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METHODOLOGY FOR OPTIMIZATION OF AN IRRIGATION SYSTEM WITH STORAGE RESERVOIRS

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METHODOLOGY FOR OPTIMIZATION OF AN IRRIGATION SYSTEM WITH STORAGE RESERVOIRS

ABSTRACT

by Mohammad Javad Khanjani, Ph.D.
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A procedure was developed to specify optimal plans for an irrigation system with temporary internal storage. The procedure was used to develop plans for 1865 ha using farm service reservoirs.

Daily potential and actual evapotranspiration for 25 years were computed. Probability distributions of potential and actual evapotranspiration for 1-30 days duration were estimated. A log-normal probability distribution was found to best fit the data, and probability equations for different durations were computed. These distributions were used to determine possible irrigation intervals for different crops growing in different soil types.

Costs of different types of irrigation subsystem components were computed including canal sections, farm service reservoirs, pumps, and sprinkler and gravity application subsystems. A marginal cost and benefit analysis was used to select the best irrigation intervals for all soil-crop combinations.

The time of occurrence of maximum evapotranspiration for each crop was analyzed and found to follow a log-normal distribution. The peak water requirement of each crop was computed to determine the peak water requirement of each subunit within the study area.

Water-use information was used to compute the volume of interval storage needed within the system. Fifteen farm service reservoirs were located at 15 specified sites by considering physical conditions and other restrictions. Costs and design capacities of farm service reservoirs and canal sections of the system were computed.

By utilizing a mixed integer programming model, the locations of farm service reservoirs were optimized; and seven of the original 15 farm service reservoir sites were selected. A linear programming model was then used to compute the optimum capacity of each farm service reservoir, and parametric programming was used to examine the effects of varying water costs of system configuration.

The cost and design capacity of the irrigation system with seven farm service reservoirs was computed. The total cost was 32% less than the cost of the irrigation system with the 15 original proposed farm service reservoirs.

CHAPTER 1

INTRODUCTION AND STATEMENT OF PROBLEM

Introduction

The relationship of man and water has been complex, vital, and dynamic throughout history. The emergence and evolution of water resource oriented technology have helped to provide answers for man's dynamic and variable demand for water (Smith, 1975).

From the dawn of civilization and history, mankind has faced both droughts and floods because of the stochastic nature of hydrologic events. As a reaction to nature, mankind naturally has sought to overcome the problems of water shortage and excess by controlling it. Only those civilizations successful in controlling water have been able to continue and develop.

History shows that hydraulic civilizations (a civilization which developed hydroagriculture on arid land) (Thomas, 1956) are among the oldest civilizations. Today the ancient remains of several hundred major hydraulic structures such as dams, irrigation channels, wells, Ghanats, and water mills indicate that man attempted to manage and utilize available water resources. Examples of hydraulic structures are abundant all over the world. Although it is difficult to give special credit for water resource development to any particular inhabitant or location, water resource development in general gives proof of the struggle against the forces of nature. The remarkable people of Egypt built the Saddel-Kafara Dam during the third and fourth dynasty, sometime between 2950 and 2750 B.C. This large structure gives the history of dam building an excellent, brilliant beginning (Smith, 1972). The desert of Iran which does not have flowing rivers for irrigation has been watered by means of Ghanats for thousands of years. It is fascinating to see traces of water mills along irrigation channels built for the purpose of taking advantage of low head hydraulic power. Many consider it a remarkable experience to see the dead dam of Kebar near the city of Qum, Save-dam, and many other old hydraulic structures in Iran (Smith, 1972). In the valley of the Euphrates and Tigris in Iraq lies the Nahrawain Canal, a large irrigation canal 10-16 m deep and 120 m wide (Fukuda, 1976). The Hope native Americans of Arizona, U.S.A., practiced and managed ditch-and-basin irrigation to utilize flood water from natural springs hundred of years ago. Hohokam, inhabitants of southern Arizona, around 500-600 A.D., built hundreds of miles of canals in the Salt River Valley for irrigation purposes (Gulhati, 1967). All of these traces of old hydraulic structures as well as new existing ones show an incredible struggle to overcome problems of hunger and suffering brought about by lack of water. Through the ages, people have sought to improve their lives and to harness the forces of nature. This struggle has taught them how to think, manage, and make effective use of available water resources.

Some societies have witnessed improvements in water resource planning, construction, and management. They know how to use water for irrigation, transportation, fisheries, hydroelectric power, and other beneficial uses by using different types of sophisticated equipment in the hydrologic system. Because of the complexity of water resource systems, interdependence with the environment and their multibeneficial nature, mankind still faces the challenge of improving its understanding about the complex dilemma of water resource management.

There are many examples of the failure of water resource projects because of short-sighted planning in evaluating projects structurally, economically, socially, politically, and environmentally (Thomas, 1956). This problem cannot be governed by a single standard in every society or country because values change from society to society and because of institutional and cultural differences. The existence of bodies of water create an ecological equilibrium condition within its environmental system. People within the system, as well as those outside, have developed cultures, traditions, and institutions which correspond to their relationship with the system. Any disturbance in the system must be carefully considered to minimize detrimental effects and improve the quality of life without major sacrifice of natural resources and the environment.

In planning a water-related project to improve the quality of human life and also national income, it is vital to evaluate each alternative economically, socially, and politically according to the culture and institution of the beneficiaries. Principles and standards (Water Resource Council, 1973) give a comprehensive criteria for the evaluation of water resource projects in the United States. Although each project must be economical, it is necessary to have some flexibility in the matter of benefit and cost, because there are many government projects in which a benefit-cost analysis would not apply. The purpose of the water resource planner should be to improve the quality of life and the environment.

One of the oldest challenges in the production of food and fiber, and the improvement of the quality of life, has been to convey water to dry land for irrigation purposes and thus assure food production to some extent. Most of the old hydraulic projects as well as new water resource projects are totally or partially related to irrigation practices. Today almost every country is involved in irrigation practices to produce agricultural products. In 1965, irrigation water accounted for 41 percent of the water used and 83 percent of consumed water in the United States; in addition, it is projected in the year 2000 that 70 percent of the consumed water will be for irrigation (National Water Commission, 1973).

Thus, irrigation can be seen to be a major consumer of water. On the other hand, there are several other demands for water which must be satisfied to some extent in a healthy society; that is, water has opportunity costs for several different uses which must be evaluated. Irrigation is one of those water consumers which is being accused of being less efficient and leading to over-consumption. Although irrigation systems have been planned, designed, and used all over the world for a long time, it is very hard to find less expensive and highly efficient irrigation systems. Today, systems analysis procedures with the tools of operation research methods are being used extensively to evaluate existing systems and plan new irrigation systems.

Although an irrigation system may exist within a multipurpose or multiobjective water resource complex system, it can be taken as an independent single system with related input to and output from the system. An irrigation system in turn is a complex system with several subsystems and components, or input and output vectors. The complexity of an irrigation system is increased by the stochastic and variable nature of most input and output components of the system, which makes it very difficult to completely analyze the system. In general, simulation study and operation research methods are two useful tools for dealing with the optimization of an irrigation system.

Statement of the Problem

Overuse of water or low efficiency is one of the major problems of an irrigation system. Some of the problems are technical such as producing extra runoff and deep percolation by the irrigation application subsystem and seepage from the irrigation water distribution subsystem. Others may be managerial, such as the unavailability of water on demand and the failure of irrigation application subsystems or the unavailability of an irrigator when water is available, causing a loss of extra water.

The objective of this study is to utilize probability analysis and mathematical programming (operations research methods) in planning the design and operation of an irrigation network with a chain of internal water storage reservoirs (Farm Service Reservoir, FSR). An attempt will be made to eliminate water shortages during peak use, make water available on demand, minimize irrigation runoff by collecting it in FSR, and improve overall irrigation efficiency. Two specific objectives are

1. To determine the best irrigation intervals and water requirements of the fields during peak water consumption by a stochastical analysis of potential evapotransporation, and to complete a cost-benefit analysis of the irrigation application subsystem.

2. To specify the locations and sizes of internal water storage reservoirs and to compute design capacity of each segment of irrigation distribution subsystem for the optimal least cost system.

Application of the Methodology

This methodology can be used in planning a new irrigation system or developing rehabilitation plans with a chain of farm service reservoirs. By this method, an existing irrigation system can be evaluated and compared with an irrigation system with a chain of farm service reservoirs to examine the possibility of increasing the efficiency of the system.

CHAPTER 2

WATER AS A MULTIBENEFICIAL RESOURCE

"Water, water everywhere," "We never miss the water, until the well goes dry." The importance of water for numerous purposes has caused man to use water in various ways accompanied by different attitudes and understanding. The alternative ways in which water can be used are often such that interests of different groups of people conflict and numerous problems arise. All life is completely dependent on water although the degree of dependency changes from society to society in time and space, according to traditions and institutions. A discussion continues about some of the more beneficial uses of water.

Domestic Use of Water

Shallow ground water and surface water, lakes, rivers, and springs are usually the sources of water for isolated rural families, villages, and their livestock. Most urban people use modern collection, storage, and distribution subsystems. The increasing urban population and their standard of living as determined by per capita income expand the demand for urban water use. For example, municipal facilities and processing subsystems for water supply as well as sewage disposal subsystems must be expanded rapidly with a growing population. Estimates by the American Waterworks Association indicates that there are about 30 thousand water utility companies in the United States. The total population receiving water through municipal water processing subsystems has been estimated to be as many as 175 million (National Water Commission, 1973).

Domestic water requirements vary from city to city depending on the population, climatic condition, degree of industrialization, and other factors such as social and cultural practices. In a particular city, domestic water requirements change from year to year usually at an increasing rate. The average daily domestic water requirement in cities in the United States varies from 150 to almost 2,000 liters/day/person (Linsley, 1964).

Flood Control

A flood is defined as "an overflow of lands which, although they are adjacent to water, are not normally covered by it, and hence are used in the same way that other lands are used" (U.S. Code, 1964). In general, flooding causes economic and environmental loss and damages.

Flooding occurs in hydrologic boundaries and is not limited by political boundaries. Flooded areas rarely coincide with existing political boundaries or such civil divisions as townships and counties. People influenced by these political boundaries are generally unable to cope with the flood problem. The inadequacy of a local political body may lead to the organization of levies and conservation districts or other legal bodies to solve some water-related problem including the control of floods (Smith, 1969).

Flood control is a responsibility that normally extends beyond the financial and economic limits of the individual areas. The calamities and damages of the major streams in the United States such as the Mississippi River nearly always arouse widespread public interest and support in the cause of flood control (Smith, 1969).

Hydropower

Water is a good medium to absorb and transport solar energy from lower to higher elevations. Whenever precipitation produces surface runoff, potential hydropower is available along river courses. The pattern of hydropower distribution depends on the physical condition of river courses and the size, shape, vegetative cover, and climatic properties of watersheds as well as the type, intensity, duration, and distribution of precipitation. Hydropower is a renewable resource, but water power must be utilized within the water course or transformed into another form such as electricity.

The renewability, cleanliness, and other distinguishing features of hydropower have encouraged many people to support the thesis that they must develop the full potential of the nation's hydropower. Unfortunately this philosophy needs a great deal of economic, financial, social, and environmental research to overcome some present problems. In the

United States the environmental problem is one of the major issues as a whole, and in the arid areas of the world sediment deposits substantially decrease the economic life of reservoirs.

Navigation

Long before the advent of the steam engine and the construction of the railroad, the only means of efficient transportation was through bodies of water. Waterways were the major trade routes which is one of the principal reasons why most of the large commercial centers of the world are located along seashores or large rivers (James and Lee, 1971). Large bodies of water such as oceans, seas, lakes, and rivers supply one of the most effective tradeways and cheapest means of mass transportation for bulky and heavy goods in today's world.

Recreation

Lakes, rivers, and streams have been the source of human relaxation and enjoyment in almost every period of history. Increasing income and decreased working time have allowed and encouraged more people to spend more time and money on leisure-time activities, and outdoor recreation has always attracted large numbers of people. Every forecast shows that the use of reservoirs and streams for recreational purposes is increasing thus placing more demands on recreational facilities along waterways (James and Lee, 1971).

Although activities such as boating, ice skating, swimming, water skiing, and fishing require the direct use of water as a medium, they generally do not consume water directly. The value of many other outdoor activities is enhanced by water, although they are not involved in water-related activities. Among these kinds of recreation, camping and hiking can be mentioned (James and Lee, 1971).

Fish and Wildlife

Fresh and marine waters play a vital role in providing habitats for wildlife populations and water-related activities. Water resource development projects on the state and federal level have, at times, given little environmental consideration and caused damage to fish and wildlife resources. Marshes have suffered from drainage and land-fill operations, thousands of miles of natural streams have been relocated or altered, and estuary habitat essential for marine life has been destroyed by dredging.

The environment available to fish and wildlife should be carefully investigated in the planning and developing of any water resource project. Each new reservoir and channel improvement, or drainage of a swamp, can harm those species of fish or wildlife whose habitats are destroyed. However, each change creates a new environment which may be suitable for other species. The planner must weigh the tangible and intangible values of new species versus the existing ones if he is to predict the real benefit of new species (James and Lee, 1971).

Today federal legislation requires careful consideration of fish and wildlife in advance of any federally funded or licensed water resource project. The Fish and Wildlife Coordination Act gives the fish and wildlife "equal consideration" with other purposes in water resource projects (Fish and Wildlife Coordination Act, 1958).

Irrigation

Water is an essential ingredient in providing a suitable environment for growing crops in the food production process. The necessity of irrigation occurs when there is a shortage of precipitation during the growing season of a crop, and drainage may be required to remove excess water from the root zone. Irrigation and drainage may be related to other agricultural activities such as temperature control, fertilizer distribution, and desalinization resulting in the general control of environmental conditions for optimum crop yield (Fukuda, 1976).

Some of the earliest of American irrigation occurred during the Spanish Era with Spanish missionaries practicing irrigation in California and the American Southwest. The Roman Catholic padres tried to introduce improved methods of irrigation for agricultural based life among the native Americans (Smith, 1975).

The modern period of irrigation began when Mormon pioneers in the state of Utah diverted the water of City Creek onto the piedmont slopes of Salt Lake Valley on July 23, 1847.

Other northern European pioneering attempts at irrigation preceding this venture included the irrigation of fields by Protestant missionaries near Walla Walla, Washington, in 1836 and Lewiston, Idaho, in 1847, as well as Fort Bend on the Arkansas River in Colorado in 1832. It was the industrialization of modern irrigation, not the date of the project, which gave the state of Utah the title of "Cradle of American Irrigation" (Widstoe, 1947).

Irrigation became an integrated part of agricultural activities as pioneer groups occupied the arid land in the western part of the United States. Irrigation in the western United States is directly related to the land development policies established by the Desert Land Act of 1877 which was designed to help bring man, water, and land together. This act helped new settlers to buy 640 acres of land providing them with a way of bringing purchased land under irrigation within three years. Because of many misuses and misunderstandings, the result of confusion about the provisions of the act, public sentiment was raised in favor of state intervention in the matter which culminated in the Carey Act of 1894. The Carey Act permitted the federal government to give each western state an amount of land of not more than one million acres. In turn, the states assumed the responsibility for the irrigation and settlement of the donated land. The Carey Act was not more successful than the previous act because state officials often lacked the necessary interest in reclamation projects. The Reclamation Act of 1902 put the federal government officially in the business of helping to solve the problem of land distribution and of construction of irrigation projects (Smith, 1969).

However, most of the irrigated areas in 17 western states of the United States are managed by private or industrial companies, rather than by the federal government. The privately developed areas comprise more than three-fourths of the total developed areas (Fukuda 1976).

Interrelationships of Alternative Uses

The various alternative uses of water in a river basin may conflict with each other and also with the existing environment. The allocation of water for each beneficial use has certain advantages and disadvantages to a society and environment, which is the basis of debate in any economic and political system. The criteria for optimization of the advantages and disadvantages of any alternative water allocation is a function of social desires and the technological development of a particular society.

The planner of a water resource system should be aware of political and economic needs, accept some standards for environmental quality, and then suggest an optimal allocation of water according to a goal or goals defined by society. The diagram in Fig. 2-1 shows the interaction of different alternative uses of water in a river basin.

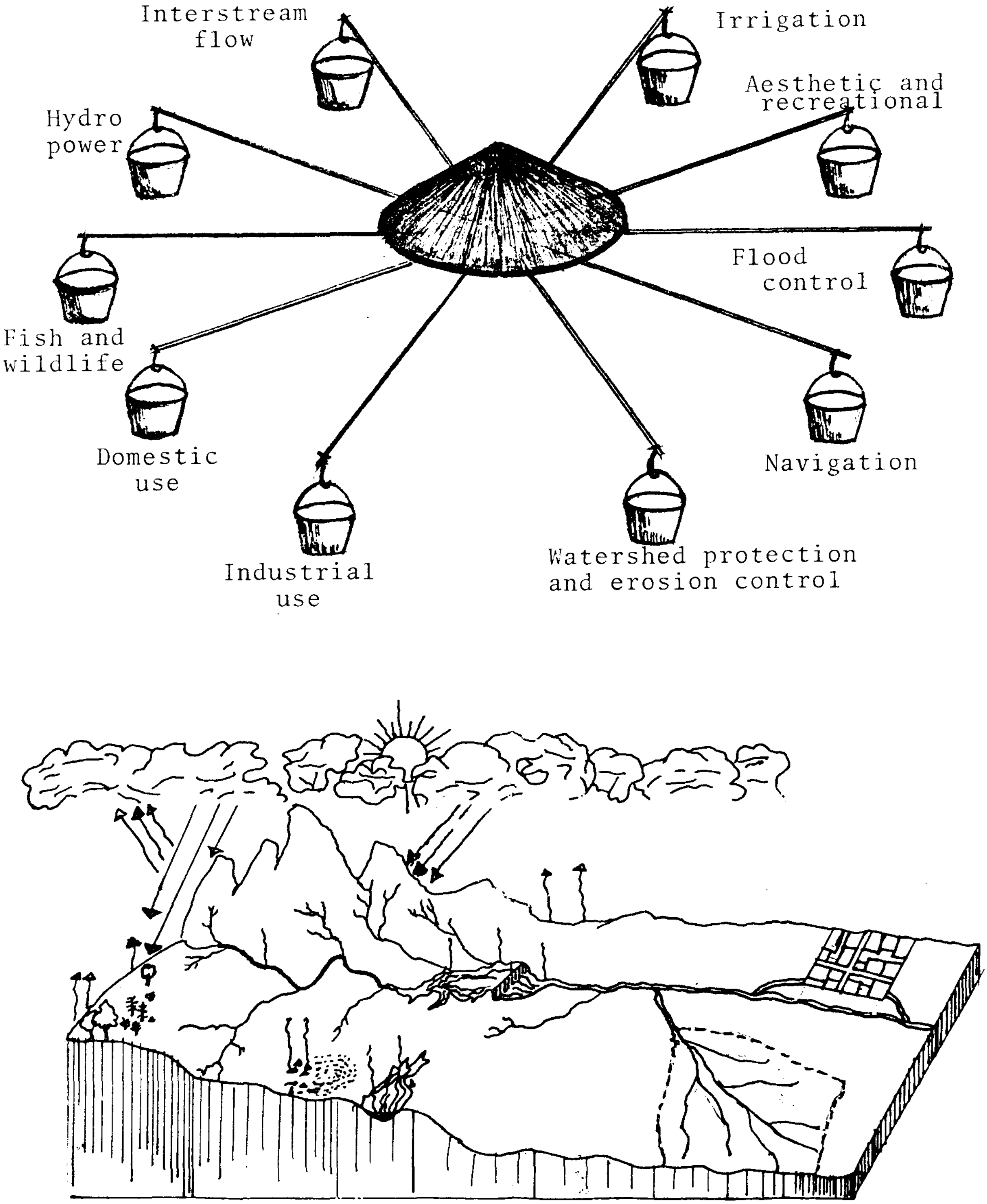


Fig. 2-1.--Alternative uses of water in a river basin

CHAPTER 3

SYSTEMS ANALYSIS

Although the knowledge and understanding of a system is a relatively new concept to man, people have always been exposed to the discipline of a system, and man has been a part or component of many different types of systems.

Definitions of Systems

The term system has been defined by many people from different disciplines and institutions; however, nearly all have tried to initiate or simulate a definition which is close to their particular discipline or which could best define their purpose in dealing with a system. Dooge (USDA, 1972) from the University College of Dublin critically reviewed some of these definitions and has given a relatively comprehensive definition of the term "system." His review is important because it is related specifically to use in hydrologic and water resource systems.

Dooge first compared the following definitions from different disciplines. Stafford Beer (1959) defined a system as "anything that consists of parts connected together." Other definitions include "an ordered arrangement of physical or abstract objects" (MacFarlane, 1964), "any entity, conceptual or physical, which consists of interdependent parts"

(Ackoff, 1962), "a device which accepts one or more inputs and generates from them one or more outputs" (Drenick, 1965). Dooge also referred to other definitions from Bellman (1961), Doebelin (1966), Draper et al. (1952), Ellis and Ludwig (1962), Koenig and Blakwell (1961), Lee (1960), Lynch and Troxal (1961), Paynter (1952), Stark (1968), and Tustin (1957).

Dooge, by considering the many definitions, gave the following definition of a system: "A system is any structure, device, scheme, or procedure, real or abstract, that interrelates in a given time reference, an input, cause, or stimulus of matter, energy, or information and an output, effect, or response of information, energy, or matter."

Classification of Systems

A complex system or environment is a system which may be divided into several other systems or subsystems, each having a distinct input and output. Generally, the complex environment interacts with its subsystems and has some influence on its internal behavior (USDA, 1973). A system or a subsystem may also be divided into various components, each of which is an input or output element.

The state of the system is a general concept, and any change in any variable of the system produces a change in the state of the system. In some systems the state might be determined historically, while in other cases by some external factor which has not been included in the system under examination. In still other cases, the state of a system may be determined stochastically by a random number.

Memory of the system is the length of time that old input affects the present output. For example, runoff from a particular watershed may be correlated with a previous rainfall over a certain period of lag time (USDA, 1973).

Systems have been classified from the point of view of business and management by Ramalingam (1976) as (1) physical and abstract systems, (2) open and closed systems, (3) natural and manmade systems, (4) permanent and temporary systems, and (5) complex systems and subsystems. Dooge (USDA, 1973) has classified systems with a greater emphasis on hddrologic systems. This classification has very little if any overlap with the Ramalingam classification. Dooge's classification is (1) zero, finite, and infinite memory systems; (2) linear and nonlinear systems; (3) time-variant and time invariant systems, (4) continuous and discrete systems, (5) deterministic and stochastic systems, (6) causal systems, and (7) stable and unstable systems. A combination of these two different classifications may provide a valid procedure for classifying, describing, and analyzing systems.

Systems Approach

The systems approach to the solution of a problem involves viewing an organization as a component of a larger system or environment with which it interacts. In seeking the solution of a problem in an applied science, certain assumptions are necessary about the nature of a system and the physical laws that govern the system and its behavior. By combining assumptions with the input it is possible to predict the output.

In general, the relation between input and output can be represented either by a rectangular box in which the output as a function of time, y(t), is produced by input, x(t), or by general mathematical equations such as:

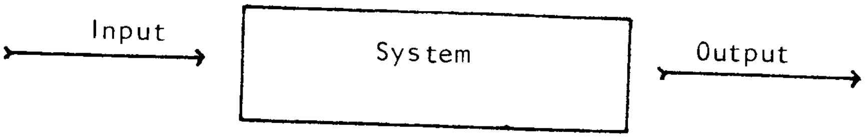
$$y(t) = (h(t), x(t)) \tag{3-1}$$

where h(t) denotes the overall "system" operation and t represents time.

The operation of the system can be divided into two general categories, input-output system and feedback system.

Input-Output System

In input-output systems, input is responsible for output, and previous output does not have any effect on present output. This type system can be shown by a rectangular box as:



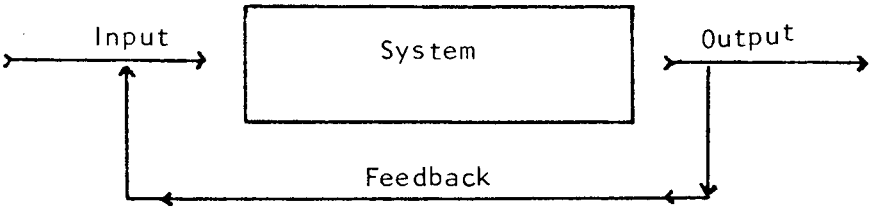
or by a mathematical equation as:

$$y(t) = f(x(t), h(t)) \qquad (3\text{-}2)$$

where f denotes a functional relationship.

Feedback System

In the feedback system, a portion of output returns to the system as an input and influences the succeeding output. The past output is partially responsible for present output. An example of this type of operation can be found in the operation of an industrial lines system or an agricultural production system. The principle of the feedback system is utilized in almost any discipline and institution. This system can be shown by a rectangular box as:



or by a mathematical equation:

$$y(t)_n = f(x(t), h(t), h(t)_{n-1}) \qquad (3\text{-}3)$$

in which n denotes the number of sequence.

Hydrologic and Water Resource Systems

The entire hydrologic cycle can be considered as a closed, natural, permanent, physical, complex, time-variant, nonlinear, continuous, causal, and stable system. The amount of water which circulates within the system remains almost constant, with the solar system providing the driving force to run the system or to move water throughout the atmosphere and on or through rivers, lakes, and the soil to the ocean and back. A hydrologic complex system can be divided into several systems with each system divided into several subsystems in time and space such as the atmospheric, ground water, and surface water systems.

Water resource systems, as part of the hydrologic complex system, are systems that man is planning, designing, and improving for political, social, and economic purposes. These systems can be classified in many ways depending on the general condition of each particular system. Examples of water resource system schemes have been defined by Busch (1974) and Buras (1972). The flow chart in Fig. 3-1 shows schematically a water resource system which includes flood control, reservoir, irrigation, domestic water, hydropower, wildlife, and water quality subsystems.

Different water resource projects may be considered as systems which have all the properties of the systems previously defined and classified. Each water resource system has some input, output, and operation activities, or system

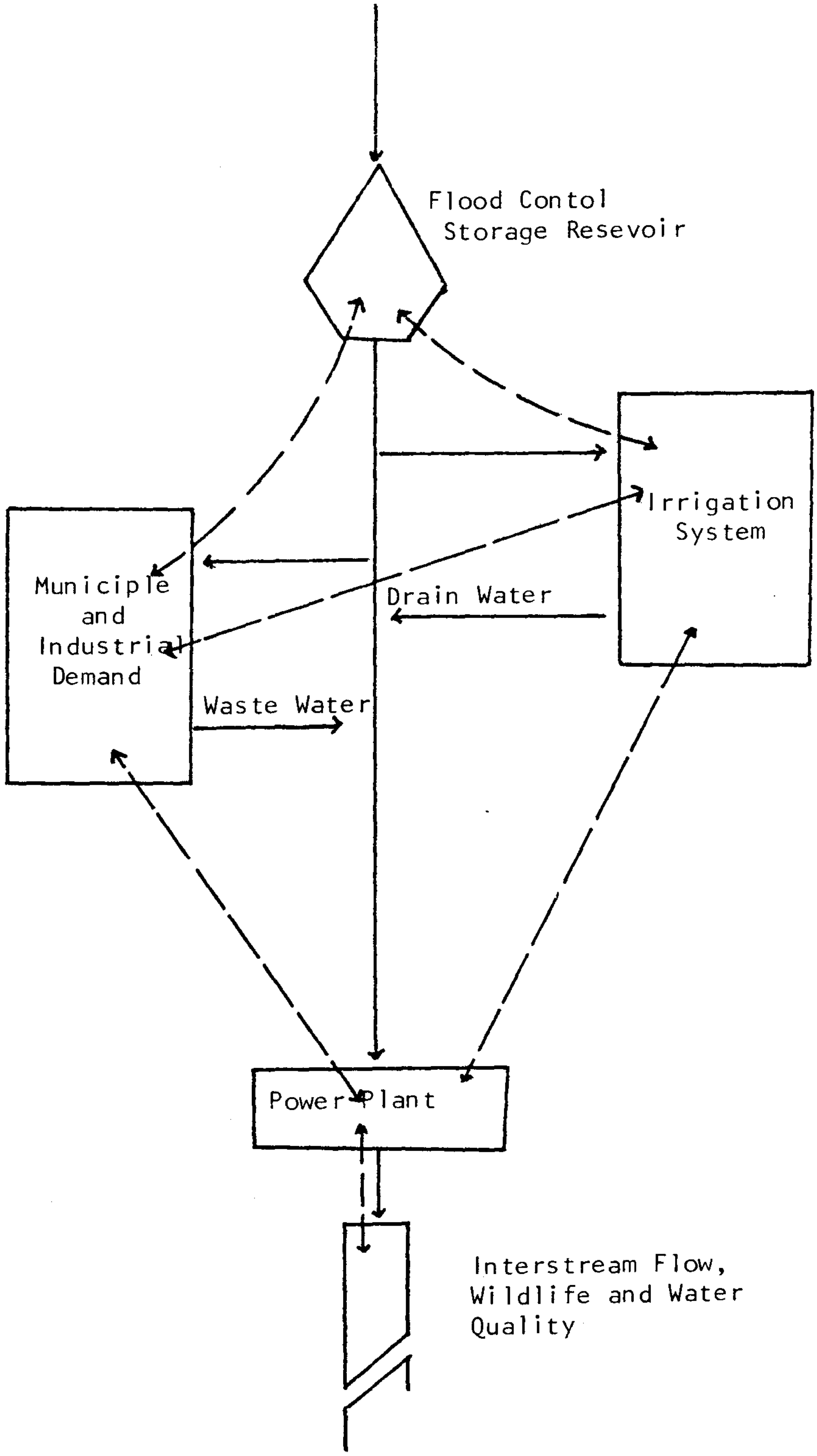


Fig. 3-1.--Schematic diagram of a water resource complex system

operation, which link the input and output of the system. Although a water resource project is a system, only during the last two decades have research workers investigated or considered it as a system in the process of understanding its structure and operation.

Today modern water resource projects all over the world constitute very complex and complicated systems which are made up of different subsystems such as watershed management subsystems, reservoir subsystems, and water distribution subsystems. Levels of output and input for each subsystem and system depend on the state of the system which in turn depends on several constraints of time, space, management, and other resources.

Systems Analysis

Systems analysis is a means and tool used to investigate the nature of a system or physical laws which govern the system. It is also often aimed at determining effective ways of planning and allocating resources to a desired goal (Ramalingam, 1976).

The objective of systems analysis and formulation is to define those combinations of input components which minimize or maximize a predefined objective and satisfy the decision maker in accordance with the requirement of the system specifications or other predefined criteria. Criteria for maximization, minimization, or optimization is a set of different design parameters or constraints which are dictated by the decision maker. Constraints may include legal, social, political, economic, technical, or material resources. It is clear that the optimal design may not be the best from the point of view of one or two sub-objectives, but rather best satisfies the overall combination of all expected functions and objectives. The importance of system optimization is that planners can be flexible in implementing almost all of the social, economic, and technical goals of a system.

The optimal design may be obtained by operations research methods whose use in water resource planning and development have increased drastically during the last two decades. The Harvard Water Program was extremely helpful in demonstrating the use and application of operations research in water resources (Mass et al., 1962). Additionally, Bellman (1962), Hall (1970), Buras (1972), and many other workers made a great contribution to the application of operations research methods in water resources.

Model Study

A system model, which is used to simulate an actual system, might be defined as a reproduction of the essence of a system without reproducing or rebuilding the system itself. Simulation or modeling is defined by Chorafas (1965) as "simply a working analogy." Dooge (USDA, 1973) says "a model may be defined as being a system which can produce some, but not all, of the properties of the prototype." The essential, important, and interesting characteristics of a system under study are represented in a model which then may be studied in an abbreviated time and space.

There are many different acceptable reasons why one may try to study a model of the "real thing" rather than the "real thing" itself. The motivations which are numerous vary from one field of study to another. The most common factors are time, money, and the desire to avoid risking an uncertainty associated with tampering with the real object.

One of the important aspects of system analysis is to evaluate and investigate the nature and operation of alternative policies which cannot be tested in an operating system because, especially in water resources, it might be costly, unsafe, and time consuming; it may also cause social and environmental problems. The possibility of trying different alternatives on a proposed system is impossible because the system does not exist. Therefore, a model of the system under study can be a very useful tool to examine and simulate different inputs or alternatives to the system.

Phillips and others (1976) give the following instructions regarding the model building process:

1. Formulation. In this step the goal and object of the model must be defined, including which properties of the prototype must be presented by the model and which must be ignored. Decisions should be made about the type of assumptions and cost of the model.

2. Deduction. This step involves the operating technique of the model, which depends on the assumptions of the model necessary to solve a given problem with specified accuracy and/or within given cost constraints.

3. Interpretation. The conclusions obtained from the model must be translated into the real world and extended to the prototype by considering limitations and the nature of the model.

The steps of modeling are shown diagramatically in Fig. 3-2. The dotted line indicates direct interpretation from the real system.

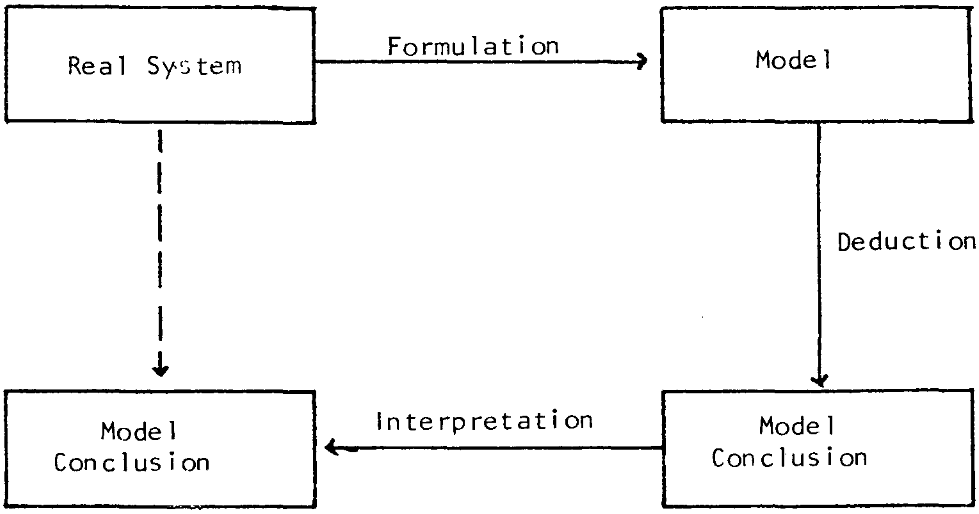


Fig. 3-2.--Steps toward model building (Phillips et al., 1976)

The analysis of water resources system si often accomplished using a symbolic model as defined by Ramalingam (1976). Such a model employs letters, numbers, and other kinds of symbols to represent the condition of prototype. The digital or analog computer is a good example. The governing laws between symbols are generally defined by some type of mathematical equations which are often called a mathematical model or mathematical programming.

Mathematical Model

A mathematical model is a suitable means and tool for the analysis of complex water resource systems for optimal formulation of resource allocation and project operation. Operations research methods are tools used to optimize the mathematical model which is formulated for water resources or other projects. The use of the mathematical modeling and optimization procedures gives the planner and decision maker an insight into the behavior of a modeled system under various conditions or constraints.

Pfaffenberger and Walker (1976) define mathematical programming as "the problem of optimizing a numerical function of one or more variables when they are constrained in some manner . . . . Specifically, the purpose of such a problem is to determine the values of n variables $x_1, x_2, \ldots, x_n$ that optimize the functions" (objective functions).

In other terms, the objective function can be written as

$$Z = f(x_j) \text{ where } j = 1,2,3,\ldots,n \qquad (3\text{-}4)$$

subject to constraints

$$g_i(x_j) \; \{\leqslant \; = \; \geqslant\} \; b_i \text{ where } i = 1,2,3,\ldots,m \text{ and} \qquad (3\text{-}5)$$

$$x_j > 0 \qquad (3\text{-}6)$$

where $Z = f(x_j)$ is an objective function, x_j are decision variables, $g_i(x_j)$'s are constraint equations, and b_i denotes resource availability.

Pfaffenberger and Walker (1976) classify mathematical programming as:

1. The functional relationship in the problems may be deterministic or stochastic.
2. The functions $f(x_j)$ and $g_i(x_j)$ may be all linear or at least one nonlinear.
3. The functions may or may not be continuously differentiable.
4. x_j may be continuous or integer.
5. The optimization procedure may be static or dynamic.

The best known mathematical programming procedures used to optimize different types of models in the field of water resources are linear programming, nonlinear programming, and dynamic programming with their extensions.

Linear Programming

Linear programming is a planning tool used to optimize linear objective functions subject to a set of predefined linear constraint equations. Linear programming meets the particular class of problems that has the following conditions:

1. Decision variables are nonnegative, $x_j \geqslant 0$.
2. The objective function, $Z = f(x_j)$ and constraint functions $g_i(x_j)$'s are completely linear.
3. The operating policies or rules governing the system should be expressed in a set of linear equalities or inequalities.

Linear programming in its general form can be shown as

$$\text{Maximize/minimize } Z = C'X \tag{3-7}$$

$$\text{Subject to constraints } AX \{\leqslant\ =\ \geqslant\} B \text{ and} \tag{3-8}$$

$$x_j \geqslant 0 \tag{3-9}$$

The matrix A is an (mxn) coefficient matrix; each element, a_{ij}, defines the allocated resource to the unit decision variable x_j. The coefficients $C' = (c_1, c_2, \ldots, c_j, \ldots, c_n)$ are corresponding coefficients of x_j in the objective function which gives the cost, benefit, or value per unit of x_j. X is a (nxl) column vector of decision variables, and B is a (mxl) column vector which designates the amount of available resources as inputs to the system.

The problem is to select a set of alternatives for matrix, X, that satisfy the constraint equations, and maximize/minimize the objective function, Z.

Phillips and others (1976) recommend the following basic steps as being necessary in constructing a linear programming model:

1. Identifying decision variables.
2. Identifying all the constraints as a function of the decision variables in the form of linear equality or inequality equations.
3. Identifying the objective function as a function of the decision variables which must be maximized or minimized.

Features and Extensions of Linear Programming

Linear programming has different features and extensions which depend on the nature of the coefficient matrixes A, C', B, and decision variables x_j. Some of these features are deterministic linear programming, stochastic linear programming, integer-linear programming, mixed integer-linear programming, and binary linear programming.

Deterministic Linear Programming

Deterministic linear programming which is one of the most thoroughly explored mathematical models is used in almost every field of science and business and has numerous applications in the field of engineering and water resource planning. In the deterministic model all of the coefficients A, B, C' in Equations 3-7, 3-8, and 3-9 are predefined and constant, and decision variables, X, are continuous variables.

Stochastic Linear Programming or Chance-Constrained Programming

In this type of model at least one element of the coefficient matrix A, B, C' may be a stochastic or random number with known probability distribution (Charnes et al., 1959). This formulation implies that at least one particular element of the coefficient matrixes must be satisfied at a given level of probability. As an example, the probability of AX

$$p\{AX \{\leqslant = \geqslant\} B\} \geqslant \alpha$$

is compared to a given level of probability, α.

The simplest chance-constrained programming contains only one constraint equation of stochastic nature. In general, chance-constrained programming becomes very complicated and impractical if several stochastic constraint equations must be satisfied at the same time (Anderson et al., 1977).

Integer-Linear Programming

Integer-linear programming is a linear programming model in which the decision variables are restricted to be integer numbers. Applying this constraint may be done for different reasons; some may be technical such as the size of pipe in a water distribution subsystem.

If all of the decision variables must be integers, this program is called pure integer-linear programming; otherwise it is called mixed integer-linear programming in which some variables are continuous.

Binary-Linear Programming

Binary or zero-one linear programming is a form of linear programming in which the decision variables are constrained to equal zero or one. This constraint requires that some of the decision variables will be selected and others ignored. This model is interesting because of its applicability to problems that are not inherently binary and also because of newly devised algorithms to solve binary problems (Pfaffenberger and Walker, 1976).

Solution of Linear-Programming Problems

The graphical model is the simplest way to solve deterministic linear programming problems if the model has only two or three decision variables. Although the applicability of the graphic solution is limited, it provides a valuable insight into the understanding of linear programming. The simplex method is a very powerful tool for the solution of deterministic linear programming with an unlimited number of decision variables (Pfaffenberger and Walker, 1976). The simplex method is an iterative procedure which moves from one feasible solution to another without decreasing the value of the objective function if it must be maximized or without increasing if it must be minimized. This procedure continues until an optimal solution is reached, if one exists. Computer packages such as Mathematical Programming System 360 (IBM, MPS, 1971) and Control Data Corporation (1973, 1975) are available for optimizing linear programming problems.

Charness and Cooper (1959) suggest three different models to transfer stochastic linear programming into deterministic programming problems which can be solved by a suitable procedure that depends on the nature of the problem. This suggestion has been used by many research workers who have solved stochastic linear programming problems (van de Panne, 1963).

A Branch and Bound algorithm (Agin, 1963) and the Cutting Plane Method (Gomory, 1960) are two important procedures used in solving pure integer and mixed-integer-linear programming problems. Most commercial computer codes for solving integer-linear programming problems are based on a Branch and Bound algorithm. Gomory (1960) has adopted his pure integer cutting plane algorithm to solve mixed-integer-linear programming. Computer packages such as UIMIP (Yoo and Busch, 1980), IBM (1972), and Hughes et al. (1977) are available for optimizing mixed-integer programming problems.

Balas (1965) has developed an implicit enumeration algorithm to solve binary linear programming. Ceoffrion (1969) has also described an efficient implicit enumeration algorithm to handle this type of problem.

Duality Theory in Linear Programming

The concept and theory of duality are one of the most important and interesting features of linear programming in view of theoretical and practical application. Every linear programming model has an associated linear program which is called its dual, and the solution of the linear problem also gives the solution for its dual (Pfaffenberger and Walker, 1976; Ramalingan, 1976).

The solution of the dual gives the value of a resource which is input to the primal model. This approach gives a relationship between the value of the decision variable and the marginal value of the resource or shadow price. The sum of the marginal values of the resources used in the product is equal to the price of the product.

Sensitivity Analysis in Linear Programming

In linear programming the optimal values of the decision variables are a function of the input coefficients A, B, C'. Generally, before running a linear programming model, the input coefficient values are provided. If these coefficients somehow change, the values of the decision variables will change and/or the optimal solution will be altered. It is very difficult to predict the coefficient values of constraints in many situations. Post-optimal analysis or sensitivity analysis is necessary to predict the effects of variation of a component of a coefficient matrix on the optimal solution. Parametric programming is a tool used to analyze the effects of jointly changing one or more elements in a linear programming model (Ramalingan, 1976).

Applications of Linear Programming

Literature has numerous examples of applications of linear programming in almost all fields of science and management. A few of these applications in the field of water resource related practices are presented. Busch (1974) developed a methodology for obtaining least cost irrigation system specifications as a function of crop distribution and the cost and efficiency of irrigation subsystems. Ridder and Eress (1977) used linear programming to optimize the conjunctive use of ground and surface water for each village in Veramin, Iran. Soltani (1972) used a linear programming model for selecting a modern surface irrigation application system versus a portable or semiportable sprinkler system in two projects in Iran. Skilled labor is included in his model as a major limiting factor to developing modern surface irrigation. Schmisseur (1976) applied a linear programming model to identify the technical and economic effects related to fixed cost, base allotment, and responsive water pricing in three diverse operating irrigation districts in Oregon. Alley (1976) structured a linear programming model by combining resulting linear difference equations from a two-dimensional artesian aquifer model with other linear physical and management constraints and a linear objective function. Solution of the model was used to determine optimal well distribution and pumping rates. Pugner (1977) used integer-linear programming to minimize the total annual cost of existing and future alternative sources related to water supply facilities with respect to capital investment and operation and maintenance costs. Rinaldi (1975), with integer-linear programming by a Branch and Bound algorithm, selected the optimal sequence for the building of a waste water treatment plant. Doyle (1977) used mixed integer-linear programming to evaluate alternative uses for storm water detention in flood plains and developing areas.

Other excellent examples of application of linear programming can be found in Thompson (1976), Lane (1976), Buras (1969), Charness (1959), Greenberg (1976), Aguado (1977), Narayanan (1977), Palacios (1976), Olson (1976), and Gibson (1976).

Nonlinear Programming and Applications

The assumption of linearity in linear programming is relaxed in nonlinear programming. If at least a single equation from an entire set of constraint equations or the objective function of a linear programming model is nonlinear, the model is considered as a nonlinear programming model. The solution cannot be obtained by using the Simplex Method Technique applied to linear programming; a special solution algorithm must be employed.

Generally, nonlinear programming does not have a unique method of solution, but in general there are three broad categories used for the solution of nonlinear programming models (Ramalingam, 1976). They are

1. Unconstrained optimization problems.
2. Equality constrained optimization problems.
3. Constrained optimization problems with inequality constraints.

Pratishthananda (1976) developed a nonlinear multilevel transportation model to study large-scale allocations in a water resource system. Nayak and Arora (1973), by using nonlinear programming, developed an optimization technique for selecting the best site for the construction of a multi-purpose reservoir system that would meet various water demands most economically. Bayer (1974) applied linear, dynamic, and nonlinear programming to the solution of a river basin water quality optimization for the Willamette River in Oregon. Panagiotakopoulos (1976) applied a linear programming model with concave and separable objective functions to allocate treatment requirements within a multiple treatment plant system along a stream. Other resources for application of nonlinear programming are Mulvihill and Dracup (1974) and Pingry and Whinston (1973).

Dynamic Programming and Applications

Dynamic programming is a mathematical tool for the optimization of multi-stage processes. The basic concept comes from the principle of optimality by Bellman (1962) which states "an optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision."

Dynamic programming is not an algorithm or a method by itself; rather, it is a solution procedure that involves the implicit enumeration of all possible solutions of a problem (Pfaffenberger, 1976).

Dynamic programming possesses a certain advantage for analyzing water resource systems because nonconvex, nonlinear, discontinuous objective functions and constraint equations can be treated with little difficulty. Dynamic programming is more amenable to stochastic input in the analysis of water resource systems than other programming techniques. The functional nature of optimal policy and optimal return make it ideally suited to system decomposition, particularly for dendritic branching systems such as are normally encountered in water resource development (Hall, 1970). The shortcomings of dynamic programming are (1) the dimension of the decision variable must be as small as possible, (2) the objective function and constraint equations must be formed by the sum or product of one decision variable (Hall, 1970).

Buras (1972) gives an excellent example and reference of applications of dynamic programming in water resources. Allen et al. (1978) utilized the stagecoach problem to optimize an irrigation distribution subsystem in connection with a linear programming model. Velinkanov (1974) investigated the feasibility of applying dynamic programming for optimal distribution of water resources based on a study of a river development system that compromises water users and consumers. Mays (1976) utilized discrete differential dynamic programming (DDDD) in an optimization model to minimize the cost of layout and design of a storm sewer system. Hopkins (1976) developed a dynamic programming model to determine what contribution of downstream and upstream uses should be encouraged to provide flood protection through longer water retention. Hall (1968) utilized dynamic programming for irrigation scheduling which was used to determine a quantity of irrigation water which maximized total net return from any crop with due allowance for the cost of irrigation. Other references in the application of dynamic programming in water resources are Froise (1975), Cole (1971), Scherer (1977), Yen (1977), Garcia (1974), Grady (1977), and Wyatt (1974).

CHAPTER 4

DESCRIBING UNCERTAINTIES IN WATER RESOURCE SYSTEMS

Many hydrologic processes are so complex that they can only be explained in a probabilistic sense. Because hydrologic events are uncertain, they must be treated as random or stochastic components. Methods of statistical analysis provide useful tools for determining the uncertain character of a particular hydrologic event (Viessman et al., 1977).

Statistical analysis includes two basic sets of problems: (1) descriptive, which is a simple application of a statistical method that requires a few decisions and some risk, and (2) inferential, which entails decision-making risks and necessary knowledge and understanding about the nature of the applied method, system, and risk. The most common inferential problem is to describe the character of the population by studying some samples from the population (Viessman et al., 1977).

Risk

Risk is defined by the American Heritage Dictionary (Morris, 1976) as a possibility of suffering, harm, loss, and danger. In water resource systems, risk often is related to the probability of exceedence (nonexceedence) for a random number of a population distribution (Shen, 1976). The level of risk can be changed by the decision of the designer or manager by increasing the size of the system and also by accepting the extra cost involved. This point needs a sophisticated analysis to justify the optimal level of risk for related benefits and costs of a particular subsystem.

Probability Distribution

Phillips et al. (1976) define probability distribution as any rule that assigns a probability to each possible value of a set of random variables. There are different mathematical probability or frequency distribution equations for different sets of random variables to describe their behavior of occurrence. Many hydrologic events are defined by different mathematical probability distributions. It is hard to find a mathematical probability distribution that exactly represents the natural process of an event. However, mathematical probability distributions are used for approximating and describing the natural behavior or occurrence of an event. For a good estimation of a mathematical probability distribution in hydrology, several years' data must be studied. Although it is hard to find the best possible mathematical probability distribution by sample data, it is quite helpful in predicting hydrological phenomena and planning and designing a hydrologic related project.

There are different types of probability distributions which describe discrete and continuous sets of random observations:

Discrete Probability Distribution

The discrete mathematical probability distribution is attributed in general to those random events in which the outcome is success or failure, and the successive trails are independent from each other. The probability of success and failure is constant.

Some of the major discrete probability distributions which have some application in hydrology are as follows (Haan, 1977):

1. Hypergeometric distribution
2. Bernoulli Process
    a. Binomial distribution
    b. Geometric distribution
    c. Negative binomial distribution
3. Poisson process
    a. Poisson distribution
    b. Exponential distribution
4. Multinomial distribution

Continuous Probability Distribution

Continuous random variables are defined as those random variables which take a continuous value or infinite value. Some of the most common continuous mathematical probability distributions with applications in hydrology are as follows (Haan, 1977):

1. Normal distribution
2. Uniform distribution
3. Exponential distribution

4. Gamma distribution
5. Lognormal distribution
6. Extreme value distribution
7. Beta distribution

Plotting Position of Cumulative Probability Distribution Function

Assigning a probability level to each available data point can be done by computing plotting position. Haan (1977) defined the plotting position as "determining the probability to assign a data point." Gumbel (1958) has given the following criteria for a plotting position formula or relationship:

1. The plotting position formula must be such that all of the data can be plotted.
2. The plotting position should lie between the observed frequency of m/n and $(m-1)/n$ where n is the number of observations and m is the rank of observation with $m = 1$ from the largest (smallest) value to the smallest (largest).
3. The data should be equally spaced on the frequency scale.
4. The plotting position should be simple and easy to use and have intuitive meaning.

Haan (1977) introduced three of the most common plotting position formulas as:

1. California (Flow in California Streams, 1923)

$$m/n \tag{4-1}$$

2. Hazen (1930)

$$(2m-1)/2n \tag{4-2}$$

3. Weibull (1939)

$$m/n+1 \tag{4-3}$$

Approximately all of the plotting position formulas give similar values near the center of plotted plotting position, but they may give different values in the tails of plot which is very important when data are being extrapolated.

Benson (1962), on the basis of the theoretical sampling from extreme values and normal distributions, in a comparative study of several plotting position formulas, found that the Weibull (1939) formula provided estimates which were consistent with his experience; in addition, the Weibull plotting position formula meets all of the Gumble requirements.

Haan (1977) recommended the following steps in computing and drawing a plotting position of a set of random observations.

1. Rank data from largest (smallest) to smallest (largest).
2. Calculate plotting position from a suitable formula.
3. Select the type of probability paper.
4. Plot data on probability paper.

Parameter Estimation of Mathematical Probability Distribution

The parameters of the mathematical probability distribution can be estimated by utilizing the characteristics of a limited data sample. Several methods are used to estimate these parameters, such as graphical, least squares, moment, maximum likelihood, and similar estimation methods (Haan, 1977; Shen, 1976). In general, the estimated parameter should be unbiased, regular, efficient, sufficient, and consistent (Haan, 1977). In the field of water resources and hydrology, the estimates of most parameters must be unbiased and efficient (Haan, 1977).

Some of the already discussed procedures are very complicated and time consuming. Chow (1951) has shown that many mathematical probability distributions can be reduced and defined in the form of a single equation such as:

$$\frac{X_T}{\overline{X}} = 1 + C_V K_T \qquad (4\text{-}4)$$

or

$$X_T = (1 + C_V K_T)\overline{X} \qquad (4\text{-}5)$$

where

X_T = magnitude of observation having a return period T

$\overline{X}$ = mean of magnitude of events

$\frac{X_T}{\overline{X}}$ = X_T-mean ratio

$C_V = \frac{S}{\overline{X}}$ = coefficient factor

K_T = frequency factor with return period T

S = standard deviation of sample

For the purpose of identifying different points with different mathematical frequency distributions, Chow (1951, 1964) gives different equations for K_T.

For a normal frequency distribution

$$K_T = \frac{X - M}{\sigma} = Z \qquad (4\text{-}6)$$

where

Z = standard normal deviation

M = mean of population

σ = standard deviation of population

Values of Z for different probability levels are given in most statistical textbooks.

Choosing the Best Possible Mathematical Probability Distribution

In general, after plotting the plotting position of available data on a suitable probability paper, several mathematical probability distributions may be assumed and plotted.

The selection from among assumed mathematical probability distributions is based on (1) visual comparison between the shape of the histogram of data and the assumed mathematical probability distribution, (2) chi-square test, and (3) Kolmogrov-Smirnov test (Shen, 1976; Haan, 1977).

Application of Mathematical Probability Distribution

The mathematical probability distribution of a random event has the following uses:

1. It provides an accurate interpolation mean between two observations of an event.
2. It makes possible extrapolation beyond the range of available observations.

3. It can be used to generate data.
4. It makes easy computer manipulation of the behavior of a random event.

Simulation Model

In hydrologic and water resource studies, many different types of statistical models are used. In general these models may be used to generate synthetic data or to regulate the system.

Monte Carlo Simulation Model

The Monte Carlo simulation model for data generation, which has been used in hydrology for a long time, helps to produce a large amount of data from known mathematical probability distributions to study the probability behavior of complex water resource systems. Random observation values might be produced from a known mathematical probability distribution.

Markov Simulation Model

The Monte Carlo model is useful when there is no significant serial coorelation between two events. In some hydrologic events, there is a good serial correlation between two events such as stream flow and the ground water table. The Markov model which is quite helpful comes from the mathematician A. A. Markov who introduced the assumption that the outcome of any trial is related to the outcome of a former trial (Haan, 1977). In the Markov model the mathematical probability distribution is not necessary, but the serial correlation coefficient is an important factor. Several types of the Markov models, such as the simple first order Markov model Multisite Markov model, Markov chain model, and the Markov model with periodicity, have many useful applications in water resource simulation (Haan, 1977).

Bayesian Model

If a prior probability of $P(A/E_k)$ and $P(E_k)$ is known with the Bayesian formula or model, a posterior probability, $P(E_k/A)$ can be found where P is probability and A and E are variables.

Because the true value of a prior probability of population can never be found exactly, the application of the Bayesian approach of uncertainty in water resources may be conceived as a semi-objective approach (Shen, 1976). Bayesian theory in an objective approach is quite a useful tool for predicting the posterior probability by having good information about prior probability.

Problems of Data Generation

Data can be generated by limited information with Monte Carlo, Markov, and Bayesian models, but the quality of generated data is no better than input information and must be used cautiously. Fiering (1966) gives the following points concerning the usage of simulation models to generate data:

1. Data generated by a model does not overcome the difficulty of biased or faulty data.

2. Simulation cannot be a substitute for an analytical model.

3. It is not justifiable to rely on an observed sequence of random events when system simulation seems to be necessary.

CHAPTER 5

IRRIGATION SYSTEMS

An irrigation system is often part of multipurpose and multiobjective water resource developments. Developing an irrigation system requires special expertise and knowledge about many subsystems and components of the larger encompassing system.

The irrigation system planner needs a thorough understanding of soil-water-plant subsystems, crop-yield functions, the evapotranspiration process, agricultural drainage and water distribution subsystems, and many other related subsystems plus social and institutional problems. Careful understanding and consideration are vital in developing a successful and viable irrigation system. Some of an irrigation system's subsystems and components may be investigated separately, but most have very specific interrelationships which require joint investigation in any comprehensive study.

The importance of each subsystem and components within the irrigation system varies from system to system and in time and space. Therefore, different irrigation systems may have different types of subsystems and components used to convey and apply water. The solution of an irrigation system optimization problem, or finding the best alternatives of each subsystem within an irrigation system, are a function of the technological, social, and political interests of all those affected.

Plant-Soil-Water Relationships

The growth of agricultural crops is dependent on soil, water, and air. Soil provides support and nutrients, air satisfies respiration, and water constitutes a considerable fraction of plant cells, facilitates transportation of nutrients in and through the plant, and controls the temperature of the plants.

Soil has a very active role in the growth of crops. Miller (1965) does not view agricultural soil simply as a mass of minerals, but rather as a mixture of organic and inorganic matter, water, air, and living micro- and macroorganisms. The contribution of each element in the soil must satisfy plant requirements for optimum growing conditions.

The water in the soil system is held by different forces which determine movement and position of the mass of water in time and space. Most loosely held water in the soil may be drained under gravity or hydraulic forces, and this type of water is generally not available for plants. Hygroscopic water which is tightly bound to soil particles by chemical bands is also not available for plants. Only capillary water, which is held in micropores of the soil, is available for plants.

Water within the plant circulates continuously, from the root hairs which absorb water from the soil to the leaf stomata which transpire water. Mayer (1956) calls this continuity a hydrodynamic system. The continuity of water in plant roots provides a means for nutrient transport and the control of temperature.

Information about plant-soil-water relationships can be found in books by Taylor (1972), Israelsen and Hanson (1962), Jensen (1973), and Withers and Vipond (1974).

Evapotranspiration

Evaporation and transpiration are similar hydrologic processes. The source of energy for both is the same, and both processes convert water from liquid to vapor. However, evaporation refers to vaporization of water from a free water surface or wet soil, and transpiration refers to vaporization of water from a plant's surface, namely leaves and young stems. It is almost impossible to measure these processes separately in the field; therefore, they are jointly considered, combined, and called evapotranspiration.

In the evapotranspiration process, pure water evaporates from plant and soil surfaces by the help of solar energy. This process leaves solute or mineral residue in the soil and plant. The first increases the salinity of the soil and the second supplies the nutrient requirements of the plant. Water also cools plant leaves as it is transpired. Therefore, evapotranspiration helps to transfer minerals to the plant as food and controls the environmental temperature. Evapotranspiration is a necessary process and cannot be eliminated, but it must be kept within the optimum range to produce maximum yield for a growing crop.

There are two types of productive and nonproductive evapotranspiration. The first produces agricultural products such as food and fiber. The second is that which is consumed by weeds and evaporates from wet soil and water surfaces and does not enhance the economic worth of the agricultural product. However, it consumes water which is not recoverable and increases the cost of an irrigation system.

Potential Evapotranspiration

Penman (1956) defined potential evapotranspiration as "the amount of water transpired in unit time by a short green crop completely shading the ground, of uniform height and never short of water." Jensen (1973) gives a definition which seems more useful in arid and semi-arid areas, because of the advection effect on irrigated land. He defines potential evapotranspiration as "the amount of water transpired by well watered alfalfa (lucerne) with 30 to 50 cm of top growth and 100 m of fetch under given climatic conditions." Fetch length is the length of area under the crop toward wind direction around the experimental alfalfa plot.

Actual Evapotranspiration

Jensen (1975) defined actual evapotranspiration as "the sum of transpiration and water evaporated from the soil, or exterior portions of the plants where water may have accumulated from irrigation, rainfall, dew, or exultation from the interior of the plant."

Theoretically, potential evapotranspiration, PET, can be converted to actual evapotranspiration, AET, by:

$$AET = CF \cdot PET \tag{5-1}$$

where CF is a soil and crop coefficient (crop factor) which shows the influence of soil, crop, and cultural factors on the rate of AET, Jensen (1973) suggests an energy balance euqation in which the crop factor is based on the stage of plant growth, the time since irrigation or rainfall, and remaining available soil moisture. Doorenbos (1977) with a very comprehensive worldwide study defines the crop factor as a function of the frequency of irrigation, type of plant, and stage of plant growth.

Estimation and Measurement of Evapotranspiration

Evapotranspiration is estimated and measured by several different means. Jensen (1973), Doorenbos (1977), and Valenzuela (1974) studied several methods and evaluated them. In general, some of the estimating equations are very simple to use with relatively little data, but they must be calibrated or tested for any new area. Some other equations which are very comprehensive need a considerable amount of input data which are difficult to obtain.

The most common methods for measuring potential evapotranspiration are as follows:

1. The soil water depletion method (Jensen, 1961).
2. The tank and lysimeter method (Harold, 1966; WMO, 1966).
3. The energy balance method (Tanner, 1942; Fritschen 1965).

The most common methods for estimating potential evapotranspiration are as follows:

1. The water balance method (Lowey and Johnson, 1942; Thornthwaite, 1948).
2. The mass transfer method (Dyer, 1961; Goddard and Pruitt, 1966).
3. The combination method (Penman, 1956; Van Bauel, 1966; Businger, 1956; Bartholic et al., 1970).
4. The radiation method (Makkink, 1957; Turc, 1961; Olivier, 1961; Jensen and Haise, 1963; Jensen, 1966b).
5. The evaporation method (Stanhill, 1961, 1962; Pruitt and Jensen, 1955; Pruitt, 1960; Jensen et al., 1961; Thompson, 1963; Linacre and Till, 1969).
6. The temperature method (Blaney and Morin, 1942; Blaney and Criddle, 1952; Balney et al., 1974; Pruitt, 1960; Jensen, 1966a; Quackenbush and Phelan, 1965; Thornthwaite, 1948; Lowery and Johnson, 1942).
7. The humidity method (Papadakis, 1966; Alpat'ev, 1954; Ostromeki, 1965; Vitkevrich, 1958; Ivanov, 1954).

8. The multicorrelation method (Christiansen, 1969; Christiansen and Hargreaves, 1968).
9. The reference crop method (Dorrenbos, 1977).

Many research workers have estimated actual and potential evapotranspiration by considering combinations of the following factors (Valenzuela, 1974).

1. Air temperature.
2. Daytime hour percentage.
3. Relative humidity.
4. Solar radiation.
5. Vapor pressure and vapor pressure slope.
6. Elevation.
7. Wind movement.
8. Crop factors.
9. Some type of constant coefficient.

Variation of Evapotranspiration

In general, evapotranspiration is influenced by the following factors:

1. Atmospheric conditions which influence water evapotranspiration such as solar radiation, air temperature, humidity, and wind movement.
2. Morphological physiological, and cultural factors of crops such as leaf shape, number, arrangement and behavior of stomata on the leaf, and stage of crop maturity and degree of coverage.
3. Soil conditions including soil moisture status and soil aeration. (Doorenbos, 1977)

Some researchers such as Jensen (1973), Penman (1956), and Doorenbos (1977) have found some parameters very useful for predicting evapotranspiration. Most of the independent variables which affect evapotranspiration rate have a stochastic nature, changing in time and space. It is clear that when independent variables in a functional relationship change with stochastic or random pattern, the dependent variable will also change accordingly. The conclusion is that evapotranspiration has a stochastic nature and changes randomly from day to day, although in general it follows an increasing and decreasing pattern at the beginning and ending of each vegetation season.

Franzoy (1970) says "the effect of climatic variation on consumptive use can be drastic, and while the annual consumptive use can be the same from year to year, the peak daily use is subject to dramatic and often erratic differences." Pruitt (1972) investigated daily actual evapotranspiration data of a weighing lysimeter at Davis, California, and found that it closely followed a normal frequency distribution in mid-summer. Gray and Murray (1966) used an extreme value distribution to estimate the rate of potential evapotranspiration for design purposes.

Basically, an irrigation system is planned and designed to satisfy water requirements of crops. One of the major components of crop water requirement is productive or actual evapotranspiration. Accuracy in estimating actual evapotranspiration rate can greatly influence the success and failure of an irrigation system and also can help in the decision making-process regarding various aspects of irrigation system planning and management. It is necessary to supply water to growing crops to satisfy evapotranspiration requirements using proper irrigation scheduling.

Irrigation Scheduling

Irrigation scheduling is defined by Hart (1975) as a decision-making process by which the amount of water and the time of irrigation can be determined by direct or indirect measurement. Irrigation scheduling requires methods to predict the water requirement of the near future by considering soil moisture and crop characteristics and prediction of the future rate of evapotranspiration. Irrigation scheduling also helps to increase the efficiency of an irrigation application subsystem and benefit per unit volume of consumed water and decrease the cost of water supply.

Several factors which affect irrigation scheduling must be fully considered to improve the accuracy of the decision-making process.

1. Effective precipitation which is the portion of precipitation infiltrated into the soil and may postpone irrigation time.
2. Evapotranspiration which is the major source of water consumption from soil storage. The rate has a great effect on irrigation scheduling which must be predicted for future scheduling.
3. The stage of crop growth has a relatively large effect on the rate of evapotranspiration and

scheduling. Generally, three stages can be shown in an annual agricultural crop:

a. Emergence of plant.
b. Period of maximum plant coverage.
c. Crop maturation.

4. Soil moisture status. Only a portion of soil water is available for plants, and this portion of moisture must be determined according to the character of the soil-plant-water relationships. Before this available soil moisture can be evapotranspired, usually the soil reservoir must be refilled after a specified amount of water is depleted from the soil. The decision of this point depends on the managerial decision-making process, which must consider return of crop yield or optimum return versus the cost of applied water. Hall (1968) used dynamic programming for this type of decision-making process.

Some of the soil-water terminology used in this study are defined (On-Farm Committee of ASCE, 1978) as:

1. Field Capacity, FC, is the moisture remaining in a soil after free drainage has practically ceased.
2. Wilting Point, WP, is the moisture content of the soil after the plant can no longer extract moisture at a sufficient rate for wilted leaves to recover overnight or when placed in a saturated environment.
3. Available Soil Moisture, ASM, is the difference at any time between the actual soil moisture content in the root zone soil and the wilting point.
4. Soil Moisture Deficit, SMD, is the difference between field capacity and the actual soil moisture in the root zone soil at any time.
5. Management Allowed Deficit, MAD, is the desired soil moisture deficit at the time of irrigation.

An irrigation scheduling decision is made on the basis of the combination of experience, observation of plant and soil characteristics, and climatic conditions which are fully discussed by Hu (1976).

Irrigation Efficiency

In planning, designing, and operating an irrigation system, there is a major difficult problem in deciding water utilization efficiency, which is usually a "guess" factor; and designers face the problem of uncertainty in their calculations. In order to eliminate this uncertainty, system components are often designed for a higher capacity than is necessary. Apart from the harmful side effects, guesswork leads to investment that may be considerably higher than otherwise necessary.

The estimation of efficiency for projection purposes requires considerable engineering judgment, expertise and information about cropping pattern, irrigation application subsystem layout, texture and structure of soil, and finally, most important of all, the competency and care with which the water is applied.

Irrigation efficiency is influenced by factors such as the rate of evaporation from wet soil and free water surfaces, transpiration of riparian vegetation along reservoirs and channels (non-productive use), seepage losses from reservoirs and channels, deep percolation losses, operational losses, and management waste.

The following irrigation efficiency terminology has been adopted by the On-Farm Irrigation Committee of the Irrigation and Drainage Division of the American Society of Civil Engineering (1978).

1. Irrigation Efficiency, IE, is the ratio of average depth of water which is used beneficially to the depth of applied water. Beneficially used water is that which is used to satisfy soil moisture demands (SMD), leaching requirements, environmental control, and pesticide and fertilizer application or management water (MW).

2. Application Efficiency, AE, is the ratio of average depth of water stored in the plant root zone to the average depth of applied water by irrigation application subsystem. AE does not give any indication of any under- or overirrigation at any part of the farm.

3. Application Efficiency of Low Quarter, AELQ, is the ratio of the average depth of stored water in the plant root zone at the low quarter of the field (ADWLQ) to the average applied water (AAW). If ADWLQ of a field exceeds SMD then AELQ equals the ratio of SMD to AAW. When water for leaching requirement, LR, is needed it must be added to SMD. When the maximum return from a unit volume of water is desired, SMD can be set as a defined amount less than actual SMD. AELQ is a useful statement because it includes the concept of uniformity especially in the lower part of the farm where there is the possibility of underirrigating.

4. Potential Application Efficiency of Low Quarter, PAELQ, is the low quarter application efficiency when the low quarter of the farm is getting at least a predetermined depth of water. In arid areas, this depth may be equal to Management Allowed Deficit (MAD). PAELQ can be estimated by theoretical analysis or by surveying existing nearby fields. The ratio of AELQ to PAELQ for a given field indicates the effectiveness of management or operation.

5. Distribution Efficiency, DE, is the ratio of average depth of water infiltrated at the low quarter of the field to the average depth of infiltrated water.

6. Coefficient of Uniformity, U.C., is the average depth of infiltrated water, minus its average deviation divided by itself.

7. Storage Efficiency, SE, is defined by Israelsen and Hanson (1962) as the ratio of output water for beneficial use to the input water to a reservoir.

8. Conveyance Efficiency, CE, is the ratio of the output water to the input water in a conveyance subsystem.

Irrigation efficiency is very seldom a precisely defined value because many different factors influence irrigation efficiency. Udeh (1978) assumed irrigation overall efficiency to be a stochastic component, using a probability distribution of efficiency to determine the optimal area to be committed to irrigation in Idaho. Hill et al. (1978), by an extensive study, show that fixed cost of application subsystems rise drastically when DE rises over 90% for trickle, sprinkler, and surface irrigation application subsystems. Worstell (1976), who reviewed almost 765 cases of channel seepage data across the United States, found that the average seepage varies widely within a given soil texture, and increases where texture of top soil changes from clay to sand. He failed to find a general correlation between efficiency and texture of the top soil of the channel. Discussion about efficiency can be found in Bos et al. (1974), Goldberg (1976), and Hagen (1967).

Irrigation Application Subsystem

The purpose of an irrigation application subsystem is to distribute water over the soil to fill the soil storage in the usable range of the root zone to satisfy the needs of actual plant evapotranspiration and management water. In general, there are four logical possibilities for the distribution of water on agricultural soil and one for soilless culture:

1. To run water over the soil (surface irrigation).
2. To run water into the soil and raise water by capillary action (subsurface irrigation).
3. To drop or rain water over the ground without damaging crops or soil (overhead or trickle irrigation) (Withers and Vipond, 1974).
4. To water some inert media such as sand or gravel to raise crops (hydroponics).

Economical irrigation requires the uniform application of water by an appropriate application subsystem at the proper time. Also any bad side effects such as raising the water table and accumulating salt should be prevented. The selection of an irrigation application subsystem should be made by taking account of local physical, economic, and social conditions such as land topography, soil character, farm size, crops and cropping pattern, local climate, source and volume of available water and water quality, cost and benefit of irrigation operation, and available skill and technology (Zimmerman, 1966).

Surface Irrigation

Surface irrigation methods, which have an advantage of being adaptable and flexible, can be used for different types of crops, soil, and management with relatively high application efficiency. The frequency of irrigation to cope with changing weather can be easily adjusted by this method. Surface irrigation does not generally require a great deal of capital investment and does not usually require energy for pumping.

The depth of infiltrated water in the surface irrigation method is a function of the slope, length of run, discharge, surface roughness, shape of the field channel, intake rate of soil, and horizontal and vertical permeability (Withers and Vipond, 1974). Skilled labor is one of the major requirements to obtain high efficiencies with this method. Some references for surface irrigation are as follows: Strelkoff et al. (1977), Katopades and Strelkoff (1977), Bassett and Fitzsimmons (1976), Rath (1970), Powell et al. (1972), SCS (1974), and Wu (1972).

Subirrigation

In the subirrigation method, water is applied into the soil by underground porous pipes or open ditches spaced a certain distance from each other. An impermeable layer is necessary at some distance under the porous pipe to create a water table at the bottom of the root zone. The water rises into the root zone by capillary action. The states of Idaho and California have several places where farmers are practicing subirrigation under favorable conditions.

Some of the advantages of subirrigation include minimal loss of water by evaporation, low labor requirement, no problem for agricultural machinery operations, and irrigation of soil with a low water-holding capacity and high intake rate. Some disadvantages of subirrigation are that it may slow the germination of crops, cause a salinity problem, have a high initial cost, and require relatively precise land grading. More information about subirrigation can be found in Israelsen and Hanson (1962), Withers and Vipond (1974), and Arar (1971).

Overhead Irrigation

The overhead irrigation method requires extensive pipe systems to carry and distribute water over growing plants or to drop water close to the top of the soil. This method is classified broadly as either sprinkler irrigation or trickle (drip) irrigation. A pump is usually required in the system to provide sufficient operating pressure.

Sprinkler irrigation has come into large-scale use during the past three decades in arid and semi-humid areas of nearly all countries of the world where irrigated agriculture is feasible. This method is one of the most flexible methods for most soil and topographic conditions for all types of crops. Water distribution patterns can be applied similarly to natural rainfall. Minimum land grading, the ability to irrigate soils with high intake rates, high application and distribution efficiencies, distribution of fertilizers and pesticides, and the ability to control temperature are the main advantages. High initial cost and plant damage with low quality water can be counted as disadvantages of this method.

Pair et al. (1975) classify sprinkler irrigation as having either stationary or moving laterals. They give six types of sprinkler irrigation with stationary laterals:

handmove, sideroll, end tow, sidemove, boom, solid set, and three major types of continuously moving laterals: circular center pivot, straight moving lateral, and traveler.

Trickle (drip) irrigation is the frequent slow application of water close to the base of the plant. This method can use low quality water for irrigation successfully by lowering soil tension to some point close to field capacity because of frequent watering. This method has many advantages, especially in arid areas such as Israel where the quantity of water is limited, the quality of water is low, and the rate of evapotranspiration is very high. Research in Israel has shown drip irrigation can increase the crop yield over sprinkler irrigation (Goldberg, 1976). Drip irrigation requires a very extensive pipe network and usually requires a pump and special filter system. The maintenance and operation of drip irrigation needs more expertise than the sprinkler irrigation method. Minimum land grading, minimum evaporation and deep percolation, high operation efficiency, weed control, and low operating pressure are the advantages. High initial cost, salt accumulation around root zone, and nozzle clogging can be disadvantages. There is some uncertainty due to lack of research about the extent of advantages and disadvantages of this method.

Hydroponics

Hydroponics (soilless agriculture) is the cultivation of plants in a container of dissolved inorganic nutrients rather than in soil. This method can be applied in some regions of the world where the capital is available or where climate does not allow for open agriculture and water is very scarce. The advantages of this method are the possibility of producing food where normal irrigated agriculture is impractical, there is very low evapotranspiration and no runoff or deep percolation, and there is the possibility of automation. The very high initial cost can be counted as the main disadvantage (Achtnich, 1971).

Irrigation Distribution Subsystem

The distribution subsystem which provides a timely supply of water in sufficient quantity to all farms within a designated area should be efficient convenient to operate and maintain, and commensurate with farm pattern.

The layout of the network is generally a function of topography, farm pattern, available technology, material, capital, and desired conveyance efficiency. Generally, the internal irrigation network begins below the primary reservoir or river diversion and runs almost exclusively through the irrigated area. In the layout and design of irrigation distribution subsystems an important goal should be the reduction of the overall length of the network to help to reduce the cost and volume of earth work. Depending mainly on topography, the nature of water supply, soil conditions, and farm deliveries, the irrigation network can be lined or unlined canals or low or high pressure pipe. Often it is possible to combine canal and pipe components in the same system. Optimization procedures can be useful tools to plan and optimize the layout of an irrigation distribution network. Allen et al. (1978) utilized dynamic and linear programming in optimizing the layout of an irrigation distribution network in Idaho. Buras and Schwing (1969) optimized a main adueduct route by dynamic programming in a development project in Iran.

The capacity of the irrigation distribution subsystem is a function of the available water in the crop growing season, the type of demand for water, the cropping pattern in the designated area, and the social and institutional structure of people within the area. Withers and Vipond (1974) show two different approaches to determine the capacity of canal sections as follows:

1. The deductive method in which the capacity of a new distribution subsystem is simulated from another existing subsystem. By observation and measurement, the discharge in each canal section of an old distribution subsystem can be adjusted according to the service area for the new irrigation distribution subsystem. This method seems reliable if the prototype can be found by considering physical, social, and institutional differences.

2. The inductive method requires basic climatological data, an estimate of cropping pattern, information about water, law, and social and institutional factors. From this information, water duty (capacity of canal per unit area under the service) can be estimated and adjusted for related efficiency and water requirements. This method requires considerable engineering judgment and expertise to be successful. The greatest shortcoming of this method is lack of reliable data in most of the study areas.

Canal capacity at each section of a distribution subsystem can be defined as:

$$q_{avg} = \frac{\Sigma q_n A_n}{E \ \Sigma A_n} \qquad (5\text{-}2)$$

where

q_{avg} = average capacity of subsystem at desired canal section (L/S)

A_n = area under crop n (ha)

E = overall conveyance efficiency

q_n = water duty (L/S)

n = indicator for type of crop

If A_n is constant, q_{ave} can be tabulated against q_n for different months; otherwise q_{ave} can be tabulated against different cropping patterns to select peak q_{ave} values which should be used as a basis in the design of a canal section.

The design capacity of a distribution subsystem, after determination of water duty as a base, should take into account cultural practices of farm managers by considering regional water laws and social and institutional factors. This decision should be an optimization process considering the kind of demand, supply of water, technology, capital, and other important related regional variables.

Generally, distribution of water among different farms is based on four types of demand, each of which has a distinguishing effect on the capacity of a distribution subsystem. These types of demands are as follows:

1. Continuous supply.
2. Strict rotation.
3. On demand.
4. Mixtures of 2 and 3 or rotation with some fluctuation.

It is highly desirable to have a continuous flow of water in a canal lateral with some seasonal fluctuation. This will decrease the cross section of the canal and minimize deterioration of unlined canals due to wetting and drying cycles. However, it is not convenient for most farm managers to irrigate continuously during the crop growing season as they need some time for other agricultural activities. In the case of power failure or failure of an application subsystem, it is possible that all of the water delivered to the farm could be lost. The farmer needs some type of flexibility to prevent unnecessary water waste. A solution to this problem would be the installation of a farm service reservoir to store water during off irrigation periods.

Strict rotation or periodic water supply to the farmer can be arranged by dividing a canal into a set of smaller canals. Each canal serves a group of farmers during a certain time with a discharge several times more than that required for the continuous discharge case. The cost of the distribution subsystem will increase and also the farmer must irrigate on a certain pre-set date. The capacity of each canal section can be defined as:

$$q_{ave} = \frac{\Sigma q_n \cdot A_n}{E \; \Sigma A_n} \cdot \frac{30}{D} \qquad (5\text{-}3)$$

where D is the rotational period in days per month for canal and the other terms are as previously defined.

Availability of water on demand to the farmer is ideal where the financial and economic feasibilities allow or where the farming method and irrigation application subsystem are very sophisticated. This type of distribution subsystem is very favorable to the farmer, but it costs much more and needs more care to prevent operational waste and to increase overall efficiency.

Sometimes with careful investigation, it is possible to mix rotation and on-demand type of distribution subsystems to have a mixed subsystem within a reasonable range of cost and operational flexibility.

Drainage Subsystem and Leaching Requirements

It has been recently accepted that a drainage subsystem is an almost unavoidable part of an irrigation system where natural drainage is insufficient. One must consider that many irrigation systems throughout the world have failed to function because of inadequate drainage. Where there is an inadequate or malfunctioning drainage subsystem, water tables are likely to rise, and salt will accumulate in the root zone. Both restrict and kill the root system and can decrease and finally destroy plant growth (Taylor et al., 1972). van Schifgaarde (1978) says "to maintain a viable agriculture over time, all irrigated land needs drainage."

The sources of excess water in agricultural land can be extremely varied, including precipitation, irrigation water, surface and underground flow, seepage from nearby areas, channels, artesian aquifers, leaching water, and water for controlling the environment. The sources of salt may be the parent material of soil, low quality irrigation water, and underground water.

Agricultural land drainage can be divided into two broad categories: surface drainage and subsurface drainage. Generally it is much easier to handle surface drainage problems by channeling or using irrigation canals with some minor adjustments. Subsurface drainage subsystems require more related engineering judgment. The effectiveness of a subsurface drainage subsystem depends on the drainage layout, material, and severity of the problem. Kirkham (1969), Luthin (1957, 1966), and Gover (1964) give several useful procedures for drainage design.

Generally in arid areas, irrigated land is affected by accumulated salt in the soil from different sources. These accumulated salts must be leached out by extra irrigation water or by heavy flooding at the end of each irrigation season. The leaching water requirement is defined by Luthin (1975) as "the fraction of the irrigation water that must be leached through the soil root zone of the plants in order to prevent the soil salinity from exceeding a specified level." Leaching water on a farm depends on the tolerance of the crop, the salinity of the irrigation water, and soil.

Today, because of extensive irrigation practices in many areas, the problems of degrading the quality of stream flow and underground water are increasing. Recovery of polluted drainage water still needs more research to be economical and to prevent the rehabilitation of one project area at theexpense of destroying another area or degrading a river system.

Computation of Runoff and Deep Percolation

Runoff and deep percolation in gravity, and deep percolation in pressurized irrigation application subsystems are frequent sources of water wastage. The reuse of runoff water is sometimes possible directly in some projects, but it can cause problems and decrease crop yields because of low quality. Runoff and drainage water can be mixed with inflowing irrigation water to improve the quality for irrigation and prevent degradation of stream flow.

The problem of determining the amount of runoff is more simple than the problem of subsurface drainage water. The amount of drainage water depends on the source of recharge and soil characteristics and may be determined by a proper drainage function (Khanjani, 1977).

Karmeli (1978a,b) developed a procedure for estimating runoff, deep percolation, and water deficiency for furrow and sprinkler irrigation application subsystems. He regressed the dimensionless infiltrated depth of water (ratio of infiltrated depth to maximum infiltrated depth) against the dimensionless fraction of area of irrigated land (percentage of land receiving a specific depth of water). More information about runoff can be found in SCS (1974).

Farm Service Reservoir, FSR

A farm service reservoir or farm pond provides a relatively temporary storage of water on the farm when water is available and cannot be used instantly due to time, labor, other agricultural activities, and/or a small rate of inflow. It would be greatly desirable for a farmer to have water on-demand by storing a small continuous flow in a farm service reservoir. Zimmerman (1966) says "the service reservoir has proved to be the greatest single water and labor saver of all irrigation projects." The farm service reservoir is used to collect water overnight and to irrigate in the daytime in most Asian countries, including Iran. The purpose of the farm service reservoir as used in this study is to collect water from all possible sources such as runoff, drainage water, and irrigation water from the wells or canals on a continuous or rotation basis. These water sources can be saved and used for irrigation whenever scheduling permits. This type of reservoir provides a flexibility for farmers in scheduling irrigation, regulates unsteady irrigation inflow, and also makes possible irrigation by a low continuous flow. The farm service reservoir and types of associated structures are functions of engineering financial, economic, social, and institutional feasibilities. In general, farm service reservoir storage can be constructed by (1) enlarging an existing irrigation channel by excavating or by building embankments and levees, or (2) excavating soil in a suitable place or building storage facilities on the ground.

Zimmerman (1966) and Clark (1950) suggest several different kinds of possibilities for the design and construction of a farm service reservoir. It is clear that the site of the farm service reservoir should be selected with an eye toward topographic advantage to keep the reservoir as high as possible and as close as possible to the irrigated areas.

The capacity of a farm service reservoir for short-term duration of retention such as one or two days is a function of irrigation durations or irrigation flexibility factor and actual evapotranspiration; however, on a long-term basis it is a function of actual evapotranspiration. The continuity equation in long- or short-term should be satisfied:

$$(\Sigma I - O)_t = 0 \qquad (5\text{-}4)$$

where I, O, and t are volume of inflow, outflow, and time, respectively. The capacity of an overnight farm service reservoir can be computed as follows:

1. Determine flexibility factor, F, on daily basis:

$$F = \frac{IR}{24} \tag{5-5}$$

   where IR = irrigation duration per day in hours. The value 24-IR is the duration of retention time in an overnight farm service reservoir, FSR.

2. Determine total land under irrigation and cropping pattern, Ai.

3. Determine maximum gross peak consumptive use of the farm by considering the crop growing season of each crop and management water requirement, ΣGW_i.

4. Compute capacity of the farm service reservoir, V, as

$$V = \frac{I-F}{E_{st}} \cdot \Sigma(Ai \cdot GW_i) \tag{5-6}$$

   where E_{st}, A, and GW are farm service reservoir efficiency (storage efficiency), area under each crop, and gross peak consumptive use rate of each crop.

The capacity of a farm service reservoir for a long term such as two or three months or one season can be determined as a function of gross farm water requirement. The gross water requirement for each month or shorter period can be determined for a certain probability of occurrence. The necessary volume of this type of farm service reservoir can be determined by applying a continuity equation and by some type of reservoir yield analysis such as a mass diagram (Hjelmfelt, 1975) and inflow-outflow analysis (James and Lee, 1971).

Sometimes a failure in some irrigation subsystems can cause problems for irrigating according to schedule. This failure could be a result of maintenance and repair of irrigation distribution or application subsystems. The capacity of an emergency farm service reservoir could be computed in the following manner:

1. Determine the duration of possible failure by estimation from prior data, B, or necessary duration of retention time of water in the FSR.
2. The volume of emergency farm service reservoir, V, is

$$V = B\Sigma A_i GW_i \tag{5-7}$$

CHAPTER 6

ECONOMIC ANALYSIS OF IRRIGATION SYSTEMS

Feasibility Study of Irrigation Systems

Water has opportunity costs for several different beneficial uses which were discussed in Chapter 2. Each use may bring different kinds of tangible and intangible benefits to a community which could be important economically and socially. History has shown that an adequate supply of water is one of those important factors in the improvement of the social and economic life of any region. On the other hand, the abundance of water without judicious use may have no advantage to a region and may create numerous economic and social problems.

In this era, the growing demands of available water by different activities, including agricultural, dictate that agricultural irrigation decision makers plan for using irrigation water as efficiently as possible and increase the productivity per unit volume of water by using contemporary technology and applied science and also by considering availability of energy. According to Hogg and Davidson (1969), the efficient use of irrigation water is possible if (1) information is available to estimate the economic contribution of irrigation water in agricultural production, and (2) available information is useful in the decision making process.

Optimization of an irrigation system to give maximum benefit at minimum cost needs careful investigation of all alternative components of the system, each of which must be realistically justified. Any over- or under-miscalculation and misunderstanding can cause a failure of the system.

In general, planners are faced with several alternatives for each system component. According to James and Lee (1971), it is necessary for each alternative to pass engineering, economic, financial, social, and political feasibilities. The economic and financial feasibilities of a component can be tested in the following ways:

1. A discounting technique may be used if the decision maker must choose only one of two alternatives. The most important discounting techniques are net present value (NPV), cutoff period (CP), pay-back period (PBP), net average rate of return (NARR), internal rate of return (IRR), and benefit-cost ratios (Sassone and Schafer, 1978). Although each of these methods may lead to the same evaluation, each has its own advantages and disadvantages.

2. By using a mathematical programming technique, the decision maker, because of some constraints, can choose some combination of available alternatives. The mathematical programming tool may be used to optimize the best combination of alternatives for a desired goal.

Cost-Benefit Terminology

Some of the definitions which may be used are as follows:

1. Fixed cost is defined as that group of costs in an ongoing activity whose total will remain relatively constant throughout the range of operational activity.

2. Variable cost is defined as that group of costs which vary in some relationship to the level of operational activity.

3. Total cost is the sum of fixed and variable costs.

4. Average total cost is the ratio of total cost to the scale of size of activity.

5. Marginal cost is the difference between successive total costs; however, it is not the cost of producing the last unit but the addition to the total cost when one more unit is being produced.

6. Benefit is the measure of the effectiveness of the action in achieving a goal.

7. Marginal benefit is the difference between successive total benefits by increasing or decreasing one unit of output.

8. Total benefit is the total induced benefit from result of an activity.

9. Average benefit is the ratio of total benefit to the scale of size of activity.

Benefit and Cost Function of Irrigation Subsystems

Specifications of the most economical alternatives for some irrigation subsystems, such as application subsystems, farm service reservoir or distribution subsystems, can be determined by discounting or mathematical programming techniques. A valid question is "Although evapotranspiration is stochastic in nature, what is the best design capacity of an irrigation application subsystem or farm service reservoir subsystem?" This question can be answered by marginal benefit and cost analysis versus evapotranspiration demand.

The output of each irrigation subsystem is direct or indirect and depends on the volume of water which is stored, transferred, or distributed. This volume can be a common characteristic for almost all of the subsystems. According to Busch (1974), "Costs associated with system components must have common characteristics so that the values of alternative components can be used to accurately compare these components." The supply or cost function of each irrigation subsystem, whenever necessary, can be developed on the basis of volume of output water from that particular subsystem. Therefore, the efficiency of each component has a direct effect on the cost function of a particular subsystem.

A general cost function for a subsystem may be written as:

$$TC = F + AQ^m \tag{6-1}$$

and if $E = Q/Q_1$, then

$$TC = F + A(E \cdot Q_1)^m \tag{6-2}$$

where

TC = total cost
F = fixed cost
A = cost coefficient
Q = volume of output water from subsystem
m = exponent
Q_1 = volume of input water to the subsystem
E = overall efficiency of the particular subsystem

Using Equations 6-1 and 6-2, the total cost, TC, of an irrigation application subsystem should be computed as a function of maximum available water in the root zone, MAW, which is transferred and distributed from the farm delivery point to the root zone during the peak evapotranspiration period by the irrigation application subsystem. Under this condition

$$Q_{max} = Q_1 = \frac{AET}{E} = \frac{MAW}{E} = \frac{Q}{E}$$

where

AET = actual rate evapotranspiration.

Cost functions of irrigation distribution, and farm service reservoir subsystems, can be computed using Equations 6-1 and 6-2 considering the maximum capacity and related efficiency.

If it is desired to compute the total cost function of two or three subsystems which are linked together, it is possible to sum their cost functions and substitute the final output for each individual output by using the proper overall efficiency.

The same principle which was suggested to determine the total cost of an irrigation subsystem should be used to calculate the benefit of the subsystem. In other words, benefit or demand should be a function of the volume of output from that subsystem.

In general, estimation of cost is much easier and more reliable than the estimation of benefits, the reason being the relatively short time between planning and construction compared to the longer time span between planning and realization of benefits during the life of a system. It is also difficult to estimate projected benefits because operational costs and benefits are both subject to change. Considering these difficulties, every effort should be made to carefully estimate benefits before proceeding to a project or system analysis.

In irrigation system planning, it is difficult to project how the total benefits of the system can be divided among the several subsystems to determine the benefits associated with each individual subsystem. This is a major part of decision making and should be investigated by a "with-and-without" or a "before-and-after" analysis. Decisions about the type of analysis depend on the nature of a particular subsystem and engineering judgment.

To determine the benefit of allocated irrigation water to a give crop under existing conditions, the relationship between the yield of the crop and its use of supplied water must be known. In general, two major types of functional relationships between crop yield and consumed water are usually considered:

1. Crop yield, Y, as a function of evapotranspiration, ET (Stewart and Hagen, 1973) or

$$Y = A + B \cdot ET \tag{6-3}$$

where A and B are constant coefficients which may change with time, space, and crop.

2. Crop yield, Y, as a function of total depleted water from the root zone of the plant, X, which in general is a concave downward curve or

$$Y = A + BX + CX^2 \tag{6-4}$$

where A, B, and C are constant coefficients and may change with time, space, and crop (Musick et al., 1976).

Hall (1968) says that "the magnitude of the losses may depend almost as much on when the soil moisture deficiency occurs as on the total magnitude of the seasonal shortage." In other words, damage to a crop caused by water deficiency cannot be recovered at any other time during the growing season. The conclusion is that damage or loss of benefit is a function of total consumptive use and is a fraction of the total benefit attainable without water deficiency.

Dimensionless Crop Yield-Water Function

As discussed, crop yield or benefit of irrigation can be estimated as a function of evapotranspiration or depleted water from the soil reservoir. If reliable data are not available for a given area, dimensionless crop yield-water functions can be developed by data from other similar areas. To obtain a dimensionless function, crop yield and depleted water should be divided by maximum crop yield and maximum depleted water, respectively, and dimensionless crop yield should be regressed against dimensionless depleted water, or:

$$Y_i = \frac{YY_i}{Y_{max}} \tag{6-5}$$

$$X_i = \frac{XX_i}{X_{max}} \tag{6-6}$$

$$Y = f(X) \tag{6-7}$$

where

Y_i, X_i = dimensionless crop yield and depleted water
Y_{max}, X_{max} = maximum crop yield and depleted water
YY_i, XX_i = actual crop yield and depleted water

Crop Production and Benefit

Because of the stochastic nature of actual evapotranspiration, it is possible sometimes to apply water less than maximum actual evapotranspiration and satisfy the contemporary water requirement without any effect of water shortage on crops. The level of risk to apply less water and satisfy the actual evapotranspiration for different irrigation intervals and amounts of applied water can be computed as:

$$R = \mathrm{Exp}(N \cdot \log(P)) \tag{6-8}$$

where

R = level of involved risk
N = life of project in years
P = probability of occurrence

Crop production can be computed as:

$$CP = PR \cdot Y_{max} \; (R + (1-R)Y) \tag{6-9}$$

where

CP = crop production benefit

PR = unit price of crop production

Y = dimensionless crop yield

Benefit-Cost Analysis

By computing the benefit and cost of an irrigation application subsystem versus amount of actual evapotranspiration or depleted water, the most economical design discharge or most economical irrigation interval can be estimated by one of the following methods:

1. Find the amount of actual ET where the difference between benefit and cost is maximum. This method requires a trial-and-error procedure.
2. Find the amount of actual ET where marginal benefit equals marginal cost.

CHAPTER 7

GENERAL MODEL AND PROCEDURE OF OPTIMIZATION OF AN IRRIGATION SYSTEM WITH CHAIN STORAGE

Introduction

The past chapters included the introduction of multi-beneficial uses of water resource systems with specific emphasis on irrigation subsystems and their operations. The purpose of this chapter is to determine how to properly position each subsystem and component, to optimize the capacity of each farm service reservoir, FSR, and to compute the design capacity of the least cost irrigation network. The procedure will include a determinization of the mathematical probability distribution of potential evapotranspiration and the most economical irrigation intervals. The least cost of supplied water with a FSR chain in the irrigation system will be computed using linear programming. A schematic flow chart of the general methodology is shown in Fig. 7-1.

Study Area

The boundaries of the study area must be defined. Topography, soil, canal distribution maps, and climatological information should be collected.

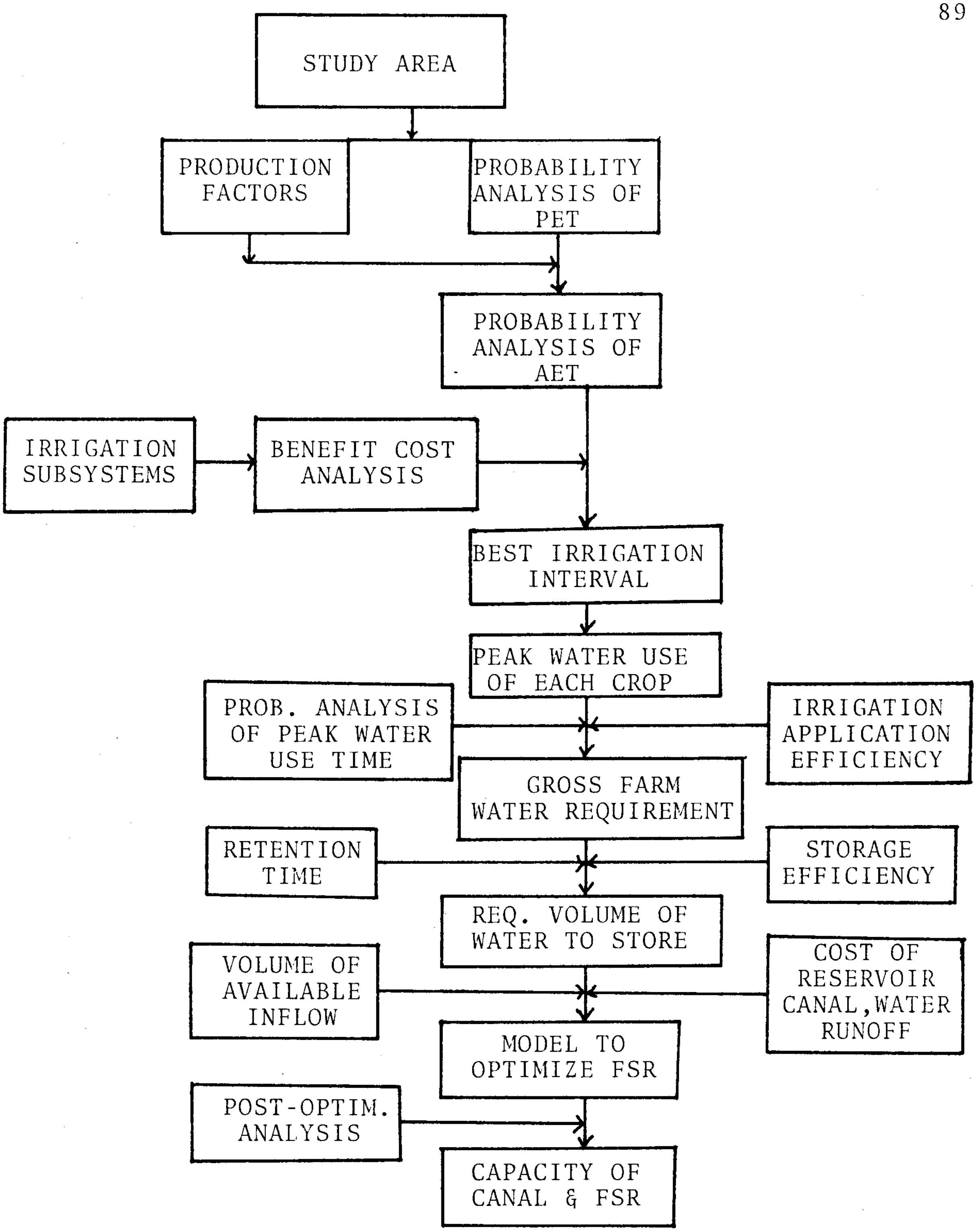


Fig. 7-1.--Flow chart for optimizing irrigation system with farm service reservoirs

Production Factors

For this analysis, the following data and information about water, crops, soils, and management are necessary and must be collected from the study area.

1. Water. The source, nature of availability, and quality of irrigation water should be investigated and the following information derived:
    a. Availability and frequency of inflow water into the irrigation system.
    b. Quality of irrigation water delivered and runoff from the farm, which could be mixed in a farm reservoir and may be reused for irrigation.
2. Crop. The varieties of crops and cropping patterns are important factors in planning an irrigation system. The following information about the nature of crops is necessary and should be collected from the study area.
    a. The cropping pattern should be explored, because it has an important effect on irrigation water demand. Changes in cropping pattern may result in the adjustment of irrigation system capacity. Cropping patterns of the study area should be judged in such a way as to avoid drastic changes in irrigation system design capacity.
    b. The depth of root zone of each crop should be estimated during the peak potential evapotranspiration. These data are used to compute maximum capacity of soil moisture storage available to plants.
    c. Maximum management-allowed soil moisture depletion should be determined for each crop in the study area, or judged from another area.
    d. Length of growing season should be determined for each crop.
    e. Sensitivity of each crop to water quality must be established.
3. Soil. The soils of the study area should be studies and their characteristics must be determined for the following factors:

   a. Infiltration rate for a given irrigation application subsystem.

   b. Texture, structure, and quality (salinity, alkalinity) of the soil.

   c. Available moisture holding capacity (mm/mm).

4. Management. Management information should be collected and analyzed for the following factors:

   a. Flexibility factor of irrigation or the percentage of time used for irrigation system operation.

   b. Management water requirement (leaching, environmental control, operational waste, etc.).

   c. Cultural habits--when farmers prefer to irrigate, social and institutional problems which conflict with and affect irrigation system design and/or operation.

Irrigation Application Subsystem

The type of irrigation application subsystems in a study area can be selected by three general procedures which depend on management decisions and regional technology availability.

1. Management prefers to have only one type of irrigation application subsystem (mutually exclusive), because of speciality, available technology, and other cultural or institutional preferences. Under this condition, the best irrigation application subsystem could be selected by a discounting technique which helps determine the most economical application subsystem (Chapter 6).

2. Management prefers to have a combination of several different types of irrigation application subsystems for irrigation of the same or different crops, because of different reasons as discussed in item number 1. Under this condition a mathematical programming technique (Chapters 4 and 6) can be used to optimize a combination of irrigation application subsystems for a least cost, or a maximum benefit, according to restrictions imposed by management.

3. Management prefers to have a predetermined type of irrigation application subsystem. Under this condition, the specified type(s) of irrigation application subsystem should be used for study.

Efficiencies of Irrigation Subsystems

The efficiencies of several different irrigation subsystems, such as the different types of efficiencies of irrigation application subsystems, farm service reservoir subsystem efficiency, water distribution subsystem efficiency, and others defined in Chapter 5, must be computed or estimated.

The efficiencies of some subsystems, such as the application subsystem, may be measured or determined theoretically with the help of the Karmeli (1978a,b) method or some similar method. If possible, efficiencies should be measured from similar existing subsystems. Expertise and engineering judgment should be used for the final decision.

It should be mentioned that according to Udeh (1978) and Brockway (1973) that the efficiency of an irrigation system is not constant from year to year or within a single irrigation season. It varies according to cultural, climatological, institutional, and managerial factors.

In general, a long record and sufficient experience are necessary to make a reliable engineering judgment on the particular efficiency of a particular subsystem.

Irrigation Water Requirement

Mathematical Probability Distribution of Potential Evapotranspiration, PET

Potential evapotranspiration, as discussed in Chapter 5, has a stochastic nature and varies with time for a given place. In order to analyze the stochastic nature of potential evapotranspiration in a given area for the purpose of this methodology, the following steps are necessary:

1. Compute potential evapotranspiration (PET). Daily potential evapotranspiration can be estimated by one of the formulas introduced in Chapter 5 such as the Penman equation or Jensen and Haise equations (Jensen, 1973). Measured potential evapotranspiration data, if available, would also be excellent for analysis. Data for several years are necessary to provide enough information to estimate a reliable mathematical probability distribution of PET.

2. Compute accumulated PET for different durations. Accumulated PET for several durations such as 1, 2, 3, 10, 15, 20, 30 days, and seasonal or any other duration which seems necessary should be computed.

3. Choose maximum accumulated PET. For each year and different duration, the maximum accumulated PET should be selected; in other words, for each year there is one piece of data for a particular duration.

4. Plot the histogram of PET for different durations. By comparing histograms of different durations of PET to the shape of the probability distribution function (PDF) of different known mathematical probability distributions, the best fit mathematical probability distribution of PET can be estimated.

5. Compute plotting position. The plotting position should be computed with the Weibull (1939) formula or another more useful formula as discussed in Chapter 4.

6. Select proper probability paper. Normal, Gumble, or another type of probability paper can be used for draft drawing of plotting position. The proper paper is selected based on estimation of a suitable mathematical probability distribution of PET.

7. Assume mathematical probability distribution of PET. The assumption of mathematical probability distributions for plotted position of PET should be tested by procedures discussed in Chapter 4. Finally, the most suitable mathematical probability distribution which can best describe the stochastic nature of PET for a given area can be defined.

8. Confidence interval of mathematical probability distribution of PET. For a predefined range of probability, the confidence interval can be estimated, if necessary, according to chosen mathematical probability distribution of PET. Examples of the probability distribution of accumulated PET are shown in Fig. 7-2.

Mathematical Probability Distribution of Actual Evapotranspiration

Actual evapotranspiration of each crop in a study area can be computed as:

$$AET = CF \cdot PET \tag{7-1}$$

where

AET = actual evapotranspiration

CF = crop factor (crop coefficient)

PET = potential evapotranspiration

The probability distribution of actual evapotranspiration for different durations can be estimated in the same manner as for potential evapotranspiration.

Readily Available Soil Moisture

The readily available soil moisture (RASM) which here is the total moisture which can be stored in the soil to satisfy the actual evapotranspiration requirement of a crop can be estimated as:

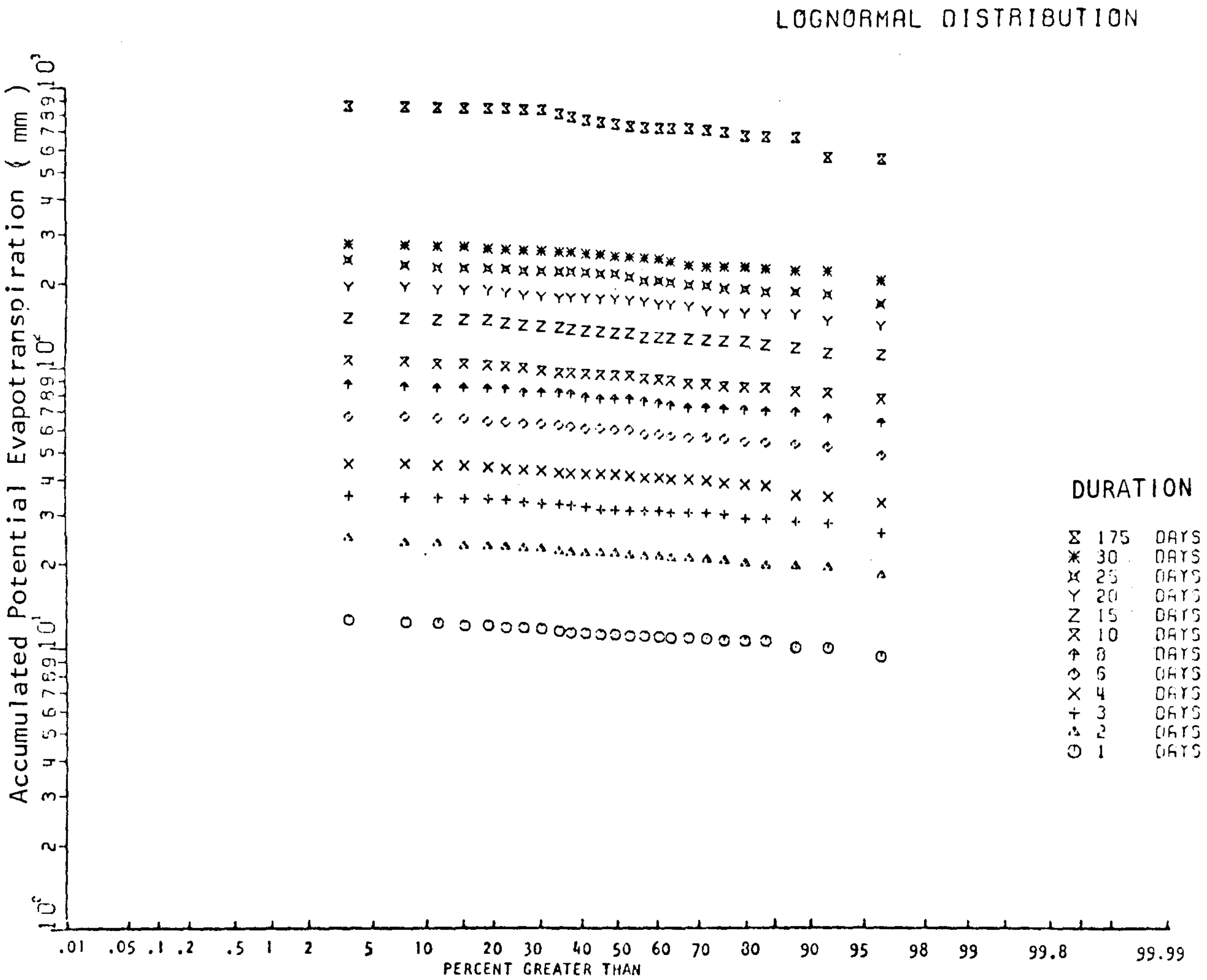


Fig. 7-2.--Probability Distribution of Potential Evapotranspiration

$$RASM = RT \cdot ASM \cdot MAD \qquad (7\text{-}2)$$

where

RASM = readily available soil moisture (mm)

RT = root zone depth of a particular crop (mm)

ASM = available soil moisture (mm/mm)

MAD = management allowed deficit for a particular crop (%)

Irrigation Interval

By estimating the probability distribution of actual evapotranspiration and assuming readily available soil moisture equal to accumulated actual evapotranspiration, irrigation intervals can be estimated from Fig. 7-3 or from related equations of line shown in Fig. 7-3 for different durations. The duration of actual evapotranspiration is assumed to be equal to irrigation interval because when total soil moisture is depleted by actual evapotranspiration requirement, the soil storage should be refilled.

Recurrence Interval and Level of Risk for Different Irrigation Intervals

Several irrigation intervals based on different levels of probability to satisfy actual evapotranspiration requirements can be computed. The recurrence interval, T, and level of involved risk of success, R, can be determined by:

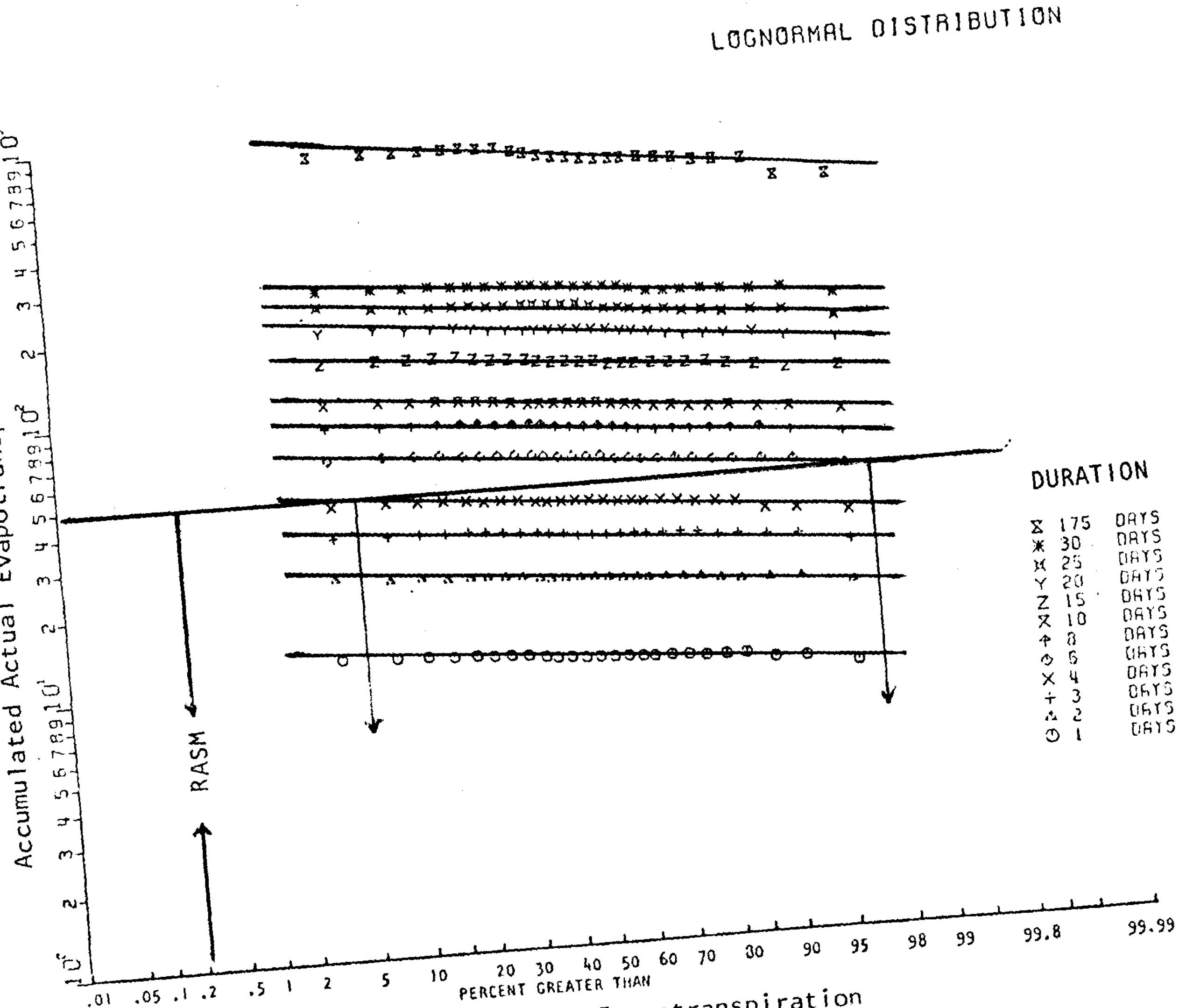


Fig. 7-3.--Probability Distribution of Actual Evapotranspiration

$$T = \frac{1}{P} \qquad (73\text{-})$$

$$R = \mathrm{Exp}(N \cdot \log_e(P)) \qquad (7\text{-}4)$$

where

T = recurrence interval

P = probability level

N = life of irrigation application system, year

Most Economical Irrigation Interval

It is assumed that total available soil moisture is equal to actual evapotranspiration of different crops for different durations with a certain probability and risk level. The most economical irrigation interval can be determined by using a cost and benefit analysis for irrigation application subsystem as was discussed in Chapter 6. The procedural steps are as follows:

1. Compute the cost of irrigation of a crop with a particular application subsystem, for different amounts of applied water.
2. Compute the benefit of irrigation for that particular crop on a particular type of soil, for different amounts of applied water.
3. Compute the marginal cost and benefit for different amounts of applied water.
4. Determine the most economical amount of applied water by computing a certain common point of marginal benefit and cost functions.
5. Assume a duration of accumulated actual evapotranspiration of assumed crop which is close to the economical amount of applied water as a most economical irrigation interval.

Peak Water Requirement

Computation of the Peak Water Requirement of a Single Crop, PWRS

By computing the optimal irrigation interval, INT, the readily available moisture for a particular plant in the root zone (RASM) and the peak water requirement for a particular crop, PWRS, can be computed as:

$$PWRS = \frac{RASM}{INT} \qquad (7\text{-}5)$$

Time of Peak Water Use of a Single Crop

The time of peak water use of a crop, PWUT, does not occur at the same time each year; it varies within certain dates as PWUT is a function of actual evapotranspiration. By probability analysis, the data of occurrence of PWUT can be determined within a certain range of a probability interval.

Probability Distribution Analysis of PWUT

By choosing a base date, sometime around seeding time or any other time, the time lag of maximum actual evapotranspiration of each crop of a farm can be individually computed for several years. By computing plotting position and defining the related mathematical probability distribution as discussed for PET the date of occurrence of peak actual evapotranspiration for each single crop or PWUT can be determined within a certain range of probability interval, such as shown in Fig. 7-4.

Peak Water Requirement of a Multicrop Farm, PWRF

By having the PWRS and PWUT during a growing season, within a certain range of probability interval, the peak water requirement of a multicrop farm, PWRF, can be estimated as follows:

1. Plot PWRS.A against two or three peak months during the growing season, where A is area under a particular crop.
2. Sum the individual PWRS.A/E's by date and plot, or

$$PWRF = \left(\sum_{1}^{n} PWRS.A/E\right)_t \qquad (7\text{-}6)$$

where n is number of available crops on the farm, t is time and E is irrigation application efficiency.

3. Choose the maximum PWRF as peak water requirement of the multicrop farm for a certain date.

The plot in Fig. 7-5 shows maximum PWRF versus time with a 50% probability level.

Features of Farm Service Reservoirs

Duration of Retention Time of Farm Service Reservoir

The farm service reservoir, FSR, was defined and several possible structures and the computation of the capacity of an FSR were discussed in Chapter 5. The duration of retention, the time which water must be retained in the FSR, is an important element in the computation of capacity of the FSR and the entire irrigation distribution subsystem. The

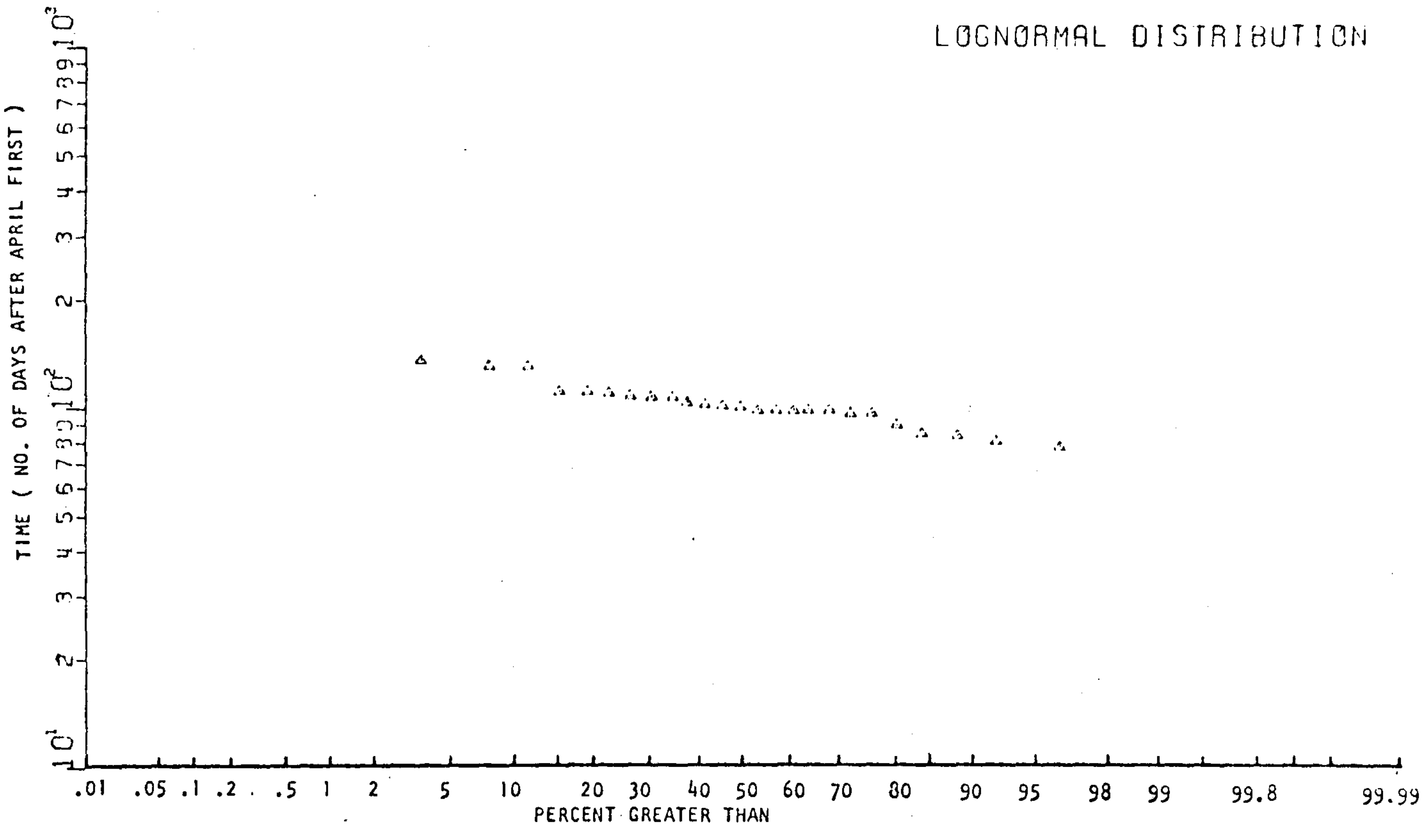


Fig. 7-4.--Probability distribution of time of occurrence of maximum actual ET

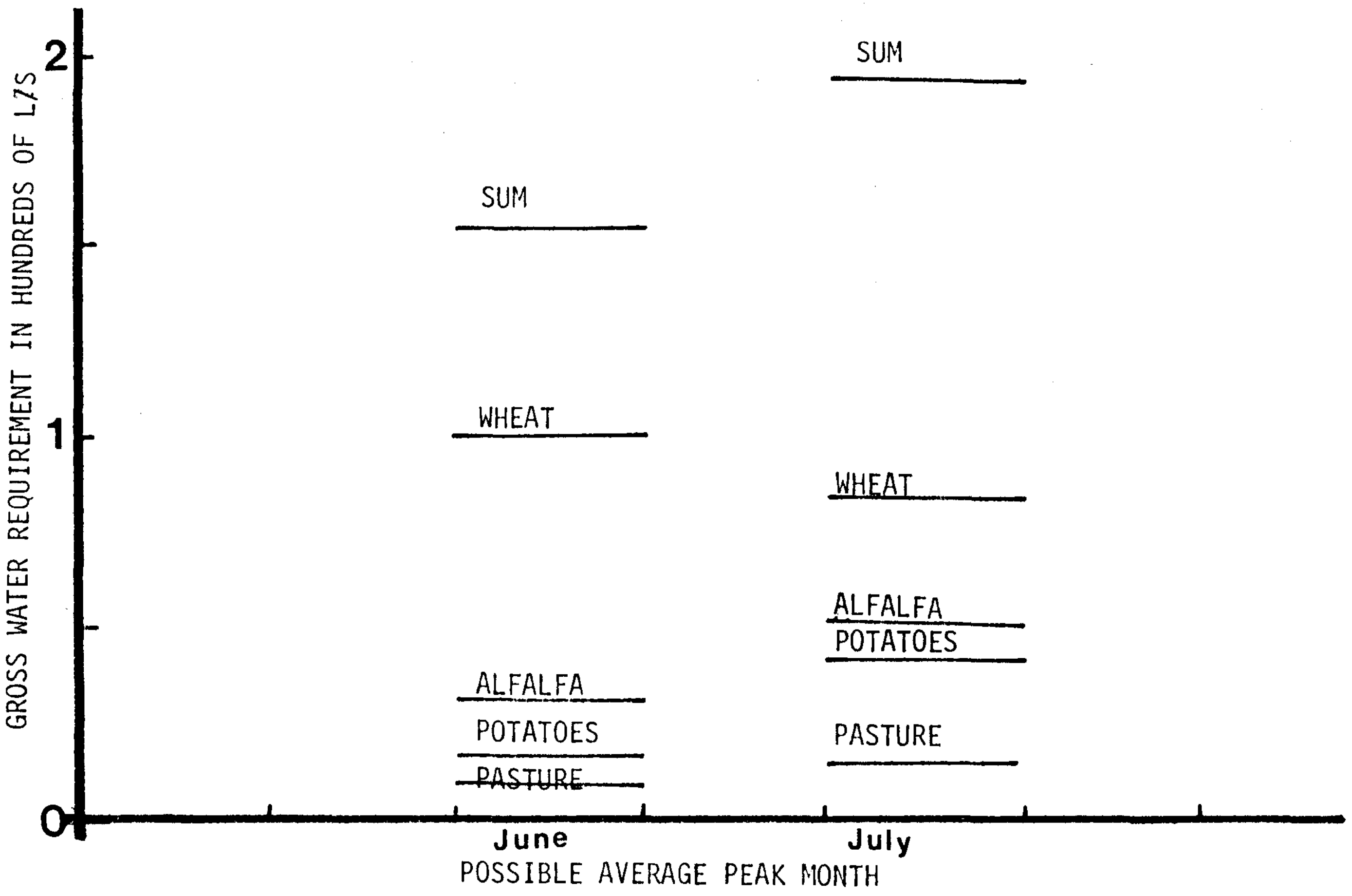


Fig. 7-5.--Peak water requirement of a multicrop farm

retention duration, in general, is a function of the frequency of inflow and outflow and managerial and technical feasibilities. The duration of retention can be from a few hours to several months. Decisions about the length of duration retention time require careful studies about the nature of inflow to a farm, practices of the irrigator, managerial skills and practices, economic and socialfactors, and institutional and technical feasibilities (Chapters 5 and 6).

Type and Structure of Farm Service Reservoir

After determining the capacity of each FSR for different farms and the volume of water that must be provided for each farm during the irrigation season, there are several alternative types of FSR's that should be considered for each farm. It may also be feasible to build a FSR for each farm or several farms may share one FSR. The capacity of an irrigation distribution subsystem is a function of the optimum decision about FSR's.

Site Selection for a Farm Service Reservoir

In each farm, one or several sites may be considered for construction of one or several FSR's to irrigate different crops. At each site several alternative structures are possible, and each should be considered according to engineering, financial, economical, and social feasibilities. For engineering feasibility, the geometry of the site, availability of construction materials, and technology; for social feasibility, the acceptance by people and their culture and institutions; for financial and economical feasibilities, a discounting technique (Chapter 6) should be considered and used. Finally, one of the best structures should be selected for each proposed site. It is also possible by using mathematical programming techniques to determine the most feasible size and location of farm service reservoirs (Chapter 3).

Optimization of Farm Service Reservoir Location and Size

Optimization of Several FSR's in an Irrigation Project

After determining the best FSR or FSR's for each site, an irrigation project or subarea may have several FSR's in different sites with different costs and benefits. An optimization procedure is necessary to increase the volume of the least cost FSR's and decrease the volume of high cost FSR's or optimize the greater system for least cost or maximum net benefit according to a set of given constraints from physical, financial, and managerial viewpoints. A linear programming model will be used as a tool for optimization of the least cost of supplied water with a chain of FSR's.

Simple Model of FSR's and Farms

For more clarification, the drawing in Fig. 7-6 shows four FSR's, RA, RB, RC, and RD with four farms, one downstream of each of them, labeled as FA, FB, FC, and FD. FSR RA can

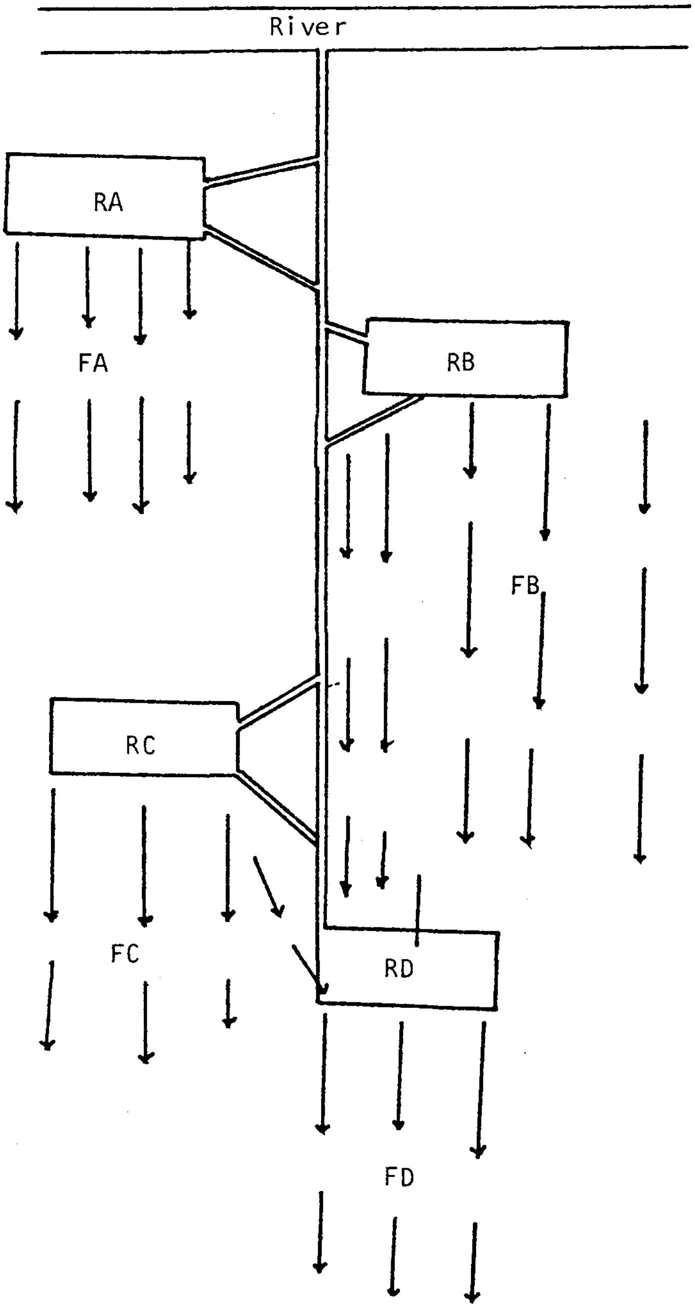


Fig. 7-6.--Irrigation system with chain farm service reservoir

irrigate FA and may store water instead of FSR's RB, RC, and RD for downstream use. This stored water may be transferred to FB, FC, and FD on demand at some additional cost for transport when needed. An alternative is to store water in FSR's RB, RC, and RD and allow FSR RA to store only the volume of water necessary for FA. FSR RB can store irrigation water for FB and may or may not store water for FC and FD. Continuing, FSR RD may or may not store water only for FD. Additionally, FSR RC may collect runoff and drainage water from FA, and FSR RD may collect runoff and drainage water from FC and FB and mix it with some inflow and reuse it for irrigation of FD. Thus Fig. 7-6 also shows a scheme of hypothetical management constraints which may vary according to different management decisions.

Optimization of Linear Programming Model of Chain FSR's

The purpose of optimization of the model is to determine the least cost irrigation system with chain FSR's within an irrigation project or along a lateral. It must be determined where water should be stored and transferred by a regular or some extra cost, based on the distribution of demand. After determination of the capacity of each FSR and the volume of water which must be transferred from one FSR to another farm or another FSR at some extra cost. The design capacity of each section of canal in the network can thus be determined. This design capacity may be based on continuous or rotation of water inflow.

Inflow Water to Each FSR

Possible sources of inflow for each farm service reservoir, FSR, may be:

1. River diversion or wells.
2. Transferred water from another FSR.
3. Runoff from upstream irrigated land.
4. Drainage and seepage water from surrounding land.
5. Rainfall and other sources of available water.

Outflow Water from Each FSR

The possible outflow from each FSR can be accounted as follows:

1. Gross irrigation water requirement of projected irrigable land.
2. Gross irrigation water requirement of other projected lands in which FSR's are eliminated during optimization of the model.
3. Management water requirement.
4. Evaporation and seepage from FSR's.

Factors affecting inflow and outflow from an FSR are shown in Fig. 7-7.

Decision Variables of Linear Programming Model

The decision variables in the linear programming model, which must be optimized for the least cost supplied water in an irrigation district or lateral, are

1. The volume of water which must be stored in each FSR for a given duration, RA, RB . . . .

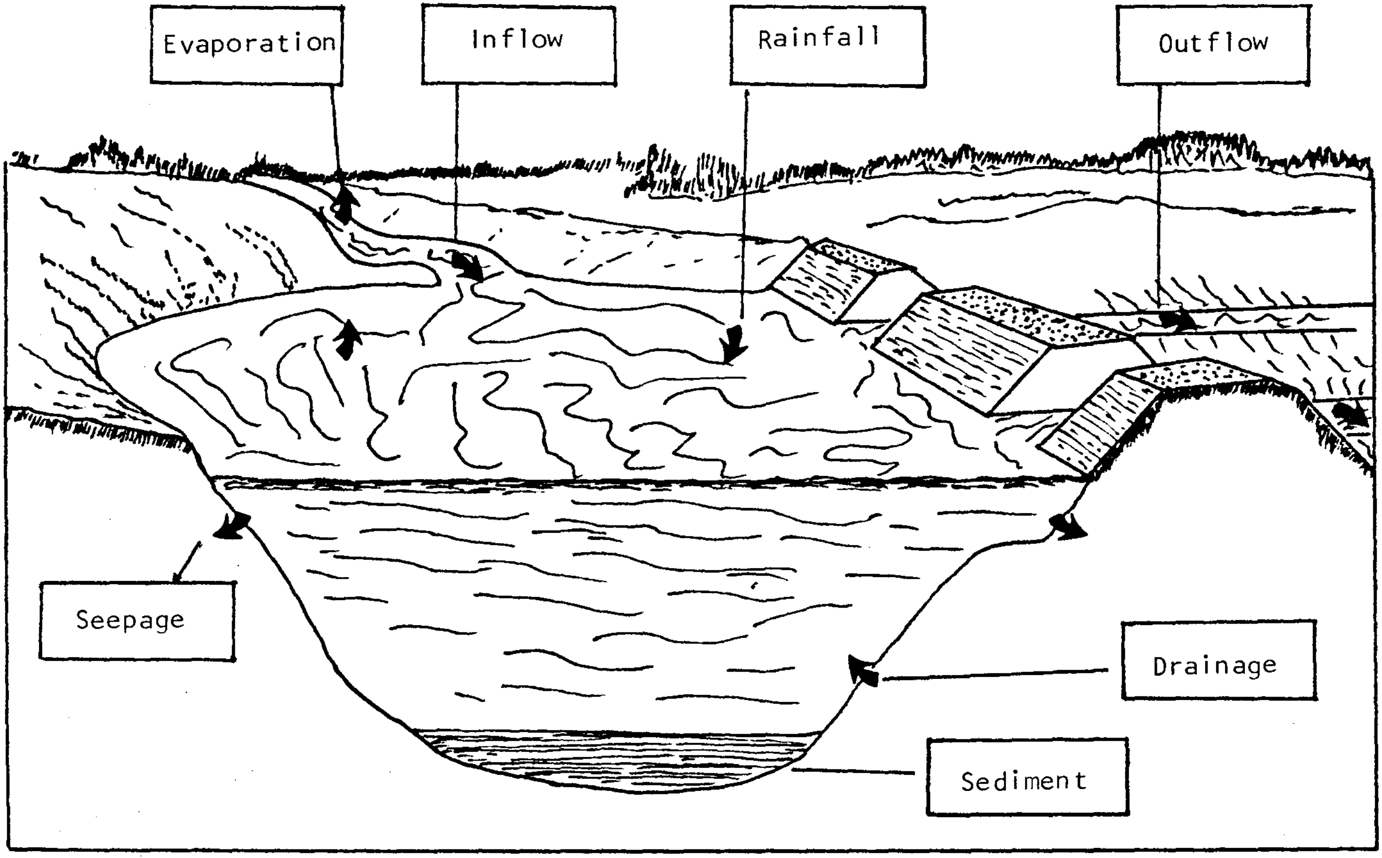


Fig. 7-7.--Factors affecting inflow, outflow, and capacity of a farm service reservoir

2. The volume of water which must be transferred from a FSR to a nearby farm in which the FSR is not justified during the optimization process, TAB, TBC, . . .

3. Runoff water from upstream farm(s) (if available), ROB, ROC, . . .

4. Drainage and seepage water from upstream or surrounding land (if available), DRCD, . . .

Objective Function of Linear Programming Model

The objective of this linear programming model is to minimize the cost of supplied water, Z, and to determine the volume of water which must be stored and transferred from different sources. The cost of each decision variable is shown as follows:

1. Cost of RA, RB, . . . per unit volume of output water, CSi, which includes structural, operation, maintenance, and replacement (OMR) costs.

2. Cost of TAB, TBC, . . . per unit volume of output water, CTi, which is the costs for channel enlargement and controlling subsystems to carry water to irrigated land as fast as possible so that water is available on demand.

3. Cost of runoff water, ROC, ROD, . . . from upstream land, CRi. This cost may be zero or minimal for collection minus some related benefits of runoff collection.

4. Cost of DRCD . . . drainage and seepage water collection, CDi. This cost depends on the physical features of the surrounding land, the cost of pumping operation, if necessary, minus some related benefits if applicable.

Finally, the objective function of linear programming model can be written as:

$$\text{Minimize } (Z) = \sum_{i=1}^{n} (CSi \cdot (RA + RB, + \ldots) + CTi \cdot (TAB + TBC + \ldots) + CRi \cdot (ROC + ROD + \ldots) + CDi \cdot (DRCD + \ldots) \qquad (7\text{-}7)$$

Constraints of the Linear Programming Model

In the hypothetical scheme of Fig. 7-6, two constraints are that water must flow downstream in an open canal subsystem and that each upstream FSR can only serve a downstream water requirement. The constraints can be relaxed for transporting water in the upstream direction if the cost of pumping water from a downstream FSR to an upstream FSR is to be considered.

According to the above assumed constraint, the constraint equations of FRS RA and RB of this very simplified model are as follows:

$$Q_A\text{min} \leqslant RA \quad \text{(volume of water in FSR A)} \leqslant Q_A\text{max} \qquad (7\text{-}8)$$

$$Q_B\text{min} \leqslant RB \quad \text{(volume of water in FSR B)}$$

$$+ \; TAB \quad \text{(volume of transported water from FSR A)}$$

+ ROB (volume of incoming runoff)

- TBC (volume of transported water to

other FSR) $\leqslant Q_B\text{max}$ (7-9)

$Q_A$min is the minimum amount of water to be stored in FSR RA and is required only for FA; $Q_B$min is the minimum amount of water to be stored in FSR RB from various sources such as river flow runoff, and drainage water that are required only for FB. $Q_A$max is the maximum volume of water from various sources which can be stored in FSR RA for the entire downstream demand, and $Q_B$max is the maximum stored in FSR RB for the entire downstream demand of FSR RB and so on.

Final Coefficient or Resource Matrix

By considering Fig. 7-6 and the imposed constraints and interrelationships of different decision variables, the coefficient or resource matrix of the linear programming model can be written as Table 7-1.

Design Capacity of Each Canal Section of Irrigation Distribution Subsystem (Network)

After optimizing the linear programming model and determining the total volume of each farm service reservoir, the design capacity of each canal section can be determined

Table 7-1.--Coefficient or resource matrix of linear programming

RA	RB	RC	RD	TAB	TBC	TCD	ROC	DRCD	DRBD		
1	1	1	1							$\geqslant$	$Q_A\max$
1				-1			-1			$\geqslant$	$Q_A\min$
	1			1	-1				-1	$\geqslant$	$Q_B\min$
		1			1	-1	1	-1		$\geqslant$	$Q_C\min$
			1			1		1	1	$\leqslant$	$Q_D\min$
							1			=	$Q_R AC$
							1			=	QR_{CD}
									1	=	QR_{BD}
CS_1	CS_2	CS_3	CS_4	CT_1	CT_2	CT_3	CR_1	CR_2	CR_3	=	Z

on a mix of continuous and rotation base. The design capacity of canal is a function of the maximum rate of allocation which in turn may be some function of some institutional and legal factors.

Design capacity, DQ, of each canal segment can be computed as:

$$DQ = \frac{\text{capacity of FSR}}{DT} \qquad (7\text{-}10)$$

where DT is duration of available inflow to the FSR, on rotation base. On continuous base the continuity equation must be satisfied for inflow and outflow during the retention time (Chapter 5).

The design capacity, ADQ, to transfer water from one FSR to other farms (if necessary) which do not have an FSR can be written as:

$$ADQ = \frac{\text{volume of transfer water}}{IR} \qquad (7\text{-}11)$$

where IR is irrigating time. The sum of DQ and ADQ should be considered when both of the above conditions apply.

Alternative Types of Farm Service Reservoirs

Figure 7-8 shows an alternative for the same example of Fig. 7-6 by enlarging canals to store water without building several sets of FSR. The same type of linear programming model can be developed and optimized for the arrangement shown in Fig. 7-8 and the capacity of each section of canal can be computed.

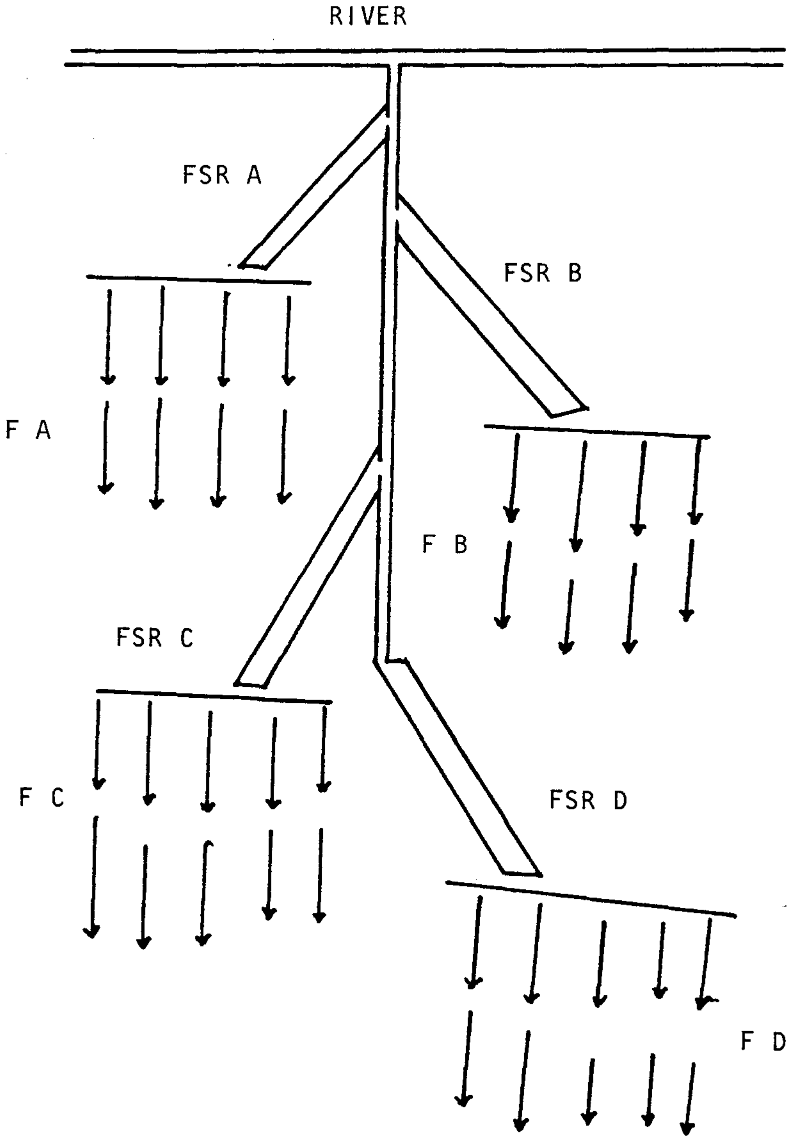


Fig. 7-8.--Irrigation system with enlarged canal as a chain farm service reservoir

CHAPTER 8

APPLICATION OF DEVELOPED MODEL

Introduction

The methodology developed and discussed in past chapters can be applied to planning new irrigation systems in a developing project or for planning rehabilitation of an existing irrigation system.

The methodology presented in this study has several different steps. Each step has a particular goal and purpose and can be used independently to plan or to evaluate discreet components of an irrigation system. The following steps should be considered in the application of the entire methodology.

1. Choose a study area within a definite geographic boundary.
2. Obtain maps of topography, soils, canal system(s) and farm ownership. Aerial photographs would also provide useful information if available.
3. Provide long-term climatological data to estimate evapotranspiration for different crops if actual evapotranspiration data are not available.
4. Provide soil, water, and crop information which is discussed in the crop production factor section of Chapter 7.
5. Provide cost data for proposed irrigation system components, farm service reservoirs, canal sections, application subsystems, and others as discussed in Chapter 6.

6. Provide data for the values of agricultural crops grown in the study area.
7. Follow the steps described in Chapter 7 (see Fig. 7-1).

Study Area

For purposes of applying this methodology, part of the Snake River Valley Irrigation District (SRVID) was chosen because of the following considerations:

1. The SRVID is being studied as a part of an ongoing project No. B-041-IDA of the Idaho Water Resources Research Institute conducted in the Agricultural Engineering Department at the University of Idaho entitled "Optimizing Project Systems for Distributing and Applying Irrigation Water." One objective of the project is to develop irrigation system rehabilitation plans and management criteria to improve irrigation system efficiency.
2. Necessary data have been collected or are available. These include topographic and soil maps, aerial photographs, long-term climatological data, and other required data.
3. The SRVID requires careful management to assure an adequate water supply during peak water use periods.

Background and Description of SRVID

The SRVID is located near the towns of Shelley and Firth, south of Idaho Falls in southeastern Idaho (Fig. 8-1). Irrigation of a small portion of the SRVID started in 1885. In 1896 the Cedar Point Canal was trebled in capacity and the water right decreed. From that time on, the area served was called the Snake River Valley Irrigation District (Carter, 1955).

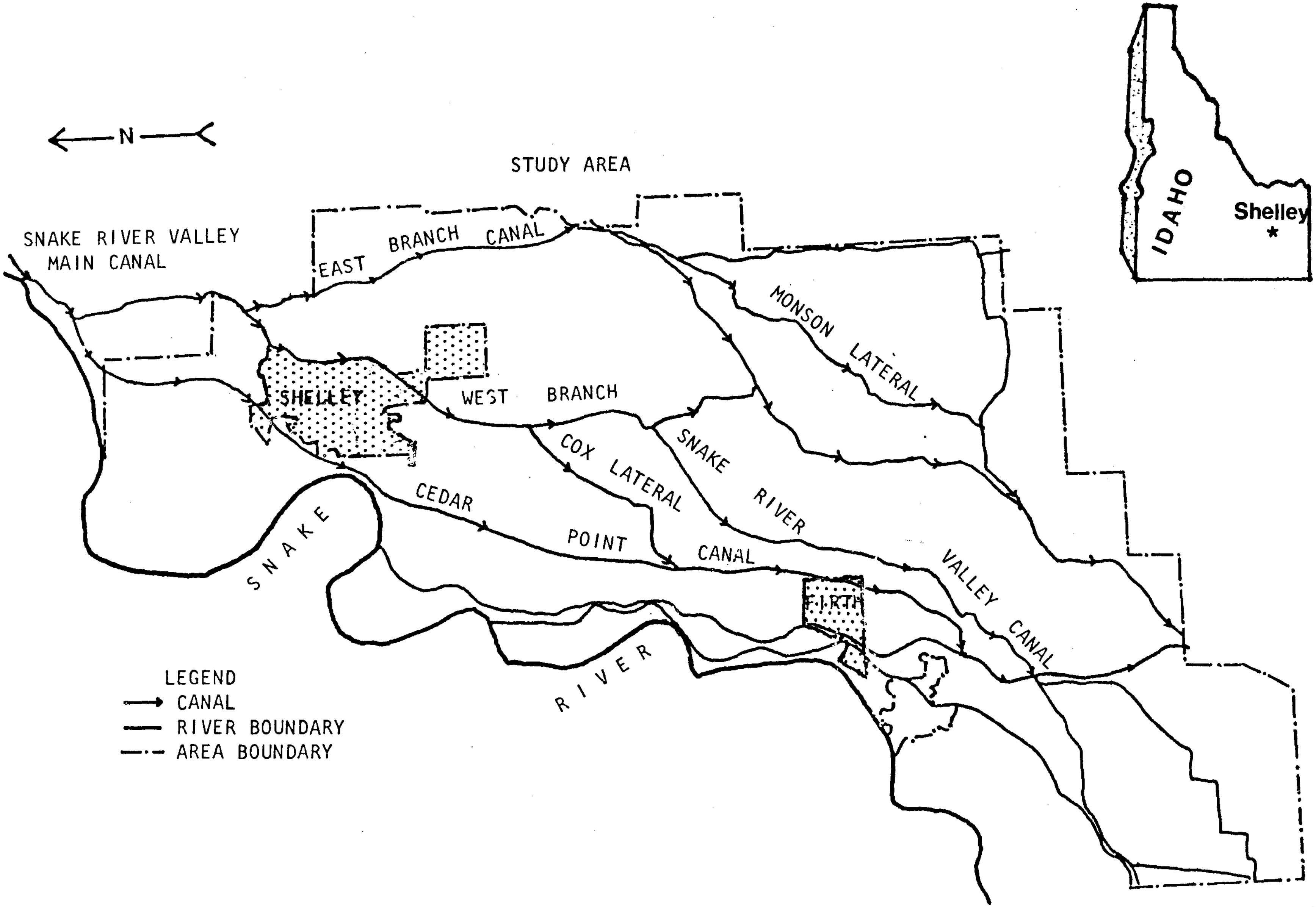


FIG (8-1) Canal Distribution System of Snake River Valley Irrigation District.

Today the Snake River Valley Irrigation District operates and maintains over 80 km of major canals. It supplies water to at least 6,950 ha of fertile land. The area served stretches nearly 32 km from the point where the main canal diverts water from the Snake River to the point where water distribution ends (Netz, 1980).

Major crops grown in the area are potatoes, alfalfa, wheat, and pasture. Major irrigation application subsystems are gravity (furrow and border) and sprinkler (hand-move and side-roll). Most pasture land is irrigated with border systems, and most of the other crops (alfalfa, wheat, potatoes) are irrigated using sprinkler systems.

The entire irrigation district is fed by the Snake River Valley Main Canal which is divided into the Cedar Point and the East and West branches. Each branch supplies part of the irrigation district. The SRVID canal distribution system is shown in Fig. 8-1. Major soil types in the study area are Bock and Bannak Series (USDA, SCS, 1973) with loam texture and good agricultural fertility.

In general climatological terms, Shelley has a desert climate with very low rainfall and high temperatures in the summer and low temperatures in the winter. Average annual rainfall for the past 25 years is 242 mm. The maximum average monthly rainfall of 34 mm occurs in June which is 14% of the annual average, and the minimum monthly average of 12 mm occurs in July which is 5% of the annual average. Mean annual maximum temperature and minimum temperatures are 13.89°C and -0.50°C. Mean maximum and minimum temperatures during the past 25 years occur in July and January, respectively, and are 30.33°C and -12.00°C. Average monthly rainfall and temperature patterns for Idaho Falls are shown in Figs. 8-2 and 8-3.

Length of growing season in Idaho Falls north of Shelley is 120 days. Killing frost season is September 19 to May 15 (USDA, 1941).

Area under Investigation

Approximately 1,865 ha of the SRVID were selected for application of the methodology. This portion of the SRVID is supplied by the Cedar Point Canal and the West Branch Snake River Valley Canal. The assigned area was divided into 24 farm units as shown in Fig. 8-4.

Application of the proposed methodology follows according to the flow chart in Chapter 7 (Fig. 7-1). The included steps in order are determining the mathematical probability distribution of potential and actual evapotranspiration, determining the most economical irrigation interval, optimizing the number and sizes of farm service reservoirs, and determining the design capacity of each channel section in the distribution system.

Crop Production Factors

Collected data and information for water, crops, and soil are discussed in this section.

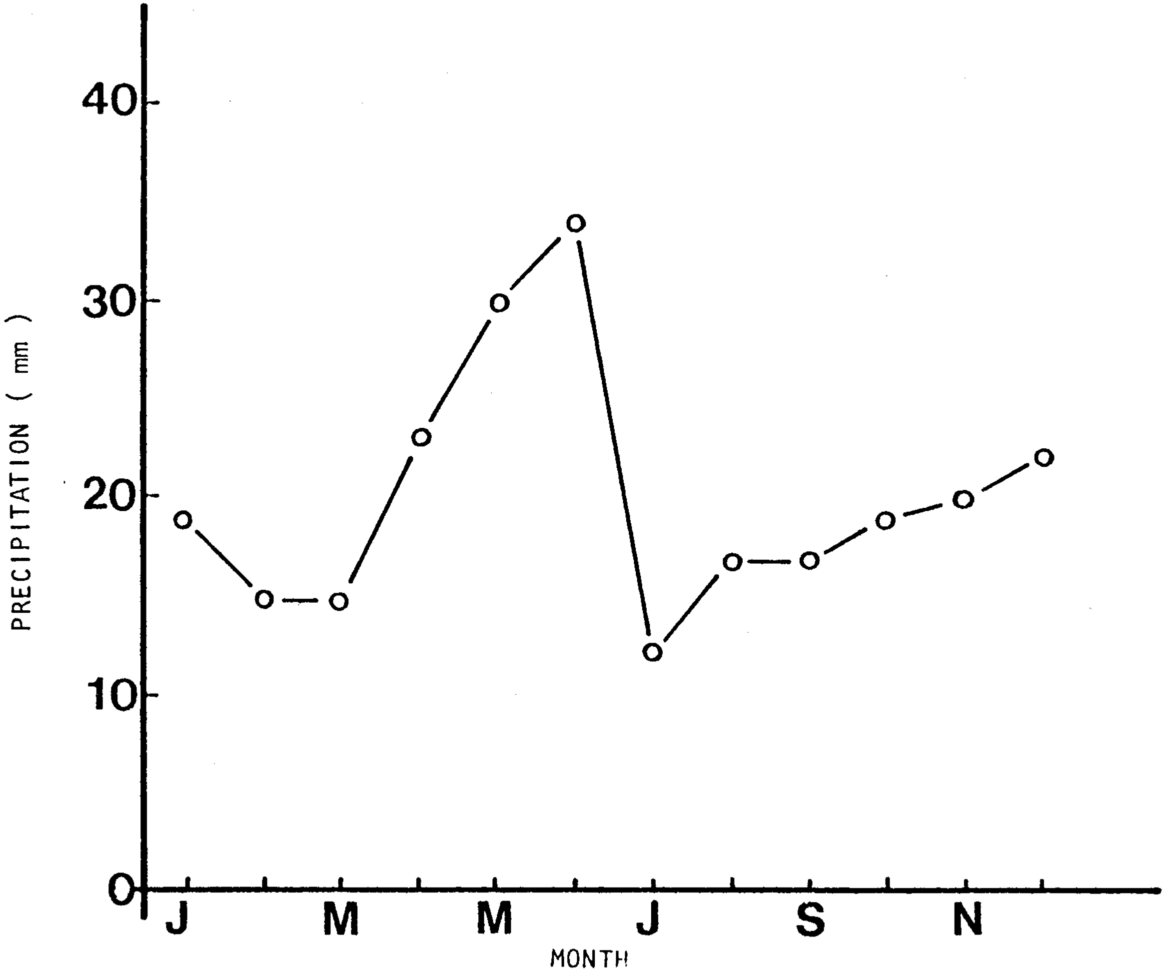


Fig. 8-2.--Mean monthly average of 25 years precipitation (1952-76) at Idaho Falls (U.S. Weather Service No. 10-4457)

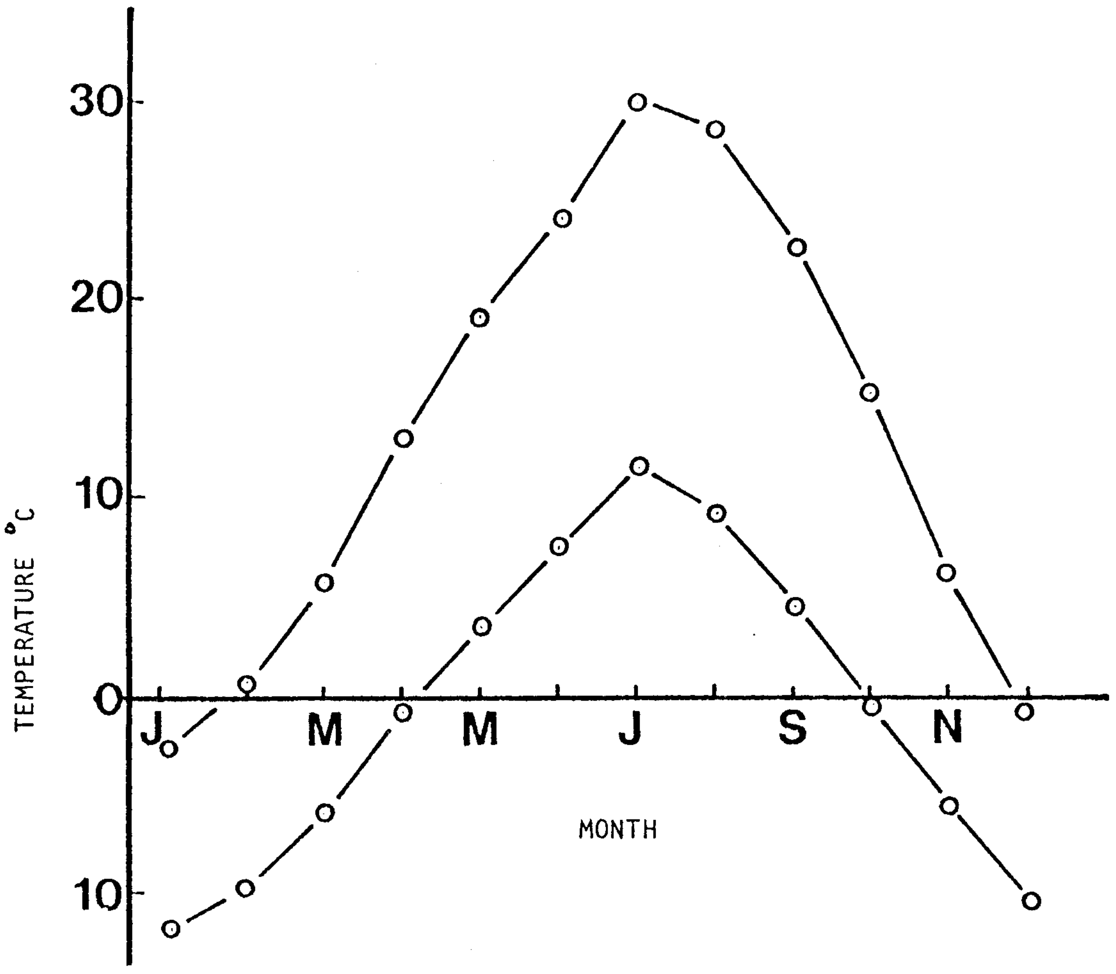


Fig. 8-3.--Average maximum and minimum temperature (1952-76) at Idaho Falls (U.S. Weather Service No. 10-4457)

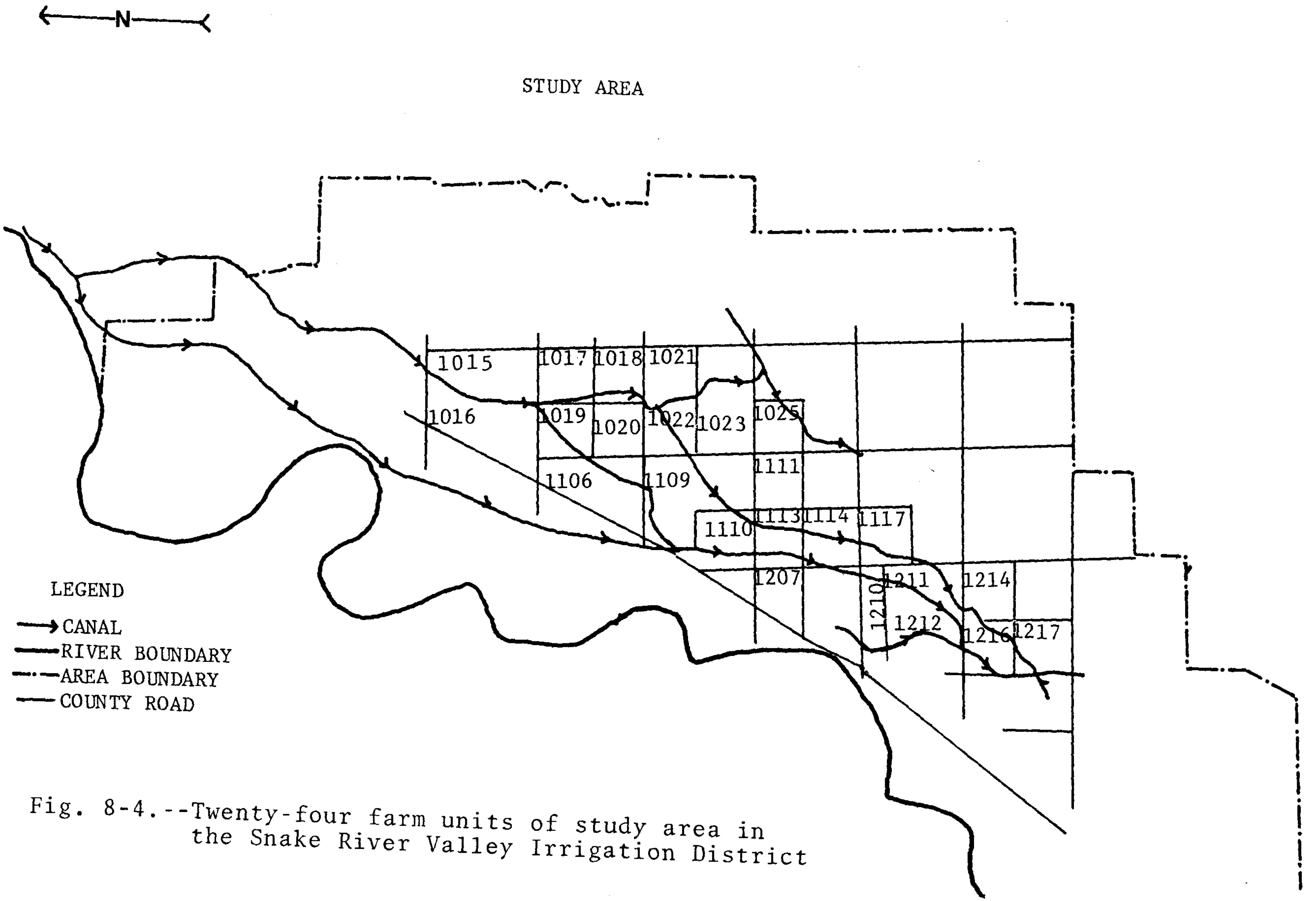


Fig. 8-4.--Twenty-four farm units of study area in the Snake River Valley Irrigation District

Water

The Snake River supplies water to the Snake River Valley Irrigation District by the Snake River Valley Main Canal. Diversion of water is shown in Fig. 8-5 (Idaho Water, 1978).

There is no complaint about the quality of water. According to the USDA (1977), from available data by Lewis (1959), and by discussion with local experts, the quality of water is excellent.

Soil

The SRVID is located on an alluvial fan. The upper layer of soil in the area is a loam of relatively shallow depth (76-152 cm) underlain by gravel and coarse sands. Permeability of the upper layer is moderate and that of the lower layer(s) is very high. According to a USDA-SCS (1973) Soil Survey, seven major soil series are found in the area: Ammon (Am), Bannock (Ba), Bock (Bo), Heiseton (Hs), Paesl (Pe), Stan (St), and Wolverine (WOF). Bock (Bo), and Bannock (Ba) are the predominate soils in the district as shown in Fig. 8-6. Soil series of each farm unit are given in Table 8-1. Brief descriptions of the soils are given in Appendix B.

Crop

Major crops grown in the study area are grain, 42.51%; potatoes, 28.18%; alfalfa hay, 23.81%; and pasture, 5.5%. The

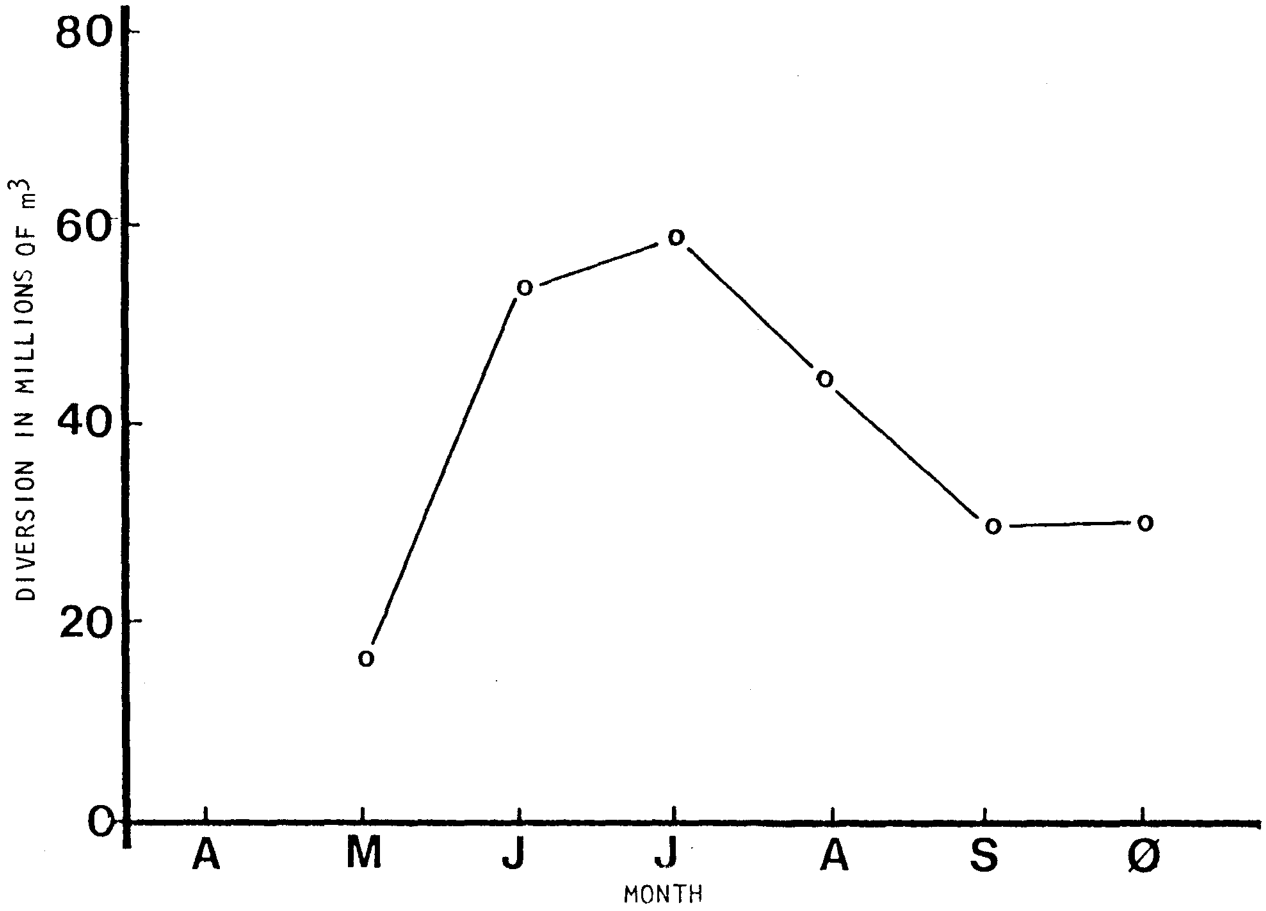


Fig. 8-5.--Monthly diversion to Snake River Valley Irrigation District

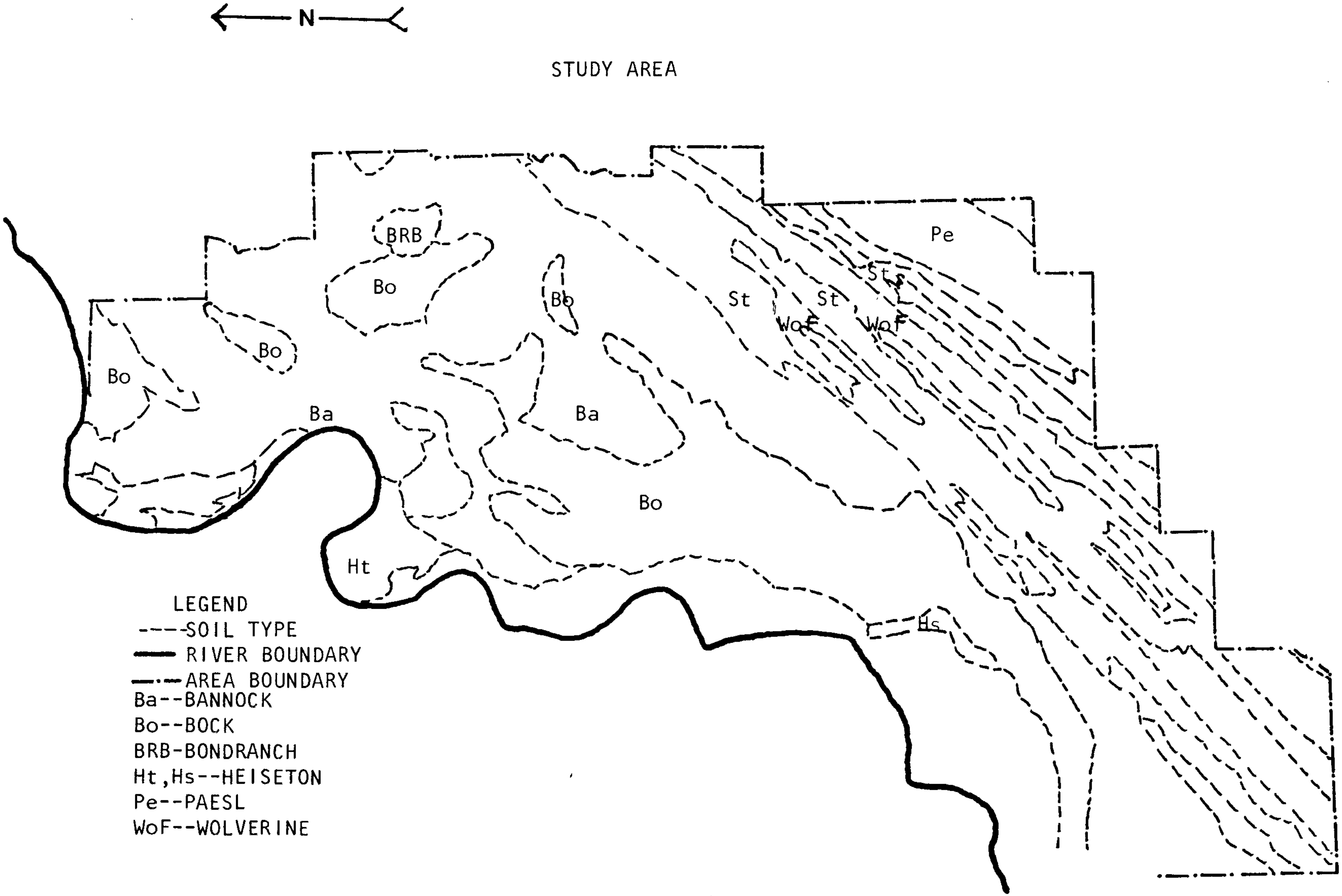


Fig. 8-6.--Soil type distribution within the Snake River Valley Irrigation District

Table 8-1.--Distribution of soil series within farm units in the study area

Farm unit No.	Soil series					Comment
	Bannock ha	Bock ha	Heiston ha	Stan ha	Wolverine ha	
1015	38.11	49.70	0	0	0	
1016	55.20	48.81	0	0	0	
1017	62.58	2.17	0	0	0	
1018	42.35	22.40	0	0	0	
1019	64.75	0	0	0	0	
1020	6475	0	0	0	0	
1021	56.82	4.69	0	0	0	
1022	26.18	42.61	0	0	0	
1023	98.51	8.29	0	0	0	
1025	65.16	0	0	0	0	
1106	26.72	79.31	0	0	0	
1109	19.69	159.18	0	0	0	
1110	0	70.42	0	0	0	
1111	41.76	22.99	0	0	0	
1113	0	64.75	0	0	0	
1114	14.66	50.09	0	0	0	
1117	16.39	48.36	0	0	0	
1207	0	42.57	14.90	0	0	
1211	14.26	51.70	0	0	0	
1210	6.89	39.51	19.16	0	0	
1212	7.60	53.10	0	0	0	
1214	20.14	0	53.26	19.47	25.15	
1216	16.22	44.72	0	3.81	0	
1217	15.65	0	0	46.36	2.74	
Total	774.39	905.39	87.32	69.64	27.89	1864.63
%	41.53	48.56	4.68	3.73	1.5	100.00

cropping pattern for each farm unit is shown in Table 8-2. Other required parameters of crops are given in Table 8-3.

Crop coefficients to estimate actual evapotranspiration from potential evapotranspiration were obtained from Wright (1979). Table 8-4 contains the 25-year average monthly actual evapotranspiration and the distribution of water requirements for each crop during growing season.

Irrigation Application Subsystem

For this study, no changes were assumed in the existing irrigation application systems. It was assumed that in the near future, farmers would not change their irrigation application systems. Under present conditions, 44.78% of the farms are irrigated by hand-move sprinklers, 16.30% by side-roll sprinklers, and 38.92% by gravity systems (border, 34.52% and furrow, 4.40%). There are no center pivot systems in the study area. Data in Table 8-5 show the distribution of different irrigation application systems for each farm unit under present conditions.

Irrigation Water Requirement

Potential Evapotranspiration in the Study Area

Because long-term data for potential or actual evapotranspiration were not available for the study area, daily potential evapotranspiration was estimated using 25 years record of climatological data. The Jensen-Haise Equation

Table 8-2.--Cropping patterns of different farm units in the study area

Farm unit No.	Crop				Comments
	Potatoes ha	Grain ha	Alfalfa ha	Pasture ha	
1015	24.09	40.28	13.70	0	
1016	13.76	38.47	25.97	3.34	
1017	0	45.30	7.50	5.04	
1018	9.01	40.55	6.37	2.71	
1019	15.99	37.48	2.26	0	
1020	31.33	31.36	0	0	
1021	0	33.75	15.88	5.81	
1022	0	26.45	23.61	11.08	
1023	46.61	44.22	22.68	5.69	
1025	0	28.13	18.99	2.41	
1106	20.26	33.91	40.80	0	
1109	73.78	52.38	24.81	0	
1110	47.32	4.99	8.86	0	
1111	25.47	30.09	6.77	0	
1113	7.21	39.09	9.80	1.13	
1114	29.86	16.62	8.56	1.75	
1117	12.30	32.90	9.02	1.76	
1207	15.24	25.29	0	3.47	
1211	33.60	2.10	17.72	1.15	
1210	0	3.80	26.13	16.60	
1212	7.74	18.05	25.10	4.53	
1214	15.41	15.22	31.08	0	
1216	16.47	1.66	19.29	13.54	
1217	0	37.53	15.73	7.98	
Total	450.43	679.64	380.62	87.93	1598.72
%	28.18	42.51	23.81	5.5	100.00

Table 8-3.--Assumed root depth and management allowed moisture deficit of different crops in the study area

Crop	Moisture extraction depth (mm)	Management allowed deficit, MAD (%)
Alfalfa	1219.2	55
Wheat	762.0	50
Pasture	762.0	55
Potatoes	762.0	35

Table 8-4.--Average monthly potential evapotranspiration (PET), crop coefficient (CF), and actual evapotranspiration (AET) for pasture, potatoes, wheat, and alfalfa in the study area

Month	Average 26 yr PET (mm)	Pasture			Potatoes			Wheat			Alfalfa		
		CF	AET (mm)	%	CF	AET (mm)	%	CF	AET (mm)	%	CF	AET (mm)	%
Jan	.35	0	0.00	0.00	.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	1.93	0	0.00	0.00	.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	10.69	0	0.00	0.00	.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apr	29.05	1	29.05	3.65	.10	2.91	0.59	0.90	26.15	7.12	0.80	23.24	2.95
May	81.88	1	81.88	10.28	.10	8.19	1.65	1.00	81.88	22.29	1.02	83.52	10.59
Jun	136.80	1	136.80	17.17	.50	68.40	13.80	1.02	139.54	37.97	1.02	139.54	17.70
Jul	239.69	1	239.69	38.08	.80	191.75	98.70	0.50	119.85	32.62	1.02	244.48	31.01
Aug	188.22	1	188.22	23.62	.80	150.59	30.39	0.00	0.00	0.00	1.02	191.98	24.35
Sep	92.10	1	92.10	11.55	.80	73.68	14.87	0.00	0.00	0.00	1.02	93.94	11.92
Oct	29.07	1	29.07	3.65	.00	0.00	0.00	0.00	0.00	0.00	0.40	11.63	1.48
Nov	5.34	0	0.00	0.00	.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec	.56	0	0.00	0.00	.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	815.46	-	795.81	100.00	-	495.52	100.00	-	367.48	100.00	-	788.33	100.00

Table 8-5.--Distribution of irrigation application subsystems within farm units in the study area

Farm unit No.	Irrigation application subsystem				Comments
	Border ha	Furrow ha	Hand-move sprinkler ha	Side-roll sprinkler ha	
1015	7.78	0	75.26	0	
1016	21.66	4.00	34.45	21.42	
1017	28.86	0	28.99	0	
1018	14.63	0	39.01	0	
1019	2.26	0	37.48	15.99	
1020	0	0	0	62.70	
1021	29.09	0	0	26.35	
1022	61.15	0	0	0	
1023	11.65	0	5.34	102.22	
1025	49.54	0	0	0	
1106	0	0	94.99	0	
1109	24.81	0	126.18	0	
1110	0	0	61.18	0	
1111	15.37	15.01	0	31.94	
1113	13.12	7.21	36.90	0	
1114	10.31	0	46.47	0	
1117	43.69	12.30	0	0	
1207	14.48	0	29.53	0	
1211	20.98	0	33.60	0	
1210	46.54	0	0	0	
1212	40.32	0	15.10	0	
1214	46.30	15.41	0	0	
1216	34.49	16.47	0	0	
1217	9.75	0	51.44	0	
Total	551.76	70.40	715.92	260.63	1598.70
%	34.52	4.40	44.78	16.30	100.00

(Jensen and Haise, 1963) was used to estimate daily potential evapotranspiration. This equation is a well known method widely used in the western region of the United States for estimating crop water use.

Nature of Data for Estimation of Daily Potential Evapotranspiration

Daily potential evapotranspiration was estimated for 25 years from climatological data which were provided by the following weather stations. Daily maximum and minimum temperature and rainfall data for 25 years (1-1-1952 to 1-1-1976) were obtained from Idaho Falls FAA Station Index No. 4457 records. Rainfall and temperature data were read from the HISARS data storage system which is available at the University of Idaho Computer Center (Molnau, 1975).

Hourly solar radiation data for 25 years (1-1-1952 to 1-1-1976) were obtained from the Pocatello WSU AP Station Index No. 7211 records. Solar radiation data were read from the SOLMET data storage which is available at the University of Idaho Computer Center (USDC, 1978).

It was assumed that the study area climatological pattern follows these two nearby climatological stations for daily temperature, rainfall, and solar radiation.

Mathematical Probability Distribution of Potential Evapotranspiration

The mathematical probability distribution of potential evapotranspiration (PET) was computed and plotted as described in Chapter 7. The available data were found to best fit a log-normal probability distribution. The plot in Fig. 8-7 shows the mathematical distribution of PET for different durations. It was assumed that the actual evapotranspiration of pasture was equal to the PET during the growing season.

Actual Evapotranspiration of Different Crops

Daily actual evapotranspiration for four major crops, grain (wheat), hay (alfalfa), potatoes, and pasture were computed for 25 years (1952-1976) as:

$$AET = CF \cdot PET \qquad (8\text{-}1)$$

where

AET = actual evapotranspiration

CF = crop factor

PET = potential evapotranspiration after rainfall

Daily crop factors, CF, were computed by linear interpolation from the data presented by Wright (1978). Maximum accumulated actual evapotranspiration for 1-30 days duration and seasonal were computed for 25 years.

Mathematical Probability Distribution of Actual Evapotranspiration

Maximum accumulated actual evapotranspiration, AAET, was ranked and the plotting position computed by the Weibull (1939) equation and plotted on different probability papers.

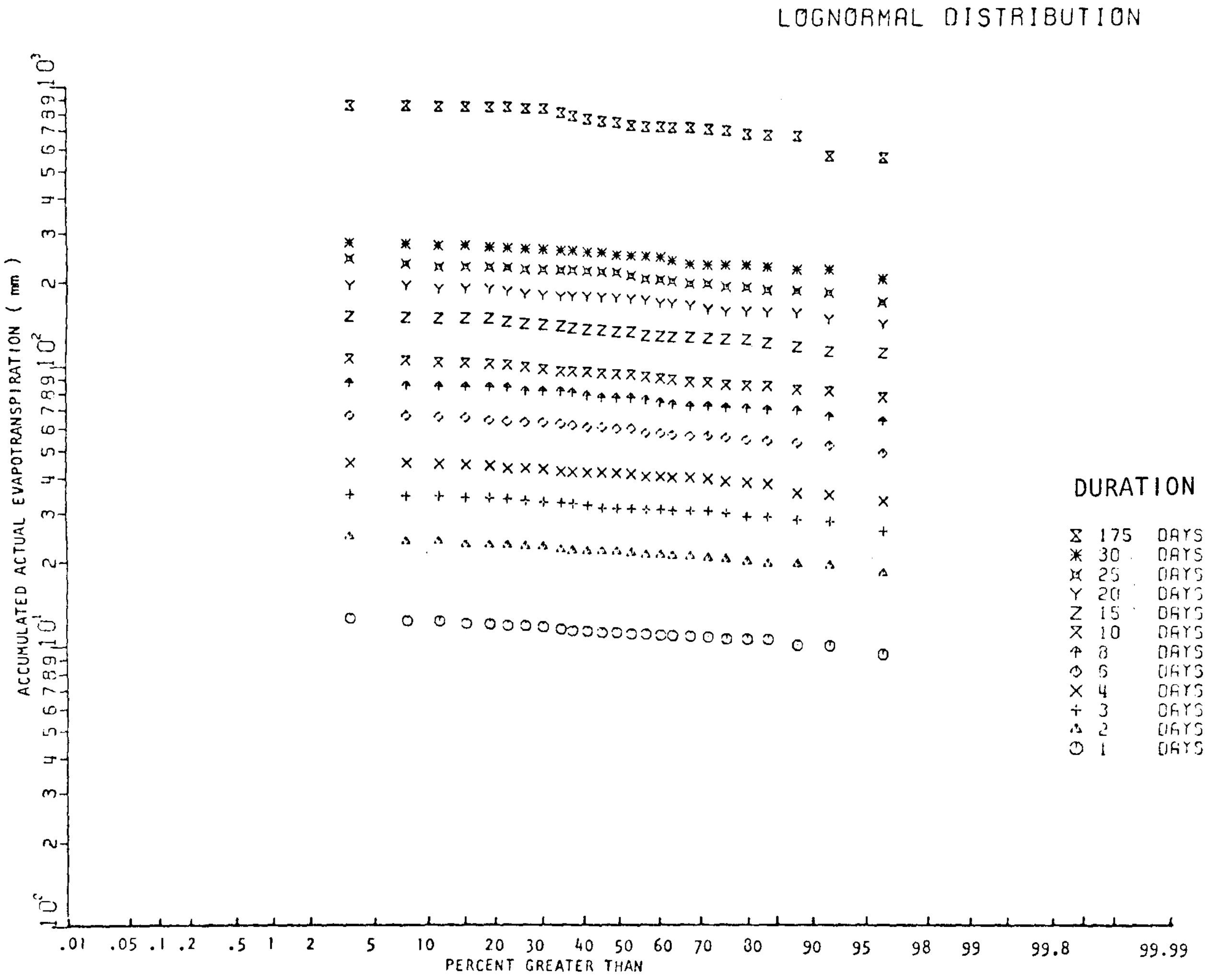


Fig. 8-7.--Log-normal probability distribution of actual ET of pasture for different durations in the study area

By visual inspection and conducting the Kolmogorov-Smirnow test (Haan, 1977) at the 10% significance level, a log-normal distribution was found as the best fit for the data. It was found that the AAET of pasture, wheat, potatoes, and alfalfa best follows a log-normal distribution within the required range (1-99%). Plotting positions of logarithm of AAET of different crops are shown in Figs. 8-7 through 8-10.

Mathematical Equations of AAET

For a log-normal probability distribution, the mathematical probability equation can be written as:

$$Y = Z \cdot S + M \tag{8-2}$$

where

Y = log (AAET)

Z = normal standard deviation

S = standard deviation of the logarithm of AAET

M = mean of log (AAET)

By using 25 years of data S and M for 1 to 30 days duration and seasonal AAET for wheat, alfalfa, potatoes, and pasture were computed and are given in Tables 8-6 through 8-9. Because the crop factor for pasture was assumed equal to 1, then AAET of pasture equals the accumulated PET during the growing season.

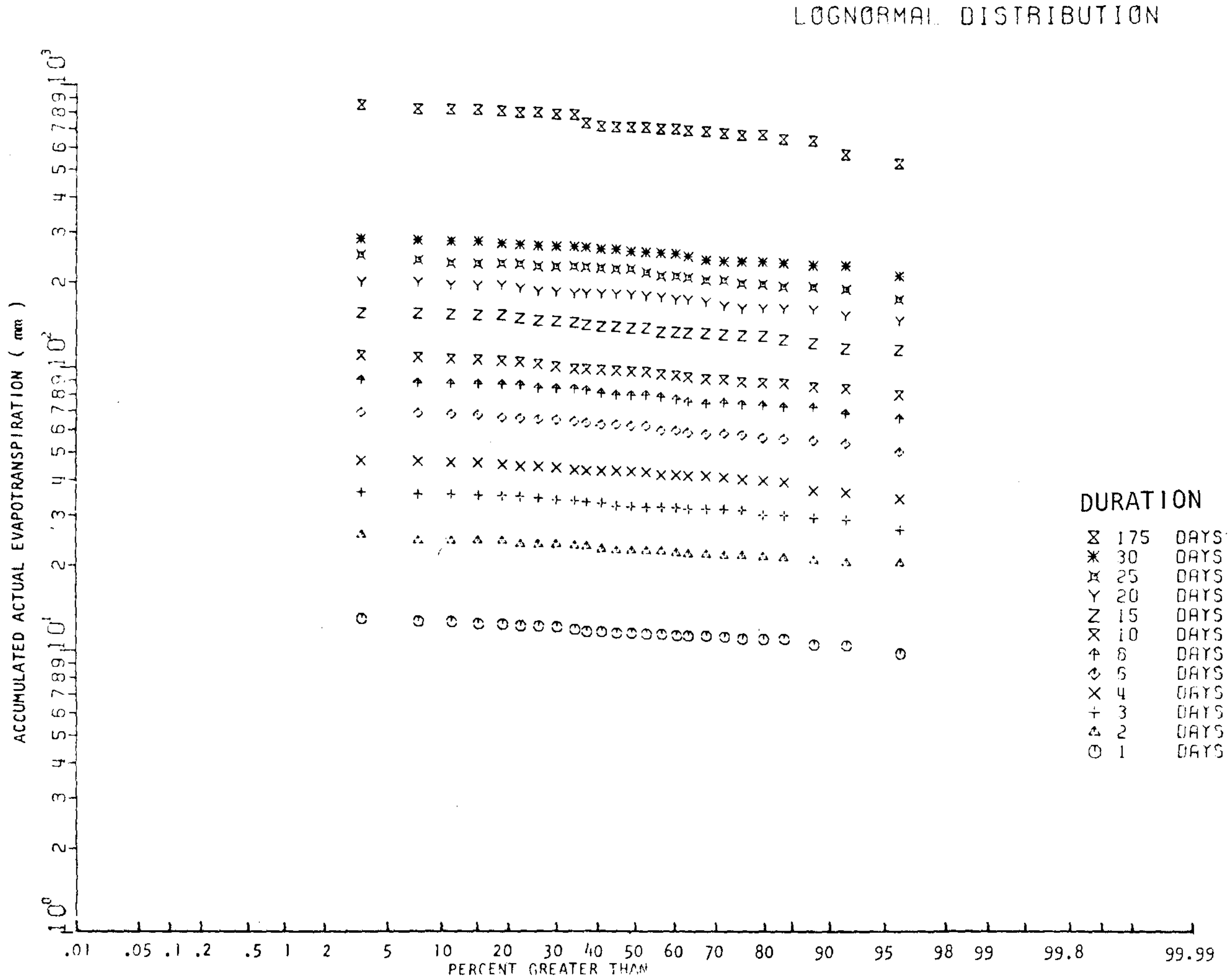


Fig. 8-8.--Log-normal probability distribution of actual ET of alfalfa for different durations in the study area

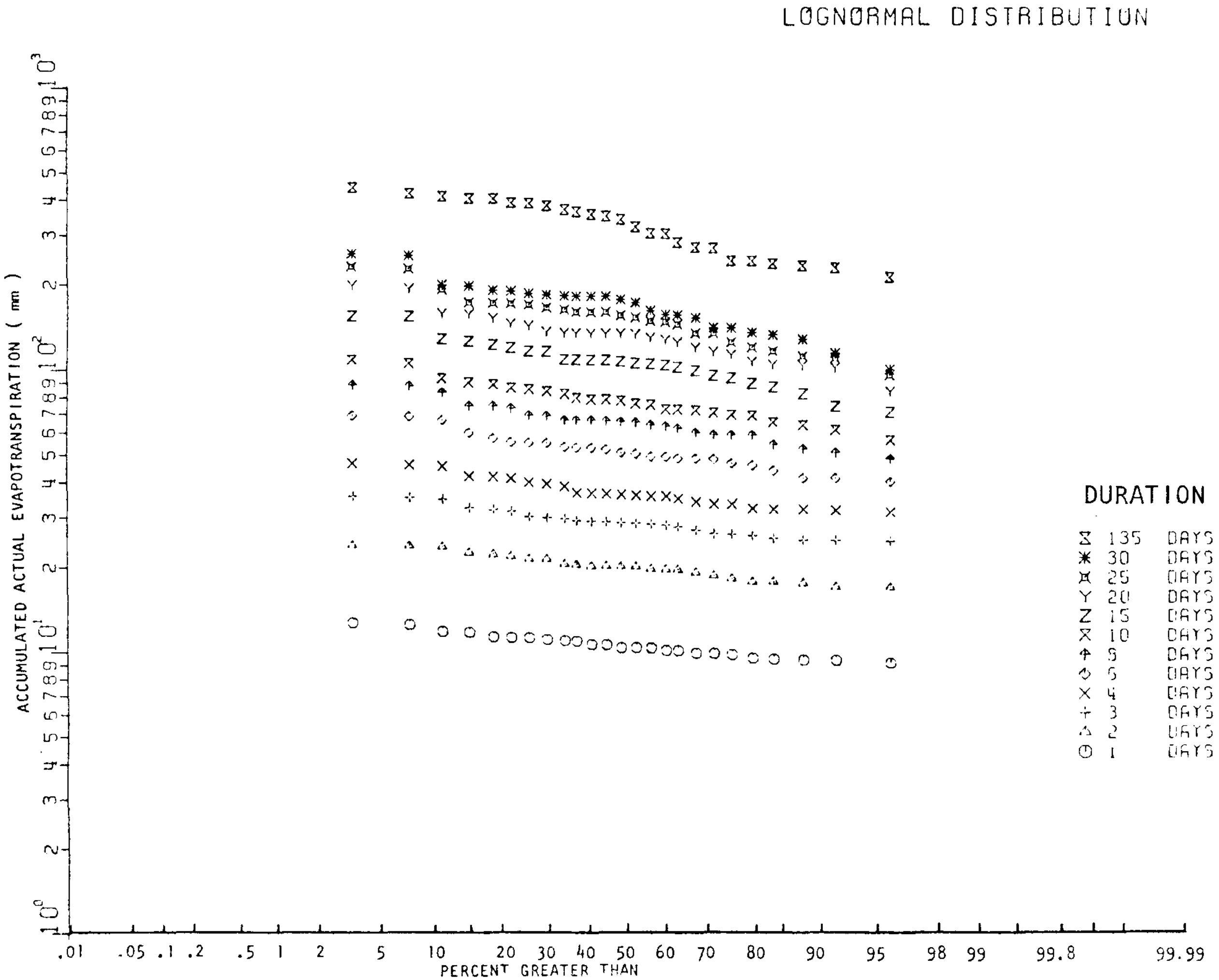


Fig. 8-9.--Log-normal probability distribution of actual ET of wheat for different durations in the study area

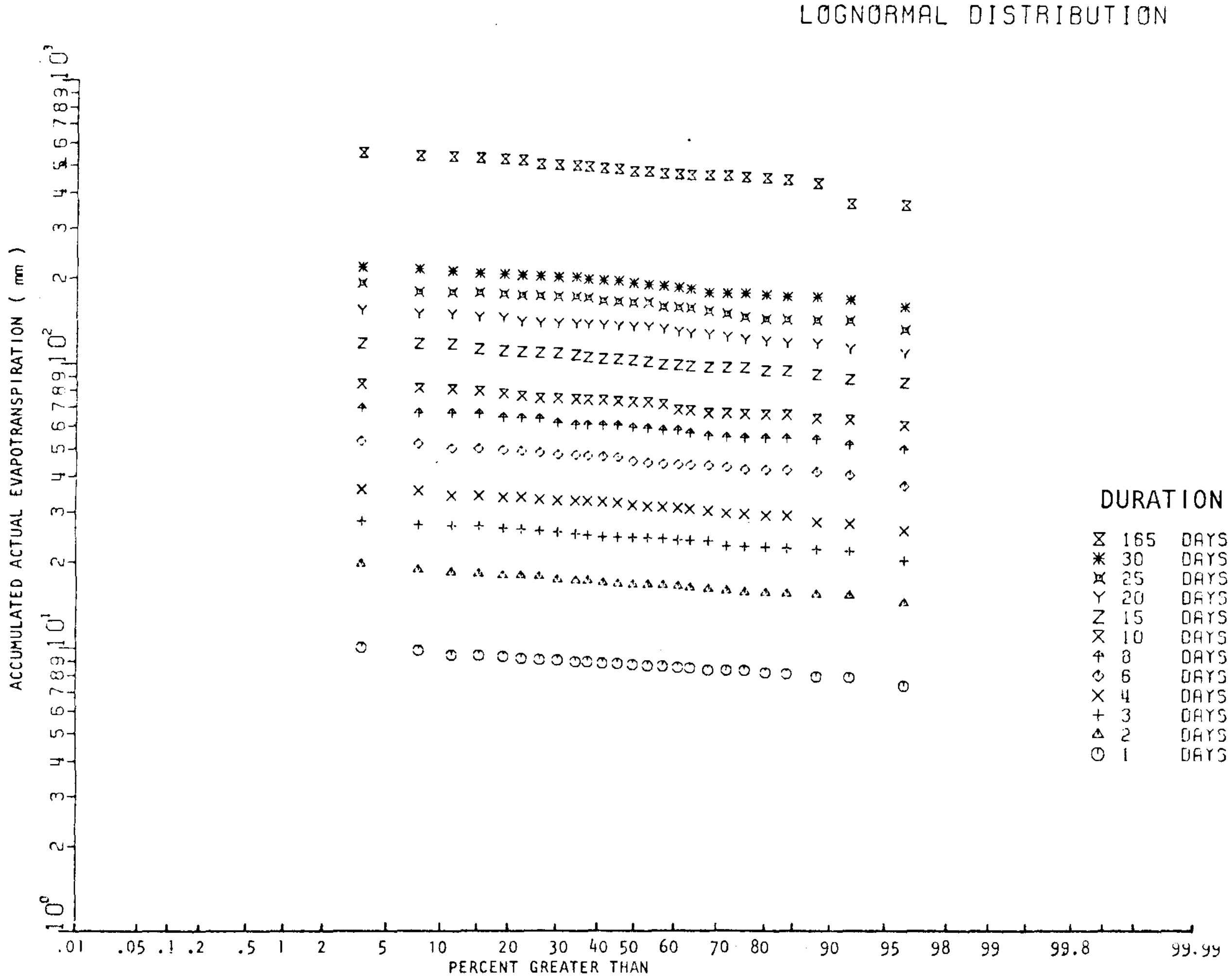


Fig. 8-10.--Log-normal probability distribution of actual ET of potatoes for different durations in the study area

Table 8-6.--Mean, standard deviation, and coefficient of variation of logarithm of actual ET (mm) of alfalfa for 1-30 days and seasonal duration in the study area

No.	Duration	Mean	Standard deviation	Coefficient of variation
1	1	1.062	0.03065	0.02886637
2	2	1.353	0.02757	0.02037209
3	3	1.508	0.03342	0.02216171
4	4	1.621	0.03550	0.02189489
5	5	1.711	0.03602	0.02105173
6	6	1.784	0.03744	0.02098463
7	7	1.845	0.03825	0.02073284
8	8	1.896	0.03788	0.01997813
9	9	1.939	0.03736	0.01926550
10	10	1.977	0.03822	0.01932866
11	11	2.015	0.03828	0.01899923
12	12	2.049	0.03929	0.01917714
13	13	2.079	0.03892	0.01871885
14	14	2.107	0.03902	0.01852176
15	15	2.133	0.03858	0.01808250
16	16	2.158	0.03725	0.01726079
17	17	2.182	0.03839	0.01759932
18	18	2.204	0.04018	0.01823498
19	19	2.225	0.03908	0.01756291
20	20	2.243	0.03837	0.01710374
21	21	2.261	0.03736	0.01652164
22	22	2.279	0.03623	0.01589772
23	23	2.297	0.03673	0.01599405
24	24	2.313	0.03853	0.01666130
25	25	2.329	0.03917	0.01682189
26	26	2.343	0.03903	0.01665407
27	27	2.359	0.03829	0.01623073
28	28	2.374	0.03698	0.01557882
29	29	2.388	0.03606	0.01510235
30	30	2.402	0.03529	0.01469552
31	175[a]	2.850	0.05271	0.01849542

[a] Seasonal duration is assumed to be 175 days.

Table 8-7.--Mean, standard deviation, and coefficient of variation of logarithm of actual ET (mm) of wheat for 1-30 days and seasonal duration in the study area

No.	Duration	Mean	Standard deviation	Coefficient of variation
1	1	1.019	0.03985	0.03909260
2	2	1.299	0.04447	0.03423779
3	3	1.456	0.04822	0.03311088
4	4	1.563	0.05275	0.03374158
5	5	1.645	0.05733	0.03484922
6	6	1.708	0.06395	0.03745131
7	7	1.761	0.06820	0.03872906
8	8	1.809	0.06788	0.03751737
9	9	1.850	0.06710	0.03626470
10	10	1.884	0.06901	0.03662888
11	11	1.916	0.07115	0.03712874
12	12	1.946	0.07440	0.03823470
13	13	1.973	0.07941	0.04025393
14	14	1.997	0.08376	0.04193775
15	15	2.020	0.08343	0.04131168
16	16	2.039	0.08425	0.04132073
17	17	2.059	0.08425	0.04091578
18	18	2.078	0.08431	0.04056882
19	19	2.095	0.08422	0.04019178
20	20	2.111	0.08512	0.04031823
21	21	2.125	0.08588	0.04041836
22	22	2.138	0.08681	0.04060019
23	23	2.150	0.08935	0.04156489
24	24	2.161	0.09143	0.04231357
25	25	2.172	0.09317	0.04288930
26	26	2.182	0.09366	0.04292807
27	27	2.192	0.09320	0.04252064
28	28	2.201	0.09346	0.04247051
29	29	2.208	0.09443	0.04275985
30	30	2.216	0.09605	0.04334517
31	135[a]	2.498	0.09875	0.03953993

[a] Seasonal duration is assumed to be 135 days.

Table 8-9.--Mean, standard deviation, and coefficient of variation of logarithm of actual ET (mm) of pasture for 1-30 days and seasonal duration in the study area

No.	Duration	Mean	Standard deviation	Coefficient of variation
1	1	1.053	0.03065	0.02910357
2	2	1.337	0.03114	0.02329296
3	3	1.500	0.03343	0.02228904
4	4	1.613	0.03550	0.02201172
5	5	1.703	0.03602	0.02115780
6	6	1.776	0.03744	0.02108641
7	7	1.837	0.03825	0.02082933
8	8	1.887	0.03788	0.02006892
9	9	1.931	0.03736	0.01935156
10	10	1.969	0.03822	0.01941325
11	11	2.006	0.03828	0.01908050
12	12	2.040	0.03929	0.01925815
13	13	2.071	0.03892	0.01879636
14	14	2.098	0.03902	0.01859758
15	15	2.125	0.03858	0.01815533
16	16	2.149	0.03725	0.01732969
17	17	2.173	0.03839	0.01766886
18	18	2.195	0.04018	0.01830656
19	19	2.216	0.03908	0.01763118
20	20	2.235	0.03837	0.01716958
21	21	2.252	0.03736	0.01658472
22	22	2.270	0.03623	0.01595798
23	23	2.288	0.03673	0.01605423
24	24	2.304	0.03853	0.01672358
25	25	2.320	0.03917	0.01688420
26	26	2.335	0.03903	0.01671537
27	27	2.351	0.03829	0.01629012
28	28	2.365	0.03698	0.01563538
29	29	2.379	0.03606	0.01515694
30	30	2.393	0.03529	0.01474840
31	175[a]	2.871	0.05314	0.01850830

[a] Seasonal duration is assumed to be 175 days.

Reasily Available Soil Moisture, RASM

Readily available soil moisture (RASM) in the soil storage can be computed as:

$$RASM = RT \cdot ASM \cdot MAD \qquad (8\text{-}3)$$

where

RT = moisture extraction depth of a particular crop (mm)

ASM = available soil moisture (mm/mm)

MAD = management allowed deficit for a particular crop (%)

The ASM and MAD for different crops and soils from the study area are given in Tables 8-3 and 8-10.

Table 8-10.--Available soil moisture of different soil types in the study area

Soil type	Available soil moisture (mm/mm)
Bannock, Ba	.15
Bock, Bo	.17
Hayeston, Ha	.12
Heiston, Hs	.13
Paesl, Pe	.19
Stan and Wolverine, St	.14

Possible Irrigation Interval

The accumulated actual evapotranspiration, AAET, of a particular crop for a given duration is equal to the water requirement of a particular crop for that duration. This water requirement should be satisfied from soil storage during the same period. It is assumed that for a particular duration AAET is equal to the RASM for the same duration. It is assumed that when the AAET is equal to RASM then the duration of AAET can be taken as the irrigation interval during the peak water use period.

Probability of Each Irrigation Interval

By using Figs. 8-7 through 8-10 or Equation 8-2, Z can be computed for different durations. Only Z in the range of -3.9 to 3.9 is computed because Z out of these ranges does not have importance in the integration of normal density functions. For different durations or different irrigation intervals, several different values of Z were computed.

By having irrigation intervals and computing the corresponding Z values, the probability of occurrence, P, of each irrigation interval was computed by using an error function (Spiegel, 1968, 1975). In noncomputerized computation, P can be obtained from standard normal density tables of any statistics textbook. The following equation was used to compute probability of occurrence P of each irrigation interval.

Error function, $EF = \frac{2}{\sqrt{\pi}} (Z - \frac{Z^3}{3.1!} + \frac{Z^5}{5.2!} - \frac{Z^7}{7.3!} \cdots)$ (8-4)

$P = (1 + EF)/2$ (8-5)

Recurrence Interval and Level of Involved Risk of Irrigation Interval

The recurrence interval, T, was computed as

$$T = \frac{1}{P} \tag{8-6}$$

The level of involved risk, P, for the life of an irrigation application subsystem was computed as

$$R = \mathrm{Exp}(N \cdot \log (P)) \tag{8-7}$$

where

N = life of project in years

Irrigation interval, P, T, and R for different crops and soils are given in Appendix C.

Most Economical Irrigation Interval

Cost of Irrigation Application Systems

The annual average cost of irrigation application systems was computed by the methods described by Allen et al. (1978). Annual cost was computed for gravity (border and furrow) and sprinkler (side-roll and hand-move) systems for each soil in the study area. The required input to the program includes soil, crop and cost data, and the output generated design specifications and the annual cost of each irrigation application system. Computation of cost of an application system for a particular soil and crop was repeated several times for different amounts of applied water. Output costs for varying levels of water application are shown in Appendix D.

Cost of Pumping Irrigation Water to Sprinklers

Annual costs of pumping irrigation water to sprinkler irrigation application systems for different crops were computed using the pump cost estimating routine described by Allen et al. (1978). Annual pumping costs were computed according to average monthly actual evapotranspiration requirements for wheat, potatoes, alfalfa, and pasture. The average monthly actual evapotranspiration is given in Table 8-4 for different crops. The program estimates annual cost of the pumping and regresses the annual cost against the discharge. The resulting general regression equation is

$$AAPC = A + BQ \tag{8-8}$$

where

AAPC = annual cost of pumping

A,B = constant coefficients

Q = pump discharge (L/S)

The coefficients A and B for different crops are given in Table 8-11.

Table 8-11.--Annual pumping cost coefficient for different crops in the study area

Crop	A	B
Alfalfa	1051	.2145
Pasture	1054	.2145
Potatoes	1076	.2019
Wheat	987	.1703

Cost of Farm Service Reservoirs

Annual costs of FSR's were estimated by the routine listed in Appendix E. Input data consist of costs of excavation, soil transportation, and geometry of the site. Pertinent site input data are given in Table 8-13.

Output of the program consists of the volume of storage, depth, width, cross section area, and average annual

Table 8-12.--Pertinent input data to compute size and cost of farm service reservoirs

Farm service reservoir[a]	Length (m)	Base-depth (m)	Maximum depth (m)	Seepage coefficient (m/m^2-day)	Side slope (m/m)
RA	451.2	3	2.44	.399	1.2
RB	762.0	3	2.44	.399	1.2
RC	609.6	3	2.44	.391	1.2
RD	457.2	3	2.44	.399	1.2
RE	914.4	3	2.44	.399	1.2
RB1	365.8	3	1.83	.399	1.2
RB2	457.2	3	1.83	.399	1.2
RB3	640.1	3	1.83	1.140	1.2
RB4	731.5	3	1.52	1.140	1.2
RB5	365.8	3	1.52	1.140	1.2
RD1	365.8	3	2.13	.399	1.2
RD2	609.6	3	2.13	.399	1.2
RD3	365.8	3	2.44	.399	1.2
RD4	457.2	3	2.13	.399	1.2
RD5	914.4	3	2.13	.399	1.2

[a] Refers to farm service reservoirs in Figs. 8-19 and 8-20.

cost of the FSR. The program regresses average annual cost against the storage capacity of the FSR. The general equation is

$$ARC = A + B \cdot V \qquad (8\text{-}9)$$

where

ARC = average annual cost of FSR

A,B = constants

V = volume of farm service reservoir

Coefficients A and B for different proposed FSR's in the study area are given in Table 8-13.

Table 8-13.--Annual cost coefficients of farm service reservoirs

Farm service reservoir	A	B	Comments
RA	4224	58.9	$ARC = A + B \cdot V$
RB	4613	88.2	where
RC	4467	74.4	
RD	4224	58.9	ARC = annual farm service reservoir cost
RE	4074	114.6	
RB1	3433	49.0	A,B = constant coefficient
RB2	3780	55.7	
RB3	4439	58.0	V = volume of farm service reservoir (1,000 m^3)
RB4	4684	63.2	
RB5	2972	55.0	
RD1	3252	154.4	
RD2	4495	67.6	
RD3	3625	57.0	
RD4	3803	62.1	
RD5	4202	106.3	

Cost of Canal Rehabilitation

Average annual cost of canal rehabilitation or construction was estimated by a program described by Allen et al. (1978). In this study it was assumed that the existing canal can be rehabilitated. The rehabilitation of canals consisted of reshaping and resizing canal sections along existing routes. The required input data consisted of different cost and geometric data. Some of the geometric data is given in Table 8-14.

In this study, it was assumed FSR's would be included in the canal system by enlarging portions of an existing canal length. The costs of two lengths of canals were computed for each reach. A short length was estimated in conjunction with FSR in its reach. A long length was estimated in a case where no FSR was included. The program output gives design information for each reach and total and annual costs. The program regresses annual cost against the design capacity of a canal or:

$$ACC = A + B \cdot Q \tag{8-10}$$

where

ACC = annual cost of canal

A,B = constant

Q = discharge of canal

Constant coefficients A and B for different projected canal reaches are given in Table 8-15.

Table 8-14.--Pertinent input data to compute size and cost of canal sections

Canal section[a]	Length (m)	Bottom elevation at outlet (m)	Bottom elevation at inlet (m)	Required minimum outlet elevation (m)	Seepage coefficient (m/m-day)[b]
ABL	1763.0	1407.0	1408.8	1407.8	.399
ABS	999.7	1407.8	1408.9	1408.1	.399
BCL	972.0	1406.0	1407.0	1406.6	.399
BCS	362.4	1406.6	1407.0	1406.7	.399
CDL	794.9	1404.9	1406.0	1405.4	.399
CDS	337.7	1405.5	1406.0	1405.7	.399
DEL	176.8	1401.8	1404.9	1402.4	.399
DES	865.6	1403.4	1404.9	1403.6	.399
EEND	1249.7	1400.9	1401.8	1401.5	.399
BB1L	1058.9	1407.0	1407.6	1407.3	.399
BB1S	693.1	1407.2	1407.6	1407.4	.399
B1B2L	1071.7	1409.6	1407.0	1405.3	.399
B1B2S	614.5	1405.9	1407.0	1406.3	.399
B2END	1178.1	1401.0	1405.0	1401.3	.399
B3B4L	1696.2	1399.6	1400.6	1399.9	1.140
B3B4S	964.7	1400.0	1400.6	1400.3	1.140
B4B5L	856.2	1399.0	1399.6	1399.2	1.140
B4B5S	490.4	1399.3	1399.6	1399.3	1.140
B5END	2842.0	1396.0	1399.0	1396.6	1.400
DDiL	772.4	1404.7	1404.9	1404.8	.399
DD1S	406.6	1404.8	1404.9	1404.9	.399
D1D2L	1271.3	1404.4	1404.7	1404.4	.399
D1D2S	661.7	1404.5	1404.7	1404.5	.399
D2D3L	862.6	1402.1	1404.1	1402.1	.399
D2D3S	496.8	1403.3	1404.1	1403.3	.399
D3D4L	881.8	1401.0	1401.9	1401.0	.399
D2D4S	424.6	1401.5	1401.9	1401.5	.399
D4D5L	1799.2	1397.4	1400.7	1397.4	.399
D4D5S	884.8	1399.3	1400.7	1399.3	.399
D5END	1614.2	1395.4	1397.1	1395.1	.399

[a] Refers to canal sections in Figs. 8-19 and 8-20.

[b] Netz (1980).

Table 8-15.--Annual cost coefficients for canal reach rehabilitation

Canal[a] reach	A	B	Comments
ABL	3752	5.33	ACC = A + B · Q
ABS	2452	2.98	
BCL	1891	3.27	where
BCS	929	1.22	
CDL	1274	3.60	ACC = annual cost of canal reach
CDS	689	1.56	
DEL	3644	3.39	
DES	1477	2.90	A,B = constant coefficients
EEND	1766	7.93	
BB1L	972	6.01	
BB1S	944	6.01	Q = discharge (1,000 m^3/day)
B1B2L	1109	4.46	
B1B2S	811	2.46	
B2END	1103	3.39	
B3B4L	1239	16.51	
B3B4S	740	8.42	
B4B5L	1022	8.29	
B4B5S	789	4.90	
B5END	1473	27.02	
DD1L	511	10.43	
DD1S	375	5.48	
D1D2L	991	11.11	
D1D2S	608	5.80	
D2D3L	1022	3.31	
D2D3S	730	1.72	
D3D4L	1118	3.76	
D3D4S	692	1.80	
D4D5L	1727	6.66	
D4D5S	1009	3.11	
D5END	1451	11.41	

[a] Refers to Fig. 8-20.

Benefits from Irrigation (Crop Yield)

Direct benefits derived from irrigation are the crops produced. The relationship of crop yield and applied water was estimated by calculating a dimensionless crop yield function for each crop. In computing the dimensionless crop yield-water functions, data from different reference sources for each crop were used: wheat from Schneider (1969), potatoes from Linsley and Franzini (1964), and alfalfa from Bauder (1978). For pasture, a linear crop yield-water function was assumed.

Dimensionless crop yield water functions for wheat, potatoes, alfalfa, and pasture are shown in Fig. 8-11. Estimated dimensionless crop yield-water function equations for different crops are as follows:

$$\text{Pasture} \quad y = x \tag{8-11}$$

$$\text{Potatoes} \quad y = 39.67 + 1.337x - .007475x^2 \tag{8-12}$$

$$\text{Wheat} \quad y = -42.52 + 1.578x - .0016795x^2 \tag{8-13}$$

$$\text{Alfalfa} \quad y = -43.23 + 2.5 - .01254x^2 \tag{8-14}$$

where

y = dimensionless crop yield

x = dimensionless applied water

and

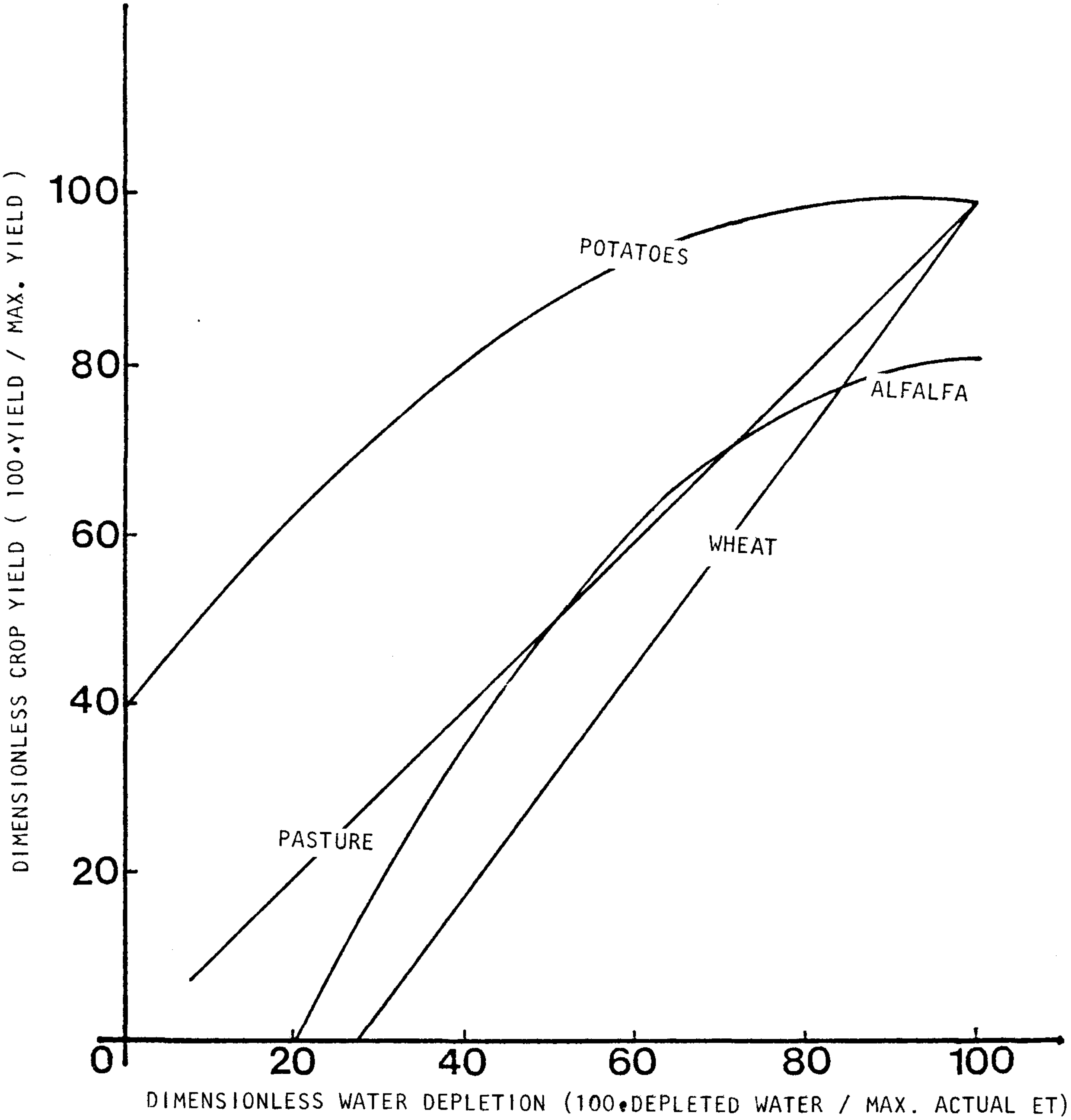


Fig. 8-11.--Dimensionless crop yield-water function of wheat, alfalfa, potatoes, and pasture

$$AY = Y \cdot Y_{max} \qquad (8\text{-}15)$$

where

AY = actual yield

Y_{max} = maximum yield

The total crop benefits for various levels of water application were determined by estimating the crop yield and combining with the unit price and level of involved risk or Equation 6-7. Estimated maximum yield data and unit prices for the study area are listed in Table 8-16.

Table 8-16.--Maximum crop yield and unit prices for the study area

Crop	Yield kg/ha	Price[a] $/kg
Wheat	2175	.1143
Potatoes	10192	.07638
Alfalfa	3628	.04082
Pasture	3175	.03628

[a] Farrell (1979).

Best Economical Irrigation Interval

The best irrigation interval for each crop-soil combination was computed by a marginal cost and marginal benefit analysis of each irrigation application subsystem. Annual benefits of irrigation for different crops and variety of soil were computed, and annual costs of irrigating different crops by different systems on different soils were calculated. Marginal benefits and marginal costs were then computed.

Optimal water depletion or actual evapotranspiration was determined by using a marginal cost and benefit analysis. By obtaining optimal actual evapotranspiration, the closest corresponding irrigation interval was selected as the most economical irrigation interval. The cost and benefit curves in Fig. 8-12 are for different irrigation application subsystems for wheat grown on Bannock soil. The plot in Fig. 8-13 shows the marginal cost and benefit analysis of each irrigation application subsystem for wheat crop. This procedure was repeated for pasture, alfalfa, potatoes, and wheat on all seven soil types of the study area with three types of irrigation application subsystems--gravity, hand-move sprinkler, and side-roll sprinkler.

Peak Water Requirement

Peak Water Requirements of a Single Crop, PWRS

Best economical irrigation interval for all combinations of crops and soil types were estimated. The peak water requirement of each crop was computed as:

$$\mathrm{PWRS} = \frac{\mathrm{RASM}}{\mathrm{INT}} \quad \text{or} \quad \frac{\mathrm{AAET}}{\mathrm{INT}} \qquad (8\text{-}16)$$

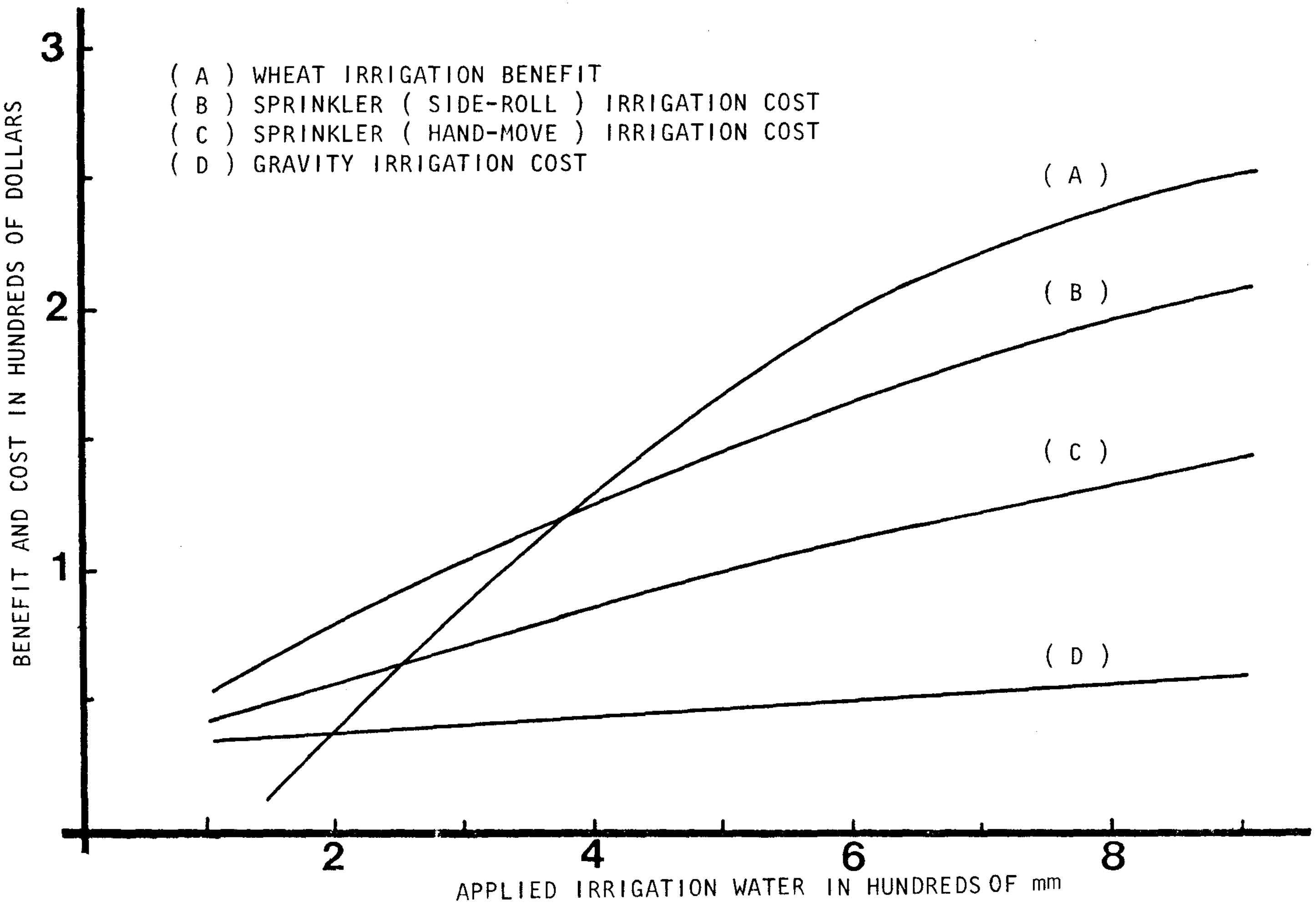


Fig. 8-12.--Cost and benefit of wheat irrigation on Bannock soil by different irrigation application subsystems

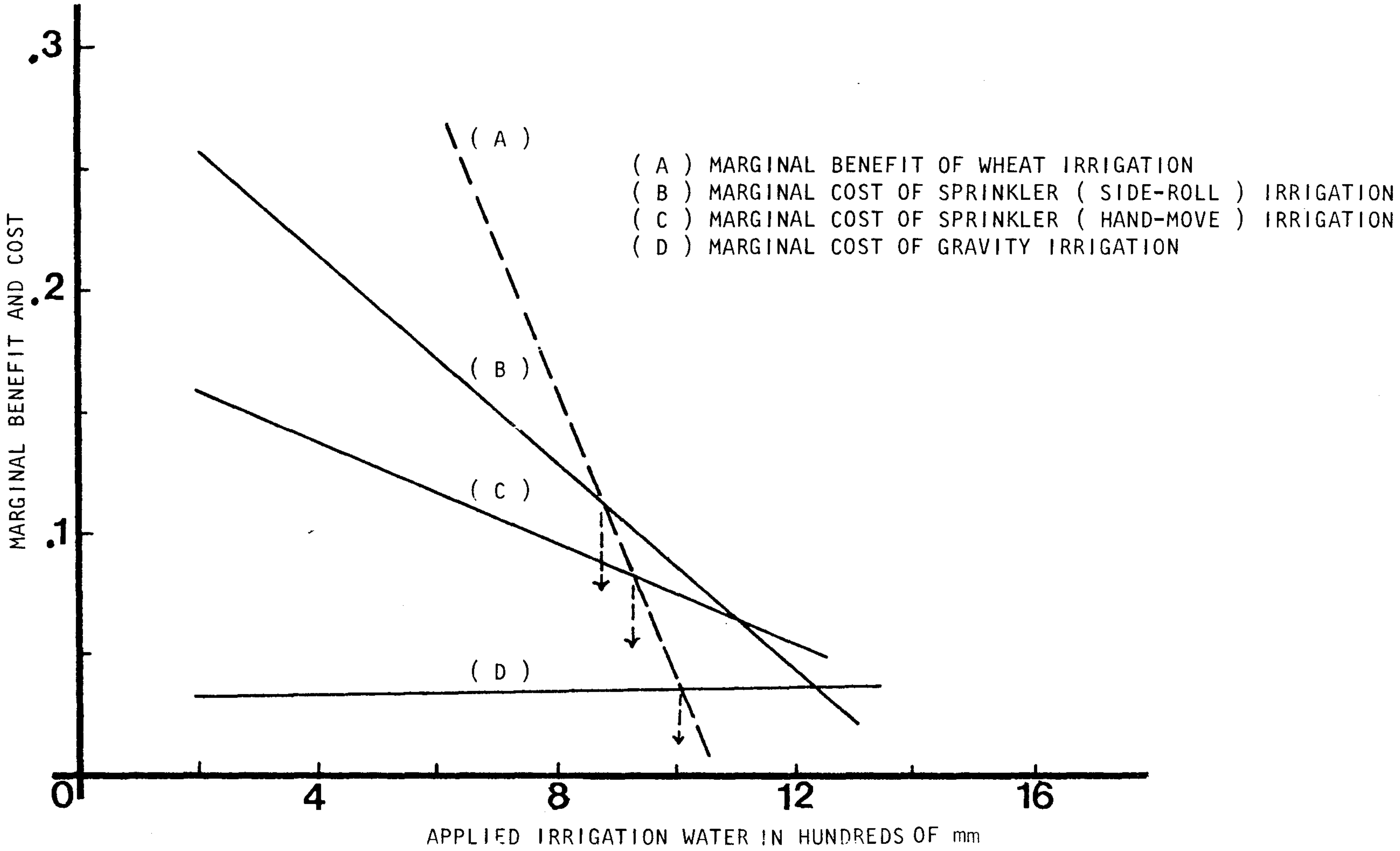


Fig. 8-13.--Marginal cost and benefit of wheat irrigation on Bannock soil by different irrigation application subsystems

where

RASM = readily available soil moisture
INT = irrigation interval
AAET = accumulative actual evapotranspiration

The peak water requirements for each crop on the different soils with different irrigation application subsystems are given in Table 8-17.

Time of Peak Water Use of a Single Crop

As stated in Chapter 7, the occurrence of peak AET varies from year to year. April first was selected as a base date, and the number of days after April first until the occurrence of maximum actual evapotranspiration of different crops for different durations for 25 years of record (1952-1976) were numbered and plotting positions computed by the Weibull (1939) equation. Next, the plotting positions were plotted on different probability papers. After visual inspection and calculation of the Kolmogorov-Smirnow test (Haan, 1977), a log-normal distribution was selected as the best to fit the data. Because the means and standard deviations of different durations were statistically the same for the data used, only the data for seven days duration were plotted.

The mathematical probability distribution of the number of days after April first until maximum actual evapotranspiration occurrence for pasture, wheat, potatoes, and alfalfa

Table 8-17.--Peak water requirement of different crops on different soil types with different irrigation application subsystems in the study area

Soil	Crop	Irrigation application subsystem					
		Gravity		Hand-move		Side-roll	
		Irrig. interval (days)	Peak water requirement (mm)	Irrig. interval (days)	Peak water requirement (mm)	Irrig. interval (days)	Peak water requirement (mm)
Bannock Ba	Pasture	5	12.57	6	10.48	7	8.98
	Alfalfa	7	14.37	7	14.37	7	14.37
	Potatoes	4	10.00	7	5.71	7	5.71
	Wheat	4	14.29	4	14.29	4	14.29
Bock, Bo	Pasture	5	14.25	6	11.87	7	10.18
	Alfalfa	8	14.25	8	14.25	10	11.40
	Potatoes	6	7.56	6	7.56	7	5.67
	Wheat	5	12.95	5	12.95	5	12.95
Hayeston Ha	Pasture	4	12.57	5	10.06	6	8.38
	Alfalfa	5	16.09	6	13.41	12	6.71
	Potatoes	4	8.00	4	8.00	4	8.00
	Wheat	4	11.43	4	11.43	4	11.43
Heiseton Hs	Pasture	4	13.62	5	10.90	6	9.08
	Alfalfa	6	14.53	8	10.90	8	10.90
	Potatoes	5	6.93	5	6.93	6	5.78
	Wheat	4	12.38	4	12.38	4	12.38
Paesl, Pe	Pasture	6	13.27	7	11.38	7	9.95
	Alfalfa	9	7.49	9	7.49	9	7.49
	Potatoes	6	8.45	7	7.24	8	6.33
	Wheat	5	14.48	5	14.48	5	14.48
Stan and Wolverine St	Pasture	4	14.67	8	7.33	8	7.33
	Alfalfa	6	15.65	8	11.73	9	10.43
	Potatoes	4	9.33	5	7.47	6	6.22
	Wheat	4	13.33	4	13.33	4	13.33

are shown in Figs. 8-14 through 8-17. The equation of mathematical probability distributions are as follows:

$$\text{Wheat} \quad Y_w = .07068Z + 1.908 \tag{8-17}$$

$$\text{Potatoes} \quad Y_p = .04273Z + 2.026 \tag{8-18}$$

$$\text{Alfalfa} \quad Y_a = .06077Z + 2.007 \tag{8-19}$$

$$\text{Pasture} \quad Y_d = .06077Z + 2.007 \tag{8-20}$$

where

Y = logarithm of number of days after April first.

Peak Water Requirement of a Multicrop Farm, PWRF

The probability curves of time of occurrence of maximum actual peak evapotranspiration show that the maximum actual water requirement of wheat occurs in June, and pasture, alfalfa, and potatoes in July at 50% of probability level. By having peak water requirement of each crop and cropping pattern, water requirements for all 24 farm units were computed. It was found that although there was a variety of cropping patterns, the peak water requirement of all farm units occurs in July. The peak water requirement of farm unit No. 1023 is shown graphically in Fig. 8-18. Peak water requirements of the different farm units are given in Table 8-18 and Appendix F.

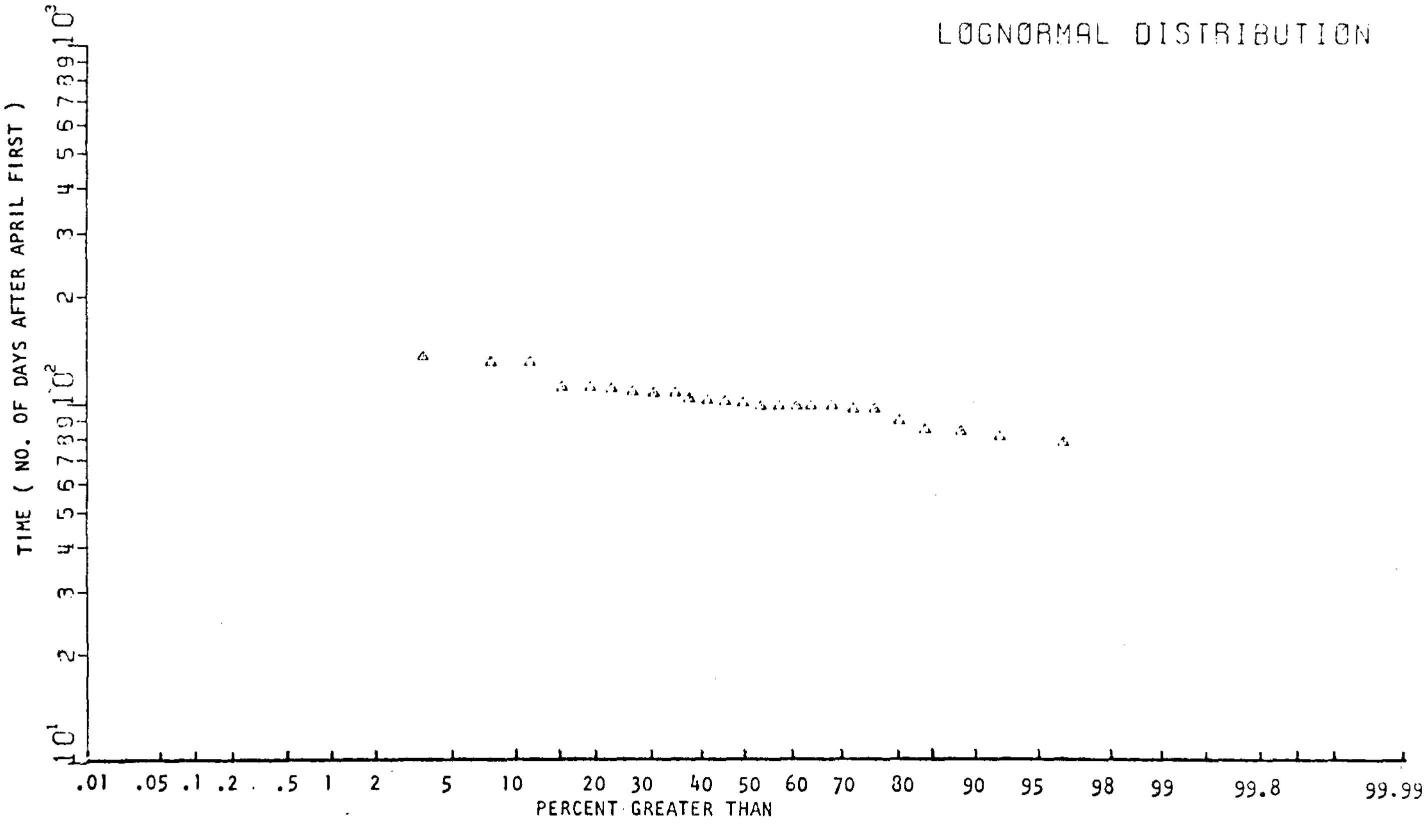


Fig. 8-14.--Log-normal probability distribution of time of occurrence of maximum actual evapotranspiration of pasture in the study area

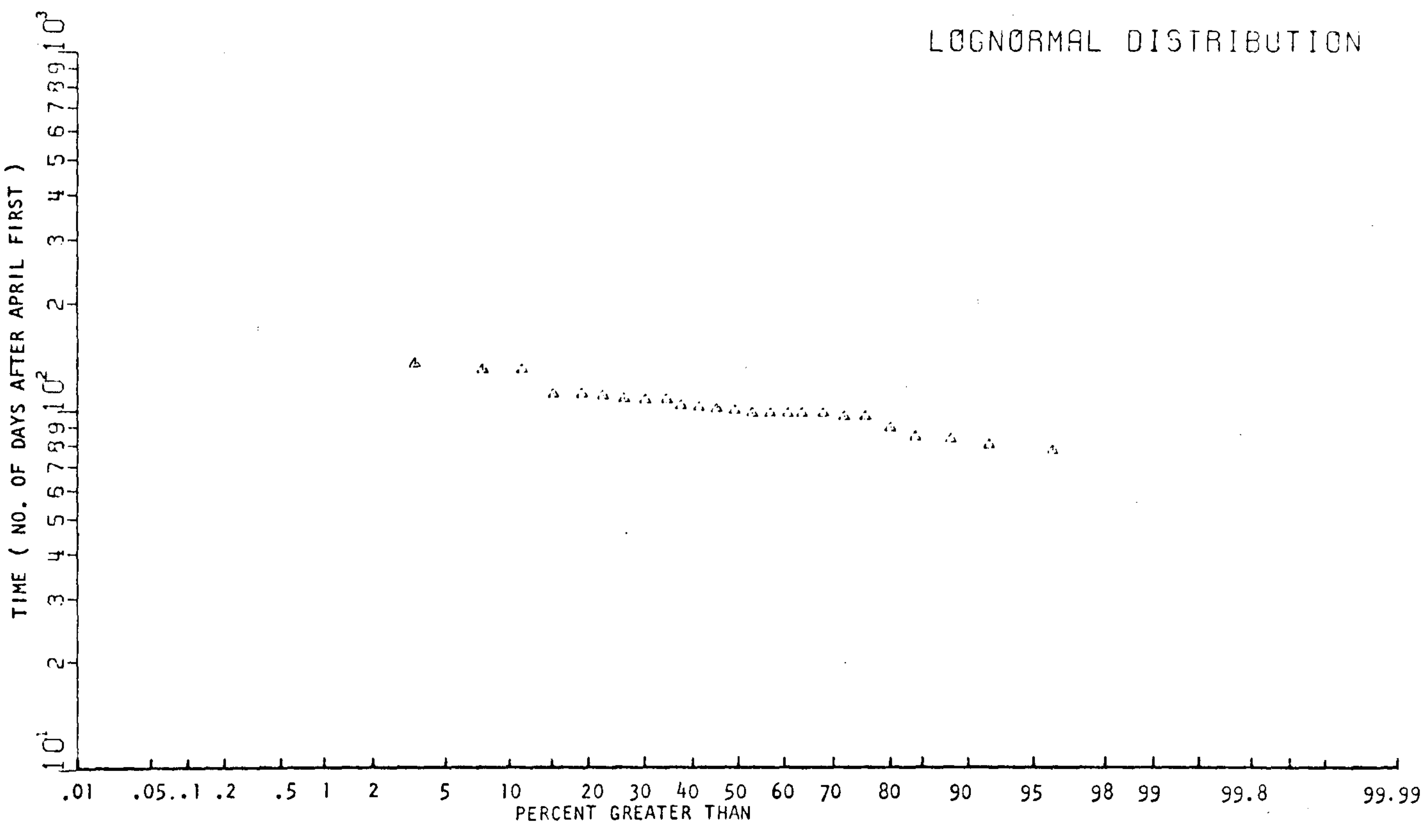


Fig. 8-15.--Log-normal probability distribution of time of occurrence of maximum actual evapotranspiration of alfalfa in the study area

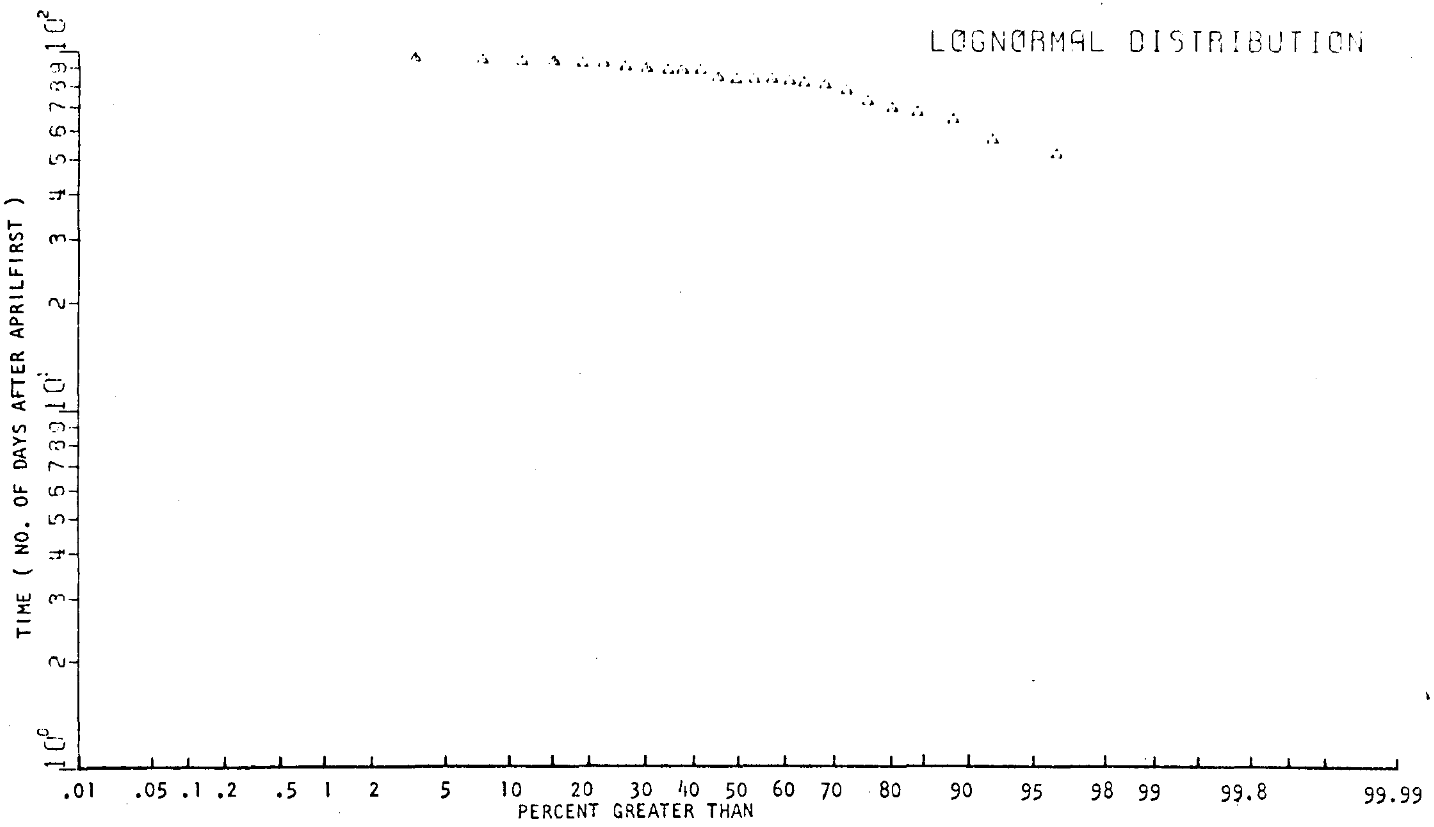


Fig. 8-16.--Log-normal probability distribution of time of occurrence of maximum actual evapotranspiration of wheat in the study area

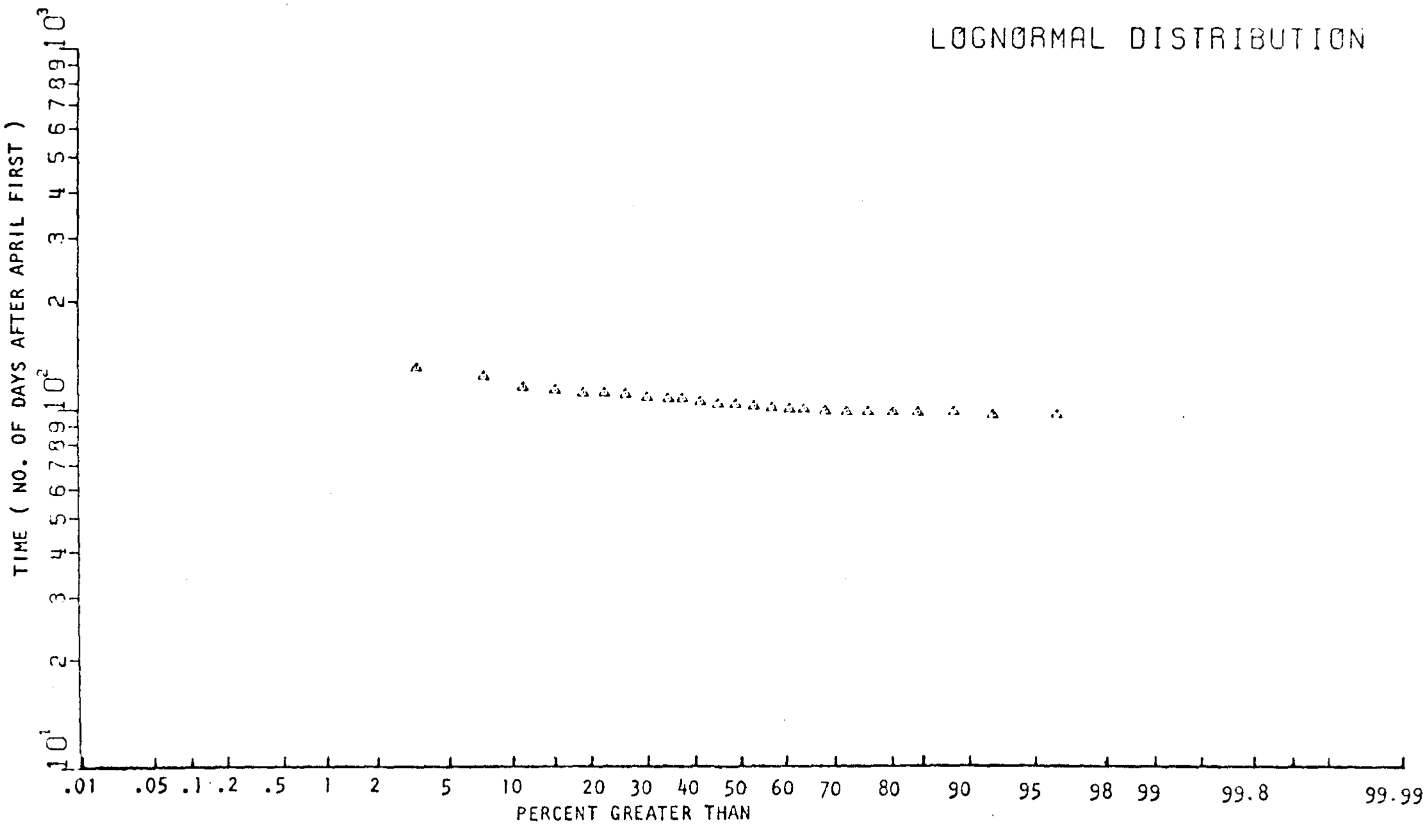


Fig. 8-17.--Log-normal probability distribution of time of occurrence of maximum actual evapotranspiration of potatoes in the study area

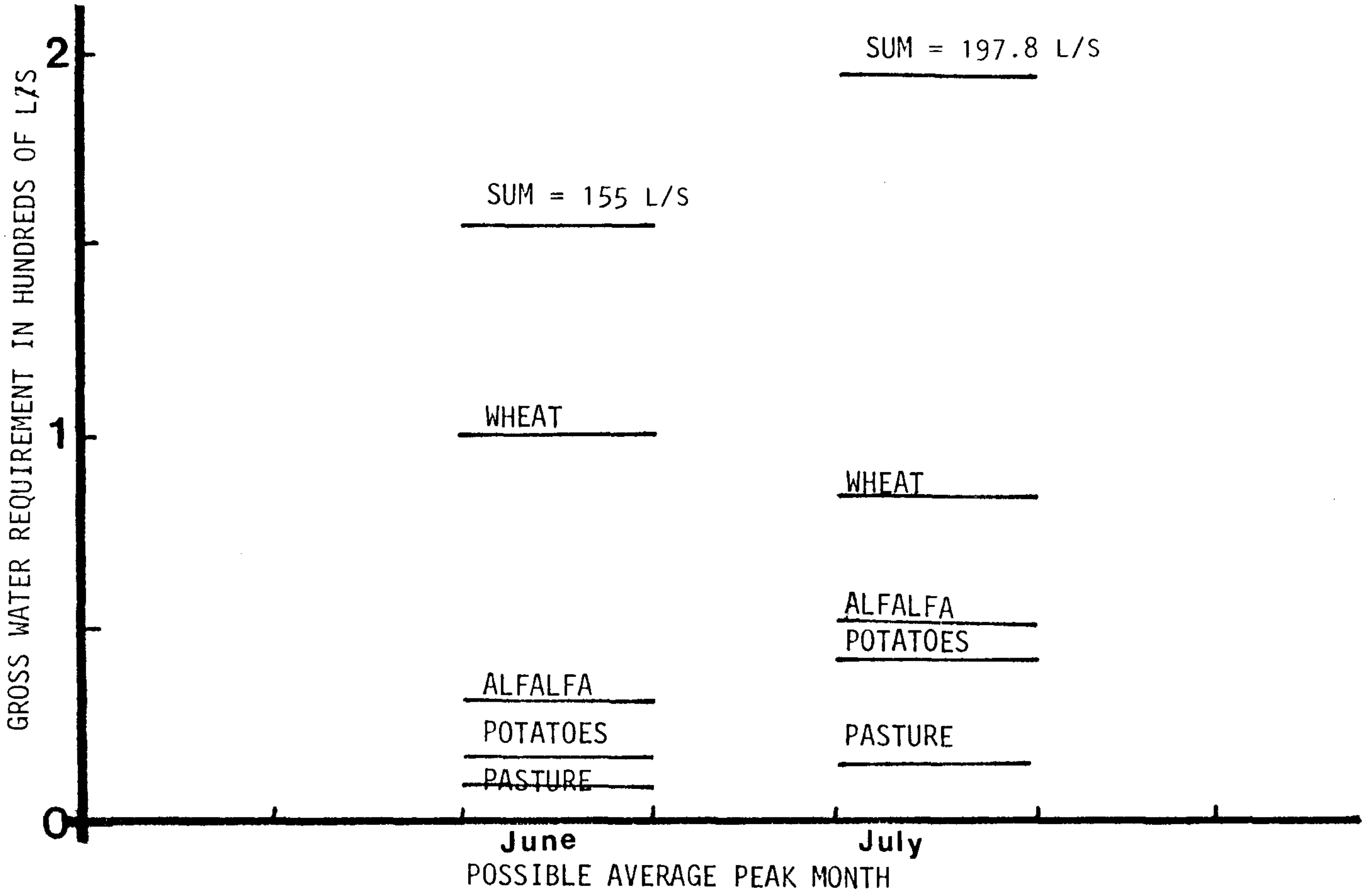


Fig. 8-18.--Peak water requirement of multicrop farm No. 1023 during months of June and July

Table 8-18.--Gross water requirement and generated runoff of each farm unit in the study area

Farm unit No.	Gross water requirement L/S	Generated[a] runoff L/S
1015	145.51	2.53
1016	178.08	11.512
1017	137.48	16.227
1018	120.71	10.789
1019	91.67	.740
1020	87.11	0
1021	133.27	12.804
1022	163.35	29.118
1023	197.78	5.173
1025	139.88	27.664
1106	165.98	0
1109	248.41	8.100
1110	83.36	0
1111	144.03	6.972
1113	117.24	5.451
1114	88.69	3.374
1117	147.29	27.155
1207	80.23	8.462
1210	135.43	17.391
1211	94.26	7.543
1212	133.29	16.774
1214	193.54	32.139
1216	147.17	13.543
1217	134.60	7.205

[a] Estimated by method described by Allen et al. (1978).

Features of Farm Service Reservoirs

Retention Duration Time of FSR

The retention duration time of water in all FSR's in this study was assumed to be 12 hours. It was assumed that all of the FSR's function as overnight reservoirs to allow farmers to irrigate only in the daytime. It was also assumed that during the night FSR's collect all of the runoff to be used on the following day.

Type and Structure of FSR

For the study area it was assumed that each FSR would be built in conjunction with existing canal systems to store and transport water. The reservoir would, therefore, be an enlarged portion of canal with an outlet water control structure. This assumption increased the complexity of the problem because in each canal section two alternative canal lengths must be considered. If a reservoir is included in a given canal section, a short canal must be selected for use in conjunction with the reservoir. However, if a reservoir is not included, a longer canal with a length equal to the entire section must be used.

Further assumptions are as follows:

1. All of the farm service reservoirs are unlined.
2. All of the canals are unlined.
3. Water moves only downstream by gravity.

Site Selection of Farm Service Reservoirs

All available data were investigated to determine the best possible locations for FSR's within existing canal systems. All physical barriers such as county roads, railroads, bridges, and also the suitability of land for FSR's were considered. The FSR's were located on the best possible places according to the available data. It was not attempted to consider all intangible benefits of each FSR. Because of complexities of the problem only one type of FSR was considered at each site.

The locations of 15 FSR's along the West Branch Snake River Valley and Cedar Point Canals are shown in Figs. 8-19 and 8-20.

Inflow and Outflow of Farm Service Reservoir

Inflow to all of the FSR's was Snake River water supplied by the West Branch Snake River Valley and Cedar Point Canals. Also, runoff generated from nearby irrigated farms could be collected by some of the reservoirs. It was also possible for drainage and nonpoint sources of water to contribute to the FSR supply. However, because of lack of reliable data, the contribution of drainage water to FSR storage was not considered.

Each reservoir was assumed to store sufficient water to satisfy assigned farm units located downstream from the FSR. The size of the outflow stream is a function of the

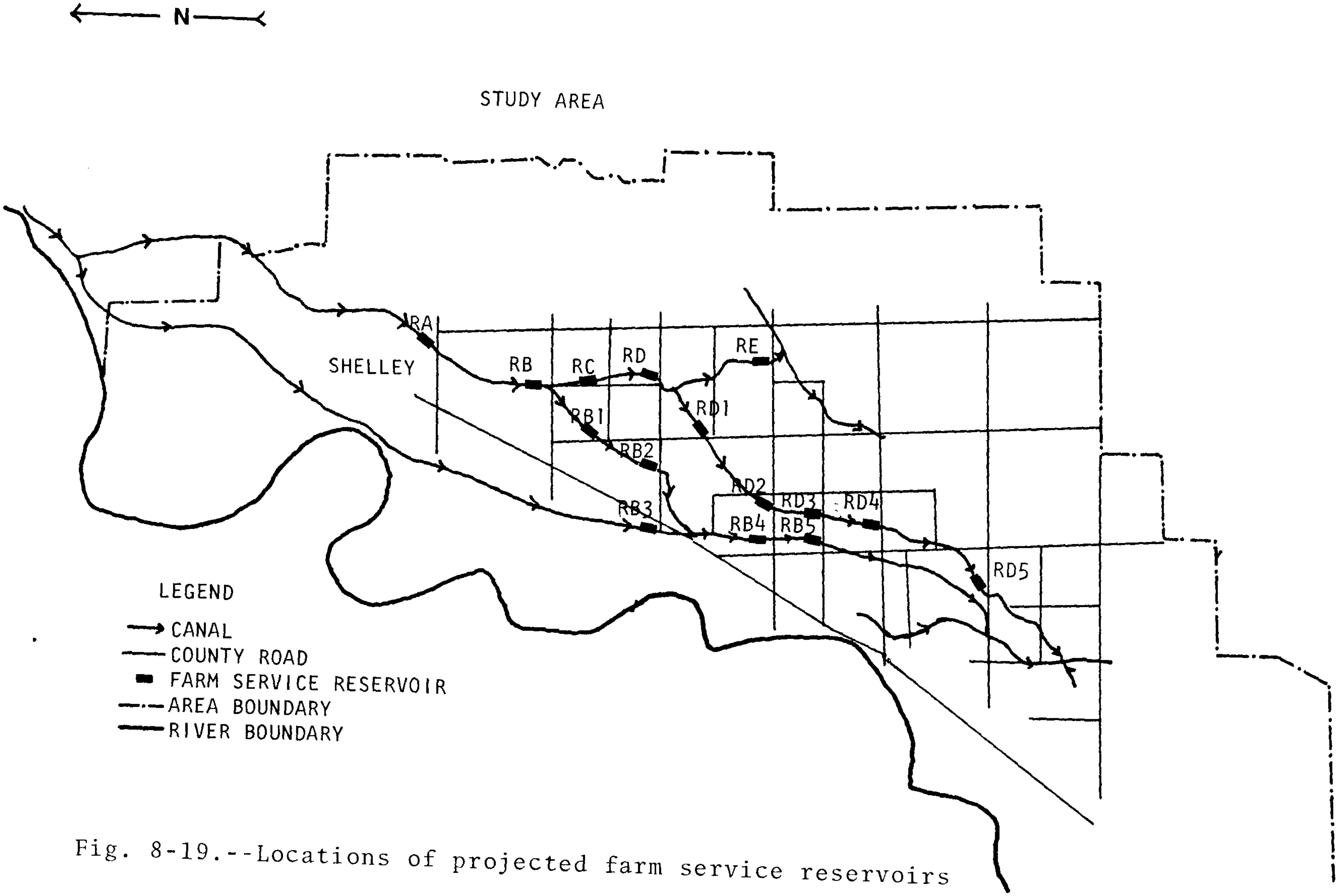


Fig. 8-19.--Locations of projected farm service reservoirs

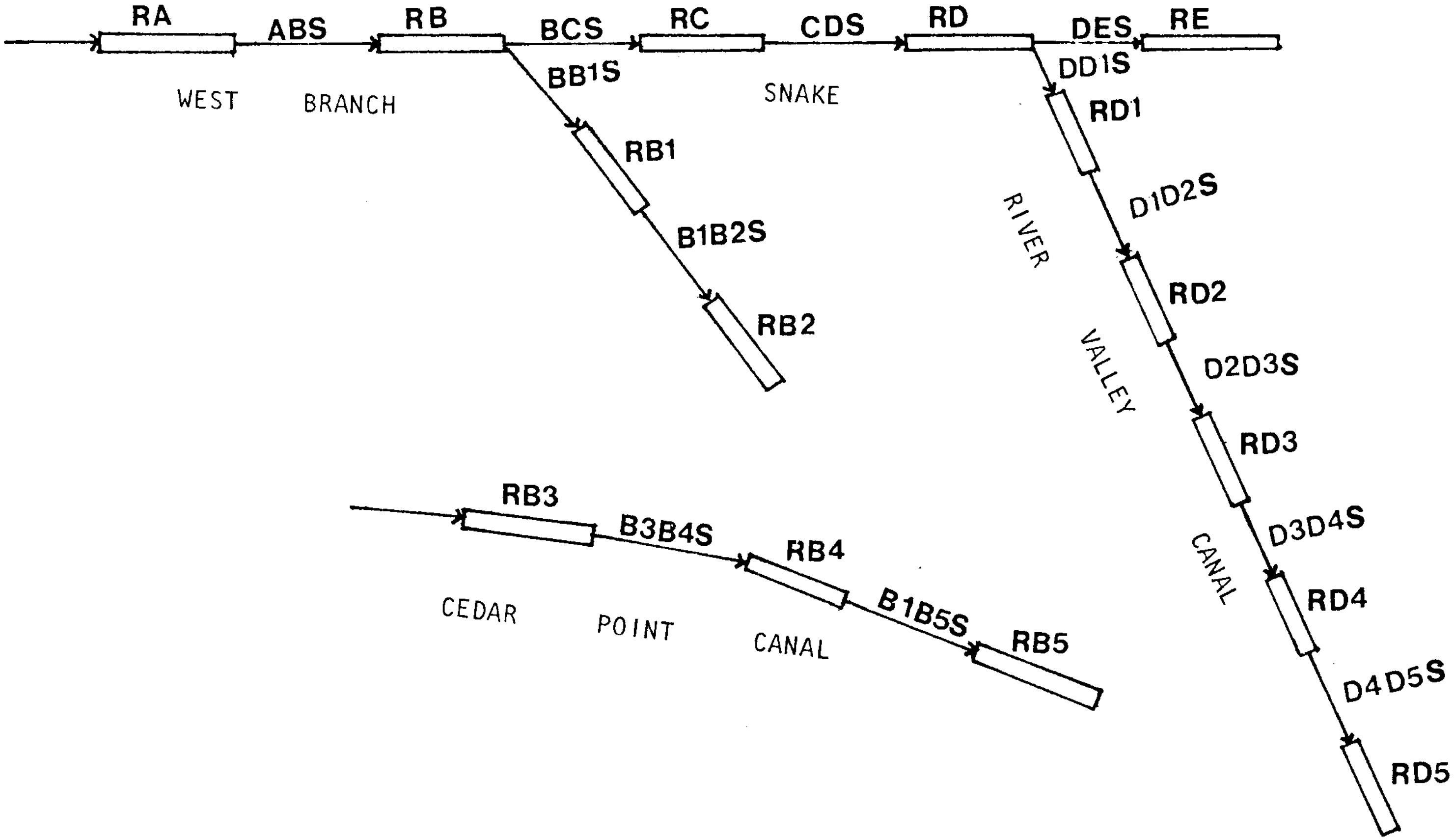


Fig. 8-20.--Schematic locations of farm service reservoirs and canal sections

assigned farm units, the overall efficiency of FSR, and conveyance canal sections.

Capacities of FSR's and Canal Sections

A total of 15 FSR sites were selected as shown in Figs. 8-19 and 8-20. Assuming that all were used, the design capacity of each FSR and canal was computed and is shown in Tables 8-19 and 8-20. The design capacity of each FSR and canal section in Tables 8-19 and 8-20 is presented as a reference in order to compare the costs, capacities, and locations of FSR's and types of canals (short or long) in each canal section. In this computation the total cost estimated is $92,815 or $58 per hectare.

Optimization of Farm Service Reservoirs--Location and Size

The peak water requirement of each farm unit was estimated according to cropping pattern, soil type, irrigation application subsystem, and crop yield by economical analysis. Locations of 15 possible farm service reservoirs were determined, and the capacities of farm service reservoirs and canals were determined for the case using all FSR's. No alternative combinations of FSR's were yet considered as would be possible by eliminating some FSR's, increasing the capacity of others, and transporting water from one FSR to other FSR's or farms. Many different combinations with different total costs or different alternative combinations would be possible.

Table 8-19.--Storage capacity and cost of farm service reservoirs

Farm service reservoir	Net storage volume (1,000 m^3)	Storage efficiency	Gross storage volume (1,000 m^3)	Cost, $/1,000 m^3		Cost	Farm number under coverage of farm service reservoir
				Constant	Variable		
RA	13.96	.80	17.45	4224	58.9	5252	1015,1016
RB	9.84	.80	12.30	4613	88.2	5698	1017
RC	8.97	.80	11.21	4467	74.4	5301	1018,1020
RD	12.80	.80	16.00	4224	58.9	5166	1021
RE	20.80	.75	27.73	4074	114.6	7252	1023,1025, 1111
RB1	7.17	.75	9.56	3433	49.0	3901	1019
RB2	7.15	.75	9.53	3780	55.7	4311	1106
RB3	1.80	.50	3.60	4439	58.0	4648	1109
RB4	3.47	.50	6.94	4684	63.2	5123	1110 (1/2)
RB5	17.52	.50	35.04	2972	55.0	4899	1207,1210, 1211,1212
RD1	3.58	.80	4.48	3252	154.4	3944	1022
RD2	6.86	.75	9.15	4495	67.6	5114	1109
RD3	3.84	.80	4.80	3625	57.0	3899	1110 (1/2), 1113
RD4	6.36	.80	7.95	3803	62.1	4297	1114
RD5	20.51	.75	27.35	4202	106.3	7109	1117,1214, 1216,1217
TOTAL						75914	

Table 8-20.--Design capacity and cost of each canal section

Canal section	Net transferred water volume for 12 hr (1,000 m^3)	Net canal capacity (m^3/S)	Conveyance efficiency	Gross canal capacity (m^3/S)	Cost, $\$/(m^3/S)$		Cost $
					Constant	Variable	
ABS	139.74	3.235	.97	3.335	2452	257.5	3311
BCS	108.34	2.508	.975	.2572	929	105.4	1200
CDS	97.12	2.248	.975	2.306	689	134.8	1000
DES	27.73	.642	.97	.662	1477	250.6	1643
BB1S	19.09	.442	.962	.459	944	519.3	1182
B1B2S	9.53	.221	.97	.228	811	212.5	859
B3B4S	41.96	.971	.93	1.044	740	727.5	1500
B4B5S	35.03	.811	.95	.854	789	423.4	1151
DD1S	53.39	1.236	.97	1.274	375	473.5	978
D1D2S	49.25	1.140	.97	1.175	608	501.1	1197
D2D3S	40.10	.928	.97	.957	730	148.6	872
D3D4S	35.30	.817	.972	.841	692	155.5	823
D4D5S	27.35	.633	.965	.656	1009	268.7	1185
TOTAL							16901

The optimization procedure, by using a type of mathematical programming model, would be a tool to select the best possible combination. By supplying necessary data, it is possible to optimize the system for minimum cost and to determine the location and size of each FSR and the design capacity of each canal section. The model must be able to select alternative components subject to technical constraints such as optimum allocation of components, and the results should provide the minimum cost system that satisfies all technical constraints. Specifically, the model must consider:

1. The constant and variable cost in decision variables in the form of $A + B \cdot Q$.
2. The selection of one of the two alternative canal lengths, long or short, depending upon whether a farm service reservoir is selected for a particular section.

Justification for Use of Mixed-Integer Programming

Mixed integer programming can be manipulated to consider the specific conditions of selecting alternative components. Mixed integer programming is a suitable procedure that can be used to optimize the irrigation system. A software package, such as UIMIP described by Yoo and Busch (1980), can be used to optimize such a problem.

MIP Model

A model for MIP was designed to cover the entire study area with 15 possible FSR's and 26 long and short alternative canal sections. The model had 82 variables of which 41 were integer variables and 83 constraints. The software package was too slow and costly to run the entire model. After several primary runs, a decision was made to decompose the complete model into two smaller models:

1. West Branch Snake River Valley Canal model with 68 decision variables and 69 constraints which contains 12 FSR's and 11 canal sections.

2. Cedar Point Canal model with 14 decision variables and 15 constraints which covers 3 FSR's and 2 canal sections.

This decomposition was possible because there is almost no water exchange between these two canal branches. The Main Snake River Valley Canal supplies water to both.

MIP Solution for West Branch Snake River Valley Canal

The UIMIP package was used to optimize the irrigation system without any constraints to define specific locations of optimal FSR sites. Two solutions were obtained. In the first solution, farm service reservoirs RA, RB, and RD3 were selected, and the size of FSR RA was limited by maximum predetermined capacity. No farm service reservoir at the end of each canal branch was selected. In this solution all of the farm would be irrigated by farm service reservoirs RA and RB, except those farms downstream of FSR's RD3, RD4, and RD5 and those served by the Cedar Point Canal. The design capacity of each canal section was also computed, and total cost for this solution was $56,058. The capacity of FSR's and associated costs are shown in Table 8-21, column 1.

Table 8-21.--Optimization of volume of farm service reservoirs

Farm service reservoir	MIP solution		MIP solution with FSR at specific sites
	(1) (1,000 m^3)	(2) (1,000 m^3)	(3) (1,000 m^3)
RA	125.8	50.1	125.8
RB	6.5	0	2.7
RC	0	77.9	0
RD	0	0	0
RE	0	0	21.0
RB1	0	0	0
RB2	0	0	7.4
RB3	-	-	11.5
RB4	-	-	0
RB5	-	-	35.0
RD1	0	0	0
RD2	0	0	0
RD3	34.5	34.5	0
RD4	0	0	0
RD5	0	0	13.2
FSR's cost	32,415	33,033	42,766
Canal's cost	23,643	23,854	20,995
Total cost	56,058	56,887	63,761

In the second solution of this model the capacity of FSR RA was decreased with a resultant increase in the capacity of FSR RC and FSR RB was eliminated. In this solution, as in the first solution, there was no farm service reservoir at the end of the canal branch to collect runoff. The design capacity of each canal selection and total cost were computed. The total cost of the second solution was $56,887 which is only 1.5% higher than the first solution. Because of computational rounding error, it can be assumed that the costs of the two solutions are essentially the same, the only difference being a change in the configuration of the system. Farm service reservoirs' capacities and associated costs of the second solution are shown in Table 8-21, column 2.

MIP Solution with FSR's Designated at Specific Sites

There was no FSR at the end of the last section of any of the canal branches in the first MIP model. As a result, most of the surface runoff from application systems would be wasted at the end of each canal branch. Constraints were imposed on the model to have an FSR located at the end of each canal branch. By specifying these FSR's, the type of canal at the end of each canal section was also implicitly determined as a short canal type.

In this model there was only one solution. This solution specified the capacity of FSR RA to the maximum predetermined level. Optimum sizes for farm service reservoirs

RE, RB2, and RD5 at the end of the canal branch were selected. FSR RB had very small capacity; by raising the upper limit on capacity of FSR RA, FSR RB may be eliminated. This solution gives the sites of the farm service reservoirs and also assigns an FSR at the end of each canal branch. This solution would provide more operational flexibility within the system. Canal capacities and costs were computed. The total cost for this solution is $63,761 which is 13.74% higher than the first solution in the first model. The capacity of farm service reservoirs and associated costs for this solution are shown in Table 8-21, column 3.

The selected sites and capacities of FSR's for this solution are given in Table 8-21. Locations of FSR's for this solution are shown schematically in Figs. 8-21 and 8-22, and the picture of the MIP matrix is shown in Fig. 8-23. In Fig. 8-23, RA,RB,... are capacities of farm service reservoirs RA, RB, ...; ARA, ARB, ... are fixed costs for RA, RB, ..., (Eq. 8-9); TABL, TABS, ... are volumes of water transferred from RA to RB by long canal (L) or by short canal (S); and ATABL, ATABS, ... are fixed costs for TABL, TABS, ... (Eq. 8-10).

The constraint equations assure water transfer and delivery in the system.

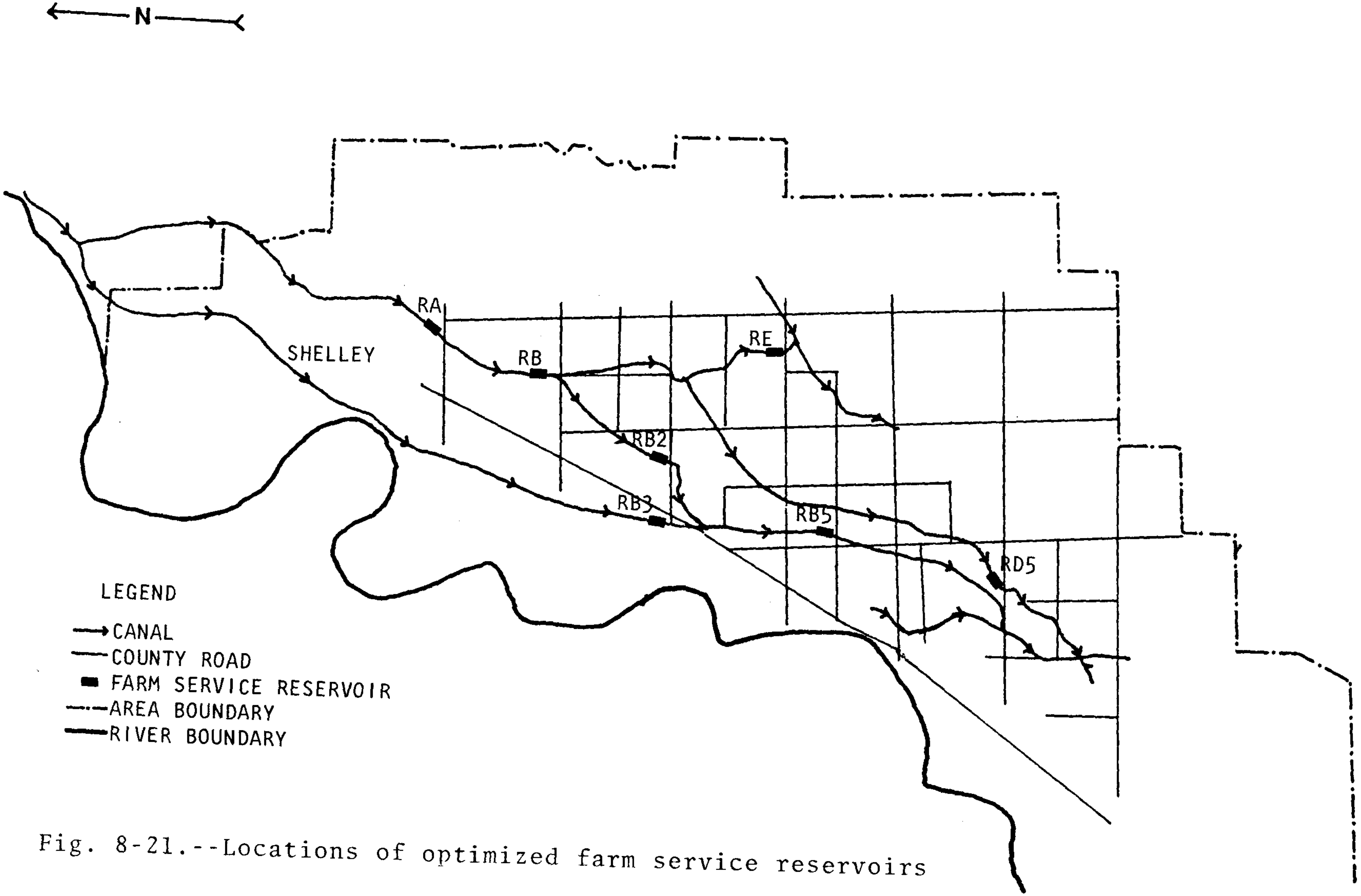


Fig. 8-21.--Locations of optimized farm service reservoirs

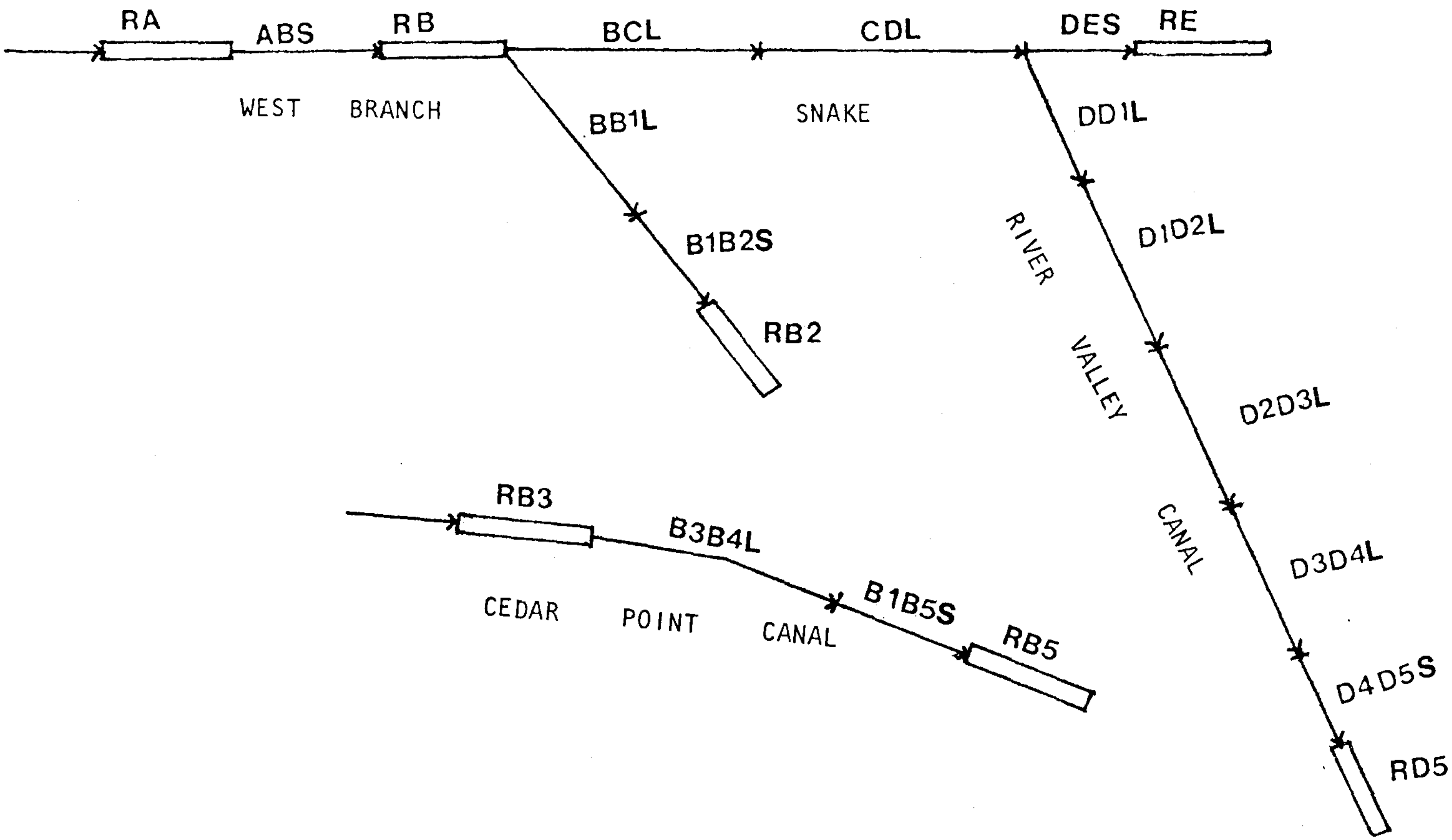


Fig. 8-22.--Schematic optimized location of farm service reservoirs and canal sections

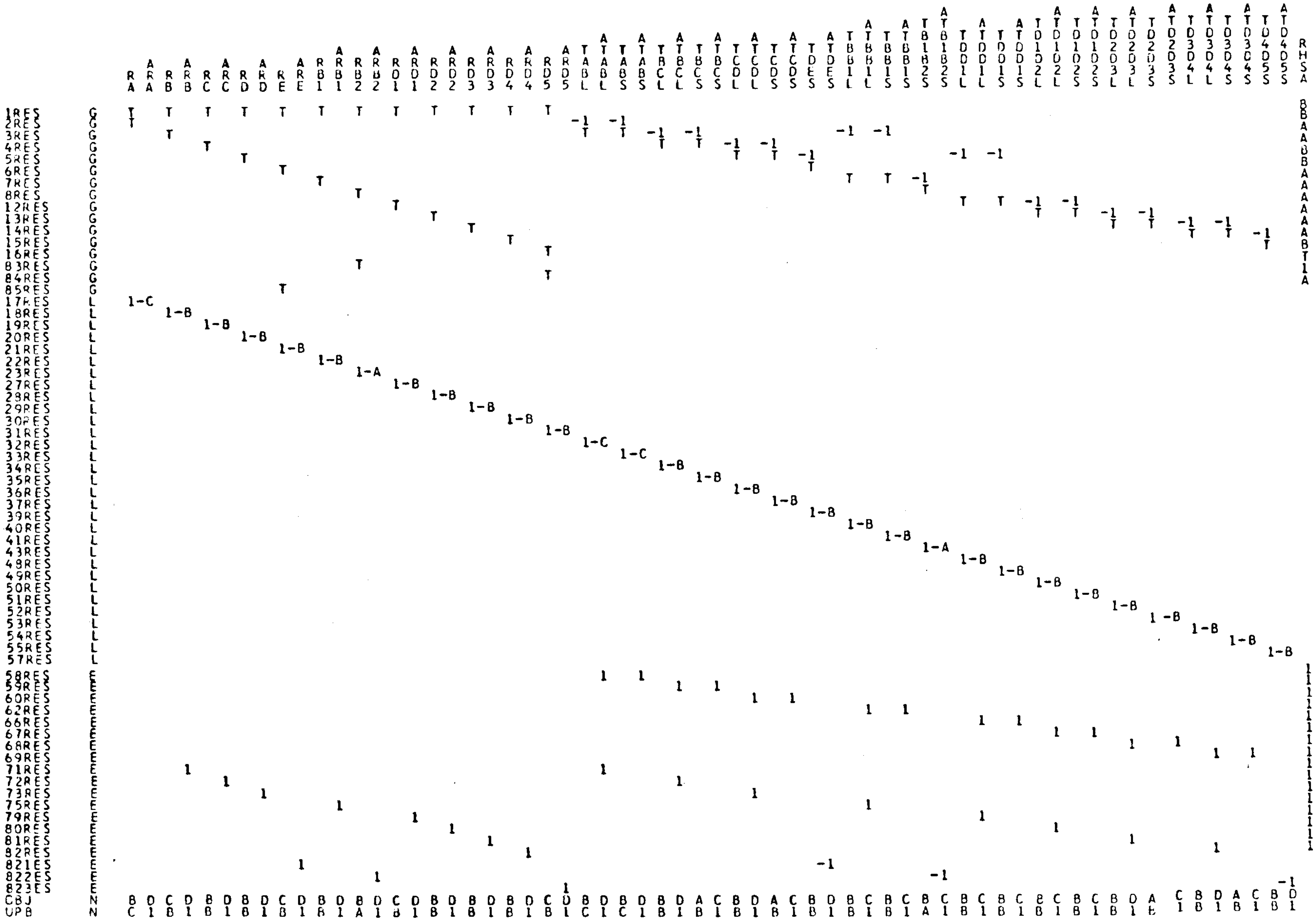


Fig. 8-23.--Picture of MIP matrix for West Branch Snake River Canal Model

MIP Solution for Cedar Point Canal with Constraint on Having FSR at End of Reach

For the Cedar Point Canal, three farm service reservoirs and two canal sections were considered. Farm service reservoir RB5 was imposed at the end of the branch. This model had 14 decision variables in which 7 are integer and 15 constraints. There was only one MIP solution. MIP solution of optimal location of FSR and corresponding capacity are shown in Table 8-21, column 3 in cooperation with the West Branch model. Locations of FSR are shown schematically in Figs. 8-20 and 8-21, and the picture of the MIP matrix is shown in Fig. 8-24. Parameters in Fig. 8-24 are defined the same as for Fig. 8-23.

Linear Programming Model

As described, the MIP software required considerable computer time and is costly to run. When integer solutions are not required, existing LP packages such as MPS (1971) can be used. These packages are quite efficient and contain post optimal analysis procedures.

Various amounts of runoff water from each farm unit and costs of supplied water were not included in the mixed integer programming model because of large computer time costs. A decision was made to avoid excessive computer costs by first obtaining FSR locations and the type of canal in each section using the MIP procedure. Then these results were used as input data in a linear programming analysis. The MPS software

```
                            A   A   A   A
                          T T T T T T T T
                          B B B B B B B B
                A   A   A 3 3 3 3 4 4 4 4 R
              R R R R R R B B B B B B B B H
              B B B B B B 4 4 4 4 5 5 5 5 S
              3 3 4 4 5 5 L L S S L L S S A

1RES      G   T   T   T                   B
2RES      G   T          -1  -1           A
3RES      G       T       T   T  -1  -1   A
4RES      G           T           T   T   B
5RES      L   1-B
6RES      L       1-B
7RES      L           1-B
8RES      L               1-B
9RES      L                   1-B
10RES     L                       1-B
11RES     L                           1-B
12RES     E                 1   1         1
13RES     E                         1   1 1
14RES     E             1           1     1
15RES     E         1       1             1
OBJ       N   B D B D B D B D B C B D B C
UPB       N   B 1 B 1 B 1 B 1 B 1 B 1 B 1
```

Fig. 8-24.--Picture of MIP matrix for Cedar Point Canal Model used was useful in performing parametric programming and post optimal analyses.

Linear Programming Model in Conjunction with Mixed Integer Programming

The linear programming model incorporated the final solution of the MIP model and costs of supplied and runoff water. This model had the following conditions:

1. Only those FSR's and canal types which were selected by final MIP solutions were used.
2. Upper bound limits for decision variables in MIP were relaxed and a minimum size for FSR RB was imposed at 6167 m^3.
3. Runoff water was entered in the model.
4. Supplied water cost and runoff costs were imposed.
5. Water was transported downstream only by gravity.
6. Water balance equations in the model werethe same as in the MIP model.

The picture of the linear programming model is shown in Fig. 8-25. This model provided the optimal capacity FSR under the given conditions. For the first run it was assumed that cost of runoff water and river wastes was equal to zero. The output from the LP model is shown in Tables 8-22 and 8-23, and the picture of the LP matrix is shown in Fig. 8-25.

In Fig. 8-25, ROB, ROE, ... are volume of runoff reared by FSR RB, RE, ...; WCA, WCB, ... are cost of water in FSR RA, RB, ...; and TW is the total water cost in the system. Other variables are the same as defined for Fig. 8-23.

Table 8-22.--Optimized storage capacity and cost of farm service reservoir

Farm service reservoir	Gross storage volume LP sol. (1,000 m^3)	Cost, \$/1,000 m^3		Cost	Farm number under coverage of farm service reservoir
		Constant	Variable		
RA	119.39	4224	58.9	11256	1015,1016,1017,1018
	6.17	4613	88.2	5157	1020,1021,1023,1025
	0	4467	74.4	0	1111,1019,1022,1109
	0	4224	58.9	0	1110(1/2),1113,1114
	1.23	4074	114.6	4215	
	0	3433	49.0	0	
	9.53	3780	55.7	4311	1106
	17.84	4439	58.0	5474	1109,1110(1/2)
	0	4684	63.2	0	
	35.03	2972	55.0	4899	1207,1210,1211,1212
	0	3252	154.4	0	
	0	4495	67.6	0	
	0	3625	57.0	0	
	0	3803	62.1	0	
	27.35	4202	106.3	7109	1117,1214,1216,1217
TOTAL				42421	

Table 8-23.--Optimized design capacity and cost of each canal section

Canal section	Rotation flow computations		Continuous flow computations			
	(1)	(2)	(3)	(4)	(5)	(6)
ABS	81.55	1.888	6.167	.798	.97	6.358
BCL	66.73	1.545	-	-	.97	0
CDL	55.75	1.291	-	-	.97	0
DES	21.44	.496	1.23	1.23	.97	0
BB1L	7.46	.173	-	-	.96	9.709
B1B2S	0	0	9.53	.504	.97	9.825
B3B4L	3.65	.084	-	-	.88	41.902
B4B5S	0	0	35.03	.269	.95	36.874
DD1L	19.84	.459	-	-	.96	32.570
D1D2L	15.47	.358	-	-	.95	31.267
D2D3L	7.83	.181	-	-	.95	29.704
D3D4L	3.65	.084	-	-	.96	28.219
D4D5S	0	0	27.35	1.252	.965	28.342
TOTAL						

(1)Volume of transferred water from upstream farm service reservoir to downstream farm during irrigation (MPS solution), 1,000 m^3/12 hours.

(2)Maximum canal design rate for Column 1, m^3/S.

(3)Volume of reservoir at the end of canal sections, 1,000 m^3 (MPS solution).

(4)Volume of runoff entered to reservoir, 1,000 m^3/ 12 hours (MPS solution).

(5)Conveyance efficiency of each canal section.

Table 8-23.--Continued

Continuous flow computations		Maximum design capacity rate m^3/S (9)	Cost, \$/m^3/S		Cost (12)
(7)	(8)		Constant (10)	Variable (11)	
52.054	.602	2.490	2452	257.5	3093
34.616	.401	1.946	1891	282.5	2441
33.577	.389	1.680	1274	310.8	1796
0.	0.	.496	1447	250.6	1571
9.709	.112	.285	972	519.1	1120
9.825	.114	.114	811	212.5	835
41.902	.485	.569	1239	1426.7	2051
36.874	.454	.454	789	423.4	981
32.570	.377	.836	511	900.5	1264
31.267	.362	.720	991	960.6	1683
29.704	.344	.525	1022	286.0	1172
28.219	.327	.411	1118	324.9	1252
28.342	.328	.328	1009	268.7	1097
					20356

(6) Column 3/Column 5 and minus Column 4 if necessary.

(7) Design capacity rate of each canal section, 1,000 m^3/day.

(8) Design capacity rate of each canal section, m^3/S.

(9) (Column 2 + Column 8), maximum design capacity rate of each canal section.

(10) Constant cost.

(11) Variable cost, \$/(m3/S).

(12) Total cost.

		RA	WCA	RB	ROB	WCB	RE	FOE	WCE	RB2	ROB2	WCB2	RD5	ROD5	WCD5	RB3	WCB3	RB5	ROB5	WCB5	TAB	TBC	TCD	TDE	TBB1	TB1B2	TDD1	TD1D2	TD2D3	TD3D4	TD4D5	TB3B4	TB4B5	TW	PO1
OBJF	N	B		C			C			B			C			B		B			B	B	B	B	B	B	B	B	B	B	B	B	B		
CHROW1	N																																	1	
1RES	G	T		T			T			T			T																						B
2RES	G															T		T																	B
3RES	G	T																			-1														B
4RES	G			T																	T	-1			-1										A
5RES	G															T																-1			A
6RES	G						1																												1
7RES	G									1																									1
8RES	G												1																						1
9RES	G						T											1																	1
10RES	G																							T											B
11RES	G									T																T									A
12RES	G												T																		T				B
13RES	G																	T															T		B
14RES	L				1																														T
15RES	L				1			1																											A
16RES	L										1																								T
17RES	L													1																					A
18RES	L																		1																T
19RES	E																																		
20RES	E	1	-1																																
21RES	E			1	-1	-1																													
22RES	E						1	-1	-1																										
23RES	E									1	-1	-1																							
24RES	E												1	-1	-1																				
25RES	E															1	-1																		
26RES	E																	1	-1	-1															
27RES	E		1			1			1			1			1		1			1														-1	
28RES	G																					T	-1												A
29RES	G																						T	-1			-1								B
30RES	G																								T	-1									A
31RES	G																										T	-1							A
32RES	G																											T	-1						A
33RES	G																												T	-1					A
34RES	G																													T	-1				A
35RES	G																															T	-1		A
36RES	G			1																															A
OBJF2	N	B		C			C			B			C			B		B			B	B	B	B	B	B	B	B	B	B	B	B	B	B	

Fig. 8-25.--Picture of linear programming matrix

Design Capacities of FSR's and Canal Sections

By using the linear programming model in conjunction with the MIP model, the location of FSR's and size for each FSR and volume of water which would be transferred from one FSR to some other FSR's or farm unit(s) was computed. The total annual cost of the irrigation system for FSR and canal system was computed by summing the cost of FSR's and canal sections which is equal to \$62,777 or \$39.27 per hectare.

The design capacity and cost of each canal section was determined by increasing the capacity of the canal to convey the extra water from FSR's during the 12-hour irrigation period. The design capacity of each canal section and FSR with related costs are given in Tables 8-22 and 8-23.

Parametric Programming and Postoptimal Analysis

Presently there is no charge for river water supplied to the irrigation district, and no water cost was imposed in the previous computations. To determine the effects of various water charges to the district, a variable water cost was assumed in the model. The cost of water allowed to change from \$0-12.15 per 1,000 m^3 (0-\$15 per acre-ft). The cost of runoff water from application systems was kept constant and equal to zero. Results obtained indicated that all runoff water instead of incoming water was used when river water costs increased from zero to \$.81 per 1,000 m^3. There was no other major change in system configuration of FSR as the cost of water increased.

CHAPTER 9

SUMMARY AND CONCLUSIONS

Summary

The main object of this study was to utilize probability analysis and mathematical programming in planning the least cost design and operation of an irrigation system with a chain of farm service reservoirs. The purposes of these reservoirs are to minimize water shortage during peak water use periods and to make water available on demand. By having water available on demand, an irrigator can do a more efficient job of irrigating, and surface runoff can be collected in farm service reservoirs for reuse downstream.

To achieve the objective, an area of approximately 1,865 ha in the Snake River Valley Irrigation District was selected as a study area for application of the proposed model. The study area was divided into 24 farm units. Cropping pattern, soil type, quantity and quality of irrigation water, and existing irrigation application systems were considered and necessary data collected.

Daily evapotranspiration values for 25 years (1952-1976) were estimated, and frequency distribution of evapotranspiration for 1 to 30 days and seasonal duration were estimated. A log-normal probability distribution was found to best fit the data. Daily actual evapotranspiration of pasture, wheat, alfalfa, and potatoes were computed. Frequency distributions of these crops for 1 to 30 days and for seasonal use were estimated. A log-normal probability distribution was again found to best fit the estimated actual evapotranspiration of the four crops. Mathematical probability equations for the prediction of actual evapotranspiration for different duration were developed.

All possible irrigation intervals for different probabilities of occurrence were computed utilizing the mathematical probability equations of actual evapotranspiration and allowable soil moisture depletion data. By incorporating irrigation application subsystem characteristics, corresponding recurrence intervals were estimated. Costs and benefits of various irrigation systems were determined.

Annual costs of irrigation application subsystems for each soil type and crop, for different amounts of applied water, were estimated. Annual costs were also estimated for canal rehabilitation and farm service reservoirs. Benefits of various levels of irrigation for each crop were estimated by dimensionless crop yield-water use functions and unit prices of crops, and by incorporating the level of risk in satisfying actual evapotranspiration requirements. By estimating the annual costs of irrigation application subsystems and benefits from different amounts of applied water, and by using a marginal cost-benefit analysis, the most economical irrigation interval for each crop on a particular soil was computed for a particular irrigation application subsystem. The peak actual water required for each different crop-soil-irrigation application system were then determined. The time of occurrence of maximum actual evapotranspiration for each crop in the study area follows a log-normal distribution, and the mathematical probability equations were defined.

The peak water requirement of each farm unit was computed as a function of cropping pattern, soil type, and irrigation application subsystem. It was found that although there were a variety of cropping patterns, soil types, and irrigation application subsystems, the peak water requirement of all farm units occurred in July.

The retention duration time of water in all farm service reservoirs was assumed to be 12 hours. Locations of possible farm service reservoirs and associated service areas were determined, and it was assumed that all of the reservoirs and canal sections were unlined. Design capacities of farm service reservoirs and canal sections were first computed by assuming that all of the possible farm service reservoirs would be used. Annual costs of farm service reservoirs and canal rehabilitation were obtained at $92,815 or $58 per hectare. By increasing the capacities of some farm service reservoirs and conveying water from one farm service reservoir to other farm units and/or farm service reservoirs, many different alternative system configurations are possible, and optimization procedures were used to find least cost farm service reservoir and canal system configurations.

A mixed integer programming model was used to determine the best possible locations of farm service reservoirs in two canal branches in the study area. After using MIP to determine the best possible farm service reservoir sites, a linear programming model was used for postoptimal analyses. The linear programming model was used to optimize the capacities of farm service reservoirs and canal sections subject to various constraints. The annual cost of farm service reservoirs and canal rehabilitation were $62,777 or $39.27 per hectare, almost 32.4% less than the first computed cost.

The effect of water cost on system configuration was examined by parametric programming for different water costs (0-$12.15/1,000 m^3). By increasing the cost of inflow water to $.81/1,000 m^3 it was found that all of the runoff water would be collected and reused. Further cost increases showed no effect on the configuration of the system within the specified range.

Conclusions

A methodology was developed to find the optimal least cost irrigation system incorporating internal water storage reservoirs.

The developed methodology was applied to the Snake River Irrigation District. The best irrigation interval for all crop-soil-irrigation application subsystem combinations, and the water requirement of each farm unit were computed by using stochastical analysis and cost benefit analysis of irrigation application subsystems. The methodology was effective in specifying the size and location of internal water storage reservoirs using mathematical programming techniques.

The following specific conclusions were obtained through the application of this methodology.

1. Actual evapotranspiration follows a probability distribution which is important to determine the design capacity of irrigation system components.
2. The costs and benefits of irrigation should be considered in selecting the design capacities of irrigation components.
3. The time of occurrence of maximum actual evapotranspiration may follow a type of probability distribution.
4. Least cost combinations of alternative farm service reservoir types and their sites and different alternative canal structures can be determined by using mixed integer programming.
5. Linear programming can be used for sensitivity and parametric analyses of the model.
6. Any type of constraints such as technical, social, or economical can be entered in the mixed integer or linear programming models.

Technical, economical, and social constraints may be conjunctive use of ground water and surface water, access to farm, bridge location, and others, using farm service reservoirs for recreational and agricultural uses or some adverse effects such as human safety or mosquito problems.

Recommendations

The mixed integer programming software which was used in this study was very slow and costly to run. Also, it did not provide any facility for sensitivity analysis and/or parametric programming. It would be favorable to use better software in order to be able to optimize the whole system in one model and carry out sensitivity analyses and/or parametric programming.

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APPENDIX A

JENSEN AND HAISE EQUATION
(Jensen, 1973)

JENSEN-HAISE EQUATION

The Jensen-Haise equation is:

$$PET = CT(T - Tx)\ Rs$$

where

$$C_T = \frac{1}{C_1 + C_2\ C_H}$$

$$C_H = \frac{50\ mb}{(e_2 - e_1)}$$

e_2, e_1 = salurated vapor pressure at the mean maximum and mean minimum temperature, respectively

$C_2 = 7.6°C$

$C_1 = 38 - (2°C \cdot \text{elevation in (m)}/305)$

$Tx = -2.5 - .14\ (e_2 - e_1)°C/mb - \text{elevation (m)}/550$

e_2 and e_1 are computed by Bosen's equation (1) or:

$$e \simeq 33.8639\ [(.00738T + .8072)^8 - .000019/1.8T$$

$$+ 48/+.001316]$$

e = saturated vapor pressure in mb at T average

temperature in °C for:

$-51°C < T < 54°C$

R_s solar radiation in 1g/day

PET = potential evapotranspiration in 1g/day

Pet is converted to mm/day by dividing to AT where

AT = 595 - .51 TA

TA = average daily temperature

Daily effective rainfall is deducted from daily potential evapotranspiration from here on, it is shown by PET.

APPENDIX B

SOIL DESCRIPTION OF THE STUDY AREA
(USDA-SCS, 1973)

SOIL DESCRIPTION

Bannock (Ba). The surface layer is grayish brown loam that is slightly gravelly and 15 cm thick. The subsoil is grayish-brown and light brownish-gray loam that is slightly gravelly and extends to the depth of 41 cm. The substratum, in the upper part, is pale brown and light brownish-bray, strongly calcareous stratified, gravelly loam, and very gravelly sandy loam. This is underlain by very gravelly coarse sand at a depth of 91 cm.

Bannock soil is well drained soil with level to moderate slope.

Bock (BO). The surface layer is grayish brown loam about 25 cm thick. The subsoil is brown loam that extends to a depth of 38 cm. The substratum is light brownish-gray and light gray, stratified alluvium that is mainly loam and fine sandy loam to a depth of 119 cm. Below 119 cm is very gravelly coarse sand.

Bock soil is well drained with level to very gentle slope.

Heiseton (Hs). The surface layer is grayish-brown sand loam 20 cm thick. The underlying soil is light brownish-gray, dominantly fine sandy loam that extends to a depth of 114 cm. Below 114 cm is underlain by light brownish-gray very gravelly coarse sand. Heiseton soil is moderately well drained, with level to very gentle slope.

Stan (St). The surface layer is grayish-brown and brown fine sandy loam 40 cm thick. The subsoil is pale brown fine sandy loam 33 cm thick. The substratum is light gray fine sandy loam to a depth of 127 cm. It is underlain by light gray, very gravelly light sandy loam. Stan soil is well drained soil with slope of 0-4 percent.

APPENDIX C

COMPUTER PROGRAM AND OUTPUT SHOWING IRRIGATION PARAMETERS FOR THE SNAKE RIVER VALLEY IRRIGATION DISTRICT

Computer program and output showing possible irrigation interval, peak period consumptive use, related probability level, recurrence interval, level of risk, annual evapotranspiration, and estimated number of irrigations for the Snake River Valley Irrigation District

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FORTRAN IV G LEVEL  21                 MAIN                DATE = 80228           09/12/25              PAGE 0001
  0001               DIMENSION TIT(6),TITL(19)
                C***************THIS PROGRAM COMPUTES ALL POSSIBLE IRRIGATION INTE-**************
                C***************VALS AND PLOT DATA  ( ET DATA ) ON A PREDEFIND       **************
                C***************PROBABILITY PAPER.  THE INPUT DATA ARE ACCUMULATED **************
                C*************** ET WITH DATE AND DURATION AND SOIL CRCP INFORMATI-**************
                C***************ON.                                                 **************
  0002               DIMENSION RCOT(100),AMW(100),AA(100),B(100),AVW(100),S1(100),S2(10
                    *0)
  0003               DIMENSION  X(100),Y(100) ,X1(100),P(100),YY(100),YR(100),IDA(100)
  0004               DIMENSION YL(100),AMLG(100),STAL(100),CVLL(100),IM(100),AMA(100),
                    *STA(100),CVA(100),IMA(100),IDAA(100)
                C    NN  LIFE OF IRRIGATION APPLICATION SUBSYSTEM (YEAR)
                C    NCROP  NO. OF CRPS
  0005               NCROP=1
                C    NSOIL  NO. OF SOILS
                C    N  NO. OF YEARS WHICH DATA ARE AVAILABLE
                C    LL NO. OF DATA POINT ON PROBABILITY AXIS
                C    LGIX=0,IF ORIGINAL DATA SHOULD BE PLOTTED OR 1 IF LOG OF DATA SHOULD BE PLO-
                C    TTED.
  0006               READ(5,52) NN,NSCIL,N,LL,LGIX
                C    READ TYPE OF PROBABILITY PAPER
  0007               READ (5,54) TIT
                C    READ TITLE FOR PLOT.
                C    READ CAPTION FOR PLOT
  0008               READ (5,56) TITL
  0009            20 FORMAT(10F8.3)
  0010            21 FCRMAT(2F10.3)
  0011            22 FCRMAT(8F10.5)
  0012            23 FORMAT(I8,F10.3,I4)
  0013            24 FORMAT(//)
  0014            25 FCRMAT('1')
  0015            26 FCRMAT(30X,'RANKED DATA',I10,5X,'DAYS')
  0016            27 FCRMAT(4(2X,'DATE',6X,'DATA',5X,'PLOTS',1X))
  0017            29 FORMAT(4(I7,F10.2,F10.6))
  0018            30 FCRMAT(///)
  0019            36 FCRMAT(20X,' LOG ORIGINAL DATA   ')
  0020            38 FCRMAT(20X,'-     ORIGINAL DATA   ')
  0021            40 FCRMAT(7X,'NO.',2X,'DURATION',9X,'MEAN',6X,'STND. DEV.', 4X,'COE.
                    *OF VARI.')
  0022            42 FORMAT(2I10,F15.3,F15.5,F15.8)
  0023            44 FCRMAT(20X,'LOGARITMIC DATA')
  0024            46 FCRMAT(20X,'ORIGINAL  DATA')
  0025            48 FCRMAT(F10.0,2A4)
  0026            49 FCRMAT(2F10.0,2A4)
  0027            52 FORMAT (5I5 )
  0028            54 FORMAT(5A4,A2)
  0029            56 FCRMAT(18A4,A2)
  0030               CALL PLOTS(0,0,13)
  0031               CALL PLOT(4.,-15.,-3)
  0032               CALL PLCT(0.,3.,-3)
  0033               M=N+2
  0034               L=LL+1
  0035               MM=M+1
                C    READ X CORRRDINATE OF PLOTTING POSITION ON A PROBABILITY PAPER
  0036               READ(5,20) (X(I),I=3,L )
                C    READ PROBAILITY NO. OF SOME POINT ON PROBABILITY PAPER BEYOND THE DATA POINT
  0037               READ(5,22) (P(I), I=MM,L)
                C    READ MAXIMUM ASSUMED ET (MAX. POSSIB. NO. )
```

```
 FORTRAN IV G LEVEL  21                  MAIN              DATE = 80228        09/12/25             PAGE 0002

   0038                READ (5,48) Y(2)
                C    READ ROOT DEPTH (MM), MANAGEMENT ALLOWED DEFICIT ( % ) AND CROP NAME
   0039                READ(5,49) (ROOT(I),AMW(I),AA(I),B(I),I=1,NCROP)
                C    READ  AVAILABLE SOIL MOISTURE ( MM/MM ) AND SOIL NAME
   0040                READ(5,48) (AVW(I),S1(I),S2(I),I=1,NSOIL)
   0041                X(1)=0.
   0042                X(2)=0.
   0043                Y(1)=0.0
   0044                IF(LGIX.EQ.0.0)  GO TO 1
   0045                Y(1)=5.0
   0046              1 CONTINUE
   0047                P(1)=0.
   0048                P(2)=.0001
   0049                DO 5 I=2,L
   0050              5 X(I)=X(I)/40.
   0051                DO 7 I=1,M
   0052              7 X1(I)=X(I)
   0053                A=X(M)
   0054                DO 8 I=3,M
   0055              8 P(I)=FLOAT(I-2)/FLOAT(M-1)
   0056                II=0.
   0057                YM=1.5
   0058                INDX=1
   0059                DO 16 J=1,31
   0060                MN=1
   0061                DO 14 I=1,N
                C    READ DATE , ACCUMU.  ET  AND DURATION.
   0062                READ(10,23) ID,ET,MDU
   0063                IDA(MN)=ID
   0064                YY(MN)=    ET
   0065                MN=MN+1
   0066             14 CONTINUE
   0067                CALL RANK(I,IDA,YY,YR,IDAA)
   0068                WRITE(6,25)
   0069                WRITE(6,26)    MDU
   0070                WRITE(6,27)
   0071                WRITE(6,29) (IDAA(I),YR(I),P(I+2),I=1,N)
   0072                WRITE(6,24)
   0073                IF(LGIX.EQ.0.0)  GO TO 2
   0074                DO 15 K=1,I
   0075             15 YL(K)=ALOG10(YR(K))
   0076                WRITE(6,36)
   0077                WRITE(6,30)
   0078                CALL STAT (N,YL,AML,STL,CVL)
   0079                AMLG(J)=AML
   0080                STAL(J)=STL
   0081                CVLL(J)=CVL
   0082                IM(J)=MDU
   0083              2 CONTINUE
   0084                WRITE(6,30)
   0085                WRITE(6,38)
   0086                WRITE(6,30)
   0087                CALL           STAT(N,YR,AM,ST,CV)
   0088                AMA(J)=AM
   0089                STA(J)=ST
   0090                CVA(J)=CV
   0091                IMA(J)=MDU
   0092                IF (J.EQ.31) GO TO 6
```

```
      IF(J.NE.INDX)  GO TO 16
      IF(J.LT.4) K=1
      IF (J.GE.4 ) K=2
      IF (J.GE.10) K=5
      INDX=INDX+K
    6 CONTINUE
      DO 11 I=3,M
   11 Y(I)=YR(I-2)
      IF(II.LT.12) GO TO 17
      II=0.
   17 II=II+1
      FP=MDU
      YM1=YM-.05
      CALL  SYMBOL(8.5,YM,.10,II,0.,-1)
      CALL NUMBER(8.7,YM1,.10,FP ,0.,-1)
      CALL SYMBOL (9.20,YM1,.10,'DAYS',0.,4)
      YM=YM+.16
      CALL  SCALE(X1,A  ,M ,1)
      IF(LGIX.EQ.0.0)  GO TO 4
      CALL  SCALG(Y,7.,M ,1)
      CALL LGLIN(X1(3),Y(3),N ,1,-1,II,1)
      GO TO 16
    4 CONTINUE
      CALL  SCALE(Y,7.,M ,1)
      CALL LINE(X1(3),Y(3),N ,1,-1,II)
   16 CONTINUE
      CALL  PLOT(0.,0.,3)
      CALL PLOT(X(L ),0.,2)
      DO 10 I=2,L
      CALL  PLOT(X(I),.0,3)
      CALL  PLOT(X(I),-.05,2)
      IF((X(I)-X(I-1)).LT..1)  GO TO 10
      CALL NUMBER(X(I),-.07,.05,P(I),270.,4)
   10 CONTINUE
      CALL SYMBOL (4.,.1,.14,'PERCENT GREATER THAN',0.,20)
      CALL SYMBOL(6.,7.5,.14,TIT                                 ,0.,22)
      CALL SYMBOL(.7,-.6,.10,TITL  ,0.,74)
      IF(LGIX.EQ.0.0)  GO TO 18
      CALL LGAXS(0.,0.,'ACCUM. ACTUAL  EVAPOTRA.',24,7.,90.,Y(M+1),Y(M+2
     *))
      GO TO  3
   18 CONTINUE
      CALL SYMBOL(6.,7.5,.14,TIT  ,0.,22)
      CALL AXIS(0.,0.,'ACCUM. POTENT. EVAPOTRA.',24,7.,90.,Y(M+1),Y(M+2)
     *)
    3 CONTINUE
      IF(LGIX.EQ.0.0) GO TO 19
      WRITE(6,25)
      WRITE(6,44)
      WRITE(6,40)
      WRITE(6,42)
      WRITE(6,42) (I,IM(I),AMLG(I),STAL(I),CVLL(I),I=1,J)
      WRITE(6,42)
      WRITE(6,30)
   19 CONTINUE
      WRITE(6,46)
      WRITE(6,42)
      WRITE(6,40)
```

```
FORTRAN IV G LEVEL  21                  MAIN                DATE = 80228          09/12/25               PAGE 0004

  0149              WRITE(6,42)
  0150              WRITE(6,42)  (I,IMA(I),AMA(I),STA(I),CVA(I),I=1,J)
  0151              CALL PLOT(14.,0.,999)
  0152              CALL        IRIN(NCROP,NSOIL,ROOT,AMW,AA,B,AVW,IM,AMLG,STAL, NN,S1,
                   *S2)
  0153              CALL PLOT (15.,0.,999)
  0154              STOP
  0155              END
```

```
FORTRAN IV G LEVEL  21                    RANK              DATE = 80228          09/12/25             PAGE 0001

 0001                  SUBROUTINE RANK(N ,DA ,A,BB, IDAT)
                 C   RANKS DATA ANC KEEP DATE WITH THE DATA.
 0002                  DIMENSION A(400),DA(400),B(400)
 0003                  DIMENSION IDAT(400),BB(400)
 0004                  INTEGER DA
 0005                  DO 15 I=1,N
 0006               15 B(I)=A(I)
 0007                  NN=N-1
 0008                  DO 100 J=1,NN
                 C
                 C     FIND LOCATICN OF BIGGEST
                 C
 0009                  L=J
 0010                  JJ=J+1
 0011                  DO 2 I=JJ,N
 0012                  IF(A(L)-A(I)) 4,2,2
 0013                4 L=I
 0014                2 CONTINUE
                 C
                 C     INTERCHANGE A(L) WITH A(J)
                 C
 0015                  T=A(L)
 0016                  A(L)=A(J)
 0017                   A(J)=T
 0018              100 CONTINUE
 0019                  M=1
 0020                  DO 16 J=1,N
 0021                  DO 17 I=1,N
 0022                  IF (B(I).NE.A(J))  GO TO 17
 0023                  IDAT(M)=DA(I)
 0024                  BB(M)=B(I)
 0025                  M=M+1
 0026               17 CONTINUE
 0027               16 CONTINUE
 0028                  LL=M-1
 0029                  RETURN
 0030                  END
```

```
      FORTRAN IV G LEVEL  21                 STAT              DATE = 80228           09/12/25            PAGE 0001

      0001                SUBROUTINE  STAT(N,Y,AM,ST,CV)
                    C   COMPUTES MEAN , STANDARD DEV. AND COEFF. OF VARIA. .
      0002                DIMENSION Y(400)
      0003             29 FORMAT(//)
      0004             30 FORMAT(10X,'MEAN IS                                          ',F10.3)
      0005             32 FORMAT(10X,'STANDARD DEVIATION IS                            ',F10.5)
      0006             34 FORMAT(10X,'COEFFICIENT OF VARIATION IS                      ',F10.5)
      0007                AM=0.
      0008                DV=0.
      0009                DO 10 I=1,N
      0010             10 AM=Y(I)+AM
      0011                AM=AM/N
      0012                DO 11 I=1,N
      0013             11 DV=DV+(Y(I)-AM)**2
      0014                ST=SQRT(DV/(N-1))
      0015                CV=ST/AM
      0016                WRITE(6,30) AM
      0017                WRITE(6,29)
      0018                WRITE(6,32) ST
      0019                WRITE(6,29)
      0020                WRITE(6,34) CV
      0021                RETURN
      0022                END
```

```
FORTRAN IV G LEVEL  21                 IRIN              DATE = 80228        09/12/25.               PAGE 0001

 0001                SUBROUTINE IRIN(NCROP,NSOIL,ROOT,AMW, A,B,AVW,MD,AMEAN,STAN,NN,S1,
                    *S2)
               C   COMPUTES ALL POSSIBLE IRRIGATION INTERVALS .
 0002                DIMENSION ROOT(100),AMW(100),A(100),B(100),AVW(100),S1(100),S2(100
                    *),YRE(200),ANIR(200)
 0003                DIMENSION MD(100),AMEAN(100),STAN(100),ZN(112    ),AGWR(112    )
 0004                DIMENSION T(100),PR(100),RIS(100)
 0005                WRITE(6,29)
 0006                DO 10 I=1,NCROP
 0007                KN=0
 0008                DO 12 J=1,NSOIL
 0009                GWR=ROOT(I)*AMW(I)*AVW(J)
 0010                KN=KN+1
 0011                WRITE(6,23)
 0012                WPITE(6,24) A(I),B(I)
 0013                WRITE(6,25) S1(J),S2(J)
 0014                WRITE(6,26) ROOT(I)
 0015                WRITE(6,27) AMW(I)
 0016                WRITE(6,28) AVW(J)
 0017                WRITE(6,30)   GWR
 0018                CALL         ZSTA(MD,AMEAN,STAN,GWR,ZN,AGWR,PR,T,RIS,NN,YRE,ANIR)
 0019                WRITE(6,48)
 0020                KM=0
 0021                DO 18 M=1,31
 0022                IF(ZN(M).GT. 3.9) GO TO 18
 0023                IF(ZN(M).LT.-3.9) GO TO 18
 0024                IF (KM.EQ.1) GO TO 5
 0025                WRITE(6,42)
 0026                IF(M.EQ.1) GO TO 5
 0027                NF=1
 0028                N=M-1
 0029                RIS(N )=100.
 0030                PR(N)=1.0
 0031                T(N)=9999.
 0032                WRITE(6,44)NF,MD(N),AGWR(N),ZN(N),PR(N),T(N),RIS(N),YRE(N),ANIR(N)
 0033              5 CONTINUE
 0034                NF=NF+1
 0035                WRITE(6,44)NF,MD(M),AGWR(M),ZN(M),PR(M),T(M),RIS(M),YRE(M),ANIR(M)
 0036                KM=1
 0037             18 CONTINUE
 0038                WRITE(6,50)
 0039                WRITE(6,29)
 0040             12 CONTINUE
 0041             10 CONTINUE
 0042             23 FORMAT(10X,' NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK'/)
 0043             24 FORMAT(10X,'1.   LOCALLY ADOPTED CROP',5X,2A4)
 0044             25 FORMAT(10X,'2.   SOIL TYPE',5X,2A4)
 0045             26 FORMAT(10X,'3.   ROOT  ZONE DEPTH ( MM ) ',F10.2  )
 0046             27 FORMAT(10X,'4.   MANAGEMENT ALLOWED DEFICIT ( % ) ',F10.2)
 0047             28 FORMAT(10X,'5.   AVAILABLE SOIL MOISTURE  (MM/MM)',F10.2 )
 0048             29 FORMAT('1')
 0049             30 FORMAT(10X,'6.   READILY AVAILABLE SOIL MOISTURE (MM)   ',F10.2   )
 0050             35 FORMAT(3(I5,2F10.0))
 0051             42 FORMAT(5X,'NO.',2X,'IRRIGATION',1X,'PEAK',7X,'Z*',3X,'PROBABILITY'
                    *,2X,'RECURENCE',2X,'RISK',4X,'ANNUAL',4X,'ESTIMATED'/,10X,
                    *'INTERVAL',3X,'PEROD',24X,'INTERVAL',4X,'(%)',4X,'ACTUAL',4X,
                    *'NUMBER OF'/,10X,'DURING',5X,'CONSUM.',22X,'(YEARS)',12X,'EVAPOT.'
                    *,3X,'IRRIGATION'/,10X,'PERIOD OF',2X,'USE RATE',42X,'(MM)',
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      FORTRAN IV G LEVEL  21                   IRIN              DATE = 80228         09/12/25              PAGE 0002
                          *5X,/,10X,'MAXIMUM',4X,'(MM/DAY)'/,10X,'CONSUMPTIVE'/,
                          *10X,'USE' ,1 X,'(DAYS)'  )
        0052           44 FORMAT(2I8 ,F10.2,F10.3,F10.4,F10.1,F10.3,F10.1,F10.1)
        0053           48 FCRMAT(////)
        0054           50 FORMAT(5X,'* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., RE
                          *C. INTER. =9999.')
        0055              STOP
        0056              END
```

```
 FORTRAN IV G LEVEL  21                  ZSTA               DATE = 80228          09/12/25              PAGE 0001

                SUBROUTINE ZSTA(MD,AMEAN,STAN,GWR,ZN,AGWR,PR,T,RIS,NN,YRE,ANIR)
           C  COMPUTES PROBABILITY LEVEL FROM  Z .
                DIMENSION MD(100),AMEAN(100),STAN(100),ZN(112    ),AGWR(112   )
                DIMENSION T(100),PR(100),RIS(100),YRE(200),ANIR(200)
                DO 18 I=1,31
                ZN(   I)=(ALOG10(GWR)-AMEAN(I))/STAN(I)
                YRE(I)=  10**(ZN(I)*STAN(31) +AMEAN(31) )
                ANIR(I)=YRE(I)/GWR
                IF(ZN(I).GT. 3.9)  GO TO 8
                IF(ZN(I).LT.-3.9)  GO TO 8
                IF(ABS(ZN(I)).LT..10) ZN(I)=0.0
                AGWR(   I)=GWR/MD(I)
                P =0.0
                SIGN=-1.0
                M=1
                DO 10 II=1,25
                A=1.
                DO 20 J=2,II
             20 A=(J-1)*A
                SIGN=-1.0*SIGN
                ZM=SIGN          *(ZN(I)/SQRT(2.))**M/(  A    *M)
                M=M+2
                P=P+2.*ZM/SCRT(3.14159)
             10 CONTINUE
                PR(I)=(1.+P)/2.
                T(I)=1./(1.-PR(I))
                IF(PR(I).LT.  .01) GO TO 8
                RIS(I)=EXP(NN*ALOG(PR(I))) *100.
                GO TO 18
              8 RIS(I)=0.0
                AGWR(I)=GWR/MD(I)
                PR(I)=0.0
                T(I)=0.0
             18 CONTINUE
                RETURN
                END
```

```
     NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.   LOCALLY ADOPTED CROP     WHEAT
     2.   SOIL TYPE     BONNOCK
     3.   ROOT ZONE DEPTH ( MM )      762.00
     4.   MANAGEMENT ALLOWED DEFICIT ( % )          0.50
     5.   AVAILABLE SOIL MOISTURE  (MM/MM)        0.15
     6.   READILY AVAILABLE SOIL MOISTURE (MM)          57.15


NO.  IRRIGATION PEAK        Z*   PROBABILITY  RECURENCE  RISK     ANNUAL     ESTIMATED
     INTERVAL   PEROD                         INTERVAL    (%)     ACTUAL     NUMBER OF
     DURING     CONSUM.                       (YEARS)             EVAPCT.    IRRIGATION
     PERIOD OF  USE RATE                                           (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       3     19.05      6.233   1.0000     9999.0   100.000    1298.5       22.7
  2       4     14.29      3.670   0.9999     8128.5    99.754     724.9       12.7
  3       5     11.43      1.953   0.9746       39.4    59.783     490.6        8.6
  4       6      9.52      0.773   0.7803        4.6     0.700     375.1        6.6
  5       7      8.16      0.0     0.5000        2.0     0.000     310.5        5.4
  6       8      7.14     -0.769   0.2210        1.3     0.000     264.2        4.6
  7       9      6.35     -1.391   0.0821        1.1     0.000     229.3        4.0
  8      10      5.71     -1.841   0.0328        1.0     0.000     207.0        3.6
  9      11      5.20     -2.239   0.0126        1.0     0.000     189.1        3.3
 10      12      4.76     -2.539   0.0               0.0     0.0       176.6        3.1
 11      13      4.40     -2.715   0.0               0.0     0.0       169.7        3.0
 12      14      4.08     -2.868   0.0               0.0     0.0       163.9        2.9
 13      15      3.81     -3.147   0.0               0.0     0.0       153.8        2.7
 14      16      3.57     -3.345   0.0               0.0     0.0       147.0        2.6
 15      17      3.36     -3.586   0.0               0.0     0.0       139.2        2.4
 16      18      3.17     -3.809   0.0               0.0     0.0       132.3        2.3
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CROP      WHEAT
     2.  SOIL TYPE     BOCK
     3.  ROOT ZONE DEPTH ( MM )      762.00
     4.  MANAGEMENT ALLOWED DEFICIT ( % )        0.50
     5.  AVAILABLE SOIL MOISTURE  (MM/MM)       0.17
     6.  READILY AVAILABLE SOIL MOISTURE (MM)        64.77



NO.  IRRIGATION PEAK       Z*    PROBABILITY  RECURENCE  RISK    ANNUAL    ESTIMATED
     INTERVAL   PEROD                         INTERVAL    (%)    ACTUAL    NUMBER CF
     DURING     CONSUM.                       (YEARS)            EVAPOT.   IRRIGATION
     PERIOD OF  USE RATE                                           (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1        4     16.19     4.700    1.0000    9999.0   100.000      916.3      14.1
  2        5     12.95     2.901    0.9981     537.5    96.344      608.7       9.4
  3        6     10.79     1.623    0.9477      19.1    34.169      455.1       7.0
  4        7      9.25     0.739    0.7700       4.3     0.537      372.2       5.7
  5        8      8.10     0.0      0.5000       2.0     0.000      317.0       4.9
  6        9      7.20    -0.581    0.2805       1.4     0.000      275.7       4.3
  7       10      6.48    -1.053    0.1461       1.2     0.000      247.6       3.8
  8       11      5.89    -1.475    0.0701       1.1     0.000      225.0       3.5
  9       12      5.40    -1.808    0.0353       1.0     0.000      208.6       3.2
 10       13      4.98    -2.031    0.0211       1.0     0.000      198.3       3.1
 11       14      4.63    -2.220    0.0132       1.0     0.000      189.9       2.9
 12       15      4.32    -2.495    0.0          0.0     0.0        178.4       2.8
 13       16      4.05    -2.700    0.0          0.0     0.0        170.3       2.6
 14       17      3.81    -2.941    0.0          0.0     0.0        161.2       2.5
 15       18      3.60    -3.164    0.0          0.0     0.0        153.2       2.4
 16       19      3.41    -3.372    0.0          0.0     0.0        146.2       2.3
 17       20      3.24    -3.522    0.0          0.0     0.0        141.2       2.2
 18       21      3.08    -3.650    0.0          0.0     0.0        137.2       2.1
 19       22      2.94    -3.764    0.0          0.0     0.0        133.7       2.1
 20       23      2.82    -3.786    0.0          0.0     0.0        133.0       2.1
 21       24      2.70    -3.822    0.0          0.0     0.0        131.9       2.0
 22       25      2.59    -3.874    0.0          0.0     0.0        130.4       2.0
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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     NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

    1.   LOCALLY ADOPTED CROP      WHEAT
    2.   SOIL TYPE      HAYESTON
    3.   ROOT ZONE DEPTH ( MM )      762.00
    4.   MANAGEMENT ALLOWED DEFICIT ( % )        0.50
    5.   AVAILABLE SOIL MOISTURE  (MM/MM)       0.12
    6.   READILY AVAILABLE SCIL MOISTURE (MM)         45.72



NO.    IRRIGATION PEAK          Z*    PROBABILITY   RECURENCE   RISK      ANNUAL     ESTIMATED
       INTERVAL   PEROD                             INTERVAL     (%)      ACTUAL     NUMBER OF
       DURING     CONSUM.                           (YEARS)               EVAPOT.    IRRIGATION
       PERIOD OF  USE RATE                                                 (MM)
       MAXIMUM    (MM/DAY)
       CONSUMPTIVE
       USE (DAYS)
  1          3    15.24      4.224     1.0000      9999.0   100.000      822.2        18.0
  2          4    11.43      1.833     0.9666        29.9    50.673      477.4        10.4
  3          5     9.14      0.263     0.6037         2.5     0.004      334.0         7.3
  4          6     7.62     -0.742     0.2290         1.3     0.000      265.8         5.8
  5          7     6.53     -1.479     0.0696         1.1     0.000      224.8         4.9
  6          8     5.71     -2.196     0.0140         1.0     0.000      190.9         4.2
  7          9     5.08     -2.836     0.0                0.0     0.0        165.1         3.6
  8         10     4.57     -3.245     0.0                0.0     0.0        150.4         3.3
  9         11     4.16     -3.601     0.0                0.0     0.0        138.7         3.0
 10         12     3.81     -3.841     0.0                0.0     0.0        131.3         2.9
* FOR   Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.   LOCALLY ADOPTED CROP      WHEAT
     2.   SOIL TYPE      HEISETCN
     3.   ROOT ZONE DEPTH ( MM )      762.00
     4.   MANAGEMENT ALLOWED DEFICIT ( % )           0.50
     5.   AVAILABLE SOIL MOISTURE  (MM/MM)          0.13
     6.   READILY AVAILABLE SOIL MOISTURE (MM)          49.53


NO.  IRRIGATION PEAK        Z*   PROBABILITY  RECURENCE  RISK     ANNUAL    ESTIMATED
     INTERVAL   PEROD                         INTERVAL    (%)     ACTUAL    NUMBER OF
     DURING     CONSUM.                       (YEARS)             EVAPCT.   IRRIGATION
     PERIOD OF  USE RATE                                           (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       3     16.51      4.944    1.0000      9999.0   100.000     968.6       19.6
  2       4     12.38      2.492    0.9936       157.3    88.027     554.5       11.2
  3       5      9.91      0.869    0.8076         5.2     1.394     383.4        7.7
  4       6      8.25     -0.199    0.4213         1.7     0.000     300.8        6.1
  5       7      7.08     -0.969    0.1662         1.2     0.000     252.4        5.1
  6       8      6.19     -1.684    0.0461         1.0     0.000     214.5        4.3
  7       9      5.50     -2.318    0.0102         1.0     0.000     185.8        3.8
  8      10      4.95     -2.742    0.0            0.0     0.0       168.7        3.4
  9      11      4.50     -3.113    0.0            0.0     0.0       155.0        3.1
 10      12      4.13     -3.374    0.0            0.0     0.0       146.1        2.9
 11      13      3.81     -3.498    0.0            0.0     0.0       142.0        2.9
 12      14      3.54     -3.610    0.0            0.0     0.0       138.4        2.8
 13      15      3.30     -3.891    0.0            0.0     0.0       129.9        2.6
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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        NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

        1.   LOCALLY ADOPTED CROP      WHEAT
        2.   SOIL TYPE      PAESL
        3.   ROOT ZONE DEPTH ( MM )       762.00
        4.   MANAGEMENT ALLOWED DEFICIT ( % )        0.50
        5.   AVAILABLE SOIL MOISTURE  (MM/MM)      0.19
        6.   READILY AVAILABLE SOIL MOISTURE (MM)        72.39


NO.  IRRIGATION PEAK        Z*   PROBABILITY  RECURENCE  RISK    ANNUAL      ESTIMATED
     INTERVAL   PEROD                         INTERVAL    (%)    ACTUAL      NUMBER OF
     DURING     CONSUM.                       (YEARS)            EVAPOT.     IRRIGATION
     PERIOD OF  USE RATE                                          (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1      4      18.10     5.616     1.0000     9999.0   100.000     1128.4      15.6
  2      5      14.48     3.744     0.9999    13189.6    99.848      737.2      10.2
  3      6      12.06     2.379     0.9913      115.1    83.980      540.4       7.5
  4      7      10.34     1.447     0.9261       13.5    21.523      437.3       6.0
  5      8       9.05     0.744     0.7715        4.4     0.558      372.6       5.1
  6      9       8.04     0.139     0.5551        2.2     0.001      324.7       4.5
  7     10       7.24    -0.353     0.3619        1.6     0.000      290.3       4.0
  8     11       6.58    -0.796     0.2129        1.3     0.000      262.5       3.6
  9     12       6.03    -1.159     0.1232        1.1     0.000      241.7       3.3
 10     13       5.57    -1.422     0.0775        1.1     0.000      227.7       3.1
 11     14       5.17    -1.643     0.0502        1.1     0.000      216.6       3.0
 12     15       4.83    -1.916     0.0277        1.0     0.000      203.5       2.8
 13     16       4.52    -2.127     0.0167        1.0     0.000      194.0       2.7
 14     17       4.26    -2.368     0.0               0.0     0.0        183.7       2.5
 15     18       4.02    -2.591     0.0               0.0     0.0        174.6       2.4
 16     19       3.81    -2.798     0.0               0.0     0.0        166.5       2.3
 17     20       3.62    -2.955     0.0               0.0     0.0        160.7       2.2
 18     21       3.45    -3.088     0.0               0.0     0.0        155.9       2.2
 19     22       3.29    -3.208     0.0               0.0     0.0        151.7       2.1
 20     23       3.15    -3.246     0.0               0.0     0.0        150.4       2.1
 21     24       3.02    -3.293     0.0               0.0     0.0        148.8       2.1
 22     25       2.90    -3.356     0.0               0.0     0.0        146.7       2.0
 23     26       2.78    -3.440     0.0               0.0     0.0        143.9       2.0
 24     27       2.68    -3.563     0.0               0.0     0.0        139.9       1.9
 25     28       2.59    -3.648     0.0               0.0     0.0        137.3       1.9
 26     29       2.50    -3.692     0.0               0.0     0.0        135.9       1.9
 27     30       2.41    -3.709     0.0               0.0     0.0        135.4       1.9
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CROP      WHEAT
     2.  SOIL TYPE      STAN
     3.  ROOT ZONE DEPTH ( MM )     762.00
     4.  MANAGEMENT ALLOWED DEFICIT ( % )        0.50
     5.  AVAILABLE SOIL MOISTURE  (MM/MM)     0.14
     6.  READILY AVAILABLE SOIL MOISTURE (MM)        53.34


NO.  IRRIGATION PEAK       Z*   PROBABILITY  RECURENCE  RISK    ANNUAL    ESTIMATED
     INTERVAL   PEROD                        INTERVAL    (%)    ACTUAL    NUMBER OF
     DURING     CONSUM.                      (YEARS)            EVAPOT.   IRRIGATION
     PERIOD OF  USE RATE                                          (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       3      17.78     5.612   1.0000     9999.0   100.000    1127.4      21.1
  2       4      13.33     3.102   0.9990     1036.7    98.088     637.1      11.9
  3       5      10.67     1.431   0.9237       13.1    20.459     435.6       8.2
  4       6       8.89     0.305   0.6197        2.6     0.007     337.2       6.3
  5       7       7.62    -0.497   0.3094        1.4     0.000     281.0       5.3
  6       8       6.67    -1.210   0.1131        1.1     0.000     239.0       4.5
  7       9       5.93    -1.838   0.0330        1.0     0.000     207.2       3.9
  8      10       5.33    -2.275   0.0114        1.0     0.000     187.5       3.5
  9      11       4.85    -2.660   0.0           0.0     0.0       171.8       3.2
 10      12       4.44    -2.942   0.0           0.0     0.0       161.2       3.0
 11      13       4.10    -3.093   0.0           0.0     0.0       155.7       2.9
 12      14       3.81    -3.226   0.0           0.0     0.0       151.1       2.8
 13      15       3.56    -3.506   0.0           0.0     0.0       141.8       2.7
 14      16       3.33    -3.701   0.0           0.0     0.0       135.6       2.5
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CROP      ALFALFA
     2.  SOIL TYPE     BONNOCK
     3.  ROOT ZONE DEPTH ( MM )     1219.20
     4.  MANAGEMENT ALLOWED DEFICIT ( % )              0.55
     5.  AVAILABLE SOIL MOISTURE  (MM/MM)       0.15
     6.  READILY AVAILABLE SOIL MOISTURE (MM)       100.58


NO.  IRRIGATION PEAK       Z*    PROBABILITY  RECURENCE  RISK    ANNUAL    ESTIMATED
     INTERVAL   PEROD                         INTERVAL    (%)    ACTUAL    NUMBER OF
     DURING     CONSUM.                       (YEARS)            EVAPOT.   IRRIGATION
     PERIOD OF  USE RATE                                           (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       7     14.37     4.115     1.0000    9999.0   100.000    1166.5      11.6
  2       8     12.57     2.810     0.9975     403.1    95.154     995.6       9.9
  3       9     11.18     1.690     0.9545      22.0    39.386     869.1       8.6
  4      10     10.06     0.655     0.7439       3.9     0.269     766.5       7.6
  5      11      9.14    -0.317     0.3758       1.6     0.000     681.2       6.8
  6      12      8.38    -1.175     0.1199       1.1     0.000     613.8       6.1
  7      13      7.74    -1.975     0.0242       1.0     0.000     557.0       5.5
  8      14      7.18    -2.669     0.0          0.0     0.0       512.0       5.1
  9      15      6.71    -3.392     0.0          0.0     0.0       469.0       4.7
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.   LOCALLY ADOPTED CROP      ALFALFA
     2.   SOIL TYPE     BOCK
     3.   ROOT ZONE DEPTH ( MM )     1219.20
     4.   MANAGEMENT ALLOWED DEFICIT ( % )          0.55
     5.   AVAILABLE SOIL MOISTURE  (MM/MM)        0.17
     6.   READILY AVAILABLE SOIL MOISTURE (MM)          114.00



 NO.     IRRIGATION PEAK          Z*    PROBABILITY   RECURENCE   RISK      ANNUAL      ESTIMATED
         INTERVAL   PEROD                             INTERVAL     (%)      ACTUAL      NUMBER OF
         DURING     CONSUM.                           (YEARS)               EVAPOT.     IRRIGATION
         PERIOD OF  USE RATE                                                 (MM)
         MAXIMUM    (MM/DAY)
         CONSUMPTIVE
         USE (DAYS)
   1         8      14.25       4.245    1.0000       9999.0    100.000     1185.0         10.4
   2         9      12.67       3.145    0.9992       1200.4     98.347     1036.9          9.1
   3        10      11.40       2.077    0.9811         53.0     68.303      910.9          8.0
   4        11      10.36       1.104    0.8651          7.4      5.514      809.4          7.1
   5        12       9.50       0.208    0.5824          2.4      0.002      726.0          6.4
   6        13       8.77      -0.578    0.2816          1.4      0.000      659.9          5.8
   7        14       8.14      -1.276    0.1009          1.1      0.000      606.3          5.3
   8        15       7.60      -1.983    0.0237          1.0      0.000      556.5          4.9
   9        16       7.12      -2.711    0.0             0.0      0.0        509.4          4.5
  10        17       6.71      -3.247    0.0             0.0      0.0        477.3          4.2
  11        18       6.33      -3.649    0.0             0.0      0.0        454.6          4.0
 * FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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          NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

          1.   LOCALLY ADOPTED CROP      ALFALFA
          2.   SOIL TYPE      HAYESTON
          3.   ROOT ZONE DEPTH ( MM )      1219.20
          4.   MANAGEMENT ALLOWED DEFICIT ( % )        0.55
          5.   AVAILABLE SOIL MOISTURE  (MM/MM)      0.12
          6.   READILY AVAILABLE SOIL MOISTURE (MM)          80.47


      NO.     IRRIGATION PEAK          Z*    PROBABILITY  RECURENCE  RISK     ANNUAL     ESTIMATED
              INTERVAL   PEROD                            INTERVAL    (%)     ACTUAL     NUMBER OF
              DURING     CONSUM.                          (YEARS)             EVAPOT.    IRRIGATION
              PERIOD OF  USE RATE                                              (MM)
              MAXIMUM    (MM/DAY)
              CONSUMPTIVE
              USE (DAYS)
       1         5       16.09      5.399     1.0000      9999.0   100.000    1363.3       16.9
       2         6       13.41      3.238     0.9994      1652.6    98.797    1048.7       13.0
       3         7       11.50      1.582     0.9431        17.6    31.004     857.7       10.7
       4         8       10.06      0.252     0.5993         2.5     0.004     729.8        9.1
       5         9        8.94     -0.904     0.1831         1.2     0.000     634.4        7.9
       6        10        8.05     -1.880     0.0300         1.0     0.000     563.5        7.0
       7        11        7.32     -2.848     0.0            0.0     0.0       501.0        6.2
       8        12        6.71     -3.642     0.0            0.0     0.0       455.0        5.7
      * FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CROP     ALFALFA
     2.  SOIL TYPE     HEISETON
     3.  ROOT ZONE DEPTH ( MM )    1219.20
     4.  MANAGEMENT ALLOWED DEFICIT ( % )       0.55
     5.  AVAILABLE SOIL MOISTURE  (MM/MM)      0.13
     6.  READILY AVAILABLE SOIL MOISTURE (MM)       87.17



NO.  IRRIGATION PEAK        Z*   PROBABILITY  RECURENCE  RISK     ANNUAL    ESTIMATED
     INTERVAL   PEROD                         INTERVAL    (%)     ACTUAL    NUMBER OF
     DURING     CONSUM.                       (YEARS)             EVAPOT.   IRRIGATION
     PERIOD OF  USE RATE                                           (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       6     14.53       4.166     1.0000     9999.0  100.000    1173.8      13.5
  2       7     12.45       2.490     0.9936      156.7   87.980     957.7      11.0
  3       8     10.90       1.169     0.8788        8.3    7.554     815.8       9.4
  4       9      9.69       0.0       0.5000        2.0    0.000     710.2       8.1
  5      10      8.72      -0.971     0.1659        1.2    0.000     629.2       7.2
  6      11      7.92      -1.940     0.0262        1.0    0.000     559.4       6.4
  7      12      7.26      -2.757     0.0           0.0    0.0       506.6       5.8
  8      13      6.71      -3.571     0.0           0.0    0.0       458.9       5.3
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CROP     ALFALFA
     2.  SOIL TYPE     PAESL
     3.  ROOT ZONE DEPTH ( MM )    1219.20
     4.  MANAGEMENT ALLOWED DEFICIT ( % )       0.55
     5.  AVAILABLE SOIL MOISTURE  (MM/MM)      0.19
     6.  READILY AVAILABLE SOIL MOISTURE (MM)      127.41



NO.  IRRIGATION PEAK       Z*    PROBABILITY  RECURENCE  RISK    ANNUAL    ESTIMATED
     INTERVAL   PEROD                         INTERVAL    (%)    ACTUAL    NUMBER OF
     DURING     CONSUM.                       (YEARS)            EVAPOT.   IRRIGATION
     PERIOD OF  USE RATE                                           (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       9     14.16     4.438    1.0000    9999.0   100.000    1213.1       9.5
  2      10     12.74     3.341    0.9996    2410.5    99.174    1061.9       8.3
  3      11     11.58     2.366    0.9910     111.1    83.458     943.3       7.4
  4      12     10.62     1.438    0.9247      13.3    20.909     842.9       6.6
  5      13      9.80     0.663    0.7463       3.9     0.287     767.2       6.0
  6      14      9.10     0.0      0.5000       2.0     0.000     704.6       5.5
  7      15      8.49    -0.731    0.2325       1.3     0.000     647.8       5.1
  8      16      7.96    -1.414    0.0787       1.1     0.000     596.3       4.7
  9      17      7.49    -1.989    0.0234       1.0     0.000     556.1       4.4
 10      18      7.08    -2.447    0.0          0.0     0.0       526.0       4.1
 11      19      6.71    -3.065    0.0          0.0     0.0       488.0       3.8
 12      20      6.37    -3.598    0.0          0.0     0.0       457.4       3.6
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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        NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

       1.   LOCALLY ADOPTED CROP      ALFALFA
       2.   SOIL TYPE      STAN
       3.   ROOT ZONE DEPTH ( MM )     1219.20
       4.   MANAGEMENT ALLOWED DEFICIT ( % )       0.55
       5.   AVAILABLE SOIL MOISTURE   (MM/MM)     0.14
       6.   READILY AVAILABLE SOIL MOISTURE (MM)         93.86


 NO.   IRRIGATION PEAK        Z*    PROBABILITY  RECURENCE  RISK     ANNUAL     ESTIMATED
       INTERVAL   PEROD                          INTERVAL    (%)     ACTUAL     NUMBER OF
       DURING     CONSUM.                        (YEARS)             EVAPOT.    IRRIGATION
       PERIOD OF  USE RATE                                            (MM)
       MAXIMUM    (MM/DAY)
       CONSUMPTIVE
       USE (DAYS)
  1        6      15.65       5.026    1.0000     9999.0   100.000    1302.8       13.9
  2        7      13.41       3.332    0.9996     2319.9    99.141    1060.7       11.3
  3        8      11.73       2.019    0.9782       46.0    64.414     904.5        9.6
  4        9      10.43       0.888    0.8127        5.3     1.581     788.5        8.4
  5       10       9.39      -0.129    0.4488        1.8     0.000     696.9        7.4
  6       11       8.53      -1.099    0.1358        1.2     0.000     619.5        6.6
  7       12       7.82      -1.938    0.0263        1.0     0.000     559.5        6.0
  8       13       7.22      -2.744    0.0           0.0     0.0       507.4        5.4
  9       14       6.71      -3.437    0.0           0.0     0.0       466.4        5.0
 * FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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        NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

       1.   LOCALLY ACOPTED CRCP      PASTURE
       2.   SCIL TYPE      BONNCCK
       3.   RCCT ZONE DEPTH ( MM )      762.00
       4.   MANAGEMENT ALLOWED DEFICIT ( % )         0.55
       5.   AVAILABLE SOIL MCISTURE  (MM/MM)       0.15
       6.   READILY AVAILABLE SCIL MOISTURE (MM)          62.86



 NC.     IRRIGATION PEAK         Z*     PROBABILITY  RECURENCE  RISK      ANNUAL     ESTIMATED
         INTERVAL   PEROD                            INTERVAL    (%)      ACTUAL     NUMBER CF
         DURING     CCNSUM.                          (YEARS)              EVAPOT.    IRRIGATICN
         PERICD CF  USE RATE                                               (MM)
         MAXIMUM    (MM/DAY)
         CONSUMPTIVE
         USE (CAYS)
   1         4       15.72      5.235    1.0000      9999.0   100.000     1410.7       22.4
   2         5       12.57      2.662    0.9961       257.4    92.511     1029.7       16.4
   3         6       10.48      0.605    0.7272         3.7     0.171      800.5       12.7
   4         7        8.98     -0.996    0.1596         1.2     0.000      658.1       10.5
   5         8        7.86     -2.352    0.0            0.0     0.0        557.5        8.9
   6         9        6.98     -3.543    0.0            0.0     0.0        481.9        7.7
 * FOR   Z   GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
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      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CRCP      PASTURE
     2.  SOIL TYPE     BOCK
     3.  RCCT ZCNE DEPTH ( MM )      762.00
     4.  MANAGEMENT ALLOWED CEFICIT ( % )        0.55
     5.  AVAILABLE SCIL MOISTURE  (MM/MM)       0.17
     6.  READILY AVAILABLE SCIL MCISTURE (MM)        71.25


NC.  IRRIGATION PEAK        Z*   PROBABILITY  RECURENCE  RISK    ANNUAL    ESTIMATED
     INTERVAL   PEROD                         INTERVAL    (%)    ACTUAL    NUMBER CF
     DURING     CONSUM.                       (YEARS)            EVAPOT.   IRRIGATICN
     PERICD CF  USE RATE                                           (MM)
     MAXIMUM    (MM/DAY)
     CCNSUMPTIVE
     LSE (DAYS)
  1       5     14.25     4.171     1.0000     9999.0   100.000    1238.5      17.4
  2       6     11.87     2.056     0.9801       50.3    66.920     956.1      13.4
  3       7     10.18     0.425     0.6645        3.0     0.028     783.1      11.0
  4       8      8.91    -0.917     0.1797        1.2     0.000     664.5       9.3
  5       9      7.92    -2.088     0.0184        1.0     0.000     575.8       8.1
  6      10      7.12    -3.038     0.0           0.0     0.0       512.6       7.2
* FCR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTEK. =9999.
```

```
      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CROP         PASTURE
     2.  SOIL TYPE       HAYESTON
     3.  ROOT ZONE DEPTH ( MM )         762.00
     4.  MANAGEMENT ALLOWED DEFICIT ( % )        0.55
     5.  AVAILABLE SOIL MOISTURE  (MM/MM)       0.12
     6.  READILY AVAILABLE SOIL MOISTURE (MM)        50.29


NO.  IRRIGATION PEAK       Z*   PROBABILITY  RECURENCE  RISK     ANNUAL    ESTIMATED
     INTERVAL   PEROD                        INTERVAL    (%)     ACTUAL    NUMBER OF
     DURING     CONSUM.                      (YEARS)             EVAPOT.   IRRIGATION
     PERIOD OF  USE RATE                                          (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1         3   16.76     6.040    1.0000    9999.0   100.000    1556.6       31.0
  2         4   12.57     2.505    0.9939     163.4    88.445    1010.1       20.1
  3         5   10.06     0.0      0.5000       2.0     0.000     740.9       14.7
  4         6    8.38    -1.984    0.0237       1.0     0.000     583.2       11.6
  5         7    7.18    -3.530    0.0          0.0     0.0       482.7        9.6
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
   NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

  1.   LOCALLY ADOPTED CROP      PASTURE
  2.   SOIL TYPE      HEISETON
  3.   ROOT ZONE DEPTH ( MM )       762.00
  4.   MANAGEMENT ALLOWED DEFICIT ( % )          0.55
  5.   AVAILABLE SOIL MOISTURE  (MM/MM)         0.13
  6.   READILY AVAILABLE SOIL MOISTURE (MM)          54.48



NO.   IRRIGATION PEAK          Z*   PROBABILITY  RECURENCE  RISK     ANNUAL     ESTIMATED
      INTERVAL   PEROD                           INTERVAL    (%)     ACTUAL     NUMBER OF
      DURING     CONSUM.                         (YEARS)             EVAPOT.    IRRIGATION
      PERIOD OF  USE RATE                                             (MM)
      MAXIMUM    (MM/DAY)
      CONSUMPTIVE
      USE (DAYS)
  1        3     18.16       7.080     1.0000     9999.0   100.000    1767.9       32.4
  2        4     13.62       3.484     0.9997     3905.3    99.489    1138.7       20.9
  3        5     10.90       0.937     0.8256        5.7     2.162     833.7       15.3
  4        6      9.08      -1.055     0.1457        1.2     0.000     653.4       12.0
  5        7      7.78      -2.621     0.0           0.0     0.0       539.5        9.9
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
  NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

 1.   LOCALLY ADOPTED CROP      PASTURE
 2.   SOIL TYPE      PAESL
 3.   ROOT ZONE DEPTH ( MM )       762.00
 4.   MANAGEMENT ALLOWED DEFICIT ( % )          0.55
 5.   AVAILABLE SOIL MOISTURE  (MM/MM)         0.19
 6.   READILY AVAILABLE SOIL MOISTURE (MM)           79.63



NO.   IRRIGATION PEAK          Z*    PROBABILITY  RECURENCE  RISK     ANNUAL     ESTIMATED
      INTERVAL   PEROD                            INTERVAL    (%)     ACTUAL     NUMBER OF
      DURING     CONSUM.                          (YEARS)             EVAPOT.    IRRIGATION
      PERIOD OF  USE RATE                                              (MM)
      MAXIMUM    (MM/DAY)
      CONSUMPTIVE
      USE (DAYS)
  1        5      15.93       5.512     1.0000     9999.0   100.000    1459.3       18.3
  2        6      13.27       3.346     0.9996     2416.1    99.175    1119.6       14.1
  3        7      11.38       1.688     0.9543       21.9    39.198     913.9       11.5
  4        8       9.95       0.359     0.6400        2.8     0.013     776.8        9.8
  5        9       8.85      -0.795     0.2132        1.3     0.000     674.5        8.5
  6       10       7.96      -1.774     0.0380        1.0     0.000     598.4        7.5
  7       11       7.24      -2.742     0.0             0.0     0.0       531.5        6.7
  8       12       6.64      -3.539     0.0             0.0     0.0       482.1        6.1
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
  NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

 1.   LOCALLY ADOPTED CROP      PASTURE
 2.   SOIL  TYPE       STAN
 3.   ROOT ZONE DEPTH ( MM )       762.00
 4.   MANAGEMENT ALLOWED DEFICIT ( % )         0.55
 5.   AVAILABLE SOIL MOISTURE  (MM/MM)        0.14
 6.   READILY AVAILABLE SOIL MOISTURE (MM)         58.67


NO.    IRRIGATION PEAK         Z*    PROBABILITY   RECURENCE  RISK     ANNUAL      ESTIMATED
       INTERVAL   PEROD                            INTERVAL    (%)     ACTUAL      NUMBER OF
       DURING     CONSUM.                          (YEARS)             EVAPOT.     IRRIGATION
       PERIOD OF  USE RATE                                              (MM)
       MAXIMUM    (MM/DAY)
       CONSUMPTIVE
       USE (DAYS)
  1        4      14.67      4.391   1.0000       9999.0   100.000    1272.3         21.7
  2        5      11.73      1.830   0.9664         29.8    50.473     930.0         15.9
  3        6       9.78     -0.196   0.4224          1.7     0.000     725.8         12.4
  4        7       8.38     -1.779   0.0376          1.0     0.000     598.0         10.2
  5        8       7.33     -3.143   0.0             0.0     0.0       506.1          8.6
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
    NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

    1.   LOCALLY ADOPTED CROP      POTATOES
    2.   SOIL  TYPE      BONNOCK
    3.   ROOT  ZONE DEPTH ( MM )       762.00
    4.   MANAGEMENT ALLOWED DEFICIT ( % )         0.35
    5.   AVAILABLE SOIL MOISTURE   (MM/MM)      0.15
    6.   READILY AVAILABLE SOIL MOISTURE (MM)          40.00



NO.   IRRIGATION PEAK          Z*    PROBABILITY  RECURENCE  RISK     ANNUAL     ESTIMATED
      INTERVAL   PEROD                            INTERVAL    (%)     ACTUAL     NUMBER OF
      DURING     CONSUM.                          (YEARS)             EVAPOT.    IRRIGATION
      PERIOD OF  USE RATE                                              (MM)
      MAXIMUM    (MM/DAY)
      CONSUMPTIVE
      USE (DAYS)
  1        3      13.33      6.407     1.0000     9999.0   100.000     937.2        23.4
  2        4      10.00      2.731     0.9968      316.3    93.863     643.1        16.1
  3        5       8.00      0.177     0.5703        2.3     0.001     495.1        12.4
  4        6       6.67     -1.857     0.0316        1.0     0.000     402.0        10.0
  5        7       5.71     -3.565     0.0         0.0     0.0       337.5         8.4
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
 NET WATER REQUIREMENT FCR DIFFERENT LEVEL OF RISK

1.   LOCALLY ADOPTED CROP      POTATOES
2.   SOIL TYPE      BOCK
3.   ROOT ZONE DEPTH ( MM )      762.00
4.   MANAGEMENT ALLCWED DEFICIT ( % )          0.35
5.   AVAILABLE SOIL MOISTURE  (MM/MM)       0.17
6.   READILY AVAILABLE SOIL MOISTURE (MM)          45.34



NO.   IRRIGATION PEAK         Z*    PROBABILITY  RECURENCE  RISK     ANNUAL     ESTIMATED
      INTERVAL   PEROD                           INTERVAL    (%)     ACTUAL     NUMBEF CF
      DURING     CONSUM.                         (YEARS)             EVAPOT.    IRRIGATION
      PERIOD CF  USE RATE                                             (MM)
      MAXIMUM    (MM/DAY)
      CONSUMPTIVE
      USE (DAYS)
  1        4      11.33       4.296     1.0000     9999.0   100.000     755.0        16.7
  2        5       9.07       1.719     0.9572       23.4    41.673     579.8        12.8
  3        6       7.56      -0.345     0.3649        1.6     0.000     469.3        10.4
  4        7       6.48      -2.055     0.0199        1.0     0.000     393.9         8.7
  5        8       5.67      -3.534     0.0           0.0     0.0       338.6         7.5
* FCR   Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
     NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CROP      POTATOES
     2.  SOIL TYPE      HAYESTON
     3.  ROOT ZONE DEPTH ( MM )       762.00
     4.  MANAGEMENT ALLOWED DEFICIT ( % )        0.35
     5.  AVAILABLE SOIL MOISTURE  (MM/MM)       0.12
     6.  READILY AVAILABLE SOIL MOISTURE (MM)         32.00


NO.  IRRIGATION PEAK       Z*   PROBABILITY  RECURENCE  RISK    ANNUAL    ESTIMATED
     INTERVAL   PEROD                        INTERVAL    (%)    ACTUAL    NUMBER OF
     DURING     CONSUM.                      (YEARS)            EVAPCT.   IRRIGATION
     PERIOD OF  USE RATE                                          (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       2  16.00     8.757     1.0000     9999.0   100.000    1192.3      37.3
  2       3  10.67     3.384     0.9996     2763.0    99.279     687.7      21.5
  3       4   8.00     0.0       0.5000        2.0     0.000     483.2      15.1
  4       5   6.40    -2.572     0.0           0.0     0.0       373.6      11.7
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
     NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

    1.  LOCALLY ADOPTED CROP     POTATOES
    2.  SOIL TYPE      HEISETON
    3.  ROOT ZONE DEPTH ( MM )      762.00
    4.  MANAGEMENT ALLOWED DEFICIT ( % )        0.35
    5.  AVAILABLE SOIL MOISTURE  (MM/MM)       0.13
    6.  READILY AVAILABLE SOIL MOISTURE (MM)        34.67


NO.  IRRIGATION PEAK       Z*   PROBABILITY RECURENCE  RISK     ANNUAL    ESTIMATED
     INTERVAL   PEROD                       INTERVAL    (%)     ACTUAL    NUMBER OF
     DURING     CONSUM.                     (YEARS)             EVAPOT.   IRRIGATION
     PERIOD OF  USE RATE                                         (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       3     11.56     4.469   1.0000     9999.0   100.000     768.4      22.2
  2       4      8.67     0.941   0.8266        5.8     2.216     535.4      15.4
  3       5      6.93    -1.586   0.0564        1.1     0.000     413.3      11.9
  4       6      5.78    -3.586   0.0           0.0     0.0       336.7       9.7
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
        NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

       1.   LOCALLY ADOPTED CROP      POTATOES
       2.   SOIL TYPE      PAESL
       3.   ROOT ZONE DEPTH ( MM )      762.00
       4.   MANAGEMENT ALLOWED DEFICIT ( % )         0.35
       5.   AVAILABLE SOIL MOISTURE  (MM/MM)       0.19
       6.   READILY AVAILABLE SOIL MOISTURE (MM)         50.67


NO.    IRRIGATION PEAK          Z*    PROBABILITY  RECURENCE  RISK      ANNUAL     ESTIMATED
       INTERVAL   PEROD                            INTERVAL    (%)      ACTUAL     NUMBER OF
       DURING     CONSUM.                          (YEARS)              EVAPOT.    IRRIGATION
       PERIOD OF  USE RATE                                                (MM)
       MAXIMUM    (MM/DAY)
       CONSUMPTIVE
       USE (DAYS)
  1         4      12.67       5.687     1.0000      9999.0   100.000      870.6       17.2
  2         5      10.13       3.089     0.9990       992.0    98.003      667.2       13.2
  3         6       8.45       0.998     0.8409         6.3     3.128      538.6       10.6
  4         7       7.24      -0.714     0.2377         1.3     0.000      451.9        8.9
  5         8       6.33      -2.187     0.0144         1.0     0.000      388.6        7.7
  6         9       5.63      -3.491     0.0            0.0     0.0        340.0        6.7
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

```
      NET WATER REQUIREMENT FOR DIFFERENT LEVEL OF RISK

     1.  LOCALLY ADOPTED CROP      POTATOES
     2.  SOIL TYPE     STAN
     3.  ROOT ZONE DEPTH ( MM )      762.00
     4.  MANAGEMENT ALLOWED DEFICIT ( % )        0.35
     5.  AVAILABLE SOIL MOISTURE  (MM/MM)       0.14
     6.  READILY AVAILABLE SOIL MOISTURE (MM)        37.34


NO.  IRRIGATION PEAK       Z*   PROBABILITY  RECURENCE  RISK     ANNUAL    ESTIMATED
     INTERVAL   PEROD                        INTERVAL    (%)      ACTUAL    NUMBER OF
     DURING     CONSUM.                      (YEARS)              EVAPOT.   IRRIGATION
     PERIOD OF  USE RATE                                            (MM)
     MAXIMUM    (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1       3      12.45     5.472    1.0000    9999.0    100.000     851.6      22.8
  2       4       9.33     1.868    0.9691      32.4     53.373     588.7      15.8
  3       5       7.47    -0.673    0.2505       1.3      0.000     453.8      12.2
  4       6       6.22    -2.691    0.0          0.0     0.0        369.1       9.9
* FOR  Z  GT. OR LT. ABS(3.9) RISK=100. %, PROB =1., REC. INTER. =9999.
```

APPENDIX D

COMPUTER PROGRAM TO COMPUTE THE COST OF FARM SERVICE RESERVOIRS

All of the subroutines used in this program are described by Allen et al. (1978).

RESERVOIR SUBROUTINE

```
                 C   THIS PROGRAM COMPUTES COST OF RESERVOIRS IN OPEN CHANNEL           00000180
                 C   R.G.ALLEN FEB 1980                                                 00000181
                 C                                                                      00000190
                 C                                                                      00000200
 0002                  COMMON UEXC, UEXST, UEXSI, UEXPT, UERC, UERST, UERSI, UERPT,     00000210
                       UBACK, UBFST, UBFSI, UBFPT, UPREP, UCOMP, UCOMB, CLN, CNSTR,     00000220
                      ICNSIP,USTEL,UCEM,UHAUL                                           00000230
 0003                  COMMON WAGE,EQUIP,AREA,IHAUL1,IHAUL2,WAGEM,STELIN,CEMINX         00000240
 0004                  CCMMON CAN,TITLE(17)                                             00000250
                 C                                                                      00000260
 0005                  DIMENSION A(50), CTANN(500),QX(500)                              00000270
 0006                  DIMENSION TNO(50), TSZ(50)                                       00000280
 0007                  DIMENSION XSTAAH(100),XS1(100),XF(100),C79(100),C80(100),        00000290
                       IP(100),XZ(100)                                                  00000300
 0008                  DIMENSION CXN(10),LXD(10),CXQ(10)                                00000310
 0009                  DATA CN1,CN2/4HEND ,4HSKIP/                                      00000320
 0010                  KXQ = 0                                                          00000330
 0011                  NNT = 0                                                          00000340
 0012              255 FORMAT('1',///)                                                  00000350
 0013              500 FORMAT(/,' TYPE THE FF INFORMATION:'/                            00000360
                      '' ''READ---LINED CANAL''...THEN REACH IDENTIFIER>>IF LINED CANAL'/00000370
                      '' ''READ---UNLINED CANAL''...IF CANAL IS NOT LINED')             00000380
 0014              502 FORMAT(/,' TYPE THE FF DATA COMMON TO ALL REACHES'/              00000390
                      '' 1-PERCENT CONTINGENCY COST, CANAL OR LATERAL STRUCTURES'/      00000400
                      '' 2-PERCENT CONTINGENCY COST , EARTHWORK'/                       00000410
                      '' 3-PERCENT CONTINGENCY COST, ROW'/                              00000420
                      '' 4-PERCENT CONTINGENCY COST, CANAL LINING'/                     00000430
                      '' 5-CANAL STRUCTURES COST INDEX, BASE IS 1976'/                  00000440
                      '' 6-CODE FOR LINING MATERIAL USED :'/                            00000450
                      ''                                 (0) NO LINING'/                00000460
                      ''                                 (1) UNREINFORCED PORTLAND CEM'/ 00000470
                      ''                                 (2) REINFORCED PORTLAND CEM'/  00000480
                      ''                                 (3) ASPHALTIC CONCRETE'/       00000490
                      ''                                 (4) SHOTCRETE'/)               00000500
 0015              504 FORMAT(/,' TYPE CHANNEL PROPERTIES'/                             00000510
                      '' 1-SIDE SLOPE OF CANAL'/                                        00000520
                      '' 2-BASE/DEPTH OF WATER RATIO FOR CANAL RESERVOIR'/              00000530
                      '' 3-MAXIMUM DEPTH OF WATER IN RESERVOIR, FT'/                    00000531
                      '' 4-SEEPAGE RATE, FT/DAY PER SQ.FT. WETTED AREA'/)               00000532
 0016              508 FORMAT(/,' TYPE THE FF DATA'/                                    00000610
                      '' 1-LIFE OF PROJECT, YEARS'/                                     00000620
                      '' 2-ANNUAL INTEREST RATE, PERCENT'/                              00000630
                      '' 3-SALVAGE VALUE AS A PERCENT OF ORIGINAL COST'/)               00000640
 0017              512 FORMAT(/,' >>AT THIS POINT, DATA ARE FOR SPECIFIC REACH ONLY<<'/ 00000690
                      '/,' TYPE THE FF DATA FOR THIS REACH:'/                           00000700
                      '' 1-PERCENT OF ROCK EXCAVATION'/                                 00000710
                      '' 2-ADDITIONAL ROW, FT'/                                         00000711
                      '' 3-VALUE OF ROW, $/AC'/                                         00000712
                      '' 4-AREA FOR SEVERANCE PAYMENT, AC'/                             00000713
                      '' 5-UNIT COSTS FOR SEVERANCE PAY, $/AC'/)                        00000714
```

```
    0018              514 FORMAT(/,' TYPE THE FF DATA:'/                                    00000770
                         '' 1-LENGTH OF REACH, FT'/                                         00000780
                         :)                                                                 00000810
    0019              524 FORMAT(/,' TYPE DATA FOR EARTHWORK--PRISM DATA'/                  00001130
                         '' 1-ROCK CUT SLOPE'/                                              00001140
                         '' 2-UPPER CUT BANK SLOPE'/                                        00001150
                         '' 3-FILL CUT SLOPE'/                                              00001160
                         '' 4-UPPER BANK WIDTH, FT'/                                        00001170
                         '' 5-LOWER BANK WIDTH, FT'/                                        00001180
                         '' 6-COMPACTED EMBANKMENT WIDTH, FT'/                              00001190
                         '' 7-COMPACTMENT FACTOR'/                                          00001200
                         '' 8-FILL COMPACTMENT FACTOR'/                                     00001210
                         '' 9-PERCENT ROCK TO BE USED IN FILL'/                             00001220
                         '' 10-DEPTH OF CUT ADJUSTMENT---->ENTER 0.'/                       00001230
                         '' 11-COMPUTED EMBANKMENT CODE----> 0.'/)                          00001240
    0020              526 FORMAT(/,' TYPE DATA FOR TERRAIN CARD'/                           00001250
                         '' 1-STATION, FEET'/                                               00001260
                         '' 2-GROUND SLOPE, FT/FT'/                                         00001270
                         '' 3-CENTER LINE CUT, FT'/                                         00001280
                         '' 4-ROCK CENTER LINE CUT, FT'/                                    00001290
                         '' 5-STA CODE (9) WHEN STA IS THE SAME AS THE PREVIOUS ONE'/       00001300
                         ''            (0) OTHERWISE'/                                      00001310
                         '' 6-PRISM CODE (9) WHEN NEXT DATA IS A PRISM DATA'/               00001320
                         ''              (0) OTHERWISE'/                                    00001330
                         '' 7-END CODE (9)  WHEN NO TERRAIN DATA FOLLOWS'/                  00001340
                         ''            (0)  MORE TERRAIN DATA FOLLOWS'///                   00001350
                         ''--------START TYPING TERRAIN DATA--------'/                      00001360
                         ')                                                                 00001370
    0021              528 FORMAT( ' TYPE MORE TERRAIN DATA'                                 00001380
                         ')                                                                 00001390
    0022              530 FORMAT(/,' --------END OF TERRAIN DATA--------'/)                 00001400
    0023              532 FORMAT(/,' TYPE MINIMUM AC-FT, MAXIMUM AC-FT AND AC-FT INT.'/)    00001410
    0024              534 FORMAT(/,' ARE THERE SOME MORE REACH TO PROCESS--------'/         00001420
                         '' IF ''NO''  TYPE.... ''END DATA'' '/                             00001430
                         '' IF ''YES'' TYPE.... ''SKIP---LINED CANAL'' OR'/                 00001440
                         ''                     ''SKIP---UNLINED CANAL'' '//)               00001450
                    C                                                                       00001460
    0025                    WRITE(9,500)                                                    00001470
    0026                  1 CONTINUE                                                        00001480
    0027                    READ(5,150) CON,CAN,TITLE                                       00001490
    0028                    WRITE(9,150)CON,CAN,TITLE                                       00001500
    0029              150 FORMAT (A4,3X,A4,17A4)                                            00001510
    0030                    IF (CON.EQ.CN1) GO TO 98                                        00001520
    0031                    IF (CON.EQ.CN2) GO TO 3                                         00001530
                    C---READ CONTINGENCIES AND COST INDEX                                   00001540
                    C                                                                       00001550
                    C                                                                       00001560
                    C       ' CTGST = PERCENT CONTINGENCY COST FOR CANAL OR LATERAL STRUCTS.00001570
                    C       ' CTGER = PERCENT CONTINGENCY COST FOR EARTHWORK                00001580
                    C       ' CTGRW = PERCENT CONTINGENCY COST FOR RIGHT OF WAY, ETC.       00001590
                    C       ' CTGLN = PERCENT CONTINGENCY COST FOR CANAL LINING             00001600
                    C       ' CIDX  = COST INDEX FOR CANAL/LATERAL STRUCTURES WITH A BASE   00001610
                    C                 YEAR IN  JAN 1976                                     00001620
                    C       ' LCODE = CODE FOR LINING MATERIALS                             00001630
                    C                                                                       00001640
    0032                    WRITE(9,502)                                                    00001650
                    C                                                                       00001660
    0033                    CALL INPUT(A,NC)                                                00001670
```

```
             C                                                                        00001680
 0034              CTGST = A(1)                                                       00001690
 0035              CTGER = A(2)                                                       00001700
 0036              CTGRW = A(3)                                                       00001710
 0037              CTGLN = A(4)                                                       00001720
 0038              CIDX  = A(5)                                                       00001730
 0039              LCODE = A(6)                                                       00001740
             C                                                                        00001750
 0040              WRITE(9,508)                                                       00002061
 0041              CALL INPUT(A,NR)                                                   00002070
             C                                                                        00002080
             C       ' TLFE = LIFE OF PROJECT                                         00002090
             C       ' RINT = ANNUAL INTEREST RATE IN PERCENT                         00002100
             C       ' SVAL = SALVAGE VALUE AS A PERCENT OF THE ORIGINAL COST         00002110
             C                                                                        00002120
 0042              TLFE = A(1)                                                        00002130
 0043              RINT = A(2)/ 100.                                                  00002140
 0044              SVAL = A(3)                                                        00002150
             C                                                                        00002160
             C                                                                        00002330
 0045            3 CONTINUE                                                           00002340
 0046              WRITE(9,512)                                                       00002350
             C                                                                        00002360
 0047              CALL INPUT(A,NS)                                                   00002370
             C                                                                        00002380
             C      ' PERK  = PERCENT OF ROCK EXCAVATION                              00002400
             C      ' RWID  = ADDITIONAL WIDTH FOR RIGHT OF WAY,FT                    00002410
             C      ' RVAL  = VALUE OF ROW, $/AC                                      00002420
             C      ' ASER  = AREA FOR SEVERANCE PAYMENT,AC                           00002430
             C      ' UCSEV = UNIT COST SEVERANCE PAYMENT,$/AC                        00002440
             C                                                                        00002450
 0048              PERK=A(1)                                                          00002460
 0049              RWID=A(2)                                                          00002461
 0050              RVAL=A(3)                                                          00002462
 0051              ASER=A(4)                                                          00002463
 0052              UCSEV=A(5)                                                         00002464
 0053              WRITE(9,514)                                                       00002520
             C                                                                        00002530
 0054              CALL INPUT(A,NL)                                                   00002540
             C                                                                        00002550
 0055              SLEN = A(1)                                                        00002560
             C                                                                        00003410
             C---- READ IN CHANNEL PROPERTIES                                         00003411
             C                                                                        00003412
             C       Z = SIDE-SLOPE OF CHANNEL                                        00003413
             C       BH = BASE:DEPTH WATER RATIO                                      00003414
             C       YMAX = MAXIMUM DEPTH OF WATER IN RESERVOIR                       00003415
             C       SR = SEEPAGE RATE FT/DAY/SQ.FT. WETTED AREA                      00003416
             C                                                                        00003417
 0056              WRITE(9,504)                                                       00003418
             C                                                                        00003419
 0057              CALL INPUT(A,NP)                                                   00003420
             C                                                                        00003421
 0058              Z   = A(1)                                                         00003422
 0059              BH  = A(2)                                                         00003423
 0060              YMAX= A(3)                                                         00003424
 0061              SR  = A(4)                                                         00003425
             C                                                                        00003426
```

```
                C---INPUT ONE PRISM CARD FOR EACH REACH                          00003427
                C   READ PRISM CARD                                              00003430
    0062              WRITE(9,524)                                               00003440
                C                                                                00003450
    0063              CALL INPUT(A,NO)                                           00003460
    0064              S3 = A(1)                                                  00003470
    0065              S4 = A(2)                                                  00003480
    0066              S5 = A(3)                                                  00003490
    0067              WL = A(4)                                                  00003500
    0068              WR = A(5)                                                  00003510
    0069              WC = A(6)                                                  00003520
    0070              C1 = A(7)                                                  00003530
    0071              C2 = A(8)                                                  00003540
    0072              PCT = A(9)                                                 00003550
    0073              CLCNG = A(10)                                              00003560
    0074              ICEMB = A(11)                                              00003570
                C                                                                00003580
                C---READ TERRAIN CARD                                            00003590
                C                                                                00003600
    0075              KM = 0                                                     00003610
    0076              WRITE(9,526)                                               00003620
    0077          553 KM = KM + 1                                                00003630
    0078              IF(KM.GT.1)WRITE(9,528)                                    00003640
    0079              CALL INPUT(A,NS)                                           00003650
    0080              XSTAAH(KM) = A(1)                                          00003660
    0081              XS1(KM) = A(2)                                             00003670
    0082              XZ(KM) = A(3)                                              00003680
    0083              XF(KM) = A(4)                                              00003690
    0084              C79(KM) = A(5)                                             00003700
    0085              C80(KM) = A(6)                                             00003710
    0086              IP(KM) = A(7)                                              00003720
    0087              IF (IP(KM).EQ.0)GO TO 553                                  00003730
    0088              WRITE(9,530)                                               00003740
                C                                                                00003750
                C     COMPUTE CANAL EARTHWORK USING USBR PROGRAM---BR031         00003760
                C                                                                00003770
    0089              WRITE(9,532)                                               00003780
                C                                                                00003790
    0090              CALL INPUT(A,NM)                                           00003800
                C                                                                00003810
    0091              MINQ = A(1)                                                00003820
    0092              MAXQ = A(2)                                                00003830
    0093              KNTQ = A(3)                                                00003840
                C                                                                00003850
    0094              WRITE(9,566)                                               00003860
    0095          566 FORMAT(/,' >>>>>>>END OF DATA FOR THIS REACH<<<<<<<'///)   00003870
                C                                                                00003880
                C    COMPUTE COSTS FOR A RANGE OF DISCHARGES                     00003890
                C                                                                00003900
    0096              KX = 0                                                     00003910
    0097              WRITE(6,760)CAN, TITLE                                     00003920
    0098              WRITE(6,793)                                               00003930
    0099          793 FORMAT( //,4X,'AF',8X,' DEPTH',4X,' AREA ','   B.WID',4X,  00003940
                     '     'ROW  ',                                              00003941
                     '     'SEEP',1X,' TOT EARTH CST',4X,'LINING CST', 4X,     00003942
                     '     ' TOT CST',4X,'ANN CST'/                            00003943
                     '     14X,' FEET ',4X,'CU.FT.',1X,'  FEET   ',1X,' FEET AF/D   ', 00003944
                     '     'CU.YD.    $      ',2X,'     $ ', 7X,'     $',6X,'  $/YR'/) 00003945
```

```
                C                                                                00003980
0100              760 FORMAT(1H1,//,T5,A4,17A4,/)                                00003990
                C                                                                00004000
0101                  TSRT = 0.                                                  00004010
0102                  LTS = 0                                                    00004020
                C                                                                00004030
0103                  DO 49 KQ=MINQ,MAXQ,KNTQ                                    00004040
0104                  KX = KX + 1                                                00004050
0105                  Q = KQ                                                     00004060
0106                  Y=SQRT(Q*43560./((BH+Z)*SLEN))                             00004070
                C...LIMIT Y TO YMAX AND ADJUST BH IF NECESSARY                   00004071
0107                  IF(Y.GT.YMAX) Y=YMAX                                       00004072
0108                  BH1=Q*43560./(Y**2.*SLEN) - Z                              00004073
0109                  BW=BH1*Y                                                   00004074
                C     WETTED PERIMETER                                           00004075
0110                  WPER = BW + 2.*Y*((1.+Z**2.0)**(1./2.))                    00004076
                C                                                                00004077
                C                                                                00005240
                C                                                                00005250
                C                                                                00005260
                C-----COMPUTE HEIGHT OF BANK ABOVE WS FOR OPEN CHANNEL           00005270
                C-----BASED ON BR CURVE                                          00005280
                C     TO USE USBR CANAL CURVES FOR FREEBOARD AND LINING, USE     00005281
                C     VELOCITY EQUAL TO 3. FPS. THIS WILL COMPENSATE             00005282
                C     FOR SIZING DISCHARGE IN CFS                                00005283
0111                  QV=3.*Q*43560./SLEN                                        00005284
                C                                                                00005290
0112                  IF( QV.LE.15.) FBC =1.2                                    00005300
0113                  IF( QV.GT.15.AND.QV.LE.1000.) FBC=.56 * QV ** .2745        00005310
0114                  IF( QV.GT.1000.) FBC = 1.1 * QV ** .1795                   00005320
                C                                                                00005330
                C     THEN COMPUTE TOTAL DEPTH                                   00005340
                C                                                                00005350
0115              612 YFB = Y + FBC                                              00005360
0116                  IF(LCODE.EQ.0) GO TO 226                                   00005370
                C-----COMPUTE HEIGHT OF LINING ABOVE  W.S.                       00005380
                C                                                                00005390
0117                  IF(QV.LE.40.) HLNG = 0.5                                   00005400
0118                  IF(QV.GT.40.AND.QV.LE.400.) HLNG = 0.1 * QV ** 0.419       00005410
0119                  IF(QV.GT.400.) HLNG = 0.275 * QV ** 0.25                   00005420
                C                                                                00005430
                C-----COMPUTE TOTAL HEIGHT OF LINING                             00005440
                C                                                                00005450
0120                  YLN = Y + HLNG                                             00005460
                C                                                                00005470
                C                                                                00005480
                C                                                                00005490
                C                                                                00005500
                C-----COMPUTE THICKNESS OF HARDSURFACE LINING                    00005510
                C-----BASED ON BR CURVES ; THICKNESS DEPENDS ON  QV  & TYPE OF MATERIAL 00005520
                C                                                                00005530
0121                  GO TO(210,212,214,216),LCODE                               00005540
                C                                                                00005550
                C-----UNREINFORCED PORTLAND CEMENT CONCRETE                      00005560
                C                                                                00005570
0122              210 IF(QV.LE.200.)THLN= 2.2                                    00005580
0123                  IF(QV.GT.200..AND.QV.LE.500.)  THLN = 2.5                  00005590
0124                  IF(QV.GT.500..AND.QV.LE.1500.) THLN = 3.1                  00005600
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 0125              IF(QV.GT.1500..AND.QV.LE.3500.)THLN = 3.5                       00005610
 0126              IF(QV.GT.3500.)THLN= 4.0                                        00005620
 0127              GO TO 218                                                       00005630
             C                                                                     00005640
             C-----REINFORCED PORTLAND CEMENT CONCRETE                             00005650
             C                                                                     00005660
 0128          212 IF(QV.LE.500.)THLN=3.5                                          00005670
 0129              IF(QV.GT.500..AND.QV.LE.2000.)THLN = 4.0                        00005680
 0130              IF(QV.GT.2000.) THLN = 4.5                                      00005690
 0131              GO TO 218                                                       00005700
             C                                                                     00005710
             C-----ASPHALTIC CONCRETE                                              00005720
             C                                                                     00005730
 0132          214 IF(QV.LE.200.)THLN=2.15                                         00005740
 0133              IF(QV.GT.200..AND.QV.LE.1500.)THLN = 3.2                        00005750
 0134              IF(QV.GT.1500.) THLN = 4.0                                      00005760
 0135              GO TO 218                                                       00005770
             C                                                                     00005780
             C-----SHOTCRETE                                                       00005790
             C                                                                     00005800
 0136          216 IF(QV.LE.100.)THLN=1.25                                         00005810
 0137              IF(QV.GT.100..AND.QV.LE.200.)THLN = 1.5                         00005820
 0138              IF(QV.GT.200..AND.QV.LE.400.)THLN = 2.75                        00005830
 0139              IF(QV.GT.400..AND.QV.LE.510.)THLN = 3.15                        00005840
 0140              IF(QV.GT.510.) WRITE(6,220)                                     00005850
 0141          220 FORMAT(/,T10,'SORRY---NO SHOTCRETE ABOVE 510 CFS',/)            00005860
             C                                                                     00005870
 0142          218 CONTINUE                                                        00005880
             C                                                                     00005890
             C     COMPUTE CONCRETE QUANTITIES FOR LINING MATERIAL                 00005900
             C     THIS COMPUTATION IS BASED ON  BR PROCEDURE;                     00005910
             C     WHERE SIDE SLOPE = 1.5 : 1                                      00005920
             C                                                                     00005930
 0143              THLN = THLN /12.                                                00005940
 0144              VOL =(BW*THLN + 4*.302775*THLN**2. + 1.8027756*YLN*THLN*2.  +   00005950
                  1 8.*THLN*2./12.) * SLEN/ 27.                                    00005960
             C                                                                     00005970
             C-----COMPUTE LINING COSTS                                            00005980
 0145              CTL = VOL * CLN                                                 00005990
 0146              CTL = CTL + (CTL* CTGLN/100.)                                   00006000
 0147          226 CONTINUE                                                        00006010
             C                                                                     00006020
             C   CALCULATE CROSS-SECTIONAL AREA OF EXCAVATION                      00006030
 0148              ZREA = YFB*(BW + Z*YFB)                                         00006040
             C                                                                     00006670
             C-----COMPUTE EARTHWORK COST                                          00006680
             C                                                                     00006690
             C-----TOTAL/ROCK/COMMON EXCAVATION                                    00006700
             C                                                                     00006710
 0149              CALL EARTH(BW,YFB,Y,Z,S3,S4,S5,WL,WR,WC,C1,C2,PCT,              00006720
                  _CLCNG,ICEMB,CAN,TITLE,                                          00006730
                  _XSTAAH,XS1,XZ,XF,C79,C80,IP,AVEROW,                             00006740
                  _TCOM,TROC,TFIL,TCEM,KM,KQ,MAXQ)                                 00006750
             C                                                                     00006760
 0150              VCLEAR=TCOM+TROC                                                00006761
 0151              IF(TROC.EQ.0.)TROC = TCOM * PERK/100.                           00006770
             C                                                                     00006780
             C                                                                     00006790
```

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 0152                 CTEX = TCOM * UEXC + TROC * UERC                              00006800
                C                                                                   00006810
                C                                                                   00006820
 0153                 TCOMP = TCEM * UCOMP                                          00006830
                C                                                                   00006840
                C-----BACKFILL - USE 10  OF  TEXC                                   00006850
                C                                                                   00006860
 0154                 TBACK = TFIL * UBACK                                          00006870
                C                                                                   00006880
                C-----PREPARING FOUNDATION - FOR LINED CANAL ONLY                   00006890
                C                                                                   00006900
 0155                 TPREP = ((TCOM + TROC) * 20./100.) * UPREP                    00006910
 0156                 IF(LCODE.EQ.0)TPREP = 0.                                      00006920
                C                                                                   00006930
                C-----TOTAL COST OF EARTHWORK                                       00006940
                C                                                                   00006950
 0157                 CTX =  CTEX + TCOMP + TBACK + TPREP                           00006960
                C                                                                   00006970
                C-----ADD  CONTINGENCIES                                            00006980
                C                                                                   00006990
 0158                 FCER = CTX +(CTX* CTGER/100.)                                 00007000
                C                                                                   00007010
                C                                                                   00007020
                C---COMPUTE COST OF DRAINAGE CROSSINGS                              00007030
 0159                 TDRA = 0.                                                     00007040
                C     STRUCTURE COST = 0.  (NO STRUCTURES)                          00007050
 0160                 FCSTR=0.                                                      00007051
                C                                                                   00007490
                C-----COMPUTE RIGHT OF WAY AND RELATED COSTS                        00007500
                C                                                                   00007510
                C-----RIGHT OF WAY  COST                                            00007520
 0161                 AVEROW = AVEROW + RWID                                        00007530
                C                                                                   00007540
 0162                 CROW = AVEROW * SLEN * RVAL/43560.                            00007550
                C                                                                   00007560
                C-----SEVERANCE COST                                                00007570
                C                                                                   00007580
 0163                 CSEV  =  ASER * UCSEV                                         00007590
                C                                                                   00007600
                C                                                                   00007610
                C-----TOTAL COST                                                    00007620
                C                                                                   00007630
 0164                 TCROW = CROW + CSEV                                           00007640
                C                                                                   00007650
                C-----ADD CONTINGENCIES                                             00007660
                C                                                                   00007670
 0165                 FCROW = TCROW + (TCROW * CTGRW/100.)                          00007680
                C                                                                   00007690
                C-----COMPUTE TOTAL  FIELD COST                                     00007700
                C                                                                   00007710
 0166                 TFCONS =  FCSTR + FCER  + TCROW + CTL + TDRA                  00007720
                C                                                                   00007730
                C-----COMPUTE ANNUAL COST EQUIVALENT                                00007740
                C                                                                   00007750
                C                                                                   00007760
 0167                 CANN  =    TFCONS * (RINT * (1.+RINT)**TLFE)/(((1.+RINT)**TLFE)-1.00007770
                     &)    -   SVAL * .01*(FCSTR + CTL)*RINT/(((RINT+1.)**TLFE)-1.)     00007780
                C                                                                   00007790
```

```
                  C                                                                     00007800
                  C-----COMPUTE SEEPAGE LOSSES                                          00007810
                  C   SEEPAGE                                                           00007820
                  C                                                                     00007821
 0168                   SEEP = SR * WPER*SLEN/43560.                                    00007822
 0169                   CTDP=0.                                                         00007823
                  C                                                                     00007824
 0170                   CTANN(KX) = CANN + CTDP                                         00008140
                  C                                                                     00008150
                  C                                                                     00008160
                  C   WRITE OUT RESULTS                                                 00008170
 0171                   IF(KQ.EQ.MAXQ)WRITE(6,797)                                      00008180
 0172               797 FORMAT(//,T30,'COST SUMMARY FOR THIS #Q# ')                     00008190
                  C                                                                     00008200
 0173                   IF(KQ.EQ.MAXQ)WRITE(6,793)                                      00008210
                  C                                                                     00008220
 0174                   WRITE(6,401) Q,Y,ZREA,BW,AVEROW,SEEP,VOLEAR,FCER,CTL,TFCONS,CANN 00008230
 0175               401 FORMAT(2X,F5.0,2X,2F10.1,F9.0,F5.0,F9.0,F9.0,F10.0,             00008231
                       *        F9.0,F12.0,F11.0)                                       00008232
                  C                                                                     00008250
 0176                   QX(KX) = KQ                                                     00008260
                  C                                                                     00008270
 0177                49 CONTINUE                                                        00008280
                  C                                                                     00008290
                  C                                                                     00008300
                  C                                                                     00008390
                  C                                                                     00008400
                  C   DETERMINE LINEAR REGRESSION COEFFICIENTS FOR THE DATA OBTAINED    00008410
 0178                   IF(CTANN(1).NE.0.)GO TO 670                                     00008420
 0179                   GO TO 675                                                       00008460
 0180               670 CONTINUE                                                        00008470
 0181                   CALL REGLIN (QX,CTANN,KX,AC,BC,R)                               00008480
 0182               675 CONTINUE                                                        00008490
 0183                   WRITE(9,534)                                                    00008500
                  C---GO TO ANOTHER REACH                                               00008510
                  C                                                                     00008520
 0184                   GO TO 1                                                         00008530
                  C                                                                     00008540
 0185                98 RETURN                                                          00008550
 0186                   END                                                             00008560
```

APPENDIX E

MOST ECONOMICAL IRRIGATION INTERVAL

Costs of different irrigation application subsystems, and crop benefits versus actual evapotranspiration and optimum irrigation interval for different crop-soil-irrigation application subsystem combinations.

```
        SOIL TYPE   BONNOCK    CROP TYPE    ALFALFA

 NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK        ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL     COST OF     BENEFIT
     INTERVAL   NUMBER OF   %   ACTUAL PERIOD     NUMBER OF SIDE-    PUMPING COST  HAND-    PUMPING COST      GRAVITY       ($)
     DURING     IRRIGATION      EVAPO. CONSUM.    LATERAL    ROLL SP   ($)    ($)  MOVE SP    ($)    ($)      IRRIGA.
     PERIOD OF                   (MM)  USE RATE   OF SPRNKLR  (($)                   ($)                        ($)
     MAXIMUM                           (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1      7.         12.  100.00 1166.50   14.37      9.         70.38    83.85  154.23   40.56   86.13  126.68    53.58  180.00
  2      8.         10.   95.20  995.60   12.57      8.         62.30    77.45  139.75   35.09   79.47  114.56    49.73  178.38
  3      9.          9.   39.40  869.10   11.18      7.         54.77    71.05  125.82   30.94   72.82  103.76    47.80  157.85
  4     10.          8.    0.27  766.50   10.06      7.         54.60    71.05  125.65   30.55   72.82  103.38    45.88  139.71
  5     11.          7.    0.00  681.20    9.14      6.         46.91    64.65  111.57   25.95   66.17   92.12    43.95  135.15
  6     12.          6.    0.00  613.80    8.38      6.         46.56    64.65  111.21   25.08   66.17   91.25    42.03  130.69
  7     13.          6.    0.00  557.00    7.74      5.         39.47    58.26   97.73   21.99   59.52   81.51    42.03  126.17
  8     14.          5.    0.00  512.00    7.18      5.         39.05    58.26   97.31   20.93   59.52   80.45    40.10  122.02
  9     15.          5.    0.00  469.00    6.71      5.         39.26    58.26   97.52   21.49   59.52   81.01    40.10  117.52


              COEFFICIENT FOR BENEFIT CURVE A,B,C
    0.6555E 02      0.1123E 00      -0.8796E-05


         COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
    0.4640E 02      0.6979E-01      -0.1061E-05
  OPTIMUM IRRIGATION INTERVAL IS     7. AND BENEFIT COST RATIO IS 1.460


         COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
    0.5327E 02      0.9081E-01      -0.3897E-05
  OPTIMUM IRRIGATION INTERVAL IS     7. AND BENEFIT COST RATIO IS 1.199


          COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
    0.3089E 02      0.1877E-01      0.5170E-06
  OPTIMUM IRRIGATION INTERVAL IS     7. AND BENEFIT COST RATIO IS 3.450
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          SOIL  TYPE   BOCK          CROP TYPE   ALFALFA

 NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL   COST OF     BENEFIT
     INTERVAL   NUMBER OF   %  ACTUAL PERIOD     NUMBER OF SIDE-   PUMPING COST  HAND-   PUMPING COST    GRAVITY       ($)
     DURING     IRRIGATION     EVAPO. CONSUM.    LATERAL   ROLL SP   ($)    ($)  MOVE SP   ($)    ($)    IRRIGA.
     PERIOD OF                  (MM)  USE RATE   OF SPRNKLR  (($)                 ($)                      ($)
     MAXIMUM                          (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1     8.         11.  100.00 1185.00  14.25   10.       63.89    85.69  149.58   37.10   87.94  125.04    51.65   180.00
  2     9.          9.   98.38 1036.90  12.67    9.       57.03    79.75  136.78   31.96   81.77  113.73    47.80   179.46
  3    10.          8.   68.30  910.90  11.40    8.       50.76    73.81  124.57   28.27   75.61  103.88    45.88   168.67
  4    11.          7.    5.51  809.40  10.36    7.       44.43    67.87  112.30   24.42   69.44   93.86    43.95   143.05
  5    12.          7.    0.00  726.00   9.50    7.       44.77    67.87  112.64   25.32   69.44   94.76    43.95   137.05
  6    13.          6.    0.00  659.90   8.77    6.       38.34    61.93  100.27   21.18   63.27   84.45    42.03   133.18
  7    14.          6.    0.00  606.30   8.14    6.       38.58    61.93  100.51   21.83   63.27   85.10    42.03   129.42
  8    15.          5.    0.00  556.50   7.60    5.       32.12    55.98   88.10   17.58   57.11   74.69    40.10   125.37
  9    16.          5.    0.00  509.40   7.12    5.       32.29    55.98   88.27   18.04   57.11   75.15    40.10   120.97
 10    17.          5.    0.00  477.30   6.71    5.       32.46    55.98   88.44   18.49   57.11   75.60    40.10   117.61
 11    18.          4.    0.00  454.60   6.33    5.       31.95    55.98   87.93   17.17   57.11   74.28    38.18   115.04


               COEFFICIENT FOR BENEFIT CURVE A,B,C
   0.6377E 02      0.1154E 00     -0.1063E-04


             COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.4858E 02      0.4672E-01      0.1517E-04
 OPTIMUM IRRIGATION INTERVAL IS    8. AND BENEFIT COST RATIO IS 1.482


             COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.5280E 02      0.6565E-01      0.1394E-04
 OPTIMUM IRRIGATION INTERVAL IS   10. AND BENEFIT COST RATIO IS 1.289


              COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
   0.3392E 02      0.9628E-02      0.4172E-05
 OPTIMUM IRRIGATION INTERVAL IS    8. AND BENEFIT COST RATIO IS 3.626
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          SOIL TYPE   HAYESTON  CROP TYPE   ALFALFA

   NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK        ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL     COST OF    BENEFIT
       INTERVAL   NUMBER OF  %   ACTUAL PERIOD      NUMBER OF SIDE-   PUMPING COST  HAND-   PUMPING COST      GRAVITY      ($)
       DURING     IRRIGATION     EVAPO. CONSUM.     LATERAL   ROLL SP   ($)     ($) MOVE SP   ($)     ($)     IRRIGA.
       PERIOD OF                  (MM)  USE RATE    OF SPRNKLR  (($)                  ($)                       ($)
       MAXIMUM                          (MM/DAY)
       CONSUMPTIVE
       USE (DAYS)
    1     5.          17.  100.00 1363.30   16.09    11.          97.25    89.76  187.01   57.48   92.11  149.59    63.20  180.00
    2     6.          13.   87.98 1048.70   13.41    10.          78.84    83.99  162.83   49.26   86.13  135.38    55.50  175.70
    3     7.          11.    7.55  857.70   11.50     8.          70.02    72.44  142.46   39.18   74.15  113.33    51.65  141.21
    4     8.           9.    0.00  729.80   10.06     7.          61.03    66.67  127.70   33.23   68.17  101.40    47.80  131.46
    5     9.           8.    0.00  634.40    8.94     7.          52.60    66.67  119.27   32.97   68.17  101.14    45.88  124.92
    6    10.           7.    0.00  563.50    8.05     6.          52.38    60.90  113.28   28.14   62.18   90.32    43.95  118.96
    7    11.           7.    0.00  501.00    7.32     5.          44.45    55.13   99.58   24.80   56.20   81.00    43.95  112.74
    8    12.           7.    0.00  455.00    6.71     5.          44.12    55.13   99.25   23.99   56.20   80.19    42.03  107.50


               COEFFICIENT FOR BENEFIT CURVE A,B,C
     0.4253E 02      0.1566E 00     -0.3915E-04


          COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
     0.2512E 02      0.1308E 00     -0.2843E-04
   OPTIMUM IRRIGATION INTERVAL IS    6. AND BENEFIT COST RATIO IS 1.249


          COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
     0.3546E 02      0.1489E 00     -0.2743E-04
   OPTIMUM IRRIGATION INTERVAL IS   12. AND BENEFIT COST RATIO IS 1.084


           COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
     0.3295E 02      0.1931E-01      0.2133E-05
   OPTIMUM IRRIGATION INTERVAL IS    5. AND BENEFIT COST RATIO IS 2.899
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        SOIL TYPE   HEISETON   CROP TYPE   ALFALFA

 NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF     BENEFIT
     INTERVAL   NUMBER OF   %  ACTUAL PERIOD     NUMBER OF SIDE-    PUMPING COST  HAND-   PUMPING COST    GRAVITY      ($)
     DURING     IRRIGATION     EVAPO. CONSUM.    LATERAL    ROLL SP   ($)    ($)  MOVE SP   ($)    ($)    IRRIGA.
     PERIOD OF                  (MM)  USE RATE   OF SPRNKLR  (($)                   ($)                     ($)
     MAXIMUM                          (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1      6.          14.  100.00 1173.80  14.53   10.        79.51    88.74  168.25   51.14   91.11  142.25   57.43   180.00
  2      7.          11.   87.98  957.70  12.45    0.        70.02    26.27   96.29   39.18   26.27   65.45   51.65   175.86
  3      8.          10.    7.55  815.80  10.90    7.        61.68    70.00  131.68   34.90   71.66  106.56   49.73   144.35
  4      9.           8.    0.00  710.20   9.69    7.        52.60    70.00  122.60   32.97   71.66  104.63   45.88   136.56
  5     10.           7.    0.00  629.20   8.72    6.        52.38    63.75  116.13   28.14   65.18   93.32   43.95   131.52
  6     11.           7.    0.00  559.40   7.92    5.        44.45    57.51  101.96   28.80   58.69   87.49   43.95   126.08
  7     12.           6.    0.00  506.60   7.26    5.        44.12    57.51  101.63   23.99   58.69   82.68   42.03   121.17
  8     13.           6.    0.00  458.90   6.71    5.        44.40    57.51  101.91   24.74   58.69   83.43   42.03   116.05


                COEFFICIENT FOR BENEFIT CURVE A,B,C

   0.6466E 02      0.1150E 00     -0.1163E-04



        COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.1342E 03     -0.1572E 00      0.1306E-03
 OPTIMUM IRRIGATION INTERVAL IS     8. AND BENEFIT COST RATIO IS 1.624



        COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.1326E 03     -0.1098E 00      0.1115E-03
 OPTIMUM IRRIGATION INTERVAL IS     8. AND BENEFIT COST RATIO IS 1.285



         COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
   0.3530E 02      0.1054E-01      0.7122E-05
 OPTIMUM IRRIGATION INTERVAL IS     6. AND BENEFIT COST RATIO IS 3.195
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        SOIL TYPE   PASEL     CROP TYPE   ALFALFA

NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK      ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL . COST OF    BENEFIT
    INTERVAL   NUMBER OF  %  ACTUAL PERIOD    NUMBER OF SIDE-   PUMPING COST  HAND-   PUMPING COST    GRAVITY      ($)
    DURING     IRRIGATION     EVAPO. CONSUM.   LATERAL   ROLL SP   ($)    ($)  MOVE SP   ($)    ($)    IRRIGA.
    PERIOD OF                  (MM)  USE RATE  OF SPRNKLR  (($)                   ($)                     ($)
    MAXIMUM                          (MM/DAY)
    CONSUMPTIVE
    USE (DAYS)
 1     9.       10.   100.00 1213.10   14.16   10.     52.89    87.07  139.96   34.09   89.29  123.38   49.73  180.00
 2    10.        9.    99.17 1061.90   12.74    9.     52.78    80.99  133.77   30.65   82.99  113.64   47.80  179.72
 3    11.        8.    83.46  943.30   11.58    8.     46.93    74.91  121.84   26.98   76.69  103.67   45.88  174.13
 4    12.        7.     2.91  842.90   10.62    7.     41.04    68.83  109.87   23.21   70.39   93.60   43.95  142.56
 5    13.        6.     0.29  767.20    9.80    7.     40.69    68.83  109.52   22.33   70.39   92.72   42.03  138.35
 6    14.        6.     0.00  704.60    9.10    6.     35.37    62.75   98.12   20.01   64.08   84.09   42.03  134.93
 7    15.        5.     0.00  647.80    8.49    6.     34.96    62.75   97.71   18.96   64.08   83.04   40.10  131.35
 8    16.        5.     0.00  596.30    7.96    6.     35.14    62.75   97.89   19.46   64.08   83.54   40.10  127.56
 9    17.        5.     0.00  556.10    7.49    5.     29.76    56.67   86.43   16.65   57.78   74.43   40.10  124.19
10    18.        4.     0.00  526.00    7.08    5.     29.29    56.67   85.96   15.74   57.78   73.52   38.18  121.41
11    19.        4.     0.00  488.00    6.71    5.     29.41    56.67   86.08   16.95   57.78   74.73   38.18  117.55
12    20.        4.     0.00  457.40    6.37    5.     29.54    56.67   86.21   16.41   57.78   74.19   38.18  114.12



             COEFFICIENT FOR BENEFIT CURVE A,B,C
   0.6527E 02     0.1077E 00     -0.6464E-05



        COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.5360E 02     0.3036E-01     0.2313E-04
 OPTIMUM IRRIGATION INTERVAL IS     9. AND BENEFIT COST RATIO IS 1.498



        COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.5011E 02     0.7030E-01     0.4665E-05
 OPTIMUM IRRIGATION INTERVAL IS     9. AND BENEFIT COST RATIO IS 1.311



         COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
   0.3104E 02     0.1433E-01     0.1082E-05
 OPTIMUM IRRIGATION INTERVAL IS     9. AND BENEFIT COST RATIO IS 3.728
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          SOIL TYPE   STAN          CROP TYPE   ALFALFA

   NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK        ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL      COST OF     BENEFIT
       INTERVAL   NUMBER OF   %  ACTUAL PERIOC      NUMBER OF SIDE-    PUMPING COST HAND-    PUMPING COST      GRAVITY       ($)
       DURING     IRRIGATION     EVAPO. CONSUM.     LATERAL    ROLL SP    ($)    ($) MOVE SP    ($)    ($)     IRRIGA.
       PERIOD OF                  (MM)  USE RATE    OF SPRNKLR  (($)                   ($)                       ($)
       MAXIMUM                          (MM/DAY)
       CONSUMPTIVE
       USE (DAYS)
   1      6.        14.     100.00 1302.80   15.65   11.          85.82    91.99  177.81   49.75   94.55  144.30    57.43  180.00
   2      7.        12.      99.14 1060.70   13.41    9.          70.38    80.04  150.43   40.56   82.13  122.69    53.58  179.70
   3      8.        10.      64.41  904.50   11.73    8.          62.30    74.07  136.37   35.09   75.93  111.02    49.73  166.27
   4      9.         9.       1.58  788.50   10.43    7.          54.77    68.10  122.87   30.94   69.72  100.66    47.80  137.26
   5     10.         8.       0.00  696.90    9.39    7.          54.60    68.10  122.70   30.55   69.72  100.27    45.88  131.43
   6     11.         7.       0.00  619.50    8.53    6.          46.91    62.12  109.03   25.95   63.51   89.46    43.95  125.97
   7     12.         6.       0.00  559.50    7.82    6.          46.56    62.12  108.68   25.08   63.51   88.59    42.03  120.92
   8     13.         6.       0.00  507.40    7.22    5.          39.47    56.15   95.62   21.99   57.31   79.30    42.03  115.84
   9     14.         5.       0.00  466.40    6.71    5.          39.05    56.15   95.20   20.93   57.31   78.24    40.10  111.33


              COEFFICIENT FOR BENEFIT CURVE A,B,C
    0.2869E 02     0.1976E 00     -0.5988E-04


          COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
    0.4655E 02     0.6665E-01      0.5953E-05
    OPTIMUM IRRIGATION INTERVAL IS     8. ANC BENEFIT COST RATIO IS 1.419


          COST COEFF. CF SIDE-ROLL SPRINKLER  A,B,C  .
    0.5532E 02     0.8355E-01      0.7398E-05
    OPTIMUM IRRIGATICN INTERVAL IS     9. ANC BENEFIT COST RATIO IS 1.171


           COST COEFFI.  OF GRAVITY IRRIGATICN  A,B,C  .
    0.2796E 02     0.2870E-01     -0.4615E-05
    OPTIMUM IRRIGATICN INTERVAL IS     6. ANC BENEFIT COST RATIO IS 3.208
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        SOIL TYPE   BONNOCK   CROP TYPE   PASTURE

   NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL   COST OF    BENEFIT
       INTERVAL   NUMBER OF  %   ACTUAL PERIOC    NUMBER OF SIDE-   PUMPING COST  HAND-   PUMPING COST    GRAVITY     ($)
       DURING     IRRIGATION     EVAPO. CONSUM.   LATERAL   ROLL SP   ($)    ($)  MOVE SP   ($)    ($)    IRRIGA.
       PERIOD OF                  (MM)  USE RATE  OF SPRNKLR  (($)                  ($)                      ($)
       MAXIMUM                          (MM/DAY)
       CONSUMPTIVE
       USE (DAYS)
    1     4.         23.   100.00 1410.70   15.72    11.       132.31    17.78 150.09   85.51   18.97 104.48   74.75  140.00
    2     5.         17.    92.50 1029.70   12.57     9.       106.80    14.55 121.35   63.39   15.52  78.91   63.20  138.47
    3     6.         13.     0.17  800.50   10.48     7.        82.60    11.32  93.92   47.11   12.07  59.18   55.50  105.52
    4     7.         11.     0.00  658.10    8.98     6.        70.96     9.70  80.66   40.12   10.35  50.47   51.65   95.62
    5     8.          9.     0.00  557.50    7.86     6.        70.29     9.70  79.99   38.52   10.35  48.87   47.80   88.01
    6     9.          8.     0.00  481.90    6.98     5.        59.08     8.08  67.16   32.48    8.63  41.10   45.88   81.83


             COEFFICIENT FOR BENEFIT CURVE A,B,C
     0.5628E 00     0.1927E 00     -0.6548E-04


         COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
     0.1644E 02     0.4710E-01      0.1110E-04
   OPTIMUM IRRIGATICN INTERVAL IS     6. AND BENEFIT COST RATIO IS 1.843


         COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
     0.2326E 02     0.9460E-01     -0.2907E-05
   OPTIMUM IRRIGATION INTERVAL IS     7. AND BENEFIT COST RATIO IS 1.175


          COST COEFFI.  OF GRAVITY IRRIGATICN  A,B,C  .
     0.3015E 02     0.3264E-01     -0.7047E-06
   OPTIMUM IRRIGATION INTERVAL IS     5. ANC BENEFIT COST RATIO IS 2.056
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        SOIL TYPE   BOCK        CROP TYPE   PASTURE

 NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL      COST OF     BENEFIT
     INTERVAL   NUMBER OF   %   ACTUAL PERIOC    NUMBER OF SIDE-    PUMPING COST HAND-   PUMPING COST      GRAVITY       ($)
     DURING     IRRIGATION      EVAPO. CONSUM.   LATERAL    ROLL SP   ($)    ($)  MOVE SP   ($)    ($)     IRRIGA.
     PERIOD OF                   (MM)  USE RATE OF SPRNKLR   (($)                  ($)                      ($)
     MAXIMUM                           (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1      5.        18.    100.00 1238.50   14.25    9.      107.59   16.50  124.09   65.34   17.63    82.96   63.15  140.00
  2      6.        14.     66.92  956.10   11.87    7.       83.30   12.83   96.13   48.86   13.71    62.57   57.43  134.38
  3      7.        11.      0.03  783.10   10.18    6.       70.96   11.00   81.96   40.12   11.75    51.87   51.65  111.33
  4      8.        10.      0.00  664.50    8.91    6.       71.04   11.00   82.04   40.42   11.75    52.17   49.73  102.55
  5      9.         8.      0.00  575.80    7.92    5.       59.08    9.17   68.25   32.38    9.79    42.17   45.88   95.46
  6     10.         8.      0.00  512.60    7.12    5.       59.58    9.17   68.75   33.82    9.79    43.61   45.88   90.07


               COEFFICIENT FOR BENEFIT CURVE A,B,C
   0.9895E 01     0.1849E 00     -0.6354E-04



        COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.3786E 02    -0.8342E-02     0.3603E-04
 OPTIMUM IRRIGATION INTERVAL IS     6. ANC BENEFIT COST RATIO IS 2.047



        COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.5632E 02     0.2298E-02     0.4208E-04
 OPTIMUM IRRIGATION INTERVAL IS     7. AND BENEFIT COST RATIO IS 1.379




         COST COEFFI. OF GRAVITY IRRIGATICN  A,B,C  .
   0.3005E 02     0.3130E-01    -0.3573E-05
 OPTIMUM IRRIGATION INTERVAL IS     5. ANC BENEFIT COST RATIO IS 2.233
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     SOIL TYPE   HAYESTON  CROP TYPE   PASTURE

 NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK        ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF    BENEFIT
     INTERVAL   NUMBER OF  %   ACTUAL PERIOD      NUMBER OF SIDE-    PUMPING COST  HAND-   PUMPING COST    GRAVITY     ($)
     DURING     IRRIGATION     EVAPO. CONSUM.     LATERAL   ROLL SP   ($)     ($)  MOVE SP  ($)     ($)    IRRIGA.
     PERIOD OF                  (MM)  USE RATE    OF SPRNKLR  (($)                  ($)                    ($)
     MAXIMUM                          (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1    3.         31.   100.00 1556.60   16.76     12.        175.85    18.60  194.45  113.84   19.92  133.76    90.15   140.00
  2    4.         20.    88.45 1010.10   12.57      9.        128.30    13.95  142.25   75.89   14.94   90.83    68.98   138.36
  3    5.         15.     0.00  740.90   10.06      7.         99.22    10.85  110.07   56.53   11.62   68.15    59.35    96.59
  4    6.         12.     0.00  583.20    8.38      6.         84.88     9.30   94.18   47.31    9.96   57.27    53.58    85.69
  5    7.         10.     0.00  482.70    7.18      5.         71.04     7.75   78.79   39.18    8.30   47.48    49.73    77.96


               COEFFICIENT FOR BENEFIT CURVE A,B,C
   -0.1685E 02     0.2245E 00    -0.7900E-04


           COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C .
    0.8095E 01     0.8345E-01    -0.1738E-05
  OPTIMUM IRRIGATION INTERVAL IS     5. AND BENEFIT COST RATIO IS 1.539


           COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C .
    0.1276E 02     0.1482E 00    -0.2023E-04
  OPTIMUM IRRIGATION INTERVAL IS     6. AND BENEFIT COST RATIO IS 0.945


            COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C .


    0.3309E 02     0.3393E-01     0.1738E-05
  OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 1.871
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          SOIL TYPE   HEISETON  CROP TYPE   PASTURE

    NO. IRRIGATION ESTIMATED RISK ANNUAL  PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF    BENEFIT
        INTERVAL   NUMBER OF  %   ACTUAL  PERIOD     NUMBER OF SIDE-    PUMPING COST  HAND-    PUMPING COST     GRAVITY      ($)
        DURING     IRRIGATION     EVAPO.  CONSUM.    LATERAL   ROLL SP   ($)     ($)  MOVE SP   ($)    ($)      IRRIGA.
        PERIOD OF                  (MM)   USE RATE   OF SPRNKLR  (($)                   ($)                      ($)
        MAXIMUM                           (MM/DAY)
        CONSUMPTIVE
        USE (DAYS)
     1     3.        33.   100.00 1767.90    18.16   12.        177.65   20.40  198.05  118.16    21.60  139.76    94.00  140.00
     2     4.        21.    99.49 1138.70    13.62    9.        129.11   15.30  144.41   77.87    16.20   94.07    70.90  139.86
     3     5.        16.     2.16  833.70    10.90    7.         99.96   11.90  111.86   58.35    12.60   70.95    61.28   97.09
     4     6.        12.     0.00  653.40     9.08    6.         84.88   10.20   95.08   47.31    10.80   58.11    53.58   85.11
     5     7.        10.     0.00  539.50     7.78    5.         71.04    8.50   79.54   39.18     9.00   48.18    49.73   77.34


                    COEFFICIENT FOR BENEFIT CURVE A,B,C
       -0.2409E 02      0.2150E 00      -0.6868E-04



               COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C .
        0.5875E 01      0.8072E-01      -0.2826E-05
      OPTIMUM IRRIGATION INTERVAL IS      5. AND BENEFIT COST RATIO IS 1.509


               COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C .
        0.1262E 02      0.1345E 00      -0.1675E-04
      OPTIMUM IRRIGATION INTERVAL IS      6. AND BENEFIT COST RATIO IS 0.933


                COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .


        0.3023E 02      0.3640E-01      -0.2083E-06
      OPTIMUM IRRIGATION INTERVAL IS      4. AND BENEFIT COST RATIO IS 1.844
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        SOIL TYPE   PAESL      CROP TYPE   PASTURE

NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK     ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL   COST OF   BENEFIT
    INTERVAL   NUMBER OF  % . ACTUAL PERIOD   NUMBER OF SIDE-   PUMPING COST  HAND-   PUMPING COST    GRAVITY     ($)
    DURING     IRRIGATION     EVAPO. CONSUM.  LATERAL   ROLL SP   ($)     ($) MOVE SP   ($)     ($)   IRRIGA.
    PERIOD OF                  (MM)  USE RATE OF SPRNKLR  (($)                  ($)                      ($)
    MAXIMUM                          (MM/DAY)
    CONSUMPTIVE
    USE (DAYS)
 1      5.       19.   100.00 1459.30   15.93   11.    105.30   16.50  121.80   65.12   17.12   82.24   67.05  140.00
 2      6.       14.    99.18 1119.60   13.27    9.     84.11   13.50   97.61   43.39   14.01   57.40   57.43  139.86
 3      7.       12.    39.20  913.90   11.38    8.     75.40   12.00   87.40   43.60   12.45   56.05   53.58  122.24
 4      8.       10.     0.01  776.80    9.95    7.     65.80   10.50   76.30   37.22   10.89   48.11   49.73  102.15
 5      9.        9.     0.00  674.50    8.85    6.     56.77    9.00   65.77   32.26    9.34   41.60   47.80   95.18
 6     10.        8.     0.00  594.40    7.96    6.     56.59    9.00   65.59   31.86    9.34   41.20   45.88   89.35
 7     11.        7.     0.00  531.50    7.24    5.     47.41    7.50   54.91   26.45    7.78   34.23   43.95   84.49
 8     12.        6.     0.00  482.10    6.64    5.     47.06    7.50   54.56   25.59    7.78   33.37   42.03   80.47



             COEFFICIENT FOR BENEFIT CURVE A,B,C
   0.1383E 01     0.1859E 00    -0.6111E-04



        COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.1745E 02     0.3071E-01     0.8686E-05
 OPTIMUM IRRIGATION INTERVAL IS    7. AND BENEFIT COST RATIO IS 2.279



        COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.1524E 02     0.8361E-01    -0.7456E-05
 OPTIMUM IRRIGATION INTERVAL IS    7. AND BENEFIT COST RATIO IS 1.408



         COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
   0.3124E 02     0.2349E-01     0.5894E-06
 OPTIMUM IRRIGATION INTERVAL IS    6. AND BENEFIT COST RATIO IS 2.281
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        SOIL TYPE   STAN       CROP TYPE   PASTURE

NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK     ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL     COST OF    BENEFIT
    INTERVAL   NUMBER OF  %   ACTUAL PERIOC   NUMBER OF SIDE-   PUMPING COST  HAND-   PUMPING COST      GRAVITY     ($)
    DURING     IRRIGATION     EVAPO. CCNSUM.  LATERAL   ROLL SP   ($)     ($) MOVE SP   ($)     ($)     IRRIGA.
    PERIOD OF                  (MM)  USE RATE OF SPRNKLR  (($)                 ($)                        ($)
    MAXIMUM                          (MM/DAY)
    CONSUMPTIVE
    USE (DAYS)
 1     4.       22.    100.00 1272.30   14.67 130.       79.85  229.96  309.81   72.83  239.05  311.88    9.00  140.00
 2     5.       16.     50.47  93C.00   11.73 100.       58.35  176.93  235.28   61.28  183.93  245.21    7.00  129.94
 3     6.       13.      0.00  752.80    9.78 86.        49.11  151.51  200.62   55.50  157.50  213.00    6.00  107.69
 4     7.       11.      0.00  598.00    8.38 72.        40.88  126.94  167.82   51.65  131.96  183.61    5.00   95.98
 5     8.        9.      0.00  506.10    7.33 71.        39.28  125.74  165.02   47.87  130.71  178.58    5.00   88.30



             COEFFICIENT FOR BENEFIT CURVE A,B,C

   0.9783E 01     0.1835E 00    -0.6325E-04



        COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C     .

   0.1190E 03     0.8439E-01     0.5313E-04
 OPTIMUM IRRIGATION INTERVAL IS    8. ANC BENEFIT COST RATIO IS 0.493



        COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .

   0.1079E 03     0.6846E-01     0.7133E-04
 OPTIMUM IRRIGATION INTERVAL IS    8. AND BENEFIT COST RATIO IS 0.538



         COST COEFFI.  OF GRAVITY IRRIGATICN  A,B,C   .



   0.3132E 01     0.2547E-02     0.1638E-05 .
 OPTIMUM IRRIGATION INTERVAL IS    4. ANC BENEFIT COST RATIO IS15.606
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        SOIL TYPE   BONNOCK    CROP TYPE   POTATOES

 NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK        ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF     BENEFIT
     INTERVAL   NUMBER OF   %  ACTUAL PERIOD      NUMBER OF SIDE-    PUMPING COST  HAND-    PUMPING COST    GRAVITY      ($)
     DURING     IRRIGATION     EVAPO. CONSUM.     LATERAL   ROLL SP   ($)     ($)  MOVE SP   ($)     ($)    IRRIGA.
     PERIOD OF                  (MM)  USE RATE    OF SPRNKLR  (($)                  ($)                       ($)
     MAXIMUM                          (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1     3.        24.   100.00 937.20   13.33   170.       98.72  683.40  782.12  99.31  705.10  804.41   12.00   778.50
  2     4.        16.    93.00 643.10   10.00   125.       67.97  511.13  579.10  77.31  527.14  604.45    9.00   778.49
  3     5.        13.     0.00 495.10    8.00    98.       52.89  405.39  458.28  69.06  417.90  486.96    7.00   763.72
  4     6.        10.     0.00 402.00    6.67    83.       43.71  349.98  393.69  60.81  360.66  421.47    6.00   746.12
  5     7.         9.     0.00 337.50    5.71    70.       37.48  299.37  336.85  58.06  308.38  366.44    5.00   728.65


                COEFFICIENT FOR BENEFIT CURVE A,B,C
    0.6134E 03     0.4407E 00    -0.2826E-03


             COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
    0.7785E 02     0.9019E 00    -0.1347E-03
  OPTIMUM IRRIGATION INTERVAL IS    7. AND BENEFIT COST RATIO IS 1.990


             COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
    0.4490E 02     0.9120E 00    -0.1333E-03
  OPTIMUM IRRIGATION INTERVAL IS    7. AND BENEFIT COST RATIO IS 2.163


              COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .


   -0.1602E 00     0.1667E-01    -0.3938E-05
  OPTIMUM IRRIGATION INTERVAL IS    4. AND BENEFIT COST RATIO IS87.295
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          SOIL TYPE   BOCK        CROP TYPE   POTATOES

  NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF     BENEFIT
      INTERVAL   NUMBER OF   %  ACTUAL PERIOD     NUMBER OF SIDE-    PUMPING COST  HAND-   PUMPING COST   GRAVITY       ($)
      DURING     IRRIGATION     EVAPO. CONSUM.    LATERAL   ROLL SP   ($)     ($)  MOVE SP  ($)     ($)   IRRIGA.
      PERIOD OF                  (MM)  USE RATE OF SPRNKLR  (($)                    ($)                     ($)
      MAXIMUM                          (MM/DAY)
      CONSUMPTIVE
      USE (DAYS)
   1    4.        17.   100.00 755.00  11.33     9.      125.87   66.36  192.23  69.95   67.80  137.75   80.06  778.50
   2    5.        13.    41.67 579.80   9.07     7.       97.75   57.59  155.34  52.89   58.71  111.60   69.06  779.99
   3    6.        11.     0.00 469.30   7.56     6.       84.16   53.20  137.36  45.51   54.16   99.67   63.56  774.01
   4    7.         9.     0.00 393.90   6.48     5.       70.37   48.82  119.19  37.48   49.62   87.10   58.06  762.79
   5    8.         8.     0.00 338.60   5.67     5.       70.29   48.82  119.11  37.38   49.62   87.00   55.31  750.22


              COEFFICIENT FOR BENEFIT CURVE A,B,C
    0.6404E 03     0.4455E 00    -0.3484E-03


            COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
    0.6854E 02     0.1538E-01     0.1013E-03
  OPTIMUM IRRIGATION INTERVAL IS     6. AND BENEFIT COST RATIO IS 7.880


            COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
    0.8923E 02     0.3508E-01     0.1347E-03
  OPTIMUM IRRIGATION INTERVAL IS     7. AND BENEFIT COST RATIO IS 6.146


             COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .


    0.3589E 02     0.5616E-01     0.2984E-05
  OPTIMUM IRRIGATION INTERVAL IS     6. AND BENEFIT COST RATIO IS12.285
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        SOIL TYPE   HEYESTON   CROP TYPE   POTATOES

NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK     ESTIMATED COST OF COST OF TATAL COST OF  COST OF TAOTL   COST OF   BENEFIT
    INTERVAL   NUMBER OF  %   ACTUAL PERIOD   NUMBER OF SIDE-    PUMPING COST  HAND-   PUMPING COST    GRAVITY      ($)
    DURING     IRRIGATION     EVAPO. CONSUM.  LATERAL   ROLL SP    ($)    ($)  MOVE SP   ($)    ($)    IRRIGA.
    PERIOD OF                  (MM)  USE RATE OF SPRNKLR   (($)                  ($)                     ($)
    MAXIMUM                          (MM/DAY)
    CONSUMPTIVE
    USE (DAYS)
 1     2.       38.    100.00 1152.30   16.00   14.    254.72   81.22  335.94  160.51   82.90  243.41  137.81  778.50
 2     3.       22.     99.28  987.70   10.67   10.    175.69   65.70  241.39   99.27   66.90  166.17   93.81  778.52
 3     4.       15.      0.00  483.20    8.00    7.    122.06   54.06  176.12   65.42   54.90  120.32   74.56  740.67
 4     5.       12.      0.00  373.60    6.40    6.    104.76   50.18  154.94   55.53   50.90  106.43   66.31  713.58


                COEFFICIENT FOR BENEFIT CURVE A,B,C
  0.6212E 03     0.3121E 00    -0.1520E-03


           COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
  0.1825E 03    -0.2877E 00     0.2816E-03
OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 6.743


           COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
  0.2300E 03    -0.2932E 00     0.3172E-03
OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 4.536


            COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .


  0.1170E 03    -0.1840E 00     0.1673E-03
OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS10.971
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          SOIL TYPE   HEISETON   CROP TYPE   POTATOES

NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF    BENEFIT
    INTERVAL   NUMBER OF   %  ACTUAL PERIOC     NUMBER OF SIDE-    PUMPING COST  HAND-    PUMPING COST   GRAVITY      ($)
    DURING     IRRIGATION     EVAPO. CONSUM.    LATERAL    ROLL SP    ($)    ($) MOVE SP    ($)    ($)   IRRIGA.
    PERIOD OF                  (MM)  USE RATE   OF SPRNKLR  (($)                   ($)                    ($)
    MAXIMUM                          (MM/DAY)
    CONSUMPTIVE
    USE (DAYS)
 1     3.         23.  100.00 768.40   11.56    10.       176.62   68.90 245.52 101.52   68.50 170.02    96.56  778.50
 2     4.         16.    2.22 535.40    8.67     7.       122.84   56.30 179.14  67.34   56.02 123.36    77.31  778.83
 3     5.         12.    0.00 413.30    6.93     6.       104.76   52.10 156.86  55.53   51.86 107.39    66.31  765.02
 4     6.         10.    0.00 336.70    5.78     5.        87.87   47.90 135.77  46.47   47.70  94.17    60.81  748.10


               COEFFICIENT FOR BENEFIT CURVE A,B,C
   0.6299E 03     0.4769E 00    -0.3691E-03



          COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.6500E 02     0.5298E-01     0.1086E-03
 OPTIMUM IRRIGATION INTERVAL IS     5. AND BENEFIT COST RATIO IS 7.245



          COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.8640E 02     0.1095E 00     0.1265E-03
 OPTIMUM IRRIGATION INTERVAL IS     6. AND BENEFIT COST RATIO IS 5.441



           COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .



   0.3325E 02     0.7994E-01     0.3279E-05
 OPTIMUM IRRIGATION INTERVAL IS     5. AND BENEFIT COST RATIO IS11.428
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        SOIL TYPE    PAESL         CROP TYPE    POTATOES

NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK     ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL   COST OF    BENEFIT
    INTERVAL   NUMBER OF  %   ACTUAL PERIOD   NUMBER OF SIDE-    PUMPING COST HAND-    PUMPING COST   GRAVITY      ($)
    DURING     IRRIGATION     EVAPO. CONSUM.  LATERAL    ROLL SP  ($)    ($)  MOVE SP   ($)     ($)   IRRIGA.
    PERIOD OF                  (MM)  USE RATE OF SPRNKLR  (($)                  ($)                     ($)
    MAXIMUM                          (MM/DAY)
    CONSUMPTIVE
    USE (DAYS)
 1     4.       18.   100.00  870.60   12.67   11.    128.18   71.78  199.96   72.47   73.25  145.72   87.81  778.50
 2     5.       14.    98.00  667.20   10.13    9.    104.44   63.62  168.06   57.54   64.82  122.36   71.81  778.55
 3     6.       11.     3.13  538.60    8.45    7.     81.20   55.46  136.66   43.61   56.39  100.00   63.56  773.91
 4     7.        9.     0.00  451.90    7.24    6.     69.61   51.38  120.99   36.72   52.18   88.90   58.06  762.40
 5     8.        8.     0.00  388.60    6.33    6.     69.54   51.38  120.92   36.62   52.18   88.80   55.31  749.79
 6     9.        7.     0.00  340.00    5.63    5.     58.39   47.30  105.69   30.73   47.97   78.70   52.56  737.00



             COEFFICIENT FOR BENEFIT CURVE A,B,C
   0.6296E 03     0.4186E 00     -0.2856E-03



        COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.4507E 02     0.9095E-01     0.2945E-04
 OPTIMUM IRRIGATION INTERVAL IS     7. AND BENEFIT COST RATIO IS 8.249



        COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.5479E 02     0.1442E 00     0.2742E-04
 OPTIMUM IRRIGATION INTERVAL IS     8. AND BENEFIT COST RATIO IS 6.516



         COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
   0.4109E 02     0.2153E-01     0.3690E-04
 OPTIMUM IRRIGATION INTERVAL IS     6. AND BENEFIT COST RATIO IS12.183
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          SOIL TYPE   STAN        CROP TYPE   POTATOES

     NC. IRRIGATION ESTIMATED RISK ANNUAL PEAK      ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF    BENEFIT
         INTERVAL   NUMBER OF  %   ACTUAL PERIOD    NUMBER OF SIDE-   PUMPING COST  HAND-   PUMPING COST    GRAVITY      ($)
         DURING     IRRIGATION     EVAPO. CONSUM.   LATERAL   ROLL SP   ($)    ($)  MOVE SP   ($)    ($)    IRRIGA.
         PERIOD OF                  (MM)  USE RATE  OF SPRNKLR  (($)                  ($)                    ($)
         MAXIMUM                          (MM/DAY)
         CONSUMPTIVE
         USE (DAYS)
      1     3.         23.   100.00 851.60   12.45    10.       176.62    72.10  248.72 101.52    73.70  175.22    96.56  778.50
      2     4.         16.    53.40 588.70    9.33     7.       122.84    58.54  181.38  67.34    59.66  127.00    77.31  778.54
      3     5.         13.     0.00 453.80    7.47     6.       105.54    54.02  159.56  57.48    54.98  112.46    69.06  764.35
      4     6.         10.     0.00 369.10    6.22     5.        87.87    49.50  137.37  46.47    50.30   96.77    60.81  747.09


               COEFFICIENT FCR BENEFIT CURVE A,B,C
      0.6289E 03     0.4336E 00    -0.3030E-03



          COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
      0.6361E 02     0.6630E-01     0.7565E-04
     OPTIMUM IRRIGATICN INTERVAL IS    5. ANC BENEFIT COST RATIO IS 6.985



          COST COEFF. CF SIDE-ROLL SPRINKLER  A,B,C  .
      0.8463E 02     0.1150E 00     0.9074E-04
     OPTIMUM IRRIGATICN INTERVAL IS    6. ANC BENEFIT COST RATIO IS 5.362



           COST COEFFI.  OF GRAVITY IRRIGATICN  A,B,C  .



      0.3114E 02     0.8598E-01    -0.1090E-04
     OPTIMUM IRRIGATION INTERVAL IS    4. ANC BENEFIT COST RATIO IS 9.992
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          SOIL TYPE   BONNOCK    CROP TYPE   WHEAT

   NC. IRRIGATION ESTIMATED RISK ANNUAL PEAK        ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    CCST OF     BENEFIT
       INTERVAL   NUMBER OF   %  ACTUAL PERIOC      NUMBER OF SICE-    PUMPING COST HAND-   PUMPING COST     GRAVITY      ($)
       DURING     IRRIGATION     EVAPO. CONSUM.     LATERAL   ROLL SP   ($)    ($)  MOVE SP   ($)    ($)   IRRIGA.
       PERIOD OF                  (MM)  USE RATE    OF SPRNKLR  (($)                  ($)                     ($)
       MAXIMUM                          (MM/DAY)
       CONSUMPTIVE
       USE (DAYS)
    1     3.          23.   100.CO 1298.50  19.C5    37.      159.55    78.37 237.92   90.08   80.56  170.64   74.75  248.60
    2     4.          13.    99.75  724.90  14.29    28.      116.23    65.31 181.54   57.31   66.96  124.27   53.50  248.39
    3     5.           9.    59.78  49C.60  11.43    22.       9C.08    56.60 146.68   41.76   57.90   99.66   47.80  196.75
    4     6.           7.     0.70  375.10   9.52    19.       73.37    52.25 125.62   34.84   53.37   88.21   43.95   94.20
    5     7.           6.     0.00  310.50   8.16    16.       65.22    47.89 113.11   29.26   48.84   78.10   42.03   76.18
    6     8.           5.     0.CO  264.20   7.14    14.       56.59    44.99 101.98   25.17   45.82   70.99   40.10   62.78
    7     9.           4.     0.CO  229.30   6.35    13.       48.71    43.54  92.25   22.58   44.31   66.89   38.18   51.80
    8    10.           4.     0.CO  207.00   5.71    11.       44.98    40.64  85.62   19.87   41.29   61.16   38.18   44.30
    9    11.           4.     0.00  189.10   5.20    10.       41.20    39.19  80.39   18.69   39.78   58.47   38.18   37.95
   10    12.           3.     0.CO  176.60   4.76     9.       36.80    37.74  74.54   15.90   38.27   54.17   36.25   33.32
   11    13.           3.     0.CO  169.70   4.40     9.       36.93    37.74  74.67   16.23   38.27   54.50   36.25   30.68
   12    14.           3.     0.CO  163.30   4.C8     8.       33.10    36.28  69.38   14.89   36.76   51.65   36.25   28.19
   13    15.           3.     0.CO  153.80   3.81     8.       33.21    36.28  69.49   15.19   36.76   51.95   36.25   24.39
   14    16.           3.     0.CO  147.CO   3.57     7.       29.33    34.83  64.16   13.73   35.25   48.98   36.25   21.59
   15    17.           3.     0.00  139.20   3.36     7.       29.43    34.83  64.26   13.99   35.25   49.24   36.25   18.29
   16    18.           3.     0.CO  132.30   3.17     6.       25.51    33.38  58.89   12.42   33.74   46.16   36.25   15.28


                 COEFFICIENT FCR BENEFIT CURVE A,B,C
  -0.7270E 02     0.6413E 00    -0.3008E-03



          COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.2568E 02     0.1785E C0    -0.5199E-04
 OPTIMUM IRRIGATICN INTERVAL IS     4. ANC BENEFIT COST RATIO IS 1.832


          COST COEFF. OF SICE-ROLL SPRINKLER  A,B,C  .

   0.2589E 02     0.2998E C0    -0.1060E-03
 OPTIMUM IRRIGATICN INTERVAL IS     4. ANC BENEFIT COST RATIO IS 1.248

            COST COEFFI. OF GRAVITY IRRIGATICN  A,B,C  .
   0.3177E 02     0.3003E-01      0.2251E-05
 OPTIMUM IRRIGATION INTERVAL IS     4. ANC BENEFIT COST RATIO IS 4.278
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        SOIL TYPE   BOCK        CROP TYPE   WHEAT

    NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL      COST OF      BENEFIT
        INTERVAL    NUMBER OF  %   ACTUAL PERIOD    NUMBER OF SIDE-    PUMPING COST  HAND-    PUMPING COST      GRAVITY        ($)
        DURING      IRRIGATION     EVAPO. CONSUM.   LATERAL    ROLL SP  ($)     ($)  MOVE SP   ($)     ($)      IRRIGA.
        PERIOD OF         .         (MM)  USE RATE  OF SPRNKLR  (($)                  ($)                        ($)
        MAXIMUM                           (MM/DAY)
        CONSUMPTIVE
        USE (DAYS)
     1      4.          14.   100.00  916.30  16.19    35.      113.43    70.74  184.17   58.96    72.63  131.59    57.43   248.60
     2      5.          10.    96.34  608.70  12.95    28.       92.14    61.53  153.67   44.03    63.04  107.07    49.73   246.32
     3      6.           7.    34.17  455.10  10.79    23.       74.68    54.95  129.63   33.50    56.19   89.69    42.03   183.74
     4      7.           6.     0.54  372.20   9.25    20.       64.94    51.00  115.94   29.98    52.08   82.06    40.10   128.05
     5      8.           5.     0.00  317.00   8.10    17.       55.11    47.05  102.16   24.20    47.97   72.17    40.10   110.63
     6      9.           5.     0.00  275.70   7.20    16.       49.05    45.73   94.78   23.65    46.60   70.25    38.18    96.95
     7     10.           4.     0.00  247.60   6.48    14.       45.48    43.10   88.58   19.19    43.86   63.05    38.18    86.97
     8     11.           4.     0.00  225.00   5.89    13.       42.51    41.79   84.30   19.10    42.49   61.59    36.25    78.47
     9     12.           4.     0.00  208.60   5.40    12.       39.51    40.47   79.98   18.20    41.12   59.32    36.25    72.00
    10     13.           3.     0.00  198.30   4.98    11.       35.86    39.15   75.01   15.62    39.75   55.37    36.25    67.79
    11     14.           3.     0.00  189.90   4.63    10.       32.81    37.84   70.65   14.60    38.38   52.98    36.25    64.26
    12     15.           3.     0.00  178.40   4.32     9.       29.75    36.52   66.27   13.53    37.01   50.54    36.25    59.29
    13     16.           3.     0.00  170.30   4.05     9.       29.85    36.52   66.37   13.80    37.01   50.81    36.25    55.69
    14     17.           3.     0.00  161.20   3.81     8.       26.75    35.20   61.95   12.63    35.64   48.27    36.25    51.52
    15     18.           3.     0.00  153.20   3.60     8.       26.84    35.20   62.04   12.87    35.64   48.51    36.25    47.75
    16     19.           3.     0.00  146.20   3.41     8.       26.93    35.20   62.13   13.11    35.64   48.75    36.25    44.36
    17     20.           3.     0.00  141.20   3.24     7.       23.78    33.89   57.67   11.82    34.27   46.09    36.25    41.88
    18     21.           2.     0.00  137.20   3.08     7.       23.26    33.89   57.15   10.46    34.27   44.73    34.33    39.87
    19     22.           2.     0.00  133.70   2.94     7.       23.31    33.89   57.20   10.60    34.27   44.87    34.33    38.08
    20     23.           2.     0.00  133.00   2.82     6.       20.19    32.57   52.76    9.37    32.90   42.27    34.33    37.72


                COEFFICIENT FOR BENEFIT CURVE A,B,C
   -0.4507E 02      0.6399E 00      -0.3385E-03


         COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
    0.2079E 02      0.1897E 00      -0.7566E-04
  OPTIMUM IRRIGATION INTERVAL IS     5. AND BENEFIT COST RATIO IS 2.024


         COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
    0.1606E 02      0.3229E 00      -0.1532E-03
  OPTIMUM IRRIGATION INTERVAL IS     5. AND BENEFIT COST RATIO IS 1.406

          COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
    0.3204E 02      0.2122E-01      0.7603E-05
  OPTIMUM IRRIGATION INTERVAL IS     5. AND BENEFIT COST RATIO IS 4.585
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          SOIL TYPE   HEISETON   CROP TYPE   WHEAT

 NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK        ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF    BENEFIT
     INTERVAL   NUMBER OF   %  ACTUAL PERIOD      NUMBER OF SIDE-    PUMPING COST  HAND-    PUMPING COST    GRAVITY      ($)
     DURING     IRRIGATION     EVAPO. CONSUM.     LATERAL   ROLL SP   ($)     ($)  MOVE SP   ($)     ($)    IRRIGA.
     PERIOD OF                  (MM)  USE RATE    OF SPRNKLR  (($)                   ($)                      ($)
     MAXIMUM                          (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1      3.        20.    100.00  968.06   16.51   30.     156.95    71.09  228.04   83.99    72.96  156.95   68.98   248.60
  2      4.        12.     88.03  554.50   12.38   23.     117.02    60.26  177.28   56.31    61.70  118.01   53.58   239.87
  3      5.         8.      1.39  383.40    9.91   18.      90.30    52.53  142.83   40.57    53.65   94.22   45.88   126.40
  4      6.         6.      0.00  300.80    8.25   15.      74.85    47.88  122.73   32.48    48.82   81.30   42.03   100.03
  5      7.         5.      0.00  252.40    7.08   13.      64.88    44.79  109.67   27.89    45.60   73.49   40.10    83.75
  6      8.         5.      0.00  214.50    6.19   12.      55.48    43.24   98.72   26.80    43.99   70.79   40.10    69.74
  7      9.         4.      0.00  185.80    5.50   10.      50.25    40.15   90.40   21.78    40.77   62.55   38.18    58.17
  8     10.         4.      0.00  167.70    4.95    9.      45.61    38.60   84.21   20.33    39.16   59.49   38.18    50.37
  9     11.         3.      0.00  155.00    4.50    8.      40.32    37.05   77.37   17.22    37.55   54.77   36.25    44.61
 10     12.         3.      0.00  146.10    4.13    8.      40.46    37.05   77.51   17.59    37.55   55.14   36.25    40.42
 11     13.         3.      0.00  142.00    3.81    7.      35.74    35.51   71.25   15.93    35.94   51.87   36.25    38.44
 12     14.         3.      0.00  138.40    3.54    7.      35.86    35.51   71.37   16.25    35.94   52.19   36.25    36.68
 13     15.         3.      0.00  129.90    3.30    6.      31.09    33.96   65.05   14.46    34.33   48.79   36.25    32.42


            COEFFICIENT FOR BENEFIT CURVE A,B,C
   -0.5313E 02       0.6668E 00      -0.3609E-03


         COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
    0.2451E 02       0.2147E 00      -0.8073E-04
   OPTIMUM IRRIGATION INTERVAL IS      4. AND BENEFIT COST RATIO IS 1.732


         COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
    0.2350E 02       0.3787E 00      -0.1736E-03
   OPTIMUM IRRIGATION INTERVAL IS      4. AND BENEFIT COST RATIO IS 1.142

          COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
    0.3055E 02       0.4100E-01      -0.1222E-05
   OPTIMUM IRRIGATION INTERVAL IS      4. AND BENEFIT COST RATIO IS 3.887
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        SOIL TYPE   HAYESTON   CROP TYPE   WHEAT

NO. IRRIGATION ESTIMATED RISK ANNUAL PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF     BENEFIT
    INTERVAL   NUMBER OF  %   ACTUAL PERIOD     NUMBER OF SIDE-    PUMPING COST  HAND-    PUMPING COST    GRAVITY       ($)
    DURING     IRRIGATION     EVAPO. CONSUM.    LATERAL    ROLL SP   ($)    ($)  MOVE SP    ($)    ($)    IRRIGA.
    PERIOD OF                  (MM)  USE RATE   OF SPRNKLR  (($)                  ($)                      ($)
    MAXIMUM                          (MM/DAY)
    CONSUMPTIVE
    USE (DAYS)
 1      3.         18.  100.00  822.20  15.24    23.       155.23   67.52  222.75   80.10   69.08  149.18   65.13  248.60
 2      4.         11.   50.67  477.40  11.43    18.       112.27   58.21  170.48   55.80   59.42  115.22   51.65  209.35
 3      5.          8.    0.00  334.00   9.14    14.        91.81   50.76  142.57   41.53   51.70   93.23   45.88  127.41
 4      6.          6.    0.00  265.80   7.62    12.        78.30   47.03  125.33   34.24   47.84   82.08   42.03  103.98
 5      7.          5.    0.00  224.80   6.53    10.        65.40   43.30  108.70   28.41   43.98   72.39   40.10   88.04
 6      8.          5.    0.00  190.90   5.71     9.        59.42   41.44  100.86   26.70   42.05   68.75   40.10   73.66
 7      9.          4.    0.00  165.10   5.08     8.        52.71   39.58   92.29   23.10   40.12   63.22   38.18   61.73
 8     10.          4.    0.00  150.40   4.57     7.        46.62   37.72   84.34   21.06   38.19   59.25   38.18   54.47
 9     11.          3.    0.00  138.70   4.16     7.        46.15   37.72   83.87   19.87   38.19   58.06   36.25   48.40
10     12.          3.    0.00  131.30   3.81     6.        40.01   35.85   75.86   17.71   36.26   53.97   36.25   44.42


            COEFFICIENT FOR BENEFIT CURVE A,B,C
  -0.4044E 02      0.6727E 00     -0.3867E-03


         COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.2623E 02      0.2367E 00     -0.1060E-03
 OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 1.674


         COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.3161E 02      0.3916E 00     -0.1945E-03
 OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 1.105


          COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
   0.3040E 02      0.4749E-01     -0.6374E-05
 OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 3.731
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         SOIL TYPE   PAESL      CROP TYPE   WHEAT

    NO. IRRIGATION ESTIMATED RISK ANNUAL  PEAK      ESTIMATED COST OF COST OF TATAL  COST OF COST OF TAOTL   COST OF    BENEFIT
        INTERVAL   NUMBER OF  %   ACTUAL  PERIOD    NUMBER OF SIDE-   PUMPING COST   HAND-   PUMPING COST    GRAVITY     ($)
        DURING     IRRIGATION     EVAPO.  CONSUM.   LATERAL   ROLL SP  ($)     ($)   MOVE SP  ($)     ($)    IRRIGA.
        PERIOD OF                  (MM)   USE RATE  OF SPRNKLR ((\$)                   ($)                     ($)
        MAXIMUM                           (MM/DAY)
        CONSUMPTIVE
        USE (DAYS)
     1     4.         16.  100.00 1128.40  18.10     35.      118.34   76.18  194.52   62.81   78.07  140.88   61.28   248.60
     2     5.         11.   99.85  737.20  14.48     28.       92.88   65.88  158.76   45.85   67.39  113.24   51.65   248.51
     3     6.          8.   83.98  540.40  12.06     23.       75.37   58.52  133.89   35.22   59.76   94.98   45.88   232.14
     4     7.          6.   21.52  437.30  10.34     20.       64.94   54.10  119.04   28.98   55.18   84.16   42.03   149.53
     5     8.          5.    0.56  372.60   9.05     17.       55.11   49.69  104.80   24.20   50.61   74.81   40.10   106.76
     6     9.          5.    0.00  324.70   8.04     16.       49.05   48.22   97.27   23.65   49.08   72.73   40.10    92.75
     7    10.          4.    0.00  290.30   7.24     14.       45.48   45.28   90.76   19.92   46.03   65.95   38.18    82.56
     8    11.          4.    0.00  262.50   6.58     13.       42.51   43.80   86.31   19.10   44.51   63.61   38.18    73.82
     9    12.          4.    0.00  241.70   6.03     12.       39.51   42.33   81.84   18.20   42.98   61.18   38.18    66.94
    10    13.          3.    0.00  227.70   5.57     11.       35.86   40.86   76.72   15.62   41.46   57.08   36.25    62.12
    11    14.          3.    0.00  216.60   5.17     10.       32.81   39.39   72.20   14.60   39.93   54.53   36.25    58.18
    12    15.          3.    0.00  203.50   4.83      9.       29.75   37.92   67.67   13.53   38.40   51.93   36.25    53.39
    13    16.          3.    0.00  194.00   4.52      9.       29.85   37.92   67.77   13.80   38.40   52.20   36.25    49.81
    14    17.          3.    0.00  183.70   4.26      8.       26.75   36.45   63.20   12.63   36.88   49.51   36.25    45.81
    15    18.          3.    0.00  174.60   4.02      8.       26.84   36.45   63.29   12.87   36.88   49.75   36.25    42.17
    16    19.          3.    0.00  166.50   3.81      8.       26.93   36.45   63.38   13.11   36.98   49.99   36.25    38.85
    17    20.          3.    0.00  160.70   3.62      7.       23.78   34.98   58.76   11.82   35.35   47.17   36.25    36.42
    18    21.          3.    0.00  155.90   3.45      7.       23.86   34.98   58.84   12.03   35.35   47.38   36.25    34.37
    19    22.          2.    0.00  151.70   3.29      7.       23.31   34.98   58.29   10.60   35.35   45.95   34.33    32.55
    20    23.          2.    0.00  150.40   3.15      6.       20.19   33.50   53.69    9.37   33.83   43.20   34.33    31.98


              COEFFICIENT FOR BENEFIT CURVE A,B,C
      -0.6725E 02      0.6588E 00     -0.3305E-03



         COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
       0.2255E 02      0.1633E 00     -0.5218E-04
     OPTIMUM IRRIGATION INTERVAL IS     5. AND BENEFIT COST RATIO IS 2.084



         COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
       0.1960E 02      0.2682E 00     -0.1012E-03
     OPTIMUM IRRIGATION INTERVAL IS     5. AND BENEFIT COST RATIO IS 1.472
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        SOIL TYPE   STAN        CROP TYPE   WHEAT

 NO. IRRIGATION ESTIMATED RISK ANNUAL  PEAK       ESTIMATED COST OF COST OF TATAL COST OF COST OF TAOTL    COST OF     BENEFIT
     INTERVAL   NUMBER OF   %  ACTUAL  PERIOD     NUMBER OF SIDE-    PUMPING COST  HAND-    PUMPING COST    GRAVITY       ($)
     DURING     IRRIGATION     EVAPO.  CONSUM.    LATERAL   ROLL SP    ($)    ($)  MOVE SP    ($)    ($)    IRRIGA.
     PERIOD OF                  (MM)   USE RATE   OF SPRNKLR  (($)                   ($)                      ($)
     MAXIMUM                           (MM/DAY)
     CONSUMPTIVE
     USE (DAYS)
  1     3.        21.   100.00 1274.40   17.78     33.      161.09   75.91  237.00   87.75   77.92  165.57    70.90  248.60
  2     4.        12.    98.09  637.10   13.33     24.      113.32   61.93  175.25   54.49   63.32  117.81    53.59  246.74
  3     5.         9.    20.46  435.60   10.67     20.       89.13   55.72  144.85   43.54   56.88  100.42    47.80  137.89
  4     6.         7.     0.01  337.20    8.89     16.       74.71   49.51  124.22   33.78   50.44   84.22    43.95   85.08
  5     7.         6.     0.00  281.00    7.62     14.       65.43   46.41  111.84   29.46   47.22   76.68    42.03   69.33
  6     8.         5.     0.00  239.00    6.67     12.       56.05   43.30   99.35   24.88   44.00   68.88    40.10   56.38
  7     9.         4.     0.00  207.20    5.93     11.       57.16   41.75   98.91   22.08   42.39   64.47    38.18   45.72
  8    10.         4.     0.00  187.50    5.33     10.       46.87   40.20   87.07   20.79   40.78   61.57    38.18   38.65
  9    11.         4.     0.00  171.80    4.85      9.       42.54   38.65   81.19   19.39   39.17   58.56    38.18   32.73
 10    12.         3.     0.00  161.20    4.44      8.       37.57   37.09   74.66   16.33   37.56   53.89    36.25   28.56
 11    13.         3.     0.00  155.70    4.10      8.       37.70   37.09   74.79   16.67   37.56   54.23    36.25   26.34
 12    14.         3.     0.00  151.10    3.81      7.       33.30   35.54   68.84   15.09   35.95   51.04    36.25   24.45
 13    15.         3.     0.00  141.80    3.56      7.       33.41   35.54   68.95   15.39   35.95   51.34    36.25   20.53
 14    16.         2.     0.00  135.60    3.33      6.       28.39   33.99   62.38   12.18   34.34   46.52    34.33   17.84


           COEFFICIENT FOR BENEFIT CURVE A,B,C
  -0.7144E 02      0.6407E 00     -0.3030E-03


        COST COEFFI. OF HAND-MOVE SPRINKLER A,B,C  .
   0.2536E 02      0.1949E 00     -0.6698E-04
 OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 1.747


        COST COEFF. OF SIDE-ROLL SPRINKLER  A,B,C  .
   0.2857E 02      0.3183E 00     -0.1221E-03

 OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 1.176

         COST COEFFI.  OF GRAVITY IRRIGATION  A,B,C  .
   0.2969E 02      0.4510E-01     -0.1008E-04
 OPTIMUM IRRIGATION INTERVAL IS     4. AND BENEFIT COST RATIO IS 3.935
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APPENDIX F

CROP WATER REQUIREMENTS

Crop water requirements for each farm unit in the study area of the Snake River Valley Irrigation District.

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        UNIT NUMBER        1015

NO.    CROP         SOIL        APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     POTATOES     BOCK          HAND-MVE      71.83      7.56      10.08       6.00     0.00
 2     GRAIN        BANNOCK       HAND-MVE      99.52     14.29      19.05       4.00     0.00
 3     ALFALFA      BOCK          HAND-MVE      14.62     14.25      19.00       8.00     0.00
 4     ALFALFA      BOCK          GRAVITY       19.23     14.25      24.57       8.00     4.91


                     FARM NET WATER REQUIREMENT

    MAX. WATER. DURING JUNE AND JULY ARE       6.21      7.37   ACRE-FEET
    TOTAL IRRIG. ACREAGE  205.20 DESIGN WAT. REQ.  7.37  ACRE-FEET/DAY  3.72  CFS 10.95  MM/DAY   105.37  L/S


                    FARM GROSS WATER REQUIREMENT

    MAX. WATER. DURING JUNE AND JULY ARE       8.47     10.18   ACRE-FEET

    TOTAL IRRIG. ACREAGE  205.20 DESIGN WAT. REQ. 10.18  ACRE-FEET/DAY  5.14  CFS 15.12  MM/DAY   145.51  L/S
    TOTAL RUN OFF IS     0.0894  CFS     2.530   L/S
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           UNIT NUMBER        1016

      NO.    CROP         SOIL       APPL. SUBSYS.   ACREAGE ET(MM/CAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

       1     POTATOES     BANNOCK      GRAVITY         9.89     10.00      29.41       4.00      2.06
       2     POTATOES     BANNOCK      SIDE-RLE       24.11      8.98      11.97       7.00      0.00
       3     ALFALFA      BOCK         HAND-MVE       43.20     14.25      19.00       8.00      C.CO
       4     ALFALFA      BOCK         GRAVITY        20.97     14.25      24.57       8.CO      4.91
       5     GRAIN        BANNOCK      SIDE-RLE       28.83     14.29      19.05       4.00      0.00
       6     GRAIN        BOCK         HAND-MVE       41.92     12.95      17.27       5.00      0.00
       7     GRAIN        BANNOCK      GRAVITY        24.31     14.29      28.02       4.00      6.30
       8     PASTURE      BANNOCK      GRAVITY         8.25     12.57      24.65       5.00      5.55


                       FARM NET WATER REQUIREMENT

        MAX. WATER. DURING JUNE AND JULY ARE       6.55      8.05   ACRE-FEET

        TOTAL IRRIG. ACREAGE  201.48 CESIGN WAT. REQ.  8.05  ACRE-FEET/DAY  4.06  CFS 12.17  MM/DAY   114.99  L/S


                      FARM GRCSS WATER REQLIREMENT

        MAX. WATER. DURING JUNE AND JULY ARE       9.97     12.46   ACRE-FEET

        TOTAL IRRIG. ACREAGE  201.48 DESIGN WAT. REQ. 12.46  ACRE-FEET/DAY  6.29  CFS 18.85  MM/DAY   178.08  L/S
        TOTAL RUN OFF IS     0.4068  CFS    11.512   L/S
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     UNIT NUMBER        1017

NO.   CROP        SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1    GRAIN       BANNOCK      HAND-MVE       71.63     14.29      19.05       4.00      0.00
 2    GRAIN       BANNOCK      GRAVITY        40.32     14.29      28.02       4.00      6.30
 3    ALFALFA     BANNOCK      GRAVITY        18.53     14.37      24.78       7.00      4.96
 4    PASTURE     BANNOCK      GRAVITY        12.45     12.57      24.65       5.00      5.55


                 FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      6.04      5.90   ACRE-FEET

   TOTAL IRRIG. ACREAGE  142.93 DESIGN WAT. REQ.  6.04  ACRE-FEET/DAY  3.05  CFS 12.88  MM/DAY    86.34  L/S


                FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      9.62      9.54   ACRE-FEET

   TOTAL IRRIG. ACREAGE  142.93 DESIGN WAT. REQ.  9.62  ACRE-FEET/DAY  4.86  CFS 20.51  MM/DAY   137.48  L/S
   TOTAL RUN OFF IS     0.5734  CFS    16.227   L/S
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            UNIT NUMBER        1018

NO.    CROP          SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     POTATOES     BOCK          HAND-MVE      22.26      7.56       10.08       6.00      0.00
 2     GRAIN        BOCK          HAND-MVE      30.00     12.95       17.27       5.00      0.00
 3     GRAIN        BANNOCK       HAND-MVE      44.14     14.29       19.05       4.00      0.00
 4     GRAIN        BANNOCK       GRAVITY       26.07     14.29       28.02       4.00      6.30
 5     ALFALFA      BANNOCK       GRAVITY       15.74     14.37       24.78       7.00      4.96
 6     PASTURE      BANNOCK       GRAVITY        6.69     12.57       24.65       5.00      5.55


                   FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE       5.34       5.49   ACRE-FEET

   TOTAL IRRIG. ACREAGE  144.90 DESIGN WAT. REQ.  5.49  ACRE-FEET/DAY  2.77  CFS 11.55  MM/DAY    78.50  L/S


                  FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE       8.16       8.45   ACRE-FEET

   TOTAL IRRIG. ACREAGE  144.90 DESIGN WAT. REQ.  8.45  ACRE-FEET/DAY  4.27  CFS 17.76  MM/DAY   120.71  L/S
   TOTAL RUN OFF IS      0.3812  CFS    10.789   L/S
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      UNIT NUMBER        1019

NO.   CROP        SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1    GRAIN       BANNOCK     HAND-MVE      92.62      14.29       19.05       4.00       0.00
 2    POTATOES    BANNOCK     SIDE-RLE      39.50       5.71        7.61       7.00       0.00
 3    ALFALFA     BANNOCK     GRAVITY        5.58      14.37       24.78       7.00       4.96


                   FARM NET WATER REQUIREMENT

    MAX. WATER. DURING JUNE AND JULY ARE       4.76       4.73    ACRE-FEET
    TOTAL IRRIG. ACREAGE  137.70 DESIGN WAT. REQ.  4.76  ACRE-FEET/DAY  2.40  CFS 10.53  MM/DAY    67.99  L/S


                  FARM GROSS WATER REQUIREMENT

    MAX. WATER. DURING JUNE AND JULY ARE       6.40       6.41    ACRE-FEET
    TOTAL IRRIG. ACREAGE  137.70 DESIGN WAT. REQ.  6.41  ACRE-FEET/DAY  3.24  CFS 14.20  MM/DAY    91.67  L/S
    TOTAL RUN OFF IS     0.0262  CFS     0.740   L/S
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          UNIT NUMBER         1020

     NO.    CROP          SOIL        APPL. SUBSYS.    ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

      1     POTATOES      BANNOCK       SIDE-RLE      77.42       5.71        7.61        7.00       0.00
      2     GRAIN         BANNOCK       SIDE-RLE      77.49      14.29       19.05        4.00       0.00


                         FARM NET WATER REQUIREMENT

        MAX. WATER. DURING JUNE AND JULY ARE       4.15       4.57    ACRE-FEET
        TOTAL IRRIG. ACREAGE  154.91 DESIGN WAT. REQ.  4.57  ACRE-FEET/DAY  2.31  CFS  8.99  MM/DAY    65.33  L/S


                         FARM GROSS WATER REQUIREMENT

        MAX. WATER. DURING JUNE AND JULY ARE       5.53       6.09    ACRE-FEET
        TOTAL IRRIG. ACREAGE  154.91 DESIGN WAT. REQ.  6.09  ACRE-FEET/DAY  3.08  CFS 11.99  MM/DAY    87.11  L/S
        TOTAL RUN OFF IS     0.0000  CFS     0.000    L/S
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          UNIT NUMBER        1021

     NO.    CROP          SOIL        APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

      1     GRAIN         BANNOCK       SICE-RLE     65.12       14.29       19.05        4.00       0.00
      2     GRAIN         BANNOCK       GRAVITY      18.28       14.29       28.02        4.00       6.30
      3     ALFALFA       BANNOCK       GRAVITY      39.23       14.37       24.78        7.00       4.96
      4     PASTURE       BANNOCK       GRAVITY      14.35       12.95       25.39        5.00       5.71


                       FARM NET WATER REQUIREMENT

        MAX. WATER. DURING JUNE AND JULY ARE       5.31       5.82    ACRE-FEET

        TOTAL IRRIG. ACREAGE  136.98 DESIGN WAT. REQ.  5.82  ACRE-FEET/DAY  2.94  CFS 12.95  MM/DAY    83.16  L/S


                      FARM GROSS WATER REQUIREMENT

        MAX. WATER. DURING JUNE AND JULY ARE       8.25       9.32    ACRE-FEET

        TOTAL IRRIG. ACREAGE  136.98 CESIGN WAT. REQ.  9.32  ACRE-FEET/DAY  4.71  CFS 20.75  MM/DAY   133.27  L/S
        TOTAL RUN OFF IS      0.4524  CFS     12.804   L/S
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        UNIT NUMBER        1022

NO.     CROP         SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1      GRAIN        BANNOCK      GRAVITY       16.00      14.29      28.02       4.00       6.30
 2      GRAIN        BOCK         GRAVITY       49.36      12.95      25.39       5.00       5.71
 3      ALFALFA      BANNOCK      GRAVITY       19.00      14.37      24.78       7.00       4.96
 4      ALFALFA      BOCK         GRAVITY       39.33      12.67      21.84       8.00       4.37
 5      PASTURE      BANNOCK      GRAVITY       18.00      12.95      25.39       5.00       5.71
 6      PASTURE      BOCK         GRAVITY        9.39      14.25      25.00       5.00       5.13


                    FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      4.98      6.18   ACRE-FEET

   TOTAL IRRIG. ACREAGE  151.08 DESIGN WAT. REQ.  6.18  ACRE-FEET/DAY  3.12  CFS 12.47  MM/DAY    88.33  L/S


                   FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      9.37     11.43   ACRE-FEET

   TOTAL IRRIG. ACREAGE  151.08 DESIGN WAT. REQ. 11.43  ACRE-FEET/DAY  5.77  CFS 23.06  MM/DAY   163.35  L/S
   TOTAL RUN OFF IS     1.0289  CFS    29.118   L/S
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      UNIT NUMBER         1023

NO.    CROP        SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     POTATOES    STAN          SIDE-RLE      53.10      6.22       8.29      6.00      0.00
 2     POTATOES    BANNOCK       SIDE-RLE      48.88      5.71       7.61      7.00      0.00
 3     POTATOES    BANNOCK       HAND-MVE      13.19      5.71       7.61      7.00      0.00
 4     GRAIN       BANNOCK       SIDE-RLE     102.27     14.29      19.05      4.00      0.00
 5     GRAIN       BANNOCK       GRAVITY        7.00     14.29      28.02      4.00      6.30
 6     ALFALFA     BANNOCK       SIDE-RLE      48.34     14.37      19.16      7.00      0.00
 7     ALFALFA     BOCK          GRAVITY        7.71     14.25      24.57      8.00      4.91
 8     PASTURE     BANNOCK       GRAVITY       14.07     12.57      24.65      5.00      5.55


                  FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE       7.76      9.87    ACRE-FEET

   TOTAL IRRIG. ACREAGE  294.56 DESIGN WAT. REQ.  9.87  ACRE-FEET/DAY  4.98  CFS 10.21  MM/DAY   141.02  L/S


                 FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE     10.85     13.84    ACRE-FEET

   TOTAL IRRIG. ACREAGE  294.56 DESIGN WAT. REQ. 13.84  ACRE-FEET/DAY  6.99  CFS 14.32  MM/DAY   197.78  L/S
   TOTAL RUN OFF IS     0.1828  CFS     5.173   L/S
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          UNIT NUMBER        1025

NO.   CROP         SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1    GRAIN        BANNOCK      GRAVITY       69.52      14.29      28.02       4.00       6.30
 2    ALFALFA      BANNOCK      GRAVITY       46.93      14.37      24.78       7.00       4.96
 3    PASTURE      BANNOCK      GRAVITY        5.96      12.57      24.65       5.00       5.55


                     FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      4.66       5.26   ACRE-FEET

   TOTAL IRRIG. ACREAGE  122.41 DESIGN WAT. REQ.  5.26  ACRE-FEET/DAY  2.66  CFS 13.09  MM/DAY   75.15  L/S


                    FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      8.84       9.79   ACRE-FEET

   TOTAL IRRIG. ACREAGE  122.41 DESIGN WAT. REQ.  9.79  ACRE-FEET/DAY  4.94  CFS 24.37  MM/DAY   139.88  L/S
   TOTAL RUN OFF IS     0.9775  CFS    27.664   L/S
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         UNIT NUMBER        1106

NO.    CROP        SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     POTATOES    BANNOCK      HAND-MVE       50.07     5.71       7.61       7.00      0.00
 2     GRAIN       BOCK         HAND-MVE       83.79    12.95      17.27       5.00      0.00
 3     ALFALFA     BOCK         HAND-MVE      100.82    14.25      19.00       8.00      0.00


                 FARM NET WATER REQUIREMENT

  MAX. WATER. DURING JUNE AND JULY ARE      6.59      8.71    ACRE-FEET

  TOTAL IRRIG. ACREAGE  234.68 DESIGN WAT. REQ.  8.71  ACRE-FEET/DAY  4.40  CFS 11.31  MM/DAY   124.48  L/S


                 FARM GROSS WATER REQUIREMENT

  MAX. WATER. DURING JUNE AND JULY ARE      8.78     11.61    ACRE-FEET

  TOTAL IRRIG. ACREAGE  234.68 DESIGN WAT. REQ. 11.61  ACRE-FEET/DAY  5.87  CFS 15.08  MM/DAY   165.98  L/S
  TOTAL RUN OFF IS     0.CC00  CFS     C.CO0   L/S
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        UNIT NUMBER        1109

NO.     CROP         SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1      POTATOES     BOCK          HAND-MVE     182.32      7.56      10.08       6.00      0.00
 2      GRAIN        BOCK          HAND-MVE     111.42     12.95      17.27       5.00      0.00
 3      GRAIN        BANNOCK       HAND-MVE      18.00     14.29      19.05       4.00      0.00
 4      ALFALFA      BANNOCK       GRAVITY       30.00     14.37      24.78       7.00      4.96
 5      ALFALFA      BOCK          GRAVITY       31.31     14.25      24.57       8.00      4.91


                     FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      8.84      12.19   ACRE-FEET

   TOTAL IRRIG. ACREAGE  373.05 DESIGN WAT. REQ. 12.19  ACRE-FEET/DAY  6.16  CFS  9.96  MM/DAY   174.25  L/S


                    FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE     12.42      17.38   ACRE-FEET

   TOTAL IRRIG. ACREAGE  373.05 DESIGN WAT. REQ. 17.38  ACRE-FEET/DAY  8.78  CFS 14.20  MM/DAY   248.41  L/S
   TOTAL RUN OFF IS     0.2862  CFS     8.100   L/S
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        UNIT NUMBER        1110

NO.    CROP         SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     POTATOES     BOCK          HAND-MVE     116.93      7.56      10.08       6.00       0.00
 2     GRAIN        BOCK          HAND-MVE      12.34     12.95      17.27       5.00       0.00
 3     ALFALFA      BOCK          HAND-MVE      21.89     14.25      19.00       8.00       0.00


                    FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      2.14      4.37   ACRE-FEET

   TOTAL IRRIG. ACREAGE  151.16 DESIGN WAT. REQ.  4.37  ACRE-FEET/DAY  2.21  CFS  8.82  MM/DAY    62.52  L/S


                   FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      2.86      5.83   ACRE-FEET

   TOTAL IRRIG. ACREAGE  151.16 DESIGN WAT. REQ.  5.83  ACRE-FEET/DAY  2.95  CFS 11.76  MM/DAY    83.36  L/S
   TOTAL RUN OFF IS     0.0000  CFS     0.000   L/S
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          UNIT NUMBER        1111

    NO.   CROP          SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

     1    POTATOES      BANNOCK      GRAVITY       37.10      10.00       29.41       4.00      2.06
     2    POTATOES      BANNOCK      SIDE-RLE      25.83       5.71        7.61       7.00      0.00
     3    GRAIN         BOCK         SIDE-RLE      20.00      12.95       17.27       5.00      0.00
     4    GRAIN         BANNOCK      SIDE-RLE      43.10      14.29       19.05       4.00      0.00
     5    GRAIN         BOCK         GRAVITY       21.25      12.95       25.39       4.00      5.71
     6    ALFALFA       BOCK         HAND-MVE      16.74      14.25       19.00       8.00      0.00


                        FARM NET WATER REQUIREMENT

      MAX. WATER. DURING JUNE AND JULY ARE       4.83       5.72   ACRE-FEET

      TOTAL IRRIG. ACREAGE  164.02 DESIGN WAT. REQ.  5.72  ACRE-FEET/DAY  2.89  CFS 10.64  MM/DAY    81.83  L/S


                       FARM GROSS WATER REQUIREMENT

      MAX. WATER. DURING JUNE AND JULY ARE       7.70      10.08   ACRE-FEET

      TOTAL IRRIG. ACREAGE  164.02 DESIGN WAT. REQ. 10.08  ACRE-FEET/DAY  5.09  CFS 18.73  MM/DAY   144.03  L/S
      TOTAL RUN OFF IS     0.2464  CFS     6.972   L/S
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        UNIT NUMBER        1113

NO.    CROP        SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     POTATOES    BOCK         GRAVITY        17.81      7.56       20.43       6.00      1.43
 2     GRAIN       BOCK         HAND-MVE       91.18     12.95       17.27       5.00      0.00
 3     GRAIN       BOCK         GRAVITY         5.41     12.95       25.39       5.00      5.71
 4     ALFALFA     BOCK         GRAVITY        24.27     14.25       24.57       8.00      4.91
 5     PASTURE     BOCK         GRAVITY         2.78     14.25       25.00       5.00      5.13


                  FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      4.98       5.23   ACRE-FEET

   TOTAL IRRIG. ACREAGE  141.45 DESIGN WAT. REQ.  5.23  ACRE-FEET/DAY  2.64  CFS 11.27  MM/DAY    74.77  L/S


                 FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      7.29       8.20   ACRE-FEET

   TOTAL IRRIG. ACREAGE  141.45 DESIGN WAT. REQ.  8.20  ACRE-FEET/DAY  4.14  CFS 17.67  MM/DAY   117.24  L/S
   TOTAL RUN OFF IS      0.1926  CFS      5.451   L/S
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         UNIT NUMBER         1114

NO.    CROP          SOIL       APPL. SUBSYS.    ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     POTATOES      BANNOCK      HAND-MVE      36.00       5.71        7.61       7.00       0.00
 2     POTATOES      BOCK         HAND-MVE      37.78       7.56       10.08       6.00       0.00
 3     GRAIN         BOCK         HAND-MVE      41.06      12.95       17.27       5.00       0.00
 4     ALFALFA       BOCK         GRAVITY       21.14      14.25       24.57       8.00       4.91
 5     PASTURE       BOCK         GRAVITY        4.32      14.25       25.00       5.00       5.13


                        FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE       3.00       4.30    ACRE-FEET

   TOTAL IRRIG. ACREAGE  140.30 DESIGN WAT. REQ.   4.30   ACRE-FEET/DAY  2.17  CFS  9.34  MM/DAY     61.46  L/S


                       FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      4.27       6.21    ACRE-FEET

   TOTAL IRRIG. ACREAGE  140.30 DESIGN WAT. REQ.  6.21   ACRE-FEET/DAY  3.13  CFS 13.48  MM/DAY     88.69  L/S
   TOTAL RUN OFF IS     0.1192  CFS     3.374   L/S
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UNIT NUMBER       1117

NO.   CROP        SOIL      APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1    POTATOES    BOCK        GRAVITY        30.40     7.56      20.43        6.00       1.43
 2    GRAIN       BANNOCK     GRAVITY        40.51    14.29      28.02        4.00       6.30
 3    GRAIN       BOCK        GRAVITY        40.79    12.95      25.39        5.00       5.71
 4    ALFALFA     BOCK        GRAVITY        22.29    14.25      24.57        8.00       4.91
 5    PASTURE     BOCK        GRAVITY         4.30    14.25      25.00        5.00       5.13


                  FARM NET WATER REQUIREMENT

  MAX. WATER. DURING JUNE AND JULY ARE       4.61      5.12   ACRE-FEET

  TOTAL IRRIG. ACREAGE  138.29 DESIGN WAT. REQ.  5.12  ACRE-FEET/DAY  2.58  CFS 11.28  MM/DAY    73.14  L/S


                  FARM GROSS WATER REQUIREMENT

  MAX. WATER. DURING JUNE AND JULY ARE       9.08     10.31   ACRE-FEET

  TOTAL IRRIG. ACREAGE  138.29 DESIGN WAT. REQ. 10.31  ACRE-FEET/DAY  5.20  CFS 22.71  MM/DAY   147.29  L/S
  TOTAL RUN OFF IS     0.9595  CFS    27.155   L/S
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        UNIT NUMBER        1207

  NO.    CROP         SOIL       APPL. SUBSYS.    ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

   1     POTATOES     BOCK         HAND-MVE      37.66      7.56       10.08       4.00      0.00
   2     GRAIN        BOCK         GRAVITY       27.19     12.95       25.39       5.00      5.71
   3     GRAIN        BOCK         HAND-MVE      35.31     12.95       17.27       5.00      0.00
   4     PASTURE      BOCK         GRAVITY        8.58     14.25       25.00       5.00      5.13


                   FARM NET WATER REQUIREMENT

     MAX. WATER. DURING JUNE AND JULY ARE      3.22       3.62    ACRE-FEET

     TOTAL IRRIG. ACREAGE  108.74 DESIGN WAT. REQ.  3.62  ACRE-FEET/DAY  1.83  CFS 10.14  MM/DAY    51.69  L/S


                  FARM GROSS WATER REQUIREMENT

     MAX. WATER. DURING JUNE AND JULY ARE      5.11       5.61    ACRE-FEET

     TOTAL IRRIG. ACREAGE  108.74 DESIGN WAT. REQ.  5.61  ACRE-FEET/DAY  2.83  CFS 15.73  MM/DAY    80.23  L/S
     TOTAL RUN OFF IS     0.2990  CFS     8.462   L/S
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      UNIT NUMBER        1210

NO.    CROP          SOIL       APPL. SUBSYS.    ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     GRAIN         BOCK          GRAVITY         9.40      12.95      25.39       5.00       5.71
 2     ALFALFA       BOCK          GRAVITY        39.56      14.25      24.57       8.00       4.91
 3     ALFALFA       HEISETON      GRAVITY        25.00      14.53      27.42       6.00       6.03
 4     PASTURE       BOCK          GRAVITY        41.03      14.25      25.00       5.00       5.13


                   FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      3.23      5.30   ACRE-FEET

   TOTAL IRRIG. ACREAGE  114.99 DESIGN WAT. REQ.  5.30  ACRE-FEET/DAY  2.68  CFS 14.06  MM/DAY    75.79  L/S


                  FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      5.81      9.48   ACRE-FEET

   TOTAL IRRIG. ACREAGE  114.99 DESIGN WAT. REQ.  9.48  ACRE-FEET/DAY  4.79  CFS 25.12  MM/DAY   135.43  L/S
   TOTAL RUN OFF IS     0.6145  CFS    17.391   L/S
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         UNIT NUMBER        1211

NO.     CROP        SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1      POTATOES    BANNOCK     HAND-MVE      35.24       5.71       7.61       7.00      0.00
 2      POTATOES    BOCK        HAND-MVE      47.79       7.56      10.08       6.00      0.00
 3      GRAIN       BOCK        GRAVITY        5.20      12.95      25.39       5.00      5.71
 4      ALFALFA     BOCK        GRAVITY       43.78      14.25      24.57       8.00      4.91
 5      PASTURE     BOCK        GRAVITY        2.84      14.25      25.00       5.00      5.13


                     FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE       2.12      4.21   ACRE-FEET

   TOTAL IRRIG. ACREAGE  134.85 DESIGN WAT. REQ.  4.21  ACRE-FEET/DAY  2.13  CFS  9.53  MM/DAY    60.24  L/S


                    FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE       3.46      6.59   ACRE-FEET

   TOTAL IRRIG. ACREAGE  134.85 DESIGN WAT. REQ.  6.59  ACRE-FEET/DAY  3.33  CFS 14.91  MM/DAY    94.26  L/S
   TOTAL RUN OFF IS     0.2665  CFS     7.543   L/S
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        UNIT NUMBER        1212

NO.    CROP         SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     POTATOES     BOCK        HAND-MVE      19.13       7.56      10.08       6.00      0.00
 2     GRAIN        BOCK        HAND-MVE      18.19      12.95      17.27       5.00      0.00
 3     GRAIN        BOCK        GRAVITY       26.42      12.95      25.39       5.00      5.71
 4     ALFALFA      BOCK        GRAVITY       62.02      14.25      24.57       8.00      4.91
 5     PASTURE      BOCK        GRAVITY       11.19      14.25      25.00       5.00      5.13


                    FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      4.02      5.53   ACRE-FEET

   TOTAL IRRIG. ACREAGE  136.95 DESIGN WAT. REQ.  5.53  ACRE-FEET/DAY  2.79  CFS 12.30  MM/DAY    78.97  L/S


                   FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      6.84      9.33   ACRE-FEET

   TOTAL IRRIG. ACREAGE  136.95 DESIGN WAT. REQ.  9.33  ACRE-FEET/DAY  4.71  CFS 20.76  MM/DAY   133.29  L/S
   TOTAL RUN OFF IS      0.5927  CFS     16.774   L/S
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          UNIT NUMBER        1214

     NO.    CROP         SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

      1     POTATOES     BANNOCK      GRAVITY      12.50     10.00       29.41       4.00      2.06
      2     POTATOES     STAN         GRAVITY      25.58      9.33       12.44       4.00      0.00
      3     GRAIN        BANNOCK      GRAVITY      12.50     12.95       25.39       5.00      5.71
      4     GRAIN        STAN         GRAVITY      25.07     13.33       45.97       4.00     14.02
      5     ALFALFA      BANNOCK      GRAVITY      25.00     14.37       24.78       7.00      4.96
      6     ALFALFA      STAN         GRAVITY      57.80     15.65       26.98       6.00      5.53


                          FARM NET WATER REQUIREMENT

        MAX. WATER. DURING JUNE AND JULY ARE       4.42       6.74    ACRE-FEET
        TOTAL IRRIG. ACREAGE  158.45 DESIGN WAT. REQ.  6.74  ACRE-FEET/DAY  3.40  CFS 12.96  MM/DAY     96.30  L/S


                         FARM GROSS WATER REQUIREMENT

        MAX. WATER. DURING JUNE AND JULY ARE       9.71      13.54    ACRE-FEET
        TOTAL IRRIG. ACREAGE  158.45 DESIGN WAT. REQ. 13.54  ACRE-FEET/DAY  6.84  CFS 26.05  MM/DAY    193.54  L/S
        TOTAL RUN OFF IS     1.1356  CFS     32.139   L/S
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        UNIT NUMBER         1216

NO.     CROP         SOIL       APPL. SUBSYS.    ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1      POTATOES     BANNOCK       GRAVITY        31.69     10.00      29.41       4.00      2.06
 2      POTATOES     STAN          GRAVITY         9.00      9.33      12.44       4.00      0.00
 3      GRAIN        BANNOCK       GRAVITY         4.10     14.29      28.02       4.00      6.30
 4      ALFALFA      BANNOCK       GRAVITY        47.66     14.25      24.57       8.00      4.91
 5      PASTURE    _ BANNOCK       GRAVITY        33.46     12.57      24.65       5.00      5.55


                  FARM NET WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      2.72      5.09   ACRE-FEET

   TOTAL IRRIG. ACREAGE  125.91 DESIGN WAT. REQ.  5.09  ACRE-FEET/DAY  2.57  CFS 12.32  MM/DAY    72.73  L/S


                 FARM GROSS WATER REQUIREMENT

   MAX. WATER. DURING JUNE AND JULY ARE      5.34     10.30   ACRE-FEET

   TOTAL IRRIG. ACREAGE  125.91 DESIGN WAT. REQ. 10.30  ACRE-FEET/DAY  5.20  CFS 24.93  MM/DAY   147.17  L/S
   TOTAL RUN OFF IS     0.4786  CFS    13.543   L/S
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UNIT NUMBER        1217

NO.    CROP         SOIL       APPL. SUBSYS.   ACREAGE ET(MM/DAY) GWR(MM/DAY) II(DAYS) RF(MM/DAY)

 1     GRAIN        BANNOCK     HAND-MVE      25.34      14.29      19.05       4.00      0.00
 2     GRAIN        STAN        HAND-MVE      62.89      13.33      17.77       4.00      0.00
 3     GRAIN        BANNOCK     GRAVITY        4.51      14.29      28.02       4.00      6.30
 4     ALFALFA      STAN        HAND-MVE      38.88      11.37      15.16       8.00      0.00
 5     PASTURE      STAN        GRAVITY       19.57      14.67      40.75       4.00     11.21


                 FARM NET WATER REQUIREMENT

MAX. WATER. DURING JUNE AND JULY ARE      5.52      5.96   ACRE-FEET

TOTAL IRRIG. ACREAGE  151.19 DESIGN WAT. REQ.  5.96  ACRE-FEET/DAY  3.01  CFS 12.01  MM/DAY    85.14  L/S


                 FARM GROSS WATER REQUIREMENT

MAX. WATER. DURING JUNE AND JULY ARE      8.26      9.42   ACRE-FEET

TOTAL IRRIG. ACREAGE  151.19 DESIGN WAT. REQ.  9.42  ACRE-FEET/DAY  4.76  CFS 18.99  MM/DAY   134.60  L/S
TOTAL RUN OFF IS     0.2546  CFS     7.205   L/S
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