RESEARCH TECHNICAL COMPLETION REPORT
PROJECT A-040-IDA

WATER for IDAHO

IMPACT OF CHANGES IN IRRIGATION WATER MANAGEMENT IN EASTERN IDAHO

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The six irrigation districts cooperating in this investigation deserve special thanks for assistance in data collection and for granting permission to utilize their facilities and monitor their irrigation operations.

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ABSTRACT

Irrigation water use data on six irrigation districts in the Upper Snake River Basin of Idaho were obtained for the 1974 season. Data on river diversions, return flow, crop consumptive use, and seepage losses were obtained and a water budget analysis performed to determine present farm, conveyance system, and project efficiencies.

Present farm irrigation efficiencies varied from 11 to 62 percent and project irrigation efficiencies varied from 10 to 42 percent. Low farm irrigation efficiencies were attributed to long field runs on high intake rate soils. Canal seepage losses contribute a significant part of the system loss; however, lining of main canal systems would not significantly increase project efficiencies.

Reasonably attainable project efficiencies were determined by evaluating the effects of reducing canal seepage losses, incremental reductions in river diversions, reasonable increases in farm irrigation efficiencies, and by a complete hypothetical conversion to sprinkler irrigation.

Reasonably attainable project irrigation efficiencies of 35 to 51 percent are estimated assuming a farm irrigation efficiency of 60 percent, which is achievable with sprinkler irrigation or well managed surface systems. On the six districts evaluated, which irrigate 252,000 acres, a potential water saving of over 800,000 acre feet per year could be achieved, making water available for irrigation of an additional 274,000 acres or for other beneficial uses.

Current and projected irrigation return flow data have added valuable input for river operation models used in planning future uses of the Snake River.

INTRODUCTION

In the Upper Snake River Basin of Idaho, where extensive use is made of river and groundwater resources, a full knowledge of the hydrology of the river and aquifer and of response to changes in water use patterns is mandatory. Irrigated lands in the Upper Snake Basin comprise over 60 percent of Idaho's irrigated lands. Future development may depend on reduction of irrigation water use on existing lands where allegations of "over use" of water are prevalent.

Several planned irrigation developments depend on the availability of additional water in the Snake River. A logical source for the additional water is water savings from increased irrigation efficiency. Continued pressure from environmental and federal agencies concerned with reduction of pollution from irrigation and the maintenance of minimum stream flows may force irrigation water users to improve water use practices.

Evaluation of planning alternatives for irrigation water use requires a knowledge of present water use practices and efficiencies as well as estimates of projected attainable efficiencies in the future.

Studies by water planning agencies have based estimates of current water use efficiencies and attainable efficiencies on limited available data. This study was designed to determine areas in the region where changes in water use practices could increase efficiency and subsequently provide additional water.

OBJECTIVES

In order to evaluate future attainable efficiencies in the region it was necessary to first determine present use patterns and efficiencies and then estimate subsequent reasonable changes in efficiency from incremental changes in on-farm efficiency, distribution system changes and management improvements.

The specific objectives of this project were therefore:

1. To assess the present irrigation water use practices and efficiencies in the Upper Snake River Valley

2. To determine reasonable changes in irrigation water use and future allocation of present water supplies.

An evaluation of the impact on the Snake River of reasonable changes in water use ascertained from this study is being performed by the Idaho Department of Water Resources utilizing the Snake River operations model. This evaluation, originally included as an objective of this project, was relegated to the Department of Water Resources rather than to dilute the effort in determining current water use efficiencies. Determination of current irrigation water use efficiencies on operating districts proved to be the most valuable, and also the most time consuming, aspect of the study.

PROJECT AREA

The study area includes irrigated lands in the Upper Snake River Basin upstream of the town of Bliss (see Figure 1). The area comprises over 2,300,000 irrigated acres and includes the Snake River Plain. Irrigation began prior to 1870 with the formation of many small irrigation organizations with gravity diversions from the Snake River and its tributaries. Transmission facilities frequently parallel each other and duplicate facilities are not uncommon. No major rehabilitation or consolidation of district facilities has taken place and water supplies of both older and newer districts have been firmed up by instream storage in reservoirs on the main stem of the Snake River and its tributaries.

Flood and border irrigation are common in the eastern part of the project area while furrow irrigation is dominant for the finer grained soils of the western and central part of the region. Sprinkler irrigation is increasing on new lands and conversion to sprinkler is proceeding rapidly in localized gravity irrigated areas.

In the Upper Snake Region nearly 4 million acres of potentially irrigable land is available; however, current water supplies are insufficient for development and future expansion may well depend on more efficient use of present water supplies.

Since the capability for field monitoring of current water use was limited, the region was arbitrarily divided into three sub-regions based upon similar climate, soils and topography and irrigation practices. Figure 1 outlines the locations of the irrigated areas in the lower, central and upper sub-regions.

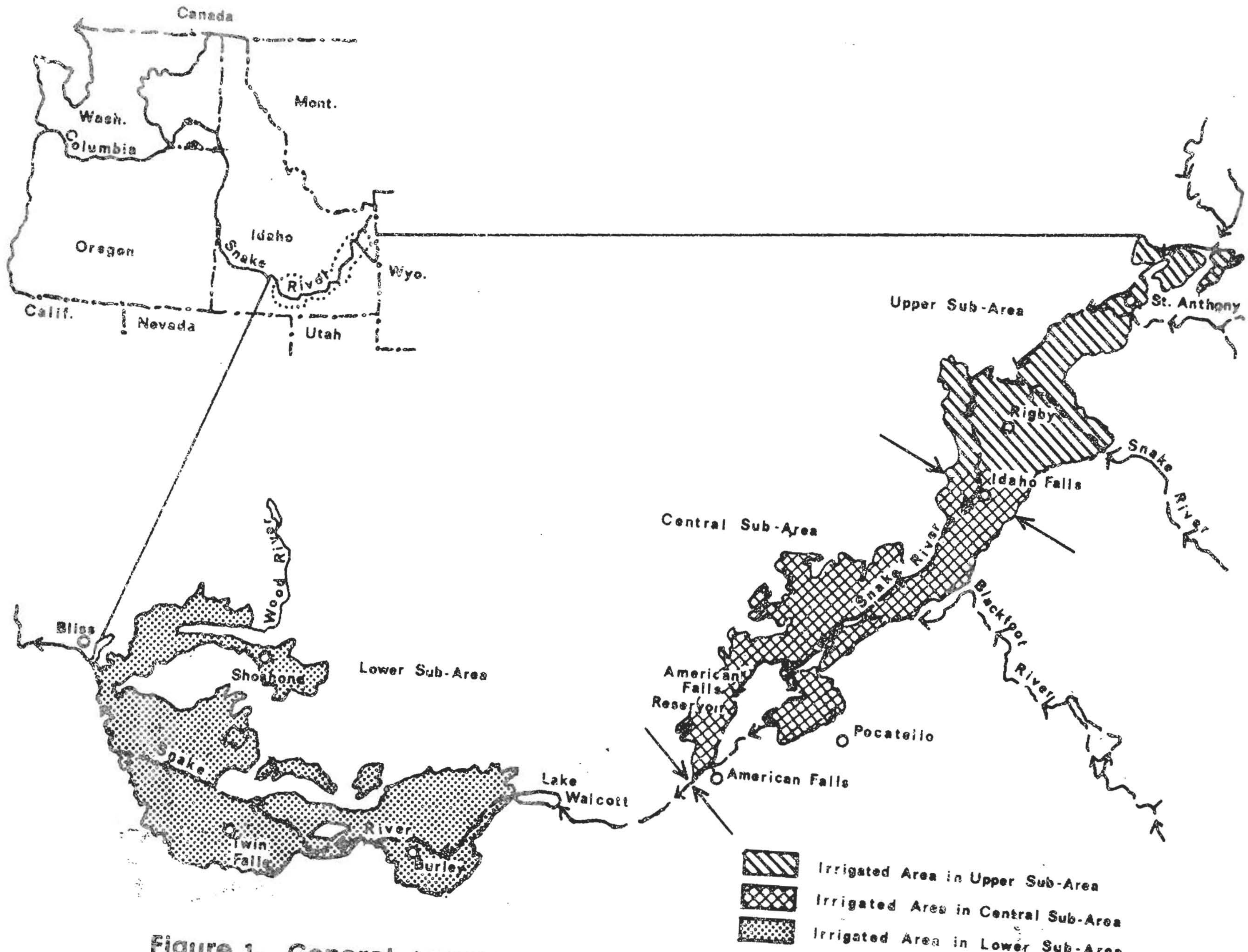

Figure 1. General Location Map and Irrigated Sub-Areas in the Upper Snake River Region

PREVIOUS STUDIES

Sylvester and Seabloom (33) used a project water and nutrient budget for determination of water quality effects in the Yakima River Valley in Central Washington and Brown, et al. and Carter, et al. (5, 6) performed a similar analysis for water quality and sediment determination on two districts comprising 360,000 acres in southern Idaho. Brockway and de Sonneville (2) developed a complete water budget for three irrigation seasons for a 96,000 acre tract in eastern Idaho to provide necessary data for a simulation model of the groundwater system.

On-farm irrigation efficiencies have been evaluated by Brockway and de Sonneville (2), the U.S. Bureau of Reclamation (39, 40) and Galinato (17) in the Snake River Basin. These studies found in general that irrigation efficiencies are much lower than expected; however, opinion is divided on the reasonable increases which could be expected. Willardson (43) and Willardson and Bishop (44) estimated attainable efficiencies of 60 to 70 percent for furrow and border irrigation and Hanson and Israelson (18) estimated surface irrigation efficiencies of 60 percent and sprinkler irrigation efficiencies of 75 percent were reasonably attainable. Measured on-farm border irrigation efficiencies of 80 to 95 percent have been reported by Jensen and Howe (27).

PROCEDURE

Many investigations have devised specific definitions of efficiency. Jensen (26) summarized previous work and concepts and defined efficiency terms which are adopted for this study. Irrigation is "the application of water to the soil supplementing natural precipitation for the purpose of supplying water essential to plant growth." Irrigation efficiency, E_i, accordingly, is "the ratio of the volume of irrigation water transpired by plants and evaporated from the soil and plant surface plus that necessary to regulate the salt concentration in the soil solution, and that used by the plant in building plant tissue to the total volume of water diverted, stored, or pumped for irrigation". Neglecting the water stored in plant tissue and changes in stored soil water (in short, assuming steady-state conditions) enables overall irrigation efficiency to be expressed as:

$$E_i = \frac{V_{et} + V_l - R_e}{W_i} \times 100\% \qquad (1)$$

Where: E_i = overall irrigation efficiency in percent

V_{et} = the volume of water required for evapotranspiration

V_l = the volume of water necessary for leaching on a steady-state basis

R_e = the volume of effective rainfall

W_i = the volume of water diverted

Water conveyance efficiency, E_c, according to Jensen is the "ratio of the amount of water delivered by a conveyance system to the amoung of water delivered to the conveyance system at the source of supply" or in equation form:

$$E_c = \frac{W_d \times 100\%}{W_r} \qquad (2)$$

Where: E_c = water conveyance efficiency in percent

W_d = amount of water delivered by the system

W_r = amount of water delivered to the system

Water conveyance efficiency is strictly dependent upon the capability of the conveyance system to deliver water. Seepage losses, evapotranspiration losses to bank phreatophytes, operational losses, return flows, and direct surface evaporational losses are the limiting constituents which govern this efficiency, Unit irrigation efficiency, E_u, is "the amount of water used by evapotranspiration plus the amount required for leaching purposes divided by the amount of water delivered."

$$E_u = \frac{V_{et} + V_l}{W_i} \qquad (3)$$

Where: E_u = unit irrigation efficiency in percent

And: V_{et} and V_l are defined previously

Unit irrigation efficiency differs only from overall irrigation efficiency by the effective rainfall.

Reservoir storage efficiency, E_s, is defined as "the ratio of the volume of water delivered from the reservoir for irrigation to the volume of water delivered to the reservoir." Reservoir storage efficiency, water conveyance efficiency, and unit irrigation efficiency can be combined to formulate the term project irrigation efficiency, E_p. The composite equation resulting from combining the three efficiencies is:

$$E_p = \frac{E_s}{100} \frac{E_c}{100} \frac{E_u}{100} \times 100\% \qquad (4)$$

Where: E_p = project irrigation efficiency in percent

E_s = reservoir storage efficiency in percent

E_c = water conveyance efficiency in percent

E_u = unit irrigation efficiency in percent

Irrigation studies based upon the application of a water balance or water budget type analysis have been conducted only to a limited extent from a total irrigation system approach. The majority of these investigations have been carried out primarily in conjunction with water quality research as opposed to investigation of water usage patterns. However, similar data are required in each and the same procedure can be applied to water-use studies.

U.S. Bureau of Reclamation studies in Nebraska (40) report present farm irrigation efficiencies from 31 to 52 percent and similar studies in Idaho (39) report 36.3 to 43.7 percent efficiency for conventional surface irrigation systems. Attainable irrigation efficiencies of 51 to 64 percent were estimated for the Idaho area.

Return flow reuse systems, sprinkler conversions, and irrigation water management by computer scheduling are methods which can be expected to increase efficiencies.

Before predictions of attainable irrigation efficiencies could be made it was necessary to establish current operating levels or irrigation efficiencies for each selected irrigation district. After defining current operation efficiencies from measured data, various parameters or conditions unique to each irrigation system which affect irrigation efficiency can be artificially adjusted. The change in efficiency of the total system can be computed and a new synthetic operating level created.

Present operating levels or irrigation efficiencies could best be evaluated by applying a total water budget analysis. This implies accounting for all major uses and significant losses of irrigation water in each distinct irrigation unit. The major uses and losses in an irrigation system as shown in Figure 2 include: diversions from a water source, Q_{rd}; supplemental inflow, Q_{if}; precipitation Q_p; system return flow, Q_{rf}; evapotranspiration or crop consumptive uses, Q_{cu}; conveyance system seepage losses, Q_{csl}, and deep percolation of applied water beyond the root zone, Q_{dpe}.

After compiling data necessary to assemble the seven system components, a water balance was used to compute various water use parameters and efficiencies. Present operating levels were then established. The next step, using economic reasoning and technical feasibility as guidelines, consisted of artificially modifying those system parameters which significantly affect irrigation efficiency. The modifications resulted in the creation of new input data to the system water budget which produced new water use patterns and new values of irrigation efficiencies. Reasonable prediction of attainable irrigation efficiencies for each sub-area of the study region, and subsequent alterations indiversions are developed in this manner.

Six individual districts were chosen according to the following criteria: districts should be considered typical and representative of the systems comprising each sub-area of the region; all relevant farm irrigation methods should be represented by at least one irrigation district; the irrigated acreage of the systems should not be a restrictive consideration, i.e. districts should not be chosen on a common size basis; and the nature and complexity of the water conveyance and distribution system should pose minimum difficulty for field measurement.

Data required to apply a complete water budget analysis to each irrigation district were determined and field facilities installed to obtain data on: river diversions, supplemental inflow, return flows from the district to the river including systems outflow not directly returned to the river, drop consumptive uses, conveyance system seepage losses, and deep percolation losses below the active root zones.

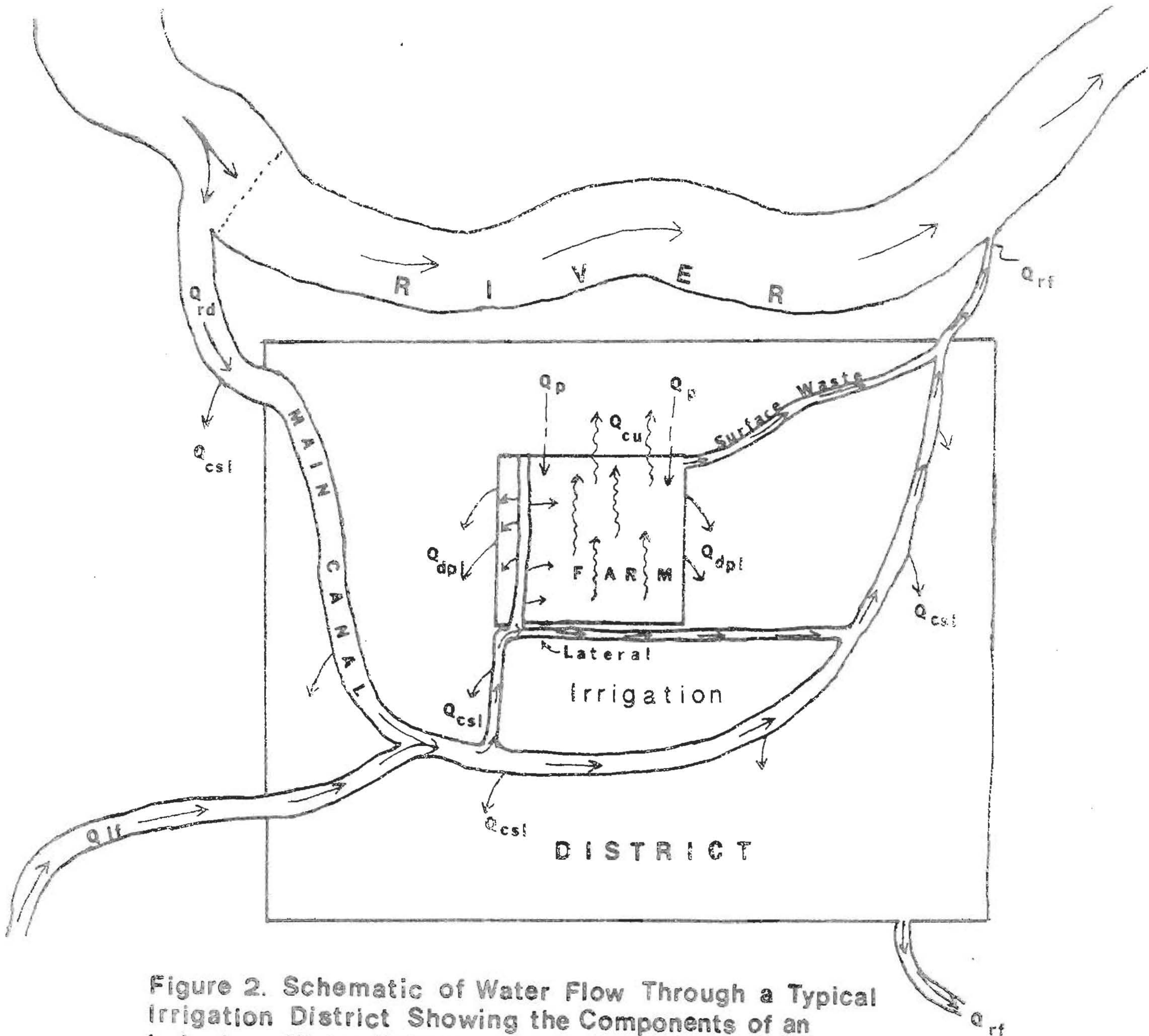

Figure 2. Schematic of Water Flow Through a Typical Irrigation District Showing the Components of an Irrigation Water Balance

DATA COLLECTION

Six irrigation districts were selected for monitoring, three districts in the lower sub-region, two in the central sub-region, and one in the upper sub-region. Table 1 shows the district climatic and topographic characteristics and location. Tables 2 and 3 outline the crops, soils, water source and operational characteristics of each district.

Data for the 1974 irrigation season were obtained on each element of the project water use for each of the six districts.

River Diversion and Supplementary Inflow

Daily diversions of irrigation water during the irrigation season from the Snake River and its major tributaries are determined by U.S. Geological Survey personnel and reported annually Additional flow measurements were necessary on three districts where supplemental inflow from ungaged sources occurred. Also early and late season flows, normally not recorded by Survey personnel, influence total water use patterns and subsequent efficiencies to a limited degree.

Irrigation District No. 2 also obtains a portion of its irrigation water from deep wells and pumpage records from the district were secured to supplement data supplied by the U.S.G.S. District 5 receives substantial amounts of flood water particularly early in the irrigation season which it distributes for irrigation purposes. After flood waters recede, the district continues to receive a significant amount of supplementary inflow at two separate locations on the district perimeter. Measuring devices were established at each location and on other districts where necessary.

The frequency of early and late season diversion measurements is lower than the mid-season frequency, therefore the reliability of early and late season flows is considered to be lower.

Return Flows

Measuring District return flows or outflows required the greatest amount of resources and effort. Fifty-three separate point sources yielding significant return flow were located and inventoried on the six districts. Few of these point sources possessed any measuring device. Before most spring return flows began, rectangular contracted weirs, automatic stage recorders, and metal staff gages were installed at sixty point sources of return flow and three inflow gaging stations.

TABLE 1. Summary of Climatic and Topographic Characteristics of Each Sub-Area and Irrigation District (Taken from 29, 30, 31)

Characteristic	Irrigation Districts 1	2	3	4	5	6
Associated Sub-Area	Lower	Lower	Lower	Central	Central	Upper
Mean Annual Temperature (°F)	50	48	48	46	44	43
Mean Annual Precipitation (inches)	10	8	9	8	7	12
Frost-Free Period (Freezing Level = 32°F)	115-135	115-135	115-135	100-125	100-125	95-105
Range of Elevation (Feet above MSL)	3500-4000	4000-4400	4000-4400	4400 -4500	4600-4800	4800-5000

TABLE 2. Summary of Crops Grown, Soil Types, and Primary Water Sources for Each Sub-Area and Irrigation District (Taken from 7,8,9,10,11,32,41,42,45)

	Irrigation Districts					
Characteristic	1	2	3	4	5	6
Sub-Area	Lower	Lower	Lower	Central	Central	Upper
Gross Acreage (acres)	178,080	14,568	54,170	6,000	37,330	5,908
Net Irrigated Acreage (acres)	151,368	14,568	42,794	4,440	33,597	5,375
Primary Water Sources	Snake River	Snake River & Deep Wells	Snake River	Snake River	Snake River & Flood Rights	Fall River
Major Crops Grown	Sugar Beets, Dry Beans, Peas Corn Silage Grains Potatoes Alfalfa Pasture	Sugar Beets Dry Beans Peas Corn Silage Grains Potatoes Alfalfa Pasture	Sugar Beets Dry Beans Peas Corn Silage Grains Potatoes Alfalfa Pasture Orchards	Sugar Beets Corn Silage Grains Potatoes Alfalfa Pasture	Sugar Beets Peas Corn Silage Grains Potatoes Alfalfa Pasture Orchards	Potatoes Alfalfa Peas Grains Corn Silage Pasture Orchards
Major Soil Types	Silt Loam Sandy Loam Sand	Silt Silt Loam	Loam Silt Loam Sandy Loam	Loam Fine Sandy Loam	Loam Silt Loam Fine Sandy Loam	Silt Loam
Average Terrain Slopes (%)	0-12	0-12	0-4	0-4	0-4	4-12

TABLE 3. Summary of Physical and Operational Characteristics of Each Irrigation District*

Characteristic	Irrigation Districts 1	2	3	4	5	6
Sub-Area	Lower	Lower	Lower	Central	Central	Upper
Type of Irrigation Delivery System	Unlined Open Channel	Unlined Open Channel	Unlined Open Channel	Unlined Open Channel	Unlined Open Channel	Unlined Open Channel
Length of Main Canal (miles)	54.7	19.3	71.3	8.7	79.0	8.5
Length of Distribution Laterals (miles)	692.7	44.7	195.8	11.2	64.0	0.0
Method of Farm Delivery	Continuous Flow	Allotment	Rotation	Combination Demand-Rotation	Combination Continuous Flow-Rotation	Continuous Flow
Are Farm Deliveries Regulated by District Personnel?	Yes	Yes	Yes	No	Some	No
Are All Deliveries Measured?	Yes	Yes	Yes	No	No	No
Major Irrigation Methods	Furrow-90% Sprinkler-10%	Furrow-98% Sprinkler-2%	Furrow-55% Border-44% Sprinkler-1%	Border-79% Furrow-16% Sprinkler-5%	Border-60% Furrow-25% Sprinkler-15%	Sprinkler-85% Furrow-10% Border-5%

*Date given on this page is taken from (28) or from field investigations

Irrigation district personnel assisted in the collection of data on return flows or water leaving the project area. Flow readings were taken on a one to two day frequency at 49 stations with either measuring devices or rated current meter sections. Fourteen stations, equipped with stage recorders, were serviced and maintained by project personnel.

In some instances measurement of 100 percent of the return flow from any one district was impractical, if not impossible, and estimates of the portion of return flow being measured versus actual return flow were developed for each district. This factor was denoted as the coefficient of return flow.

Farm surface runoff entering the conveyance system was considered to be operational waste and computed farm irrigation efficiencies are higher than actual.

Crop Consumptive Irrigation Requirement

Two to five years of crop distribution data were averaged to give mean crop distribution percentages on each district. Gross acreages for each district were obtained from de Sonneville (12), Bureau of Reclamation records, and Soil Conservation Service data (32) (see Table 2).

Sutter and Corey (34) combined the modified Blaney-Criddle method of calculating monthly crop consumptive use and average monthly rainfall data to compute consumptive irrigation requirements for 42 climatic areas in Idaho. The Modified Blaney-Criddle formula used is:

$$u = 00.1tpk_c(0.0173t - 0.314) \qquad (5)$$

Where: u = monthly consumptive use (inches)
t = mean monthly temperature, ^oF
p = monthly percentage of annual daylight hours
k_c = crop growth stage coefficient

Three assumptions were made in our analysis: 1) seasonal or monthly consumptive use is proportional to the climatic factor, f, where f = 0.01tp; 2) crops are not limited by an inadequate water supply at any time during the growing seasons; 3) all factors other than temperature, percentage of daylight hours, and growing season are similar from location to location.

Monthly rainfall is subtracted from monthly consumptive use, to obtain values for consumptive irrigation requirement assuming that all rainfall during the irrigation season is effective. Computed monthly consumptive irrigation requirements were applied to the crop distributions for each district and used to supply drop water use data to the water budget analysis. Actual field measurements incorporated with a U.S. Geological Survey topographical map supplied similar data on Irrigation District No. 6.

General soil type information was then collected from Idaho Water Resource Board Special Soil Surveys (7, 8, 9, 10, 11) and Soil Conservation Service maps (42, 45). Soil type information correlated with seepage rate coefficients for general soil classifications developed by Worstell and Brockway (3).

Deep Percolation Losses

No direct data collection was made in determining this constituent of the water budget. Deep percolation is calculated as the residual in the district water budget.

DATA PROCESSING

Two digital programs were written in Fortran IV for processing water flow, crop irrigation requirements, and canal seepage data. Two smaller programs were also written to process water measurement field data.

Canal Seepage Program

This program computes maximum (full channel) seepage losses for each main canal and lateral and total district losses using canal reach lengths, topwidths, and seepage coefficients based on soil type for each reach. Canal wetted areas were computed from topwidth measurements using topwidth coefficients varying from 1.05 to 1.30 depending on the canal cross section shape.

Water Budget Program

All components of the water budget for each district were computed for bi-monthly intervals during the 1974 irrigation season. From inflow-outflow data, thirty-six related water use components and three irrigation efficiency variables were calculated for each district for each bi-monthly time period.

The general equation used in the water budget program is:

$$Qin - Qout + ds/dl = 0 \qquad (6)$$

Where: Qin = total system inflow
Qout = total system use and outflow
ds/dl = change in system storage per time period

No districts utilized surface storage facilities in which bimonthly changes in storage were significant. Pre-season soil moisture depletion data were examined which showed soil moisture deficits averaging 3.4 inches in a 3 foot silt loam soil horizon prior to the first irrigation. This deficit could be significant in calculating irrigation efficiency for the first irrigation; however, several factors tend to nullify the significance of the deficit. First, it is unrealistic to assume that the deficit will be satisfied for all land in the district during the first irrigation. On some districts irrigation had occurred prior to the first calculated water budget period thereby reducing the total district soil moisture depletion. Only two of the six districts began diverting water during the first time intervals of the water balance. Soil types on five of the districts indicated that the average water holding capacity of these soils was less than or equal to soils in District 2.

The storage term ds/dl in equation (6) was therefore considered negligible for all districts except for the first time interval on districts 2, 3 and 6.

The simplified water budget equation, eliminating the ds/dl term is:

$$Qrd + Qif - Qrd - Qcsl - Qdpl = 0 \qquad (7)$$

Where:
- Qrd = river diversion
- Qif = supplementary inflow to district
- Qrd = return flow
- Qcir = consumptive irrigation requirement consumptive use - precipitation
- Qcsl = canal and lateral seepage losses
- Qdpl = deep percolation losses

Details of the operation of the water budget program are given by Claiborn (12). Output from the programs includes all components of the input and computed values of deep percolation and water use efficiencies for each bi-monthly period during the irrigation season.

Average annual totals for river diversion, return flow, consumptive irrigation requirements, total district inflow, net district water use, total distribution system seepage loss, and deep percolation loss on a per acre basis are computed for each irrigation district. These values are obtained by dividing season totals of water budget components by irrigated acreages of the appropriate district.

District return flow fraction, F_r, is computed in percent as a comparator of return flow for irrigation districts.

Expressed as an equation:

$$F_r = \frac{Qrf}{Qrd + Qif} = \frac{Qrf}{Qtf} \times 100\% \qquad (8)$$

Return flow fraction is the ratio of seasonal return flow to seasonal total district inflow expressed as a percentage.

The three most useful and meaningful output components of the water budget program are the average annual figures for district water conveyance efficiency, farm irrigation efficiency and the composite project irrigation efficiency.

Average annual district conveyance efficiency, E_c, is defined as:

$$E_c = \frac{Qtf - Qrf - Qcsl}{Qtf} \times 100\% \qquad (9)$$

TABLE 4. Starting Dates for River Diversion and the Water Balance Analysis

Irrigation District Number	Starting Date of Season Diversion	Starting and Ending Dates for Water Balance Analysis
1	March 25	April 15 to October 15
2	April 22	May 1 to September 15
3	April 17*	April 15 to October 15
4	May 9	May 15 to October 30
5	May 2	May 15 to September 30
6	June 2*	June 1 to September 30

* After Water Balance Starting Date

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* After Water Balance Starting Date

Where: Qtf = total district inflow
Qrf = district return flow
Qcsl = canal and lateral seepage losses

District conveyance efficiency is a measure of the effect of system water management and system seepage losses on district water use. This efficiency term is dependent upon both the physical characteristics of the distribution system and water management practices of the district. Furthermore, it may be somewhat dependent upon on-farm irrigation practices within the district if return flow also includes water received as surface runoff from fields.

The ratio of the amount of water consumptively used by farm crops to the amount of water delivered to the farm is defined as average unit of farm irrigation efficiency, E_u, or algebraically:

$$E_u = \frac{Qcir}{Qtf - Qrf - Qcsl} \times 100\% \qquad (10)$$

Where: Qcir = consumptive irrigation requirement
Qtf = total district inflow
Qrf = district return flow
Qcsl = canal and lateral seepage losses

Farm irrigation efficiency is strictly dependent upon farm irrigation practices and irrigation water application management. Deep percolation rates are also reflected in this characteristic. Only district-wide averages of farm irrigation efficiency can be computed in the water budget program.

Because the objective of this study was to analyze irrigation efficiency from a total system or irrigation district concept, a total project irrigation efficiency term was considered appropriate. Project irrigation efficiency, E_p, is defined as:

$$\begin{aligned} E_p &= E_u \times E_c \\ &= \frac{Qcir}{Qtf - Qrf - Qcsl} \times \frac{Qtf - Qrf - Qcsl}{Qtf} \times 100\% \qquad (11) \\ &= \frac{Qcir}{Qtf} \times 100\% \end{aligned}$$

Where: E_u = average farm irrigation efficiency
E_c = district conveyance efficiency
Qcir = consumptive irrigation requirement
Qtf = total district inflow
Qrf = district return flow
Qcsl = canal and lateral seepage losses

From equation 11, project efficiency is obviously a composite product of conveyance and farm irrigation efficiency with the reservoir storage efficiency term omitted. Project efficiency is an overall system operational index dependent upon all parameters affecting the system's irrigation efficiency.

RESULTS AND ANALYSIS OF DATA

Distribution System Seepage Loss

Present, or 1974 level, daily base seepage rates were computed with the seepage program for each district. Seepage coefficients used on canals and laterals in each district depend on soil types and are listed in Table 5 along with the coefficients determined by Worstell and Brockway (3), which are denoted as SRCRC coefficients. These SRCRC coefficients were used as a guide and when better seepage coefficients could not be determined or estimated.

On District 2 all distribution channels were assigned an average seepage coefficient of 0.67 cfd (cubic feet per square foot per day) based upon ponding test data developed by Brockway and Worstell (4) on this district.

Brockway and Worstell in field studies found that ponded seepage rates could be estimated at 56 percent of the rate obtained from inflow-outflow analysis. The differences between the two methods is attributed to unavoidable system operational losses, such as headgate leakage. The gross seepage coefficient for the main canal system of District 6 was developed similarly from inflow-outflow data for a two week time interval after the end of the 1974 irrigation season. By assuming that all farm headgate diversion had ceased, that the conveyance channel was full, and by calculating the total wetted area of the main canal channel, an inflow-outflow seepage loss coefficient of 1.73 cfd was computed. The actual seepage rate was taken as 56 percent of the inflow-outflow value or 0.97 cfd. This estimate compares closely to the SRCRC value of .95 cfs for loam soils.

Combining the wetted areas obtained from photographic surveys and the estimated seepage coefficients for each district yielded present base daily seepage rates in acre-feet per day for each distribution system. Main canal, lateral system, and total system seepage losses are listed in Table 6.

Column 1, Table 6 lists "present base seepage" values which are estimates of maximum daily losses during 1974. These values were used in computing present level water balances for each district.

Simulated main canal lining projects to upgrade conveyance efficiencies were examined. The seepage loss reduction analysis was confined to lining only the main or largest canal systems in each irrigation district. Lining of the distribution laterals would be subject to stringent questions of economic feasibility, which is beyond the scope of this study.

Four commonly used canal lining materials were selected for

TABLE 5. Seepage Coefficients Used to Compute Present Distribution System Seepage Losses

Irrigation District	Soil Type			
	Clays (cfd)	Silts (cfd)	Loams (cfd)	Sands (cfd)
SRCRC Coefficients	0.31	0.81	0.95	1.33
1	0.35	0.67	0.95	1.33
2	-	0.67	-	-
3	-	-	0.95	1.33
4	-	-	0.95	1.33
5	-	-	0.95	1.33
6	-	-	0.97	-

Table 6. Base Daily Seepage Rates Used to Calculate System Seepage Losses in the Water Budget Program

Irrigation Distict No.		Present Base Seepage Rate (AF/DAY)	Loss With Simulated Main Canal Linings: Unreinforced Concrete (AF/DAY)	Buried Plastic Membrane (AF/DAY)	Compacted Clay (AF/DAY)	Unreinforced Shotcrete (AF/DAY)
1.	Main Canal	743.9	489.4	275.8	239.0	201.7
	Remaining System	1642.5	1642.5	1642.5	1642.5	1642.5
	Total System	2386.4	2131.9	1918.3	1881.5	1844.2
2.	Main Canal	29.9	18.7	5.9	3.6	1.4
	Remaining System	30.0	30.0	30.0	30.0	30.0
	Total System	59.9	48.7	35.9	33.6	31.4
3.	Main Canal	239.5	105.8	32.6	15.9	7.4
	Remaining System	162.5	162.5	162.5	162.5	162.5
	Total System	402.0	268.3	195.1	178.4	169.9
4.	Main Canal	33.2	13.3	4.2	2.6	1.0
	Remaining system	15.7	15.7	15.7	15.7	15.7
	Total System	48.9	29.0	19.9	18.3	16.7
5.	Main Canal	352.2	137.4	48.2	26.1	9.8
	Remaining System	100.4	100.4	100.4	100.4	100.4
	Total System	452.6	237.8	148.6	126.5	110.2
6.	Main Canal	23.2	10.7	3.1	1.9	0.7
	Remaining System	0.0	0.0	0.0	0.0	0.0
	Total System	23.2	10.7	3.1	1.9	0.7

use in the seepage reduction portion of this analysis. Table 7 lists each lining material and the associated range and average value of seepage coefficients of each material (44, 45, 46) used to compute new base daily seepage rates.

Base daily seepage rates were then recalculated by simulating the installation of each lining material in the main canals only. Total system base daily seepage rates decreased accordingly. Pneumatically applied, unreinforced shotcrete is discussed because it offers the maximum reduction in permeability of the four seepage reducing materials. The use of the shotcrete liner in the following discussion does not imply that it would be the most suitable liner for any or all of the channels. The reduction in total seepage for each district by lining the main canals depends on the relative size of the main canals to the total system. For instance, in District 1, present system loss in the main canal amounts to one-third of the total system loss whereas on District 4 almost seven-tenths of the total system loss is attributed to the main canals and on District 6 the entire distribution system consists of one main canal.

Present Irrigation Water Use Patterns and Irrigation Efficiencies

Irrigation water use patterns and irrigation efficiencies for the 1974 study season were compiled and evaluated using the water budget program. Tables 8 and 9 show the output of the water balance program for District No. 1 including bi-monthly and seasonal values for each parameter along with irrigation efficiencies. Similar information was compiled for each of the other five districts by Claiborn (12).

The starting and ending dates for the water balances correspond to the normal irrigation seasons or primary water delivery periods of each district. Net district water use, total inflow minus return flow is given also in each district water balance table. The three irrigation efficiency terms are computed for each time period and for the entire season, appearing in both the district water balance (Table 8) and the summary water balance table (Table 9).

Seasonal distribution of the five major water use components of the district water balances, total district inflow, total consumptive irrigation requirements, average deep percolation losses, distribution system seepage losses and total district return flow, are depicted for District No. 1 in Figure 3. Seasonal variation of the present condition irrigation efficiency terms is shown in Figure 4; a detailed discussion of water use practices for each district is given by Claiborn (12).

One important parameter in the water balance is irrigation return flow. The magnitude and seasonal distribution of return

TABLE 7. Seepage Coefficients of Four Commonly Used Irrigation Canal Lining Materials

Lining Material	Range of Values (cfd)	Average Seepage Coefficient (cfd)
Unreinforced Concrete[1]	0.07 - 0.83	0.42
Buried Plastic Membrane[2]	0.05 - 0.22	0.13
Compacted Clay or Thick[1] Compacted Earth	0.05 - 0.13	0.08
Unreinforced (Pnuematically[1] Applied) 1½" Thick Shotcrete	0.03	0.03

[1]Reference 44 and 45.

[2]Reference 46

Table 8. Seasonal District Water Balance 1974

IRRIGATION DISTRICT IDENTIFICATION NUMBER --- 1---
IRRIGATED ACREAGE IN THIS DISTRICT 151368.

TIME PERIOD (MON.)		RIVER DIVERSION (AC-FT)	SUPPLE-MENTARY INFLOW (AC-FT)	TOTAL INFLOW (SUPL.+ RIVDV.) (AC-FT)	TOTAL CONSUMPTIVE IRRIGATION REQUIREMENT (AC-FT)	AVERAGE DEEP PERCOLATION LOSSES (AC-FT)	DISTRIBUTION SYSTEM SEEPAGE LOSSES (AC-FT)	TOTAL DISTRICT RETURNFLOW (AC-FT)	NET DISTRICT WATERUSE (TINF-RET) (AC-FT)	DISTRICT CONVEYANCE EFFICIENCY (%)	FARM IRRIG. EFFIC. (%)	PROJECT IRRIG. EFFIC. (%)
APRIL	15-30	47743.	-2637.	45106.	1676.5	18283.6	20195.9	4950.0	40156.	44.25	8.40	3.72
MAY	1-15	91893.	-4810.	87083.	9197.2	42332.6	29279.8	6273.3	80810.	59.17	17.85	10.56
MAY	15-31	108019.	-8416.	99603.	9810.3	49321.4	33768.9	6702.2	92901.	59.37	16.59	9.85
JUNE	1-15	104029.	-8920.	95109.	28587.2	27319.5	32359.0	6843.3	88266.	58.78	51.13	30.06
JUNE	15-30	109787.	-9237.	100550.	28587.2	32892.6	33819.7	5250.0	95300.	61.14	46.50	28.43
JULY	1-15	115505.	-7761.	107744.	42741.5	25832.6	35270.5	3898.9	103845.	63.65	62.33	39.67
JULY	15-31	123294.	-8075.	115219.	45590.9	27557.8	37644.4	4425.6	110793.	63.49	62.33	39.57
AUGUST	1-15	110197.	-7182.	103015.	27083.4	36812.4	33924.0	5195.6	97820.	62.03	42.39	26.29
AUGUST	15-31	107646.	-7688.	99958.	28888.9	31789.1	33674.3	5605.6	94352.	60.70	47.61	28.90
SEPTEMBER	1-15	92095.	-8095.	84000.	6655.8	41821.0	29331.2	6192.2	77808.	57.71	13.73	7.92
SEPTEMBER	15-30	69716.	-7573.	62143.	6655.8	25133.8	23653.1	6700.0	55443.	51.16	20.94	10.71
OCTOBER	1-15	46315.	-5149.	41166.	986.4	14770.2	19497.7	5911.1	35254.	38.28	6.26	2.40

RIVER DIVERSION LEVELS, COEFFICIENT OF RETURNFLOW, AND MAXIMUM SEEPAGE RATE:

MAXIMUM SEASONAL RIVER DIVERSION (CFS) = 3950.
RIVER DIVERSION AT 50% SEEPAGE LOSS RATE (CFS) = 1580.
COEFFICIENT OF RETURNFLOW (%) = 0.90
MAXIMUM INPUT SEEPAGE RATE (AF/DAY) = 2386.

DIVERSION REDUCTION FACTOR (%) = 100.00

Table 9. Water Balance Summary
District No. 1, 1974

TOTAL ANNUAL RETURNFLOW	(AC-FT)	67948.	
TOTAL ANNUAL RIVER DIVERSION	(AC-FT)	1126236.	
TOTAL ANNUAL INFLOW (DIVERSIONS + SUPPLEMENTARY)	(AC-FT)	1040694.	
TOTAL ANNUAL CONSUMPTIVE IRRIGATION REQUIREMENT	(AC-FT)	236461.	
TOTAL ANNUAL SYSTEM SEEPAGE LOSSES	(AC-FT)	362418.	
TOTAL ANNUAL DEEP PERCOLATION LOSSES	(AC-FT)	373866.	
TOTAL ANNUAL NET DISTRICT WATERUSE	(AC-FT)	972746.	
AVERAGE ANNUAL RETURNFLOW PER ACRE	(AF/AC)		0.45
AVERAGE ANNUAL RIVER DIVERSION PER ACRE	(AF/AC)		7.44
AVERAGE ANNUAL CONSUMPTIVE IRRIGATION REQUIREMENT	(AF/AC)		1.56
AVERAGE ANNUAL TOTAL INFLOW TO DISTRICT PER ACRE	(AF/AC)		6.88
AVERAGE ANNUAL SEEPAGE LOSSES PER ACRE	(AF/AC)		2.39
AVERAGE ANNUAL DEEP PERCOLATION LOSSES PER ACRE	(AF/AC)		2.47
AVERAGE ANNUAL NET DISTRICT WATER USE PER ACRE	(AF/AC)		6.43
AVERAGE ANNUAL DISTRICT RETURNFLOW FRACTION	(%)		6.53
AVERAGE ANNUAL DISTRICT CONVEYANCE EFFICIENCY	(%)		58.65
AVERAGE ANNUAL FARM IRRIGATION EFFICIENCY	(%)		38.74
AVERAGE ANNUAL PROJECT IRRIGATION EFFICIENCY	(%)		22.72

Figure 3

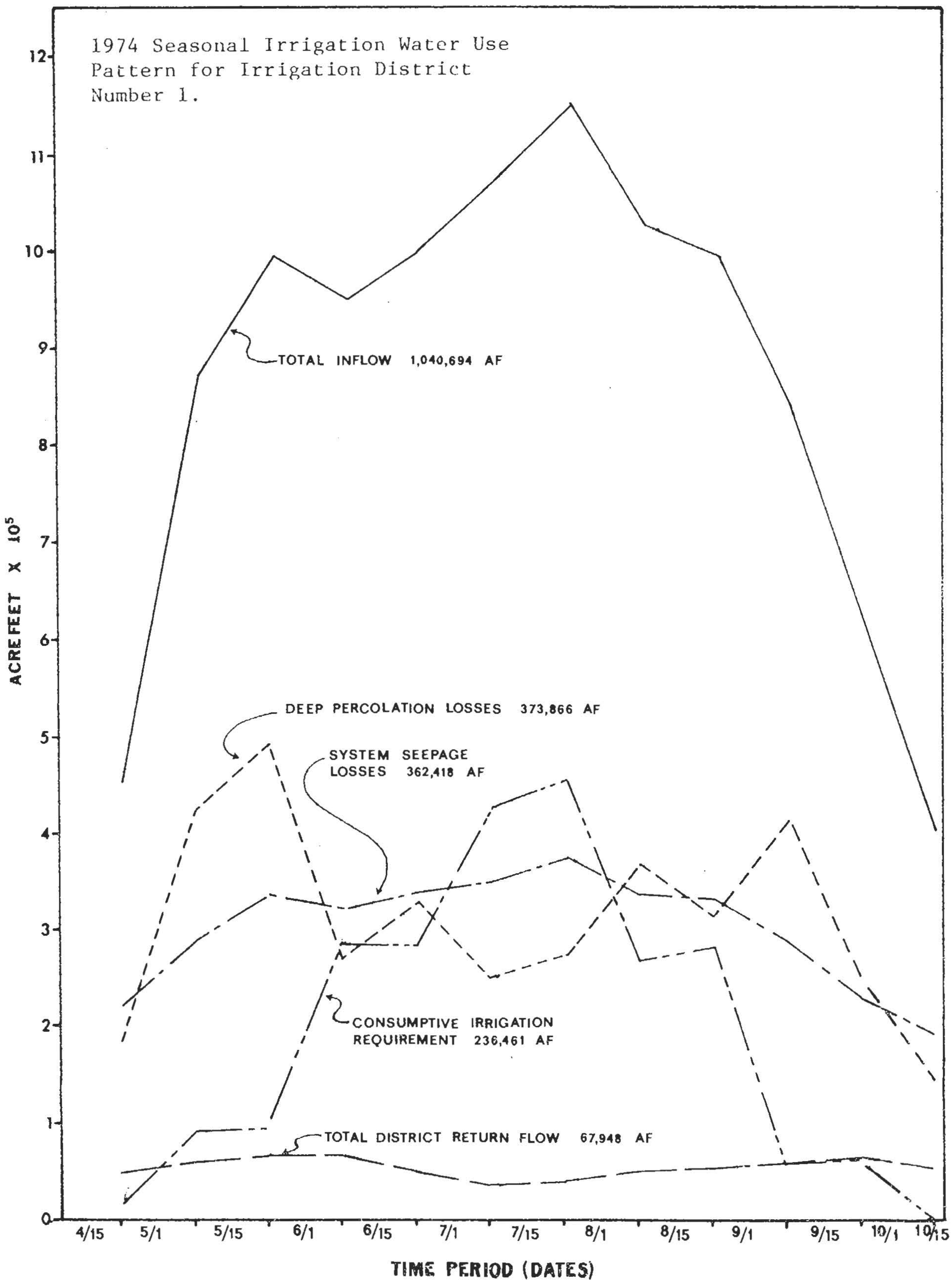
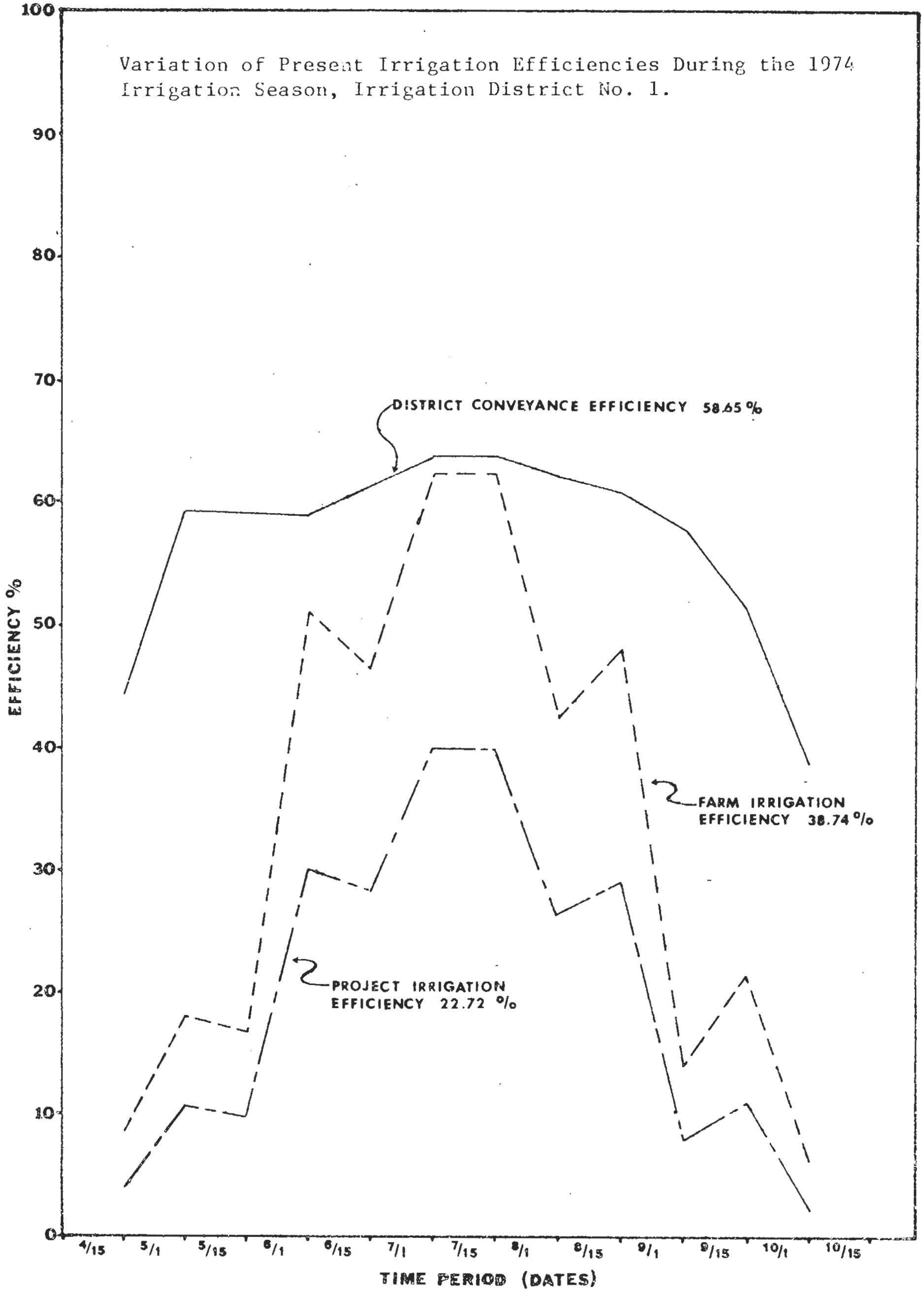

1974 Seasonal Irrigation Water Use Pattern for Irrigation District Number 1.
TOTAL INFLOW 1,040,694 AF
DEEP PERCOLATION LOSSES 373,866 AF
SYSTEM SEEPAGE LOSSES 362,418 AF
CONSUMPTIVE IRRIGATION REQUIREMENT 236,461 AF
TOTAL DISTRICT RETURN FLOW 67,948 AF
ACREFEET X 10^5
0
1
2
3
4
5
6
7
8
9
10
11
12
4/15
5/1
5/15
6/1
6/15
7/1
7/15
8/1
8/15
9/1
9/15
10/1
10/15
TIME PERIOD (DATES)

Figure 4


Variation of Present Irrigation Efficiencies During the 1974 Irrigation Season, Irrigation District No. 1.
100
90
80
70
60
50
40
30
20
10
0
EFFICIENCY %
DISTRICT CONVEYANCE EFFICIENCY 58.65 %
FARM IRRIGATION EFFICIENCY 38.74 %
PROJECT IRRIGATION EFFICIENCY 22.72 %
4/15
5/1
5/15
6/1
6/15
7/1
7/15
8/1
8/15
9/1
9/15
10/1
10/15
TIME PERIOD (DATES)

flow to the Snake River tributary streams is an important factor in river operations and an integral part of the operations model of the Snake River. The bi-monthly return flow as a percentage of the bi-monthly river diversion or total district inflow for each district is shown in Table 10. Present seasonal irrigation efficiencies for each district are shown in Table 11.

Discussion of Basin Sub-Areas

In the Lower Sub-Area of the Upper Snake River Region calculated irrigation efficiencies on the three districts ranged from 25 to 62 percent as shown in Table 11. Most districts in the sub-area could be expected to be operating close to or within this range of efficiencies since these three study districts are typical and representative of this area. District 2 with the highest farm efficiency represents perhaps the upper limit of farm irrigation efficiencies for gravity systems which the other districts in the sub-area could potentially approach in the future. This district, topographically and soil-wide, is not dissimilar from the other major districts in the sub-area. The irrigation efficiency of District 3 is probably indicative of the operating levels of irrigation districts located in the eastern portion of the Lower Sub-Area, except District 2. Those districts in the central and western portions of the Lower Sub-Area are probably achieving irrigation efficiencies comparable to those measured on District 1.

The lowest project irrigation efficiencies, 10 and 15 percent, in this investigation occurred on the two districts in the Central Sub-Area. This occurred primarily because farm irrigation efficiencies were lower on these two districts. District 4 had simultaneously the lowest overall farm irrigation efficiency and the highest conveyance efficiency. Both farm irrigation and district conveyance efficiency were lower on District 5. The performance of District 5 is representative of those irrigation districts south of the Bonneville-Jefferson County line on either side of the Snake River to the Bingham County line. This district probably represents an average to upper operating limit of most districts in the Central Sub-Area. Those districts south of the Bonneville-Bingham County line to American Falls and those districts in the Snake River Fan Area are probably operating at or above the performance level of District 4.

Irrigation District 6 is not representative of the districts lying on bottom lands in the Upper Sub-Area. Since very high rates of diversion and low irrigation efficiencies have been previously measured in portions of this area, District 6 should represent a potentially higher irrigation performance level for the sub-area. It is doubtful that more than one or two of the irrigation districts in this area are achieving anywhere near the 42 percent farm irrigation efficiency measured on District 6.

Table 10. Bi-Monthly Return Flow Fractions (Percentages)

Time Period	Irrigation District Number					
	1	2	3	4	5	6
April 15-30	11.0	-	5.1	-	-	-
May 1-15	7.2	19.0	2.8	-	-	-
May 15-31	6.7	20.0	6.1	2.6	56.8	-
June 1-15	7.2	17.1	10.3	5.3	22.7	22.9
June 15-30	5.2	18.8	5.6	5.7	20.8	18.8
July 1-15	3.6	22.2	14.2	4.9	18.0	19.8
July 15-31	3.8	20.9	14.3	3.4	10.1	14.6
August 1-15	5.0	21.7	14.7	3.9	35.4	24.5
August 15-31	5.6	17.5	14.9	6.3	32.4	22.3
September 1-15	7.4	19.9	15.7	5.0	28.7	20.0
September 15-30	10.8	-	16.4	3.2	35.1	22.9
October 1-15	14.3	-	17.7	6.6	-	-
October 15-31	-	-	-	47.0	-	-
Season Averages	6.5	19.8	8.6	5.2	26.8	20.4

TABLE 11. Present Irrigation Efficiencies

Irrigation District	Farm Irrigation Efficiency (%)	District Conveyance Efficiency (%)	Project Irrigation Efficiency (%)
1	39	59	23
2	62	68	42
3	25	76	19
4	11	85	10
5	25	58	15
6	42	70	30

Conveyance efficiencies in all districts except District 2, peaked during the mid-irrigation season and were in general at their lowest during the beginning and end of the irrigation seasons. Return flows are the primary influence causing conveyance efficiencies to follow this trend.

REASONABLY ATTAINABLE IRRIGATION EFFICIENCIES

The analysis of reasonable and attainable changes in irrigation efficiencies was approached using four procedures involving manipulation of the water balances for each district. The third procedure consisted of combining two of the initial approaches. Changes in irrigation efficiency were examined by the following procedures:

1. Changing main canal system seepage losses.
2. Simulated incremental reductions in river diversions.
3. Combination (changing seepage losses and reducing diversions simultaneously).
4. Conversion to sprinkler irrigation.

Reducing Main Canal System Seepage Losses

After new base daily seepage rates were calculated, the water budget program was run with the original 1974 data files except for four new base daily seepage rates introduced for each district. These primary computer runs reduced the bi-monthly seepage loss component and the total district seepage losses were then subtracted from each corresponding 1974 equivalent to obtain actual reductions in the seepage component. To restore and hold farm irrigation efficiencies constant at their present (1974) levels, the differences between the bi-monthly seepage components were then subtracted from the appropriate bi-monthly supplementary inflow figures. The water budget program was run a second time with the new supplementary inflow values and the new base seepage rates for each lining material. The secondary run computed changes in conveyance and project efficiencies while holding farm irrigation efficiency constant at existing 1974 levels. Such a constraint is logical since changes in canal seepage losses would not necessarily mean a change in farm irrigation efficiency except on perhaps water deficient tracts. None of the irrigation districts investigated in this study fall into such a category.

The results of this analysis are given in Table 12. Some minor variations in farm irrigation efficiency occur; however, they are relatively insignificant compared to the larger changes observed in the conveyance efficiencies. These minor variations are due to the internal adjustments made in the water balance during the secondary computer runs.

In general, this table shows that the impact of lining the main canals in any of the districts did not change district conveyance efficiency more than about 7.5 percent. The greatest

TABLE 12. Effect of Lining Main Canals on Seasonal Average Irrigation Efficiencies and Seasonal River Diversions

Irrigation District No.	Efficiencies and Diversion	Unit	Present Operating Level	Unreinforced Concrete Lining	Operating Levels With Buried Plastic Membrane Lining	Operating Levels With Compacted Clay Lining	Unreinforced Shotcrete Lining
1	Farm Irrigation Efficiency	%	38.74	38.74	38.74	38.74	38.74
	Conveyance Efficiency	%	58.65	60.90	62.95	63.31	63.68
	Project Irrigation Efficiency	%	22.72	23.60	24.39	24.53	24.67
	Season River Diversion	AF	1,040,694	1,002,115	969,608	963,988	958,368
2	Farm Irrigation Efficiency	%	61.69	61.67	61.69	61.69	61.69
	Conveyance Efficiency	%	67.57	69.18	71.16	71.48	71.96
	Project Irrigation Efficiency	%	41.69	42.66	43.90	44.10	44.39
	Season River Diversions	AF	52,614	51,407	49,957	49,735	49,404
3	Farm Irrigation Efficiency	%	24.57	24.57	24.57	24.57	24.57
	Conveyance Efficiency	%	76.09	80.18	82.60	83.18	83.46
	Project Irrigation Efficiency	%	18.69	19.70	20.29	20.44	20.50
	Season River Diversion	AF	379,104	359,767	349,217	346,762	345,599
4	Farm Irrigation Efficiency	%	11.46	11.46	11.46	11.46	11.46
	Conveyance Efficiency	%	85.37	88.79	90.42	90.79	90.97
	Project Irrigation Efficiency	%	9.78	10.17	10.36	10.40	10.43
	Season River Diversion	AF	62,538	60,130	59,045	58,804	58,684
5	Farm Irrigation Efficiency	%	25.34	25.43	25.34	25.34	25.34
	Conveyance Efficiency	%	58.40	62.74	64.85	65.40	65.79
	Project Irrigation Efficiency	%	14.80	15.95	16.44	16.57	16.67
	Season River Diversion	AF	297,366	274,307	265,583	263,188	261,512
6	Farm Irrigation Efficiency	%	42.39	42.38	42,39	42.38	42.41
	Conveyance Efficiency	%	69.90	73.94	76.31	76.66	77.00
	Project Irrigation Efficiency	%	29.63	31.34	32.34	32.49	32.66
	Season River Diversion	AF	23,304	22,034	21,348	21,251	21,143

percentage change was observed on District 5. A 7.4 percent increase over the present and district conveyance efficiency was obtained with the unreinforced shotcrete lining. Consequently, the largest improvement in project irrigation efficiency occurred on this same district. River diversions would be reduced by about 12 percent under this simulated operating condition.

Main canal seepage loss on any of the six districts is not a large component of the district water balances. Therefore, any canal lining action confined to the main canal systems will modify project irrigation efficiency up to about 7.4 percent and would not be an effective measure for large reductions in river diversion requirements.

Simulated Incremental Reductions in River Diversions

An analysis of the effect of changes in farm irrigation efficiency on river diversions throughout the irrigation season was made. The most convenient manner in which to study this response was to reduce river diversions by increments for each time interval and re-run the water budget program. The primary constraint controlling this procedure was to avoid invalidating the water balance for any time period by causing the deep percolation term to become negative. Therefore, a maximum reduction of 30 percent was observed by trial and error methods to satisfy the constraint on all but two of the districts. Four increments of river diversion reduction; 5, 10, 20, and 30 percent, were selected. The results of this portion of the investigation are summarized in Table 13.

During this analysis, district return flows were left unchanged for each round of reduced river diversion computations. This was done because no valid criteria for reducing the return flow could be determined. With gradually increasing reductions in diversions it is recognized that changes in conveyance system operation would occur, thereby increasing the conveyance efficiency before farm irrigation efficiency reached unreasonable levels. As a result, as the total district inflow drops, district conveyance efficiency tends to decrease also since return flow is held constant. The decreases in system seepage only slightly offset the effect of declining total district inflows. This situation is not of great concern since the primary purpose here is to study the river diversion-farm irrigation efficiency relationship. From Table 13 a specific change in farm irrigation efficiency can be observed in terms of the incremental reductions in river diversions for each district.

Negative deep percolation values were encountered at the 20 and 30 percent reduction levels for District 2 hence the first two levels are meaningful only. For the same reason, the

TABLE 13. Changes in Irrigation Efficiencies by Simulated Incremental Reductions in River Diversion

Irrigation District No.	Efficiencies and Diversion	Unit	Present Operating Levels	Percent Reduction in Diversion 5%	10%	20%	30%
1	Season River Diversion	(AF/YEAR)	1,040,694	988,659	936,625	832,555	728,486
	Farm Irrigation Efficiency	(%)	38.74	42.68	47.51	61.41	86.79*
	Conveyance Efficiency	(%)	58.65	56.28	53.63	47.22	38.77
	Project Irrigation Efficiency	(%)	22.72	24.02	25.48	29.00	33.64
2	Season River Diversion	(AF/YEAR)	52,614	49,983	47,352	42,091	36,830
	Farm Irrigation Efficiency	(%)	61.69	66.81	72.39	87.57*	>100.00*
	Conveyance Efficiency	(%)	67.57	65.87	63.98	59.48	--
	Project Irrigation Efficiency	(%)	41.69	43.88	46.31	52.09	--
3	Season River Diversion	(AF/YEAR)	379,104	360,149	341,194	303,283	265,373
	Farm Irrigation Efficiency	(%)	24.57	26.30	28.28	33.33	40.56
	Conveyance Efficiency	(%)	76.09	74.83	73.43	70.11	65.84
	Project Irrigation Efficiency	(%)	18.69	19.68	20.77	23.37	26.70
4	Season River Diversion	(AF/YEAR)	62,538	59,411	56,284	50,030	43,776
	Farm Irrigation Efficiency	(%)	11.46	12.17	12.98	14.97	17.67
	Conveyance Efficiency	(%)	85.37	84.60	83.74	81.71	79.10
	Project Irrigation Efficiency	(%)	9.78	10.30	10.87	12.23	13.98
5	Season River Diversion	(AF/YEAR)	297,366	282,498	267,629	237,893	208,156
	Farm Irrigation Efficiency	(%)	25.34	27.54	30.15	37.21	48.58
	Conveyance Efficiency	(%)	58.40	56.37	54.13	48.88	42.27
	Project Irrigation Efficiency	(%)	14.80	15.52	16.32	18.19	20.54
6	Season River Diversion	(AF/YEAR)	23,304	22,139	20,974	18,643	16,313
	Farm Irrigation Efficiency	(%)	42.39	45.65	49.46	59.38	74.26
	Conveyance Efficiency	(%)	69.90	68.32	66.56	62.38	57.00
	Project Irrigation Efficiency	(%)	29.63	31.19	32.92	37.04	42.33

* Some bi-monthly deep percolation values change sign at these levels.

30 percent column for District 1 is not meaningful.

Combined Improved Irrigation Efficiency and Reduced Seepage Loss

The third approach consisted of looking at the combined effects of increased irrigation efficiency at the farm level and simultaneously reduced system seepage losses. Increased farm irrigation efficiencies were obtained by using the incremental reductions in river diversion procedure. Simultaneously, the corresponding seepage data developed using the simulated compacted clay lining on main canals was introduced into the water budget program. Running the program with the modified 1974 data files produced the results summarized in Table 14.

Because of the deep percolation non-negativity constraint, uniform levels of reduced river diversion could not be obtained for each of the six districts. The predicted river diversion figures reflect a combined reduction caused by the incremental decreases in river diversion and the supplementary inflow reductions calculated from changes in the seepage losses.

The primary purpose of this table is to show the compounding effect of seepage reduction and improved farm irrigation efficiency on river diversions. For example, on District 1, the compacted clay lining raises the project efficiency from 29 to 32 percent at the 20 percent river reduction level (Tables 13 and 14).

Conversion to Sprinkler Irrigation

Conversion to sprinkler irrigation is considered to be the practical upper limit of average farm irrigation efficiency attainable on the six districts in this study. To assume that sprinkler irrigation will replace surface irrigation as the major irrigation method implies that energy for pumping is not a limiting factor. Such a presumption may not be realistic at the present time.

Sprinkler irrigation efficiencies fall normally between 60 and 70 percent on the type of soils found in the Upper Snake River Region. Hence, these two values were chosen as reasonable levels of maximum potential farm irrigation efficiency for the six districts. Most soils in the study area are adaptable to sprinkler irrigation, including soils on the six districts studied.

Table 15 presents the results of this portion of the predictive analysis. In this procedure, the assumption was made that no major changes occur in the operation and functioning

TABLE 14. Changes In Irrigation Efficiencies Caused by Combining Canal Seepage Loss Reductions with Reductions in River Diversion

Irrigation District No.	System Parameter	Units	Present Operating Level	Reduced River Diversion (%)	Main Canal Liner Used: Type	Main Canal Liner Used: Seepage Coefficient (cfd)	Predicted* Operating Level
1.	Seasonal River Diversion	(AF/YEAR)	1,040,694	20			738,741
	Farm Irrigation Efficiency	(%)	38.74	--	Compacted		61.41
	District Conveyance Efficiency	(%)	58.65	--	Clay	0.08	52.13
	Project Irrigation Efficiency	(%)	22.72	--			32.01
	Base Daily Seepage Rate	(AF/DAY)	2,386	--			1,881
2	Seasonal River Diversion	(AF/YEAR)	52,614	10			44,547
	Farm Irrigation Efficiency	(%)	61.69	--	Compacted		72.39
	District Conveyance Efficiency	(%)	67.57	--	Clay	0.08	68.11
	Project Irrigation Efficiency	(%)	41.69	--			49.30
	Base Daily Seepage Rate	(AF/DAY)	60	--			34
3	Seasonal River Diversion	(AF/YEAR)	379,104	30			233,031
	Farm Irrigation Efficiency	(%)	24.57	--	Compacted		40.56
	District Conveyance Efficiency	(%)	76.09	--	Clay	0.08	74.98
	Project Irrigation Efficiency	(%)	18.69	--			30.41
	Base Daily Seepage Rate	(AF/DAY)	402	--			178
4	Seasonal River Diversion	(AF/YEAR)	62,538	10			52,550
	Farm Irrigation Efficiency	(%)	11.46	--	Compacted		12.98
	District Conveyance Efficiency	(%)	85.37	--	Clay	0.08	89.69
	Project Irrigation Efficiency	(%)	9.78	--			11.64
	Base Daily Seepage Rate	(AF/DAY)	49	--			18
5	Seasonal River Diversion	(AF/YEAR)	297,366	20			225,671
	Farm Irrigation Efficiency	(%)	25.34	--	Compacted		37.21
	District Conveyance Efficiency	(%)	58.40	--	Clay	0.08	56.28
	Project Irrigation Efficiency	(%)	14.80	--			20.94
	Base Daily Seepage Rate	(AF/DAY)	452	--			126
6	Seasonal River Diversion	(AF/YEAR)	23,304	20			16,590
	Farm Irrigation Efficiency	(%)	42.39	--	Compacted		59.37
	District Conveyance Efficiency	(%)	69.90	--	Clay	0.08	70.10
	Project Irrigation Efficiency	(%)	29.63	--			41.62
	Base Daily Seepage Rate	(AF/DAY)	23	--			2

*Return Flow Levels held constant; Seepage Reductions Subtracted from river diversions

TABLE 15. Predicted River Diversions Due to Total District Conversion to Sprinkler Irrigation

Irrigation Dist. No.	Present Farm Efficiency (%)	Potential Farm Efficiency (%)	Present Conveyance Efficiency (%)	Calculated Project Efficiency (%)	Present Consumptive Irrigation Requirement (AF)	1974 River Diversion (AF)	1974 River Diversion (AF/ACRE)	Reduction in 1974 Diversion (AF)	Percent Reduction in 1974 Diversion (%)	Predicted River Diversion (AF)	Predicted River Diversion (AF/ACRE)
1	38.74	60.00	58.65	35.19	236,641	1040,694	6.88	368,739	35.4	671,955	4.44
	38.74	70.00	58.65	41.06	236,641	1040,694	6.88	464,803	44.7	575,891	3.80
2	61.69	60.00	67.57	40.54	21,964	52,614	3.61	0	0	52,614	3.61
	61.69	70.00	67.57	47.30	21,964	52,614	3.61	6,178	11.7	46,436	3.19
3	24.57	60.00	76.09	45.65	70,864	379,104	8.86	223,871	59.1	155,233	3.63
	24.57	70.00	76.09	53.26	70,864	379,104	8.86	246,051	64.9	133,053	3.11
4	11.46	60.00	85.39	51.22	6,118	62,538	14.09	50,593	80.9	11,945	2.69
	11.46	70.00	85.39	59.76	6,118	62,538	14.09	52,300	83.6	10,238	2.31
5	25.34	60.00	58.40	35.04	47,257	297,366	8.85	162,500	54.6	134,866	4.01
	25.34	70.00	58.40	40.88	47,257	297,366	8.85	181,767	61.1	115,599	3.44
6	42.39	60.00	69.90	41.94	6,905	23,304	4.34	6,840	29.4	16,464	3.06
	42.39	70.00	69.90	48.93	6,905	23,304	4.34	9,192	39.4	14,112	2.63

Total 1974 River Diversions (Acre-feet) - - - - - - - - - - - - 1,855,620

Totals at 60% Farm Irrigation Efficiency (AF/YEAR) - - - - - - - - - - - - - - - - 812,543 - - - - - 1,043,077

Totals at 70% Farm Irrigation Efficiency (AF/YEAR) - - - - - - - - - - - - - - - - 960,291 - - - - - - 895,329 of the irrigation distribution systems, and that sprinkler pumps would pump directly from the existing canals and laterals in each district. Based upon this assumption, conveyance efficiencies (column 3, Table 15) would remain at 1974 levels.

Calculated project efficiency is the product of farm efficiency and conveyance efficiency. The predicted river diversion was calculated by dividing the present consumptive irrigation requirement by the calculated project efficiency. The new predicted river diversion was subtracted from the 1974 diversion to obtain the reduction in the 1974 diversions.

Significantly reduced river diversions and improvements in project irrigation efficiencies resulted on at least four of the districts. The predicted changes in irrigation efficiency are least on District 2. Because of the high percentage of measured return flow which is direct farm surface runoff on this district, the calculated farm irrigation efficiency under present conditions, 62 percent, is higher than actual. Therefore, it is believed that a 60 percent farm irrigation efficiency is reasonable for planning purposes. Since District 6 is 85 percent sprinkler irrigated by direct pumping from the main canal, changes in irrigation efficiencies and river diversions may, under actual conditions, be somewhat less than those figures shown on the table.

The largest reductions in river diversion and improvements in irrigation efficiencies were simulated on Districts 3, 4, and 5. These districts have high deep percolation losses which would decline by converting to sprinkler irrigation.

Estimated maximum reasonably attainable irrigation efficiencies, assuming no modification in the existing distribution systems which might alter seepage losses or district return flows, are shown in Table 16. These attainable irrigation efficiencies are predicted if sprinkler irrigation with pumping from the existing canal system evolved as the major irrigation method on each district. However, the attainment of such levels of irrigation efficiencies may be achieved with other than sprinkler irrigation methods.

Low existing distribution system efficiencies on Districts 1 and 5 cause potential project irrigation efficiencies to be lower relative to the other districts. District 4 which is presently operating at the lowest farm irrigation efficiency level, could attain the highest potential project irrigation efficiency as shown in Table 16.

Irrigation districts in the Lower Sub-Area should be capable of attaining potential project efficiencies in the range of 35 to 46 percent.

Districts 4 and 5 are representative of most irrigation districts located in the Central Sub-Area. Therefore, districts

TABLE 16. Maximum Reasonably Attainable Irrigation Efficiencies

Irrigation District	Potential Farm Irrigation Efficiency (%)	Present District Conveyance Efficiency (%)	Potential Project Irrigation Efficiency (%)
1	60	59	35
2	60	68	40
3	60	76	46
4	60	85	51
5	60	58	35
6	60	70	42

in this sub-area could be expected to approach the 35 to 51 percent range in project irrigation efficiencies.

District 6 is not necessarily representative of most irrigation districts located in the Upper Sub-Area. However, it does serve as an example of the potential operating levels achievable with sprinkler irrigation in this area. The predicted attainable project irrigation efficiencies for this area are estimated in the 42 percent range.

Control and Management of District Water Distribution

Proper management and responsible control of the diversion and distribution of irrigation water on a district can improve irrigation efficiencies and reduce river diversion requirements. Several means of improving irrigation efficiencies exist with current operational levels of irrigation districts in the Upper Snake River Region.

Measurement of water within a distribution system is essential to maximize conveyance efficiency. Adequate control and management of the distribution system can be achieved only when measuring devices are used effectively to monitor flows within the distribution system. A reduction in return flow and initial river diversions should occur in systems where water measurement is conscientiously employed. Water measuring devices are essential to insure uniform deliveries and flow regulation at the farm headgate. In the Central and Upper Sub-Areas of the Upper Snake River Region, water measurement after the initial river diversion is limited and irregular. Few measuring devices were observed on Districts 4, 5, and 6.

CONCLUSIONS

Present water use patterns and irrigation efficiencies found on six typical irrigation districts in the Upper Snake River Region are variable. During the 1974 irrigation season, river diversions ranged from 3.61 to 14.09 acre-feet per irrigated acre and present farm irrigation efficiencies varied from 11 to 62 percent. Reasonably attainable farm irrigation efficiencies of 60 to 70 percent could be achieved on the same districts by fully implementing sprinkler irrigation and taking other measures to increase efficiencies.

With the exception of one irrigation district, farm irrigation efficiencies on districts in the study area are low. Three of the six districts investigated are operating at farm irrigation efficiency levels at or below 25 percent. In five of the districts deep percolation losses were the largest outflow component in the 1974 water balances developed.

The pricing schedule for water delivery costs on District 2 where costs for diversions in excess of a base volume per acre are significantly higher may have been a contributing factor to the higher farm irrigation efficiencies measured.

Since main canal seepage losses are not large components of the water balances on most districts, lining of main canal systems has limited effect on decreasing river diversions. A 12 percent decrease in seasonal river diversions was the maximum simulated reduction, using the 1974 water year as a basis. The lower district conveyance efficiencies are constrained due to either high volumes of return flow or proportionally larger seepage losses in the distribution laterals in the systems. Total system seepage losses are appreciable components on three districts. The total system seepage losses inherently possess the largest probable error factor. This is a critical factor since farm irrigation efficiencies are sensitive to this component.

District return flow was a large component of the water balances on three districts in the investigation; however, the seasonal return flow fractions were less than 10 percent on the other three districts. According to data collected on District 6, the conversion of a district to sprinkler irrigation with pumping from the canal system may not reduce the amount of return flow leaving the district.

Improvement of flow measurement and regulation are needed to provide more control and management of irrigation water in Districts 4, 5, and 6, and additional measurement and control of flows on the other three districts would probably increase irrigation efficiency on these systems.

Upgrading irrigation efficiencies on only these six districts, representing 252,142 acres, could potentially result in about 960,000 acre-feet of water remaining in the river for other uses. At a diversion rate of 3.5 acre-feet per acre per year, an additional 274,000 acres could be put into agricultural production on Upper Snake River lands. Simultaneously, non-beneficial over-irrigation would be reduced on presently irrigated lands on the six districts.

Before changes in irrigation systems or irrigation practices can be anticipated, stronger incentives to increase irrigation efficiency must become apparent to farm operators and the management of irrigation districts. Visible economic benefits from reducing over-irrigation would be expected to encourage farm operators to re-evaluate their irrigation programs and systems. Economic gains or benefits must outweight costs before irrigation districts can justify taking action to increase their conveyance efficiencies. Presently, economic or other incentives provide farm operators and irrigation districts with little reason to alter their current practices and operating levels in the Upper Snake River Region of Idaho.

RECOMMENDATIONS

1. Seepage loss in distribution systems can be an important component of the water balance. More refined procedures for accurately assessing system seepage losses are needed. Additional data should be collected to identify the relationship between water levels in the channels or diversion rates and the actual seepage rates.

2. Additional research is needed to investigate the influence of water costs upon irrigation efficiencies in the Upper Snake River Region. Data collected in this study raised the question of the allotment water pricing policy being an effective incentive to increase farm irrigation efficiency.

3. Irrigation efficiencies are now known only on a fraction of the districts in this region. Furthermore, the data collected in this study represents only one year of investigation. Additional studies of a similar nature are needed for periods exceeding one irrigation season to establish average values of irrigation efficiency.

4. Socioeconomic studies to evaluate the relationships between attitudes and economic return to farm and district operating efficiencies should be pursued.

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