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THE EFFECTS OF AVAILABILITY OF WATER ON IRRIGATION SYSTEMS OPERATIONS

A Thesis

Presented in Partial Fulfillment
of the Requirements for the

DEGREE OF MASTER OF SCIENCE
Major in Agricultural Engineering

in the

UNIVERSITY OF IDAHO GRADUATE SCHOOL

by

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Moscow, Idaho

October 12, 1978

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AUTHORIZATION TO PROCEED WITH THE FINAL DRAFT:

This thesis of James R. Worstell's for the Master of Science degree with major in Agricultural Engineering and titled "The Effects of Availability of Water on Irrigation Systems Operations," was reviewed in rough draft form by each Committee member as indicated by the signatures and dates given below and permission was granted to prepare the final copy incorporating suggestions of the Committee; permission was also given to schedule the final examination upon submission of two final copies to the Graduate School Office:

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Committee Members C. E. Brockway Date 2/27/1978

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FINAL EXAMINATION; By majority vote of the candidate's Committee at the final examination held on the date of Feb. 27/78 Committee approval and acceptance was granted.

Major Professor J. R. Busch Date 10/12/78

GRADUATE COUNCIL FINAL APPROVAL AND ACCEPTANCE:

Graduate School Dean ____________________ Date __________

ACKNOWLEDGEMENTS

The author would like to express his great appreciation to his major professor, Dr. John R. Busch of the Department of Agricultural Engineering, for all the instructional guidance he provided. Without his guidance and technical counseling, this investigation would not have been possible.

Thanks are also due to Professor Calvin Warnick of the Department of Civil Engineering for his instructional advice throughout the duration of the investigation, and for his suggestions and review of this thesis.

I am indebted to Dr. Charles Brockway of the Department of Civil Engineering for serving on the graduate committee and for his technical assistance while I was located in Southern Idaho.

Individual thanks go to: The Water Resources Research Institute, University of Idaho, for administering the project and funding the assistantship; Department of Agricultural Engineering for providing office space and additional assistance; Snake River Conservation Research Center, Kimberly, Idaho for furnishing office space, use of equipment, and technical assistance; James Eakin of the Wood River Valley Irrigation District; Personnel of the Salmon River Canal Company, Ltd., for allowing me to conduct this study and supplying me with all necessary information.

Finally, special notes of thanks to the author's wife, Sharon, for her patient understanding, encouragement, and moral support during this study; and to the author's son Jacob, for providing all additional incentive needed to complete this thesis.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

CHAPTER I

INTRODUCTION AND PURPOSE OF STUDY

Introduction

In 1860, Mormon settlers established the first permanent irrigation-based agricultural community in Idaho. Since that time many people have recognized the abundance of clean water and fertile land in the Gem State. Extensive irrigation development has taken place, so that today over 4 million acres of land are irrigated in the state.

In order to bring about this development, it was necessary to stretch the limit which nature imposes upon the full utilization of the state's water resource. Streamflows vary seasonally: increasing in the spring as snowpacks melt and decreasing greatly in mid-summer at the peak of the irrigation season. To help stretch these seasonal limits, storage reservoirs have been constructed to save excessive snowmelt during spring runoff for use during periods of peak use.

Until recently, people generally have not been overly concerned with the conservation of irrigation water in Idaho. This lack of concern has resulted in the overapplication of water to crops. The overapplication has not only increased water use and depleted water supplies, but has also led to erosion and leaching of soil and nutrients and a deterioration in the quality of surface and ground water which receive silt, nutrients, pesticides, and herbicides from surface runoff and subsurface drainage.

The efficiency with which irrigation water is used is dependent upon a number of physical, technological, and economic factors. Recent trends to increase irrigation efficiency include replacement of surface systems with sprinkler systems. Some other consequences brought about by conversion to sprinklers include increased crop production and reductions in irrigation labor and management costs at the cost of increased energy use.

Competition among users of Idaho's available water supplies will inevitably increase. This increase may be brought about in two ways. Primarily, an increased number of users for existing supplies of water will result in an increase in competition. On the other hand, a decrease in the amount of available water in existing supplies will also result in increased competition.

In order to satisfy the increased demand for water, it will be necessary to effectively allocate, develop, and use these existing supplies.

PURPOSE OF STUDY

The process of supplying water to an irrigated farm is usually accomplished through a distribution system. There are two levels of such systems. That at the farm or unit level, and that at the project (Irrigation District or Canal Company) level. In order to measure the effectiveness of a system, the efficiency of the system may be determined at the various levels.

A number of studies have concentrated on the determination of the efficiency of an individual irrigation project for a given irrigation season. Some attention has been given to irrigation efficiency analysis of different projects in any given irrigation season (8, 14)[1/] The purpose of this study is to determine irrigation efficiencies of two basically different irrigation projects for two years in which the amount of water available for irrigation differed significantly.

By comparing the various efficiency terms, the effects that a drought year (such as 1977) might have on these projects may be determined.

The two representative irrigation projects chosen for the comparison are located in south central Idaho. One project (Salmon River Canal Company, Ltd.) is an Irrigation Company. The other project (Wood River Valley Irrigation District) is an Irrigation District.

The purposes for the existence of each project, herein referred to as each system, are essentially the same. These

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1/ Numbers in parentheses refer to listed references.

are to distribute allocated water to farms for beneficial use by crops, to operate and maintain the distribution system, and to collect charges which are assessed. The distribution methods which each system employs are similar as both use canal and lateral systems to convey water from the source to the farm turnouts.

There are, however, some basic differences between the two systems. The basic structure of each organization differs in the fact that the canal company holds the water rights and delivers water to the stockholders. Each share of stock receives a set amount of water, depending on the available supply, and charges are assessed according to the number of shares of stock a particular water user holds. The district, however, does not hold the water rights, and there are no stockholders. The actual water users hold the water rights, and charges are assessed by the district according to the amount of the water right and date on which a particular right was established. Other differences exist, for instance the company must transport its water from the source through some 95 miles of major canals to the lands which it serves. The district, on the other hand, diverts directly from the source into its canals which deliver the water to immediately adjacent lands. The company has virtually no groundwater pumping to supplement its surface supply; however, approximately twenty-five percent of the water applied to the district lands is pumped from a groundwater source.

One other important difference exists in the fact that the company has had a history of water short years to deal with, and the district is less familiar with working with water shortages.

In order to evaluate these effects, it was necessary to obtain various water use data during 1976, a water sufficient season, and 1977, a water short season.

Specific objectives are:

1. To determine project irrigation efficiencies during the water short year and water full year for the two representative irrigation projects in the region on a bi-weekly basis.
2. To determine statistical relationships between the project irrigation efficiencies of both systems for each of the two years and between both years for each system.

CHAPTER II

LITERATURE REVIEW

There has been a considerable amount of research devoted to the subject of irrigation efficiency, and many types of analyses are used to compute the efficiency of a particular phase of an irrigation operation. Most studies have determined irrigatin efficiency at the farm or field level; however, some investigators have determined irrigation efficiencies for entire irrigation projects. (8).

In order to fully understand the meaning of irrigation efficiency, the term irrigation must be defined. Israelson defines irrigation as the application of water to the soil, supplementing natural precipitation, for the purpose of supplying water to provide a suitable environment for plant growth (19). Irrigation efficiency is then, in a general sense, the measure of the effectiveness of the method of irrigation.

Various Definitions for Irrigation Efficiencies

Israelson cites studies in 1939 as the first attempt to define irrigation efficiency and to identify factors upon which efficiency is based. He also refers to concepts previous to this which enable the measurement of irrigation efficiency as early as 1919. He defines water application efficiency as "the ratio of the volume of water stored in the soil in one irrigation to the volume of water delivered to the field". Mathematically stated:

$$E_a = V_r(100\%)/V_f \tag{1}$$

where:

E_a = Water Application Efficiency (percent)

V_r = Depth of water (inches) stored in the root zone

V_f = Depth of water (inches) delivered to the field

Israelson also breaks down the factors which influence the application efficiency into two groups: those which are subject to such control. Controllable factors include: land preparation, method of water application, and the rate of application. Factors beyond irrigation control include: soil texture, soil depth, soil variability and intrinsic soil permeability (20).

Willardson (48) found some twenty definitions of irrigation efficiency, and presented the concept of water distribution efficiency, known also as the uniformity coefficient. Willardson did not define water distribution efficiency; however, he did examine several methods of irrigation and showed that high application efficiencies were related to a high value of uniformity coefficient, estimating that furrow and border irrigation efficiencies of 60 to 70 percent are reasonably attainable and may be increased to over 80 percent by use of recovery systems.

Water distribution efficiency is defined by Hansen and Israelson (21) as:

$$E_d = 100\%(1-Y/d_s) \qquad (2)$$

where:

E_d = Water Distribution Efficiency (percent)

Y = Average numerical deviation of depth of water stored during the irrigation

d_s = Average depth of water stored during the irrigation

Meriam defines distribution efficiency as the percent ratio of the minimum depth of water infiltered into the ground to the average depth infiltered, where depth infiltered = depth of water stored at any point in the field (29).

Hall goes on to describe many different irrigation efficiencies and the parameters on which these are based (15). Some of the most useful are:

Operational Efficiency - The ratio of actual system application efficiency to the ideal system application efficiency. It is a measure of how well the system is operated.

Season Application Efficiency - The ratio of the useful water applied during the entire irrigation season to the total volume delivered.

Economic Irrigation Efficiency - The ratio of the total production under actual conditions to the expected production under ideal conditions.

For design purposes the following are valuable:

System Application Efficiency - This is defined as the application efficiency of a system at satisfactory output. Satisfactory output is the output obtained when 45 percent or some other designated percentage of the field has received adequate irrigation. This parameter is useful when it is not economically justifiable to achieve adequate irrigation of an entire field.

Ideal System Efficiency - This is defined as the highest application efficiency a system can attain as it is designed, and can be useful when comparing systems.

Keller (26) defines several types of irrigation efficiencies. He starts by giving a general definition previously defined by Blaney and Criddle (3) where irrigation efficiency is: "The percentage of (delivered) irrigation water that is stored in the soil and available for the consumptive use by crops. When the (delivered) water is measured at the farm headgate (or well), it is called farm-irrigation efficiency; when measured at the field, it is designated as field-irrigation efficiency; and when measured at the point of diversion, it may be called project-efficiency.

Keller then presents evidence which suggests that farm-irrigation efficiency depends more upon management and the actual irrigation facilities used than on the method of irrigation.

Some of the most extensive work on the subject of irrigation efficiency is reported by Jensen (23). He states: Irrigation Efficiency defined as E_i 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."

This definition takes into account all losses of water that occur after the water has left its natural course.

Assuming that the conditions are steady state (by neglecting any water in the plant tissue, and any change in stored soil moisture) an algebraic expression for the overall irrigation efficiency (E_i) can be obtained:

$$E_i = (W_{et} + W_1 - R_e)/W_i \times 100\% \tag{3}$$

where:

E_i = The overall irrigation efficiency in percent for the farm, project, or basin as specified.

W_{et} = The volume of water vaporized by evapotranspiration.

W_1 = 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, stored, or pumped specifically for irrigation.

This definition of overall irrigation efficiency differs from previous definitions, primarily in the fact that he includes the leaching requirement (W_1) in the numerator. Reeve (34) and Hall (15) also recognize the fact that certain parameters such as soil moisture tension and salinity are essential in providing an environment in the soil which is suitable to plant growth, and should be reflected by the efficiency.

Jensen further breaks irrigation efficiency into the following components:

Reservoir Storage Efficiency, E_s, is the ratio of the volume of water delivered from a reservoir for irrigation, to the volume of water delivered to the storage reservoir--surface or underground--for irrigation.

Water Conveyance Efficiency, E_c, is the ratio of the volume of water delivered by an open or closed conveyance system to the volume of water delivered into the conveyance system at the supply source or sources.

Unit Irrigation Efficiency, E_u, is the ratio of the volume of irrigation water used in evapotranspiration in a specified irrigated farm area, plus that necessary to maintain a favorable salt concentration in the soil solution, to the volume of water delivered to the farm.

In algebraic terms:

$$E_s = (W_d/W_r) \times 100\% \qquad (4)$$

where:

E_s = Reservoir storage efficiency in percent.

W_d = Volume of water delivered from the reservoir for irrigation.

W_r = Volume of water delivered to the reservoir.

$$E_c = (W_D/W_R) \times 100\% \quad (5)$$

where:

E_c = Water conveyance efficiency in percent

W_D = Volume of water delivered by the system

W_R = Volume of water diverted into the system

$$E_u = (W_{et}+W_1)/W_i \times 100\% \quad (6)$$

where:

E_u = Unit irrigation efficiency in percent

W_{et} = Volume of irrigation water required for evapotranspiration in the specified irrigated area

W_1 = Volume of water required for leaching

W_i = Volume of water delivered to the area

Jensen further explains that the product of the component efficiency terms, expressed as ratios, gives the overall irrigation efficiency, E_i (or project efficiency):

$$E_i = (E_s/100) \times (E_c/100) \times (E_u/100) \times 100\% \quad (7)$$

where all terms are previously defined.

Jensen goes on to point out that the key to evaluating any irrigation efficiency is accurate water measurement. In practice this may be a difficult objective to accomplish as actual water measurements may be biased. For example, the ditch rider may deliver more water than records indicate in order to keep good relations with the irrigators. Natural conditions may also exist which prevent accurate measurement such as the accumulation of sediment in front of a weir.

Jensen also brings out the fact that the major problem encountered when trying to determine the unit irrigation efficiency, E_u, is the determination of W_{et}. He describes various methods by which W_{et} can be estimated. Most of the methods he presents are based on soil sampling techniques.

A method of estimating W_{et} for crops in Idaho has been used by Sutter and Corey (41). They applied the modified Blaney-Criddle (3) method to determine the consumptive use of water by different crops using climatological data and geographical location within the state. Other methods for estimating the amount of water necessary for W_{et} have been determined by Penman and Jensen and Haise (32).

Factors Which Influence Irrigation Efficiencies

"The objective of irrigation efficiency", as defined by Willardson (49), "is to show where improvements may be made in irrigation practice which will save water, labor, soil, and plant nutrients".

Erie (12) points out that the present demand for water is not satisfied and that irrigated agriculture accounts for 80-90 percent of all water consumed in the U.S. Therefore, it would seem that the greatest opportunity for water conservation is in this area as nearly 42 percent of water delivered to irrigated farms in the U.S. is not beneficially used by plants.

Erie (12) and Tyler (42) both conclude that irrigation efficiency is dependent, to a large part, on irrigation management and the ability of the farmer. Other factors determined by Tyler (42) to influence irrigation efficiency are: length of field head ditches, length of irrigation runs, crop distribution, field gradients, weather conditions and irrigating only for the purpose of conditioning the soil. He proposed that 75 percent of the variation in irrigation efficiencies could be attributed to four factors: soil variation, irrigation frequency, duration of irrigation, and irrigating for soil conditioning purposes.

Willardson and Bishop (50) list some other factors on which surface irrigation efficiency is dependent. These are: amount of water applied, intake characteristics of the soil, and rate of advance. They also present curves which show efficiency-advance, and advance-infiltration relationships. Other studies which deal with advance-infiltration relationships are: Phillip and Farrell (33), Smerdon and Glass (36), and Wu and Bishop (54).

Pair (30) lists the factors which affect the irrigation water application efficiency at any one site as: climate, soil, crop, water supply, topography, method of irrigation, labor, irrigation system design, and irrigation system operation. He predicts that as the cost and scarcity of water increase, it will become more economical for the irrigator to invest in good water control equipment, proper land preparation, correct irrigation system design, and adequate labor.

Good water management practices will also cause farm and field water application efficiencies to increase.

Upgrading Irrigation Efficiencies

Stewart and Hagan (40) recognize the importance of the proper utilization of irrigation water and state: "Water shortage in irrigated agriculture is becoming more commonplace, and simultaneously more serious in its consequences."

Clyde (9) emphasizes the importance of the efficient management of water supplies for irrigated agriculture and has determined that by increasing the irrigation efficiency in the Western States to an average of 50%, existing water supplies would be supplemented by approximately 25 million acre-feet without the construction of a single reservoir, diversion, or main canal.

Jensen, Wright, and Pratt (25) describe how irrigated farms may be more effectively managed by the application of evapotranspiration technology in conjunction with the use of digital computers.

Hall (15) presents a discussion of the evaluation of the performance of an irrigation system, and distinguishes inadequacies due to design from those due to operation. "Design" id defined to include the physical characteristics of the system, whether intentionally designed or not. "Operation" is defined to include those characteristics of the system which are under the control of the operator such as discharge rates, period of the set, the condition in which the physical system is maintained, etc.

There have been a variety of ways proposed by which the efficiency of an irrigation operation may be increased. Jensen (24) describes how computerized irrigation scheduling can raise the efficiency of overall irrigation system operations. Wiser (51) evaluates a model which uses climatological data to synthesize an irrigation program which, if implemented, would lead to increased efficiency.

Hall and Buras (16) present a simple graphical procedure based on dynamic programming analysis which will permit determination of the optimum policy for irrigation of homogenous lands under conditions of less than adequate water supplies. Brinser (4) discusses the intervention of government in the implementation of water resources planning for the purpose of more efficient water use.

Bagley (1) presents the concept of the competition-efficiency relationship, and gives examples of the effect of increased competition for water use on efficiency. He concludes that the law of price and demand suggests that increased competition leads to increased efficiency. This seems to suggest that efficiency will improve with time as competition for water use increases.

Stewart, Hagen, and Pruitt (39) have added some insight to the problem of increasing existing irrigation efficiencies. They point out the fact that irrigation requirements are some-times estimated using methods which may tend to over-design the systems, resulting in higher investment costs and over irrigation.

Decreased seepage and operational losses would greatly enhance the efficiency of many irrigation projects. A major problem facing designers and managers of irrigation operations is the determination of these losses. Analytical studies, analogs, simulators, hydraulic models, and field tests have been used to show the relationships between seepage and depth and shape of channel, position of the water table, and saturated permeability of the soil (10).

Worstell (53) lists the principle methods by which seepage and operational losses from distribution systems may be measured. The method which he developed relates a range of seepage losses to canal size (geometry) and soil texture. Other methods listed include: inflow-outflow measurements, ponding to operating depth and measuring the change in depth with change in time, and the use of seepage meters to make spot measurements in different reaches of a canal system.

There are several ways by which seepage losses may be reduced (10). Designers of unlined earth canals can design the canals as deep as permissible, as deep canals are more efficient in conveying water than shallow canals. Methods by which seepage may be reduced in existing canals include: the addition of chemical amendments to the soil (sodium carbonate on clays), lining the canal with a prefabricated material (butyl rubber, polyethylene or pvc), and lining with more permanent materials (concrete or asphalt).

Evaporation control is another method of improving irrigation efficiency. The majority of research has centered largely on the development and use of monomolecular films which inhibit the passage of water vapor (10).

A more prevalent means of increasing irrigation efficiency is through automechanization. This makes it possible to apply more water efficiently with a minimum of labor, using automatic or semi-automatic control devices in combination with conventional irrigation methods (10).

The application of runoff reuse systems can increase irrigation efficiency. Fischback and Somerhalder (13) report that average efficiencies of automated surface systems increased from 65 percent to 92 percent through the use of recovery systems.

Programs to increase irrigation efficiency have been developed, however, they have not been well accepted. Some reasons for this have been identified (10) as:

1) The irrigator has tended to optimize water use in terms of economic efficiency, taking into account the cost of water as compared with the cost of irrigating, but not recognizing the inefficient use of fertilizer or decreased crop yields.
2) Fear of losing part of the water right encourages that the full right be diverted.

3) Lack of capital may deter increased efficiency.

4) The technology upon which recommendations for improved irrigation practices have been based does not lend itself easily to the skills and understanding of the irrigator.

Carlson (7) found that some farmers adopt new techniques more rapidly than others. Factors which correlate with the rate of adoption include: sources of information, benefits of the innovation, educational level of the farmer, age of the farmer, and size of farm. He also emphasizes the importance of the social structure in affecting the adoption of a new practice or idea.

Hammond (17) refers to legal incentives which may lead to more efficient use of irrigation water in Idaho. Under Idaho's water law, unappropriated water is diverted for beneficial use only. The amount of water which an irrigator may acquire is determined by the needs of the proposed beneficial use. Limits on the amount of water which may be diverted are given by the doctrines of priority (first in time, first in right) and beneficial use. The date on which the water was first beneficially used establishes the priority of the right relative to other rights on the same water course. Under the law an irrigator must use the water beneficially.

If an irrigator wastes water, under Idaho statutes he is guilty of a misdemeanor. Wasted water is any water which an irrigator diverts which he cannot economically and reasonably put to beneficial use. The courts have deemed that some waste is reasonable. The "reasonableness" of the waste is dependent upon such variables as soils, technology, and economics.

The priority and beneficial use doctrines could then, if more adequately enforced, promote water conservation and in turn increase irrigation efficiency.

Previous Studies Dealing with Irrigation Efficiency

Numerous previous studies have been conducted which analyze various levels of irrigation efficiency under actual field conditions (5, 6, 8, 11, 14, 26, 27, 30, 31, 37, 46, 47). One such study involved 22 irrigation projects in the western U.S. (46). It revealed an average conveyance efficiency of 62.4 percent, an average farm water-use efficiency of 57.9 percent, and an overall project-use efficiency of 36.1 percent.

Claiborn (8) investigated the efficiencies of six irrigation districts in southern Idaho. He determined that farm irrigation efficiency values varied from 11 to 62 percent and project efficiencies varied from 10 to 42 percent.

Some studies compared application efficiencies of sprinkler and surface irrigation systems (27, 31, 37). Somerhalder compared efficiencies of sprinkler irrigation with surface systems (furrow) on alfalfa. The average sprinkler application efficiency was found to be 84 percent. Surface application efficiency was 72 percent (37).

Pair (31) investigated the effects of irrigation methods on water application efficiency using controlled plots. His results indicate:

E_a for downslope border = 36%
E_a for contour border = 62%
E_a for sprinkler = 61%

These values are representative of the results obtained from other similar studies, and illustrate the range of values of observed irrigation efficiencies.

CHAPTER III

DESCRIPTION OF STUDY AREAS

Upper Big Wood River Region

The Big Wood River heads in a rugged, mountainous section of the Sawtooth National Forest. Flowing southward, it drops from an elevation of 8,572 feet at Galena Summit to Hailey (4 miles north of Bellevue), elevation 5,347 feet. Its drainage area above Hailey totals about 640 square miles. From Hailey, the river flows southwestward about 15 miles to Magic Reservoir, and then on to the Snake River below Hagerman.

The primary agricultural industries in the area are the production of livestock and feed crops. Local stock raisers with access to adjacent forest and range grazing lands provide a substantial local market for local hay; however, much of the hay produced is exported. Other major industries include logging and mining.

The climatic conditions of the area are considered to be semi-arid as normal annual precipitation at Hailey is 15.33 inches. Snowfall during the year averages 81 inches. June, July, and August are extremely dry. During the May-September growing season precipitation averages three inches, making irrigation necessary for satisfactory crop production. The frost free season lasts an average of 103 days which limits crops largely to hay and grain. The average maximum temperature at Hailey during July and August is 67°. The average date of the last killing frost in spring is June 4, and that of the earliest killing frost is September 17.

The soils of the area are fairly uniform gravelly silt loams. These are relatively high in organic matter and are naturally fertile. Good crop yields are obtained under adequate irrigation. Topsoil depth averages 30 inches (ranging from 18 to 48 inches) over larger gravel and cobbles. The stones in the upper horizon for the most part are smaller than golf balls and account for 30 to 50 percent of the soil mantle volume.

Generally, the topography of the area is ideal for irrigated farming; however, an area consisting of several hundred acres bordering the river and extending along the crest of the alluvial fan from about one mile south of Bellevue to the lower end of the valley has the irregular relief typical of channel erosion and fan deposition. This area is not cleared of natural vegetation and has little agricultural value.

Natural drainage in the area is excessive, due to the high porosity of the gravelly soils and subsoils, with the exception of several thousand acres near Gannett which are too wet for use of other than for pasture. These lands would probably be benefited if the water table could be lowered (45).

Primary crops grown in the area consist of hay, grain, and pasture. The hay/grain rotation carried out on most farm operations averages 6 to 8 years of hay followed by 2 years of grains. When the water supply is adequate alfalfa produces two cuttings, averaging 3.5 to 4 tons per acre for the two cuttings. Grain yields average 45 to 50 bushels per acre. When no water is availble after July 15, yields are reduced about 25 percent. According to most farmers, the late season water accounts for the difference between 30 and 40-50 bushels of wheat, and between 2½-3 tons and 4 tons of alfalfa per acre.

Water use in the area varies with the streamflow (61,000 acre-feet diverted in 1934, a poor water year, to 182,000 acre-feet diverted in 1951, an excellent water year). If equally distributed to all land, these diversions would have provided 4 acre-feet per acre in 1934 to 12 acre-feet per acre in 1951.

In years when streamflows are high, large diversions in excess of requirements are made in spring and early summer in order to achieve high soil moisture levels before water is shut off according to water right priority. This overapplication leads to some deep percolation losses which result in a recharging effect on the Silver Creek aquifer.

If water is available, alfalfa receives six applications (three per cutting) and grain receives four or five applications. Four to six or more acre-feet per season is applied in a good water year. These high rates cause little damage to the gravelly soils other than leaching of plant nutrients.

Water rights on the Big Wood River were established by the S.C. Frost Decree, filed December 17, 1909. The decree does not specify the acreage appurtenant to each right, but lists only the right holder, the priority, and the flow. Other diversions made under permits and licenses issued by the State Engineer are generally limited to flood flows (44).

Wood River Valley Irrigation District

The Wood River Valley Irrigation District is a legally organized water users association controlled by a three member Board of Directors and serves 32 stockholders.

The district lays directly south of Bellevue, Blaine County, Idaho in what is known as the Bellevue Triangle. It includes some 8,177 acres with 6,912 acres presently being irrigated from the canal system. (See Figure I)

The actual canal system consists of approximately 24 miles of open canals with water control structures. It is made up of three main canals with a common diversion point on the Big Wood River. High seepage losses together with inadequate late season diversions account for an inadequate late season water supply from the canal system about 50 percent of the time.

The area served by the district is undergoing significant land use and agricultural technological changes. Currently, approximately ¼ of the land is sprinkler irrigated, ½ is surface irrigated, and ¼ is not irrigated. The conversion to sprinkler has taken place since 1972.

Approximately 2,000 acres of the area have received preliminary approval for subdivision. These subdivided parcels range from five to forty acres.

The decreed water rights are dated between 1881 and 1952. Records show rights for 1881 to 1902 decree to be 343.8 cfs. The 1902 and later rights total 100 cfs.

The water rights on the Wood River Valley Irrigation District are held by the stockholders and not by the District. The years in which the rights were established range from prior to 1883 to 1902 and establish the amount which the user is assessed. Costs for water charged by the district for 1976 and 1977 are assessed as follows:

1883 and prior rights -- $0.67/miners inch
1884 - 1885 -- $ .62/miners inch
1886 -- $ .60/miners inch
1887 - 1891 -- $ .56/miners inch
1902 and later -- $ .31/miners inch (Flood rights)

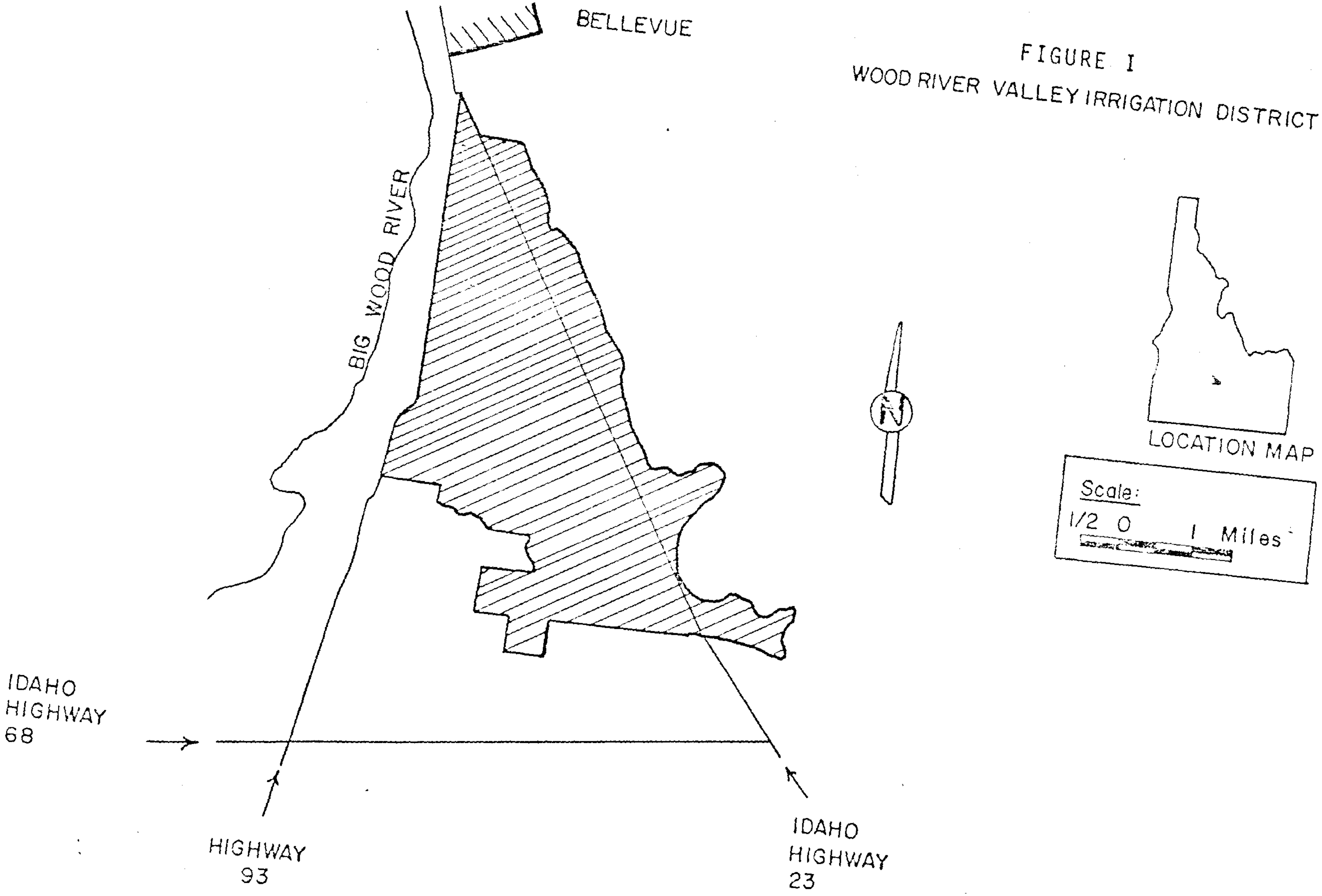
(In Idaho, 50 miners inches = 1 cubic foot per second.)

The development of wells to supplement late season stream flows has increased in the last few years particularly in the south end of the project area. These have been developed on an individual farm basis, primarily in conjunction with the installation of sprinkler irrigation systems.

The area has the potential for further development of supplemental water from the known groundwater source. This development could occur on an individual farm basis (as in the past), or the Irrigation District could install wells to supplement the water supply by pumping into the existing delivery system since the Idaho Department of Water Resources has recommended that no restriction on groundwater development be initiated at this time.

Other methods which have been proposed by which the amount of water available for irrigation might be increased include: the development of storage facilities by the installation of a reservoir, and improved operation, management and maintenance of the delivery system.

FIGURE I
WOOD RIVER VALLEY IRRIGATION DISTRICT



Salmon Falls Creek Region

The Salmon Falls Creek Region of south central Idaho lies on the southern edge of the wide and relatively level Snake River Plain. Basalt shields or broad swells in the area rise several hundred feet above the plain. The basalt plain is mostly mantled with soil ranging in depth from a few inches to several feet. The southern edge of area is marked by older rhyolitic material forming the Rock Creek Hills. Small intermittent and perennial streams flow from these hills and have deposited alluvial material as valley fill and as fans which extend several hundred to several thousand feet onto the plain (43).

The soils in the region are mainly developed from loess and range in texture from sandy loam to the predominating silt loam. Only insignificantly small scattered areas with considerable salt concentration occur in the region. The basic topography of the area is characterized by smooth, gentle slopes which are excellent for the purpose of irrigation. Natural drainage channels are dispersed throughout the project lands, providing good surface drainage, and resulting in very few drainage problems. Some lands in the project exhibit localized high water tables, but are not extensive enough to be considered a significant problem (28).

The semi-arid climatic conditions in the area are representative of most of the Snake River Plain. The average irrigation season lasts about 170 days. Annual precipitation averages nine to ten inches, with about four inches falling during the irrigation season. Temperatures at Twin Falls located five miles north of the area have ranged from a maximum of 106°F to a minimum of -30°F with a mean annual temperature of 49°F (43).

The economy of the area is based on agriculture. Irrigated lands are devoted to cash crops and forage production. The availability of extensive grazing lands in conjunction with a large portion of the forage production make the area valuable for beef cattle production (43).

The agricultural-product processing plants in the area (sugar factories, packing plants, canneries, feed yards, seed plants, cheese factories, and dehydrating plants) rely almost entirely on the production from local irrigated lands.

Gold miners were the first to settle in the area. Gold deposits were placer, however, and were soon depleted. Cattlemen replaced the miners, and by the early twentieth century irrigation and cattle raising had become the basis of the area's economy. Snake River water was being applied to the Twin Falls South Side Irrigation Project by 1905. This project lies due north of the Salmon Falls Creek Region and is part of one of the largest single irrigated areas in the United States and one of the most successful developments under the Carey Act (43).

Salmon River Canal Company, Ltd.

The system begins at a concrete arch dam located on Salmon Falls Creek, which creates a storage reservoir with 180,000 acre feet storage capacity available. When the Salmon River

Canal Co., Ltd. constructed the dam in 1909-10 it was the largest of its type in the country, with a height of 210 feet and a crest length of approximately 550 feet. Water is diverted through a tunnel driven 1000 feet through the east canyon wall, about 90 feet above streambed, to the main canal system (35). At the outlet of the first tunnel the canal flows through an open cut section approximately 2600 feet long and through a second tunnel 1500 feet long. Main canals and main laterals within the system total approximately 300 miles. The design capacity of the 37-mile main canal is 600 cfs (28).

The Salmon Falls Development began in 1908 under the Carey Act. The Twin Falls--Salmon River Land and Water Company and the State of Idaho segregated lands in the original project by contract dated April 30, 1908. The Salmon River Canal Co., Ltd. was formed to operate and maintain the facilities constructed by the Twin Falls--Salmon River Land and Water Co., as well as to collect assessments and charges. Water was first delivered to Salmon Tract lands in 1911 (28).

Original plans were to irrigate some 150,000 acres; however, shortly after completion of the reservoir, it became apparent that the water supply from Salmon Falls Creek had been greatly overestimated. In addition, large water losses had developed to the extent that the reservoir has never filled. After it became obvious that sufficient water was not available for the 150,000 acres, the area to be irrigated was reduced to 72,000 acres (28).

When it was determined that sufficient water was not available even with the reduction in area, land owners resisted payments of the water contracts. Many suits resulted in State and Federal courts and extended even to the United States Supreme Court. On March 16, 1918, a Federal Court decreed a further reduction to 35,000 acres in what is known as the "Whiffen Cut", named after the "Carey Act" special agent who recommended the reduction. The Federal Court decree also restrained the construction company from selling additional stock. At the time of the reduction, 60,050.65 shares of stock were limited to the 35,000 acres, of which 31,060 acres have been classified by the Bureau of Reclamation as arable. Of these arable lands there is, on the average, water available for only 18,450 acres (see Figure II, p. 34) with an average application of 2.34 acre-feet per acre (28).

Problems which have risen as a result of the limited water supply include interference with the supply from users in Nevada where nearly all the water originates. Many lawsuites over the years were carried on between the Canal Company and the large ranches in Nevada owned by the Utah Construction Company. Federal Court action in 1912 gave the Vineyard Land and Stock Company a prior decreed right to Salmon Falls Creek water. In 1916 a Federal Decree established the relative rights of the Canal Company and the Vineyard Land and Stock Company, but was not binding on other users (28).

Water rights are held by the Canal Company and water is distributed according to the number of shares owned by a user.

During a full water year such as 1976, 1.167 acre feet are allocated per share at a cost to the user of $3.20 per share. During 1977, which was a water short year, each share was allocated 1 acre foot per share resulting in a reduction of 14.3%. The charge remained $3.20 per share for both years.

Severe water shortages have existed since the beginning of the project and have caused the Canal Company to take actions to conserve and enlarge their water supply. In the middle 1940's negotiations were made to obtain most of the ranches at the headwaters of the Salmon Falls Creek. This involved some 70,000 deeded acres, a large area of grazing land, and accompanying right to 8,000 acre-feet of prior decreed water right in Salmon Falls Creek. The Canal Company acquired the water rights, and the cattlemen's association acquired the range rights (28).

In 1945, a portion of the main canal was rerouted around a high water-loss area, and concrete control structures and pipelines were installed in smaller canals in other high water-loss areas. In 1955, the canyon wall near the dam was grouted to reduce reservoir leakage (43).

Another controversy arose when other land owners in Nevada attempted to pre-empt the water in Salmon Falls Creek by claiming that it could not be transferred out of the State of Nevada. A settlement was finally reached in May, 1952 which prohibited increased use of Salmon Falls Creek water in Nevada (by Federal Court decrees in both Idaho and Nevada and official ruling by the Nevada State Engineer) (28).

In 1967, the Secretary of the Interior approved an application for a loan under the Small Reclamation Projects Act, submitted by the Canal Company to improve its irrigation distribution system. About five miles of the main canal were to be lined with a part of the loan. At the present, only about 1.12 miles have been lined (43).

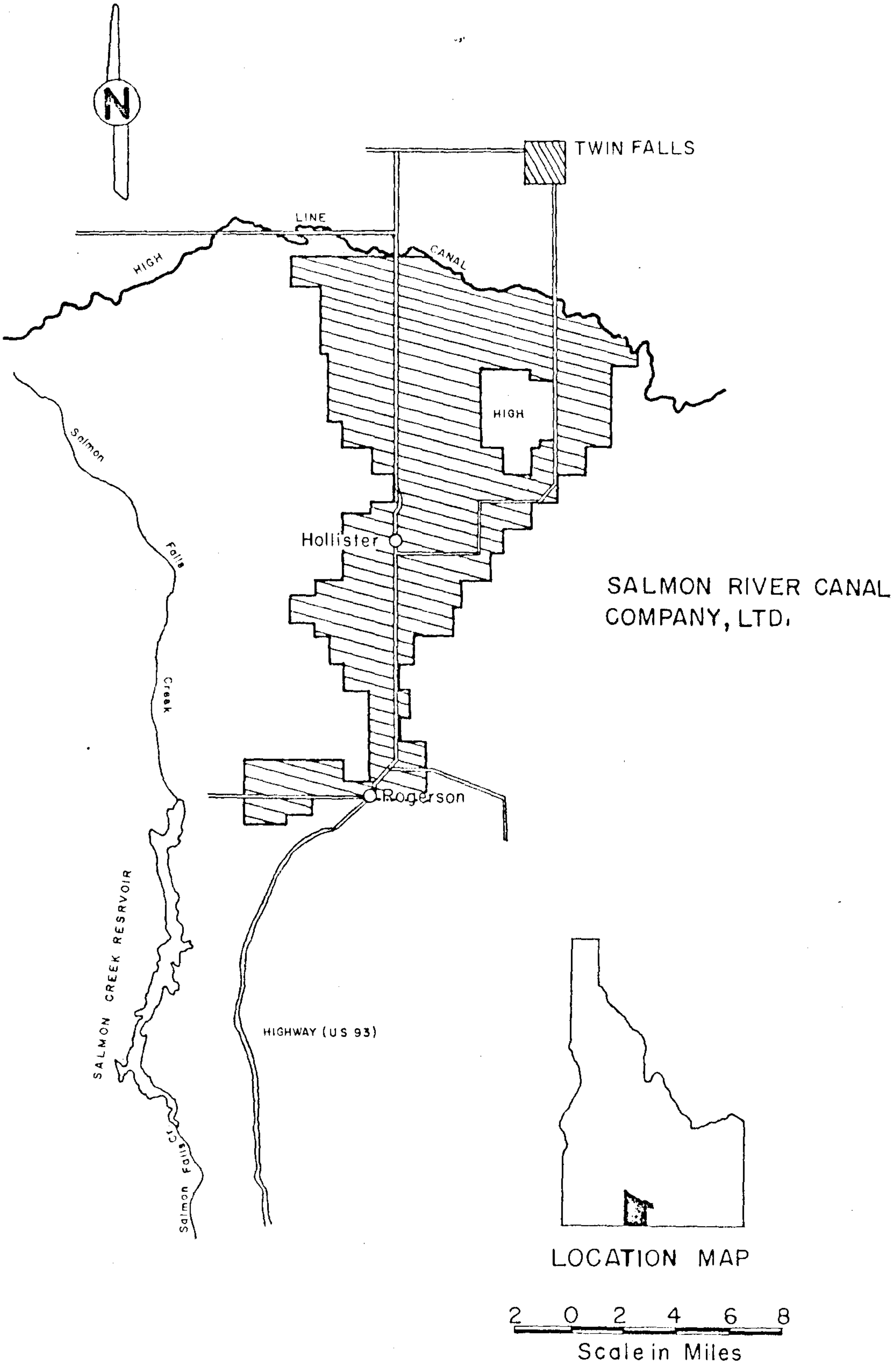
Although climatic conditions in the area are favorable for the production of most cash crops such as sugarbeets, beans, and potatoes, limitation of water supply and the variation of available supply each year produce a situation where the growth of early maturing crops of low water requirement is desirable. In the upper area of the project there are several large operations in which only beef is produced. The majority of beef production, however, is undertaken in connection with forage crops grown on irrigated lands. Beans constitute the largest single crop. Small grains are also extensively grown. In short water years, water is taken from hay lands and placed on cash crop lands (28).

With adequate irrigation, average yields are: alfalfa--4 to 5 tons per acre, grains -- 50 to 60 bushels per acre, and beans -- 20 hundredweight per acre (43).

Rotation of crops (hay--beans--grain) is generally based on three year cycles, but is dependent on the amount of water available.

At present, a vast majority of the irrigated farms (average size of about 170 acres) in the area employ gravity surface systems with water delivered on demand basis. However, more area is being sprinkler irrigated each year.

FIGURE II


N
TWIN FALLS
LINE
HIGH
CANAL
HIGH
Salmon
Falls
Creek
Hollister
SALMON RIVER CANAL
COMPANY, LTD.
Rogerson
SALMON CREEK RESRVOIR
HIGHWAY (US 93)
Salmon Falls Cr.
LOCATION MAP
2 0 2 4 6 8
Scale in Miles

CHAPTER IV

PROCEDURES OF ANALYSIS

Project Irrigation Efficiencies (E_i)

The calculation of a total Project Irrigation Efficiency (E_i) involves the calculation of the Conveyance Efficiency (E_c), and Unit Irrigation Efficiency (E_u), and when applicable, the Reservoir Storage Efficiency (E_s) (23). In neither project was a reservoir considered part of the project since no reservoir is involved with the Wood River Irrigation District's System, and no data were available for Salmon Falls Creek Reservoir. Therefore, the term E_s was omitted from the overall Project Irrigation Efficiency (E_i) (See Equation 7).

In the cases at hand:

$$E_i = (E_c/100) \times (E_u/100) \times 100\% \qquad (8)$$

where:

E_i = Overall Project Irrigation Efficiency (%).

E_c = Conveyance Efficiency (%) = (The quantity of water delivered by the system)/(The quantity of water diverted into the stream) x 100%.

E_u = Unit Irrigation Efficiency (%) = (The quantity of water consumtively used by crops)/(The quantity of water applied to the crops) x 100%.

Effective rainfall was considered to be a part of the quantity of water applied to the crops. Any precipitation rate under one inch per day was considered as effective rainfall.

Salt accumulation in the soils of either project is not a problem and, therefore, any leaching requirements were assumed to be insignificant.

Separate efficiency terms (E_c and E_u) were computed on a bi-weekly basis using a water balance. Actual data required to compute these terms were determined to be:

1) Diversion Records
2) Delivery Records (when obtainable)
3) Pumping Records (where applicable)
4) Consumptive Use Estimates

Diversion-Delivery and Pumping Estimates

Wood River Valley Irrigation District (#45) daily diversion records for each season were supplied by the watermaster for that area, however, no delivery records were available.

These diversion records account for only part of the total amount of water applied to the district since there is a significant amount of groundwater used.

Actual pump tests were made to determine relationships between the amount of electric power consumed and the quantity of water pumped during the specified time periods of 1976 (18).

Idaho Power Company officials were able to supply total power consumption estimates for the area during 1976 and 1977. From the increase in both the amount of power used and the average depth to groundwater in the area (determined from well hydrographs contained in the Blaine County Drought Summary Report (2)), estimates of amounts of water pumped during 1977 were determined according to the procedures presented in Appendix A.

The amount of water delivered by the canal system ot the farms was based on the amount diverted and the amount lost to seepage (see Determination of Conveyance Efficiencies (E_c)).

The quantity of water pumped from the aquifer during a specific period of time was then added to the quantity of water delivered by the canal system during the same period to estimate the total quantity of water delivered to the farms or units.

The Salmon River Canal Company, Ltd, supplied daily diversion and delivery records for both years. Since no groundwater is pumped for irrigation on this project, these were all the data necessary.

All rainfall data were taken from National Oceanic and Atmospheric Administration records. Data taken at Hollister, Idaho were used as reference for the Salmon River Canal Company, Ltd.; and those taken at Hailey, Idaho were used as reference for the Wood River Valley Irrigation District.

Determination of Consumptive Use Estimates

Consumptive use estimates were based on Penman's Equation (32) for the computation of potential evapotranspiration (ET_p) on a daily basis using the procedure outlined in Appendix B.

A Wang 2200S computer system was programmed to compute potential ET on a daily basis. A listing of the program is contained in Appendix C. Input to the program is as follows:

1) Average elevation of project (feet above sea level; 4500 feet for Salmon River Canal Co., 5100 for Wood River Irrigation District).
2) Mean solar radiation for cloudless skies for month (R_{so} in lanleys).
3) Date (month and day).
4) Maximum temperature for the day (^{o}F).
5) Minimum temperature for the day (^{o}F).
6) Relative humidity (%).
7) Wind run (miles/day at 12 feet).
8) Incoming solar radiation (R_s in langleys).

All necessary temperature data were provided by National Oceanic and Atmospheric Administration (NOAA) Climatological Data. Minimum and maximum temperatures recorded at the Hailey Ranger Station, Idaho were used to calculate potential ET at the Wood River Valley Irrigation District (#45) for 1976 and 1977. Minimum and maximum temperatures recorded at Hollister, Idaho were used to calculate potential ET for the Salmon River Canal Company, Ltd. for 1976 only since actual ET estimates (based on Penman's Equation) for this area were available from the U.S. Bureau of Reclamation for 1977, making potential ET calculations for that season unnecessary.

Solar radiation (R_s) data, wind run data, and relative humidity data taken at Kimberly, Idaho during 1976 and 1977 were used in all potential evapotranspiration calculations for both projects due to the fact that this is the nearest location at which data of this type were available.

The relationship between solar radiation (R_s) data taken at Kimberly and that taken at the Bellevue Triangle (Wood River Valley Irrigation District lies within this area) has been shown by Wright and Jensen (52). Values for the Bellevue Triangle are proportionally higher on days previous to May 15 and were adjusted accordingly for all potential ET calculations for that area. After this date any differences between the values taken at the two areas were assumed to be insignificant.

As previously mentioned, daily actual ET data based on Penman's Equation were available for Kimberly, Idaho from a U.S. Bureau of Reclamation irrigation scheduling program during the 1977 season. These were used to determine consumptive use estimates for the Salmon River Canal Company for that season.

To determine actual consumptive use estimates for each crop, it is necessary to adjust the potential ET by multiplying it by an appropriate crop coefficient:

$$\begin{array}{c}\text{Actual Consumptive Use}\\ \text{For a Given Crop}\end{array} = \text{(Crop Coefficient)(Potential ET)} \qquad (9)$$

Crop coefficients vary according to the crop grown and the time of season. These coefficients were supplied by the U.S. Bureau of Reclamation from an irrigation scheduling program.

In order to compute the total consumptive use for an irrigation project, it is necessary to determine the irrigated area, the types of crops grown, and the percentage of the total area covered by each crop.

The personnel at the Wood River Valley Irrigation District were not able to provide this type of information. It was necessary to make a "windshield survey" with the aid of aerial photographs for each season. This procedure established the necessary information for each year.

The personnel at the Salmon River Canal Company provided all the necessary information in the form of crop reports for 1976 and 1977. Listed on each report were the number of irrigated acres and the number of acres of each crop grown.

Total consumptive use estimates for each time period were then made on the basis of the following equation:

$$\begin{array}{ll} & (\#\ \text{Irrigated acres})(\text{Potential ET-inches}) \\ \text{Total CU for the} & ((\%\ \text{Crop } 1 \times \text{Crop Coefficient } 1)/100\ + \\ \text{project over given} = & (\%\ \text{Crop } 2 \times \text{Crop Coefficient } 2)/100\ + \\ \text{period} & (\%\ \text{Crop } 3 \times \text{Crop Coefficient } 3)/100\ + \\ & (\%\ \text{Crop } n \times \text{Crop Coefficient } n)/100) \end{array} \qquad (10)$$

where:

n = Number of crops grown

CU = Consumptive Use in acre-inches

Determination of Conveyance Efficiencies (E_c)

In order to evaluate the conveyance efficiency (E_c) of a system, it is necessary to determine the total quantity of water diverted into a canal system and the total quantity of water delivered by the system.

When only the diversion data were available, as was the case for the Wood River Valley Irrigation District, estimates must be made as to the amount of water lost to seepage in the canal system.

Seepage loss is related to conveyance efficiency in the following way:

$$\text{Conveyance Efficiency} = (1 - \text{Seepage Loss}) \times 100\%$$

Canal seepage estimates for the Wood River Valley Irrigation District were made using data taken from the Silver Creek Aquifer Study Model (18). The maximum diversion for both years was established and denoted as Q_{max}. When the actual diversion (Q) was less than 40% of Q_{max}, seepage losses were assumed to be equal to 0.5(Q). When the actual diversion (Q) was greater than 40% of Q_{max} seepage losses were assumed to follow the linear relationship:

$$\text{Canal Seepage (cfs)} = 0.7 - (0.5\ Q/Q_{max}) \qquad (11)$$

For the determination of the <u>total</u> conveyance efficiency for a given time period on the Wood River Valley Irrigation District it was necessary to consider the quantity of groundwater pumped as well as canal water. The <u>total</u> conveyance efficiency was then:

$$E_c = (\text{Total Water Delivered})/(\text{Total Water Diverted}) \qquad (12)$$

-OR-

$$E_c = \frac{(Q\ \text{diverted into canal}) \times (1 - \text{Seepage Loss}) + (Q\ \text{Pumped})}{(Q\ \text{diverted into canal}) + (Q\ \text{Pumped})} \qquad (13)$$

When daily diversion and delivery records are available, as was the case for the Salmon River Canal Company, and there is no groundwater pumped, the conveyance efficiency can be determined simply by dividing the sum of the deliveries for a given period of time by the sum of the diversions for the same period.

Determination of Unit Irrigation Efficiencies (E_u)

Unit Irrigation Efficiencies were determined on the basis of total water delivered by the system plus any effective rainfall during specified time periods; and consumptive use estimates over the same periods. (See Equation 8)

Determination of E_u for the Wood River Valley Irrigation District was based on consumptive use estimates for the area and the amount of water applied to the units or farms; where the amount applied equals the amount of water pumped from the Silver Creek Aquifer plus the amount delivered by the canal system, plus the amount of effective rainfall.

For the determination of E_u on the Salmon River Canal Company, Ltd. lands only the farm delivery records, precipitation records, and consumptive use estimates were needed.

Determination of Correlation Coefficients

One method of comparing two sets of paired variables (i.e. Project Irrigation Efficiencies) is to determine the correlation coefficients between the various parts of variables.

A correlation coefficient (r) is a measure of the linear association between the variables. Values for the correlation coefficients are dimensionless and range between -1 and +1.

If r is -1 or +1, the variables have a perfect linear relationship. A negative value for r indicates that as one variable increases, the other decreases. A positive value of r indicates that as one variable increases, the other also increases. If r is 0, then there would be no linear association between the variables (38).

The correlation coefficient r may be defined as:

$$r = \frac{S_{xy}}{S_x S_y} \tag{14}$$

where:

$$S_{xy} = \frac{1}{n-1} \quad \Sigma x_i y_i \; - \; \frac{1}{n} \quad \Sigma x_i \; \Sigma y_i \tag{15}$$

$$S_x = \frac{\Sigma x_i^2 - (\Sigma x_i)^2/n}{n - 1} \tag{16}$$

$$S_y = \frac{\Sigma y_i^2 - (\Sigma y_i)^2/n}{n - 1} \tag{17}$$

where:

x_i = The independent variable.

y_i = The dependent

n = Number of pairs of variables (1 to i).

CHAPTER V

RESULTS

Determination of Various Irrigation Efficiencies

In order to statistically determine the correlations between the project efficiencies of the two systems, similar time periods were used for both years.

The common time periods used in all efficiency calculations were determined by the diversion records of the limiting season. Time frames established for the Wood River Valley Irrigation District were May 11 through September 30 of each year. For the Salmon River Canal Company, Ltd., the time periods used were May 11 through August 18, of 1976 and May 11 through August 29, 1977.

Values for the project irrigation efficiencies estimated for the Wood River Valley Irrigation District ranged from 39 percent to as low as 5 percent over the two years. Unit irrigation efficiencies for the project ranged from 55 percent to 8 percent, total conveyance efficiencies ranged from 89 percent to 53 percent, and conveyance efficiencies of the canal system ranged from 80 percent to 50 percent.

Estimated values for the Salmon River Canal Company, Ltd. ranged as follows: project irrigation efficiencies - 88 percent to 19 percent; unit irrigation efficiencies - 130 percent to 41 percent; and conveyance efficiencies - 75 percent to 53 percent.

Water was diverted in the Wood River Valley Irrigation District canals as early as April 8 during the 1977 season. These diversions were primarily used to raise the level of the water table in the area to aid in groundwater pumping, and not for application to crops.

Table 1 contains a list of crop cultural practices and dates on which these practices were estimated to occur. Cropping practices for both years were assumed to occur on the same dates. Dates for the various cultural practices on Wood River Valley Irrigation District lands were determined from Wright and Jensen (52). Dates for the various cultural practices on Salmon River Canal Company, Ltd. lands were determined from a U.S. Bureau of Reclamation Irrigation Scheduling Program.

Tables 2 and 5 list the diversions, total deliveries, and effective rainfall for the Wood River Valley Irrigation District during 1976 and 1977. It may be noted that diversions are generally higher during the early months of the season and then taper off in relation to river flows. This is due to the fact that there is no reservoir storage to supplement late season flows. Canal conveyance efficiencies were generally lower during the 1977 season as a result of decreased canal diversions in 1977.

Irrigated areas, cropping patterns, and consumptive use estimates are shown in Tables 3 and 6. In addition to the 33 percent reduction in irrigated area from 1976 to 1977, there was a considerable amount of alfalfa which was irrigated but only recieved enough water to produce one cutting. Other than this, actual crop breakdown remained relatively constant over the two seasons.

Various efficiency values for the district are listed in Tables 4 and 7 for 1976 and 1977. Although the conveyance efficiencies of the canal system were generally lower during 1977 than 1976, the total conveyance efficiencies for the two years did not differ appreciably. The primary reason for this is that a higher proportion of the total water delivered during 1977 was pumped groundwater which was considered delivered at 100 percent conveyance efficiency.

Table 1. General Summary of Assumed Crop Cultural Practices - 1976 and 1977 - Wood River Valley Irrigation District

Dates	Cultural Practices
May 15 - 20	Spring grain being planted.
July 10-15	Grain began heading.
July 8 - 20	First crop hay cut.
Sept. 5 - 15	Second crop hay cut.
Sept. 5 - 25	Grain harvested.

Salmon River Canal Company

Dates	Cultural Practices
May 25	Beans planted.
July 15	Grain began heading.
July 15	First crop hay cut.
Aug. 4	Peas harvested.
Sept. 15	Grain harvested.
Sept. 18	Second crop hay harvested.
After Sept. 18	Potatoes, corn and beans harvested.

Table 2

Wood River Valley Irrigation District
Water Applied -- 1976

Time Period	Water Diverted Into Canal (Acre-Feet)	Conveyance* Efficiency (%)	Water Delivered to Farm Units (Acre-Feet)	Effective Rainfall (Acre-Feet)	Groundwater Pumped (Acre-Feet)	Total Water Applied (Acre-Feet)
May 11-15	1212	50	606	84	115	805
16-31	10,558	73	7700	60	1136	8896
June 1-15	12,298	80	9858	132	2279	12,269
16-30	10,359	72	7170	252	1252	8674
July 1-15	8299	64	5290	-	1264	6554
16-31	6978	58	4073	168	2173	6414
Aug. 1-15	5341	52	2764	546	2253	5563
16-31	5661	53	3001	690	1369	5060
Sept. 1-15	4600	50	2300	1079	1372	4751
16-30	5008	50	2504	384	299	3187

*Reflects efficiency of canal only. Does not consider groundwater pumped.

Table 3

Wood River Valley Irrigation District
Consumptive Use -- 1976

Total Irrigated Area = 7196 acres

Cropping Pattern: Alfalfa = 64% Grain = 19% Pasture = 17%

Time Period	Potential ET (inches)	Average Crop Coefficients			Actual ET	
		Alfalfa	Grain	Pasture	Acre-Inches	Acre-Feet
May 11-15	1.6	0.50	--	0.62	1867	406
16-31	4.8	.86	.37	.75	25,897	2158
June 1-15	4.0	1.00	.54	.75	24,920	2077
16-30	4.9	1.00	.88	.75	33,025	2752
July 1-15	4.7	1.00	1.02	.75	32,443	2704
16-31	4.4	.75	1.01	.75	25,202	2100
Aug. 1-15	3.2	1.00	.75	.75	20,758	1730
16-31	3.2	1.00	.53	.75	19,117	1593
Sept.1-15	3.2	.74	.20	.75	14,763	1230
16-30	2.1	.80	.20	.75	10,287	857

Table 4

Wood River Valley Irrigation District Efficiencies -- 1976

Time Period	Total Conveyance Efficiency (%)*	Unit Irrigation Efficiency (%)	Project Efficiency (%)
May 11-15	54	50	27
16-31	76	24	18
June 11-15	83	17	14
16-30	75	31	23
July 1-15	69	41	28
16-31	68	33	22
Aug. 1-15	66	31	20
16-31	62	31	19
Sept.1-15	61	26	16
16-30	53	27	14

---

*Includes canal conveyance efficiency and pumped water efficiency at 100%.

Table 5

Wood River Valley Irrigation District
Water Applied -- 1977

Time Period	Water Diverted Into Canal (Acre Feet)	Conveyance* Efficiency (%)	Water Delivered to Farm Units (Acre-Feet)	Effective Rainfall (Acre Feet)	Groundwater Pumped (Acre Feet)	Total Water Applied (Acre-Feet)
May 11-15	551	50	276	--	171	447
16-31	2081	50	1040	554	1693	3287
June 1-15	7849	62	4866	259	3395	8520
16-30	5338	52	2760	--	1865	4625
July 1-15	2781	50	1390	105	1883	3378
16-31	1836	50	918	218	3258	4374
Aug. 1-15	959	50	480	263	3357	4100
16-31	698	50	349	222	2040	2611
Sept. 1-15	606	50	303	105	2044	2452
16-30	1203	50	602	206	446	1254

---

*Reflects efficiency of canal only. Does not consider groundwater pumped.

Table 6

Wood River Valley Irrigation District
Consumptive Use -- 1977

Total Irrigated Area = 1850 acres

Cropping Pattern: Alfalfa (1 cutting)* = 21% Alfalfa (2 cuttings) = 12%
Grain = 21% Pasture = 16%

Time Period	Potential ET (inches)	Average Crop Coefficients			Actual ET	
		Alfalfa	Grain	Pasture	Acre-Inches	Acre-Feet
May 11-15	1.24	0.50	--	0.62	2491	208
16-31	2.94	.86	.37	.75	10,545	879
June 1-15	3.89	1.00	.51	.75	16,289	1358
16-30	5.52	1.00	.88	.75	25,027	2086
July 1-15	4.76	1.00	1.02	.75	22,260	1855
16-31	4.81	.75	1.04	.75	15,338	1278
Aug. 1-15	3.81	1.00	.75	.75	12,889	1074
16-31	3.59	1.00	.33	.75	10,609	881
Sept. 1-15	3.82	.74	.20	.75	8760	730
16-30	2.13	--	--	.75	1240	103

---

*1 cutting Alfalfa was assumed idle after July 15.

Table 7

Wood River Valley Irrigation District
Efficiencies -- 1977

Time Period	Total Conveyance Efficiency (%)*	Unit Irrigation Efficiency (%)	Project Efficiency (%)
May 11-15	62	47	29
16-31	72	27	19
June 1-15	73	16	12
16-30	64	45	29
July 1-15	70	55	39
16-31	82	29	24
Aug. 1-15	89	26	23
16-31	87	34	30
Sept.1-15	89	30	27
16-30	64	8	5

---

*Includes canal conveyance efficiency and pumped water efficiency at 100%

There was a considerable decrease in the amount of water diverted into the Salmon River Canal Company's system from 1976 to 1977, as can be seen from the data contained in Tables 8 and 11. This reduction led to an overall decrease in conveyance efficiencies from 1976 to 1977, and to a 27 percent reduction in the number of acres irrigated from 1976 to 1977 as can be noted from the data contained in Tables 9 and 12. No appreciable changes in cropping patterns occurred over the two seasons.

The data contained in Tables 10 and 13 indicate that the unit irrigation efficiencies exceeded 100 percent during the second two weeks of June for both years. During these time periods, consumptive use exceeded the amount of water applied. To make up for this, the high water storage capacity of the silt loam soils was filled during previous irrigations, and the consumptive use which exceeded the amount delivered during the low delivery periods was supplied by the water stored in the soil. Unit irrigation efficiencies did change somewhat from 1976 to 1977; and, project efficiencies generally decreased during 1977 as a result of decreased conveyance efficiencies.

Table 8

Salmon River Canal Company, Ltd.
Water Applied -- 1976

Time Period	Water Diverted Into Canal (Acre-Feet)	Conveyance Efficiency (%)	Water Delivered to Farm Units (Acre-Feet)	Effective Rainfall (Acre-Feet)	Total Water Applied (Acre-Feet)
May 11-15	2108	61	1281	-	1281
16-31	13,980	73	10,149	--	10,149
June 1-15	13,337	75	10,052	128	10,180
16-31	10,125	68	6837	150	7287
July 1-15	15,205	72	10,918	--	10,918
16-31	15,149	73	11,281	2139	13,420
Aug. 1-15	10,021	69	6903	1914	8817
16-31	8318	66	5474	788	6262
Sept.1-15	6348	64	4085	173	4558
16-18	509	53	271	450	721

Table 9

Salmon River Canal Company, Ltd.
Consumptive Use -- 1976

Total Irrigated Area = 27,018 acres

Cropping Pattern: Alfalfa = 20% Pea = 8% Potato = 5% Spring Grain = 32%
Corn = 5% Beans = 30%

Time Period	Potential ET (inches)	Alfalfa	Pea	Potato	Grain	Corn	Beans	Actual ET Acre-Inches	Actual ET Acre-Feet
		Average Crop Coefficients							
May 11-15	1.75	0.50	0.67	0.19	0.20	0.19	--	12,415	1035
16-31	4.96	.99	.96	.27	.85	.23	.12	85,766	7147
June 1-15	4.17	.86	.97	.41	1.02	.35	.26	83,185	6932
16-30	5.16	.78	.93	.58	.93	.55	.51	113,552	9463
July 1-15	4.66	.96	.79	.77	.74	.78	.83	119,308	9942
16-31	4.31	.97	.25	.91	.39	.95	1.02	113,872	9489
Aug. 1-15	3.20	.84	.03	.91	.36	.98	.82	65,993	5499
16-31	3.25	.76	--	.90	.15	.92	.45	48,716	4060
Sept. 1-15	3.21	.94	--	.79	.09	.75	.15	38,490	3207
16-18	0.27	.95	--	.68	--	.81	.15	3085	257

Table 10

Salmon River Canal Company, Ltd.
Efficiencies -- 1976

Time Period	Total Conveyance Efficiency (%)	Unit Irrigation Efficiency (%)	Project Efficiency (%)
May 11-15	61	81	49
16-31	73	70	51
June 1-15	75	66	50
16-30	68	130	88
July 1-15	72	91	66
16-31	73	71	52
Aug. 1-15	69	62	43
16-31	66	65	43
Sept.1-15	64	70	45
16-18	53	36	19

Table 11

Salmon River Canal Company, Ltd.
Water Applied 1977

Time Period	Water Diverted Into Canal (Acre Feet)	Conveyance Efficiency (%)	Water Delivered to Farm Units (Acre-Feet)	Effective Rainfall (Acre Feet)	Total Water Applied (Acre Feet)
May 11-15	2219	62	1367	-	1367
16-31	5710	63	3615	2059	5674
June 1-15	8815	63	5561	857	6418
16-30	9144	60	5486	112	5898
July 1-15	11,725	65	7565	1466	9031
16-31	13,230	65	8544	1153	9697
Aug. 1-15	9521	61	5765	--	5765
16-29	9629	62	5985	791	6776

Table 12

Salmon River Canal Company, Ltd.
Consumptive Use -- 1977

Total Irrigated Area = 19,766 acres

Cropping Pattern: Alfalfa - 26% Pea = 5% Potato = 5% Spring Grain - 23%
Corn = 5% Bean = 36%

Time Period	Actual ET (Inches)*						Total ET	
	Alfalfa	Pea	Potato	Grain	Corn	Bean	Acre-Inches	Acre Feet
May 11-15	0.94	0.83	0.23	0.65	0.23	-	9227	769
16-31	2.92	2.81	.79	2.50	.69	.34	33,707	2809
June 1-15	3.36	3.79	1.58	3.95	1.37	1.02	50,081	4173
16-30	4.31	5.11	3.22	5.76	3.03	2.80	77,556	6463
July 1-15	4.58	3.74	3.68	3.53	3.70	3.95	78,623	6552
16-31	4.69	1.20	4.11	1.87	4.58	4.96	76,965	6414
Aug. 1-15	3.62	0.13	3.92	1.54	4.21	3.57	58,231	4853
16-29	2.71	--	3.21	.54	3.28	1.61	33,197	2766

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*Data taken from unpublished ET data, U.S. Bureau of Reclamation irrigation scheduling program, 1977.

Table 13
Salmon River Canal Company, Ltd.
Efficiencies -- 1977

Time Period	Total Conveyance Efficiency (%)	Unit Irrigation Efficiency (%)	Project Efficiency (%)
May 11-15	62	56	35
16-31	63	50	32
June 1-15	63	65	41
16-30	60	110	66
July 1-15	65	73	47
16-31	65	66	43
Aug. 1-15	61	84	51
16-29	62	41	25

Determination of Various Correlation Coefficients

Tables 14 through 19 contain the correlations for the various efficiencies between 1976 and 1977 for the two projects. Tables 14 and 15 contain two correlations (0.81 and 0.77) relating the project efficiencies of each project between the two seasons. There is no significant difference between the two correlations which indicates that equally linear relationships exist between the two years for each project.

Two correlations (0.75 and 0.74) contained in Tables 16 and 17 relate the unit irrigation efficiencies of each project between the two seasons. Again, there is no significant difference between the two correlation coefficients, indicating the existence of equally linear relationships between the two years.

The correlation coefficients determined between the conveyance efficiencies of each project over the two seasons are contained in Tables 18 and 19 and do differ significantly (0.02 and 0.53). This is due to the fact that the conveyance efficiencies for the Salmon River Canal Company were reduced in a more linear fashion during the 1977 season. The conveyance efficiencies for the Wood River Valley Irrigation District for 1976 increase and decrease over the season varying approximately with canal diversions. In 1977, however, a higher proportion of the total water applied was groundwater, and this proportion increased through the season as the amount of canal water decreased. This resulted in a very low value for r and practically no linear relationship between the district's total conveyance efficiencies for the two years.

The conveyance efficiencies for the Wood River Valley Irrigation District Canal System were computed for the two seasons as shown in Table 20. The correlation between these conveyance efficiencies was determined to be 0.68 which is comparable to the correlation between the Salmon River Canal Company's conveyance efficiencies for the two seasons.

Table 14

Correlation Between 1976 and 1977 Project Irrigation Efficiencies for the Wood River Valley Irrigation District

	May		June		July		August		Sept.	
x_i 1976	27	18	14	23	28	22	20	19	16	14
y_i 1977	29	19	12	29	39	24	25	30	27	5

$S_{xy} = 38.70$

$S_{xy}' = 34.85$

$r = 0.81$

$r^2 = 0.65$

Table 15

Correlation Between 1976 and 1977 Project Irrigation Efficiencies for the Salmon River Canal Company, Ltd.

	May		June		July		August	
x_i 1976	49	51	50	88	66	52	45	45
y_i 1977	35	32	11	56	47	45	51	25

$S_{xy} = 146.57$

$S_{xy}' = 128.25$

$r = 0.77$

$r^2 = 0.59$

Table 16

Correlation Between 1976 and 1977 Unit Irrigation Efficiencies for the Wood River Valley Irrigation District

	May		June		July		August		Sept.	
x_i 1976	30	24	17	31	41	33	31	31	26	27
y_i 1977	47	27	16	45	35	29	25	34	30	8

$S_{xy} = 97.14$

$S_{xy}' = 87.45$

$r = 0.75$

$r^2 = 0.56$

Table 17

Correlation Between 1976 and 1977 Unit Irrigation Efficiencies for the Salmon River Canal Company

	May		June		July		August	
x_i 1976	81	70	66	130	91	71	62	65
y_i 1977	56	50	65	110	73	66	84	41

$S_{xy} = 357.21$

$S_{xy}' = 312.36$

$r = 0.71$

$r^2 = 0.51$

Table 18

Correlation Between 1976 and 1977 Conveyance Efficiencies for the Wood River Valley Irrigation District

	May		June		July		August		Sept.	
x_i 1976	54	76	83	75	69	68	66	62	61	53
y_i 1977	62	72	73	64	70	82	89	87	89	64

$S_{xy} = 1.73$

$S_{xy}' = 1.36$

$r = 0.02$

$r^2 = 0.0004$

Table 19

Correlation Between 1976 and 1977 Conveyance Efficiencies for the Salmon River Canal Company

	May		June		July		August	
x_i 1976	61	73	75	68	72	73	69	66
y_i 1977	62	63	63	60	65	65	61	62

$S_{xy} = 4.27$

$S_{xy}' = 3.73$

$r = 0.53$

$r^2 = 0.28$

Table 20

Correlation Between 1976 and 1977
Canal Conveyance Efficiencies for the
Wood River Valley Irrigation District

	May		June		July		August		Sept.	
x_i 1976	50	73	80	72	64	58	52	53	50	50
y_i 1977	50	50	62	52	50	50	50	50	50	50

$S_{xy} = 29.02$

$S_{xy}' = 26.12$

$r = 0.68$

$r^2 = 0.46$

Tables 21 through 28 indicate the correlation between the various efficiency terms of each project for each year.

Table 21 shows that a very low linear relationship (r equals 0.58) exists between the project efficiencies of each project during 1976.

For 1977, Tables 22 through 24 show that there are practically no linear relationships which exist between the 1977 project efficiencies (Table 22, r equals 0.15), 1977 unit irrigation efficiencies (Table 23, r equals 0.31), and 1976 unit irrigation efficiencies (Table 24, r equals 0.24).

A relatively high degree of linear association is shown between the conveyance efficiencies of the two systems for 1976 (Table 25, r equals 0.86), however, almost no linear relationship exists between the conveyance efficiencies for 1977 (Table 26, r equals 0.08). This is a result of the fact that the conveyance efficiencies differed considerably more over the two seasons for the Salmon River Canal Company than for the Wood River Valley Irrigation District.

For the purpose of comparison, the conveyance efficiencies of the Wood River Valley Irrigation District's canal system were computed, and correlations between these and the conveyance efficiencies of the Salmon River Canal Company, Ltd. were computed for each season as shown in Tables 27 and 28. There was a relatively high amount of correlation between the canal conveyance efficiencies of the two projects in 1976; however, there was essentially no correlation during the 1977 season.

Table 21

Correlation Between Wood River Valley Irrigation District and Salmon River Canal Company, Ltd. Project Irrigation Efficiencies -- 1976

	May		June		July		August		Sept.	
x_i WRVID	27	18	14	23	28	22	20	19	16	14
y_i SRCC	49	51	50	88	66	52	43	43	45	19

$$S_{xy} = 49.93$$

$$S_{xy}' = 44.94$$

$$r = 0.58$$

$$r^2 = 0.33$$

Table 22

Correlation Between Wood River Valley Irrigation District and Salmon River Canal Company, Ltd. Project Irrigation Efficiencies -- 1977

	May		June		July		August	
x_i WRVID	29	19	12	29	39	24	23	30
y_i SRCC	53	52	41	66	47	43	51	23

$$S_{xy} = 14.93$$

$$S_{xy}' = 13.96$$

$$r = 0.15$$

$$r^2 = 0.02$$

Table 23

Correlation Between Wood River Valley Irrigation District and Salmon River Canal Company, Ltd. Unit Irrigation Efficiencies -- 1976

	May		June		July		August		Sept.	
x_i WRVID	50	24	17	31	41	33	31	31	26	27
y_i SRCC	81	70	66	130	91	71	62	65	70	36

$$S_{xy} = 67.68$$

$$S_{xy}' = 60.91$$

$$r = 0.31$$

$$r^2 = 0.09$$

Table 24

Correlation Between Wood River Valley Irrigation District and Salmon River Canal Company, Ltd. Unit Irrigation Efficiencies -- 1977

	May		June		July		August	
x_i WRVID	47	27	16	45	33	29	26	34
y_i SRCC	56	50	63	110	73	66	84	41

$$S_{xy} = 67.45$$

$$S_{xy}' = 59.02$$

$$r = 0.24$$

$$r^2 = 0.06$$

Table 25

Correlation Between Wood River Valley Irrigation District and Salmon River Canal Company, Ltd. Conveyance Efficiencies -- 1976

	May		June		July		August		Sept.	
x_i WRVID	54	76	83	75	69	68	66	62	61	53
y_i SRCC	61	73	75	68	72	73	69	66	64	53

$S_{xy} = 55.80$

$S_{xy}' = 50.22$

$r = 0.86$

$r^2 = 0.75$

Table 26

Correlation Between Wood River Valley Irrigation District and Salmon River Canal Company, Ltd. Conveyance Efficiencies -- 1977

	May		June		July		August	
x_i WRVID	62	72	73	64	70	82	89	87
y_i SRCC	62	63	63	60	63	63	61	62

$S_{xy} = 1.38$

$S_{xy}' = 1.20$

$r = 0.08$

$r^2 = 0.01$

Table 27

Correlation Between Wood River Valley Irrigation
District and Salmon River Canal Company, Ltd.
Canal Conveyance Efficiencies -- 1976

	May		June		July		August		Sept.	
x_i WRVID	50	73	80	72	64	58	52	53	50	50
y_i SRCC	61	73	73	68	72	73	69	66	64	53

$S_{xy} = 53.13$

$S_{xy}' = 47.82$

$r = 0.70$

$r^2 = 0.49$

Table 28

Correlation Between Wood River Valley Irrigation
District and Salmon River Canal Company, Ltd.
Canal Conveyance Efficiencies -- 1977

	May		June		July		August	
x_i WRVID	50	50	62	52	50	50	50	50
y_i SRCC	62	63	63	60	65	65	61	62

$S_{xy} = 0.11$

$S_{xy}' = 0.09$

$r = 0.01$

$r^2 = 0.0002$

CHAPTER VI

SUMMARY AND CONCLUSIONS

A drought year such as 1977 was expected to have a greater impact on the irrigation efficiencies of a project such as the Wood River Valley Irrigation District than on the irrigation efficiencies of a project such as the Salmon River Canal Company, Ltd. This expectation stemmed from the fact that a large number of the years which make up the history of the Salmon River Canal Company, Ltd. have been what may be considered water short years. These water short conditions are a result of a combination of the following:

1) Generally inadequate flows in Salmon Falls Creek, and
2) A relatively long canal system which lies on fractured basalt with high seepage losses.

The Wood River Valley Irrigation District is representative of the type of project with a history made up of relatively water sufficient years.

The question was then raised as to how each system might adjust in order to meet the consumptive irrigation requirements with a less than sufficient supply of water.

In order for an irrigation project to adjust to meet drought conditions, it is necessary for project management to make certain decisions. Two basic alternatives exist. The decision may be made to increase the efficiency with which the project distributes or applies irrigation water through improvements such as canal lining, the adoption of sprinkler systems, or computer scheduling to determine how to irrigate most effectively.

A second alternative which management may decide upon is to decrease the number of acres irrigated in relation to the reduced water supplies.

The managers of the Salmon River Canal Company, Ltd. have learned to deal with less than sufficient water supplies by altering the number of acres irrigated according to the available water supply.

The range of values and seasonal averages of the various irrigation efficiencies for the two seasons in percent are:

	Wood River Valley Irrigation District				Salmon River Canal Co., Ltd.			
	1976		1977		1976		1977	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
E_u	17-50	28	8-55	30	36-130	77	41-110	69
E_c	50-80	65	50-62	54	53-75	70	60-65	63
E_i	14-27	18	5-39	16	19-88	54	32-66	43

E_u = The farm or unit irrigation efficiency.

E_c = The conveyance efficiency of the canal.

E_i = The project irrigation efficiency.

There is no significant difference between the correlation coefficients calculated in Tables 14 and 15 (See page 63), or those calculated in Tables 19 and 20 (See pages 65, 66). This suggests that the drought year had essentially the same negligible effect on the Project, Unit and Canal Conveyance efficiencies for both districts.

In order for the efficiencies to remain as consistent as they did from the water sufficient to the drought year, some changes must have been made. No changes were made to upgrade the physical system of either project. No irrigation scheduling was employed to help better manage the water they did have. There was a 49 percent increase in the amount of water pumped to supplement surface supplies on the Wood River Valley Irrigation District lands from 1976 to 1977. This indicates the willingness to pay increased prices for water under drought conditions.

The common decision which management made on each project was to reduce the number of irrigated acres to meet the drought conditions. The net result of this decision was relatively consistent irrigation efficiencies from water sufficient conditions to water short conditions.

Accurate data of operating irrigation projects are difficult to obtain under field conditions. Some possible weaknesses which may exist in the data used in this analysis are identified as:

1) Windrun and relative humidity data taken at Kimberly, Idaho were used in Penman's Equation to establish consumptive use estimates for each area. These may have varied from the actual conditions which existed at these areas; however, Kimberly was the closest location at which data of this type were available.

2) Crop reports furnished by the Salmon River Canal Company, Ltd. were estimates based on a formula supplied by the Bureau of Reclamation and may have varied from the actual cropping patterns and number of acres irrigated.

3) Inherent accuracy of the water measuring devices used at both locations is limited to plus or minus five percent of the actual flow.

4) Estimates of the amount of water pumped onto Wood River Valley Irrigation District lands in 1977 were based on the increase of electric power consumed and the drop in the water table from 1976 to 1977 and may have varied from the actual amounts pumped in 1977.

The author would suggest to the investigators of any similar studies to make "windshield" surveys to establish actual cropping patterns and irrigated areas using aerial photographs. Using this method, accurate estimates of actual irrigated areas are obtainable from the aerial photos and actual cropping patterns can be established firsthand.

The amount of land irrigated on the Wood River Valley Irrigation District was reduced 33 percent from 1976 to 1977. On the Salmon River Canal Company, Ltd. the reduction from 1976 to 1977 amounted to 27 percent.

The total amount of water applied to the Wood River Valley Irrigation District lands was reduced 44 percent from 1976 to 1977 and this reduction amounted to 31 percent for the Salmon River Canal Company, Ltd.

The amount of water which was pumped onto Wood River Valley Irrigation District lands rose from 22 percent of the total amount applied in 1976 to 57 percent of the total amount applied in 1977.

There are many other ways by which the management of each project might have altered their systems in order to adjust or compensate for the lack of irrigation water during drought conditions. Improved operation, management and maintenance of their respective delivery systems would improve conveyance efficiencies and thus make more of the water diverted available for delivery.

Both canal systems are located in soils with high permeabilities resulting in high seepage losses. There are several alternatives which would decrease these losses. Canal lining, either earth or concrete, could reduce seepage losses in each delivery system. The installation of pipelines would not only decrease seepage losses, but also decrease evaporation losses. Some canals could be consolidated in order to keep them flowing at closer to design capacity and therefore make them more efficient, however, the benefits versus costs of these alternatives would need to be considered to determine the economic feasibility of such undertakings.

Due to the fact that the Wood River Valley Irrigation District has no surface storage they are faced with the problem of inadequate late season water supplies. There are two basic alternatives which would increase late season supplies.

The first is to construct surface storage facilities. This presents a problem for the district stemming from the fact that storage rights would be junior to the Magic Reservoir water right (located downstream from the Wood River Valley Irrigation District). This means that water could not be stored upstream of Magic Reservoir each year without providing an exchange supply for Magic Reservoir. An exchange supply could be provided by pumping in winter months from wells located in the Wood River Valley Irrigation District area, and diverting the pumped water into Magic Reservoir. Rather than create surface storage to offset inadequate late season supplies, management has made the decision to divert excessive amounts of water into the Wood River Valley Irrigation District's canals during peak flow periods in the spring. These large diversions, when coupled with high seepage and deep percolation losses result in a source of recharge for the aquifer. This water is then stored in the aquifer for use when needed. Using the aquifer for storage in this manner would tend to discourage upgrading the canal system to reduce seepage losses.

Improved maintenance and management can result in increased efficiency. These improvements may take the form of replacing deteriorating water control structures, improving and/or increasing the number of maintenance access roads, improving and/or increasing the number of water measurement devices and employing irrigation scheduling to determine the proper timing and amount of each irrigation.

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APPENDICES

Appendix A

Determination of Amount of Water Pumped Onto Wood River Valley Irrigation District Lands -- 1976

$$Q = \frac{(Kw)\ (e)\ (11.8)}{h}$$

where:

Kw = Used power (kilowatt).

e = Pump efficiency (decimal).

h = Head (feet) = Pressure head + Static head
(Assume constant pressure head = 41 feet)

Q = Flow rate (cfs).

Multiply by time factor (1 cfs-hour = 0.992 acre-inches) to get:

$$(0.992)\ \text{Acre-inches} = \frac{(Kw\text{-}hr)\ (e)\ (11.8)}{h}$$

-OR-

$$0.99\ \text{Acre=feet} = \frac{(kw\text{-}hr)\ (e)\ (11.8)}{(12)\ (h)}$$

Combining:

$$\text{Acre-feet} = \frac{(0.99)\ (kw\text{-}hr)\ (e)}{h}$$

For 1976:

Total number of acre-feet pumped = 13,606

Total Kw-hr used = 1,974,620

Average pump efficiency = 0.60

$$h = \frac{(0.99)\ (Kw\text{-}hr)\ (e)}{\text{Acre-feet}}$$

$$\text{Average } h = \frac{(0.99)\ (1,974,620)\ (0.60)}{13,606}$$

$$= 86.2 \text{ feet}$$

Pressure head = Total head - Static head

1976 Average Static Head (from well hydrographs) = 44 feet

Pressure Head = 86.2 - 44

Pressure Head = 42.2 feet

<u>For 1977</u>:

Assume Pressure head remained constant from 1976 to 1977.

Total Kw-hr used = 4,089,780

Assume pump efficiency = 0.50

Average Increase in Static Head from 1976 (from well hydrographs) = 30.8%

Average Static Head 1977 = 44 + (0.308) (44)

= 57.6 feet

Total Head 1977 = 42.2 + 57.6

= 99.8 feet

Total Acre-Feet pumped in 1977 = $\frac{(.99)\ (4,089,780)\ (0.50)}{99.8}$

= 20,285

Increase in water pumped from 1976 = 20,285/13,606

= 1.49 or 49%

<u>Water pumped in 1977</u>

May		June		July		August		September	
171	1693	3395	1865	1883	3238	3357	2040	2044	446

Appendix B

Procedures for Determining Various Components of Penman's Equation for Estimating Potential Evapotranspiration

A Wang mini-computer system 2200s was used to calculate potential evapotranspiration estimates based on Penman's Equation (32):

$$E_t = \frac{\Delta}{\Delta + \gamma} R_n + \frac{\gamma}{\Delta + \gamma} (0.35)\ (1.0 + 0.01\ W_2)\ (e_a - e_d)$$

where:

E_t = Potential Evapotranspiration (mm/day)

R_n = Net Radiation (mm/day)

Δ = Slope of the saturation vapor pressure curve at mean air temperature

γ = The constant of the wet- and dry-bulb psychrometric equation

W_2 = Mean windspeed at a height of 2 m in miles/day

e_a = Saturation vapor pressure at mean air temperature in mm Hg

e_d = Saturation vapor pressure at dew-point or the vapor pressure of the atmosphere in mm Hg

Various components were determined as follows (22):

$$\Delta = 33.8639\ \{0.05904\ (0.00738T + 0.8072)^7 - 0.0000342\}$$

where:

$$T \geq -23^{o}C$$

$$\gamma = \frac{C_p\ P}{0.622\gamma}$$

where:

C_p = Recommended value for the Specific Heat of dry air at constant pressure.

$= 0.240\ \text{ITcal}\ g^{-1\,o}K^{-1}$

P = Atmospheric Pressure at elevation Z (meters).
= $1013 - 0.1055 \times Z$; in mb

γ = Latent heat of vaporization (cal g^{-1}).
= $595 - 0.51T$; ($T = {}^{\circ}C$)

From which the quantities $\frac{\Delta}{\Delta + \gamma}$ and $\frac{\gamma}{\Delta + \gamma}$ may be derived.

The Net Solar Radiation (R_n) was estimated from Incoming Solar Radiation (R_s) data using the following relationships:

$$R_n = (1 - \alpha) R_s - R_b$$

<u>where</u>:

R_s = Incoming Solar Radiation (langleys).

R_n = Net radiation density (langleys).

α = The albedo, assumed to be 0.23.

R_b = Net outgoing thermal radiation (langleys).

R_b was estimated using the following relationships:

$$R_b = \{a \frac{R_s}{R_{so}} + b\} R_{bo}$$

<u>where</u>:

R_{so} = Mean Solar Radiation for cloudless skies (langleys)

a, b = Experimental coefficients for net radiation estimation. $a = 1.22$, $b = 0.18$ for Southern Idaho. (22)

R_{bo} = Net outgoing longwave radiation on a clear day (langleys)

R_{bo} may be calculated as follows:

$$R_{bo} = (a_1 + b_1 \quad e_d) \, 11.71 \times 10^{-8} T^4$$

<u>where</u>:

a_1, b_1 = Experimental Coefficients, $a_1 = -.325$, $b_1 = -0.044$ for Southern Idaho.

T = Temperature (${}^{\circ}K$).

e_d = Saturation vapor pressure at mean dew point temperature or water vapor pressure of the atmosphere (mb).

To compute e_d:

$$e_d = rh \times e_a$$

<u>where</u>:

rh = Relative Humidity (decimal).

e_a = Saturation vapor pressure at mean air temperature (mb).

To compute e_a (mb):

$$e_a = 33.8639 \{(0.00738T + 0.8072)^8 - 0.000019 \quad 1.8T + 48| + 0.001316\}$$

<u>where</u>:

T = Temperature, ($-51^{\circ}C < T < 54^{\circ}C$)

Windspeed data taken at Kimberly was taken at 12 feet and needed to be adjusted to a height of 2 meters using the equation (32):

$$W_{2M} = W_z \left(\frac{2}{z}\right)^{0.2}$$

<u>where</u>:

W_{2M} = Windspeed at 2 meters above ground.

W_z = Windspeed at specified elevation (z = 12 feet in this case).

Useful conversion factors include:

1 inch Hg = 33.864 mb

1 mm H_2O evaporation = 0.0171 langleys (assuming heat of vaporization of 585 cal/gm).

Appendix C

Computer Program Used to Determine Potential Evapotranspiration Estimates

The following is a computer program written in basic language for a Wang system 2200s mini-computer which is based on Penman's Equation for potential ET estimates. Tape storage is provided for the following data: Date, Maximum Temperature, Minimum Temperature, Relative Humidity, Wind Run, and Solar Radiation.

The input data required are:

Z = Elevation of project in feet above sea level.

R3 = R_{so} in langleys.

A$ = Date (Month, Day).

T2 = Maximum Temperature in ^{o}F.

T3 = Minimum Temperature in ^{o}F.

R = Relative Humidity in %.

W = Windrun in miles/day at 12 feet.

R1 = Solar Radiation in langleys.

All data must be input on a daily basis.

Printout includes the date and potential evpotranspiration in mm of H_2O per day.

```
        THIS IS A PROGRAM TO COMPUTE POT ET BASED ON PENMAN EQ
        READ ELEV(FT), R(SO), DATE, T(MAX), T(MIN), REL HUM,
             WIND RUN, SOLAR RADIATION
10 READ Z,R3,A$,T2,T3,R,W,R1
11 REM CONVERT REL HUM % TO DECIMAL
15 R-R/100
16 REM COMPUTE T(MEAN)
20 T1-(T2+T3)/2
25 REM COMPUTE T'S FAHR TO T'S CENTIGRADE
30 T1-5/9*T1-160/9
40 T2-5/9*T2-160/9
50 T3-5/9*T3-160/9
55 REM COMPUTE PRESSURE AT ELEVATION
60 P-1013-.1055*Z*.3048
65 REM CONVERT WINDRUN AT 12 FT TO 2 METERS
70 W-W*((2/3.6576)↑.2)
75 REM N-LATENT HEAT OF VAPORIZATION
80 N-595-.51*T1
85 REM G-GAMMA
90 G-.24*P/(.622*N)
95 REM D-DELTA
100 D-33.8639*(.05904*(.00738*T1+.8072)↑7-.0000342)
110 D1-(D/(D+G))
120 D2-1-D1
125 REM COMPUTE E(A) BASED ON T(MEAN)
130 E1-33.8639*((.00738*T1+.8072)↑8-.000019*(1.8*T1+48)+.001316)
135 REM COMPUTE E(A) BASED ON T(MAX)
140 E2-33.8639*((.00738*T2+.8072)↑8-.000019*(1.8*T2+48)+.001316)
145 REM COMPUTE E(A) BASED ON T(MIN)
150 E3-33.8639*((.00738*T3+.8072)↑8-.000019*(1.8*T3+48)+.001316)
155 REM COMPUTE E(D) BASED ON T(MEAN)
160 E4-R*E1
170 E5-R*((E2+E3)/2)
175 REM COMPUTE R(BO)
180 R2-(.325-.044*(E4↑.5))*.0000001171*((T1+273)↑4)
185 REM COMPUTE R(B)
190 R4-(1.22*R1/R3-.18)*R2
195 REM COMPUTE R(N)
200 R5-(1-.23)*R1-R4
205 REM CONVERT R(N) IN LANGLEYS TO MM H20
210 R5-R5*.0171
215 REM CONVERT E'S IN MB TO MM HG
220 E8-(E2+E3)/2*1.33322
230 E9-E4*1.33322
235 REM COMPUTE POT EVAP IN MM H20
240 C-D1*R5+(D2*.35*(1.0+.01*W)*(E8-E9))
250 SELECT PRINT 215
260 PRINTUSING 270,A$,C
270%                   ######          ET-##.##
280 DATA 5100,798,"JUN 30",90,49,50,154,614.3
290 DATA SAVE /10B,A$,T2,T3,R,W,R1
```