the dotted hydrograph totals 39,800 acre-feet (col. 6, table 1) for the winter storage period. The solid-line hydrograph shows the daily quantities that were withdrawn from storage in Bear Lake. These were computed by subtracting the combined discharge of the Rainbow and Dingle Inlet Canals from the discharge of the Outlet Canal when the differences were greater than zero. The double cross-hatched area under the solid-line hydrograph represents stored water that was withdrawn from Bear Lake for power production.

High-Water Storing Period

The high water storing period in 1947 extended from April 1 to

July 7. In this period the combined total streamflow above Stewart Dam (area under dash-dot hydrograph) was 217,600 acre-feet (col. 8, table 1) of which 180,000 acre-feet (col. 9, table 1) was diverted to storage in Bear Lake (area under dotted hydrograph). In addition to these two hydrographs the hydrograph of discharge for the Bear River near Collinston gaging station is shown as a short-dash line on Figure 2. As the time interval for water to travel from Bear Lake to Cutler Dam is three days, this hydrograph is plotted three days early (day of occurrence at Collinston minus three days). Plotting in this manner eliminates the time lag and superimposes on the hydrographs of water entering the upper end of the unit, or released from Bear Lake, the hydrograph of water passing out of the lower end of the unit. Included in the Collinston hydrograph would be any water arriving from the upper end of the unit.

If all of the storable water above Stewart Dam had been diverted into storage in Bear Lake the dotted line would have been about 20 cubic-feet per second, or 40 acre-feet daily, below the dash-dot line. For the periods May 20 to May 30, June 1 to June 11, and June 18 to July 7, the dotted-line hydrograph is much more than 20 cubic-feet per second below the dash-dot line. This indicates that storable water was by-passing Bear Lake. In the first period, May 20 to May 30, and part of the last period, June 21 to July 7, the hydrograph for Bear River near Collinston drops and approaches zero. It was assumed that the water by-passing Bear Lake in these two periods represents natural-flow water that was by-passed for prior-irrigation rights. The water by-passed for prior-irrigation rights is indicated by the areas in large dots.

During the periods June 1 to 11 and June 18 to 20, when the dotted line dropped below the dash-dot line, there was sufficient inflow below Stewart Dam to fill all irrigation requirements. Water by-passing Bear Lake at these times could have been stored in the lake, but as it was by-passed when not needed for prior-irrigation rights, it was assumed to have been used for power production. The water assumed to have been used for power purposes is indicated by the shaded areas above the dotted line, and amounted to 7,800 acre-feet (col. 11, table 1). This quantity was computed for the periods indicated, by subtracting the amount actually diverted to Bear Lake from the total streamflow above Stewart Dam less the Stewart diversion loss. By adding this quantity to the quantity actually diverted to Bear Lake the total maximum storable of 187,800 acre-feet (col. 13, table 1) from Bear River was obtained.

## Release Period

Natural-flow irrigation rights for canals that divert above Cutler Dam are older in priority than any rights below Cutler Dam. These canals would divert all available natural flow water and make up the difference between available natural flow water and their irrigation requirements from stored water. If no more water was released from Bear Lake than was necessary with the natural-flow water available to fill irrigation requirements, there would be no water passing the

Cutler Dam except leakage. If more water was released from Bear Lake than required to fill irrigation requirements, or if water was released to be passed through the Cutler plant for power production, then the extra water or power water would pass out of the lower end of the river unit and be measured at the Bear River near Collinston gaging station. As power is always produced with any water that passes the dam except leakage, it follows that any amount of water, up to the limit of the amount released from Bear Lake three days earlier, that passes Cutler Dam during the release period is stored water used for power production.

If Bear Lake was operated entirely for irrigation purposes the total stored water required for this purpose would be the amount of water consumed in irrigation, the losses in delivering the stored water to the lands, and the losses in the reservoir. In treating the river between Bear Lake and Cutler Dam as a unit, all losses are taken into account except leakage loss at the last point of diversion and losses in the reservoir. The leakage loss at the last point of diversion is the Cutler diversion loss. The reservoir loss would be the evaporation loss in Bear Lake during the release period.

In 1947 the release period extended from July 8 to September 30, which is the period of time that the discharge in the Outlet Canal exceeded the combined discharges of the Rainbow and Dingle Inlet Canals. The amount of water released from Bear Lake in 1947 is indicated on Figure 3 by the solid-line hydrograph. The total amount of water represented by this hydrograph is 133,013 acre-feet (col. 23, table 1). The normal time of travel for water that is released from Bear Lake to reach Cutler Dam is three days. On Figure 3 the discharge of the Bear River at the Collinston gaging station (short-dash line) is plotted three days early, thus superimposing on the daily Bear Lake storage-release hydrograph the same water arriving at Cutler Dam.

The portion of stored water released from Bear Lake which passed Bear River near Collinston gaging station is represented by the double cross-hatched area. This area is defined by the hydrograph for Bear River near Collinston for the period July 11 (plotted 11-3 day) to August 8 (plotted 8-3 day); the hydrograph for the release from Bear Lake August 6 to August 17; the hydrograph for Bear River near Collinston August 21 (plotted 21-3 day) to September 17 (plotted 17-3 day); and the hydrograph for the release from Bear Lake September 15 to September 30. The amount of water released from Bear Lake that passed the Collinston gaging station (col. 24, table 3) is summarized as follows:

| Gaging station | Period | Acre-feet |
|---|---|---|
| Bear River near Collinston. . . . | July 11 to Aug. 8 | 16,221 |
| Bear Lake storage release . . . | Aug. 6 to Aug. 17 | 18,363 |
| Bear River near Collinston . . . | Aug. 21 to Sept. 17 | 34,034 |
| Bear Lake storage release . . . | Sept. 15 to Sept. 30 | 12,038 |
| Total . . . . . . | | 80,656 |

The apparent amount of water released from Bear Lake that was used for irrigation is represented by the single hatched area on Figure 2. This is the area under the hydrograph of water released from Bear Lake in excess of the amount of Bear Lake released water that passed the Collinston gaging station. By deducting the amount of stored water passing the Collinston gaging station from the total water released from Bear Lake the apparent amount of stored water used for irrigation is obtained. This amounted to 52, 357 acre-feet (col. 25, Table 1) in 1947.

In these computations the Cutler diversion loss is included in the computed amount of Bear Lake water passing the Collinston gaging station and excluded from apparent amount of Bear Lake water used for irrigation. To obtain the quantity of water used in power production the Cutler Dam diversion loss must be deducted from the amount of Bear Lake water passing the Collinston gaging station. In 1947 the irrigation-storage release period was 85 days. This number of days multiplied by the average daily diversion loss of 45 acre-feet gives a total diversion loss of 3, 825 acre-feet (col. 26, table 1). Deducting this from the 80, 656 acre-feet of stored water that passed the Collinston gaging station gives 76, 800 acre-feet (col. 28, table 1) as the amount of water used in power production. The 76, 831 acre-feet by actual subtration is rounded off to 76, 800 acre-feet in Table 1.

The total storage requirement for irrigation is the sum of the Cutler diversion loss of 3, 825 acre-feet, (col. 26, table 1), the Bear Lake evaporation loss of 25, 630 acre-feet (col. 27, table 1), and the apparent Bear Lake storage used for irrigation of 52, 357 acre-feet.

These total 81,800 acre-feet (col. 29, table 1). The actual total of 81,831 acre feet is rounded off to 81,800 acre feet in Table 1.

Summary of 1947 Water Year

Answers to the four questions set up for the segregation study for the 1947 water year are contained on Table 1.

The maximum storable water in Bear Lake Reservoir in 1947 was 385,100 acre feet (col. 19, table 1). Of this 301,000 acre-feet (col. 18, table 1) would have come from Bear River and 84,100 acre-feet (col. 17, table 1) from Bear Lake tributary inflow. During the irrigation season the irrigation stored water requirement was 81,800 acre-feet (col. 29, table 1). In this year the maximum storable water exceeded the irrigation stored water requirement by 303,300 acre-feet (col. 30, table 1).

The total Bear Lake stored and storable water used for power production during the 1947 water year is the sum of stored water used for power production during the release period and the storable water used for power production during the storing period. This quantity totalled 158,700 acre-feet (col. 32, table 1) for the 1947 water year.

## CONCLUSIONS

Because of the assumptions and factors involved in the simplified segregation study the derived data summarized on Table 1 can be regarded only as reasonably accurate approximations. In view of the magnitude of the problem the data is considered to be sufficiently accurate to warrant its use in supplying information on the adequacy of Bear Lake storable supplies and historical uses of Bear Lake storage for irrigation and power-production purposes.

On page 11 four basic questions were listed outlining the information needed to be derived from the segregation study. Answers to these questions are contained in the summary data on Table 1. On the following pages the quantities of water pertinent to the basic questions are graphically illustrated and discussed. A computation is also made of the amount of Bear Lake storage that should be reserved for irrigation purposes. On the assumption that the irrigation water users, dependent on Bear Lake for stored water, should be fully protected against overdraft on the reservoir for power production this computation includes an estimated amount of additional storage equal to the estimated deficiency in stored water supply that occurred in 1935. If the compact makes provision for additional storage upstream from Bear Lake the irrigation reserve should be increased to offset the increased depletion in Bear Lake storable supplies that would result from additional upstream storage.

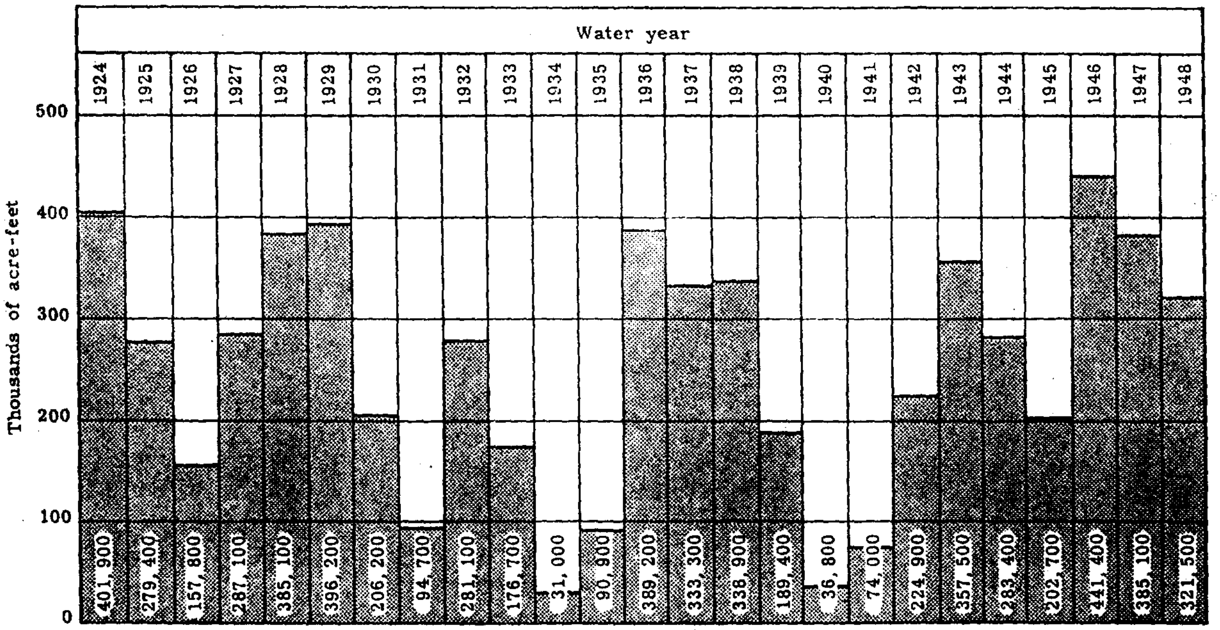


Figure 4.--Maximum amounts of storable water in Bear Lake.

In Figure 4 are shown the computed maximum amounts of water (col. 19, table 1) that could have been accumulated in Bear Lake during each storing period, if the reservoir had been operated entirely for irrigation purposes. The amounts of storable water have ranged from 31,000 to 441,000 acre-feet. The annual average for the 25-year period is 254,000 acre-feet. A reservoir with a detention capacity of about 3.1 times the average annual storable supply would be required to equate the annual reservoir yield to the average annual storable supply of water. The capacity of Bear Lake is more than ample for this purpose as the usable capacity is 5.58 times the computed average annual storable supply.

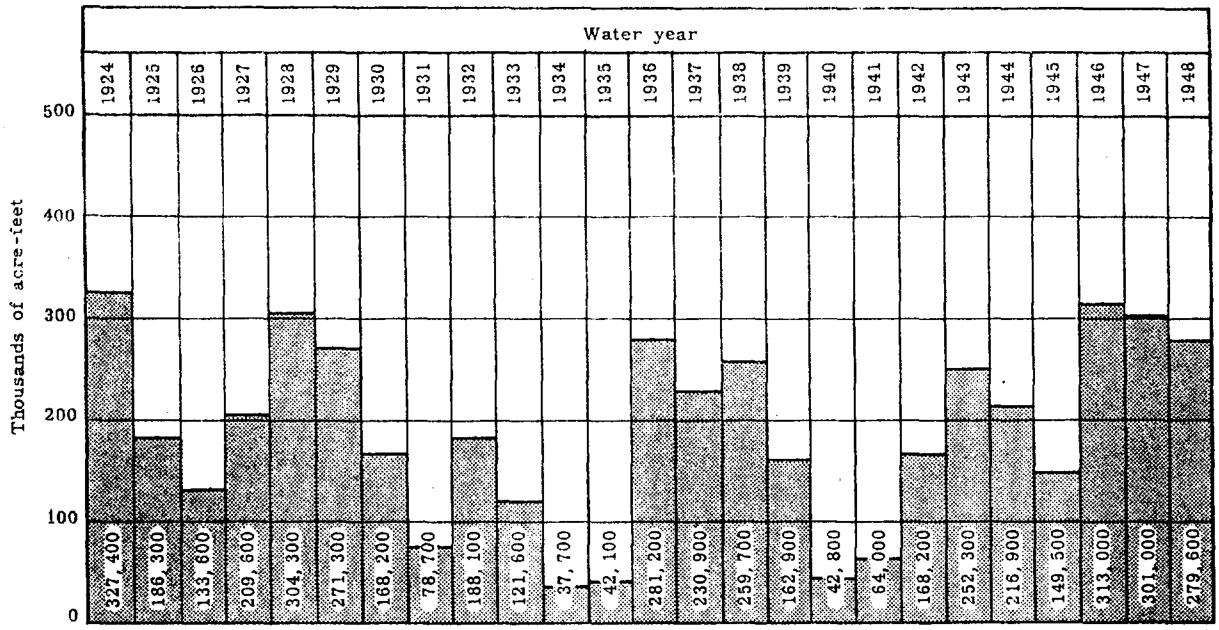


Figure 5.--Maximum amounts of storable water in Bear Lake from Bear River.

In Figure 5 are shown the computed maximum amounts of water (col. 18, table 1) that could have been diverted from Bear River and stored in Bear Lake during each storing period, if the reservoir had been operated entirely for irrigation purposes. The storable quantities have varied from a minimum of 37,700 acre-feet to a maximum of 327,400 acre-feet, the 25 year average being 191,600 acre feet. Bear River could have yielded substantial annual storable supplies except in 1931, 1934, 1935, 1940, and 1941. Low storable supplies in these years indicate that storable supplies at any potential reservoir site upstream from Stewart Dam would also be limited.

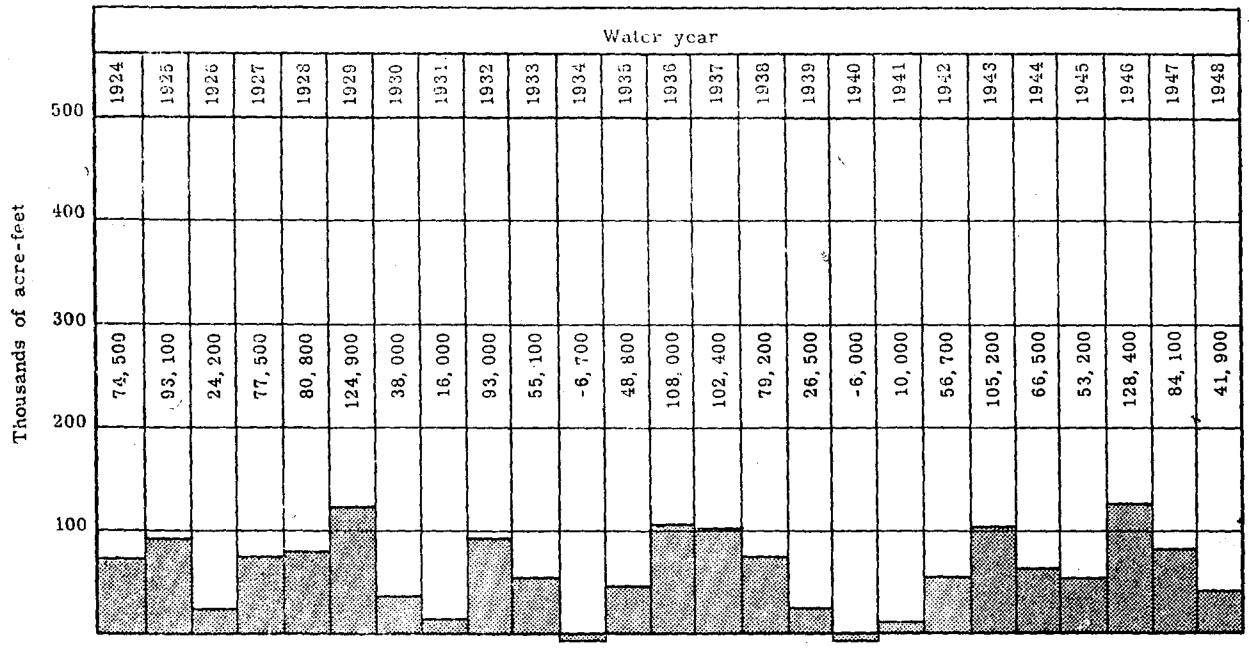


Figure 6.--Maximum amounts of storable water in Bear Lake from tributary inflow.

Figure 6 shows the computed amounts of water (col. 17, table 1) that would have accumulated in Bear Lake during each storing period from tributary inflow if no water had been released from the reservoir or diverted into the reservoir from Bear River during the storing period. The quantities that would have accumulated, in the storing periods, have varied from a net loss of 6,700 acre-feet to a net maximum of 128,400 acre-feet and averaged 63,000 acre-feet for the 25-year period. In the two years of lowest run-off the losses due to evaporation from the reservoir's surface during the storing period, exceeded the tributary inflow.

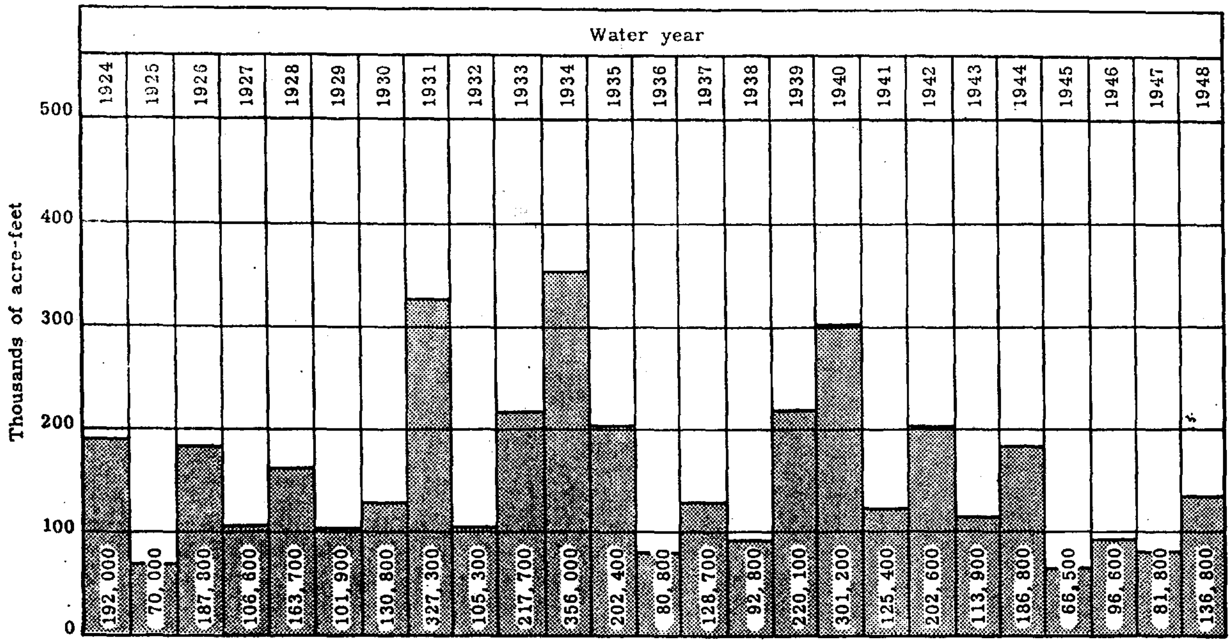


Figure 7.--Irrigation stored water requirements of lands below Bear Lake.

Figure 7 shows the computed annual stored water requirements for irrigation (col. 29, table 1) of lands dependent on Bear Lake for supplemental irrigation water. These computed quantities are based on the assumption that Bear Lake was used entirely for irrigation purposes. In all years, available stored water was adequate to meet irrigation requirements, except in 1935 when the supply of stored water was completely depleted before the end of the irrigation season. Water users who are dependent on Bear Lake for stored water have estimated that as much as 100,000 acre-feet more stored water would have been used for irrigation purposes in 1935 had it been available.

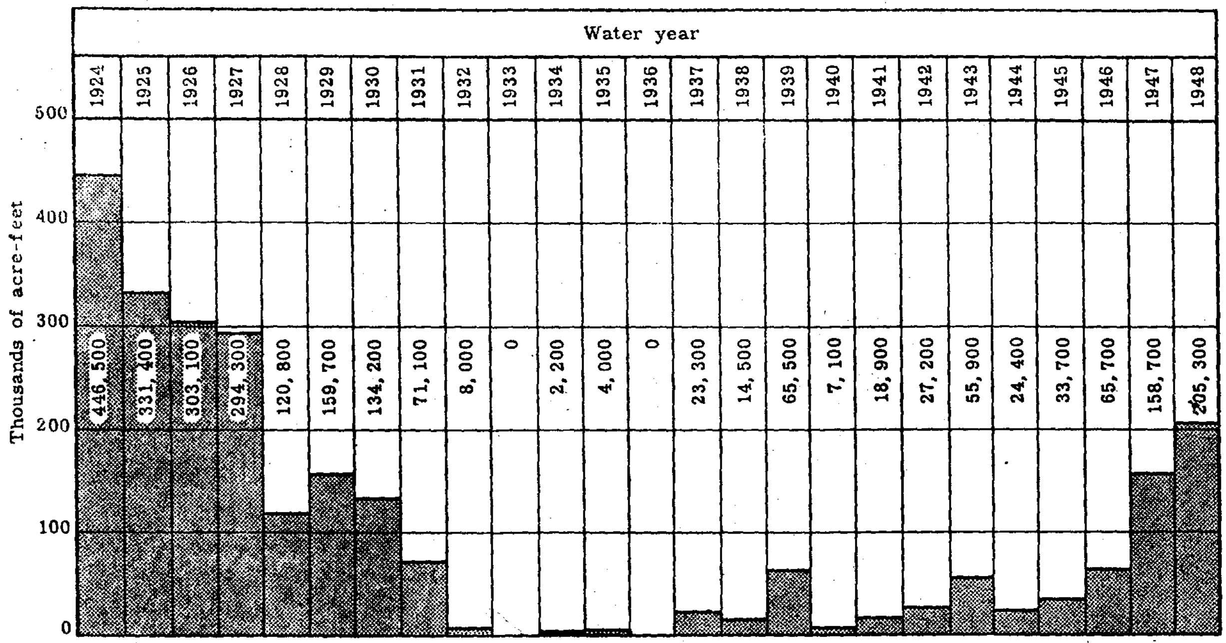


**Figure 8.**--Bear Lake stored and storable water used in power production at Cutler power plant.

Figure 8 shows the annual quantities of Bear Lake stored and storable water (col. 32, table 1) computed to have been passed through the Cutler Power Plant for the production of electric power. Before the drought years large quantities of water were used for power purposes. Continuance of the high draft on stored water for power production in the early part of the drought period depleted the reservoir to a point that the stored supply of water in the last year of the drought was not sufficient to meet irrigation demands.

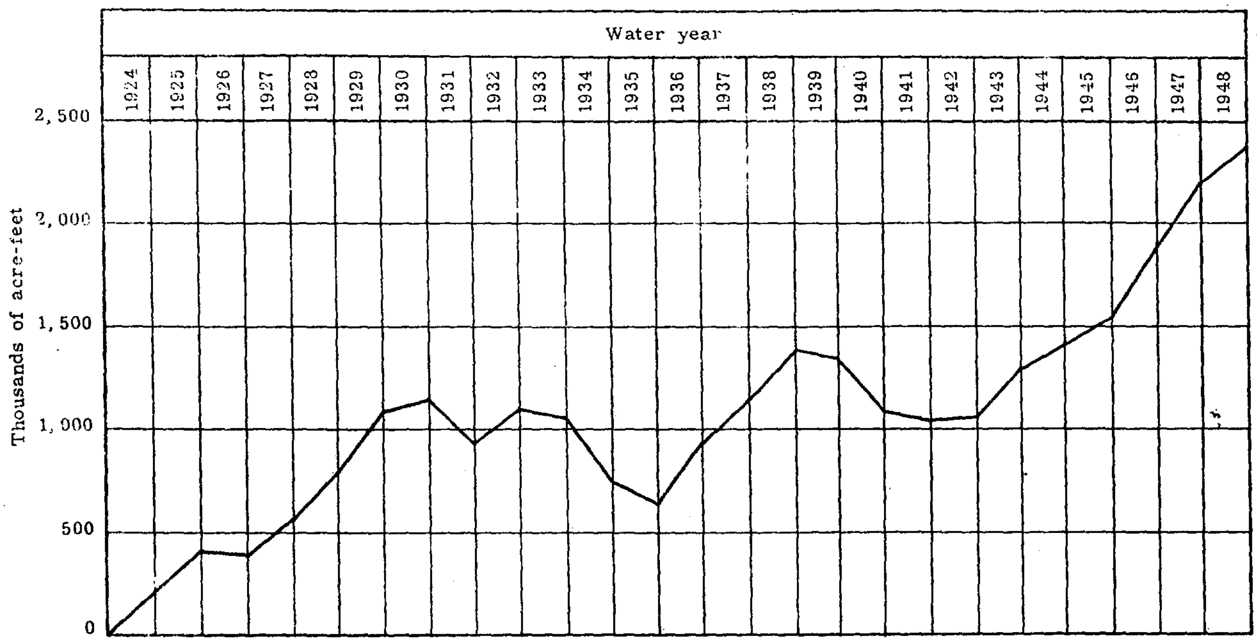


Figure 9.--Cumulative Bear Lake storable water in excess of irrigation stored water requirement.

Figure 9 shows the accumulative excess of annual Bear Lake storable water supplies over annual storage requirements for irrigation, beginning with zero storage on October 1, 1923 (col. 31, table 1). The period 1931 through 1935 was the most severe period of drought in the 25-year period as shown by the graph. The decline in the graph during this period is indicative of the quantity of water that should be reserved in Bear Lake for irrigation. The amount that should be reserved in the reservoir would be the amount that the irrigation requirements, beginning May 22, 1930 and ending September 30, 1935, exceeded the total storable supplies, plus the estimated 100,000 acre-feet shortage of stored water in

1935. The following table shows the extent that irrigation requirements for the indicated period exceeded the storable water:

| Water Year | Maximum Storable Water (acre-feet) | Irrigation Requirement (acre-feet) |
|---|---|---|
| 1930 | - | 130, 800 |
| 1931 | 94, 700 | 327, 300 |
| 1932 | 281, 100 | 105, 300 |
| 1933 | 176, 700 | 217, 700 |
| 1934 | 31, 000 | 356, 000 |
| 1935 | 90, 900 | 302, 400 (a) |
| Total | 674, 400 | 1, 439, 500 |

(a) Includes estimated 100, 000 acre feet shortage in 1935.

The irrigation requirement exceeded the total storable supply by 765, 100 acre-feet. From this the following are indicated: whenever the stored water in Bear Lake Reservoir drops below about 765, 100 acre-feet all stored and storable waters should be reserved for irrigation purposes; and, whenever the stored water in the reservoir is less than this amount, water should not be released from the reservoir for the purpose of producing power at the Cutler Power Plant.