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Irrigation Water Management Potential in the Bear River Delta

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IRRIGATION WATER MANAGEMENT POTENTIAL IN THE BEAR RIVER DELTA

by

Tom Al Austin

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil Engineering

Approved:

Thesis Director

Major Professor

Committee Member

Dean of Graduate Studies

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A very special thanks is expressed to my wife, Loretta, who constantly encouraged me throughout this project. Her cheerful attitude and willingness to assist was a continual encouragement thoughout my studies.

Tom Al Austin

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ABSTRACT

Irrigation Water Management Potential in the Bear River Delta

by

Tom Al Austin

Major Professor: Frank W. Haws
Department: Civil Engineering

The purposes of this study were to evaluate the present irrigation efficiencies of the Bear River delta area of northern Utah and to propose a set of management proposals to improve the irrigation efficiency. In order to evaluate the present use, all pertinent data on the water resources of the Bear River delta had to be assembled and analyzed.

A hydrologic budget is a method used to account for all inflows, outflows, and changes in storage within a given area. In this study, all inflows and changes in storage were evaluated and the outflow was predicted. In this manner the management proposals could be tested to determine their effect on the outflow. The time base used in the budget analysis was chosen as monthly over the period 1931 - 1960. The mean annual outflow from the delta area to the Great Salt Lake was estimated to be 891,000 acre feet as surface outflow and 27,500 acre feet as groundwater outflow.

Irrigation requirement can be defined as the volume of water, measured at the point of diversion, required to meet crop potential consumptive uses. Irrigation requirement is a function of the system efficiency and includes the water "lost" from the conveyance and storage facilities. When compared to the present mean cropland diversions, a deficit or surplus water supply exists. These parameters were evaluated for both the present and the future estimated irrigation system efficiencies.

The present irrigation efficiency was estimated from potential consumptive use data and seepage loss data from surrounding areas. The present system efficiency was estimated to be 44 percent but with the implementation of the outlined general set of management proposals, the system efficiency was estimated to be increased to 62 percent. These management proposals result in an adequate water supply for all crop needs under the present cropland diversions, assuming adequate additional storage could be provided to redistribute the water to coincide with the demands. Under the present irrigation efficiency, the crop requirements are only being partially met.

It was estimated from the estimated future system efficiency, irrigation requirements, and the mean cropland diversions that water is available for export. The mean annual quantity of water available for export was estimated to be 630,000 acre feet. Most of this water is available for export during the non-growth months which requires large storage facilities at the points of useage. Further investigation is needed to determine the effect of this exportation on the ecology of the Great Salt Lake and the surrounding marsh lands.

(127 pages)

NOMENCLATURE

Symbol	Defination
AGW	Addition to ground water.
AIR	Annual irrigation requirement.
ASMS	Accumulated soil moisture storage.
ASR or ADEF	Annual surplus or deficit excluding root zone storage.
AWLSM	Accumulated wetland soil moisture storage.
CD	Cropland diversions.
DEF or SR	Monthly deficit or surplus excluding root zone storage.
DRES	Change in reservoir storage.
DWRZ	Diverted water to root zone.
EMI	Municipal and industrial uses.
EVAPO	Water surface evaporation.
EXPO	Exports.
GWIN	Ground water inflow.
GWOF	Ground water outflow.
GWRT	Ground water return flow.
GWTS	Ground water to surface.
MIR	Monthly irrigation requirement.
PAIR	Percent of annual irrigation requirement satisfied.
PCL	Precipitation on croplands.
PMIR	Percent of monthly irrigation requirement satisfied.

CHAPTER I

INTRODUCTION

General

Today's increasing resource demands have forced more and more emphasis to be placed on obtaining the most efficient uses of the valuable and often irreplaceable resources available. This re-evaluation of resource use is not limited to water resources alone; however, the water supply shortage in the western United States has probably been instrumental in increasing public reaction to the wasteful uses of all our valuable resources.

With the advent of such forward looking projects as the California Water Plan and the proposed Texas Water Plan, the emphasis on long range planning and resource management has been sharpened. However, a first step in any long range resource management scheme is the evaluation of present uses and the present efficiency of these uses. This study evaluates the irrigation water uses and the present efficiency of use for the Bear River delta area of northern Utah.

Irrigation system efficiency can be defined as the ratio of the quantity of water actually consumed by the crops to the total quantity diverted for irrigation. Irrigation system efficiency will not nor should not be equal to one. Conveyance losses, evaporation, phreatophyte evapotranspiration, application losses, operational waste, and water applied in excess of crop requirements to leach salts from the root zone all dictate the total quantity of water diverted must exceed the crop requirements. These losses are not losses to the system as a whole, because this water enters other phases of the hydrologic cycle such as groundwater, atmospheric water vapor, or return flows.

In the arid and semiarid western states, irrigation has become vital to the economy. Competition for the use of the limited water resource has forced the management and efficient use of the water available. In the Great Basin and the Colorado River Basin alone, more than 90 percent of the water diverted is used for irrigation. (U. S. Congress, 1960a, Figure 6, p 5) This fact indicates the importance of efficient irrigation water management of the water resources of the western United States.

Purpose

The purposes of this study were to: 1. evaluate the present irrigation system efficiency of the Bear River delta area of northern Utah, and 2. outline a set of management proposals for improving the irrigation water uses. In order to evaluate the irrigation system efficiency, all pertinent data on the water resources of the delta area had to be collected and analyzed.

The hydrologic equation of continuity states the sum of all inflow items into a given area for a particular time period minus the sum of all outflow items from the area must equal the change in storage within the area. This basic principle formed the nucleus of the hydrologic budget model developed for the Bear River delta. Each component of inflow and storage was evaluated and a predicted outflow was generated. The responses of the model to changes in management parameters such as inflow and storage items could easily be measured in terms of the generated outflows. This analysis provided a means of evaluating the management proposals.

Scope

This study covered only the technical aspects of improving irrigation system efficiency. The author realizes that this type of analysis alone is limited in use, because it does not consider the institutional, political, and economic aspects of water management or the interactions between all of these parameters. Evaluation of these parameters is difficult and was beyond the scope of this thesis.

The proposed management schemes for the Bear River delta are presented primarily to illustrate the methodology and usefullness of a hydrologic model as a management tool. Efficient utilization of the water of the Bear River can be accomplished only through an integrated total basin approach to water management.

CHAPTER II

DESCRIPTION OF THE STUDY AREA

Geographical Location

The Bear River drainage area is located in northern Utah, western Wyoming, and southeastern Idaho. (Figure 1) The drainage area is subdivided into twenty-one subareas of which the Bear River delta is subarea twenty. (Figure 1)

The Bear River delta extends from Cutler Dam on the north to the northern edge of the Great Salt Lake on the south. (Figure 2) The delta area extends basically in a north-south direction and is approximately 35 miles long and varies in width from 10 to 30 miles. The area is bounded on the east and west sides by mountains which rise some 2000 to 5000 feet above the valley floor. The valley floor is relatively smooth and slopes gently from north to south, toward the Great Salt Lake.

Figure 2 shows the municipalities that are located within the delta area. The largest of these municipalities is Brigham City, Utah, with an approximate population of 13,000.

The economy of the delta area is based largely on agriculture with alfalfa, small grains, corn, sugar beets, and orchards being the major crops grown within the area. The delta contains approximately 600,000 acres of land area with approximately 92,800 acres of irrigated cropland and approximately 123,100 acres of dryland crops. The remainder of the land area is either non-crop lands,

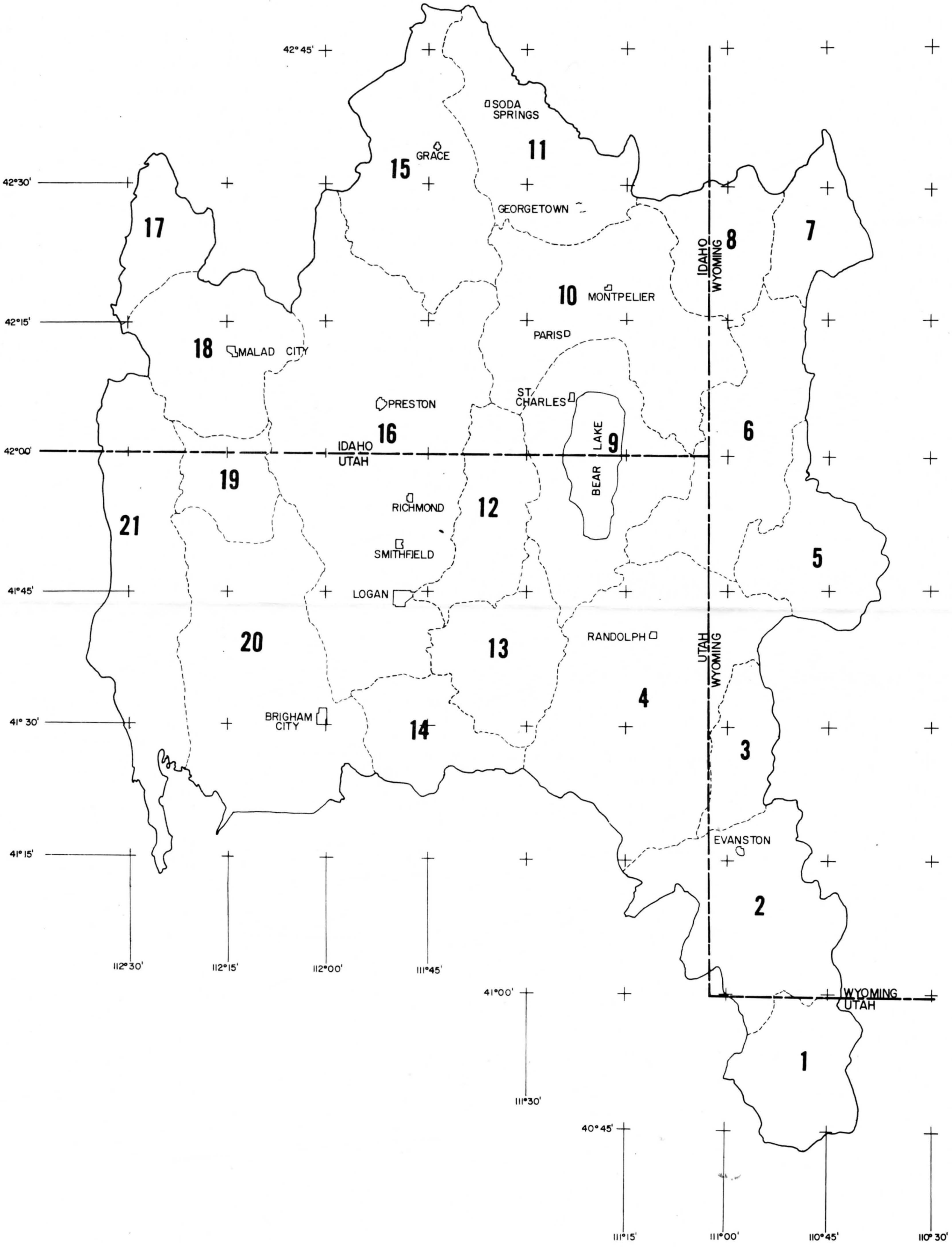


Figure 1. Hydrologic subareas of the Bear River drainage area.

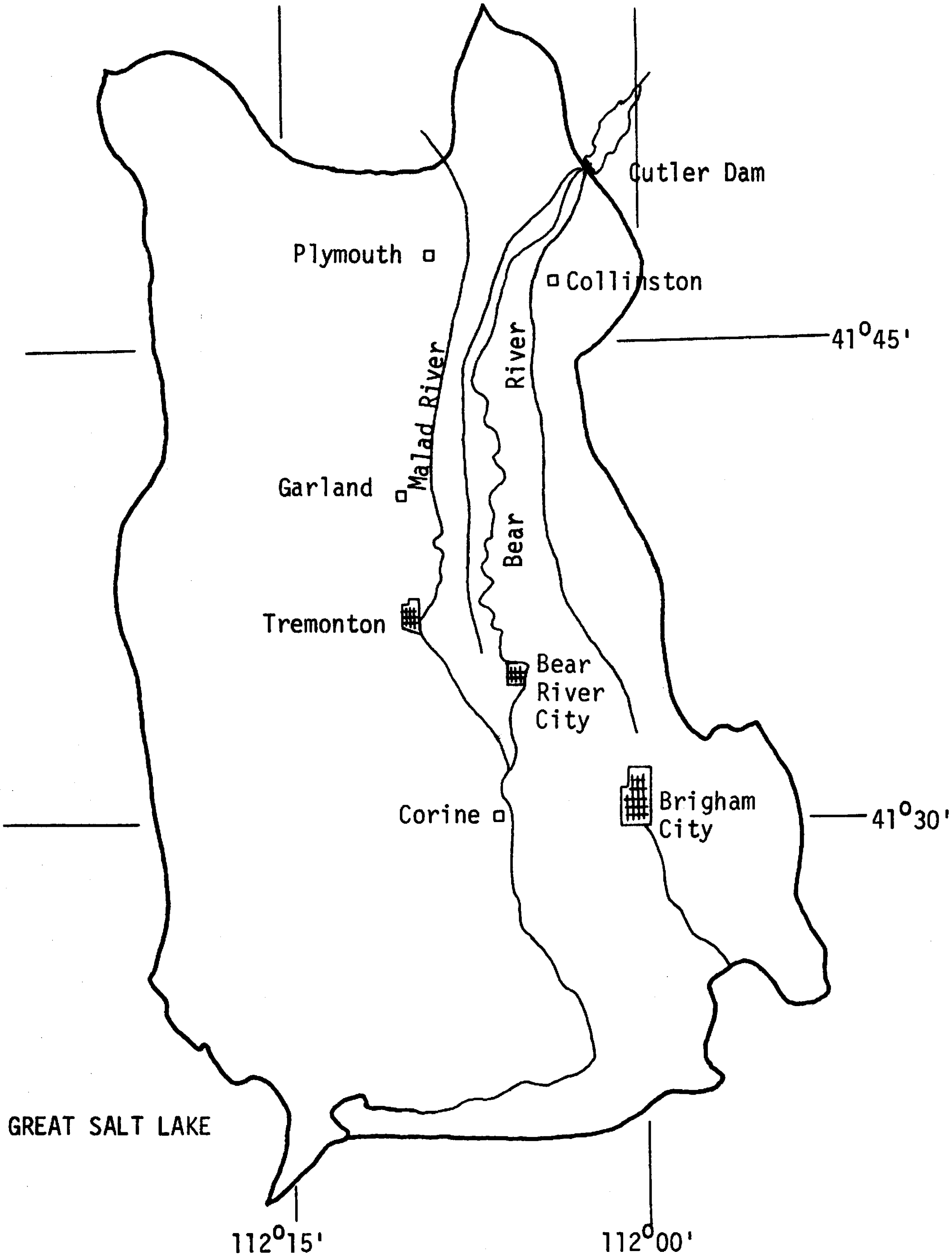


Figure 2. Bear River delta of northern Utah.

water surface, or native grasslands. Much of the lowlands surrounding the Great Salt Lake is swampy marshes with high water tables and high consumptive use requirements.

Climate

The climate of the delta area can be classified as semiarid with moderate temperatures. An area is classified as semiarid if the mean annual precipitation is greater than 10 inches but less than 20 inches. (Thorne and Peterson, 1954, p 3) The area is characterized by relatively low precipitation, low humidity, high evaporation and evapotranspiration rates. Much of the valley floor and mountain slopes is vegetated with native grasses and sagebrush. In the higher elevations, the dominate types of vegetation are native grasses, sagebrush, greasewood, saltbrush, juniper, and aspen.

A large portion of the southern delta area is swampy marshes and mud flats. Very little cropland is available in this part of the study area because of the waterlogged condition of the soil. The major type of vegetation in this area is high water table grasses and native phreatophytes. The consumptive use rate for this portion of the delta is very high in comparison to the consumptive use rate for the crops.

Precipitation

The precipitation in the delta area varied from more than 35 inches on the mountain peaks to less than 15 inches on the valley floor for the study period 1931 - 1960. The mean annual precipitation on the valley floor of the delta is approximately 13.7 inches.

A substantial percentage of the precipitation which falls on the area occurs during the winter months in the form of snow. Precipitation during the growing season varies greatly but as a general rule, it tends to decrease as the growing season progresses. The minimum mean monthly precipitation occurs during the months of July and August, when the potential consumptive use requirements of the crops are a maximum.

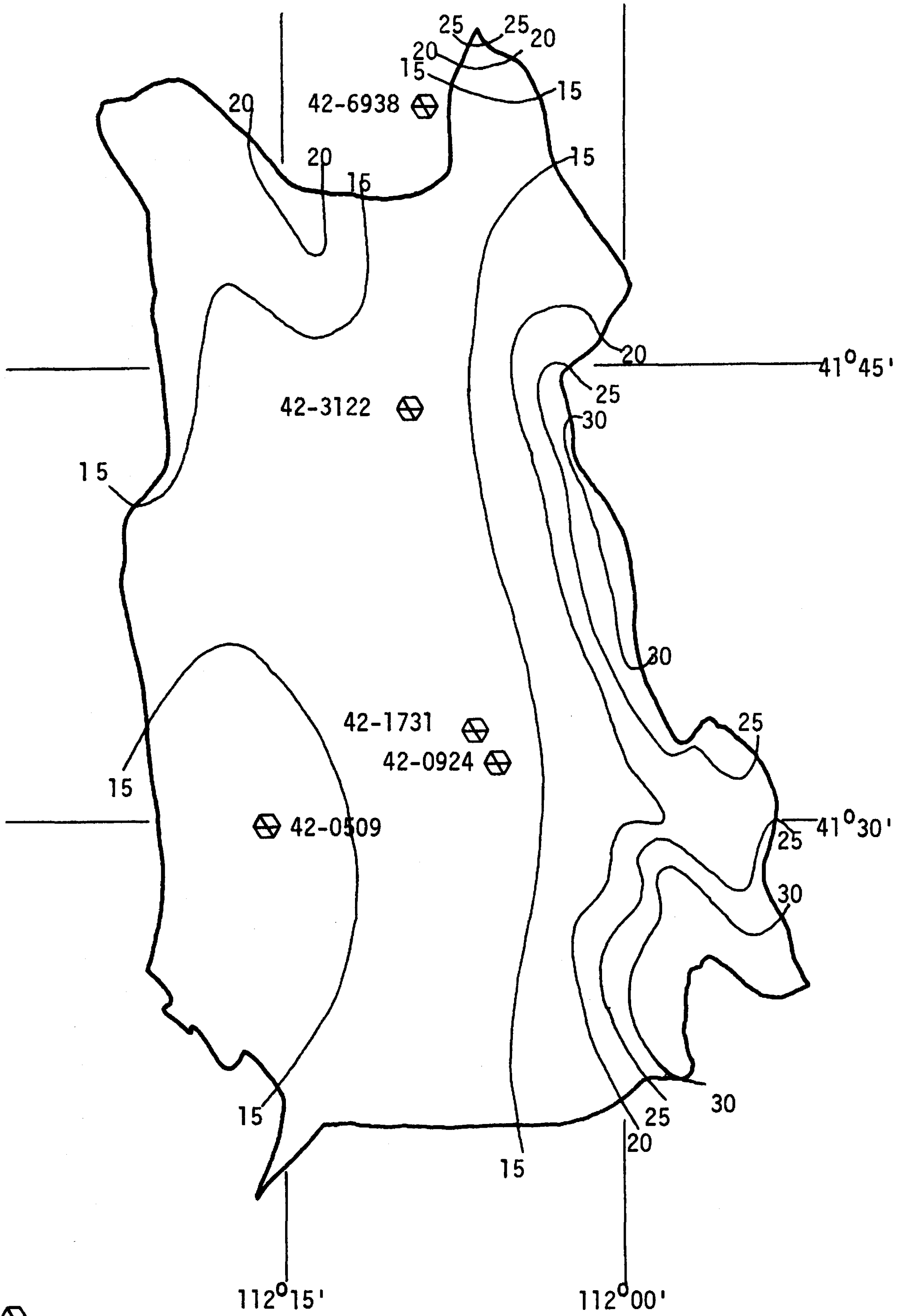
Figure 3 is an isohyetal map of the delta area showing the contours of equal mean annual precipitation depths in inches for the study period. The physiographic effects on the precipitation patterns can easily be seen from this map.

Temperature

In general the temperature of any area varies with altitude and latitude. Lapse rate can be defined as the decrease in the mean annual temperature for each additional 1000 feet increase in the altitude. In general it has been shown that for northern Utah the average annual lapse rate is approximately 3 F per 1000 feet increase in altitude.(Bagley, ed., 1963, p 5-7)

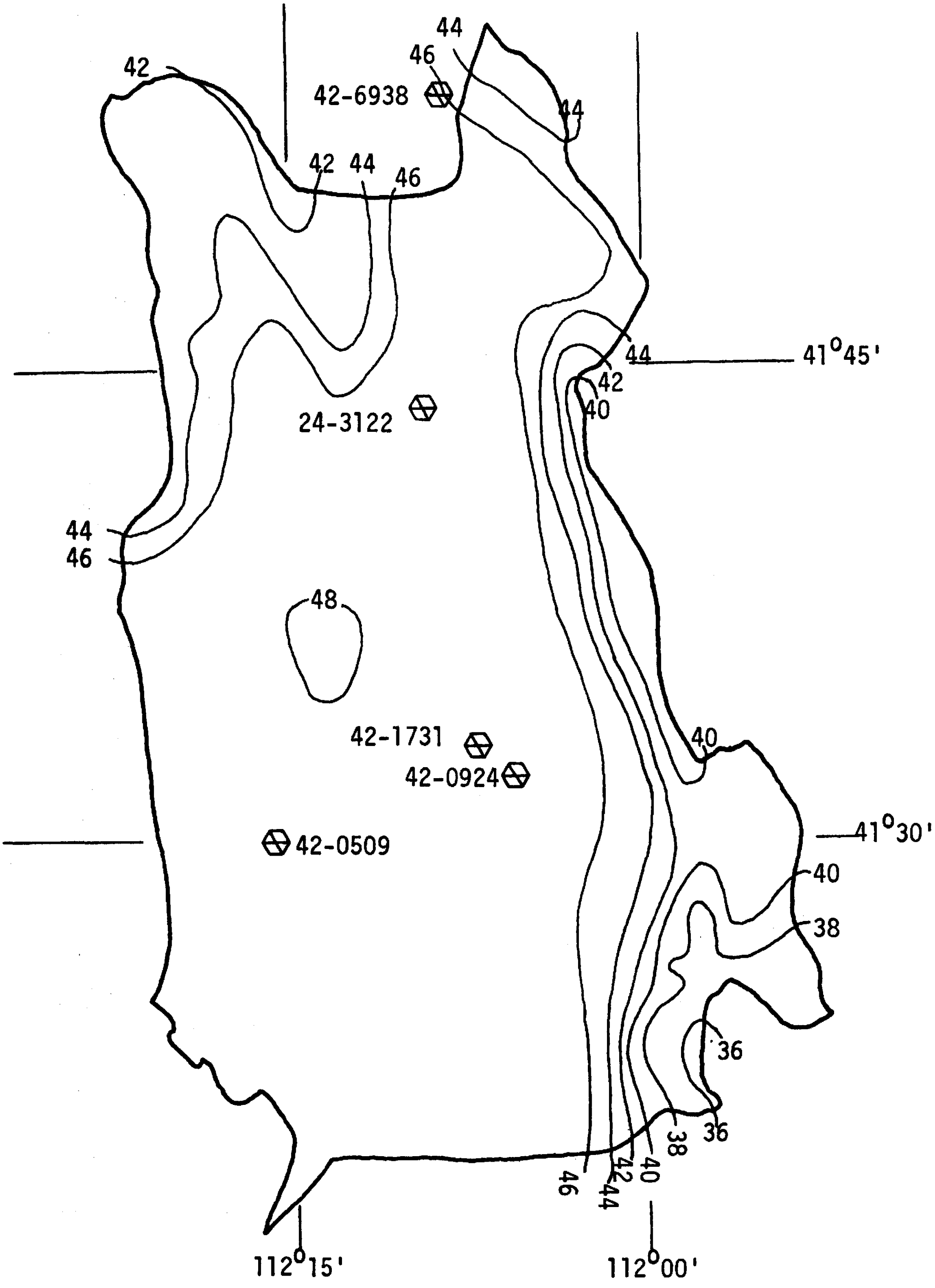
Latitude also has an effect on the mean annual temperature of an area. In general it has been shown that for northern Utah the effect of latitude is approximately 2 F decrease in the mean annual temperature for each one degree increase in latitude.(Bagley, ed., 1963, p 5-7)

The mean annual temperature of the Bear River delta is approximately



⊕ Precipitation and Temperature station.

Figure 3. Isohyetal map of the Bear River delta showing mean annual precipitation depths in inches for the study period 1931-1960.



⊕ Precipitation and Temperature stations.

Figure 4. Isothermal map of the Bear River delta showing mean annual temperature in degrees Fahrenheit for the study period 1931-1960.

46 F. This mean annual temperature varies from a low of 45 F in the northern parts of the area to a high of 48 F in the south.

Figure 4 is an isothermal map for the delta area showing contours of equal mean annual temperature for the study period.

Growing Season

For this study, the length of the growing season was defined as the number of days between the last day in the spring and the first day in the fall when the temperature falls below 28 F.

The length of the growing season for the delta area varies from 190 days at the lower elevations on the valley floor to 170 days at the higher elevations on the bench areas. The mean growing season for Corinne, Utah, is 181 days between April 24 and October 15. (Ashcroft and Derksen, 1963, p 16-17) This growing period is sufficiently long to permit most agricultural crops to be grown within the area.

As previously stated, the mean annual temperature varies with latitude and altitude; therefore, the length of the growing season will also vary with latitude and altitude, with altitude playing the dominant role in the delta area. For this reason, the length of the growing season is shorter for the bench areas than the valley floor.

The integrated average length of the growing season for the delta area is approximately 180 days.

Hydrology

Streamflow

The Bear River delta is drained by two major rivers, the Bear

River and the Malad River, with the Bear River being by far the larger of the two. Several smaller streams help drain the area; however, most of these streams are ungaged or have only limited periods of record.

Bear River. The Bear River is the largest river flowing into the Great Salt Lake with a mean annual flow of approximately one million acre feet. It drains approximately 6,600 square miles of mountain and valley lands in the northeastern part of the Great Salt Lake Basin. The river has its beginnings on the northern slopes of the Unita Mountains in northeastern Utah, about 80 miles east of the Great Salt Lake; however, it flows nearly 500 miles, winding its way through three states before it empties into the Great Salt Lake.

The U. S. Geological Survey has established a good streamflow gaging network on the Bear River. One of the U. S. Geological Survey streamflow gages is located near Collinston, Utah. The quality of the data from this gage is considered excellent with continuous records from 1889 to the present. This gage is located immediately below two major diversions, Hammond East Side Canal and Hammond West Side Canal. Therefore, to determine the actual flow of the Bear River near Collinston, the combined flows of these two diversions must be added to the recorded flow of the Bear River.

Malad River. The Malad River rises in the northern end of the Blue Spring Mountains, northwest of Malad City, Idaho. The U. S. Geological Survey presently maintains two gaging stations on this river. The gaging station near Woodruff, Idaho, has complete records from 1939 to 1960. The quality of these records is good

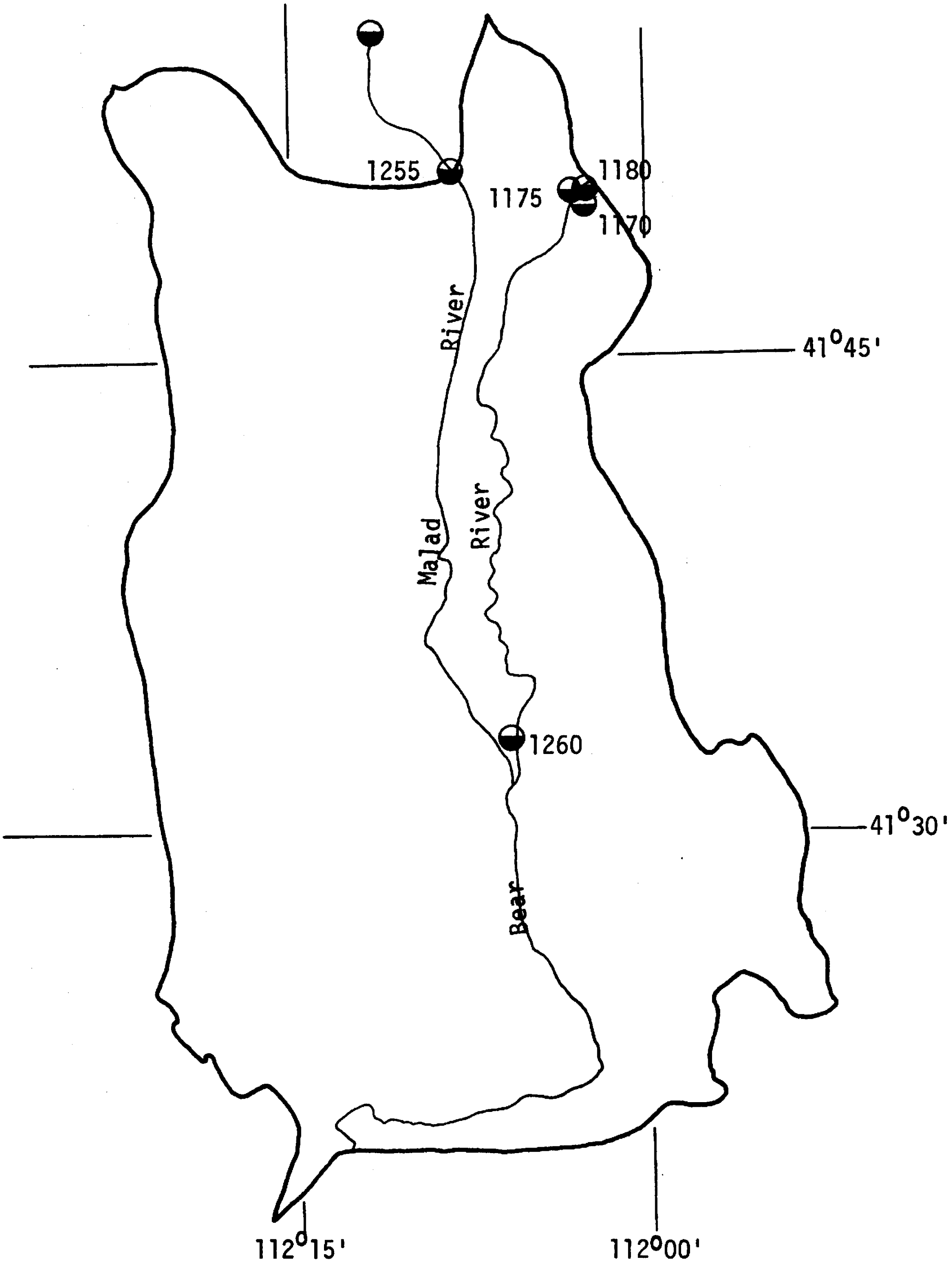


Figure 5. Location of U. S. Geological Survey streamflow gages in the Bear River delta.

during the summer months and fair during the winter months and periods of ice. The second gage on the Malad River is located near Plymouth, Utah. This gage was established in 1964 and is located on the northwestern boundry of the delta area.

A monthly regression analysis between the gages at Woodruff, Idaho, and Plymouth, Utah, was prepared by Hsieh. (Hsieh, 1965, p 69-70) The results of this analysis indicated little significant inflow into the Malad River between these two gaging stations; therefore, the records from the gage at Woodruff, Idaho, was used in this study.

Since the data from the gaging station at Woodruff was to be used, it was necessary to generate streamflow data for this station for the nine years of missing record, namely 1931-1939. Therefore, a computer program was written to correlate the monthly streamflow records from the gage at Woodruff with the Bear River flow at Collinston. Straight line and log-log transformations were used in this analysis. The log-log transformation resulted in the highest correlation coefficient, r, equal to 0.896. Table 1 shows a summary of the results of this regression analysis for the annual flows. The missing data was obtained using the monthly regression equations developed above.

Ungaged Streams and Springs. The small, largely intermittent streams that enter the Bear River rise in the Wellsville and Blue Spring Mountains surrounding the delta area. These streams flow during the spring runoff and periods of high intensity rainfall but have little or no flow during the dry summer months. As a general rule these streams are ungaged or have only short, intermittent periods of record.

Table 1. Regression Analysis of Malad River near Woodruff, Idaho, on the Bear River near Collinston, Utah.

R	0.828	0.857	0.870	0.776	0.780	0.639	0.867	0.885	0.855	0.810	0.670	0.869	
A	1.260	0.028	0.169	0.047	0.004	0.000	0.006	0.873	24.169	56.326	78.113	126.666	
B	0.671	1.051	0.898	1.011	1.244	2.175	1.163	0.702	0.394	0.317	0.279	0.223	
WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
*1931	2039.	3207.	3392.	3311.	4073.	3407.	3229.	1410.	912.	1063.	1029.	975.	28045.
*1932	793.	1656.	2515.	2347.	3143.	8797.	7386.	4655.	2200.	1263.	1054.	1131.	36939.
*1933	1361.	2152.	2937.	2772.	3150.	4968.	4785.	3599.	1775.	1077.	1039.	983.	30599.
*1934	1347.	2124.	3304.	3042.	4101.	3784.	3545.	1530.	1230.	1055.	1018.	1027.	27106.
*1935	1584.	2070.	2444.	2993.	3098.	4822.	2790.	2470.	1649.	1053.	1019.	1026.	27017.
*1936	1088.	1908.	2222.	2716.	4326.	3935.	9509.	5183.	2137.	1052.	1020.	1026.	36123.
*1937	1735.	3190.	3349.	2970.	3759.	11826.	5739.	3974.	1689.	1197.	1014.	967.	41408.
*1938	1893.	2530.	3799.	3130.	4753.	8119.	6946.	4206.	1580.	1473.	1015.	1020.	40464.
*1939	1940.	4298.	4361.	3180.	3946.	11028.	4324.	1899.	921.	1052.	1018.	1270.	39236.
1940	1920.	2280.	2950.	4680.	6860.	5140.	4100.	1490.	1070.	1020.	1070.	1150.	33730.
1941	1830.	2830.	3230.	3100.	7710.	7960.	6300.	2940.	1630.	1100.	2170.	1340.	42140.
1942	1920.	3510.	3940.	3650.	3740.	8740.	9520.	6070.	2040.	1400.	1220.	1260.	47010.
1943	1560.	3720.	4620.	7680.	6330.	9080.	8360.	3210.	3110.	1530.	1380.	1230.	51810.
1944	1790.	3740.	4520.	3760.	5270.	9600.	5250.	2800.	3540.	1390.	1270.	1070.	44000.
1945	1590.	3500.	3330.	4170.	10010.	6990.	5630.	3360.	5310.	1710.	1720.	1670.	48990.
1946	3120.	5670.	7370.	5560.	5140.	15330.	11470.	4190.	1740.	1420.	1420.	1520.	63950.
1947	3130.	5920.	7020.	4300.	8430.	8810.	4990.	2170.	1990.	1420.	1370.	1640.	51190.
1948	3050.	4860.	4930.	4090.	10260.	9420.	10410.	4900.	1670.	1420.	1280.	1290.	57580.
1949	1640.	2920.	3440.	3490.	3480.	13130.	5270.	3970.	1620.	1410.	1330.	1320.	43020.
1950	2820.	4100.	3630.	5870.	7170.	9960.	6740.	7030.	2540.	1830.	1580.	1500.	54770.
1951	2960.	5020.	6910.	4600.	9270.	9910.	7350.	5880.	1700.	1740.	1630.	1740.	58710.
1952	3300.	4970.	4920.	5750.	5730.	8170.	16670.	5450.	1940.	2050.	2480.	1530.	62960.
1953	2310.	4760.	6030.	9210.	6730.	6360.	4950.	2940.	2430.	1610.	1340.	1260.	49930.
1954	1890.	2900.	3510.	3670.	5350.	5840.	3250.	1990.	1480.	1420.	1260.	1260.	33820.
1955	1690.	2510.	3270.	2990.	2980.	5780.	5980.	3090.	2480.	1230.	1420.	1320.	34740.
1956	1670.	3410.	4720.	4910.	3460.	7510.	3990.	2510.	1350.	1120.	1140.	1050.	36840.
1957	1350.	2160.	3020.	2460.	4540.	5390.	4040.	4960.	1680.	1170.	1120.	1310.	33200.
1958	1590.	2440.	3390.	2750.	6270.	6900.	6120.	2330.	1150.	1080.	1060.	1120.	36200.
1959	1480.	2270.	2940.	2540.	4290.	3750.	3230.	2230.	1250.	1140.	1130.	1060.	27310.
1960	1680.	1630.	2270.	2480.	2818.	1230.	3070.	1480.	1000.	719.	1020.	962.	20359.
AVE.	1936.	3275.	3943.	3939.	5340.	7523.	6165.	3464.	1894.	1307.	1288.	1234.	41307.

* DATA CORRELATED WITH STATION10-1180 BEAR RIVER NEAR COLLINSTON UTAH

Several large springs rise at the base of the Wellsville and Blue Spring Mountains. In general, these springs are unmeasured and the only available data is short, intermittent records kept by some irrigation companies. These records are generally of poor quality.

Hsieh estimated the mean annual flow from these springs to be 58,500 acre feet per year. (Hsieh, 1965, p 24) This estimate of the flow from these springs was used in this study.

Figure 6 is an isorunoff map of the delta area showing contours of equal mean annual ungaged tributary flow in inches for the study period 1931-1960.

Diversions and Imports. There are two major diversions from the Bear River in the delta area. These diversions are used principally for irrigation. Records of the quantity of flow of these diversions are measured and published by the U. S. Geological Survey and are in general excellent in quality. There are several smaller diversions along the Bear River which are not measured. For this study, these unmeasured diversions were estimated to be approximately 5 percent of the total diversions; therefore, the total recorded diversions were adjusted to account for these unmeasured diversions.

Irrigation water is imported from the Weber River Basin through the Brigham City-Ogden canal. This canal has been in operation since 1937 and diverts a mean annual flow of 18,000 acre feet into the delta area. This water is used for irrigation in the east and southeast portion of the delta area. Diversion records are available for the operation period 1937-1960 and are excellent in quality.

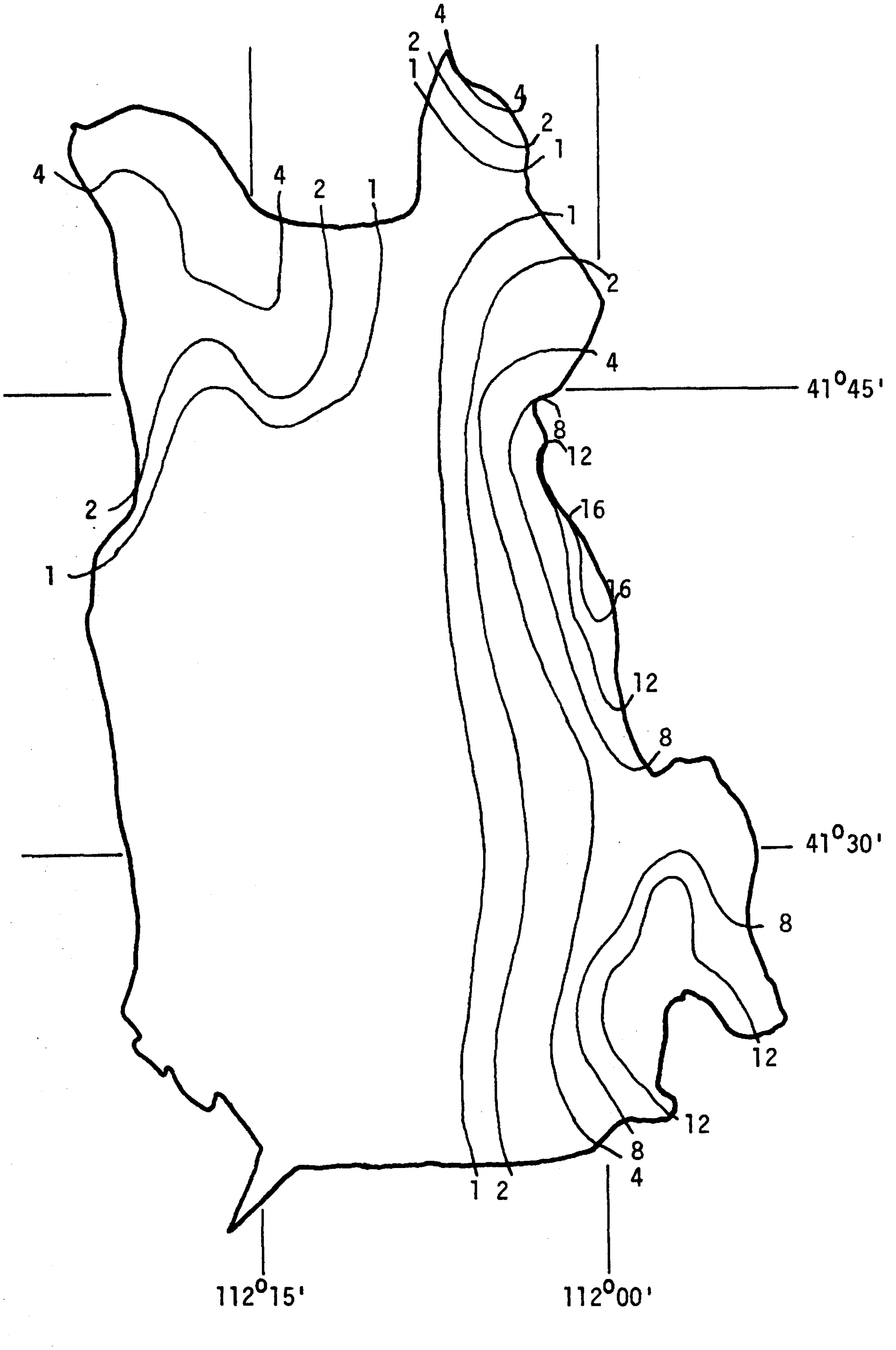


Figure 6. Isorunoff map of the Bear River delta showing mean annual runoff in inches for the study period 1931-1960.

Evapotranspiration

Few measurements of consumptive use are available for the Bear River delta; therefore, the potential consumptive use or evapotranspiration must be estimated from the available climatological data. The Blaney-Criddle method was used to estimate the potential consumptive use in this study. This method will be discussed in detail in another section of this thesis.

The amount of water lost by evapotranspiration in the Bear River delta was estimated in this study to be approximately 340,000 acre feet per year.

Land Use

Since each crop has a different consumptive use rate, before an estimate of the potential consumptive use can be estimated, the acreages of each crop needs to be determined. During 1967 and 1968, such a land use study for the Bear River drainage was conducted by Utah Water Research Laboratory using aerial photography and field identifications. Table 2 shows the summary of the agricultural land use for the delta area. This land use pattern was used in all budget calculations in this thesis.

A simular land use study for the non-agricultural lands on the delta floor was conducted by Utah Water Research Laboratory during this same period. Table 3 summarizes the findings of the non-agricultural land use study.

Table 2. Agricultural Land Use Pattern, 1965.

Crop	Area in Acres	Percent of Total Area
Alfalfa	23,139	24.94
Pasture	18,991	20.47
Hays	1,716	1.85
Small Graina	22,016	23.73
Corn	8,007	8.63
Sugar Beets	10,549	11.37
Orchards	2,505	2.70
Idle Farm Land	5,854	6.31
Total Irrigated Land	92,777	100.00

Table 3. Non-agricultural Land Use Pattern, 1965.

Phreatophyte	Area in Acres	Percentage of Total Area
Water Surface	64,621	54.32
Dense Covering	4,378	3.68
Water Table Grasses	36,486	30.67
Dry Land Grasses	13,479	11.33
Total Phreatophyte	118,964	100.00

CHAPTER III

HYDROLOGIC BUDGETS

Introduction

The hydrologic cycle is the interchange of water between the atmosphere, the lands, and the oceans. (Figure 7) It has no real beginning or ending, for as the water evaporates from the oceans and lands, it becomes part of the atmospheric moisture and is lifted and carried by the atmosphere until it eventually falls again as precipitation. This precipitation may be intercepted by the plants, may run overland to the stream channels or infiltrate into the ground. A large percentage of the intercepted water and surface runoff returns to the atmosphere by evaporation. The infiltrated water may be taken up by the plants and transpired or percolate into the deeper soil zones to be stored as ground water, later to flow to the surface as springs or effluent streams. Much of this infiltrated water eventually evaporates back to the atmosphere. It is easily seen that the hydrologic cycle is a closed cycle consisting of complicated interrelated processes.

The hydrologic cycle is dynamic, constantly moving through many phases in as erratic pattern in time and space. Every phase of the cycle varies in a more or less stochastic manner and is governed by the laws of probability. The outcome of today's event is somewhat dependent on the outcome of yesterday's events and to a lesser degree, on the events of other past days.

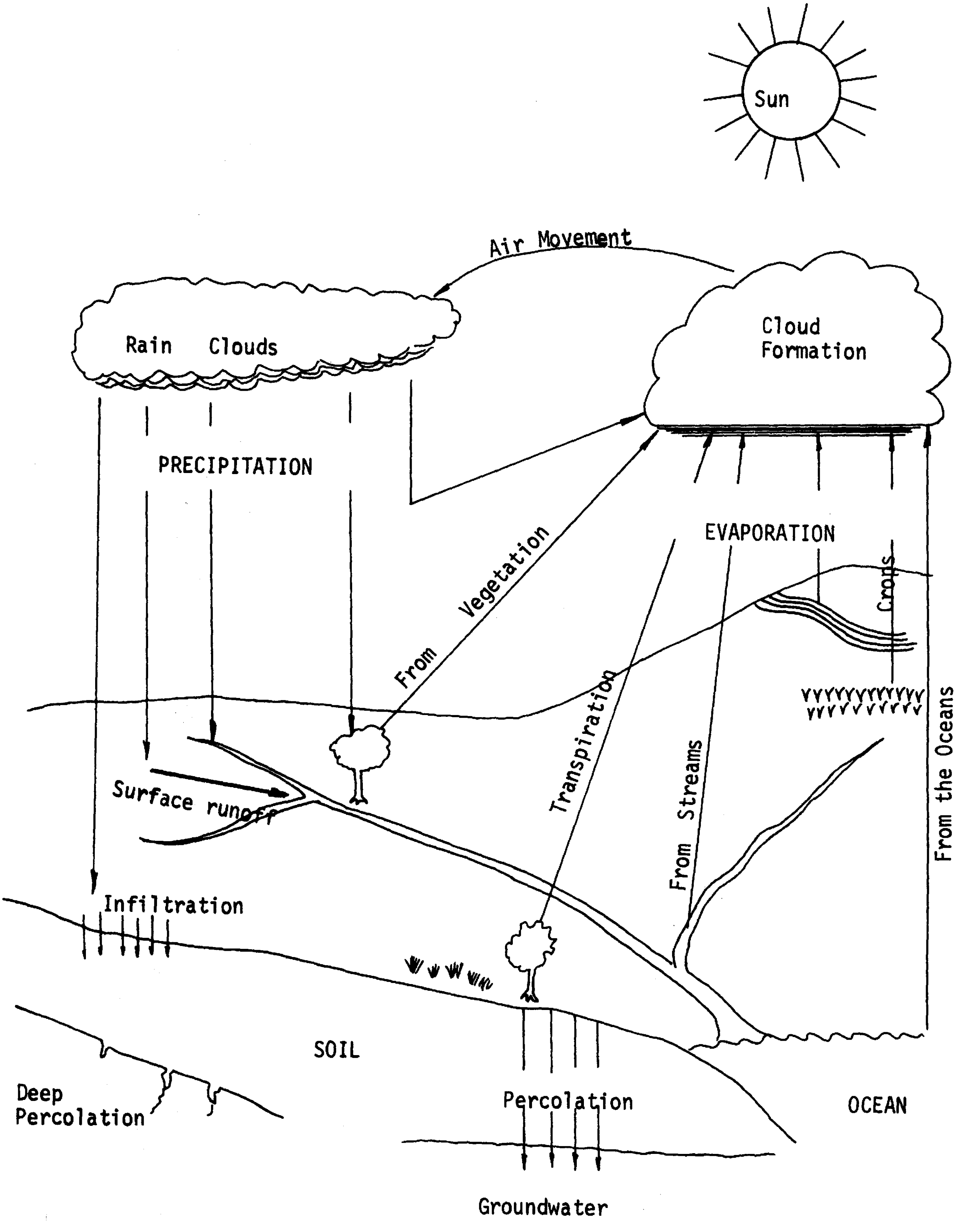


Figure 7. Pictorial representation of the hydrologic cycle.

The quantities of water moving through any phase of the hydrologic cycle can be evaluated using the hydrologic or storage equation. This equation simply states:

$$I - O = \Delta S \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 1$$

where:

I is the sum of all inflows into the study area and includes surface and subsurface inflows and precipitation.

O is the sum of all outflows from the study area and includes surface and subsurface outflows, evaporation, and evapotranspiration.

ΔS is the change in the sum of all storage items within the study area during the study period and includes detention, depression, interception, surface and subsurface storage.

The above equation is the basis of the hydrologic budget model used in this study. Each of the individual components of inflow and change in storage was evaluated and the resulting outflow was generated. The results obtained from the hydrologic budget analysis are only as good as the estimates of each individual components; therefore, it is important to look in some detail at each of the components of this equation.

Available Data

Precipitation

Several methods of determining the average depth of precipitation over an area have been developed. All of these methods are based on some type of averaging of a finite number of point measurements. Due to the wide variations in precipitation with distance and elevation, an error is introduced in using these point measurements as a basis of determining the average depth over the entire area. The largest error is usually due to inadequate number of sampling points. In recent years many attempts have been made to make adjustments in the averaging techniques to account for as much of the variations in precipitation with distance and elevation as possible.

The isohyetal map is probably the most accurate method for determining the average depth of precipitation over an area. An isohyetal map shows contours of equal depth of precipitation and can be prepared for individual storms or mean annual precipitation. This method allows full use of all data including orographic and physiographic effects and storm morphology.

The average depth of precipitation can be determined from an isohyetal map by multiplying the area between two isohyets by the mean precipitation depth between the isohyets and dividing by the total area. By summing the above factors over the entire area, the total depth of precipitation over the area can be determined.

An isohyetal map was prepared for the Bear River delta (Figure 3) and was based on mean U. S. Weather Bureau records for key precipitation stations in the drainage area for the study period 1931-1960.

Runoff

The U. S. Geological Survey, in cooperation with various state agencies, collects and publishes runoff data on most major streams and rivers in the United States. The data from these gages are generally good; however, care should be exercised in the selection of runoff gages to avoid man made obstructions which effect the true runoff measurements.

A large portion of the small intermittent streams within the delta area are ungaged or have only short periods of record. These ungaged inflows can be estimated using an isorunoff map. The water yield from an area was defined for this study to be that portion of the precipitation which falls on the area and is not entrapped or lost by evapotranspiration and moves as overland flow into surface and subsurface channels to become available for beneficial uses. An isorunoff map shows contours of equal water yield.

An isorunoff map was prepared by applying the hydrologic continuity equation to the mean inflow and outflow data for the delta area. The long term mean change in storage was considered to be negligible. The water yield was used as a balance for the continuity equation. The total water yield from the delta area can be determined similarily to the methods used to determine the average depth of precipitation.

Evapotranspiration

Many methods of determining potential consumptive use or evapotranspiration have been developed in recent years. These methods can be grouped into three major categories: empirical methods based on climatological data, theoretical methods based on the physics of the vapor process, and theoretical methods based on the energy balance. (Blaney and Criddle, 1950) The empirical methods that relate certain climatological and water supply data to potential consumptive use are most widely used because the climatological data is readily available and these methods are in general easy and simple to apply.

Blaney and Criddle (1950) developed an empirical formula which relates the consumptive use to the mean monthly temperature and the percentage of daylight hours. The Blaney-Criddle formula simply states:

$$u = k \times f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 2$$

$$U = \Sigma(k \times f) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 3$$

where:

u is the monthly potential consumptive use by a crop expressed in inches

k is the empirical monthly potential consumptive use crop coefficient.

f is the monthly consumptive use factor and is related to the mean monthly temperature and the percentage of daylight hours.

U is the seasonal or annual potential consumptive use by a crop in inches.

The monthly consumptive use factor was determined by the relationship:

$$f = \frac{t \times P}{100} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 4$$

where:

f is the monthly consumptive use factor.

t is the mean monthly air temperature in degrees Fahrenheit.

P is the percent of daylight hours.

Table 4 contains a summary of the mean annual potential consumptive uses for the Bear River delta for the study period 1931- 1960.

Storage

The changes in the storage items in the hydrologic equation are changes in storage in reserviors, soil moisture, ground water, interception, detention, and depression storage. If the time base is relatively short, the changes in storage items can become relatively large when compared to the inflow and outflow items; however, as the time base increases, these changes in storage tends to become progressively smaller in influence. When dealing with long base time intervals, the changes in storage often can be reduced to changes in reservoir, ground water, and soil moisture storage.

Table 4. Mean Annual Potential Consumptive Use Data for the Bear River delta for the study period 1931-1960.

	Potential Consumptive Use in acre feet per year	Potential Consumptive Use in inches per year
Irrigated Cropland	213,734	27.64
Phreatophytes	127,227	28.09
Water Surface Evaporation	241,714	44.89
Total	582,675	

Potential Consumptive Use data based on 1965 land use pattern.

Since there are no major surface storage reservoirs within the delta area and the amount of water pumped from the ground water basin is roughly equal to the natural recharge, the mean change in storage for the thirty year study period can be assumed to be negligible. The changes in soil moisture and interflow storage for the thirty year mean was adjusted to zero.

Time Base

The budget model used for this study was verified using the monthly hydrologic data from the period 1931-1960; therefore, the time base used in this study was one month.

A hydrologic budget can be calculated for any selected time period provided all data is available for that time period. Some items used in the budget calculations, such as soil moisture and interflow, are difficult to evaluate for any short time periods, but these items tend to balance out over longer time periods. These items can be neglected if the time period chosen is long enough to allow an averaging effect.

Model Development

A hydrologic budget is basically an accounting proceedure that balances the total items of supply with those of disposal for a particular time period. The usefulness and dependability of the hydrologic budget analysis is limited by the accuracy with which each individual component of the continuity equation can be measured or estimated.

A digital computer model was developed to calculate the monthly hydrologic budgets for each year of the study period 1931-1960. Due credit should be given to Mr. A. Leon Huber for the development of the basic computer model used in this study. This computer model has several basic assumptions built in:

(1) The land use pattern for 1965 was representative of the mean land use pattern for the study period.

(2) The potential consumptive use for the irrigated crops was estimated using the Blaney-Criddle formula. The potential consumptive use for the phreatophyte areas in the higher elevations was included in the ungaged inflows. The potential consumptive use of the phreatophyte areas on the

valley floor was estimated using the Blaney-Criddle formula.

(3) The percentage of the water applied to the croplands that enters the soil column and becomes available for plant uses was assumed to be constant over the entire growing period. This infiltration rate depends on the soil conditions and the moisture content. These factors will tend to balance over the long haul.

(4) The total precipitation which falls on the croplands was assumed to be effective precipitation. Effective precipitation was defined in this study as the percentage of the precipitation which falls on the croplands that enters the soil column and becomes available for crop uses. For arid and semiarid basins with low intensity precipitation, the soil infiltration rate is high enough to allow all precipitation to enter the soil. (Thorne and Peterson, 1954, p 143)

(5) It was assumed that the changes in storage over the thirty year study period was negligible; that is, there were no changes in the long term mean ground water or interflow or soil moisture storage.

(6) For the thirty year mean, all potential consumptive uses for the croplands were assumed to be fulfilled; that is, there were no consumptive use deficits for the long term mean, but this does not prevent a consumptive use deficit from occuring for any single year or month.

(7) The total supply to the wetlands or lowland phreatophyte areas was assumed to be available to be used by the phreatophytes.

(8) The soil moisture capacity, for the croplands and the wetlands, was calculated using a weighted mean based on the area occupied by each soil class as shown on the Soil Conservation Service soil maps of the area. This soil moisture capacity was computed using the soil moisture capacity of the individual soils, the average crop rooting depth, and the area of the soil within the study area.

(9) The municipal and industrial uses were estimated from population data and an estimated per capita consumption rate. Mean population data was used and assumed to be representative for the study period.

(10) The mean ungaged inflow for the study period was determined from the isorunoff map. This mean value was distributed on a yearly and monthly basis by multiplying the mean value by the ratio of the yearly or monthly Bear River flow to the mean yearly or monthly Bear River flow.

The model developed was a macroscopic model in time as opposed to a microscopic model. This fact allows the model to look at long term variations in the parameters, but does not attempt to accurately model the short time variations in parameters. This type of model is useful in development and analysis of management proposals. The results of such a model is accurate enough for long term planning but will not account for the short term variations in flow that occur.

Figure 8 shows a simplified diagram of the budget model. The next section attempts to familiarize the reader with the calculations involved in the model.

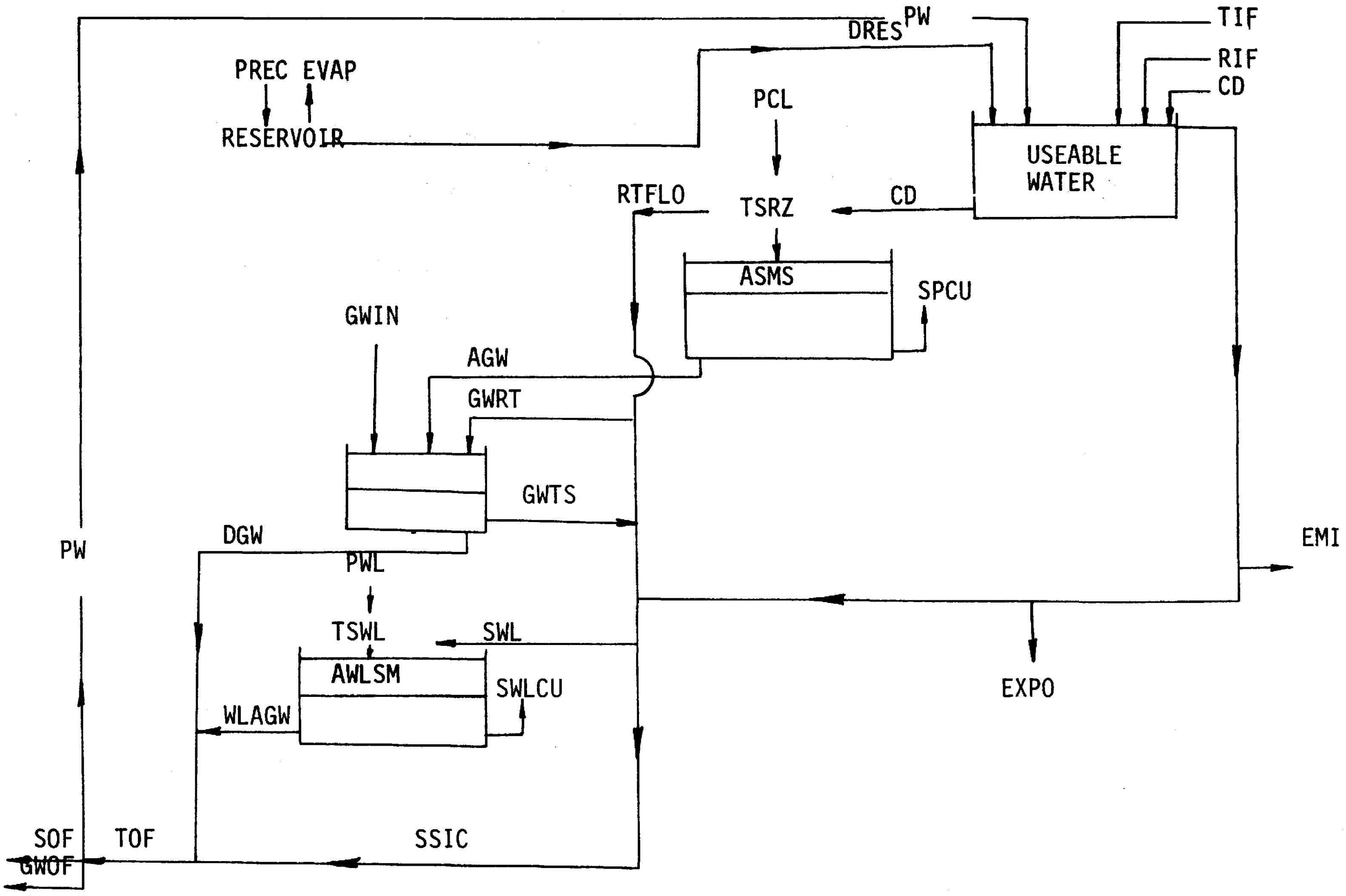


Figure 8. Simplified diagram of the Budget Computer Model.

Model Calculations

The total available water supply or total manageable water supply consists of the sum of the gaged inflows, ungaged inflows, changes in reservoir storage, and the water pumped from the ground water basin. A portion of this total available supply is diverted to the croplands for irrigation with the remainder becoming available for other beneficial and non-beneficial uses further downstream.

The total supply to the irrigated croplands is the sum of the cropland effective precipitation, cropland snow melt, and the diverted water to be used for irrigation. A portion of the cropland supply enters the soil profile and becomes available to the crops to satisfy their consumptive uses. The remainder becomes available as return flow, both surface and subsurface.

The water that enters the soil profile and is stored in the root zone is called soil moisture. This, added to the soil moisture already in storage in the root zone, combines to make up the total soil moisture storage from which the crops can draw moisture. If not enough water is available in storage to satisfy all potential cropland consumptive uses, a deficit occurs. The deficit is the amount of water over and above that available which would be required to satisfy all potential consumptive uses. If the total amount of water entering the soil profile exceeds the soil moisture capacity, the excess water becomes an addition to interflow. The interflow is basically a time lag stage which attempts to redistribute the water in time, with the outflow from interflow decreasing as an exponential decay function. Two outflows from interflow storage are possible; these are additions to the ground water basin and ground water return flow.

The water supply in the surface channel consists of the total manageable supply less the diversions for irrigation and municipal and industrial uses. The surface and ground water return flows enter the surface channel and becomes available for reuse. A certain percentage of this water becomes available for phreatophyte uses and evaporation with the remainder being a component of the surface outflow from the area.

The phreatophyte supply combined with the precipitation and snow melt on the phreatophyte areas make up the total supply to the wetlands or non-beneficial lands. This supply enters the soil profile and is stored as soil moisture in the root zone. This soil moisture, added to the soil moisture already in storage in the root zone, combines to make up the total soil moisture storage from which the phreatophytes draw moisture to satisfy their consumptive uses. If not enough soil moisture is available to meet all potential consumptive uses, a deficit occurs. If the supply exceeds the soil moisture storage capacity, the remainder of the water enters the ground water basin as an addition to the ground water.

The total outflow from the area, both surface and subsurface, is the sum of the wetland addition to ground water, the surface supply in the channels, and the net difference between the addition to ground water from interflow and the water pumped from ground water. If no knowledge is available on the ground water outflow, the model will divide the outflow into surface outflow and subsurface outflow according to a fixed percentage furnished.

Model Verification

The model was verified using monthly data for the period 1964-1965. The initial condition parameters were adjusted so that the two year mean changes in soil moisture storage and interflow storage could be neglected. The model's operational parameters were adjusted to force the outflow to agree with the recorded outflow at the new U. S. Geological Survey streamflow gage located near Corinne, Utah.

The model was used to calculate the thirty year mean monthly budget for the Bear River delta. The initial condition parameters had to be readjusted so the long term mean changes in soil moisture and interflow storage was negligible. The estimated mean annual outflow to the Great Salt Lake was 891,071 acre feet as surface outflow and 27,559 acre feet as ground water outflow; therefore, the total outflow from the delta area was estimated to be 918,630 acre feet. The ground water outflow from the delta area was estimated based on the ground water outflow being 3 percent of the total outflow.

Hsieh (1965, p 59-60) estimated the total outflow from the delta area to be approximately 950,000 acre feet or approximately 3.4 percent greater than the estimated outflow in this study. This independent study was used as aid in verifying the accuracy of the model's outflow.

Table 5 shows a summary of the results of the mean hydrologic budget for the delta area for the study period 1931-1960.

Table 5. Mean hydrologic budget for the Bear River delta for the study period 1931 - 1960.

ITEM--YEAR MEAN		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR
MEASURED INFLOW		71587.	74722.	80314.	79333.	85109.	115343.	149948.	164054.	104236.	63954.	66179.	61236.	1116010.
UNMEASURED INFLOW		7686.	7231.	7006.	6848.	6749.	8269.	16375.	17391.	8977.	6880.	6507.	6375.	106293.
PUMPED WATER	O	607.	259.	124.	64.	46.	20.	45.	1549.	2266.	2743.	2642.	1940.	12503.
TOTAL MANAGEABLE WATER	I	80080.	82212.	87443.	86245.	91903.	123632.	166368.	182993.	115479.	73577.	75328.	69551.	1234805.
GROUNDWATER INFLOW		711.	742.	798.	797.	846.	1148.	1487.	1635.	1044.	634.	658.	607.	11108.
CROPLAND DIVERSIONS		15934.	5056.	2426.	1260.	897.	401.	864.	30190.	44397.	52920.	50999.	37450.	242795.
AMOUNT TO ROOT ZONE		7782.	2469.	1185.	616.	436.	196.	422.	14745.	21684.	25846.	24908.	18291.	118580.
CROPLAND RETURN FLOW		8152.	2587.	1241.	645.	459.	205.	442.	15445.	22714.	27074.	26091.	19159.	124213.
SURFACE RETURN FLOW		3261.	517.	248.	129.	92.	41.	177.	9267.	18171.	27074.	20873.	11496.	91345.
GW RETURN FLOW		4891.	2069.	993.	516.	367.	164.	265.	6178.	4543.	0.	5218.	7664.	32868.
CROPLAND PRECIPITATION	I	8815.	9399.	9945.	9557.	9167.	10431.	11324.	11668.	8647.	4032.	5223.	7551.	105758.
SNOW STORAGE ADDED		0.	1569.	8356.	8776.	5635.	722.	0.	0.	0.	0.	0.	0.	25060.
ACCUM SNOW STORAGE		0.	0.	1379.	9490.	17879.	21452.	14085.	900.	0.	0.	0.	0.	0.
SNOW MELT	I	0.	190.	246.	387.	2063.	8089.	13185.	900.	0.	0.	0.	0.	25060.
ROOT ZONE SUPPLY		16597.	10489.	3019.	1784.	6032.	17993.	24931.	27313.	30331.	29878.	30131.	25842.	224339.
CROPLAND P.C.U.		11622.	4237.	1994.	1425.	3363.	7104.	15996.	29294.	41469.	46806.	31221.	19204.	213734.
RZ SUPPLY-P.C.U.		4975.	6252.	1025.	359.	2669.	10890.	8935.	-1981.	-11139.	-16928.	-1090.	6637.	10605.
ACCUM SOIL MOISTURE	I-O	53542.	58041.	63726.	64161.	64227.	66381.	73719.	79211.	76304.	65155.	48253.	47384.	54021.
CONS. USE DEFICIT		0.	0.	0.	0.	0.	0.	0.	0.	0.	-26.	-222.	0.	-248.
SURPLUS		476.	567.	590.	293.	515.	3552.	3443.	926.	11.	0.	0.	0.	10373.
ACTUAL CROPLAND C.U.	O	11622.	4237.	1994.	1425.	3363.	7104.	15996.	29294.	41469.	46780.	30999.	19204.	213487.
INTERFLOW ADDED		476.	567.	590.	293.	515.	3552.	3443.	926.	11.	0.	0.	0.	10373.
ACCUM INTERFLOW	I-O	3784.	4392.	4018.	3628.	2971.	2657.	2973.	2891.	4716.	3906.	2392.	4942.	3782.
GROUNDWATER ADDITION		2081.	2416.	2210.	1996.	1670.	1635.	1876.	1774.	2594.	2148.	1523.	2718.	24641.
GROUNDWATER TO SRFCE		3389.	1337.	561.	266.	371.	2914.	3402.	5140.	3814.	0.	1803.	6713.	29710.
DOMESTIC USE	O	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
EXPORTS	O	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SURFACE SUPPLY TO WL		22413.	7090.	4708.	8515.	4562.	10076.	0.	38267.	58017.	41035.	36751.	34569.	266005.
WETLAND PRECIPITATION		12879.	13731.	14530.	13963.	13392.	15239.	16544.	17047.	12633.	5890.	7630.	11032.	154512.
SNOW STORAGE ADDED	O	0.	2293.	12209.	12822.	8233.	1055.	0.	0.	0.	0.	0.	0.	36612.
ACCUM SNOW STORAGE		0.	0.	2015.	13865.	26121.	31340.	20578.	1314.	0.	0.	0.	0.	0.
SNOW MELT	I	0.	278.	359.	566.	3014.	11818.	19264.	1314.	0.	0.	0.	0.	36612.
TOTAL SUPPLY TO WL		35292.	18807.	7388.	10222.	12735.	36078.	35808.	56629.	70650.	46925.	44382.	45601.	420517.
POTENTIAL WETLAND CU		21516.	8794.	3474.	2883.	7374.	16908.	29599.	46915.	58626.	72337.	61866.	38647.	368941.
TSWL-WL P.C.U.		13776.	10013.	3914.	7338.	5361.	19170.	6209.	9714.	12024.	-25412.	-17485.	6954.	51576.
ACCUM WL SOIL MOIST	I-O	51434.	59784.	66313.	67830.	71444.	75404.	88039.	89881.	91211.	85218.	60044.	47189.	49936.
WETLAND DEFICIT		-88.	0.	0.	0.	0.	0.	0.	0.	0.	-3705.	-8006.	-1651.	-13449.
ACTUAL WETLAND C.U.	O	21428.	8794.	3474.	2883.	7374.	16908.	29599.	46915.	58626.	68633.	53861.	36996.	355491.
WL ADD TO SRFC AND GW		5513.	3483.	2397.	3725.	1401.	6534.	4368.	8384.	18016.	3467.	3375.	5858.	66524.
SURF WATER TO CHANNEL		47627.	71693.	80891.	76637.	86686.	115875.	168778.	128112.	34074.	5596.	9188.	14815.	839970.
TOTAL OUTFLOW	R	54414.	77332.	85374.	82294.	89713.	124023.	174977.	136722.	52418.	8469.	11444.	21452.	918630.
GW OUTFLOW		2305.	2673.	2450.	2237.	1885.	1842.	2179.	2050.	2824.	2403.	1706.	3004.	27559.
SURFACE OUTFLOW		52109.	74660.	82924.	80057.	87827.	122181.	172798.	134672.	49594.	6066.	9738.	18448.	891071.
GAGED OUTFLOW		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DIFFERENCE (COMP-GAGED)		52109.	74660.	82924.	80057.	87827.	122181.	172798.	134672.	49594.	6066.	9738.	18448.	891071.

CHAPTER IV

IRRIGATION EFFICIENCY

Definitions

Any irrigation system can be broken into three components: (1) the source or storage system, (2) the distribution system, and (3) the application system. Each component of the total system is subjected to certain water losses which reduce the quantity of water available for beneficial uses. These losses include evaporation, evapotranspiration, seepage, surface runoff, and deep percolation. An efficiency of water use can be associated with each component of an irrigation system. These efficiencies are defined as the ratio of the total usable outflow from the component to the total flow into the component. These efficiencies are useful in the evaluation of the performance of a present irrigation system or in the determination of the amount of water required to satisfy the future water needs of a new system.

Irrigation System Efficiency

Irrigation system efficiency is defined as the ratio of the volume of water necessary to satisfy crop potential consumptive uses to the total volume of water diverted for irrigation. The irrigation system efficiency can be expressed mathematically in terms of the efficiencies of each component of the system by the following expression:

$$E_i = E_s \cdot E_c \cdot E_a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad 8$$

where:

E_i is the irrigation system efficiency.

E_s is the storage efficiency.

E_c is the conveyance efficiency.

E_a is the application efficiency.

It can be easily seen from the above relationship that improving the efficiency for only one component of the system may not significantly increase the total system efficiency. It is necessary, therefore, to analyze each component of the system to determine the best method of improving the overall system efficiency.

Storage Efficiency

Storage efficiency can be defined as the ratio of the volume of water diverted from storage for irrigation to the total volume of water stored for irrigation. Storage efficiency can be expressed mathematically as:

$$E_s = \frac{V_{os}}{V_{is}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad 9$$

where:

E_s is the storage efficiency.

V_{os} is the volume of water diverted from storage for irrigation.

V_{is} is the volume of water stored for irrigation.

The main water losses from any storage component are phreatophyte evapotranspiration, water surface evaporation, and seepage.

The average storage efficiency for the United States was estimated to be between 90 and 96 percent (U. S. Congress, 1960b, p 4) but due to the high evaporation and evapotranspiration rates in the western United States, the storage efficiency may be considerable less. Since there are no major storage reservoirs within the delta area, the importance of the storage efficiency is minimized. For use in this study, a storage efficiency of 100 percent was used in the calculations of irrigation system efficiency.

Conveyance Efficiency

Conveyance efficiency is defined as the ratio of the volume of water delivered for irrigation to the volume of water entering the conveyance system at the point of diversion. Conveyance efficiency can be expressed mathematically as:

$$E_c = \frac{V_{oc}}{V_{ic}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad 10$$

where:

E_c is the conveyance efficiency.

V_{oc} is the volume of water delivered by the conveyance system.

V_{ic} is the volume of water entering the conveyance system at the point of diversion.

The main water losses in conveyance systems are phreatophyte evapotranspiration, water surface evaporation, and seepage.

The average conveyance efficiency throughout the United States was estimated to be 65 percent of the total diverted flow.(Stamm, 1964, p 88) A look as several Bureau of Reclamation projects in Utah indicates the average conveyance efficiency of the main canal systems to vary from 75 to 90 percent of the total diverted flow.

(U. S. Department of Interior, 1964, p 7)

Very little quantitative data on conveyance efficiency and canal seepage losses was found for the Bear River delta area; therefore, the conveyance efficiency was estimated based on the Bureau of Reclamation estimates of conveyance efficiency for the southern Utah Valley and the northern Juab Valley. (U. S. Department of Interior, 1964, p 211) For use in this study, a conveyance efficiency of 80 percent was used in the calculation of irrigation system efficiency.

Application Efficiency

Application efficiency can be defined as the ratio of the volume of water consumed by crops to the volume of water delivered to the farm. Application efficiency can be expressed mathematically as:

$$E_a = \frac{V_{ea}}{V_{ia}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 11$$

where:

E_a is the application efficiency.

V_{ea} is the volume of water consumed by evapotranspiration.

V_{ia} is the volume of water delivered to the farm.

In recent years several modifications of the application efficiency formula have been proposed. One of the newest modifications was proposed by Jensen. (1967, p 86) Jensen proposed that application efficiency should be the volume of water required to satisfy crop potential consumptive use plus the volume of water required to leach toxic salts from the root zone and increase the available soil moisture minus the effective precipitation divided by the total volume of water delivered to the farm. This definition can be expressed mathematically as:

$$E_a = \frac{V_{ea} + V_{la} + \Delta V_{sm} - V_{ep}}{V_{ia}} \quad . \quad . \quad . \quad . \qquad 12$$

where:

E_a is the application efficiency.

V_{ea} is the volume of water consumed by evapotranspiration.

V_{la} is the volume of water required to leach the toxic salts from the root zone

ΔV_{sm} is the change in the available soil moisture.

V_{ep} is the volume of effective precipitation.

V_{ia} is the volume of water delivered to the farm.

This Jensen modification is more realistic for short time periods where the change in soil moisture storage can be a significant factor or in areas where large volumes of water have to be applied to the soil in order to leach salts from the root zone. In the first efficiency formula, water used to leach salts from the root zone and water in excess of evapotranspiration that is added to increase the soil moisture storage are considered inefficient water uses; however, these uses are important in the operation of any irrigation system and should be considered efficient water uses. The Jensen modification considers these used as efficient water uses.

The Jensen modification was used in this study to calculate application efficiency.

Leaching Requirement. A build up of toxic salts in the root zone has been the cause for the failure of most irrigation systems in the past; therefore, it is important for any irrigation system to survive over long periods of operation that enough excess water be applied to the land to leach these toxic salts from the root zone.

Leaching requirement can be defined as the volume of water entering the soil profile that must pass through the root zone in order to prevent the build up of soil salinity above a specified toxic level. (Thorne and Peterson, 1954, p 114) The U. S. Salinity Laboratory (1953) has defined leaching requirement as:

$$LR = \frac{V_{dw}}{Viw} \times 100 \quad . \quad . \quad . \quad . \quad . \quad . \qquad 13$$

where:

LR is the leaching requirement expressed as a percent of the water applied.

V_{dw} is the volume of drainage water leaving the root zone.

V_{iw} is the volume of water applied.

This estimate of leaching requirement assumes a uniform application of irrigation water and no salt removal by deep percolation of the natural precipitation.

In arid and semiarid areas with loose sandy soils, the water moves through the root zone easily and the leaching requirements are low. The build-up of toxic salts in the root zone is a significant problem in areas of saline or alkali soils and adequate water has to be applied in order to leach these salts from the root zone. (U. S. Department of Agriculture, 1964, p 22) In cases where application efficiencies are highly variable or where a uniformity of water application is not controlled, the leaching requirement is unimportant (Richards, 1954, p 38); therefore, leaching requirement will be neglected in this study.

Effective Precipitation. Effective precipitation was defined for this study as that percentage of the total precipitation that enters the soil profile and becomes available for plant uses. This effective precipitation supplies a portion of the consumptive use of the crops; however, it may be an insignificant portion in arid regions. (U. S. Department of Agriculture, 1964, p 21)

In arid areas where total growing season precipitation is light, the moisture level in the soil profile at the time precipitation occurs is usually such that almost all of it enters the soil profile and becomes available for consumptive use. Losses due to surface runoff or to percolation below the root zone are usually negligible; therefore, the effectiveness of rainfall in arid regions is relatively high. (U. S. Department of Agriculture, 1964, p 24)

When the consumptive use of the crops is high, available moisture in the soil profile is depleted rapidly thereby providing storage capacity in the root zone at a relatively rapid rate. This storage capacity allows most of the precipitation to enter the soil moisture storage reservoir easily.

Curves have been plotted showing the relationship between mean growing season effective precipitation and the growing season consumptive use for various values of total growing season precipitation. (U. S. Department of Agriculture, 1964, p 26-27) For a growing season precipitation of 6.26 inches and a growing season consumptive use of 27.5 inches, the effective precipitation would be 5.36 inches or 86 percent of the total precipitation is actually effective. The assumption that all precipitation was effective would introduce an error of approximately 14 percent. The effective precipitation used in the calculation of irrigation system efficiency was calculated using the above percentage of the total precipitation.

Changes in Soil Moisture Storage. Changes in soil moisture storage can be a significant factor when dealing with short time periods; however, when dealing with long term mean annual values, these changes in soil moisture storage can be neglected.

The changes in the thirty year mean annual soil moisture storage was neglected in the calculation of application efficiency.

Calculation of Application Efficiency. With the assumptions outlined above, the irrigation application efficiency formula was reduced to:

$$E_a = \frac{V_{ea} - V_{ep}}{V_{ia}} \quad . \quad . \quad . \quad . \quad . \quad . \qquad 14$$

where the terms of the equation are the same as defined before.

Factors Effecting Efficiency

Many factors affect the efficient use of irrigation water. The most important of these factors are: seepage losses, water surface evaporation, phreatophyte evapotranspiration, operational waste, and poor irrigation practices. The following sections will discuss each of these factors in detail.

Seepage Losses

Seepage losses can be defined as the quantity of water lost from a storage or conveyance facility due to subsurface percolation. Seepage does not include deep percolation losses from the agricultural lands.

Loss of water due to seepage is influenced by the type of storage or conveyance facility (lined or unlined) and the type and condition of the soil. Seepage losses vary widely and may represent a sizeable percentage of the total diverted flow.

Very little quantitative data has been obtained from which seepage losses can be determined. Because of the expense involved in collecting accurate data, attempts to estimate these losses empirically have been made but these methods are generally not compatible. Houk has estimated seepage losses for large projects to vary from 15 to 45 percent of the total diverted flow, depending on the soil type and condition. (Houk, 1951, p 392) Israelsen estimated that for long unlined canals, the seepage losses may be as high as 50 percent of the total diverted flow. (Israelsen, et al., 1946, p 9)

No published data on seepage losses for the Bear River delta was found. An estimated value for the percent of the total flow lost by seepage was obtained by comparing the data, soil type, and general soil conditions of the delta area to that published by the Bureau of Reclamation for the southern Utah Valley and northern Juab Valley. (U. S. Department of Interior, 1964, p 211) These estimates of seepage losses are summarized in Table 6.

Phreatophyte Evapotranspiration

A phreatophyte is a non-beneficial, water loving plant that often grows along rivers and canals where an adequate water supply is available. In semiarid regions phreatophyte evapotranspiration can be a significant water loss. In a recent study by the U. S. Geological survey in the Malad River valley in southeastern Idaho, the estimated loss due to a dense phreatophyte covering on approximately 16,000 acres was 37,200 acre feet per year or approximately 2.3 acre feet per acre per year. (Mower and Nace, 1957)

It has been estimated that phreatophytes in the state of Utah alone consume more water annually than the quantity of water consumed benefically by all the irrigated crops within the state. (Bagley, 1963, p 27)

In the Bear River delta phreatophytes cover approximately 54,343 acres or 45.68 percent of the non-agricultural lands with an annual loss of 127,227 acre feet per year.

Operational Waste

Operational waste consists of mismeasurements of diversions, leaking canal gates, intentional and unintentional releases of water during conveyance, and other preventable losses. In a properly managed and operated irrigation system, operational wastes have a minor effect on the irrigation system efficiency. Estimates of operational waste vary greatly between individual irrigation systems. On large irrigation systems, the operational waste has been estimated to vary from 1 to 30 percent of the total diverted flow. (Houk, 1951) However, Jensen estimates that under normal operations, the operational waste should not be more than 5 to 10 percent of the total diverted flow. (Jensen, 1967)

Irrigation Practices

Irrigation practices refer to factors that can be controlled by the individual farmer on his farm. The purpose of any irrigation system is to supply an adequate amount of readily available moisture in the soil profile to be used by the plants. This purpose sounds simple but is often difficult to achieve.

Low irrigation system efficiency often results from poor irrigation practices. Improper preparation of the land for irrigation often results in uneven distribution of the irrigation waters, high surface return flows, and deep percolation. These factors are classified as poor irrigation practices because they can be controlled by proper land preparation. Another irrigation practice which often results in poor application efficiency is careless handling of the water once it is delivered to the farm and the application of excess quantities of water due to the uncertainty involved in determining the amount of water to apply.

Estimates of Irrigation System Efficiency

Very little quantitative data was available for the Bear River delta from which irrigation system efficiency could be determined. The conveyance efficiency was estimated from the data presented by the Bureau of Reclamation for the southern Utah Valley and northern Juab Valley. (U. S. Department of Interior, 1964, p 211) Application efficiency was estimated from the available potential consumptive use data and effective precipitation data using equation 14. Since there are no major storage reservoirs within the delta area, the storage efficiency was estimated to be 100 percent.

Table 7 shows a summary of the estimated efficiencies of each component of the system as well as an estimate of the irrigation system efficiency for the Bear River delta.

Table 7. Irrigation system efficiency for the Bear River delta.

Conveyance Efficiency in percent	Application Efficiency in percent	Storage Efficiency in percent	Irrigation System Efficiency in percent
80	55	100	44

CHAPTER V

IRRIGATION REQUIREMENT

Definitions

Net irrigation requirement or net irrigation demand can be defined as the quantity of water exclusive of precipitation, stored soil moisture, or groundwater required to meet consumptive use and leaching requirements. Net irrigation requirement is independent of irrigation system efficiency in that it is the quantity of water actually required by the growing plant and does not include deep percolation losses.

Irrigation water requirement or irrigation demand is defined as the quantity of water, measured at the point of diversion, exclusive of precipitation, stored soil moisture, or groundwater that is required to meet the crop potential consumptive uses. Irrigation requirement differs from net irrigation requirement by the inclusion of the water losses involved in the irrigation system.

Irrigation requirement can be determined on a monthly or seasonal basis. Monthly irrigation requirement (MIR) is the total monthly crop potential consumptive use (SPCU) divided by the irrigation system efficiency (E_i). Annual or seasonal irrigation requirement (AIR) is the sum of the monthly irrigation requirements for the growth months.

In the Bear River delta the growing season begins the last of

April and ends the middle of October; therefore, the seasonal or annual irrigation requirement is the sum of the monthly irrigation requirements for the months of May to October.

The present diversion quantities, when compared to the irrigation requirement, will result in a surplus (SR) or a deficit (DEF) water supply at the diversion point. A surplus exists when the quantity of water diverted exceeds the irrigation requirement. For this study, a surplus was considered a negative quantity. A deficit will occur when the quantity of water diverted is less than the irrigation requirement and indicates a shortage of water that is, not all crop potential consumptive uses are being met at the present irrigation system efficiency. For this study, a deficit was considered a positive quantity.

Similar to irrigation requirement, the surplus or deficit can be considered on a monthly or annual basis. Monthly surplus or deficit is determined by subtracting the mean monthly cropland diversions from the monthly irrigation requirements. If the quantity is negative, a surplus exists. If the quantity is positive, a deficit exists. Annual or seasonal surplus (ASR) or deficit (ADEF) is the sum of the monthly surplus or deficit.

The surplus or deficit quantities defined above assume all cropland potential consumptive use is supplied by cropland diversions. The effect of cropland precipitation and moisture stored in the root zone is neglected. Annual surplus (TASR) or deficit(TADEF) can be defined as the annual irrigation requirement minus the sum of the annual cropland effective precipitation and cropland diversions.

Calculation of Irrigation Requirement

Monthly irrigation requirement is calculated from the potential consumptive use data and the irrigation system efficiency. The equation used in this study to calculate the monthly irrigation requirement independent of precipitation and root zone storage was:

$$MIR = \frac{SPCU}{E_i} \times 100 \quad . \quad . \quad . \quad . \quad . \quad . \quad 15$$

where:

MIR is the monthly irrigation requirement in acre feet.

SPCU is the sum of the monthly potential consumptive uses from the crops in acre feet.

E_i is the irrigation system efficiency in percent.

Equation 15 assumes all potential consumptive uses are satisfied from cropland diversions. The effect of precipitation and root zone storage on the irrigation can be seen by modifying equation 15 to include precipitation and root zone storage.

$$TMIR = \frac{SPCU - PCL - (ASMS - SMC)}{E_i} \times 100 \quad . \quad . \quad . \quad 16$$

where:

TMIR is the monthly irrigation requirement considering precipitation and soil moisture storage in acre feet.

PCL is the mean monthly effective precipitation in acre feet.

ASMS is the mean monthly accumulated soil moisture storage in acre feet.

SMC is the soil moisture capacity in acre feet.

E_i is the irrigation system efficiency in percent.

Equation 16 is similar to equation 12 used to calculate irrigation application efficiency. With a few modifications and simple substitutions, equation 16 can easily be reduced to the more familiar form:

$$E_i = \frac{\text{SPCU} + (\text{SMC} - \text{ASMS}) - \text{PCL}}{\text{TMIR}} \times 100 \quad . \quad . \quad . \qquad 17$$

where the terms are the same as previously defined.

The term (SMC - ASMS) represents the volume of storage remaining in the root zone and is similar to the change in the available soil moisture (ΔV_{sm}) used in equation 12. The irrigation requirement is the volume of water delivered to the farm that is required to meet crop potential consumptive uses and is equivalent to the volume of water delivered to the farm (V_{ia}). The irrigation requirement is the sum of the cropland diversions and the deficit or surplus. With the above simple substitutions, equation 17 can be reduced to an equation similar to equation 12.

Since the monthly deficit or surplus is equal to the irrigation requirement for the month minus the mean monthly diversions for the same month, we can substitute this relationship into equation 17 and simplify to obtain the following relation:

$$\text{TMDEF (or TMSR)} = \frac{\text{SPCU} + (\text{SMC} - \text{ASMS}) - \text{PCL}}{E_i} - \text{CD} \quad . \quad . \qquad 18$$

where:

TMDEF (or TMSR) is the monthly deficit or surplus considering precipitation and root zone storage in acre feet. A surplus exists if the right hand side of the equation is negative.

CD is the mean monthly diversion in acre feet.

The other terms are the same as previously defined.

This equation is the basic equation used to calculate the monthly deficit or surplus considering precipitation and root zone storage.

The root zone storage is important because water may be placed on the land in order to increase the soil moisture content to some predetermined level. This water is being used efficiently and is being placed in the root zone storage reservoir, to be used by the plants when the supply of diverted water is not adequate to meet all crop potential consumptive uses.

Another useful indicator of water management potential is the deficit or surplus, independent of precipitation and root zone storage, necessary to meet all crop potential consumptive uses. These monthly deficit or surplus terms are easily determined by modifying equation 15.

$$\text{DEF (or SR)} = \frac{\text{SPCU}}{E_i} - \text{CD} \quad . \quad . \quad . \quad . \quad . \quad . \quad 19$$

where:

DEF (or SR) is the monthly deficit or surplus in acre feet. A surplus exists if the right hand side of the equation is negative.

The other terms are the same as previously defined.

Irrigation Requirement, Deficit or Surplus

Annual Irrigation Requirement, Deficit or Surplus

Annual irrigation requirement (AIR) and annual irrigation requirement considering precipitation and root zone storage (TAIR) can be determined at various irrigation system efficiencies. Figure 9 and Tables 12 and 13 show the variations of these annual irrigation requirements with irrigation system efficiency. It is easily seen from Figure 9 that the rate of change of irrigation requirement decreases as the irrigation system efficiency increases. This means at low irrigation system efficiencies, a small increase in the irrigation system efficiency will result in a large decrease in the irrigation requirements. However, at high system efficiencies, a small increase in the system efficiency will result in a much smaller decrease in irrigation system requirement. This can be interpreted as meaning the system losses are more significant at low irrigation system efficiencies.

Figure 9 also shows the annual deficit or surplus excluding precipitation and root zone storage (ADEF or ASR) and the annual deficit or surplus including precipitation and root zone storage (TADEF or TASR) versus irrigation system efficiency. The curve of (TADEF or TASR) versus E_i shows the volume of water in addition to or in excess of the present mean cropland diversion, effective precipitation, and root zone storage needed to fully meet all crop potential consumptive uses. The (ADEF or ASR) versus E_i curve shows the volume of water in addition to or in excess of the present

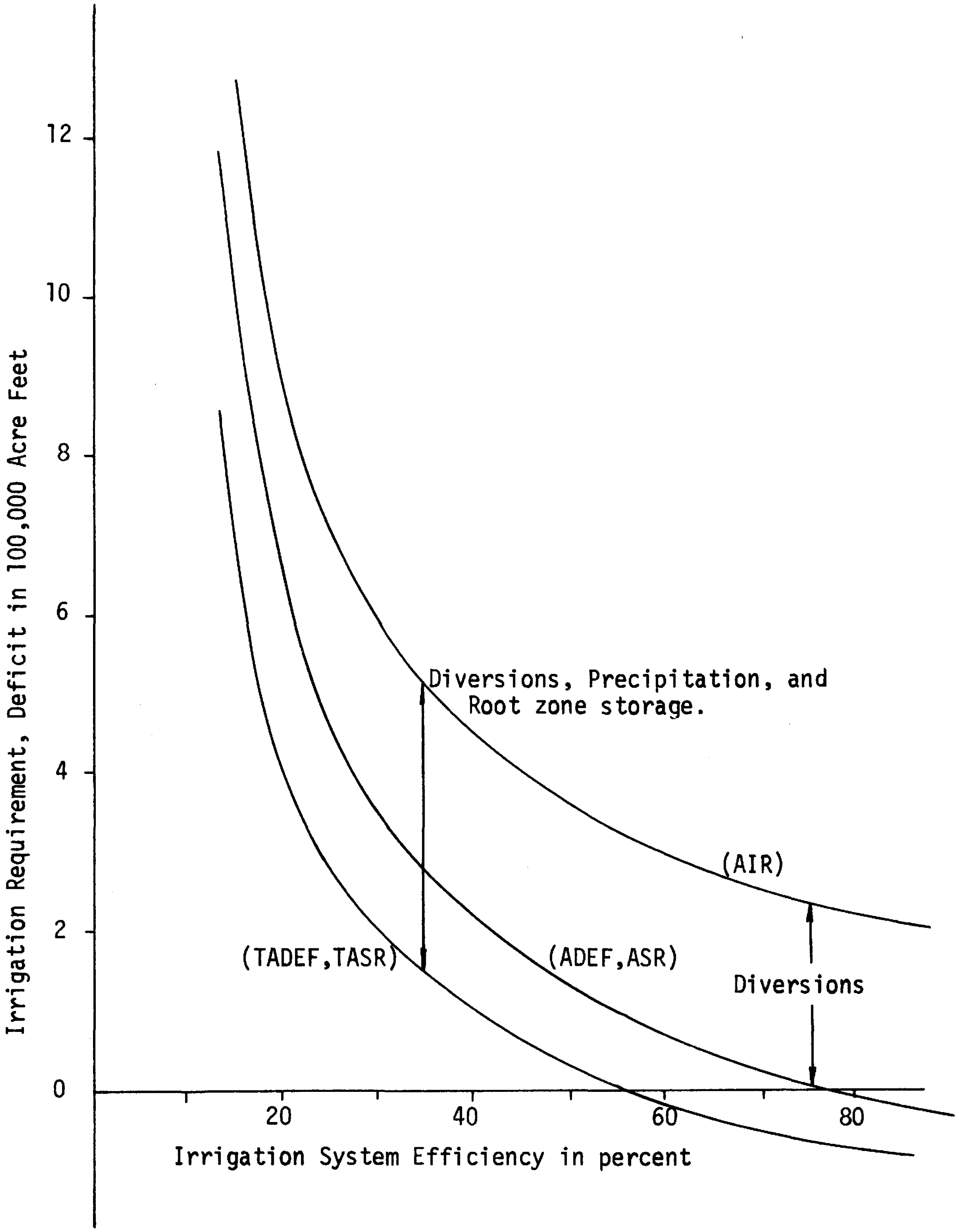


Figure 9. Annual irrigation requirement (AIR), annual deficit (TADEF) or surplus (TASR) including root zone storage, and annual deficit(ADEF) or surplus (ASR) excluding root zone storage versus irrigation system efficiency (E_i), Bear River delta.

mean cropland diversions that would be needed to meet all crop potential consumptive uses provided all crop potential consumptive uses are to be met by cropland diversions only. From these curves the irrigation requirement and the required cropland diversions can be determined provided the irrigation system efficiency is known.

Monthly Irrigation Requirement, Deficit or Surplus

Figures 10 to 15 show the variations in monthly irrigation requirement (MIR), monthly deficit (DEF) or surplus (SR) excluding precipitation and root zone storage, and the monthly deficit or surplus including precipitation and root zone storage (TMDEF or TMSR) at various irrigation system efficiencies for the months in the growing season. These curves were developed similarly to the curves developed for the annual values in the previous section.

The highest irrigation requirement occurs in the month of July and results in a large deficit for that month. The early growth months, April and May, show small deficits or in some instances small surpluses at the higher irrigation system efficiencies. The late season months, September and October, normally exhibit a surplus at the higher efficiencies.

The monthly effect of the water stored in the root zone and the effective precipitation on the quantity of water required can be seen by examining Figures 10 to 15. Figures 12 and 13 show the effect of these parameters for the months of July and August respectively. For these two months the available storage in the root zone is relatively large, but the precipitation is extremely small and the

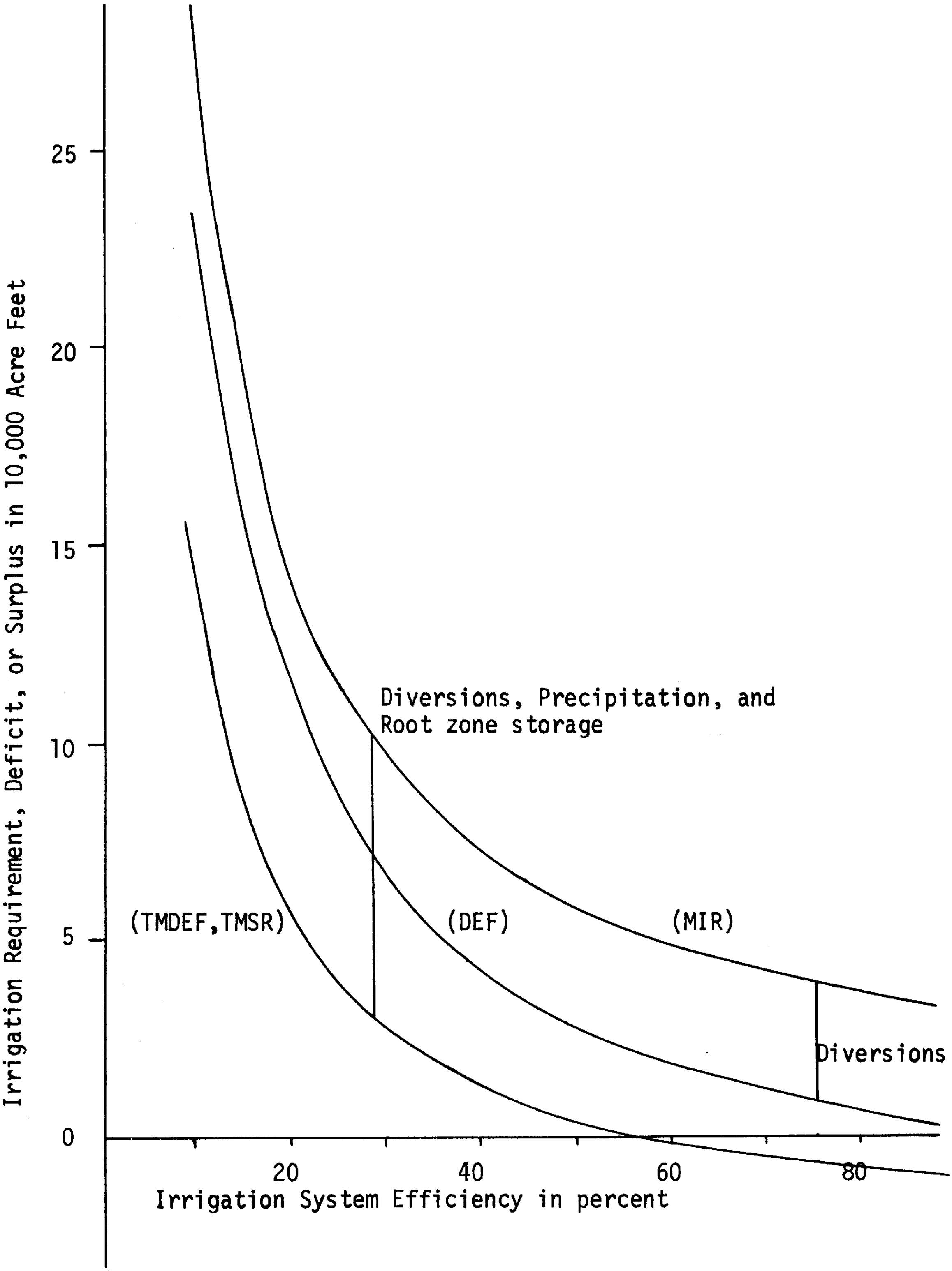


Figure 10. Mean monthly irrigation requirement (MIR), monthly deficit (TMDEF) or surplus (TMSR) including root zone storage, and monthly deficit (DEF) or surplus (SR) excluding root zone storage versus irrigation system efficiency (E_i) for May, Bear River delta.

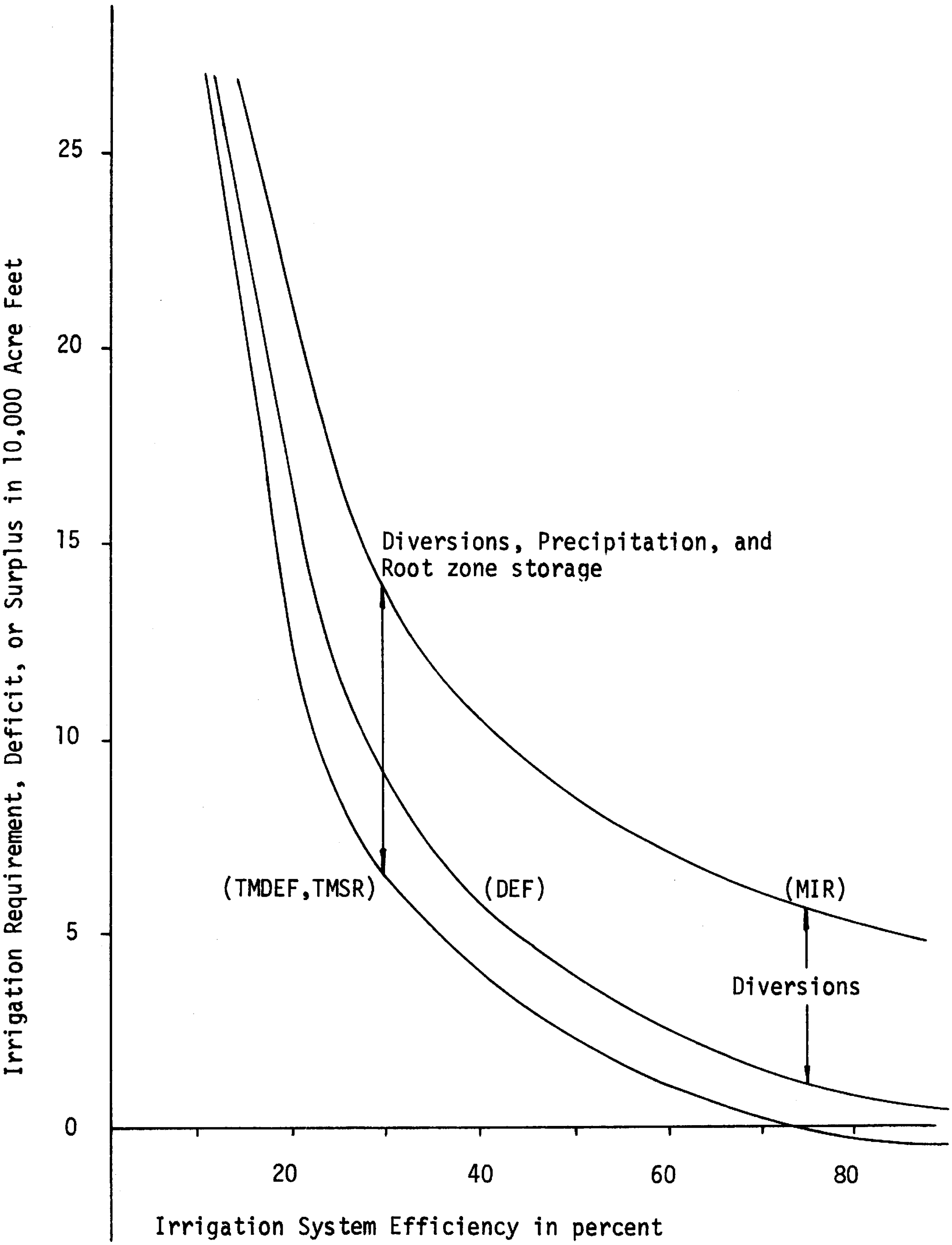


Figure 11. Mean monthly irrigation requirement (MIR), monthly deficit (TMDEF) or surplus (TMSR) including root zone storage, and monthly deficit (DEF) or surplus (SR) excluding root zone storage versus irrigation system efficiency (E_i) for June, Bear River delta.

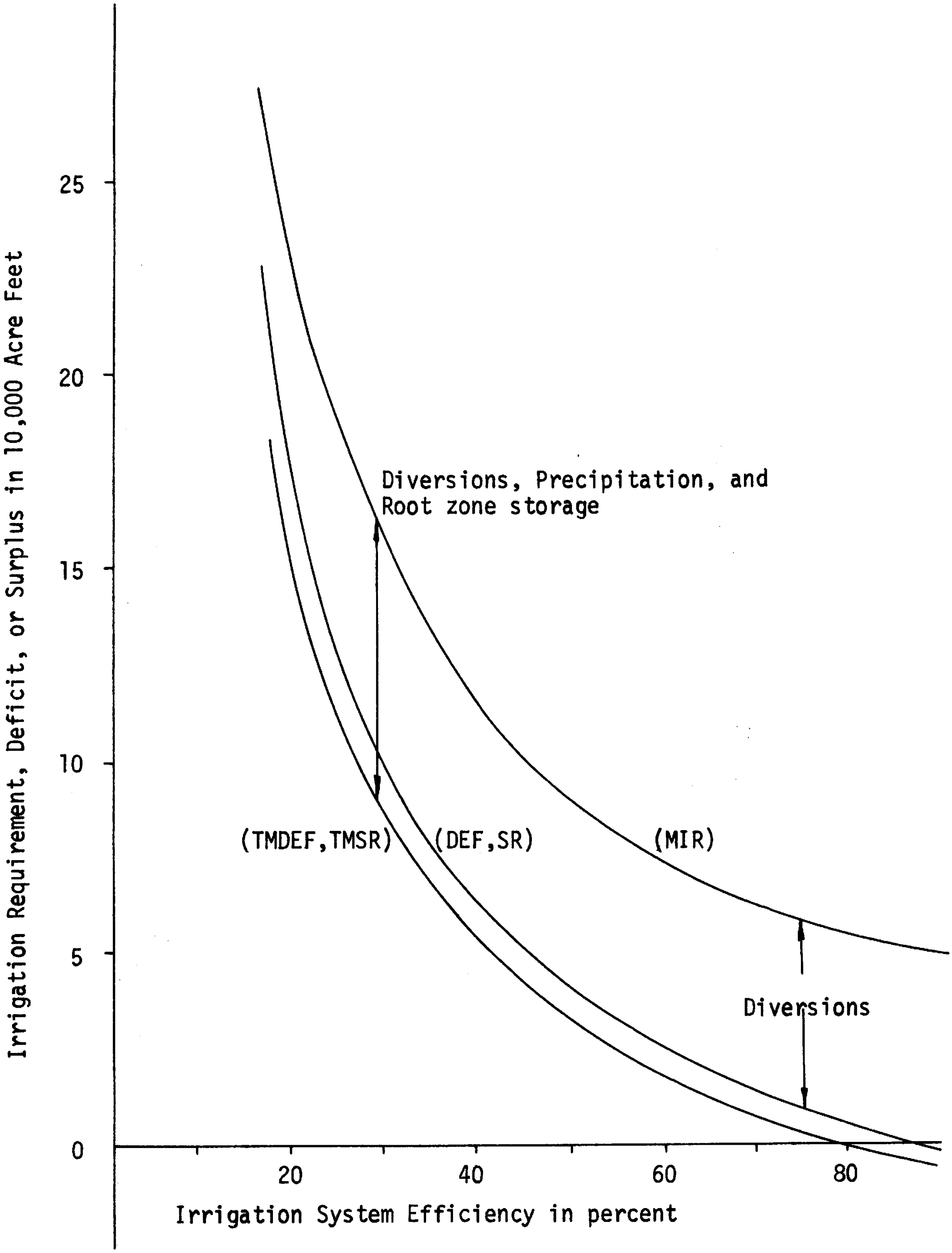


Figure 12. Mean monthly irrigation requirement (MIR), monthly deficit (TMDEF) or surplus (TMSR) including root zone storage, and monthly deficit (DEF) or surplus (SR) excluding root zone storage versus irrigation system efficiency (E_i) for July, Bear River delta.

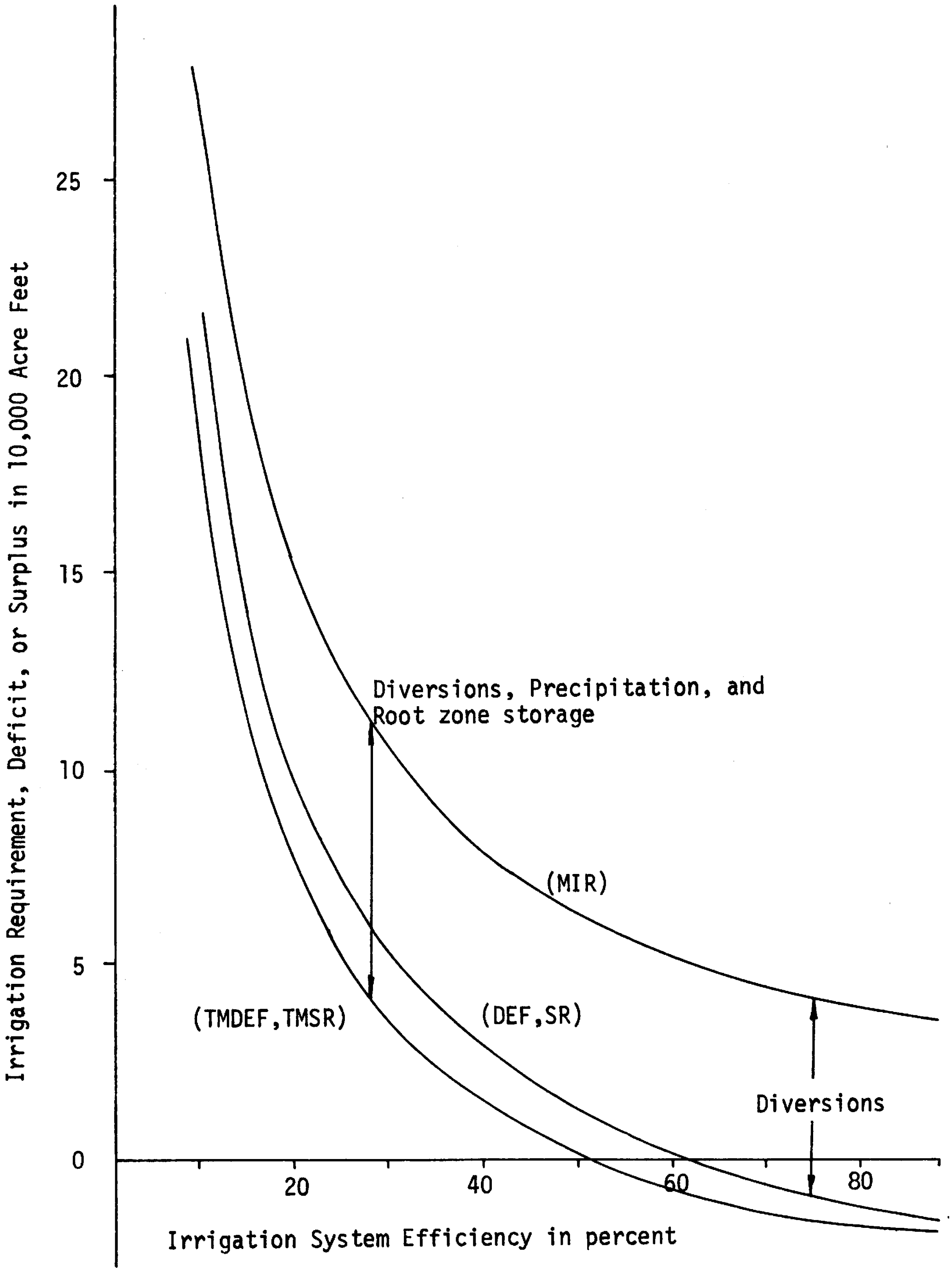


Figure 13. Mean monthly irrigation requirement (MIR), monthly deficit (TMDEF) or surplus (TMSR) including root zone storage, and deficit (DEF) or surplus (SR) excluding root zone storage versus irrigation system efficiency (E_i) for August, Bear River delta.

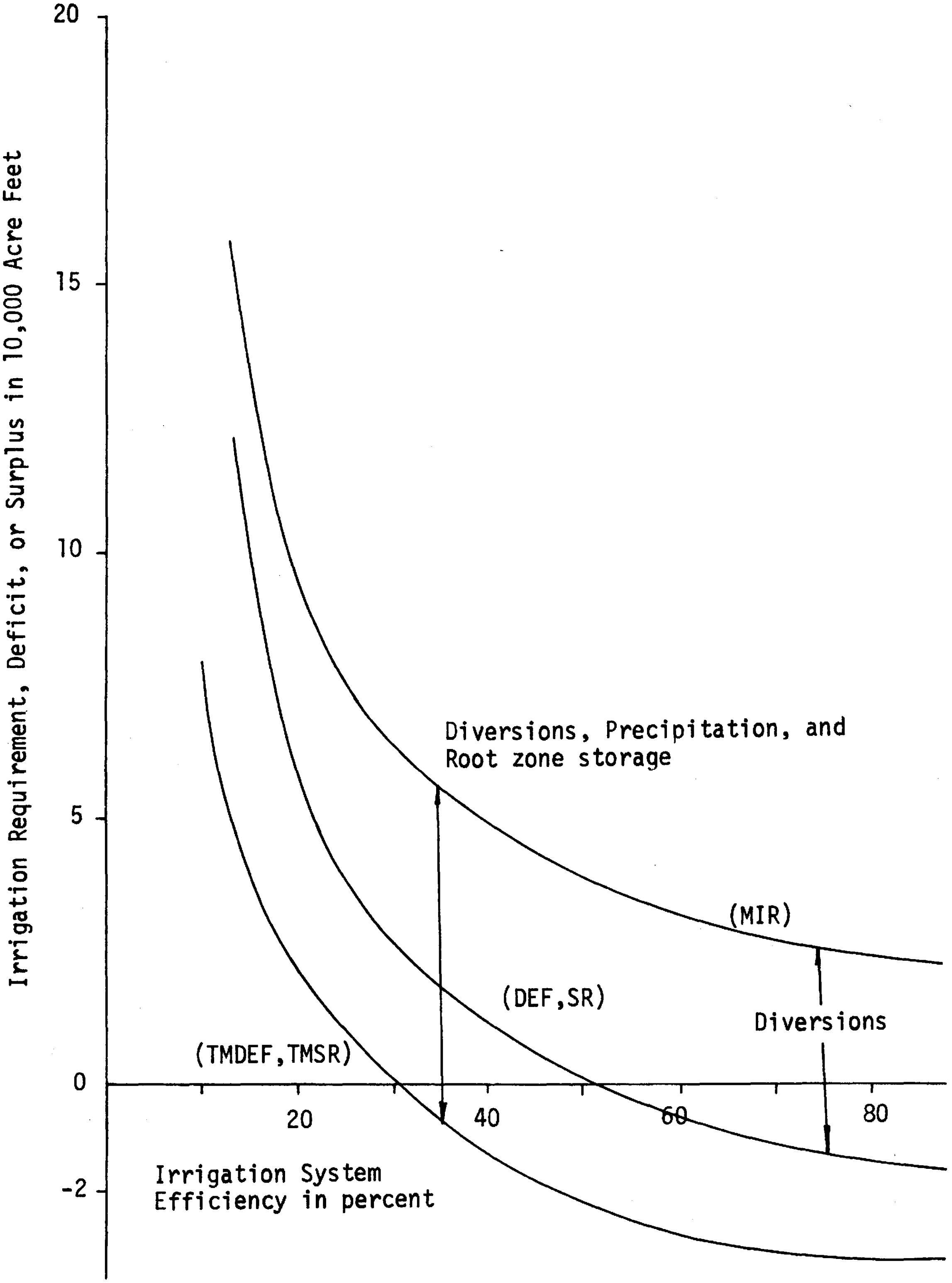


Figure 14. Mean monthly irrigation requirement (MIR), monthly deficit (TMDEF) or surplus (TMSR) including root zone storage, and monthly deficit (DEF) or surplus (SR) excluding root zone storage versus irrigation system efficiency (E_i) for September, Bear River delta.

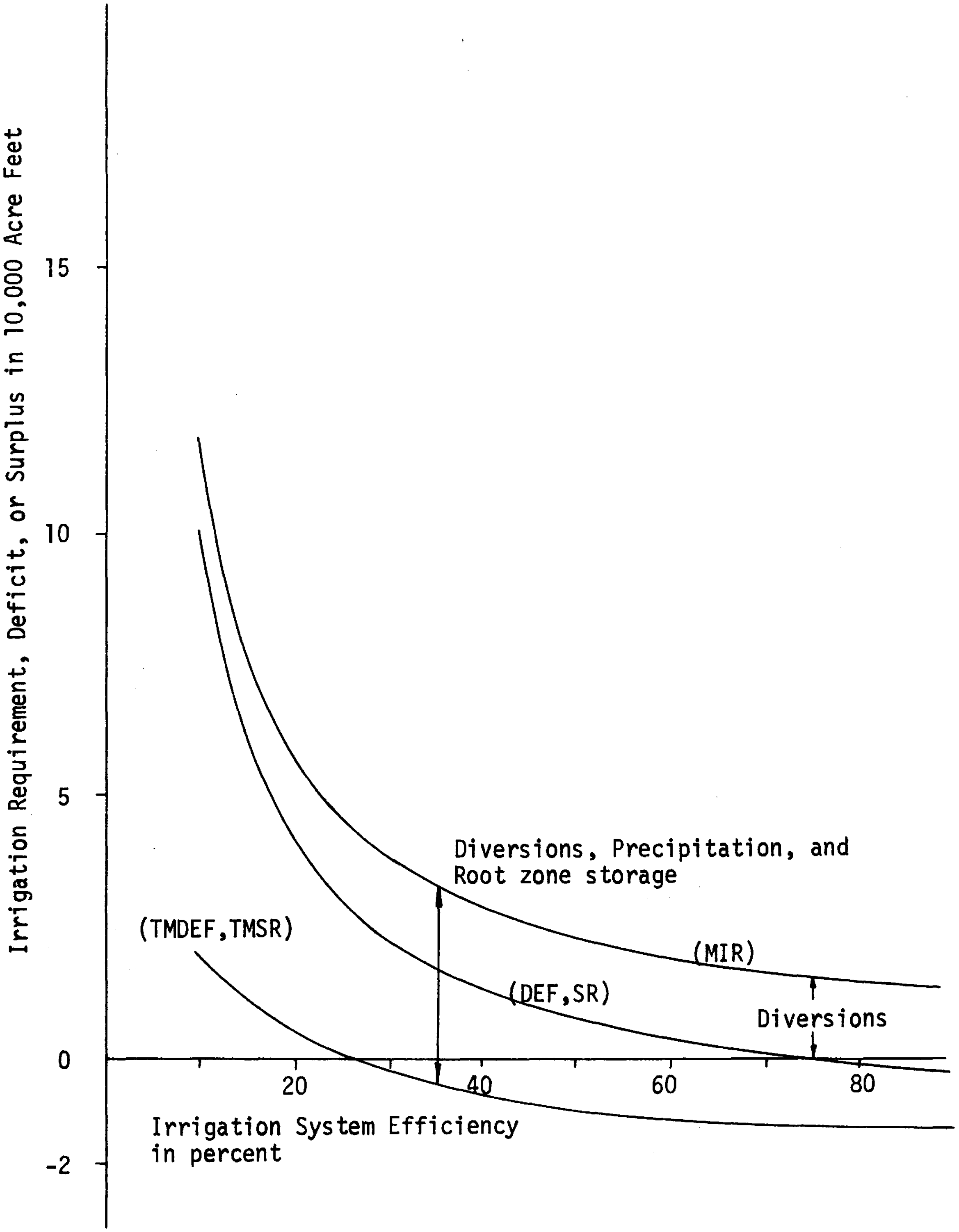


Figure 15. Mean monthly irrigation requirement (MIR), monthly deficit (TMDEF) or surplus (TMSR) including root zone storage, and monthly deficit (DEF) or surplus (SR) excluding root zone storage versus irrigation system efficiency (E_i) for October, Bear River delta.

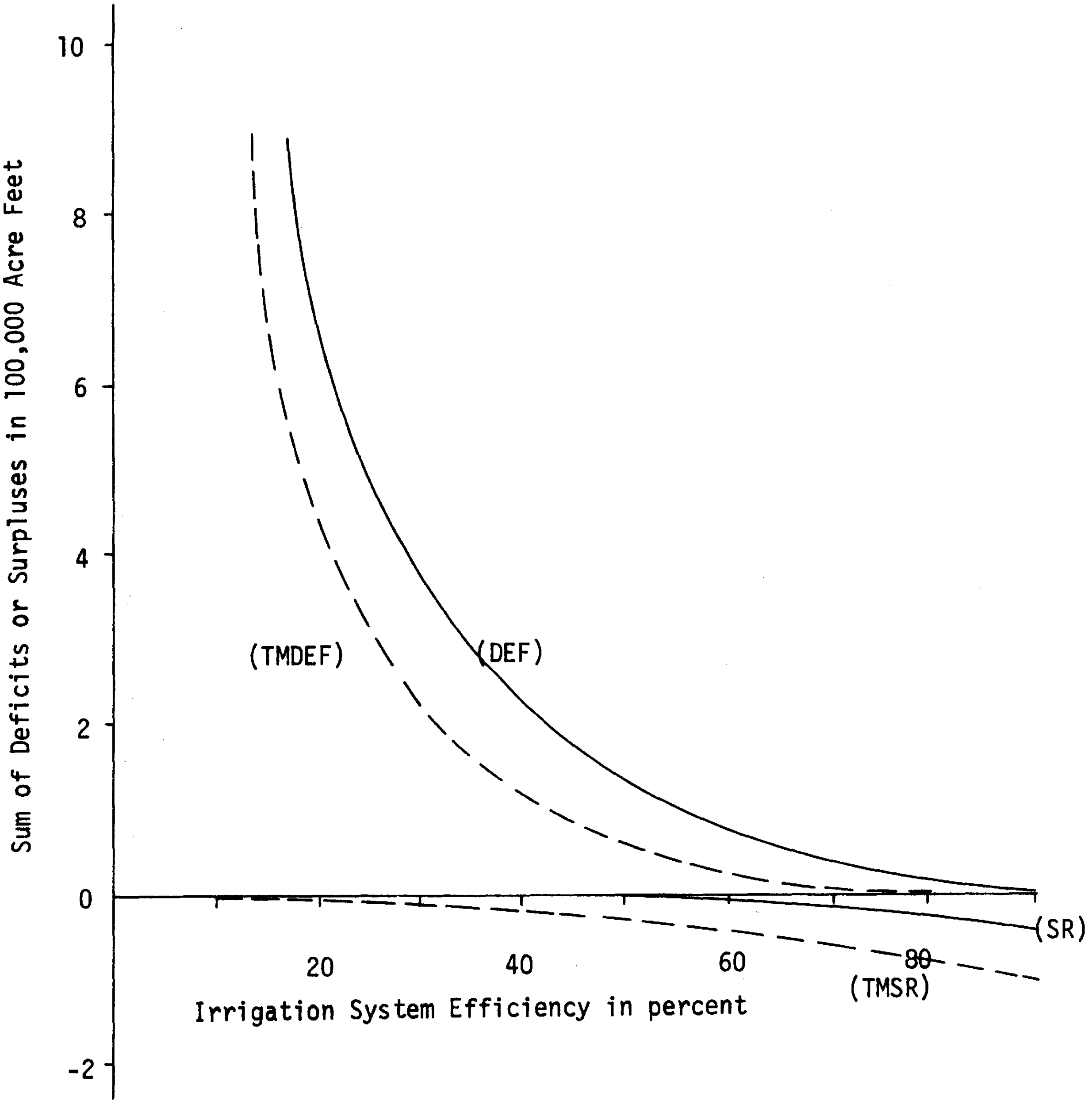


Figure 16. Sum of monthly deficit (DEF) excluding root zone storage, and deficit (TMDEF) including root zone storage; or monthly surplus (SR) excluding root zone storage, and surplus (TMSR) including root zone storage versus irrigation system efficiency (E_i), Bear River delta.

irrigation requirement is high. The two curves (TMDEF or TMSR) and (DEF or SR) are, therefore, close together indicating very little effect due to the available root zone storage or the effective precipitation. Root zone storage and precipitation, however, are significant factors in the early growth months of May and June and in the late growth months of September and October. In the early months (Figures 10 and 11) very little root zone storage is available because of the large concentration of water in the root zone which accumulated during the winter or non-growth months. The soil moisture reservoir is filled to near capacity during the early spring due to the low consumptive use requirements and the large supply available from spring snow melt. The precipitation during the early growth months is large enough to cause a significant effect on the deficit or surplus. In the late growth months (Figures 14 and 15) the available root zone storage is significantly larger because of the depletion of the soil moisture by the plants during the high consumptive use months of July and August. The precipitation for these months is larger than the maximum growth months and more of this precipitation will satisfy the crop consumptive uses.

Annual Deficit or Surplus

The annual or seasonal deficit or surplus is the sum of the monthly deficits or surpluses, summed over the growing season.(Figure 16) This curve alone tells very little about any time maldistribution of the water supply. For example, a deficit may occur during the maximum growth months and a surplus exist in the early and late growth months with the annual deficit equaling zero. The crops would have more than adequate water during the early and late growth months but would be suffering from a water shortage during the high growth months. The result of this type of analysis would be to conclude that based on the annual deficit, all crop potential consumptive uses are being met and no additional cropland diversions are needed; when in fact, the crop yield is being reduced due to the shortage of water in the high growth months.

Figures 9 to 16 show the irrigation requirements, deficits, and surpluses for the annual and monthly time periods. Tables 12 to 17 contain the tabulated values for the annual and monthly irrigation requirements, deficits, and surpluses for the Bear River delta.

Percent of Irrigation Requirement Satisfied

The percent of the irrigation requirement that is satisfied by the present cropland diversion quantities, at any given irrigation system efficiency, was determined. For this study the percent of the irrigation requirement satisfied was based on the cropland diversions, effective precipitation, and the available storage in the root zone.

The percent of the irrigation requirement satisfied may be determined for both the monthly irrigation requirement (PMIR) and the annual irrigation requirement (PAIR) using the following simple expression:

$$\text{PMIR} = \frac{\text{TMIR} - (\text{TMDEF or TMSR})}{\text{TMIR}} \times 100 \quad . \quad . \quad . \quad . \qquad 20$$

where:

PMIR is the percent of the monthly irrigation requirement satisfied by present cropland diversions, precipitation, and available root zone storage.

TMIR is the monthly irrigation requirement in acre feet.

TMDEF or TMSR is the monthly deficit or surplus including precipitation and root zone storage in acre feet. A surplus is represented by a negative quantity.

Equation 20 is written for monthly percent of irrigation requirement satisfied. In order to calculate the percent of the annual irrigation requirement satisfied (PAIR), substitute the annual deficit or surplus (TADEF or TASR) and the annual irrigation requirement (TAIR) into equation 20.

Since a surplus is by defination a negative quantity, when a surplus exists the percent of the irrigation requirement satisfied will be greater than 100 percent. Similarly, when no deficit or surplus exists, the percent of the irrigation requirement satisfied will be 100 percent. If a deficit occurs, the percent of the irrigation requirement satisfied will be less than 100 percent.

The relationship between irrigation requirement satisfied and the irrigation system efficiency is shown in Figures 17 to 19 and Tables 16 and 17. In general as the irrigation system efficiency increases, the percent of the irrigation requirement satisfied increases.

Another inportant relationship is between deficit (TMDEF or TADEF) or surplus (TMSR or TASR) and the percent of the requirement satisfied. Figures 20 to 22 and Tables 16 and 17 show this variation for the Bear River delta. For any given percent of irrigation requirement satisfied, the required irrigation system efficiency (E_i) can be determined from Figures 17 to 19 and the deficit or surplus at that irrigation system efficiency can be determined from Figures 9 to 15.

The percent of irrigation requirement satisfied varies inversly with the deficit and directly with the surplus. (Figures 20, 21, 22) This indicates as the deficit increases, the percent of the irrigation requirement satisfied will tend to decrease. All curves have zero deficits or surpluses at 100 percent of the irrigation requirement satisfied. As the surplus increases, the percent of irrigation requirement satisfied will tend to increase.

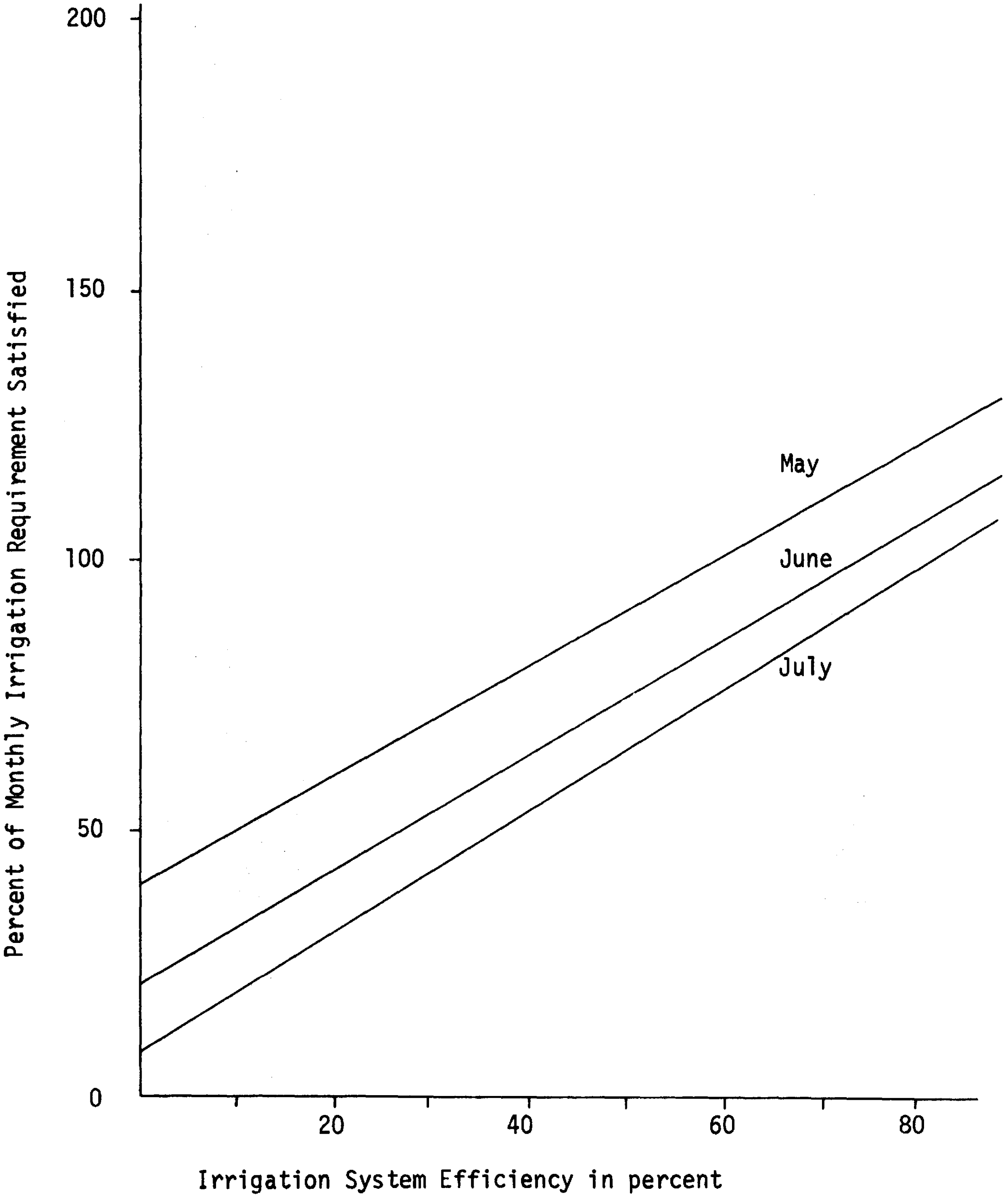


Figure 17. Percent of monthly irrigation requirement satisfied (PMIR) versus irrigation system efficiency for June, July, and May.

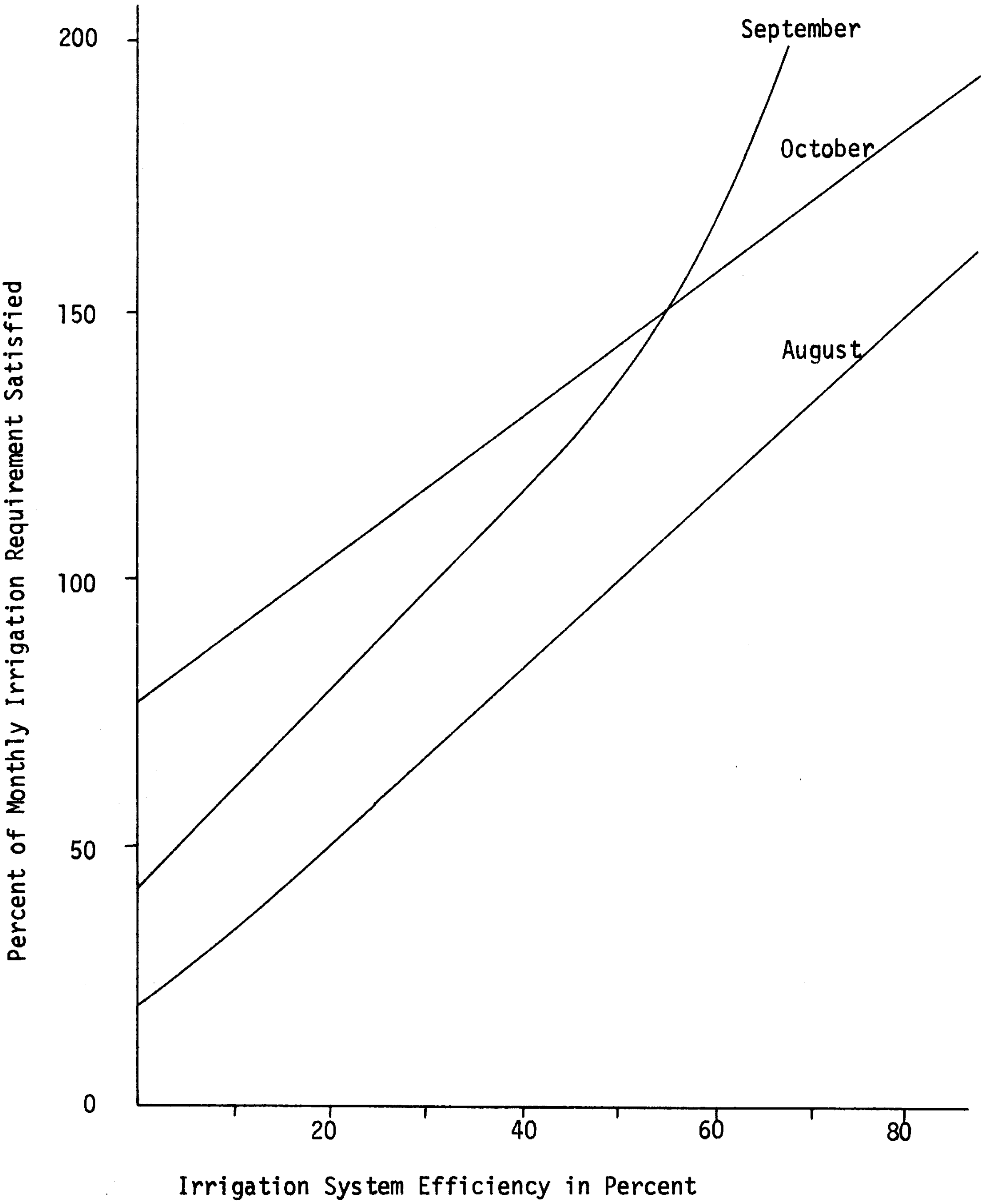


Figure 18. Percent of irrigation requirement satisfied (PMIR) versus irrigation system efficiency for August, September, and October.

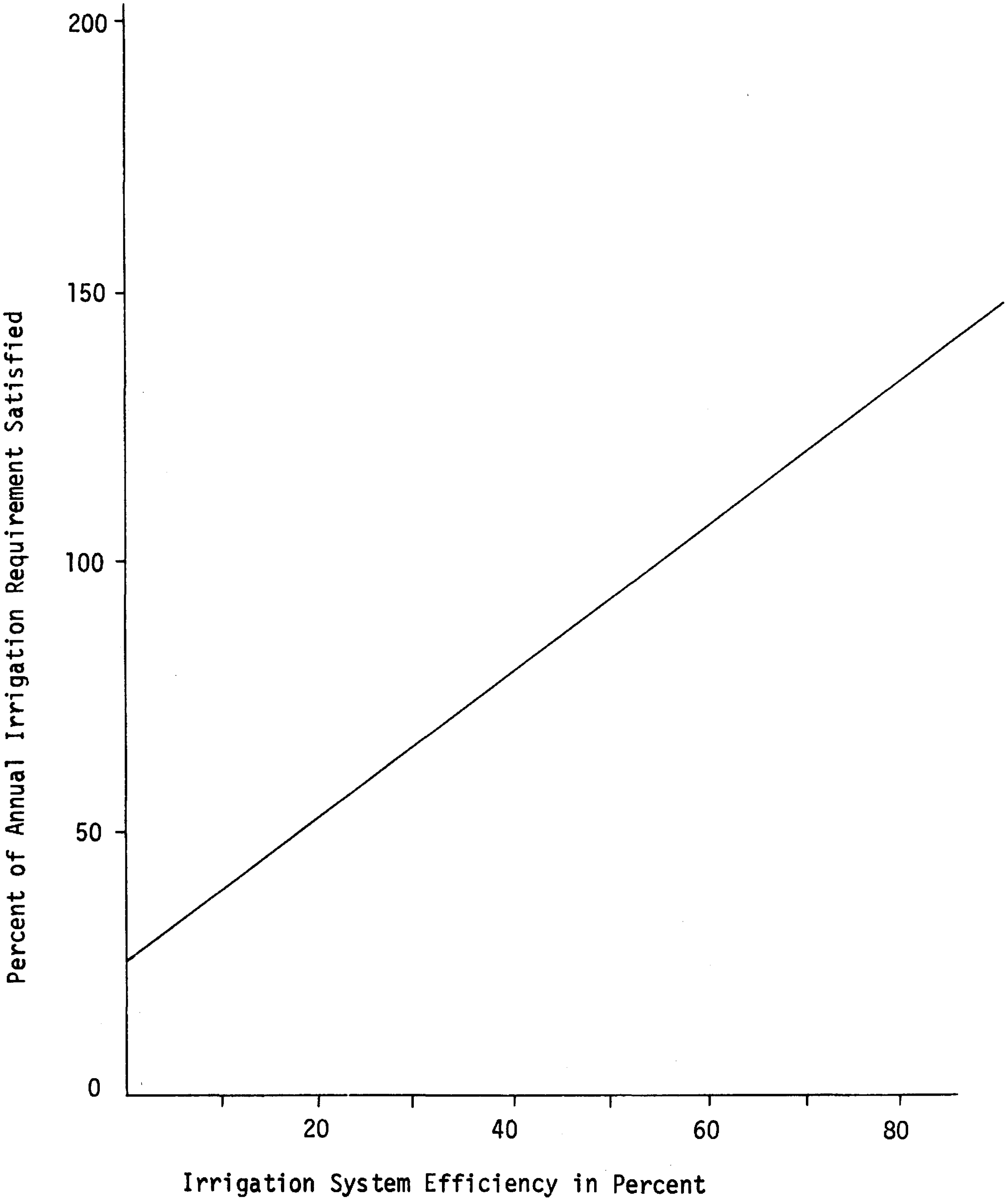


Figure 19. Percent of annual irrigation requirement satisfied (PAIR) versus irrigation system efficiency, Bear River delta.

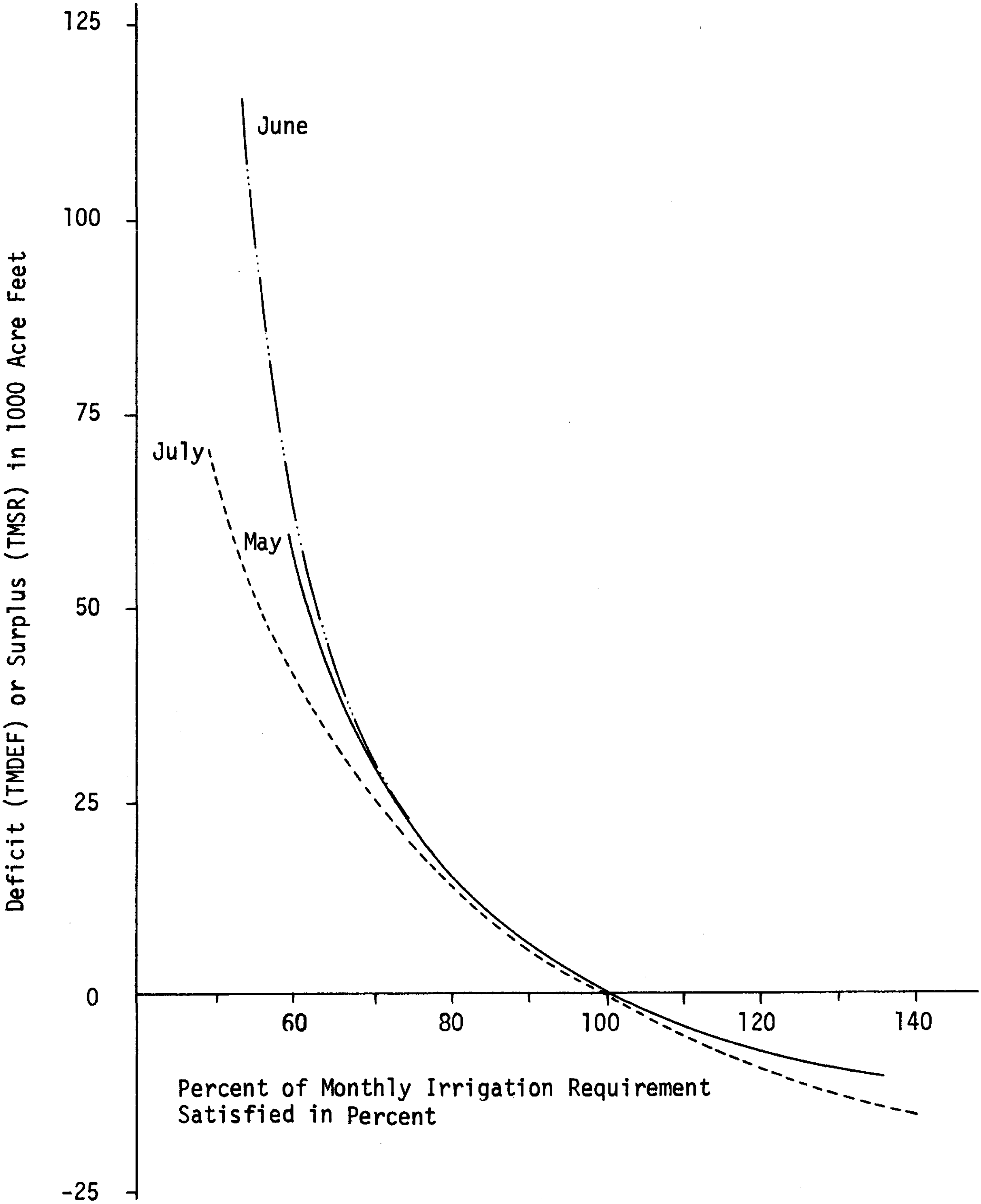


Figure 20. Percent of monthly irrigation requirement satisfied (PMIR) versus monthly deficit or surplus including root zone storage, Bear River delta.

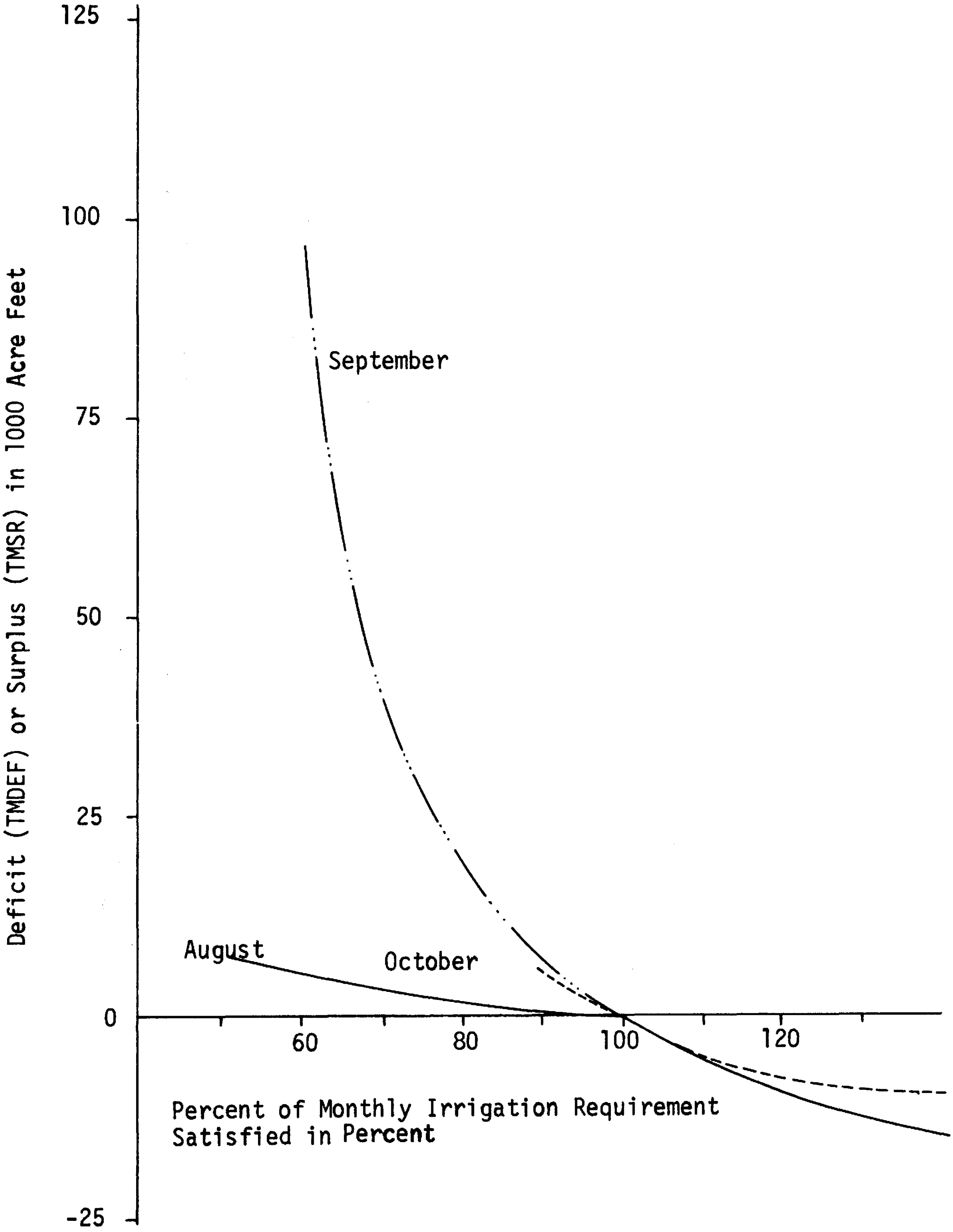


Figure 21. Percent of monthly irrigation requirement satisfied (PMIR) versus monthly deficit (TMDEF) or (TMSR) including root zone storage, Bear River delta.

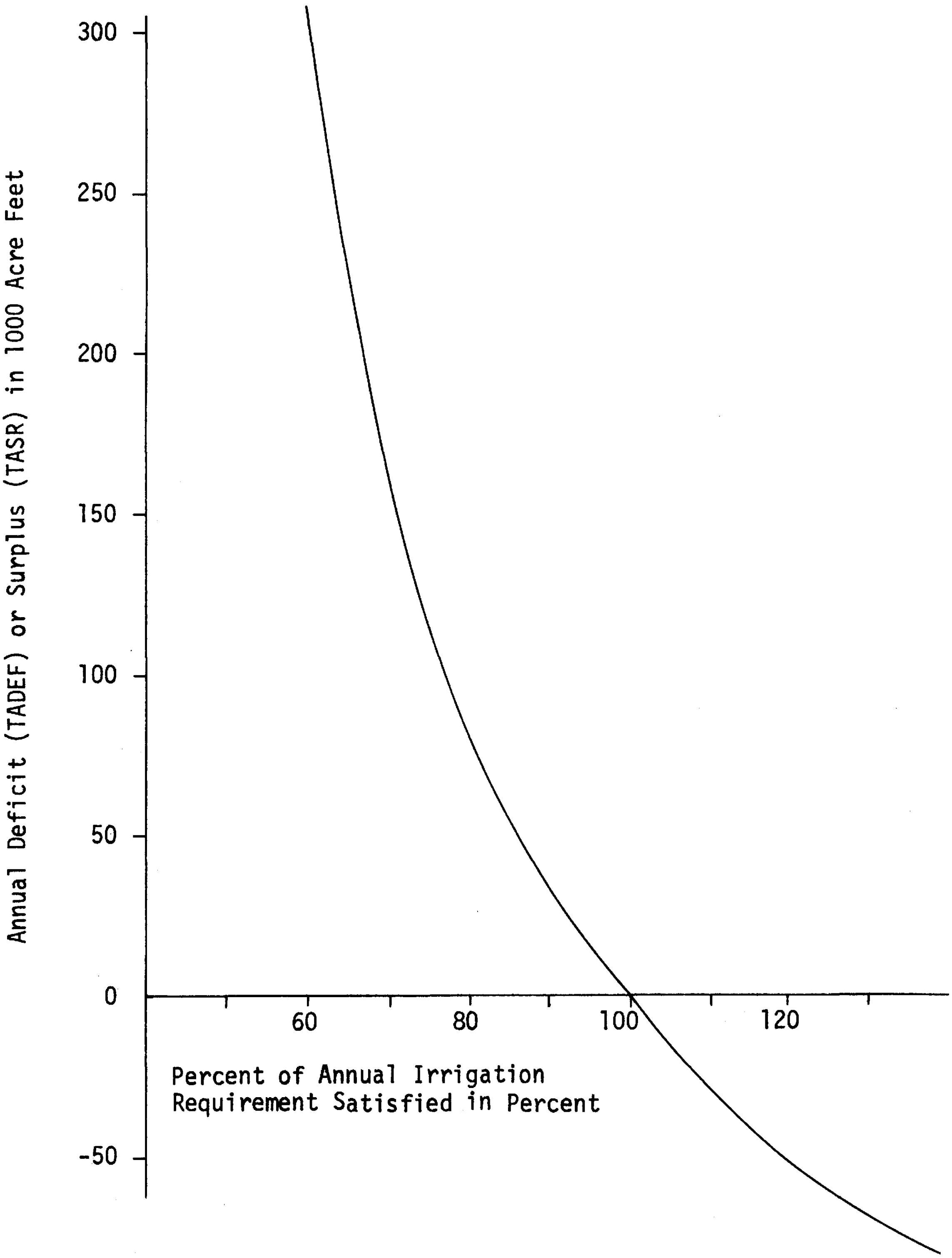


Figure 22. Annual deficit (TADEF) or surplus (TASR) including root zone storage versus percent of annual irrigation requirement satisfied (PAIR), Bear River delta.

CHAPTER VI

WATER MANAGEMENT POTENTIAL

Procedure

Water management may be defined as the application of technical and organizational skills in order to provide adequate water supply in the desired place at the desired time for the intended use. (Mizue, 1968, p 76) In the evaluation of present water management potential, several variables are important to consider. These quantities were derived and discussed in detail in the previous chapter. The relationships between irrigation system efficiency, deficit or surplus, and the percent of irrigation requirement satisfied are important indicators of the water management potential.

Management Potential, Bear River Delta

In Chapter IV it was estimated that the irrigation system efficiency for the Bear River delta was 44 percent. At a system efficiency of 44 percent, the annual irrigation requirement was 439,000 acre feet. The present mean annual cropland diversions was only 243,000 acre feet; therefore, not all crop consumptive uses are being met at present operating efficiencies. Table 8 shows the summary of the water management potential variables for the delta area. Deficits exist in the months of May, June, July, and August at the present irrigation system efficiency with the total deficit for these months being 110,000 acre feet. Surpluses exist

Table 8. Summary of water management potential variables[1]

	May	June	July	August	September	October	Annual
Irrigation Requirement Acre Feet	71	102	109	76	48	29	435
Percent of Irrigation Requirement Satisfied in percent	82	65	55	85	132	119	81
Deficit in Acre Feet	13	35	50	12	0	0	89
Surplus in Acre Feet	0	0	0	0	-13	-8	0

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[1] Obtained from figures 10 to 20. All entries in 1000 acre feet

in the months of September and October and results in a total surplus for these months of 21,000 acre feet. The total annual deficit is the sum of the monthly deficits and surpluses and is, therefore, 89,000 acre feet; however, this points out a basis weakness in this type of analysis and will be discussed in more detail later.

From Table 8 it can be seen that only 81 percent of the annual irrigation requirement is being satisfied at the present irrigation system efficiency. This figure may be misleading because the percent of monthly irrigation requirement satisfied varied from a minimum of 55 percent in July to a maximum of 132 percent in September. This indicates a time maldistribution of the water supply.

Limitations of Water Management Potential Analysis

As previously stated, the annual deficit or surplus is the sum of the deficit or surplus for the individual months. By using the annual deficit or surplus alone as an indicator of water management potential, any time maldistribution of the supply is concealed. For example, in the delta area the early growth months and the maximum growth months all show a deficit with a total deficit of 110,000 acre feet. The late growth months, however, show a surplus with a total surplus of 21,000 acre feet. The annual deficit is, therefore, 89,000 acre feet; however, with an additional cropland diversion of 89,000 acre feet per year, the crop potential consumptive use will still not be completely met in the month of July. In order to avoid this problem, the management analysis should be conducted on a monthly basis instead of an annual basis.

It should be pointed out that all calculations are based on mean monthly data. Therefore, it can be expected that on the average an additional 89,000 acre feet would be required to meet all crop requirements; however, this value can be expected to vary considerably for any particular year. For example, the standard deviation of the total river inflow into the delta area about its mean value is 346,638 acre feet while the mean value of the river inflows is 1,116,010 acre feet. This example points out the expected large variations of the input variables about their mean values. The annual requirement and the annual deficit or surplus will also vary about their mean values in a similar manner. Some method will have to be incorporated into any water management scheme to store the excess water in years of surplus, to be redistributed in years of short supply.

Water Management Proposals

Table 7, Chapter IV, shows the estimated irrigation system efficiency for the Bear River delta. It is difficult and somewhat arbitrary to try to propose a management scheme to improve water management because of the difficulty in evaluating the economics of each management proposal. Therefore, an attempt has been made to outline broad proposals which would tend to improve water management and to estimate the expected improvement in the irrigation system efficiency and the management potential variables.

First it is necessary to look at some of the possible factors that effect the efficient use of water in each component of an irrigation system. Most of these factors have been discussed in detail in Chapter IV; however, we are now interested in evaluating the best means of improving the efficiency of each component of the system.

Storage Efficiency

As previously stated, there are no large storage reservoirs located within the Bear River delta; however, any management scheme will most likely include some type of storage facility in order to provide an adequate storage reserve during periods of short supply. Any storage facility that is added to the system will tend to decrease the storage efficiency, but care in the selection of the reservoir sites will tend to minimize the effects of these reservoir losses. If storage reservoirs are added to the system, it is estimated that the storage efficiency would be 85 to 90 percent, provided proper site selection procedures were followed.

Conveyance Efficiency

The two major factors which affect the conveyance efficiency are seepage losses in the canals and laterals and evaporation and evapotranspiration losses. Seepage losses can be reduced or effectively stopped by lining the major canals and laterals. Several types of lining material have been effectively used in controlling seepage losses. The most inexpensive of these linings would be compacted earth linings, but these are usually the most ineffective method. In general, the effectiveness of compacted earth linings tend to decrease with use, especially if a program of phreatophyte control is not practiced. Other linings that have proven to be sucessful include polyester plastics, concrete, and asphalt. Seepage losses can also be reduced or eliminated by using pipelines to replace the open surface canals that are presently being used. This method would be effective in reducing water surface evaporation and phreatophyte evapotranspiration but is more expensive to implement.

Evapotranspiration losses can be an important factor in the conveyance losses of an irrigation system. Comprehensive programs of phreatophyte control have been shown to be an effective means of reducing these losses from the system; however, it is often difficult and uneconomical to completely eliminate all phreatophyte growths in and around an irrigation canal. Water surface evaporation can be reduced by proper design of the canals in order to minimize the exposed surface area.

Another factor in conveyance efficiency is operational losses. These losses are a direct result of poor management in the operation of the system but in general are insignificant in most properly operated systems.

It is estimated that the conveyance efficiency could be increased to 88 to 92 percent by lining the canals and implementing a comprehensive program of phreatophyte control. However, by implementing a closed conduit conveyance system, the estimated conveyance efficiency could be increased to 96 to 98 percent.

Application Efficiency

The present application efficiency for the Bear River delta was estimated to be approximately 55 percent. However, by proper water and land management practices, the farmer could increase this considerable. The estimates of component efficiency made in Chapter IV shows the application component to be the most inefficient for the Bear River delta system. Therefore, an increase in this component efficiency would have a greater effect on the total irrigation system efficiency than an increase in the two previously discussed factors.

The farmer could improve his application efficiency by properly preparing his land. This would include properly leveling the irrigated lands whenever possible in order to achieve a more uniform application of irrigation water and adequately working the land during the growing season in order to provide a good seed bed at planting time and to maintain a high infiltration rate throughout the growing season.

The individual farmer, in the management of his farm, is faced with the problem of determining when to irrigate and how much water to apply. To answer these questions, he needs to know the moisture holding capacity of the soil and the day to day variations in the soil moisture content. The soil moisture capacity can be determined by soil classification and crop rooting depths. There are several methods of determining the soil moisture content, some more sophisticated than the others. The farmer may obtain this information by taking daily samples and determining the soil moisture content, or he may install remote sensing instruments which will provide him with a continuous monitor on the soil moisture level.

Uniform application of irrigation water is a basic assumption in all the analysis to this point. One method of achieving a more uniform distribution of applied water is by sprinkler irrigation systems. Under controlled conditions, surface irrigation systems reached an application efficiency of 70 percent while sprinkler irrigation systems under similar conditions reached an application efficiency of 70 to 80 percent. (Bagley, 1956; Myers and Haise; Woodward, 1959) Field test by Bagley and others (1956) show sprinkler shstems had application efficiencies of approximately 72 percent as compared to surface irrigation systems with application efficiencies of approximately 50 percent. These studies all point out the increase in application efficiency due to the implementation of a sprinkler irrigation system. Sprinkler systems have also made possible the irrigation of lands that were previously not irrigable. These lands could not be irrigated by surface methods because of steep slopes or topography that would have required considerable leveling.

Another factor to be considered in this management study is providing water on an "on call" basis. This indicates the farmer has the ability to order water in the quantities required and at the time required instead of the "term" basis presently being used in most systems. During the maximum growth months, July and August, it is possible for the crops to require more water than is available using the turn method and the result is a reduction in the crop yield. In order to provide water on an "on call" basis, large storage and substantially larger canal facilities would have to be provided. In general the advantages in the "on call" system is offset by the increased losses due to larger storage and canal facilities and the cost of providing these facilities. It is estimated that having the water supply on the "on call" basis for surface irriagtion systems would tend to increase the irrigation application efficiency by an estimated 1 to 4 percent.

Tables 9 and 10 show the summaries of the estimated efficiencies for each management proposal.

Table 9. Summary of the estimated conveyance efficiencies for each management proposal.

Management Proposal	E_c	Average
Lining main canals and laterals	90-92	91
Evapotranspiration Control	81-83	82
Both the above management proposals	91-95	93

Table 10. Summary of the estimated application efficiencies for each management proposal.

Management Proposal	E_a	Average
Improving farm management and irrigation practices (1)	56-60	58
Sprinkler irrigation (2)	65	65
Water on call (3)	56-59	57
(1) and (2)	66-70	68
(1) and (3)	56-60	58

There are fifteen combinations of the management proposals listed in Table 9 and 10 that are feasible. The maximum future irrigation system efficiency was calculated to be approximately 62 percent and represents the optimal efficiency under the outlined management proposals. This optimum management proposal consisted of:

(1). Lining the main canals and laterals.

(2). Phreatophyte control and properly designed canal systems that minimize the evaporation losses.

(3). Eliminating or effectively reducing operational wastes through good management of the operations of the system.

(4). Improving farm management and irrigation practices by improving land preparations and education of the farmer as to methods of determining when to irrigate and how much water to apply.

(5). Using sprinkler irrigation systems whenever possible.

Deficit or Surplus at Future Irrigation System Efficiency

The maximum future irrigation system efficiency was estimated in the previous section to be 62 percent. From Figures 9 to 22, the water management potential variables for that irrigation system efficiency can be determined. Table 11 shows a summary of these water management potential variables. By comparing the results presented in Tables 8 and 11, the effect of these management schemes on the system can easily be seen.

For the future estimated irrigation system efficiency, no net annual deficit exists; however, there still is a time maldistribution in the diverted water. A deficit of 26,000 acre feet in the months of June and July still exists at this future efficiency. The percent of the annual irrigation requirement satisfied is 109 percent, but

Table 11. Summary of the water management potential variables for the future irrigation system efficiency.[1]

	May	June	July	August	September	October	Annual
Irrigation Requirement Acre Feet	48	68	71	53	31	19	290
Percent of Irrigation Requirement Satisfied in Percent	103	87	78	118	174	158	109
Deficit in Acre Feet	0	9	17	0	0	0	0
Surplus in Acre Feet	-2	0	0	-9	-29	-12	-26

[1] Obtained from Figures 10 to 20. All entries in 1000 acre feet.

only 87 percent and 78 percent of the monthly irrigation requirement is being met in the months of June and July respectively.

CHAPTER VII

CONCLUSIONS

Under the present cropland diversions and irrigation system efficiency, the crop needs for the Bear River delta are not being fully met. A net increase of 89,000 acre feet in the mean annual cropland diversion would be required in order to meet all crop potential consumptive uses. However, by looking at the monthly deficits, an increase of 110,000 acre feet would be required to meet crop requirements for the months of May, June, and July provided the surplus of 21,000 acre feet in September and October could not be redistributed and used in May, June,and July.

It should be pointed out at this time that decreasing the system "losses" may not increase the quantity of water available downstream. As stated earlier, these losses are not losses to the system as a whole because the water enters other phases of the hydrologic cycle. It may be that a large portion of the downstream flow is made up of return flows from the upstream agricultural lands. In this case, lining the canals and laterals may actually decrease the net quantity of water available downstream. Therefore, the statement that lining the canals and laterals would tend to increase the system efficiency has to be made with the above possible reservation. It is believed because of the small size of the study area and the location in relation to the Great Salt Lake that lining the canals would improve the quantity of water available in the Bear River delta area.

By implementing the management scheme outlined in the previous chapter, the estimated irrigation system efficiency would be increased from 44 percent to 62 percent. At this system efficiency, the above deficit would disappear however, the crop requirements would still not be adequately met on the monthly basis since a deficit would still exist in the months of June and July. This deficit could be eliminated by providing storage facilities to store the surplus water from the non-growth months and redistribute it in the months of deficits.

The frequency distribution of the available river supply is such that this additional diversion required under present system efficiency is not available at the time this additional water is required. If there is no expansion of the irrigated crop acreages within the delta area, this additional water could be stored during the early season months (February, March, April, and May) and redistributed during the peak demand months. It should be pointed out that enough water is available within the delta area to meet all crop needs provided this water could be redistributed in time to coincide with the peak water demands.

As pointed out earlier in this report, an analysis of this type is limited in its usefulness unless it is integrated into a total basin management study. Therefore, a similar study is needed for all the subareas of the Bear River system in order to evaluate the water management of the scheme and the effect of upstream management decisions on the Bear River delta. Another useful future study would be to evaluate the economics of the management scheme proposed.

Future Exportation of Bear River Water

The Bear River flows into the Great Salt Lake with an annual flow of close to 900,000 acre feet. This water is lost by evaporation and wasted as far as other potential beneficial uses are concerned. Some people are discussing the possibility of exporting water from the Bear River into the Ogden - Salt Lake City areas to be used for municipal, industrial, and irrigation water supplies.

Under the present uses in the Bear River delta, there is water available for export; however, as pointed out in the previous section the crop needs in the delta are are not presently being fully met. If an additional 110,000 acre feet were diverted and stored within the delta area alone, the total outflow would be approximately 750,000 acre feet. If it can be assumed that the additional diversions required in the other subareas of the Bear River system are not significantly large, the flow of 750,000 acre feet would be available subject to water quality requirements and the requirements of the ecology of the Great Salt Lake and sorrounding areas.

One major consideration in any water resource planning is the effect the plan will have on water quality. Even though no major water quality problems exist now, a minimum flow would probably be required in order to assure no water quality problems arise in the future. A minimum low flow of 120,000 acre feet per year or approximately 10,000 acre feet per month was selected for this study. Considering this minimum required low flow, a total available supply for export of 630,000 acre feet would be possible. This water would be available, to a large extent, during the winter months and would therefore require large storage facilities at the point of useage in order to provide the water at the time required.

This study has arbitrarily classified the recreational uses of the Great Salt Lake as insignificant beneficial uses. It also assumed that water flowing into the lake is lost for other beneficial uses. The diversion of 630,000 acre feet of thelake's supply into other basins would tend to increase the rate of decline in the water level of the lake. At present the water levels in the Great Salt Lake are declining slowly, but eliminating the lake's largest source of fresh water supply would rapidly increase this decline. The diversion of this Bear River water would effect the marshes located along the northern edge of the lake. These marshes are presently the location of bird refuses and resting places for migrating water fowl.

Therefore, before any exportation scheme can be implemented, the water management and future water requirements of the remaining subareas of the Bear River will have to be evaluated. Also the effect of the loss of supply on the ecology of the Great Salt Lake and the surrounding areas would have to be investigated.

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APPENDICES

APPENDIX A

Table 12 to 16

Table 12. Mean irrigation requirement not including precipitation and root zone storage at various irrigation system efficiencies.

	MIR IN 1000 Acre Feet						AIR
E_I percent	May	June	July	August	September	October	Annual
10	292.9	414.7	468.0	312.2	192.0	116.2	1796.0
20	146.5	207.3	234.0	156.1	96.0	58.1	989.0
30	97.5	138.2	156.0	104.1	64.0	38.7	598.6
40	73.2	103.7	117.0	78.1	48.0	29.1	449.1
50	58.6	82.9	93.6	62.4	38.4	23.2	359.1
60	48.8	69.1	78.0	52.0	32.0	19.4	299.3
70	41.8	59.2	66.9	44.6	27.4	16.6	256.5
80	36.6	51.8	58.5	39.0	24.0	14.5	224.4
90	32.6	46.1	52.0	34.7	21.3	12.9	199.6

Table 13. Mean irrigation requirement including precipitation and root zone storage at various irrigation system efficiencies for the Bear River delta.

	TMIR IN 1000 Acre Feet						TAIR
E_I percent	May	June	July	August	September	October	Annual
10	176.2	328.2	428.7	260.8	116.5	28.0	1338.4
20	88.1	164.0	214.4	130.4	58.2	14.0	669.1
30	62.6	99.4	142.9	87.0	38.8	9.3	440.0
40	44.0	82.1	108.1	65.3	29.1	7.0	335.6
50	35.2	65.6	85.9	52.1	23.3	5.6	267.5
60	29.4	54.7	71.4	43.4	6.8	4.7	210.4
70	25.1	46.8	61.3	37.3	5.8	4.0	180.3
80	22.0	41.0	53.6	32.6	5.1	3.5	157.8
90	19.6	39.5	47.6	29.0	4.5	1.9	142.4

Table 14. Annual and monthly deficit or surplus not including precipitation and root zone storage at various irrigation system efficiencies.

1000 Acre Feet

E_I	May	June	July	August	September	October	Annual	ΣSR	ΣDef
10	268.1	370.9	415.1	261.2	154.6	100.4	1570.3	0	1570.3
20	116.6	163.6	181.1	105.1	58.6	42.3	667.3	0	667.3
30	67.8	94.5	103.1	53.1	26.6	22.9	367.9	0	367.9
40	43.4	59.9	64.1	27.1	10.6	13.2	218.2	0	218.2
50	28.7	39.2	40.7	11.4	0.9	7.4	128.4	0	128.4
60	19.0	25.4	25.1	1.0	-5.4	3.5	68.6	-5.4	74.0
70	12.0	15.5	13.9	-6.4	-10.0	0.8	25.8	-16.4	42.2
80	6.8	8.1	5.6	-12.0	-13.4	-1.3	-6.3	-26.7	20.4
90	2.7	2.3	-0.9	-16.3	-16.1	-2.9	-31.2	-36.3	5.0

Table 15. Annual and monthly deficit or surplus including precipitation and root zone storage at various irrigation system efficiencies.

1000 Acre Feet

E_i percent	May	June	July	August	September	October	Annual	TSR	TDEF
10	146.0	283.8	375.8	209.8	79.1	12.2	1106.7	0	1106.7
20	57.9	119.7	161.5	79.6	20.8	-1.9	437.6	-1.9	439.5
30	32.4	55.0	90.0	36.0	1.4	-6.6	208.2	-6.6	214.8
40	13.8	37.7	55.2	14.3	-8.3	-8.9	103.8	-17.2	121.0
50	5.0	21.2	33.0	1.1	-14.1	-10.3	35.9	-24.4	60.3
60	-0.8	10.3	18.5	-7.6	-30.6	-11.2	-21.4	-50.2	28.8
70	-5.1	2.4	8.4	-13.7	-31.6	-11.9	-51.5	-62.3	10.8
80	-8.2	-3.4	0.7	-18.4	-32.3	-12.4	-74.0	-74.7	0.7
90	-10.5	-4.9	-5.2	-22.0	-32.8	-14.0	-89.4	-89.4	0

Table 16. Percent of irrigation requirement satisfied at various irrigation system efficiencies.

	Percent						
E_i percent	May	June	July	August	September	October	Annual
10	50.2	31.6	19.7	32.8	58.8	89.5	38.4
20	60.5	42.3	31.0	49.0	78.4	103.0	51.2
30	66.7	60.1	42.3	65.4	97.8	117.0	65.3
40	81.2	63.7	52.8	81.7	117.1	130.3	73.3
50	91.5	74.5	64.8	98.4	136.5	144.2	90.0
60	101.5	85.0	76.3	114.8	196.0	157.5	107.1
70	112.1	97.0	87.5	130.5	215.5	167.5	120.0
80	122.2	106.2	97.3	140.7	234.5	182.0	133.0
90	132.2	110.3	110.0	168.2	254.0	196.1	144.9

Table 17. Annual and monthly deficit or surplus at various percent of the irrigation requirement satisfied.

Deficit (+) or Surplus (-) in 1000 Acre Feet

PMIR or PAIR Percent	May	June	July	August	September	October	Annual
50	-	121	69	8	-	-	449
60	59	69	42	5	96	-	296
70	29	28	26	3	44	-	156
80	15	15	14	2	19	-	81
90	6	6	6	1	7	12	36
100	0	0	0	0	0	0	0
110	-4	-5	-5	-5	-5	-5	-28
120	-7	-	-	-10	-10	-8	-51
130	-10	-	-	-13	-12	-9	-70
140	-	-	-	-17	-15	-10	-85

APPENDIX B

Data

Table 18. Bear River near Collinston, Utah in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	60395.	64900.	62100.	62100.	63300.	75000.	82000.	37416.	9966.	10486.	10258.	9598.	547519.
1932	14795.	34600.	44500.	44200.	51400.	116000.	167000.	205216.	92976.	18086.	11168.	18728.	818669.
1933	33095.	44400.	52900.	52100.	51500.	89200.	115000.	142216.	53976.	10926.	10628.	9958.	665899.
1934	32585.	43860.	60310.	57110.	63650.	78700.	88860.	42016.	21276.	10236.	9868.	12148.	520619.
1935	41465.	42790.	43110.	56210.	50810.	87980.	72320.	83186.	44776.	10176.	9898.	12108.	554829.
1936	23705.	39610.	38760.	51060.	66450.	80130.	207500.	239216.	86456.	10156.	9948.	12108.	865099.
1937	47505.	64580.	61230.	55780.	59350.	132900.	134433.	163816.	47586.	15246.	9748.	9248.	801422.
1938	54095.	51790.	70470.	58760.	71670.	111800.	158400.	177616.	40156.	29306.	9758.	11758.	845579.
1939	56095.	85750.	82160.	59680.	61710.	128700.	105400.	57156.	10226.	10156.	9878.	31518.	698429.
1940	47495.	39760.	48500.	54050.	65870.	85960.	73210.	61006.	9346.	10116.	9878.	21408.	526599.
1941	39875.	46060.	52280.	47550.	73550.	84290.	88060.	58556.	13986.	10226.	12998.	15268.	544699.
1942	50425.	50700.	61680.	57980.	61320.	99900.	159000.	138016.	27766.	11046.	9958.	12878.	740669.
1943	39015.	55340.	66750.	79750.	79380.	113000.	206100.	131416.	126376.	17956.	15588.	19718.	950389.
1944	59395.	67550.	64920.	56270.	57740.	86610.	102900.	123316.	85166.	10846.	10238.	9828.	734779.
1945	30015.	53090.	46910.	49500.	92040.	92370.	91880.	142816.	169876.	14586.	31148.	46588.	860819.
1946	50445.	83410.	86040.	86620.	66060.	151400.	258900.	164616.	71826.	17036.	43848.	48228.	1128429.
1947	77985.	99340.	108200.	89730.	92995.	110700.	115800.	134716.	94086.	23496.	59788.	66658.	1073494.
1948	83955.	94790.	98980.	79010.	93440.	88570.	160300.	218916.	111876.	27176.	37188.	44448.	1138649.
1949	82935.	85580.	96960.	101500.	101400.	149800.	159108.	160616.	59756.	16796.	26758.	41585.	1082794.
1950	97675.	82520.	90510.	112700.	130400.	138000.	216008.	275316.	211676.	123766.	91878.	100638.	1671087.
1951	144095.	140800.	161000.	154400.	167500.	177000.	214308.	231816.	98156.	57306.	89478.	84298.	1720157.
1952	110895.	109300.	124400.	138100.	124300.	147500.	309108.	278016.	113776.	58766.	62808.	69698.	1646667.
1953	85545.	92050.	113500.	121100.	106700.	110600.	122308.	100036.	113176.	13246.	18908.	16538.	1013707.
1954	37705.	56960.	58930.	63030.	66650.	84070.	91328.	35546.	20166.	11666.	10798.	21918.	558767.
1955	37515.	45200.	46950.	53740.	48300.	84810.	115008.	93556.	53466.	10886.	13508.	19408.	622347.
1956	40555.	59830.	105400.	111400.	70920.	117300.	158208.	158016.	39666.	13556.	17298.	15380.	907529.
1957	42325.	58810.	67510.	66360.	87020.	107700.	128108.	222416.	135876.	16236.	36198.	44518.	1013077.
1958	81945.	81180.	74450.	74460.	101800.	98650.	159908.	141316.	23976.	13046.	31628.	39458.	921817.
1959	44465.	62890.	70210.	66200.	71530.	72920.	99758.	29876.	11356.	11046.	10178.	24338.	574817.
1960	49755.	45060.	47410.	51520.	54070.	111500.	116608.	53696.	10116.	9996.	10108.	10348.	570187.
AVE	56592.	56150.	73568.	73732.	78429.	107102.	142561.	136715.	66962.	20786.	24711.	30011.	877315.

Table 19. Malad River near Woodruff, Idaho in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	2039.	3207.	3392.	3303.	4070.	4847.	1901.	908.	773.	990.	980.	843.	27253.
1932	754.	1655.	2515.	2359.	3141.	3735.	7336.	4438.	2153.	1283.	1042.	1152.	31563.
1933	1354.	2152.	2937.	2776.	3149.	6125.	4736.	3527.	1838.	1027.	1008.	870.	31499.
1934	1033.	2124.	3304.	3040.	2933.	2705.	1958.	1347.	1736.	1966.	944.	1045.	24135.
1935	1966.	2070.	2444.	1936.	3096.	4245.	2790.	2585.	1736.	1960.	947.	802.	26577.
1936	1070.	1908.	2222.	2724.	4324.	5300.	9509.	4326.	2109.	957.	952.	1032.	36433.
1937	1734.	3190.	3349.	2970.	3756.	10496.	5737.	3966.	1769.	1214.	930.	939.	40050.
1938	1894.	2530.	3799.	3127.	4750.	8310.	6944.	4100.	1677.	1444.	932.	1023.	40530.
1939	1941.	4298.	4361.	3176.	3943.	10050.	4324.	2162.	994.	957.	945.	1278.	38429.
1940	1920.	2280.	2950.	4680.	6860.	5140.	4100.	1490.	1070.	1020.	1070.	1150.	33730.
1941	1830.	2830.	3230.	3100.	7710.	7960.	6300.	2940.	1630.	1100.	2170.	1340.	42140.
1942	1920.	3510.	3940.	3650.	3740.	8740.	9520.	6070.	2040.	1400.	1220.	1260.	47010.
1943	1560.	3720.	4620.	7680.	6330.	9080.	8360.	3210.	3110.	1530.	1380.	1230.	51810.
1944	1790.	3740.	4520.	3760.	5270.	9600.	5250.	2800.	3540.	1390.	1270.	1070.	44000.
1945	1590.	3500.	3330.	4170.	10010.	6990.	5630.	3360.	5310.	1710.	1720.	1670.	48990.
1946	3120.	5670.	7370.	5560.	5140.	15330.	11470.	4190.	1740.	1420.	1420.	1520.	63950.
1947	3130.	5920.	7020.	4300.	8430.	8810.	4990.	2170.	1990.	1420.	1370.	1640.	51190.
1948	3050.	4860.	4930.	4090.	10260.	9420.	10410.	4900.	1670.	1420.	1280.	1290.	57580.
1949	1640.	2920.	3440.	3490.	3480.	13130.	5270.	3970.	1620.	1410.	1330.	1320.	43020.
1950	2820.	4100.	3630.	5870.	7170.	9960.	6740.	7030.	2540.	1830.	1580.	1500.	54770.
1951	2960.	5020.	6910.	4600.	9270.	9910.	7350.	5880.	1700.	1740.	1630.	1740.	58710.
1952	3300.	4970.	4920.	5750.	5730.	8170.	16670.	5450.	1940.	2050.	2480.	1530.	62960.
1953	2310.	4760.	6030.	9210.	6730.	6360.	4950.	2940.	2430.	1610.	1340.	1260.	49930.
1954	1890.	2900.	3510.	3670.	5350.	5840.	3250.	1990.	1480.	1420.	1260.	1260.	33820.
1955	1690.	2510.	3270.	2990.	2980.	5780.	5980.	3090.	2480.	1230.	1420.	1320.	34740.
1956	1670.	3410.	4720.	4910.	3460.	7510.	3990.	2510.	1350.	1120.	1140.	1050.	36840.
1957	1350.	2160.	3020.	2460.	4540.	5390.	4040.	4960.	1680.	1170.	1120.	1310.	33200.
1958	1590.	2440.	3390.	2750.	6270.	6900.	6120.	2330.	1150.	1080.	1060.	1120.	36200.
1959	1480.	2270.	2940.	2540.	4290.	3750.	3230.	2230.	1250.	1140.	1130.	1060.	27310.
1960	1680.	1630.	2270.	2480.	2818.	1230.	3070.	1480.	1000.	719.	1020.	962.	20359.
AVE	1936.	3275.	3943.	3904.	5300.	7360.	6064.	3412.	1917.	1358.	1270.	1220.	40958.

Table 20. Hammond East Side Canal in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	2110.	411.	0.	0.	0.	0.	329.	7320.	8930.	9780.	9410.	7620.	45910.
1932	3580.	452.	0.	0.	0.	0.	0.	3840.	7260.	10000.	9220.	8090.	42442.
1933	4510.	1510.	296.	0.	0.	0.	0.	1160.	9340.	10200.	10600.	8920.	46536.
1934	6190.	916.	0.	0.	0.	0.	1550.	7070.	5700.	5880.	5500.	3630.	36436.
1935	1950.	880.	0.	0.	0.	0.	518.	3690.	7060.	7320.	6810.	4140.	32368.
1936	2820.	750.	0.	0.	0.	0.	0.	7050.	6370.	7710.	7450.	5820.	37970.
1937	2530.	109.	0.	0.	0.	0.	0.	4950.	6320.	6300.	8440.	6190.	34839.
1938	2220.	746.	0.	0.	0.	0.	186.	3840.	8130.	5840.	8520.	7000.	36482.
1939	2750.	419.	0.	0.	0.	0.	81.	7690.	7120.	8910.	8480.	3980.	39430.
1940	2350.	853.	377.	0.	0.	0.	0.	7510.	7420.	8360.	8840.	2170.	37880.
1941	1320.	256.	0.	0.	0.	0.	0.	5060.	6500.	8330.	7680.	5710.	34856.
1942	1130.	565.	0.	0.	0.	0.	0.	1480.	7400.	8790.	8820.	5440.	33625.
1943	2230.	510.	0.	0.	0.	0.	127.	6980.	4520.	8750.	8050.	5820.	36987.
1944	2030.	446.	0.	0.	0.	0.	0.	3150.	3150.	9350.	9090.	7210.	34426.
1945	2670.	306.	0.	0.	0.	0.	0.	2950.	4900.	9450.	7620.	4820.	32716.
1946	2820.	451.	0.	0.	0.	0.	91.	7410.	7700.	9410.	8430.	5520.	41832.
1947	1180.	0.	0.	0.	0.	0.	0.	6300.	4990.	9480.	7840.	4730.	34520.
1948	2110.	0.	0.	0.	0.	0.	0.	4270.	6010.	9340.	9150.	6760.	37640.
1949	1870.	16.	0.	0.	0.	0.	0.	3500.	7360.	9280.	9000.	6100.	37126.
1950	1930.	129.	22.	0.	0.	0.	0.	3950.	9250.	6750.	9320.	6320.	37671.
1951	1660.	12.	0.	0.	0.	0.	881.	2930.	8860.	8900.	8150.	6150.	37543.
1952	2070.	140.	0.	0.	0.	0.	0.	6260.	8410.	9190.	9120.	6390.	41580.
1953	2940.	91.	0.	0.	0.	0.	0.	4260.	6230.	9900.	9340.	7300.	40061.
1954	3040.	0.	0.	0.	0.	0.	662.	9050.	8810.	9680.	9560.	6200.	47002.
1955	2170.	533.	2.	0.	0.	0.	0.	5900.	7010.	10030.	8640.	6460.	40745.
1956	2720.	35.	0.	0.	0.	0.	631.	5650.	9210.	9930.	9580.	6590.	44396.
1957	2990.	424.	0.	0.	0.	0.	0.	1470.	7040.	9760.	9580.	7040.	38304.
1958	2330.	391.	65.	0.	0.	0.	0.	7010.	9490.	9600.	9580.	6670.	45136.
1959	3130.	545.	0.	0.	0.	0.	0.	7330.	9040.	9620.	8760.	5280.	43705.
1960	1480.	700.	0.	0.	0.	0.	0.	7540.	9760.	10080.	9460.	6780.	45800.
AVE	2494.	420.	25.	0.	0.	0.	169.	5219.	7310.	8866.	8668.	6028.	39199.

Table 21. Hammond West Side Canal in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	8850.	5090.	2360.	1490.	1330.	572.	786.	21400.	36700.	36300.	34100.	27700.	176678.
1932	1400.	1410.	4610.	738.	575.	615.	1961.	14100.	21000.	37500.	36500.	28400.	148809.
1933	19500.	5920.	2160.	1230.	833.	607.	171.	15570.	37500.	35700.	39400.	31400.	189991.
1934	21630.	4990.	1940.	813.	726.	476.	6380.	32130.	26180.	25990.	26530.	17350.	165135.
1935	6610.	2380.	1160.	1160.	924.	506.	1230.	16380.	33240.	31770.	27190.	18850.	141400.
1936	10640.	3290.	2180.	861.	748.	807.	363.	27990.	30650.	31070.	30180.	26720.	165499.
1937	13890.	4340.	1870.	1180.	778.	466.	24.	18970.	30100.	29970.	34460.	28920.	164968.
1938	13190.	4390.	1120.	778.	863.	877.	359.	19030.	36270.	27530.	37260.	29910.	171577.
1939	13340.	3550.	2040.	1660.	1190.	897.	24.	31590.	31250.	38170.	36070.	18570.	178351.
1940	9720.	4810.	3600.	2000.	639.	0.	0.	31990.	33810.	35710.	38030.	13290.	173599.
1941	9630.	3770.	3170.	1110.	789.	553.	0.	22070.	30600.	34400.	31360.	25940.	163392.
1942	7720.	5100.	3870.	1170.	1060.	627.	387.	7130.	34020.	38040.	35390.	26380.	160894.
1943	12270.	5060.	2970.	1100.	565.	0.	412.	28610.	21540.	36600.	33580.	27270.	169977.
1944	11120.	5570.	3300.	1100.	946.	180.	0.	14960.	17850.	40570.	35680.	30430.	161706.
1945	15090.	6260.	2930.	1660.	129.	0.	0.	16540.	22430.	39330.	29190.	22750.	156309.
1946	14010.	1980.	1310.	0.	0.	0.	317.	29660.	32250.	37890.	35140.	28150.	180707.
1947	10810.	5020.	1810.	639.	528.	481.	0.	27270.	24980.	39240.	32990.	24210.	167978.
1948	10770.	2840.	2250.	1060.	706.	177.	0.	19540.	32110.	37190.	34390.	28540.	169573.
1949	11600.	3950.	1350.	839.	615.	486.	0.	15540.	34820.	36560.	37570.	28200.	171530.
1950	8450.	3340.	1710.	645.	545.	0.	0.	13360.	38880.	36620.	36220.	26810.	166580.
1951	9260.	3540.	1450.	369.	278.	79.	3250.	13130.	40220.	38010.	33370.	28700.	171656.
1952	12190.	3490.	1330.	1110.	1040.	143.	0.	26540.	36350.	38030.	35930.	29970.	186123.
1953	18020.	4440.	1070.	1990.	1310.	202.	0.	20080.	32280.	40510.	37710.	31570.	189182.
1954	15020.	5420.	2190.	1720.	1460.	28.	1780.	38270.	34550.	39030.	39240.	25910.	204618.
1955	11030.	5060.	3180.	1550.	924.	452.	0.	21100.	29710.	42140.	35340.	30910.	181396.
1956	13380.	5260.	1530.	1180.	978.	728.	0.	27390.	40890.	40640.	40680.	31790.	204446.
1957	16480.	4340.	3190.	1870.	1260.	391.	0.	6440.	31630.	41960.	41010.	30380.	178951.
1958	14250.	5140.	2870.	1440.	1220.	372.	0.	29310.	41160.	39470.	38040.	29540.	202812.
1959	16680.	6010.	859.	1180.	1220.	58.	0.	30360.	39770.	39560.	37920.	25900.	199517.
1960	10030.	5540.	2940.	2250.	1360.	647.	0.	30730.	42060.	42820.	42190.	33680.	214247.
AVE	12219.	4377.	2277.	1196.	851.	381.	581.	22239.	32493.	36944.	35422.	26938.	175920.

Table 22. Brigham City - Ogden Canal flow in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1932	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1933	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1934	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1935	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1936	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1937	72.	0.	0.	0.	0.	0.	0.	735.	1771.	2593.	3066.	1964.	10201.
1938	285.	0.	0.	0.	0.	0.	0.	679.	1780.	1950.	2720.	1509.	8923.
1939	87.	0.	0.	0.	0.	0.	0.	1600.	1978.	3129.	3149.	1072.	11015.
1940	7.	0.	0.	0.	0.	0.	137.	3198.	4305.	4788.	5108.	1322.	18865.
1941	7.	0.	0.	0.	0.	0.	0.	1341.	2329.	4259.	4085.	1655.	13676.
1942	407.	0.	0.	0.	0.	0.	0.	282.	2273.	4794.	5453.	2737.	15946.
1943	440.	0.	0.	0.	0.	0.	0.	2095.	2308.	6492.	6811.	6811.	24957.
1944	438.	0.	0.	0.	0.	0.	0.	639.	915.	5671.	5194.	3007.	15864.
1945	438.	0.	0.	0.	0.	0.	0.	1281.	1161.	6235.	5637.	2822.	17574.
1946	263.	0.	0.	0.	0.	0.	0.	3008.	4490.	6177.	5175.	2745.	21858.
1947	417.	0.	0.	0.	0.	0.	0.	2056.	2345.	6279.	6013.	3363.	20473.
1948	251.	0.	0.	0.	0.	0.	0.	1162.	2669.	5637.	6353.	3066.	19138.
1949	507.	0.	0.	0.	0.	0.	0.	764.	2564.	5085.	6035.	3377.	18332.
1950	672.	0.	0.	0.	0.	0.	141.	1086.	3616.	6095.	5377.	3620.	20607.
1951	719.	0.	0.	0.	0.	0.	306.	828.	4340.	5800.	6024.	3796.	21813.
1952	1335.	0.	0.	0.	0.	0.	39.	1615.	3691.	6638.	6494.	4428.	24240.
1953	1322.	0.	0.	0.	0.	0.	60.	624.	2431.	4510.	5351.	2087.	16385.
1954	349.	0.	0.	0.	0.	0.	485.	1560.	3037.	9999.	4165.	7636.	27231.
1955	1479.	0.	0.	0.	0.	0.	27.	3818.	4451.	5650.	5869.	3330.	24624.
1956	945.	0.	0.	0.	0.	0.	340.	1416.	3465.	6308.	6826.	3972.	23272.
1957	534.	0.	0.	0.	0.	0.	92.	923.	1593.	6489.	6268.	3381.	19280.
1958	826.	0.	0.	0.	0.	0.	208.	1852.	4415.	4147.	4360.	2234.	18042.
1959	0.	0.	0.	0.	0.	0.	54.	1152.	3239.	6331.	6115.	3027.	19918.
1960	583.	0.	0.	0.	0.	0.	176.	1779.	4683.	5970.	6391.	3364.	22946.
AVE	413.	0.	0.	0.	0.	0.	69.	1183.	2328.	4368.	4268.	2544.	15173.

Table 23. Pumped water used for irrigation in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	513.	168.	80.	42.	30.	13.	29.	990.	1450.	1760.	1690.	1250.	8020.
1932	733.	240.	113.	59.	42.	18.	41.	1400.	2060.	2500.	2400.	1760.	11366.
1933	648.	211.	99.	52.	37.	16.	36.	1240.	1820.	2200.	2120.	1560.	10039.
1934	393.	129.	61.	32.	23.	10.	22.	760.	1110.	1350.	1300.	955.	6150.
1935	478.	155.	73.	39.	27.	12.	26.	925.	1335.	1625.	1565.	1150.	7410.
1936	783.	255.	120.	63.	45.	20.	43.	1500.	2200.	2660.	2560.	1880.	12129.
1937	746.	243.	115.	60.	43.	19.	41.	1430.	2100.	2530.	2440.	1790.	11557.
1938	783.	155.	120.	63.	45.	20.	43.	1500.	2200.	2660.	2560.	1880.	12029.
1939	680.	222.	104.	55.	39.	17.	38.	1310.	1910.	2310.	2230.	1640.	10555.
1940	524.	171.	80.	42.	30.	13.	29.	1050.	1470.	1780.	1710.	1260.	8159.
1941	557.	179.	85.	45.	32.	14.	31.	1060.	1560.	1890.	1820.	1330.	8603.
1942	704.	229.	108.	57.	40.	18.	39.	1350.	1980.	2400.	2310.	1690.	10925.
1943	877.	285.	135.	71.	50.	22.	49.	1690.	2470.	2990.	2880.	2110.	13629.
1944	698.	227.	107.	56.	40.	17.	39.	1335.	1960.	2370.	2290.	1680.	10819.
1945	794.	259.	122.	64.	46.	20.	44.	1520.	2230.	2700.	2600.	1910.	12309.
1946	1025.	335.	158.	83.	59.	26.	57.	1980.	2890.	3500.	3370.	2480.	15963.
1947	963.	313.	147.	78.	55.	24.	53.	1845.	2700.	3280.	3150.	2320.	14928.
1948	1019.	332.	156.	82.	59.	25.	56.	1950.	2860.	3460.	3330.	2440.	15769.
1949	969.	315.	216.	73.	56.	24.	54.	1850.	2710.	3290.	3170.	2320.	15052.
1950	1405.	458.	222.	114.	61.	35.	78.	2700.	3950.	4775.	4610.	3380.	21808.
1951	1445.	470.	216.	116.	83.	36.	80.	2770.	4060.	4900.	4720.	3470.	22366.
1952	1405.	458.	143.	78.	56.	35.	78.	2700.	3950.	4775.	4610.	3380.	21668.
1953	934.	304.	143.	75.	54.	23.	52.	1790.	2620.	3180.	3060.	2250.	14485.
1954	603.	196.	92.	49.	35.	15.	33.	1150.	1690.	2050.	1970.	1450.	9333.
1955	636.	207.	98.	51.	37.	16.	35.	1220.	1780.	2160.	2080.	1530.	9850.
1956	875.	284.	134.	70.	50.	22.	48.	1670.	2450.	2960.	2850.	2090.	13503.
1957	918.	298.	140.	74.	53.	23.	51.	1760.	2580.	3110.	3000.	2200.	14207.
1958	875.	284.	134.	70.	50.	22.	48.	1670.	2450.	2960.	2850.	2090.	13503.
1959	613.	199.	94.	49.	35.	15.	34.	1170.	1720.	2080.	2000.	1470.	9479.
1960	613.	199.	94.	49.	36.	16.	34.	1172.	1720.	2080.	2000.	1470.	9483.
AVE	807.	259.	124.	64.	46.	20.	45.	1549.	2266.	2743.	2642.	1940.	12503.

Table 24. Precipitation on the irrigated lands of the Bear River delta in inches.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	0.96	1.10	1.93	0.90	0.91	1.16	1.11	1.07	1.17	0.76	0.49	0.74	12.30
1932	0.96	0.96	1.19	1.59	1.49	1.50	2.20	0.88	1.44	0.95	0.85	1.26	15.27
1933	0.76	1.03	1.43	1.26	0.43	0.82	1.65	1.40	1.31	1.38	0.66	1.23	13.36
1934	0.88	1.29	1.11	0.96	1.27	0.66	1.21	0.98	1.82	1.49	1.03	1.34	14.04
1935	1.01	1.14	0.85	0.47	2.07	1.20	1.93	2.47	0.38	0.45	0.18	1.46	13.61
1936	2.20	0.47	2.27	1.77	2.91	1.77	0.85	0.80	0.94	1.01	0.36	0.97	16.32
1937	1.05	1.47	0.88	0.99	1.87	1.39	1.67	2.08	0.67	1.15	0.96	1.21	15.39
1938	2.04	1.09	0.65	0.97	1.28	2.19	0.69	1.73	0.78	0.95	0.86	0.95	14.18
1939	1.23	0.99	0.53	0.85	1.09	0.77	2.28	1.02	1.01	0.49	0.96	1.54	12.76
1940	2.20	0.95	1.76	1.50	1.06	1.39	2.10	0.54	0.25	0.18	1.23	1.85	15.01
1941	2.10	1.15	2.58	1.96	1.36	1.69	2.73	3.43	0.70	0.59	0.89	0.55	19.73
1942	0.93	1.63	1.18	1.19	0.95	1.25	1.37	1.18	0.40	0.31	0.12	0.90	11.41
1943	1.41	0.77	1.01	0.82	1.00	1.71	2.14	1.57	2.81	0.60	1.24	1.03	16.11
1944	0.24	1.95	1.13	1.20	0.90	1.14	2.67	1.04	3.77	0.21	0.66	0.23	15.14
1945	1.10	2.59	2.69	0.42	2.64	1.62	0.92	1.92	3.42	0.22	1.42	1.77	20.73
1946	2.69	1.24	2.64	0.56	0.48	2.86	1.61	2.88	0.16	0.56	0.33	0.63	16.64
1947	1.22	1.16	1.34	0.73	0.93	1.71	2.00	1.75	2.02	0.30	1.07	1.65	15.88
1948	1.14	1.36	1.36	1.20	1.28	1.88	1.75	1.59	1.87	0.54	0.28	0.53	14.78
1949	2.31	1.80	1.28	1.58	0.65	2.00	1.00	2.42	1.16	0.50	0.28	0.70	15.68
1950	0.85	2.27	1.68	1.44	1.15	1.76	1.57	1.71	0.61	1.23	0.63	1.37	16.27
1951	0.96	1.33	1.21	2.01	1.46	0.74	1.77	1.75	0.63	0.38	1.04	0.18	13.46
1952	0.99	0.96	0.70	1.96	1.40	1.16	1.38	1.25	1.27	0.32	0.25	1.08	12.72
1953	0.61	0.99	0.82	2.23	0.40	1.26	1.29	1.58	1.13	0.16	0.28	0.62	11.37
1954	0.59	1.63	1.29	1.46	0.72	1.44	0.58	0.81	1.02	0.38	0.42	1.62	11.96
1955	0.65	0.94	1.62	2.18	1.38	0.55	1.09	1.58	1.61	0.14	1.46	1.04	14.25
1956	0.93	0.74	1.34	2.19	0.69	0.61	1.58	2.20	0.71	0.19	0.54	0.41	12.13
1957	0.92	1.34	1.36	1.28	1.31	1.80	2.33	3.72	0.54	0.18	0.44	0.40	15.62
1958	0.88	0.82	1.03	1.23	1.64	2.10	0.77	0.56	0.63	0.21	1.10	1.21	12.18
1959	0.64	1.25	1.12	1.05	1.20	1.12	1.20	1.37	1.06	0.39	0.87	1.51	12.78
1960	1.66	2.10	0.77	1.21	1.64	1.49	0.96	0.53	0.14	0.30	0.50	0.96	12.26
AVE	1.20	1.28	1.36	1.31	1.25	1.42	1.55	1.59	1.18	0.55	0.71	1.03	14.44

Table 25. Mean temperature in degrees Fahrenheit.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	46.0	31.6	27.4	27.2	31.3	35.0	45.0	49.5	62.0	65.4	66.9	60.2	46.0
1932	44.3	36.2	15.6	14.5	23.1	32.9	43.6	53.2	59.7	67.9	65.1	58.0	42.8
1933	51.4	35.7	31.9	19.5	14.2	31.8	41.4	47.1	65.3	71.0	65.4	59.4	44.6
1934	48.6	38.0	28.6	30.3	37.2	43.8	50.9	59.6	69.9	69.7	68.5	55.6	49.3
1935	46.0	31.6	27.4	27.2	31.3	36.0	45.0	49.5	62.0	66.4	66.9	60.2	46.0
1936	46.8	33.3	29.1	24.0	27.4	35.2	46.4	55.6	63.7	69.7	67.0	55.8	46.2
1937	43.7	32.6	31.4	10.3	22.5	34.2	41.3	55.4	59.7	68.3	67.5	59.7	44.8
1938	47.7	29.9	20.8	32.5	33.6	37.0	45.9	50.2	62.9	66.5	66.5	61.6	46.9
1939	46.6	37.9	32.4	24.9	20.9	35.1	47.2	55.0	58.6	57.4	65.0	57.3	45.6
1940	48.4	32.3	27.9	27.9	31.5	41.1	47.4	57.9	65.7	70.3	69.1	56.5	48.0
1941	44.7	35.0	29.6	25.1	31.1	38.7	43.6	55.1	58.8	67.4	64.8	52.9	45.6
1942	42.9	35.1	28.6	16.0	20.5	29.0	45.3	48.7	58.0	69.4	64.9	57.1	42.9
1943	49.1	34.9	23.9	27.1	27.9	34.4	46.9	51.9	58.6	66.9	65.1	58.7	45.4
1944	49.1	33.3	26.9	16.9	22.0	31.7	41.0	52.8	55.4	66.3	64.6	57.5	43.1
1945	47.7	33.5	26.1	27.9	31.0	34.4	39.7	52.8	54.7	67.0	65.6	52.4	44.5
1946	41.8	33.7	31.8	24.0	25.2	38.9	48.4	50.5	60.8	68.6	67.3	56.0	45.9
1947	47.7	32.3	23.0	16.9	32.2	33.9	42.7	54.3	56.5	67.5	64.4	56.8	44.4
1948	46.7	30.7	22.2	23.9	26.4	31.1	42.7	51.9	60.4	66.8	65.7	56.2	43.9
1949	42.1	39.5	25.0	12.2	19.4	35.8	48.0	53.3	58.4	66.4	66.1	59.0	43.8
1950	49.9	36.0	30.5	20.9	30.0	34.4	42.2	47.3	56.9	64.6	63.9	56.0	44.4
1951	44.4	32.3	22.4	21.9	23.3	31.7	45.7	51.9	56.1	66.8	63.6	56.2	43.5
1952	50.6	30.7	27.0	20.5	21.6	27.1	44.9	53.1	59.2	66.6	66.2	60.4	44.0
1953	47.5	39.0	25.3	34.6	31.0	37.8	41.0	46.6	58.5	68.7	66.0	58.9	46.2
1954	46.4	33.9	26.6	27.5	30.2	34.1	46.5	54.7	57.7	68.7	64.5	57.5	46.1
1955	46.3	23.9	26.6	14.9	19.9	28.9	39.9	51.6	57.8	66.1	67.1	56.3	42.0
1956	46.4	29.8	24.9	29.8	17.8	35.2	44.7	54.2	61.1	68.4	63.3	57.5	44.6
1957	46.2	30.2	28.3	20.3	32.4	37.6	42.6	51.6	59.5	66.9	66.9	56.7	44.9
1958	48.8	33.9	33.1	23.0	34.9	33.9	41.5	56.1	61.9	66.4	68.5	57.1	46.6
1959	45.0	32.8	25.9	23.4	30.0	35.6	44.7	49.7	63.5	68.0	65.0	54.3	45.2
1960	45.9	35.3	26.3	20.1	23.7	36.1	44.4	51.4	62.5	71.3	63.9	60.1	45.1
AVE	46.5	34.0	27.2	23.0	27.1	35.0	44.3	52.4	59.9	67.9	65.9	57.5	45.1

Table 26. Municipal and industrial uses in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1932	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1933	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1934	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1935	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1936	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1937	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1938	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1939	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1940	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1941	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1942	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1943	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1944	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1945	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1946	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1947	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1948	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1949	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1950	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1951	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1952	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1953	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1954	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1955	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1956	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1957	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1958	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1959	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
1960	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.
AVE	756.	227.	227.	227.	220.	235.	305.	830.	975.	1100.	1065.	925.	7092.

Table 27. Ungaged inflow from isorunoff map in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	5257.	5015.	4894.	4810.	4758.	5563.	9952.	9446.	6947.	5810.	5610.	4558.	72625.
1932	9316.	8748.	8464.	8267.	8143.	10045.	20331.	21492.	10934.	8267.	7798.	7674.	129479.
1933	7203.	6771.	6555.	6405.	6311.	7757.	15578.	16460.	8433.	6405.	6049.	5955.	99882.
1934	5667.	5430.	5312.	5230.	5180.	5970.	8747.	9230.	6339.	5230.	5035.	4984.	72354.
1935	5650.	5318.	5152.	5037.	4965.	6075.	12084.	17262.	6595.	5037.	4763.	4691.	82629.
1936	10023.	9409.	9103.	8889.	8756.	10810.	21921.	23174.	11770.	8889.	8382.	8249.	139375.
1937	7616.	7158.	6928.	6769.	6669.	8204.	16506.	17443.	8922.	6769.	6390.	6291.	105665.
1938	8183.	7688.	7440.	7268.	7161.	8818.	17781.	18793.	9593.	7268.	6859.	6752.	113604.
1939	6014.	5659.	5481.	5357.	5280.	6469.	12902.	13628.	7025.	5357.	5064.	4987.	83223.
1940	5768.	5493.	5356.	5260.	5200.	6121.	10101.	10663.	6551.	5260.	5033.	4973.	75779.
1941	5139.	4904.	4787.	4705.	4654.	5439.	9684.	9163.	5806.	4705.	4512.	4461.	67959.
1942	4901.	4618.	4476.	4377.	4316.	5265.	10399.	10947.	5709.	4377.	4143.	4081.	67609.
1943	8435.	7924.	7668.	7440.	7379.	9091.	18348.	19392.	9891.	7440.	7068.	6957.	117083.
1944	5979.	5626.	5449.	5326.	5250.	6432.	12823.	13545.	6984.	5326.	5035.	4958.	82733.
1945	6839.	6431.	6227.	6085.	5996.	7363.	14759.	15094.	8003.	6085.	5747.	5659.	94288.
1946	10268.	9639.	9324.	9105.	8968.	11075.	22471.	23657.	12060.	9105.	8585.	8449.	142706.
1947	7558.	7132.	6903.	6744.	6645.	8174.	16443.	17377.	8889.	6744.	6367.	6268.	105274.
1948	8820.	8284.	8016.	7829.	7713.	9507.	19213.	20309.	10346.	7829.	7386.	7270.	122522.
1949	8470.	7956.	7700.	7521.	7409.	9138.	18426.	19476.	9932.	7521.	7097.	6985.	117631.
1950	11842.	11112.	10746.	10492.	10333.	12780.	26013.	27506.	13924.	10492.	9887.	9730.	164857.
1951	11206.	10506.	10171.	9931.	9731.	12090.	24580.	25990.	12170.	9931.	9361.	9212.	154879.
1952	11304.	10608.	10260.	10018.	9887.	12196.	24801.	26523.	13286.	10018.	9443.	9291.	157635.
1953	7875.	7399.	7162.	6997.	6894.	8484.	17089.	18060.	9228.	6997.	6605.	6501.	109291.
1954	6112.	5750.	5569.	5444.	5365.	6575.	13122.	13861.	7141.	5444.	5145.	5066.	84594.
1955	6199.	5822.	5640.	5511.	5432.	6659.	13296.	14045.	7232.	5511.	5209.	5129.	85685.
1956	9233.	8670.	8389.	8193.	8071.	9954.	20142.	21292.	10835.	8193.	7728.	7606.	128306.
1957	8666.	8140.	7877.	7694.	7579.	9340.	18867.	19942.	10164.	7694.	7259.	7145.	120367.
1958	8428.	7917.	7662.	7484.	7373.	9083.	18332.	19376.	9882.	7484.	7062.	6951.	117034.
1959	6364.	5968.	5797.	5666.	5563.	6884.	13689.	14461.	7439.	5666.	5354.	5271.	88142.
1960	6217.	5848.	5664.	5536.	5456.	6689.	12859.	14111.	7266.	5536.	5232.	5152.	85566.
AVE	7686.	7231.	7006.	6848.	6749.	8269.	16375.	17391.	8977.	6880.	6507.	6375.	106293.

Table 28. Ground water inflow into the Bear River delta in acre feet.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1931	709.	736.	675.	669.	687.	804.	850.	618.	490.	486.	461.	397.	7582.
1932	180.	382.	516.	473.	551.	1204.	1763.	2224.	1161.	580.	493.	503.	10030.
1933	560.	540.	583.	561.	555.	959.	1199.	1573.	954.	490.	529.	451.	8954.
1934	590.	520.	655.	610.	673.	819.	987.	773.	476.	352.	341.	286.	7082.
1935	495.	481.	467.	593.	548.	927.	769.	1006.	795.	424.	362.	299.	7166.
1936	357.	455.	431.	546.	715.	862.	2173.	2733.	1183.	410.	398.	396.	10659.
1937	632.	722.	664.	599.	638.	1438.	1404.	1872.	802.	464.	479.	412.	10126.
1938	691.	594.	753.	626.	772.	1210.	1659.	2000.	807.	572.	550.	451.	10685.
1939	717.	940.	885.	645.	668.	1396.	1098.	949.	449.	524.	498.	504.	9273.
1940	594.	477.	554.	607.	733.	911.	554.	999.	486.	511.	542.	333.	7301.
1941	476.	549.	586.	518.	819.	928.	943.	848.	478.	494.	499.	439.	7577.
1942	591.	598.	694.	628.	661.	1097.	1698.	1477.	661.	552.	521.	427.	9605.
1943	530.	646.	743.	885.	862.	1220.	2149.	1670.	1505.	624.	567.	548.	11949.
1944	722.	773.	727.	611.	639.	963.	1082.	1396.	1033.	590.	528.	455.	9519.
1945	473.	631.	531.	553.	1022.	994.	975.	1617.	1964.	624.	666.	726.	10776.
1946	681.	915.	947.	922.	712.	1667.	2708.	2037.	1108.	631.	853.	801.	13982.
1947	910.	1103.	1170.	946.	1029.	1199.	1208.	1673.	1211.	710.	993.	946.	13098.
1948	976.	1025.	1062.	841.	1044.	981.	1707.	2436.	1470.	718.	796.	780.	13836.
1949	960.	924.	1017.	1058.	1055.	1634.	1643.	1792.	988.	602.	720.	748.	13141.
1950	1090.	900.	958.	1192.	1381.	1479.	2229.	2955.	2587.	1662.	1357.	1329.	19119.
1951	1561.	1493.	1693.	1593.	1770.	1869.	2260.	2494.	1460.	1029.	1299.	1187.	19708.
1952	1273.	1179.	1307.	1449.	1310.	1558.	3256.	3127.	1570.	1058.	1082.	1060.	19229.
1953	1076.	1013.	1206.	1323.	1147.	1172.	1273.	1227.	1493.	609.	639.	527.	12705.
1954	555.	652.	646.	684.	734.	900.	975.	812.	607.	629.	563.	568.	8325.
1955	515.	533.	534.	582.	522.	910.	1210.	1222.	899.	610.	561.	554.	8652.
1956	569.	685.	1115.	1175.	754.	1255.	1632.	1898.	873.	627.	669.	527.	11779.
1957	611.	657.	737.	707.	928.	1135.	1322.	2310.	1705.	667.	855.	806.	12440.
1958	984.	891.	808.	786.	1093.	1059.	1662.	1766.	729.	584.	760.	730.	11852.
1959	632.	717.	740.	966.	771.	767.	1030.	657.	775.	588.	554.	535.	8732.
1960	610.	529.	526.	562.	582.	1135.	1199.	900.	603.	607.	605.	491.	8349.
AVE	711.	742.	798.	797.	846.	1148.	1487.	1635.	1044.	634.	658.	607.	11108.

VITA

Tom Al Austin

Candidate for the Degree of

Master of Science

Thesis: Irrigation Water Management Potential in the Bear River Delta

Major Field: Civil Engineering

Minor Field: Statistics

Biographical Information:

Personal Data: Born at Fort Worth, Texas, November 21, 1943, the only son of George Allen and Vaye Tom Austin; married; two children--Lowell Christopher, Laura Jean.

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Professional Experience: 1963 to 1967 student draftsman and estimator for the City of Lubbock, Texas. 1967 to 1968 Civil Engineer with the U. S. Department of Agriculture Forest Service, located on the Cache National Forest, Logan, Utah. Presently employed as a research assistant on the Urban Water Quality project at Texas Tech University.