METHODOLOGY FOR OBTAINING LEAST COST IRRIGATION SYSTEM SPECIFICATIONS

A Dissertation
Presented in Partial Fulfillment of the Requirement for the
DEGREE OF DOCTOR OF PHILOSOPHY
Major in Civil Engineering

in the
UNIVERSITY OF IDAHO GRADUATE SCHOOL
by

JOHN ROBERT BUSCH
November 1974

ACKNOWLEDGMENTS

As author of this dissertation I wish to express my appreciation to many people for their support and encouragement. First, I thank my wonderful family, Susie, Tim, and Tom, for their endless encouragement, support, and understanding. I wish to acknowledge and thank my committee, Dr. F. J. Watts and Professor C. C. Warnick for serving as major professors and Drs. D. W. Fitzsimmons, D. O. Everson, and G. L. Bloomsburg for their guidance and support. I am especially grateful to Dr. Fitzsimmons, Head of the Department of Agricultural Engineering, for his encouragement and suggestions.

The study reported in this dissertation was supported by the Idaho Agricultural Experiment Station and the Office of Water Research and Technology under the project "Socio-Economic Analysis of a Major Rehabilitation of Irrigation and Water Management Systems in Eastern Idaho."

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS iii

LIST OF TABLES vii

LIST OF ILLUSTRATIONS ix

ABSTRACT xi

Chapter
1. INTRODUCTION AND STATEMENT OF PROBLEM 1

    Introduction 1
    Statement of the Problem 3

2. IRRIGATION AND WATER RESOURCES SYSTEMS 5

    Irrigation Systems 5

        Irrigation Scheduling 5
        Application Systems 8
        Distribution Systems 16
        Drainage Systems 18
        Irrigation Efficiencies 19

    Water Resources Systems 22
    Irrigation Systems within Water Resources Systems 25

3. SELECTION OF OPTIMAL SYSTEMS 31

    Optimization Techniques 31

        Simulation 32
        Analytical Techniques 33

    Applications of Optimization Techniques . . . 41

4. PROCEDURES 47

    Irrigation System Configuration 48
    The Analytical Model 51

        Cost Functions 51
        Constraints 55

Chapter Page

4. (Continued)

Hypothetical Model Formulation 55
Two-Stage Dynamic-Linear Programming Extension 60

Summary of Procedures 67

5. DETERMINATION OF ANNUAL COSTS AND RELATED EFFICIENCIES OF SYSTEM COMPONENTS 69

Determination of Application System Annual Costs and Efficiencies 70

Costs and Efficiencies for Sprinkler Systems 70
Costs and Efficiencies for Surface Systems 73

Determination of Distribution System Annual Costs and Efficiencies 75

Costs and Efficiencies for Open Channels . 75
Costs for Pipelines 77
Costs for Pumping Plants 79

6. MODEL FORMULATION FOR THE NORTH RIGBY IRRIGATION DISTRICT 81

Study Area 81
Field Layout, Cropping Patterns, and Evapotranspiration Rates 85
Distribution System Routes 88
Costs and Efficiencies of System Components . 90

Application Systems 90
Distribution Systems 94

Distribution System Component Combinations . . 101
Pruning of Distribution System Component Combinations 103
Linear-Programming Problem Formulation 105
Linear-Programming Solution and Post-Optimal Analysis 110
Linear-Programming Matrix Revision 113

Chapter Page

7. RESULTS 115

   Effects of Changes in System Efficiency . . . 116
   Effects of Changes in Water Costs 122
   Effects of Changes in Deep Percolation Charges 125
   Summary of Results 129

8. CONCLUSIONS AND RECOMMENDATIONS 131

   Conclusions 131
   Recommendations 134

REFERENCES 137

APPENDIXES
A. DEFINITION OF TERMS 145

B. DOCUMENTED LISTING OF COMPUTER PROGRAMS 147

C. INPUT DATA FOR MODEL FORMULATION 190

LIST OF TABLES

Table Page

1. Cost functions, efficiencies, and maximum flow rates for application systems in a hypothetical model 57

2. Cost functions and efficiencies for the distribution system in a hypothetical model 57

3. Soil series associated with each unit within the North Rigby Irrigation District 87

4. Maximum evapotranspiration rates and a summary of crop acreages for each unit within the North Rigby Irrigation District 87

5. Surface application systems considered for the North Rigby Irrigation District 91

6. Sprinkler application systems considered for the North Rigby Irrigation District 92

7. Application system parameters for the North Rigby Irrigation District 95

8. Annual cost relationships and water conveyance efficiencies for distribution system components 97

9. Annual cost relationships for various pumping plants operating at various efficiencies 99

10. Distribution system component configurations remaining after pruning 104

11. Number of pumps and wells for each unit and estimated operating efficiencies 112

12. Total annual system costs for varying efficiencies for a gravity distribution system 117

13. Total annual system costs for varying efficiencies for a low head well supply 118

Table Page

14. Total annual system costs for varying efficiencies for high pressure pipeline and high head well supplies 119

15. Total annual system costs for varying water costs for a gravity distribution system 123

16. Total annual system costs for varying water costs for a high pressure pipeline system 124

17. Total annual system costs for varying deep percolation charges for a gravity distribution system 127

18. Total annual system costs for varying deep percolation charges for high pressure pipeline and high head well supplies 128

LIST OF ILLUSTRATIONS

Figure Page

1. Schematic diagram of a simple irrigation system 6
2. Various types of gravity irrigation systems . . . 10
3. Schematic view illustrating the basic variables involved in the hydraulics of surface irrigation 13
4. Illustrations of water-application and distribution efficiencies 21
5. The relation of water resources engineering to natural and social sciences 24
6. Components of an irrigation system 27
7. Matrix form of linear-programming problem 39
8. Component configuration of an irrigation system 49
9. Area for hypothetical model formulation 56
10. Linear-programming matrix for hypothetical model 59
11. Section component combinations for an irrigation distribution system 62
12. Non-intersecting distribution system component cost functions 64
13. Intersecting distribution system component cost functions 65
14. Input parameters used to calculate annual costs and efficiencies of irrigation application systems 71
15. Input parameters used to calculate annual costs and efficiencies of open channel sections 76

Figure Page

16. Input parameters used to calculate annual costs of pipeline sections 78

17. Input parameters used to calculate annual costs of pumping plants 80

18. Irrigation district served by the North Rigby Canal 82

19. Soil series and units established within the North Rigby Irrigation District 86

20. Alternative distribution system routes established within the North Rigby Irrigation District 89

21. Linear-programming matrix for gravity supply to North Rigby Irrigation District 107

22. Summary of linear-programming matrix 108

23. Linear-programming matrix for well supply to North Rigby Irrigation District 111

24. MPS/360 control program 114

25. Total annual system costs for various specified system efficiencies 120

26. Total annual system costs for various water costs 124

27. Overall system efficiency versus water cost . . . 125

28. Total annual system costs for various deep percolation penalty charges 128

METHODOLOGY FOR OBTAINING LEAST COST IRRIGATION SYSTEM SPECIFICATIONS

by

John Robert Busch

ABSTRACT

A methodology for obtaining least cost irrigation system specifications was developed and applied. Irrigation systems, as defined, consisted of application system and distribution system components and did not include reservoirs of any type.

An analytical model employing a two-stage dynamic-, linear-programming technique was used to select and arrange system components such that a least cost overall system would result.

First, the annual cost of each component considered was determined in relation to the component's size or its ability to convey and/or control water. The cost-size relationships for all components were approximated very well by linear relationships. All costs were adjusted to September, 1973, prices.

Utilizing the cost functions developed, a dynamic-programming technique was used to eliminate all distribution system component combinations that were more costly and at the same time less efficient than other combinations. Linear programming was used to select optimal (least cost) system configurations consisting of distribution and application system components and subject to specified constraints. The linear-programming problem was revised for each distribution system not eliminated by the dynamic-programming stage. Parametric programming was used in a post-optimal analysis to determine the effects of various parameter variations within the linear-programming stage.

The model was applied to the North Rigby Irrigation District located in Jefferson County, Idaho, to determine least cost rehabilitation schemes for various specified constraining conditions. The constraining conditions were minimum allowable overall system efficiency, cost of water entering the system, and charge for water lost to deep percolation. The application system components considered were unimproved gravity, improved gravity, hand-line sprinkler, and side-roll sprinkler. Distribution system components were unlined channels, lined channels, low head pipelines, high head pipelines, and wells with pumps.

Specified allowable system efficiency ranged from 17.1 percent to 70 percent. Results obtained indicate that the least cost rehabilitation scheme necessary to achieve an increase in efficiency would be to install wells with pumps supplying water to sprinkler systems. Increasing the cost of surface water would increase the overall system efficiency and the total cost of operating the system. If a charge of $0.50 or greater were levied against deep percolation losses, the least cost system configuration would be the well-pump-sprinkler combination.

The results obtained indicate that the analytical model developed and used is a valid tool for determining least cost irrigation system specifications.

CHAPTER 1

INTRODUCTION AND STATEMENT OF PROBLEM

Introduction

Irrigated agriculture in the United States dates back to the nineteenth century when westward-bound settlers began applying water to the arid and semi-arid lands found in the western states. Water was first diverted from streams to land adjacent to the streams in order to grow crops necessary for the survival of the settlers and their livestock. The diversions were simple structures, and the supply canals were constructed to minimize excavation since all the work was done by men and animals. As additional settlers arrived in the same area, their lands were located further away from the rivers at higher elevations. Water diversion points for these lands were located further upstream at higher elevations, necessitating longer and larger supply canals (7, 13).[1]

Although each early irrigation canal was planned at the time of construction, little or no consideration was given to the overall planning of the resultant complex of systems. The result was often two or more canals serving essentially the same area. Such an arrangement caused much duplication of effort as two supply canals might run

---

[1] Refers to reference number.

parallel and/or cross each other. Although such systems were constructed years ago, many are still in use contributing to inefficiency of land use and wastage of water (7, 72).

Development of the Columbia Basin Project of central Washington State contrasts to the usual sequential development of small duplicate systems supplying water to a local area. This project was planned, designed, and constructed as a large, multi-purpose project by the United States Department of Interior, Bureau of Reclamation, for delivering irrigation water, producing power, and providing recreational opportunities. The irrigation system is presently supplying water to approximately 500,000 acres of land through a distribution system network that incorporates several reservoirs and over 2,000 miles of canals and pipelines. Sixteen large canal siphons and two tunnels which carry water over, under, and through natural barriers are integrated into the distribution system. The system utilizes water and land resources efficiently and will ultimately deliver water to more than 1,000,000 acres (68).

Increased demands on this country's limited land and water resources will require comprehensive planning and the coordination of several disciplines for the development of future irrigation projects and the rehabilitation of existing systems. Projects will not only be required to be economically feasible, but they must also meet other standards such as environmental standards.

The degree of complexity and efficiency of water use for an irrigation system depends on a combination of historical, physical, and legal factors. The legal water rights doctrine on which the water law of the western states is based is referred to as the "doctrine of appropriation." This doctrine in essence states that the water of a stream (and in some cases the water of an underground aquifer) may be appropriated for beneficial consumptive or nonconsumptive use. This use is subject only to the rights of any prior appropriation to waters of the stream (or aquifer) (44). The doctrine of appropriation grew from the early need of appropriating the limited waters of the western states for various uses including that of irrigation. However, legal rights to water often hinder attempts to improve older irrigation systems (72).

Statement of the Problem

Since irrigated agriculture is the nation's largest consumer of water (70), it is imperative that irrigation systems be designed for efficient use of water if the limited national water resources are to be used most effectively. Good irrigation system design for a project or area must consider many input constraints and specify a system or combination of systems that comply with the specified constraints. The specified systems must incorporate distribution and application systems in such a manner that they are effectively and efficiently integrated within a given area. It is not only desirable that the final system configuration fall within given constraints and use water efficiently, but it must also be economically efficient for the general welfare of irrigators using the system and other portions of society also affected by the system. The final specified systems should be economical to build, maintain, and operate. Also, dollar values should be attached to wastage from the system and to factors such as esthetics, safety, recreation, and other social values used to evaluate the overall worth of an irrigation system.

The purpose of this dissertation is to develop a methodology for obtaining least cost irrigation system specifications. Such a procedure will be useful for specifying changes necessary for the rehabilitation and/or consolidation of existing systems. The procedure would also be helpful in specifying system layouts for new irrigation developments.

The specific objectives are:

1. To define the possible components and constraints associated with an irrigation system.
2. To select and arrange components so that the result will be a minimum cost overall system that complies with all constraints.

CHAPTER 2

IRRIGATION AND WATER RESOURCES SYSTEMS

Irrigation Systems

The main components of an irrigation system are the distribution and application systems as shown in Fig. 1. The distribution system conveys water from a source of supply and distributes it to various areas of use where the water is delivered to the application system(s). The function of the application system is to apply the delivered water to various areas of fields within a farm or other specified unit. The systems used to convey and apply water must not only be integrated into a workable unit, but they must also deliver water to a crop in the proper amounts at the proper time in order to provide a suitable environment for growing plants. It should be noted that the distribution systems described and referred to hereafter will not include reservoirs of any type.

Irrigation Scheduling

The total amount of water that a particular soil can supply to a plant without the addition of water is referred to as the total available moisture, TAM, for that soil-plant combination. The TAM depends on several factors including soil texture and structure throughout the soil profile. The plant rooting depth determines how much of the soil

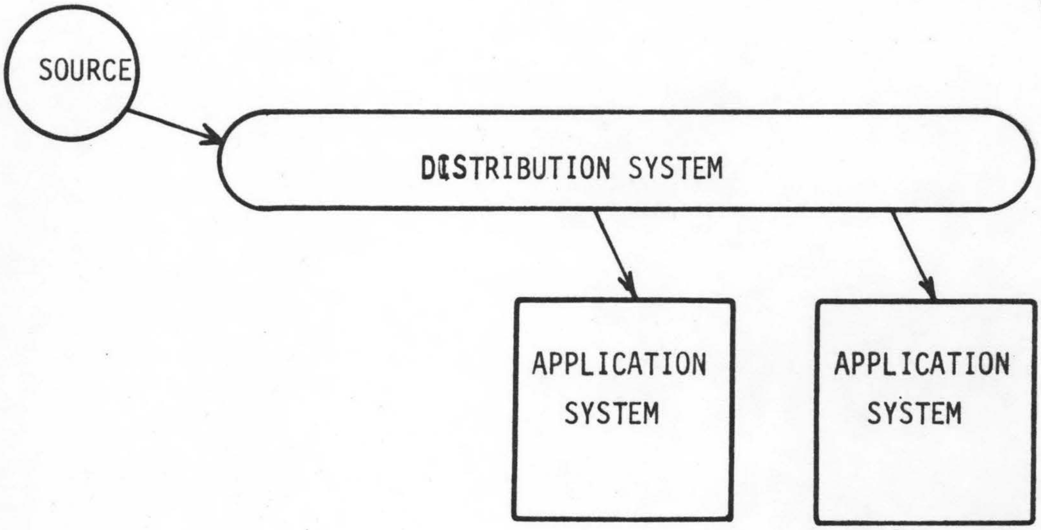


Fig. 1.--Schematic diagram of a simple irrigation system.

profile is actually used for storage and may be influenced by factors in the soil profile such as restricting layers and changes in texture and/or structure and water table elevation. Expressed more precisely, TAM is the difference between the amount of moisture present in the root zone at field capacity and the amount present when the growing plant permanently wilts and dies (the permanent wilting point). The permanent wilting point is governed by the highest total tension, matric plus osmotic, at which the plant can extract water from the soil. Since plant growth is curtailed before the entire TAM is removed from the root zone, it is desirable to add water to the soil reservoir when a certain percentage of the TAM is depleted. This portion of the TAM is often referred to as the total readily available moisture, TRAM, for a specific soil-plant combination.

Since the permanent wilting point is approximately the same for most plants and since field capacity is independent of plant influence by definition, the TAM per unit depth, called the moisture holding capacity of a soil, is a very useful term. The units used to quantitatively describe the moisture holding capacity of a soil profile are length per unit length and may vary throughout the profile as a result of nonhomogeneity of soil in the profile. For example using British units, the common expression presently used in the United States is inches per foot of depth of soil. Therefore, for a crop with a rooting depth of 30 in growing in a soil with a moisture holding capacity of 2 in per foot the TAM will be 5 in. If the TRAM is 50 percent of the TAM, the TRAM is 2.5 in, and water should be added to the root zone when 2.5 in are depleted. If soil moisture measurements indicate that the 2.5 in were depleted in 10 days, the average rate of evapotranspiration, ET rate, for the crop is 0.25 in per day.

In addition to soil moisture measurements, evapotranspiration may also be determined by lysimetry, water balance, and energy balance methods (59). According to Pair (59), evapotranspiration may be estimated for areas and crops where no detailed studies have been conducted. Estimates of ET are generally based on the correlation of one or more climatic factors with measured ET. The main advantage to such an approach is that climatological data which are rather easily obtained may be used to estimate ET for various crops over a rather large area. Some of the more common methods used to estimate ET include the Blaney-Criddle, Thornthwaite, Penman, Jensen-Haise, and pan evaporation methods. Each of these methods is described and documented by Pair (59). Sutter and Corey (69) have utilized climatic data from 42 weather stations located throughout Idaho in a Modified Blaney-Criddle method to estimate ET requirements for a wide variety of crops throughout the entire state.

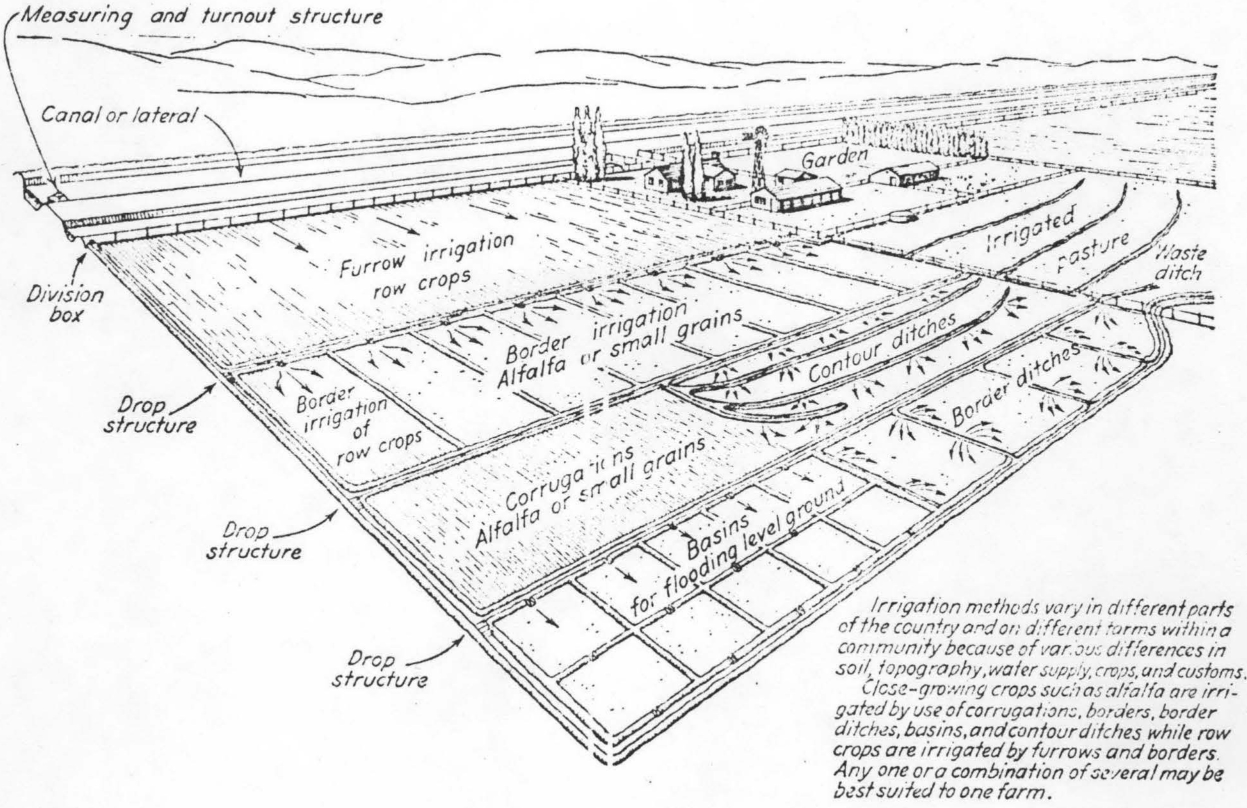
The TRAM may be thought of as the amount of stored water available to a plant, and ET as the amount of water required to maintain proper plant growth. If naturally occurring precipitation is insufficient to keep soil moisture levels within the TRAM range for a crop, supplemental irrigation water may be supplied to the crop in order to maintain a suitable environment for plant growth. Utilizing ET determinations or estimates and knowing the TRAM available to a crop can help an irrigator determine when to irrigate and how much water to apply (45).

Application Systems

A great number of different types of systems and combinations of systems are used to transport water and apply it to cropland, and many different management schemes are employed in the operation of the systems.

Surface Systems.--Irrigation water may be applied on the surface of the land, from the subsurface, or from overhead by sprinkling (44). Bishop (8) stated that in gravity surface irrigation, water is conveyed to the point of infiltration directly on the soil surface. Thus, the soil surface may be considered as the conveyance channel boundary. Surface irrigation channels vary widely in size and shape resulting in different types of systems with varying hydraulic characteristics. The main types of gravity surface irrigation systems employed throughout the world are: (1) flooding from field ditches, (2) border strip flooding, (3) border check or level basin flooding, and (4) furrow irrigation (8, 44). The various types of surface systems are illustrated in Fig. 2.

For flood type irrigation, water is applied directly to the field from ditches without any dikes or levees to control the flow. Field ditches vary in spacing and number depending upon topography, land slope, and crop grown; and they may be crudely constructed or constructed with a uniform slope. As water is diverted from the ditches, it is controlled primarily by the slope and topography of the land. As a result, small additional ditches, usually hand dug, are used to lead the water to high points and areas difficult to flood. Since precise land leveling is seldom used to prepare land for flood irrigation, the rate of water advance and depth of application may be



Irrigation methods vary in different parts of the country and on different farms within a community because of various differences in soil, topography, water supply, crops, and customs. Close-growing crops such as alfalfa are irrigated by use of corrugations, borders, border ditches, basins, and contour ditches while row crops are irrigated by furrows and borders. Any one or a combination of several may be best suited to one farm.

Fig. 2.--Various types of gravity irrigation systems (after Israelsen and Hansen, 1962 [44]).

highly variable. Hence, non-uniform water application is common and the results achieved are highly dependent upon the skill and diligence of the irrigator (8).

Border strip flooding is a controlled flooding process. Water is diverted from field ditches into strips or wide channels formed by border dikes or levees. The border strips may vary in width, length, and slope, depending upon cultural practices and field conditions.

However, border strips should have no cross-slope to assure proper water distribution (8, 44).

Shockley (63) referred to both a "guide border" and a "graded border." In the guide-border method the irrigation stream is allowed to run in the border strip until a sufficient amount of water has infiltrated into the soil. This method is usually used on steep slopes and/or soils having low intake rates or where proper engineering design has been overlooked. The graded-border method utilizes a balanced advance-recession relationship for the water advancing in the border strip. As the advancing front nears the end of the border strip, the irrigation supply stream is cut off. The volume of water temporarily stored in the upper portion of the border moves down the strip and is sufficient to provide the proper depth of water to the strip. The graded border method requires a certain amount of engineering design. As a result, the applied irrigation water is uniformly distributed.

A border check or basin is an area completely surrounded by a dike. Water is applied quickly and ponded over the entire surface of the basin. The basin should have no slope so that the water is uniform in depth when ponded. The stream size used to supply the water is not critical as long as erosion is curtailed and the surface of the basin is covered in a short enough time so that a relatively uniform depth infiltrates into the root zone.

Properly designed and constructed basins may be used for uniform application of water on soils of varying intake rates (8, 63).

With the furrow method of irrigation small channels or furrows are used to convey and distribute water over the field. Furrow spacing and size depends upon the crop, slope of land, and soil type. As water is transported down parallel furrows it infiltrates into the surrounding soil moving both laterally and vertically to fill the soil moisture reservoir. The amount of water applied to the soil and the uniformity of distribution are highly variable and are difficult to predict due to many influencing variables (8, 37, 43).

Hansen (38) has proposed the following basic variables involved in the hydraulics of surface irrigation:

1. Size of stream
2. Rate of advance
3. Length of run and time required
4. Depth of flow
5. Intake rate
6. Slope of land surface
7. Surface roughness
8. Erosion hazard
9. Shape of flow channel
10. Depth of water to be applied.

These factors are shown schematically in Fig. 3. The factors and their interrelationships are indeed complex as they are influenced not only by the physical characteristics of the irrigated land but also by many varied cultural practices. The above factors are usually empirically grouped in one form or another. The resulting groups are then evaluated on previously constructed systems. Although such an empirical approach may not be the best, Davis (22) pointed out that it is an effective means of initiating a fairly competent design.

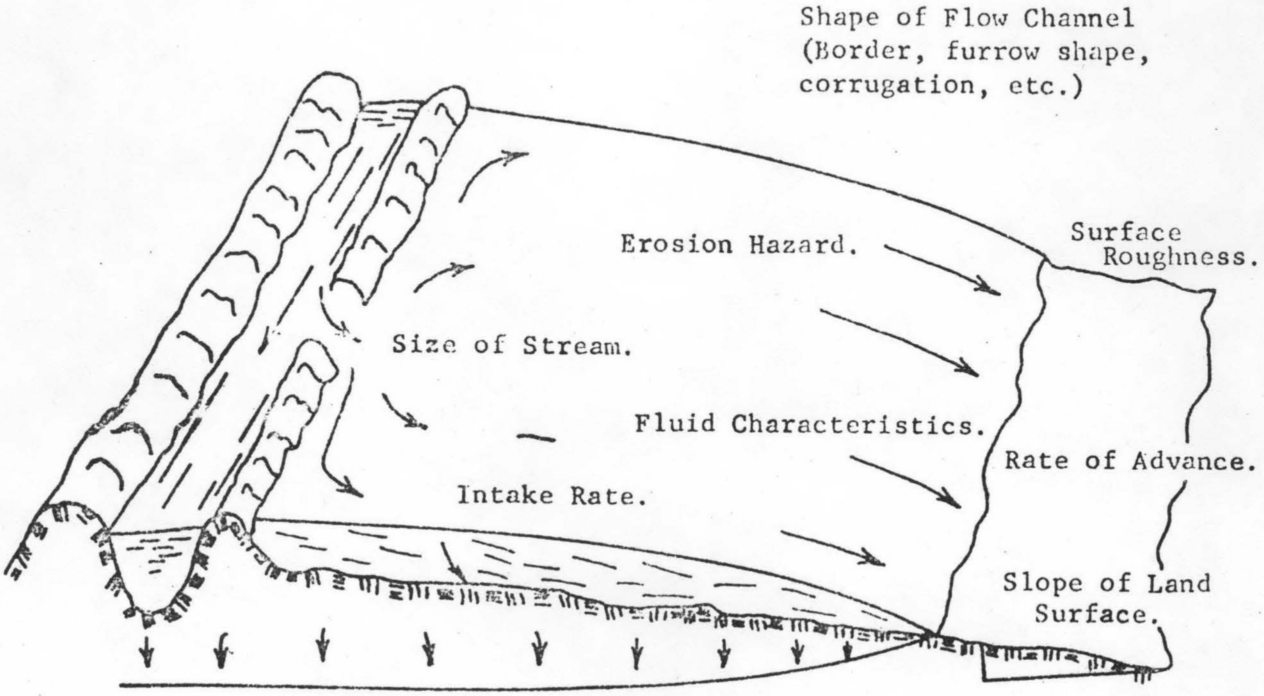


Fig. 3.--Schematic view illustrating the basic variables involved in the hydraulics of surface irrigation (after Hansen, 1960 [38]).

Subsurface Systems.--Subsurface irrigation is the method of applying irrigation water directly under the soil surface. This method may be accomplished by maintaining the water table at a high enough elevation so that it will furnish water to the root systems of growing crops. Unique physical conditions are necessary to assure that a proper combination of water and air in the root zone is maintained (20, 44). Water is sometimes added to the subsurface soil by means of buried, porous pipe supplying water to the root zone without necessarily maintaining a high water table. Complex hydraulic theory dealing with one- and two-phase flow of water and air through soils is necessary to accurately describe the phenomena associated with subirrigation.

Sprinkler Systems.--Sprinkler irrigation, as the name implies, is a method by which water is sprinkled over the land surface. A sprinkler system consists of a network of tubing or pipes with attached sprinkler heads or nozzles that spray water over the area irrigated. Water must be supplied to the system at proper pressures in order for the system to operate properly. Sprinkler systems may be classified according to the area covered (59). The three main classes are field systems, farm systems, and project systems. Field systems are usually portable and are adaptable to irrigate one or more fields sometimes as a supplement to an existing surface system. A farm system is planned exclusively for a specific area or farm unit as the primary method of water application. Project systems are those that supply water under pressure to two or more individual farms to operate individual field or farm systems.

Sprinkler systems may also be classified according to their installation and operation. The system may either be permanent, semi-portable, or portable (17, 59). A permanent system consists of permanently located pipes and sprinklers. The system may either be suspended above the ground, laid on the ground, or buried with risers leading to above-ground sprinklers. A semi-portable system is made up of both permanent and portable piping. The permanent pipe is usually a buried mainline that supplies water to portable lateral lines. A portable system consists entirely of portable piping from the pumping plant to the last sprinkler. The portable laterals of a sprinkler system may be either hand-move, mechanical-move, or continuous-move. The mechanical and continuously moving systems vary in complexity and configuration and are designed to reduce to varying degrees the amount of labor required for operation of a hand-move system.

The hydraulics involved in the design of sprinkler systems are different from those given for surface systems. Since water is conveyed and distributed through a pipe network, hydraulic theory involving branching and non-branching pipe flow must be used. Pair (59) indicated that the factors governing sprinkler performance include patterns, risers, and wind conditions. Sprinkler discharge and spacing must be considered in conjunction with the intake rate of the soil to which water is applied.

Trickle Systems.--Another type of irrigation system that applies water on or slightly below the ground surface is referred to as drip or trickle irrigation. DeRemer (25) describes trickle irrigation as a solid set system that uses very low rates of application. Factors favoring this system include a highly controlled placement of water at or very near the point of demand and a distribution pattern unaffected by wind. Most trickle irrigation systems require extensive lengths of pipe; however, small pipe sizes may be used due to the low flow rates involved. Several approaches have been taken in the design and layout of trickle irrigation systems (41, 46, 58, 60).

Distribution Systems

The purpose of an irrigation distribution system is to convey and distribute water from the point of supply to the point(s) of demand. The size and complexity of irrigation distribution systems vary greatly from those serving a few acres to those supplying water to thousands of acres. Larger distribution systems are dendritic in nature with larger components of the system supplying water to several smaller components. This branching may proceed for several steps as outlined by Hall and Dracup (36).

Irrigation distribution systems may consist of open or closed conduits or combinations of the two. Open conduits are those which are not enclosed on the top, and the flow of water in these conduits is referred to as open channel flow. These conduits may be lined with various types of materials or the natural material from which the conduit is excavated may serve as the lining. Various types of control structures are necessary to control and divert water to and from open conduits (15).

Although closed conduits are completely covered, the flow may be either open-channel or pipe flow. If the conduit is not running completely full, a free surface will be present within the conduit, and the flow is open-channel flow. Closed conduits are constructed of various types of materials and may be located above, on, or below the surface of the ground. The types of control structures used in conjunction with closed conduits can take advantage of the fact that the water surface is contained. Thus pressure within the system can be substituted for freeboard (15, 44, 59).

Simons (64) has pointed out that irrigation distribution systems should be designed in accordance with the fundamentals of hydraulics, fluid mechanics, soil mechanics, and structural engineering. Irrigation water demand and the quality and quantity of water supply are necessary inputs to the system design. Possible demands other than irrigation, such as municipal, industrial, and water for livestock, should be considered. Also, flood control should be a factor to be considered as some systems may divert and convey excess water and/or possibly intercept overland flows. Safety, nuisance factors, and esthetics must also be considered, especially if the conveyance and distribution system is large and serving the diversified needs of a large area (64, 68).

Drainage Systems

The purpose of drainage, like that of irrigation, is to provide a suitable environment for growing plants. Drainage is required when water tables rise to the point where there is no longer an adequate zone of aeration in the plant root zone. High water tables may be lowered by means of a drainage system or by determining and controlling the source of excess water (44, 48).

Subsurface drains used to lower the water tables may either intercept the water moving underground before it reaches the problem area (interceptor drain) or relieve a high water table problem for a general area (relief drain). Materials and methods used for subsurface drains include concrete and clay tile, plastic drain pipe, open ditches, and drainage wells. Design and layout of drainage systems vary greatly and are dependent on many factors. Mathematical techniques, both analytical and numerical, are used to describe the flow through the soil to the drains themselves and are thus very useful for design. However, careful subsurface investigations must also be conducted so that the physical field situation is properly understood and described for each proposed installation (44, 48, 50).

Some of the irrigation application systems described usually require surface drainage systems. In order for flood, guide-border, or furrow systems to distribute water properly over the surface, a certain amount of surface drainage water must run off the lower end of the field. This drainage water is collected and may be allowed to either percolate into the soil, flow to a natural drainageway or creek, or be diverted for reuse as an irrigation supply at a lower elevation or pumped to a higher elevation for reuse. Surface drainage systems are an integral component of most surface irrigation systems and are usually integrated into the distribution system so that water can be used and reused. Subsurface drainage water may also be collected and reused if quality and economic considerations permit (44).

Irrigation Efficiencies

Irrigation "efficiency" is a broad term with many different meanings. An irrigation systems' efficiency is a measure of the effectiveness of the system to utilize input water for supplying the water requirements of the crop(s) being irrigated. As different factors contribute to water loss, Israelsen and Hansen (44) have described different water-related efficiencies that are useful for irrigation system planning. These different efficiencies listed in equation form are:

1. Water-conveyance efficiency, E_c

$$E_c = 100 \frac{W_o}{W_i} \tag{2.1}$$

where W_o = water delivered by a distribution system, and W_i = water input to a distribution system

2. Water-application efficiency, E_a

$$E_a = 100 \frac{W_s}{W_f} \tag{2.2}$$

where W_s = water stored in the root zone during irrigation, and W_f = water delivered to the farm

3. Water-distribution efficiency, E_d

$$E_d = 100 \left[1 - \frac{y}{d}\right] \tag{2.3}$$

where y = average numerical deviation in depth of water stored from average depth stored during irrigation, and d = average depth of water stored during irrigation

It may be noted that the value for E_d in Equation 2.3 is the same as the uniformity coefficient developed by Christiansen (16).

The ability of a distribution system to deliver a certain proportion of the water that enters the system is described by Equation 2.1. Once the water is delivered to the farm, the water-application efficiency is used to describe how much of the delivered water ends up in the root zone of the crop being irrigated. While a high percentage of the water delivered may end up in the root zone, high E_a value, the distribution of water within the area of a field may be very poor thus making for a low water distribution efficiency. Variations in application and distribution efficiencies are illustrated in Fig. 4. It is desirable that irrigation systems be designed so that high values of both E_a and E_d are attained thus assuring uniform application with minimal waste.

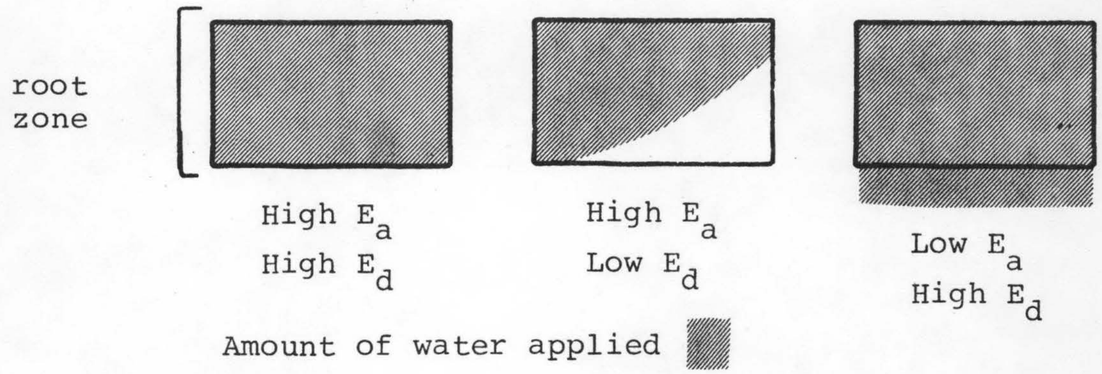


Fig. 4.--Illustrations of water-application and distribution efficiencies.

A factor that will necessarily lower the application efficiency of a system is the leaching requirement. The leaching requirement for a particular soil-plant-water combination is that portion of the irrigation water applied that must be leached completely through the root zone to maintain a favorable salt balance in the root zone. However, the application of excess water as a leaching requirement results in a low water application efficiency. In some cases necessary operational losses are considered as beneficial use of water even though this water is not used consumptively by plants (73).

Willardson (73) pointed out that not only physical, but also economic and political constraints affect irrigation efficiencies. Economic factors that may influence irrigation efficiencies include water costs, canal lining costs, land preparation costs, labor costs, and the value of the crop being irrigated. Political factors that affect efficiency of water use include water laws and geographical location (73). Irrigation practices of water users also greatly affect irrigation efficiencies (66).

Water Resources Systems

A system according to Hall and Dracup (36) may be defined as a set of objects that interact in a regular, interdependent manner. The purpose of systems engineering is to obtain certain objectives by controlling to varying degrees certain portions of the system. Such is the case with the systems engineering encountered in the field of water resources engineering. Buras (12) stated "that the increasing complexity of water resource systems gives rise to a host of problems connected with development, control, allocation treatment, utilization, and re-use of water. The analysis and solution of these problems form the field of <u>water resources engineering</u>."

Water resources engineering is a discipline that must deal with broad-based problems. Many factors interact in a water resources system; therefore, an interdisciplinary approach must be used in studying and solving system problems. This point was realized by the originators of the Harvard Water Program where one of the principle objectives of the program was to improve existing methodology by more effectively joining engineering and economics (49). The relation of water resources engineering to natural and social sciences is illustrated in Fig. 5. Water resources engineering incorporates many disciplines, and according to Buras (12) has a close affinity to the following traditional disciplines:

Agricultural Engineering
Civil Engineering
Hydrology
Chemical Engineering
Economics
Public Administration
Law

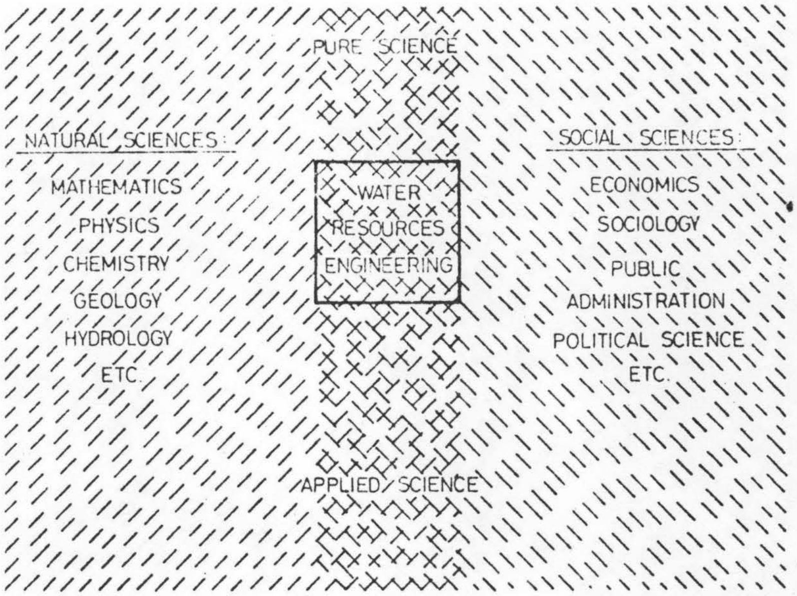


Fig. 5.--The relation of water resources engineering to natural and social sciences (after Buras, 1972 [12]).

Since irrigation systems of one type or another are included in many water resources systems, they may be thought of as subsystems of a total water resources system. Irrigation systems vary in complexity and size, and are integral and interact with the total large system. Irrigation systems engineering is a broad field that encompasses the disciplines illustrated in Fig. 5. Marr (52) indicated that irrigation system planning should include the human factor, problems of changes in the agricultural economy, and planning for change. Pair (59) also stated that planning an irrigation system is a job for specialists.

The many factors that affect each of the possible components of an irrigation system described earlier in this chapter increase dramatically when the irrigation system is considered as an integral part of an encompassing water resources system. When considering the irrigation system within the larger system, the controlling factors must also be considered from the viewpoint of their possible effects on the surrounding environment of the irrigation system. Feedback generated from interactions and outputs must then be used to govern certain controllable inputs (36). In order to obtain a better understanding of irrigation-water resources system relationships it will be necessary to consider the "location" of the subsystem within the system. The "location" of the irrigation system will be considered from both its physical and socio-economic standpoints.

Irrigation Systems within Water Resources Systems

A water resources system may be thought of as a system that controls and utilizes water as it passes through a portion of the hydrologic cycle (47). Such a system will include one or more river systems depending upon its size and complexity. An irrigation system may be thought of as a subset of a water resources system. The irrigation system has many internal objects that interact and many factors that interact between the system and its environment. The environment of an irrigation system will be assumed to be completely contained within the encompassing water resources system. Also, as stated previously, reservoirs will be considered as a source of water located within the water resources system external to the irrigation system. An irrigation system as it will be considered is shown in Fig. 6.

The socio-economic location of an irrigation system within a water resources system influences the entire system and vice-versa. In order to determine the imprint of a subsystem upon a system, Wiener (71) referred to a "cut" of the subsystem. This cut isolates the subsystem from the system by introducing boundaries around the subsystem. By determining the boundary conditions of the cut, the influence of the subsystem upon the encompassing system may be represented. However, the functions used to describe the boundary conditions are usually incomplete. Wiener (71) warned that these basic dysfunctions should be recognized and possibly corrected if results are to be realistic. This fact is one reason why Buras (12) stated that the relative accuracy of basic design data cannot be overemphasized.

The dysfunctions associated with a cut boundary exist not only because of the complexity of the boundary but also because of rather intangible socio-economic aspects Howe (40) stated that a good project appraisal ". . . not only has always compared the monetarily measured benefits and costs, but also has described in whatever terms where feasible the nonquantifiable, nonmeasurable benefits and costs." If monetarily measured benefits are alone

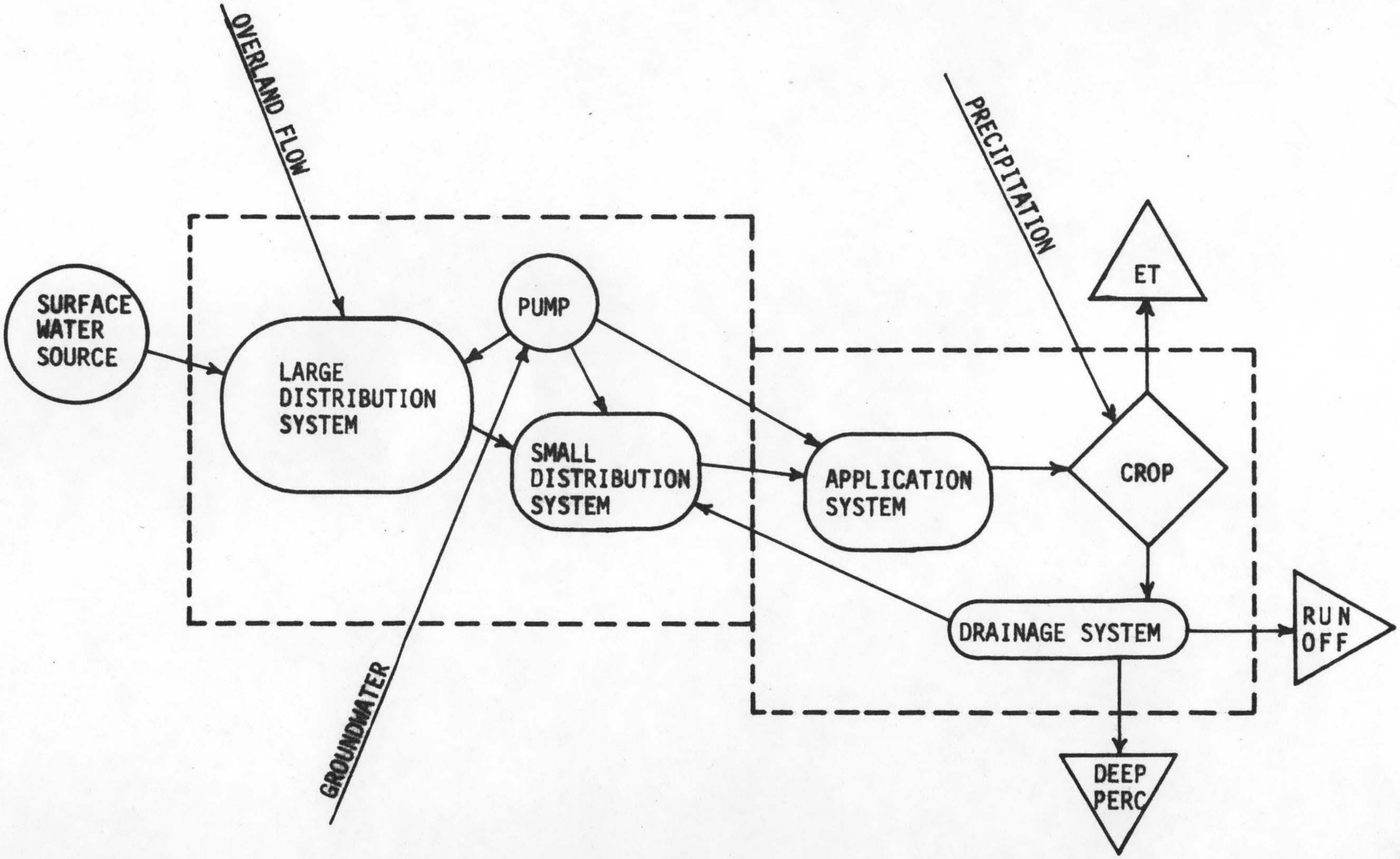


Fig. 6.--Components of an irrigation system.

considered, the results will not encompass many hard-to-identify and/or intangible factors. For this reason many water resources problems cannot be reduced to a set of mathematical expressions. Therefore, when there is no realistic way to assign values to these factors, their effect upon the system as a whole may be evaluated by handling them as constraints (12).

The main component common to all irrigation systems is water which, during the peak of an irrigation season, is often a scarce resource. The general economic problem is to use available scarce resources to maximize resultant human welfare (40). The many intangible factors associated with human welfare make this problem very difficult to approach. It is even more difficult when dealing with irrigation water because of a distorted price pattern. Wiener (72) pointed out that in most countries the price charged for irrigation water is well below its real cost to the economy. This fact of distorted prices complicates the economics of the total water resources system in which various users are competing for the same resource. Also, rural areas in the United States consume about 6 times as much water as urban areas (70). Water consumed is that water that does not return to surface or groundwater.

The size of an irrigation system is largely determined by the geographical area served and the peak flow rates of water required by that area. The size and configuration of the system along with other socio-economic factors dicate the capital costs and the operation, management, and replacement (OMR) costs associated with the system. The capital and OMR costs associated with various distribution systems vary considerably as reported by Brockway and Herbig (9). Numerous data have been collected and presented dealing with the various cost aspects of irrigation application systems (11).

The computed capital and OMR costs associated with an irrigation system must be carefully evaluated because of many variables and uncertainties that may be associated with them. Hufschmidt (42) stated that weighing factors may be necessary when referring to capital and/or OMR costs in order to reflect budgetary constraints, opportunity costs, and/or divergencies between real costs and money costs. Ultimately the planner, developer, or designer must choose the system(s) that provide(s) the greatest benefits compared to the cost of construction, operation, maintenance, and esthetics (9).

The design process for an irrigation system within a water resources system is indeed complicated. The problem must be attacked on a broad front that sometimes requires a novel approach (12). Hufschmidt (42) listed steps for use in the methodology of water resources systems design. The steps listed are:

1. Specifying the objectives
2. Translating these objectives into <u>design criteria</u>
3. Using the <u>design criteria</u> to formulate specific designs
4. Evaluating consequences of designs developed

Formulation of a specific design is a very comprehensive process. Problems which were once considered insurmountable are presently being attacked with the use of high speed digital computers and accompanying technology. The solutions are oftentimes very difficult to obtain, and there are many different methods used in seeking desirable and realistic solutions (12, 36, 49).

CHAPTER 3

SELECTION OF OPTIMAL SYSTEMS

There are many influences and restrictions associated with the location of an irrigation system within a water resources system. There are also many possible combinations of system components within an irrigation system. As a result there may be many possible different solutions to the objective of specifying a minimum cost irrigation system. Such a system is said to be underdetermined; and, as a result, an optimization technique may be used to obtain an optimal solution for the objective (6). Beveridge and Schechter (6) pointed out that objectives, competing influences, and restrictions are essential features for an optimization process. The methods and procedures used in the optimization process are many and varied, and the best approach should be selected and utilized for each individual problem.

Optimization Techniques

In order to find an optimal solution to a given problem in the field of water resources engineering, Buras (12) stated that there are usually three methods of attack:

1. Use of simulation
2. Application of analytical techniques
3. A combination of these two methods

Simulation

Simulation involves conceptualizing, building, and operating a model designed to represent the complex and dynamic environment of the real-life situation under consideration (37). In short, simulation is a method of modeling reality. There are different methods of modeling reality for use in simulation. They include actual scale models with similar physical characteristics, analog models such as those described by Hall and Dracup (36) and Corey and Fitzsimmons (19), or digital models as used by Halter and Miller (37). Once the real system is simulated by a model, changes in boundary conditions and constraints can be variable inputs into the model. The resultant output of the model is then related to the expected real-life outcome for a given set of inputs. In using a simulation model to obtain an optimal solution Hall and Dracup (36) warned "that a local optimum may be determined and a global optimum bypassed in essentially what is a trial-and-error approach."

Many details and different combinations of inputs can be incorporated into a simulation model. However, such a detailed model is difficult to construct and at best may be valid only for the real-life situation it is intended to duplicate. As larger irrigation systems are never the same, a simulation approach would entail the construction of a different model for each different system taken under consideration.

Analytical Techniques

Beveridge and Schechter (6) stated that a mathematical model may be postulated to represent a system in which analytical relationships, together with appropriate restrictions, define the response of the system. This analytical approach is in contrast to the simulation approach of conducting experiments on a constructed model (1). In using an analytical approach the purpose of an optimization process is to choose a set of values of independent variables, subject to various restrictions, which will produce the desired optimum response for the particular problem under consideration.

A general approach or procedure for an analytical solution has been set forth by Beveridge and Schechter (6):

1. Define a suitable objective for the problem under consideration.
2. Examine external restrictions imposed upon the problem.
3. Choose a system or systems for study.
4. Examine the structure of each system and the interrelationship of the system elements and streams.
5. Construct a model of the system. This is the technical design stage which allows the objective to be defined in terms of the system variables.
6. Examine and define internal restrictions placed upon the system variables.
7. Express the objectives in terms of the system variables using the system model. This is the objective function.

8. Analyze the problem and reduce it to its essential features.
9. Verify that the proposed model in fact represents the system being studied.
10. Determine the optimum solution for the system and discuss the nature of the optimum conditions.
11. Using the information thus obtained, repeat this procedure until a satisfactory result is found.

Different types of systems may be described differently by different analytical models in order to achieve the objectives set forth in the above list. Optimal solutions for the objectives of different models may be obtained by various methods. Three most used methods are dynamic programming, nonlinear optimization, and linear programming.

Dynamic Programming.--Dynamic programming is a mathematical technique whose development is largely due to Bellman (4). Bellman (4) stated the following principle basic to dynamic programming.

> Principle of Optimality. 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.

This principle is applicable to a wide variety of problems including those dealing with sequential systems and allocation (1, 6). It is especially useful for determining optimal policies for large complex systems by requiring that single sequential decisions be made (5), and that the payoffs from each decision be additive or multiplicative (24). The dynamic programming approach has provided a means to answer some problems previously considered unsolvable (67).

Nonlinear Optimization.--If the objective for which an optimal solution is sought is a nonlinear function, a nonlinear optimization technique must be used. Stark and Nicholls (67) suggested two broad categories of classifying the techniques for nonlinear optimization. The two categories are classical optimization techniques and search techniques. The classical techniques seek to find optimal solutions by using systems of equations.

Classical techniques include differential calculus, Lagrange multipliers, Kuhn-Tucker Theory, and geometric programming. These methods are discussed in some detail by Stark and Nicholls (67), Beveridge and Schechter (6), and in all or in part by others. Although a nonlinear equation might best describe the desired objective and/or constraints, the classical techniques usually require the simultaneous solution of these nonlinear equations which is sometimes impractical (67).

In contrast to the simultaneous solutions required by the classical techniques, a search technique employs an iterative process. In this iterative process, the response surface created by the objective function is searched until an optimum point is reached that lies within specified constraint boundaries. Green (30) pointed out various methods of locating the optimum of a surface and some associated advantages and disadvantages. Various search techniques are also described by others (1, 6, 36, 67). Although search techniques can be used to solve difficult problems, they are subject to limitations in locating a global optimum; and they can also be rather inefficient in that they may require a great amount of time for solution (36).

Linear Programming.--In special cases the objectives for a problem and all the associated constraints can be described by linear functions with respect to the independent variables. When the objective function and all constraint functions are linear, the problem is said to belong to the linear-programming (LP) class. Linear programming is the process of finding an optimal solution for the objective function subject to all linear constraint conditions and the non-negativity of all independent variables (1, 6, 21, 31, 57, 62, 67).

The linear-programming problem may be expressed mathematically as follows:

Minimize (maximize):

$$c_1 X_1 + c_2 X_2 + \ldots\ldots + c_n X_n = Y \qquad (3.1)$$

subject to:

$$a_{11}X_1 + a_{12}X_2 + \ldots\ldots + a_{1n}X_n\ (\leq, =, \geq) b_1$$

$$a_{21}X_1 + a_{22}X_2 + \ldots\ldots + a_{2n}X_n\ (\leq, =, \geq) b_2 \qquad (3.2)$$

$$\vdots \qquad\qquad\qquad \vdots$$

$$a_{m1}X_1 + a_{m2}X_2 + \ldots\ldots + a_{mn}X_n\ (\leq, =, \geq) b_m$$

and

$$X_1, X_2, \ldots\ldots, X_n \geq 0 \qquad (3.3)$$

The above equations form a linear analytical model with n independent unknowns (decision variables) subject to m constraints. The left-hand side of Equation 3.1 is the linear objective function for which an optimal value (maximum or minimum) is sought. If the function represents costs, a minimum value is sought, whereas if it represents profits or net benefits, a maximum value is desired. The c_j's in the objective function represent the unit costs (profits) of associated alternative activities, X_j's. Various physical and socio-economic boundaries and resource demands and availabilities are specified by the b_i's of the constraint equations. The various a_{ij}'s are coefficients which relate a unit of activity, X_j, to the amount of resource used by or the location of the j^{th} activity (1, 6, 21, 31, 57, 62, 67).

Many parallel operations are performed on the system of equations in 3.1 and 3.2. For instance the variable in each column, X_j, is multiplied by one cost coefficient, c_j, and m constraint coefficients, a_{ij}. Elements in columns, column vectors, may be multiplied by unknowns and added across so that their sums will give the corresponding elements in the right-hand column (21). Using this principle, Equations 3.1 and 3.2 can be written in the form shown in Fig. 7. The m+1 elements in the column beneath each variable are a column vector, each element of which is multiplied by the variable. Likewise, the coefficients in each row, $c_j, a_{1j}, a_{2j}, \ldots, a_{mj}$, $j = 1,n$, may be considered a row vector. Figure 7 is referred to as a linear-programming (LP) matrix. The matrix form provides an orderly manner for writing all coefficients, and it saves time and effort by not requiring repetitious writing of the variables. A blank element in the matrix is considered to be zero, and all elements are considered to be positive in sign unless otherwise indicated.

Physical interpretation of the linear programming model is a necessity for the complete understanding of the model and the results obtained therefrom. Milligan (57) describes the significance of the model as it pertains to water resources systems:

> The objective function describes the economic relationships of the area (system) being modeled. The values of the objective function might be the total cost of all of the alternative water activities considered in the solution, or it might represent the total net benefits, depending upon whether the problem is formulated as a cost minimization problem or a net benefit maximization problem. The system of constraints defines the technical relationships of

Variables	X_1	X_2	X_n	Sign	Right-hand side
Objective	c_1	c_2	c_n	$=$	Y
LRow 1	a_{11}	a_{12}	a_{1n}	$\leq = \geq$	b_1
Row 2	a_{21}	a_{22}	a_{2n}	$\leq = \geq$	b_2
.	.	.	.		.
.	.	.	.		.
.	.	.	.		.
.	.	.	.		.
Row m	a_{m1}	a_{m2}	a_{mn}	$\leq = \geq$	b_m

Fig. 7.--Matrix form of linear-programming problem.

the area (system) being modeled. For example, a group of constraints may define the condition of hydrologic continuity within the model, whereas another group of constraints might define the relationships between sources of water supply and areas of demand, including return flows and wastes that might occur due to the allocation from supply to demand. Still other constraints might describe the legal limitations on availability of a certain water supply, for example. Thus, the constraint system is the part of the model wherein the economic relationships, or measure of accomplishment of objectives, are spelled out.

In applied problems one is not only interested in the solution of the problem, but also in how the solution changes when various parameters in the linear-programming model change. As Stark and Nicholls (67) stated, the latter may be more important than the former. Milligan (57) pointed out that the optimal solution of a linear-programming problem may be very sensitive to various parameters in the problem, and it is desirable to determine the effects of changing parameter values without resolving the entire problem. Meier et al. (56) have used a model to quantify possible variations in system response due to uncertain inputs.

Stark and Nicholls (67) listed the following five basic types of parameter changes that affect the solution of a linear-programming problem.

1. Changes in the objective coefficients, c_j
2. Changes in the resource limits, b_i
3. Changes in the constraint coefficients, a_{ij}
4. The effect of including additional constraints
5. The effect of including additional variables

In sensitivity analysis a given coefficient is allowed to vary while all others are held to their original values. Sensitivity analysis determines the range over which a given coefficient can vary without changing the configuration of an optimal design and investigates changes in the optimal value of the objective function. In parametric programming the values of one or more parameters are allowed to vary over a specified range. The resulting changes in the optimal objective value and design configuration are investigated relative to the parameter changes (24, 53).

Linear programming models have proven to be a powerful tool in the area of water resources research. Probably the greatest advantage of the linear-programming approach is the relative ease of solution. The development of high-speed electronic computers has provided large-scale routines such as IBM's MPS/360 that have capabilities of solving problems with hundreds of independent unknowns and constraints (53). The biggest disadvantage of linear programming is that it may require the oversimplification of a real-life system in order to analytically describe the system in the form of Equations 3.1 and 3.2. However, the unusual success with which linear programming problems have been solved has motivated many to seek means for reducing nonlinear problems to linear forms. One approach is to replace an arc by small chords thus creating a segmented linearization referred to as separable programming (32, 53, 67). The versatility of linear programming makes it a powerful tool for use in conjunction with some of the other optimization techniques such as dynamic programming and simulation (12, 36).

Applications of Optimization Techniques

Optimization techniques have been employed in many different ways to obtain optimal solutions for various objectives related to irrigation systems in water resources systems. Applications range in complexity from specifying individual components of a small irrigation system to the operation of large multipurpose water resources systems in which an irrigation system is one of many components (a subset). The types and complexities of the optimization techniques used are also quite diverse.

Systems analysis and optimization techniques dealing with large systems over an extensive area include those reported by Clyde, King, and Anderson (18). These authors reported the use of linear programming to determine the optimal allocation of water in Utah that would minimize the cost of meeting an assumed set of requirements. Anderson (3) used linear programming with nonlinear functions approximated by linear segments to maximize net return for the Jordan River basin of Utah. He considered municipal, industrial, and irrigation competitive uses of water. A simulation approach was employed by Halter and Miller (37) to model and maximize net return for the Calapooia River basin of western Oregon. Various constraints and alternatives included reservoirs, recreation, and irrigation. Hall and Shephard (34) used dynamic programming for determining the integrated system optimum outputs for the Sacramento River basin of California. Young and Bredehoeft (76) modeled the interdependency of the river-aquifer system for a portion of the South Platte River in eastern Colorado. They utilized a digital computer simulation model which was both a hydrologic and an economic model that combined alternative institutional and hydrologic conditions.

Optimization procedures have also been employed in conjunction with various aspects of irrigation systems as subsets in a larger water resources system. Different aspects that have been treated include the structure and operation of distribution systems, irrigating with a limited supply of water, timing of irrigations, and the components and operation of irrigation systems.

The structure and operation of an irrigation distribution system presents a complex problem for optimization. Huszar, Seckler, and Rhody (43) presented the results of a simulation approach. They used a simulation technique to consider the feasibility of alternative consolidation plans for existing duplicate supply canals serving essentially the same area. Linear programming was used by Schmisseur and Conklin (61) to simultaneously evaluate several investment levels and irrigation supply and water conservation practices. The interrelationships of practices and investments in both distribution and application systems were evaluated for three separate areas in Oregon.

Considerable effort has been expended in trying to determine optimal distribution of an inadequate supply of irrigation water. An inadequate water supply is one which will not supply the necessary evapotranspiration requirements of the crops supplies. Hall and Buras (33) used dynamic programming to obtain a maximum net return for an irrigated area using a limited supply of water. To accomplish their objective they had to assume that a statistically expected value of net economic benefit was known as a function of the quantity of water applied annually to each crop on a farm. Dynamic programming was also used by Hall and Butcher (35) to determine the optimum policies for the application of any given quantity of water. The method presented would work towards optimum production by properly timing irrigations to conform to critical stages of crop growth. Anderson and Maass (2) utilized a digital computer simulation model of an irrigation delivery system to model the characteristics of an inadequate water supply. The procedure developed evaluated and compared various schemes of timing the distribution of water for a given amount of water.

Procedures for specifying optimal (least cost) system components have also been developed and used. Horn (39) presented a procedure utilizing nonlinear optimization for combining border strip width and supply pipe size to obtain the most economical combination for the two components. Mandry (51) developed a nonlinear method for the most economical design of pressure pipe distribution systems for large sprinkler projects. A direct, nonlinear approach was also used by Deb and Sakar (23) to determine the most economical pipe size for a distribution pipe network. Capital and OMR costs were considered in the procedure presented. Cembrowicz and Harrington (14) used, in part, fundamental graph theory in determining minimum capital costs for a hydraulic network.

The combination of optimal irrigation systems and their operation for a single farm has been described by Windsor and Chow (74, 75). They employed a two-stage dynamic and linear programming technique. Climatic, crop and soil data were initially used in the dynamic programming problem to determine the optimal irrigation policy, the maximum expected profit, and the expected monthly irrigation labor and water requirements per acre for each soil-crop combination and for each level of irrigation development. The second stage, employing linear programming, required input characteristic data for different irrigation systems in order to specify the optimal irrigation development level, crop mix, and irrigation system. The methodology and procedures presented (74) are quite comprehensive for farm irrigation systems and show the applicability of an optimization process in a practical sense for an individual farm unit receiving varying amounts of irrigation water.

The various types of models described vary in complexity, accuracy, and completeness. A model, analytical or simulation, is a necessary tool for an optimization process; however, the optimal values obtained are only as good as the model from which they are obtained and the data used in the model. Smith (65) has compiled a rather complete list of the attributes of good models. The model should:

1. Demand an explicit statement of assumptions used to lead to the optimum.
2. Permit systematic sensitivity analyses to be performed on assumptions of most interest. This process should be computationally automated if possible.
3. Foster the transmission of highly technical information to interested portions of the public.
4. Use available data efficiently.
5. Achieve a satisfactory balance between realism and computability.
6. Provide useful planning information when desired.
7. Use preliminary screening processes when possible for the sake of economy.

CHAPTER 4

PROCEDURES

As set forth in Chapter 1, the objectives of this dissertation are to define the possible components and constraints associated with an irrigation system and to select and arrange the components such that a minimum-cost overall system will result. The resulting system must comply with specified constraints including those of achieving certain specified water conveyance, application, and distribution efficiencies.

The objectives of this study are different from those reviewed in Chapter 3. Anderson and Maass (2) assumed a constant irrigaton system efficiency of 50 percent regardless of the types of systems used to deliver and apply varying amounts of irrigation water. An overall efficiency figure of 38.91 percent was used by Anderson (3) for that portion of water diverted for irrigation purposes. The model developed by Windsor and Chow (74) incorporated a rather complete physical description and a systematic procedure for the design and analysis of a farm-size irrigation system. Their procedure, however, did not attempt to integrate distribution and application systems for a multi-farm area.

Irrigation System Configuration

A rather general representation of an irrigation system is presented in Fig. 6. For most irrigation systems the possibility exists for many different types of application and distribution systems and structures to be utilized as system components. A more detailed arrangement of alternative component configurations is shown in Fig. 8.

The distribution system is dendritic in nature with the larger components feeding several smaller components. The means of transporting and distributing water may vary quite drastically. As illustrated, the open channel and gravity pipeline may deliver water to a gravity-type application system or to a booster pump necessary to develop pressure to properly operate a sprinkler system of one or more types. The open channel and gravity pipeline may be used in conjunction with each other if conditions permit. The pressure pipe system may be pressurized as a result of pumping, a diversion at a high enough elevation to provide sufficient pressure, or a combination of the two. Deliveries from the pressure pipe may be made to any one of the distribution system alternatives or to the booster pump if necessary. Groundwater may also be pumped to several alternative locations.

Water is applied to all irrigated crops by one or more of the application systems. For this example it is assumed that the number of crops is four and that Crop 1

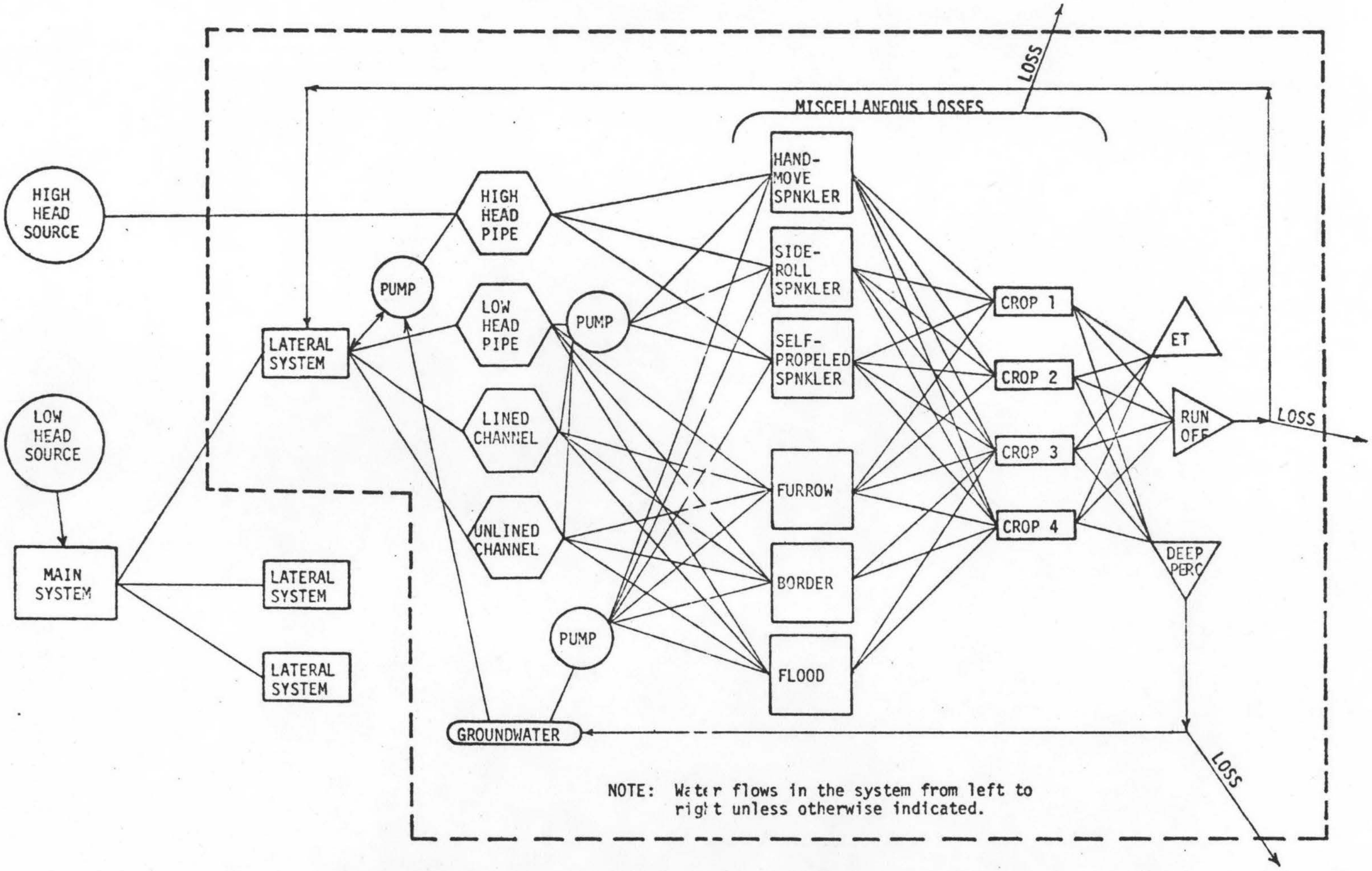


Fig. 8.--Component configuration of an irrigation system.

is potatoes, Crop 2 is sugar beets, Crop 3 is alfalfa, and Crop 4 is small grain. It is also assumed that water is applied to Crop 1 and Crop 2 only by the furrow method or any one of the sprinkler methods. No restriction is placed on the application method used for Crops 3 and 4.

Once the water is applied to the crop, it may either be beneficially used as the evapotranspiration requirement of the crop (ET) or it may be lost to surface drainage or deep percolation (DP). As illustrated, the surface drainage may be transported from the irrigated area or it may be returned to the application system for reuse. Likewise, the deep percolation may either be lost from the irrigated area or it might return to an aquifer and be beneficially used within the area. The miscellaneous losses are lost from the system and include operational waste and evaporation losses from surfaces not contributing to crop growth.

The logical order in which water might pass through an irrigation system to its ultimate use or fate is illustrated in Fig. 8. Components may be arranged to accurately represent each particular case in study. By describing each component of an irrigation system with an equation or set of equations, it is possible to construct an analytical model describing the actual system. Such a model would be flexible and could be used for analyzing more than one specific system.

The Analytical Model

The cost of each component of an irrigation system can be represented by an analytical equation or set of equations, and these equations can be combined to form an analytical model describing the cost of the entire system. If each analytical cost function can be expressed as a linear equation then the individual linear cost functions can be added together to form a composite linear cost function for the entire system. Such a function has the form of a linear objective function of the linear-programming problem. If the technical relationships of the system can be properly defined by a set of linear constraint equations, linear programming can then be used to determine the minimum cost of the complete system. It is necessary to use a non-sequential decision process such as linear programming to determine the minimum cost because of the interaction of all possible components and the possible recycling of surface runoff and deep percolation.

Cost Functions

The determination of cost functions for individual system components includes many input factors dealing with "costs" of many types. These input factors must include data describing the net costs of many physical aspects of each component. Socio-economic considerations dealing with the interaction of system components with human welfare must also be evaluated. Once determined, all individual "costs" for each system component must be combined to adequately describe the true cost of that component to the society in which it is to function.

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 cost of each component is to be expressed in monetary terms of dollars. Money has a time-value depending upon the interest rates associated with the use of that money. For a given interest rate, future sums of money can be expressed in an equivalent series of uniform payments by using the proper uniform-series compound-amount factor, and a present amount of money can likewise be expressed as a similar uniform series by using the proper capital-recovery factor. The two factors mentioned allow capital investment costs associated with systems to be expressed on the basis of annual costs and these annual costs can therefore be added directly to the various other annual costs associated with the system. All costs used in the description of the system components will be computed on an annual basis. All costs must also be adjusted to a common point in time in order to compensate for inflationary trends.

The annual costs of irrigation system components should be functions of system parameters that are common to all components. For distribution system components such as conduit sections and structures the system parameter of greatest importance is the maximum volume flow rate of water that the component can convey and/or control. System components must have equal capacity at all node or junction points where water is transmitted from one component to another. Also, the necessary size and cost of each distribution system component is a function of the flow rate it must transmit or control. The cost function for a component in equation form may be expressed as

$$\text{Annual cost} = f(Q) \tag{4.1}$$

where Q = maximum volume flow rate.

There is a minimum specified cost associated with most distribution system components regardless of the capacity of the component. This cost may result from fixed operation and maintenance costs and/or from minimum construction costs. Allowing for fixed specified costs regardless of the size of component, and assuming that the relationship between cost and component capacity can be estimated by a linear function, Equation 4.1 can take the form

$$\text{Annual cost} = c\,Q + d \tag{4.2}$$

where

c = annual cost per unit volume flow rate

Q = maximum volume flow rate

d = annual fixed specified cost.

The first term in the right-hand side of Equation 4.2 is identical to the left-hand side of Equation 3.1, the objective function of a linear-programming problem. The second term in the right-hand side of Equation 4.2 is a constant. All constant terms associated with system components under consideration in any one problem are additive as fixed specified costs.

The annual cost for an application system is best expressed on a per acre basis due to factors other than system capacity that affect the costs of applying water. Some of the factors include variations in crops irrigated, soil types, hours of operation per day, and other cultural practices. If the annual cost per acre, c, is known for an application system supplying water to N acres, then

$$\text{Annual cost} = c\ N \qquad (4.3)$$

Equation 4.3, like Equation 4.2, is a linear function which is identical to the left-hand side of a linear-programming objective.

Provision must also be made within the model to account for operation and maintenance costs and for the cost(s) associated with the water flowing through the system. Water costs will be incorporated in different ways as shown later in this chapter and in later chapters.

Constraints

The constraints of a linear programming model, Equation 3.2, define the technical relationships of the system being modeled. They are useful in defining continuity within the model and in defining relationships between sources of supply and areas of demand. An example of continuity within a model is that of transferring water from one distribution system component to another without any unspecified losses or gains.

Specification of the maximum flow rate required by an application system is a necessary relationship between a source of supply and an area of demand. The flow rate required is best expressed in equation form as

$$Q_{max} = \frac{1}{23.8} \; \frac{ET'_{max}}{Eff} \, N \tag{4.4}$$

where

Q_{max} = maximum required flow rate in cfs

ET'_{max} = maximum rate of evapotranspiration in inches per day

Eff = system efficiency expressed as a decimal

N = number of acres

Hypothetical Model Formulation

Consider an irrigated area as shown in Fig. 9 consisting of two separate farms, units I and II. Water may be supplied to the units by either an unlined channel or

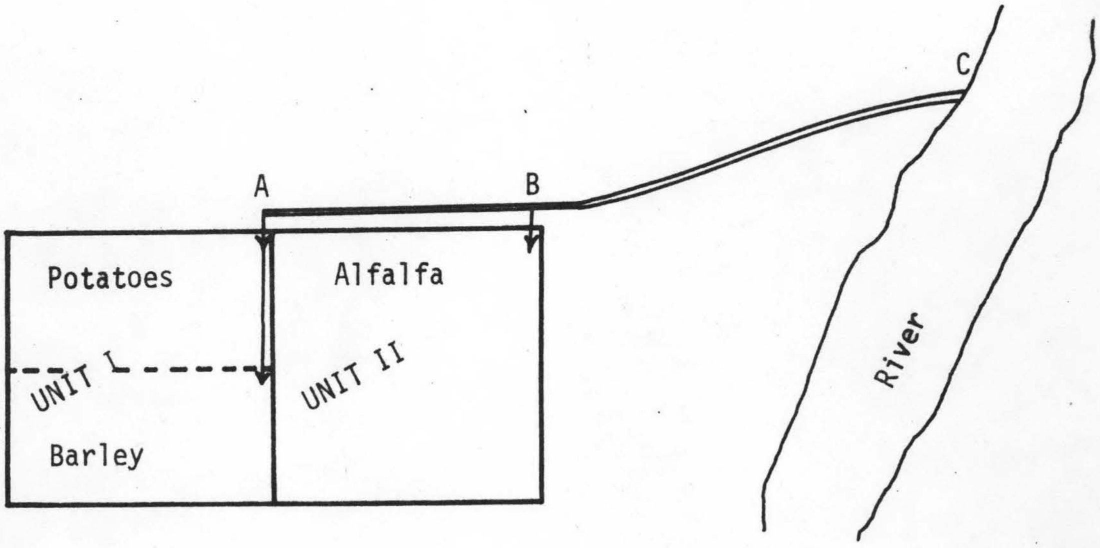


Fig. 9.--Area for hypothetical model formulation.

by a low-head pipeline. Water is supplied to unit I at point A and to unit II at point B. Point C is the point of supply; in this case it is a diversion from a river. The alternative application systems to be considered for each crop are as follows:

Potatoes	Sprinkler or furrow
Barley	Sprinkler or border
Alfalfa	Border or flood

If the entire system is required to meet a certain specified overall efficiency, Eff, then the maximum flow rate entering the system, Q_{max}, would be computed from Equation 4.4. The ET'_{max} value used must be a weighted average for those crops under consideration. The overall system efficiency, Eff, is the portion of diverted water that is used consumptively by the growing crops. It should be noted that Q_{max} might also be defined or specified by a legal water right constraint.

The alternative systems under consideration and the costs and efficiencies associated with each system are given in symbol form in Tables 1 and 2. The Q_{max} values listed in Table 1 would be computed from Equation 4.4.

Table 1.--Cost functions, efficiencies, and maximum flow rates for application systems in a hypothetical model

System	Acres covered	Cost per acre	Efficiency (decimal)	Q_{max} required
Potatoes, sprinkler	SP	CSP[a]	ESP	QSP
Potatoes, furrow	FP	CFP	EFP	QFP
Barley, sprinkler	SB	CSB[a]	ESB	QSB
Barley, border	BB	CBB	EBB	QBB
Alfalfa, border	BA	CBA	EBA	QBA
Alfalfa, flood	FA	CFA	EFA	QFA

[a] Includes pumping costs.

Table 2.--Cost functions and efficiencies for the distribution system in a hypothetical model

System	Flow rate in system	Cost per unit flow rate	Fixed cost	Efficiency (decimal)
Section A-B	QCAB	CCAB	FAB	ECAB
Section B-C	QCBC	CCBC	FBC	ECBC

The linear-programming matrix for the hypothetical model is presented in Fig. 10. The sum of the elements in the objective row, each multiplied by its proper variable, is the total annual cost of operating the entire system. Water costs for water entering the system, QENT, are related to the total diversion at C by the factor CWTR shown in the objective. The solution of the problem will give the minimum value for the objective subject to the constraints given in the rows beneath the objective. The CCON term in the objective is a constant that is the sum of all fixed specified costs, FAB and FBC, for distribution system components. The ACOM term is the operation and maintenance cost associated with the specified distribution system. This term is considered to be dependent upon the distribution system and completely independent of the application systems.

The constraint rows define boundary conditions, continuity within the model, and relationships between the source of supply, point C, and areas of use, units I and II. The Potato area row simply indicates that the potato acreage irrigated by sprinkler and furrow systems must total 80 acres. The same concept holds true for the Barley area and Alfalfa area rows. The supply system connecting points A and B must supply the demands imposed by the furrow, border, and sprinkler systems in unit I indicated by the coefficients of row A-B Q. The efficiency figure, ECAB, signifies that the flow rate of water entering the conveyance system at

Variables	SP	FP	SB	BB	BA	FA	QCAB	QCBC	QENT	CON	OEM	Sign	right-hand side
Objective	CSP	CFP	CSB	CBB	CBA	CFA	CCAB	CCBC	CWTR	CCON	ACOM		
Potato area	1.0	1.0										=	80.0
Barley area			1.0	1.0								=	80.0
Alfalfa area					1.0	1.0						=	160.0
A-BQ	QSP	QFP	QSB	QBB			-ECAB					$\le$	0.0
B-CQ					QBA	QFA	+1.0	-ECBC				$\le$	0.0
Supply								1.0				$\le$	$QSPEC_{max}$
Cost								1.0	-1.0			=	0.0
Const										1.0		=	1.0
COEM											1.0	=	1.0

Fig. 10.--Linear-programming matrix for hypothetical model

point B must include conveyance losses in that section. In the B-C Q row it can be seen that the B-C supply section must supply water to both the alfalfa field and the supply leading to point A. The supply entering the entire system must not exceed the specified value of $QSPEC_{max}$, and the water cost is proportional to the rate of diversion.

An optimal (least cost) solution can be obtained for the problem described by using linear programming. The results would indicate how the limited resource, water, would be distributed among the three crops in the two units and how many acres would be served by each type of application system in each unit. The effects of variations in water availability and cost could be incorporated into the same problem by using parametric programming to alter specified parameters within the matrix.

Two-Stage Dynamic-Linear Programming Extension

The solution obtained for the hypothetical problem described in the previous section is valid only for the distribution system specified in the problem formulation. Alternative distribution system components with different fixed and continuous variables (costs) cannot be considered in the same linear-programming problem (32). As a result, the problem must be revised for each distribution system to be considered. For distribution systems with many different possible section component combinations the number of problem revisions can be quite large if each component combination is to be considered.

The number of section component combinations possible in an irrigation distribution system is dependent upon the number of alternative components to be considered at any one section and the number of sections. If two component alternatives, for example lined and unlined channels, are to be considered at any of three sections, the number of possible system alternatives is 2^3 or 8 as illustrated in Fig. 11. It must be assumed that the components are compatible, i.e., that both types may receive water from and discharge water to each type. If M different components are to be equally considered for each of N sections the total number of possible combinations for the system is

$$\mathrm{COMB} = M^N \tag{4.5}$$

where COMB = number of combinations. Incompatible components such as open channels and pressurized pipelines must be considered in systems independent of each other.

Dynamic programming may be employed to eliminate or prune out combinations of alternatives that are dominated by more attractive solutions. The process is a simple, multi-staged process based upon Bellman's Principle of Optimality, quoted in Chapter 3 (4). If the decision is made to prune a branch somewhere in the system, all future decisions must constitute an optimal policy with regard to

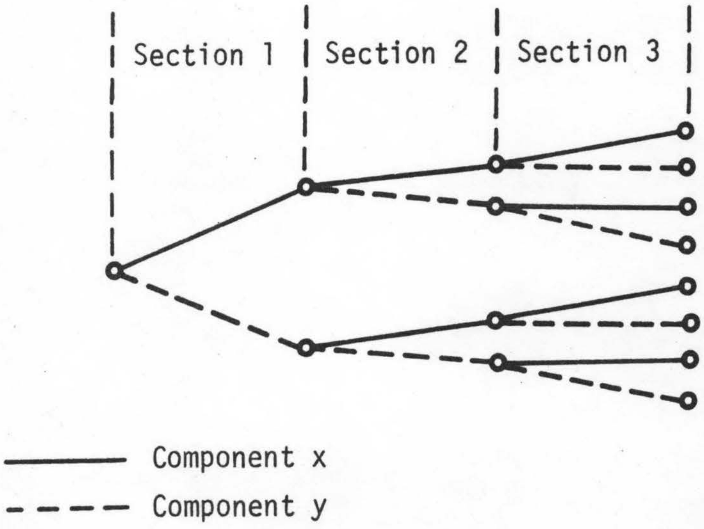


Fig. 11.--Section component combinations for an irrigation distribution system.

this first decision. The decision process must take into account non-uniform flow within the system due to the dendritic nature of a distribution system and diversions being made from the system.

As with any optimization process an objective must be defined which the process must seek to optimize. The objective may also be subject to constraints. The objective for distribution system component selection is to select those components and combinations thereof that will most efficiently convey water at the least cost. Constraints for the objective include the range of discharges for any given section and the types of components to be considered at any section. A component or a combination of components will be pruned if the cost of delivering water within a specified range of discharges at a computed conveyance efficiency is greater than the cost for another component or combination delivering water at an equal or greater conveyance efficiency. A component may also be pruned if it does not meet the criterion of being a specific type specified for a given section.

The pruning process eliminates less desirable component combinations with greater annual costs and lower efficiencies than other more efficient lower cost combinations. The computational technique used utilizes the annual component costs computed using Equation 4.2 and the component water conveyance efficiencies computed from Equation 2.1. Consider two alternative compatible components, component x and component y. The annual costs and water conveyance efficiencies for components x and y are $C_x = c_xQ + d_x$, $C_y = c_yQ + d_y$, E_{c_x} and E_{c_y}. If $c_x > c_y$ and $d_x > d_y$. then the cost for component x is greater than the cost for component y for all Q. This point is illustrated in Fig. 12. If $E_{c_y} \geq E_{c_x}$, the less desirable component x can be eliminated because of the higher cost and lower efficiency. If $E_{c_x} > E_{c_y}$, component x must be retained because the higher efficiency warrants the increased cost.

Sometimes, when comparing the costs and efficiencies for two components x and y, the constant terms of the cost functions have values such that $c_x < c_y$ when $d_x > d_y$. The

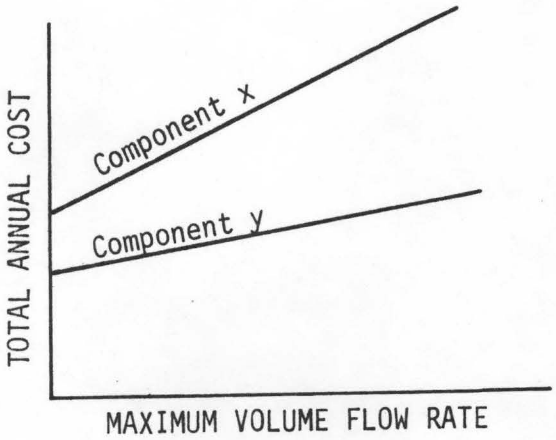


Fig. 12.--Non-intersecting distribution system component cost functions.

result is that the cost functions are lines that intersect at some point, Q_I, as illustrated in Fig. 13. The total annual costs for component y are less than those for component x for all discharges less than Q_I. If $E_{c_x} \leq E_{c_y}$ and if the specified range of discharges is $0 \leq Q \leq Qi$ then component x can be eliminated because of the lower efficiency and higher costs for the range of discharges specified.

The total annual cost for a component branch consisting of two compatible components is

$$\text{Cost} = (c_1 + c_2)\ Q + (d_1 + d_2) \qquad (4.6)$$

The water conveyance efficiency for the same two components joined together is

$$E_c = (E_{c_1})(E_{c_2}) \qquad (4.7)$$

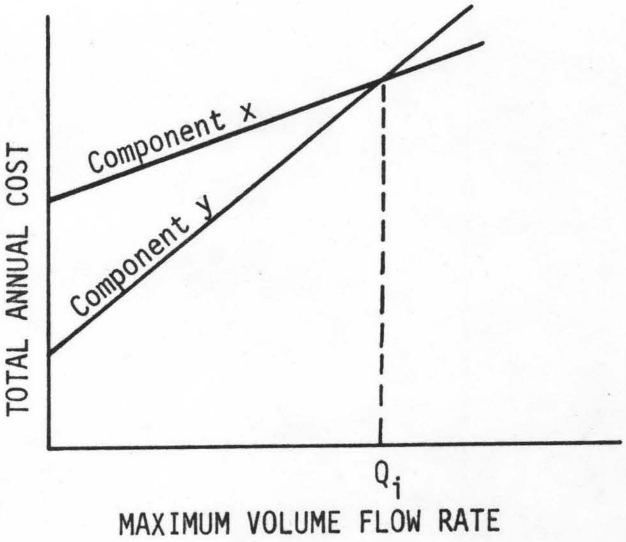


Fig. 13.--Intersecting distribution system component cost functions.

Total annual costs and efficiencies for each branch consisting of two components are compared in the same manner as for single components. Those branches are eliminated that have lower efficiencies and higher costs for a specified range of discharges than other branches. If $Q_2 \leq Q_1$ all branches consisting of two components are within the discharge range for the first element and the constraint is not conflicting. Flow rates normally decrease with distance downstream within a distribution due to the dendritic nature of distribution systems.

For the general case of n components within a distribution system branch, the cost and water conveyancy efficiency are determined as follows:

$$\text{Annual cost} = \left(\sum_{i=1}^{n} c_i\right) Q + \sum_{i=1}^{n} d_i \tag{4.8}$$

where

c_i = annual component costs per unit volume flow rate

Q = maximum volume flow rate

d_i = annual component fixed specified costs

and

$$OE_c = \prod_{i=1}^{n} E_{c_i} \tag{4.9}$$

where

OE_c = overall water conveyance efficiency

E_{c_i} = individual component water conveyance efficiencies.

Costs and efficiencies are compared for each branch for all i = 1,n and all higher cost, less efficient combinations are pruned at each step. There are no conflicting constraints as long as $Q_1 \geq Q_2 \geq \cdots \geq Q_n$.

The number of comparisons, and thus the computation time, is reduced as a result of pruning less desirable component combinations at each step in the process. The process does constitute an optimal policy because the decisions (pruning) at each succeeding step constitute an optimal policy with regard to the state resulting from the previous decision(s).

The process described is repeated for each lateral and branch within a dendritic distribution system.

Because of the large number of decisions involved in the pruning process, a digital computer program was written. The documented program, written in Fortran IV, is listed in Appendix B.

Once all less desirable component combination branches are pruned using the dynamic programming process described, the remaining branches are inserted, one at a time, into a linear-programming matrix containing application system elements, and a least-cost solution is obtained for each branch. These solutions are then compared to obtain a minimum cost value for all distribution system combinations.

All noncompatible distribution systems are considered completely independent of one another. The dynamic programming-linear programming is repeated for each set of compatible systems to establish a global optimum for all distribution systems considered.

Summary of Procedures

A systematic approach must be used if all input data are to be properly and efficiently used to obtain a realistic optimal solution. The recommended procedure is outlined as follows:

1. Specify the study area to be considered.
2. Specify field layout.

3. Specify cropping pattern.
4. Calculate maximum rate of evapotranspiration.
5. Specify distribution system route(s).
6. Compile necessary data and determine cost functions and efficiencies of system components.
7. Employ dynamic programming to prune less desirable distribution system component combinations.
8. Formulate objective function(s).
9. Formulate constraint equations.
10. Solve the linear programming problem for minimum cost objective and specify optimal flow rate values for each component of the objective.
11. Perform sensitivity analysis and/or use parametric programming to determine the sensitivity of the optimal solution to parameter changes in the constructed linear programming model.
12. Repeat steps 8-11 for each distribution system component combination to be considered.

The above points outline a logical approach to the problem and provide the flexibility necessary for a large array of system components.

CHAPTER 5

DETERMINATION OF ANNUAL COSTS AND RELATED EFFICIENCIES OF SYSTEM COMPONENTS

A step in the methodology outlined at the end of Chapter 4 includes the compilation of data necessary to determine the cost function and related efficiency for each system component. Just as the cost functions and efficiencies listed in Tables 1 and 2 were necessary for the formulation of the hypothetical model, similar functions are required for the solution of any given real problem. Even though the annual cost and efficiency of a component appear to be simple terms, there are many factors that must be included in their formulation.

Since many inputs are required to determine the annual cost and efficiency for each system component, digital computer routines are utilized to perform the necessary computations and manipulations. Two different routines are used, one for application systems and one for distribution systems. Each of these routines employs subroutines designed to compute costs and efficiencies for different types of system components.

Determination of Application System Annual Costs and Efficiencies

The routine APSYSCST is used to calculate the total annual costs and the efficiencies for various types of irrigation application systems. The subroutine SPNKLR is used to calculate annual costs and efficiencies for side-roll and hand-line sprinkler systems, and the subroutine SURFCE is used to calculate the same for furrow and border surface systems. A documented listing of APSYSCST and the subroutines SPNKLR and SURFCE is given in Appendix B.

The list of input parameters necessary for the execution of APSYSCST is shown in Fig. 14. As shown in that figure, the main routine reads in soil-plant-water information for a particular soil-crop combination. The information from these parameters is then utilized by the subroutines SPNKLR and SURFCE to calculate the desired outputs for sprinkler and surface systems respectively.

Costs and Efficiencies for Sprinkler Systems

Subroutine SPNKLR is designed to calculate the annual costs associated with a hand-line or side-roll sprinkler system that may or may not be used in conjunction with a mainline supplying water to the laterals. The data for the laterals are entered separately from those pertaining to the mainline.

Input Parameters for APSYSCST

Soil water-holding capacity
Root zone depth
Percent of TAM usable as TRAM
Total annual ET
Maximum ET rate incurred

Input Parameters for Subroutine SPNKLR

- Lateral data:
  - Lateral length and spacing
  - Alternative set-length times
  - Overall system efficiency
  - Evaporation losses
  - Maximum allowable water intake rate
  - Time required to move lateral
  - Time required to transport lateral between irrigations
  - Labor wage rate
  - System cost
  - System life
  - Salvage value
  - Interest rate
  - Other expenses
- Mainline data:
  - Area supplied
  - System cost
  - System life
  - Salvage value
  - Interest rate
  - Other expenses
- Value of land lost to production
- Net value of water lost to deep percolation

Input Parameters for Subroutine SURFCE

Field length and width
Set width
Flow rate applied
Depth of infiltration vs time relationship
Advance and recession vs time relationship
Labor requirement per set
Additional labor requirements per irrigation
Labor rate
Cost of irrigation system equipment
Major land forming costs
System life
Salvage value
Interest rate
Annual land preparation costs necessary for system operation
Annual maintenance cost
Other expenses
Value of land lost to production
Net value of water lost to surface runoff
Net value of water lost to deep percolation
Set-length time (option)
Specified set efficiency (option)
Water runoff control (option)

Fig. 14.--Input parameters used to calculate annual costs and efficiencies of irrigation application systems.

Lateral input parameters include a physical description of the system, associated labor requirements, and the costs associated with the system. The physical description includes the lateral length and spacing, specified alternative set-length times, and the expected efficiency for the system. This description is necessary to compute the area served by a lateral and the resulting schedule of operation. Labor requirements for system operation and the labor-wage rate are necessary for computing annual labor costs. The initial system cost, life, and salvage value are utilized along with the interest rate in computing the annual depreciation costs for the lateral. Other expenses include taxes and insurance and are computed as a percentage of the average capital investment.

The mainline input parameters are similar to those for a sprinkler lateral. The area supplied by the mainline is necessary for reducing the associated costs to a per-acre basis. Annual depreciation costs for the mainline are computed from the necessary inputs.

Two additional parameters are used in the computation of the total annual cost for a sprinkler system. The first parameter is the net value of land lost to production for a particular system configuration. The second is the net value of water lost to deep percolation. This value may be positive or negative depending upon leaching requirements, fertilizer losses, water table buildup, etc.

The flexibility of subroutine SPNKLR permits computations of annual costs for many different lateral-mainline combinations. The routine would have to be altered somewhat if it were to encompass continuously moving systems such as center-pivot systems.

Costs and Efficiencies for Surface Systems

The subroutine SURFCE utilizes the soil-crop data passed to it from APSYSCST in conjunction with the inputs listed in Fig. 14 to compute the efficiency and annual cost for a particular system. System dimensions and labor and equipment costs are utilized in much the same manner as they are in the SPNKLR subroutine. In addition, land-forming costs are considered as necessary inputs. The amount of land lost to production due to the system and the values of water lost to surface runoff and deep percolation are also input and used in computing the total cost.

Whereas the efficiency of a sprinkler is usually known from manufacturers' specifications, the determination of system efficiency for a surface system is quite difficult. This fact is due to the many variables that affect the hydraulics of surface irrigation as described in Chapter 2 and illustrated in Fig. 3. The method used in the subroutine SURFCE to compute efficiency utilizes the depth of infiltration vs time relationship and the advance and recession vs time relationships for a given system.

By utilizing the given relationships, the volumes of water lost to surface runoff and deep percolation are determined. Variations in water distribution along the irrigation run are also determined and can be used to determine the distribution efficiency or as a basis for a penalty term if the depleted moisture at some points is not replaced during irrigation.

One of three options must be used to determine costs and efficiencies. The first option, set-length time, allows input of a specified length of time that water is applied during an irrigation set. The corresponding efficiency is then calculated for the time input. Using the specified set efficiency option allows for input of a desired efficiency. Set-length time is then adjusted so that the specified efficiency may be met. The water runoff control option adjusts the set-length time and water application rate to ensure that all root zone moisture depletion is satisfied with minimum waste. The last option makes the adjustments necessary for a given set of physical conditions and thus eliminates much variability due to individual irrigators.

The entire APSYSCST routine requires input data that are known or that can be readily obtained. Some of the methods incorporated in the routine may be oversimplified concerning finer points of hydraulic theory, but the assumptions made are realistic in light of the accuracy of most data available for input.

Determination of Distribution System Annual Costs and Efficiencies

The routine for computing the annual costs and efficiencies associated with distribution system components, SYSC0ST, utilizes four subroutines. Three of the subroutines, DITCST, PIPCST, and PMPCST, independently calculate annual costs and efficiencies for open channel, pipeline, and pumping plant components respectively. These three utilize the fourth subroutine, REGLIN, to perform simple linear regression analyses. The complete documented listing of SYSC0ST and its subroutines is located in Appendix B.

Costs and Efficiencies for Open Channels

The subroutine DITCST computes the annual cost and efficiency for a section of trapezoidal channel for the input parameters shown in Fig. 15. The section length and the inlet and outlet elevations are used for computing a uniform slope for the section. If a break in slope is encountered the section must be divided. Cost data for different sizes of each different type of structure are entered along the number of structures of each type contained in a given section. Total excavation costs (and lining costs if lined) are computed from the unit costs and computations involving channel properties, channel slope, and the flow rate under consideration. Annual cost of the

DITCST

Input Parameters for Trapezoidal Channels

System length
Elevation of inlet and outlet
Cost and size data for structures
    Turnout structures
    Drop structures
    Combination turnout-drop structures
    Weirs
    Highway bridges
    Farm bridges
Number of each kind of structure
Cost per unit volume of excavation
Unit cost and thickness of lining
Channel properties
    Side slope
    Base width-water depth ratio
    Manning's roughness coefficient
    Maximum allowable velocity
    Minimum allowable channel depth
System life
Salvage value
Interest rate
Right-of-way width and cost
Other expenses
Public values
Seepage rate
Net value of water lost to operational waste
Range of flow rates

Fig. 15.--Input parameters used to calculate annual costs and efficiencies of open channel sections.

channel excavation (lining) and structures is computed using the inputs of system life, salvage value, and interest rate.

Other values necessary for the computation of the total cost of a channel section include right-of-way costs, other expenses, net public values, and the value of water lost in operational waste. Right-of-way costs may vary depending upon channel location and alignment. The other expense input is used to accommodate expenses such as taxes and insurance. Public value inputs include hard-to-define expenses or benefits such as esthetics, wildlife habitat, and safety. Care must be exercised with a factor such as safety so that it is not charged as a public nuisance and again charged in the form of an insurance premium. The water lost in operational waste, usually to deep percolation, may either be a positive or a negative factor depending upon water costs, groundwater recharge, etc.

The above inputs are used for computation of annual costs for a range of maximum discharges flowing through a channel section. The result is a cost-discharge relationship for the given section. A simple linear regression analysis is then run on the given relationship data using the subroutine REGLIN. The results of the analysis are given in the form of Equation 4.2.

The operational waste computed from the seepage rate is used in computing the water conveyance efficiency for the section under consideration.

Costs for Pipelines

The annual costs for pipelines are computed by subroutine PIPCST using the parameters listed in Fig. 16. In addition to the section length under consideration and the elevations at each end of the section, the head at each

PIPCST

Input Parameters for Pipes Flowing Full

- System length
- Elevations of inlet and outlet
- Head at inlet and outlet
- Hazen-Williams friction coefficient
- Standard pipe diameters considered
- Costs associated with each diameter
    - Cost of pipe
    - Cost of laying pipe
    - Cost of trenching
    - Cost of valves
    - Cost of turnouts
    - Cost of meters
    - Cost of pressure regulators
- System life
- Salvage value
- Interest rate
- Right-of-way width and cost
- Other expenses
- Public values
- Range of flow rates

Fig. 16.--Input parameters used to calculate annual costs of pipeline sections.

end is also specified in order to establish the hydraulic gradient. The Hazen-Williams friction coefficient and standard pipe diameters are necessary in specifying the proper size of pipe for given conditions. Annual costs for pipeline materials and accessories are computed using the costs associated with each diameter and the number of valves, turnouts, meters, and pressure regulators included in conjunction with system life, salvage value, and interest rate.

Right-of-way costs, other expenses, and public values are also input for their contribution towards the total cost. The factors affecting these inputs are much the same as for open channels. No input is given for seepage losses as such losses are negligible for a well maintained pipeline. The conveyance efficiency for such a pipe may be considered as 100 percent.

The subroutine REGLIN is employed to calculate the coefficients of a linear equation, Equation 4.2, for the cost-discharge relationship of a given pipeline section.

Costs for Pumping Plants

The costs for pumping plants, determined by subroutine PMPCST, take into account equipment costs, power costs, and operation and maintenance costs. A range of costs and discharges for pumps supplying water at a given head is used in determining initial costs and power requirements. The initial pump costs must be added to those of structures and/or wells and used in conjunction with the pump life, salvage value, and interest rate inputs to determine the annual capital recovery costs. The energy costs used in conjunction with the power requirements, plant efficiency, and annual volume demand are necessary in computing the total annual energy costs. The operation and maintenance costs are determined by the method described by Eyer (26). The annual costs for pumping plants are computed from the parameters listed in Fig. 17.

PMPCST

Input Parameters for Pumping Plants

Total dynamic head
Costs and discharges of pumping plants
Costs of structures and fittings
  and/or wells
Pump life
Salvage value
Interest rate
Energy costs
Pumping plant efficiency
Annual volume demand
Operation and maintenance cost inputs
Other expenses
Public values

Fig. 17.--Input parameters used to calculate annual costs of pumping plants.

Other expenses and public values are also incorporated into the calculation of total annual cost for a given installation. A linear relationship, Equation 4.2, is used to relate annual cost and discharge for similar plants operating at a specified total dynamic head.

Many computational procedures utilizing the parameters illustrated and described are incorporated into the routines APSYSCST and SYSCST. These procedures can be followed in detail in the documented listings found in Appendix B.

CHAPTER 6

MODEL FORMULATION FOR THE NORTH RIGBY IRRIGATION DISTRICT

The material presented in previous chapters provides the methodology and information necessary for the formulation of a model of a given area encompassing one or more irrigation systems. The steps involved in the model formulation are those listed in the summary of Chapter 4. Each step in the formulation will be explained as to its significance and as it relates to other steps.

Study Area

The area selected for study and modeling is the area served by the North Rigby Irrigation and Canal Company, Inc. It is located in Jefferson County, Idaho, approximately 1.5 miles north of the city of Rigby. The area served is less than one mile wide and is approximately four miles long. The main canal, the North Rigby Canal, is supplied by the Great Feeder Canal (13, 29) and conveys an average of approximately 55 cfs during the peak irrigation season from June through September. The shaded area in Fig. 18 is the irrigation district served by the North Rigby Canal.

Organization of the irrigation company took place on April 1, 1884, and canal construction commenced at that

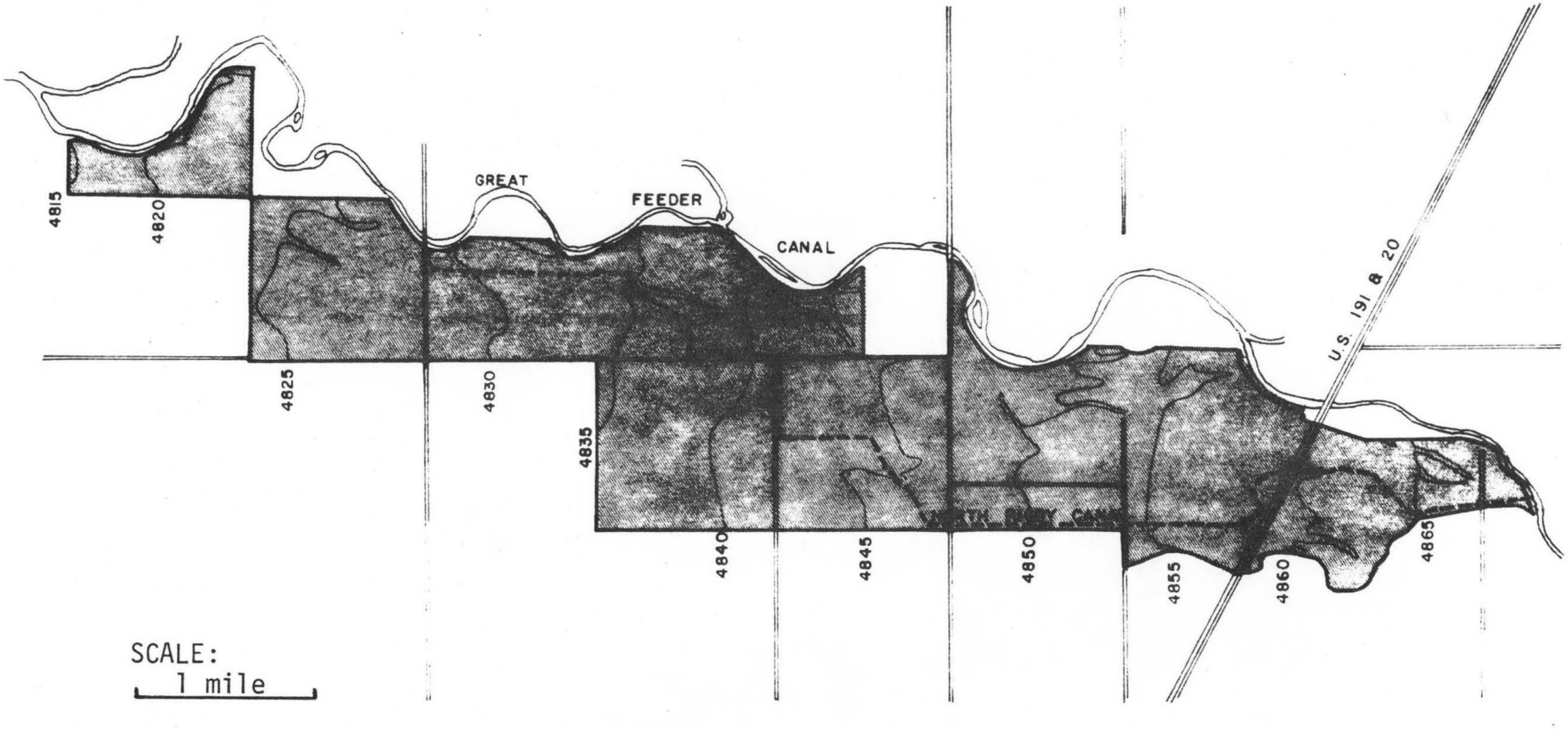


Fig. 18.--Irrigation district served by the North Rigby Canal.

time (13). The main distribution canal and laterals were constructed along property lines and natural contours to minimize excavation as all the work was done by men and animals. Improvements have been made on the system, but the main canal follows basically the original established route. Approximately half of the diversion and drop structures are concrete with the other half being made from wood. No water measuring devices are installed in the system. Most of the maintenance work is done by the water users using farm equipment. Periodically a small bulldozer is used to clean and reshape sections of the main canal.

Crops grown in the irrigation district are potatoes, hay, grain, and pasture; and the application systems used to apply water to these crops are all surface type systems. Potatoes are irrigated by the furrow method, and the remaining crops by the border method. Due to the slight uniform slope of the area as depicted by the contour lines on Fig. 18, most irrigation runs are quite long. Earthen ditches are used as laterals, and the water is diverted to the fields by means of cuts in ditchbanks, buried pipe turnouts, and siphon tubes. Very few turnout and check structures, wood or concrete, exist within the application systems. Water control is accomplished with portable canvas and nylon dams and the irrigator's shovel. The degree of water control varies greatly depending upon individual irrigation practices.

In addition to the general maintenance and operation of the irrigation system described above, two primary factors influence irrigation practices and system efficiencies. First is the price paid for water, approximately \$1.50 per irrigated acre per year. As about 10 acre-feet per acre per year are diverted into the system, the assessment is only \$0.15 per acre-foot diverted. The second factor influencing system operation is due to the geographic location of the area served.

The entire portion of Jefferson County lying south and east of the Snake River is an alluvial fan. The soils in this area are usually quite shallow underlain by sands and coarse gravels. The soils themselves are medium to coarse textured with high water intake rates. High intake-rate soils coupled with long irrigation runs result in low distribution and application efficiencies. Galinato (28) has reported field efficiencies in the 20-50 percent range. Low conveyance efficiencies for canals are also common as the bottoms of canals often penetrate the shallow soils. The canals then have no impervious barrier between flowing water and deep gravelly and sandy subsoils. Brockway and deSonneville (10) reported an average seepage rate of 3.50 ft/day from all canals in the Rigby area of Jefferson County.

The particular soil series in the irrigated area under consideration are Blackfoot and Lobenzo silt loams, Heiseton loam, Hayeston sandy loam, and Worboro gravelly loam. The locations of different soil series are shown in Fig. 19. As can be seen, the coarser textured soils tend to lie closer to the Great Feeder Canal channel.

Field Layout, Cropping Patterns, and Evapotranspiration Rates

The field layout and cropping pattern for the study area were obtained from reconnaissance observations and from large scale aerial photos. Field measurements taken from the aerial photos were combined with cropping data to obtain a crop distribution for the entire study area and for units within the area. Factors affecting the choice of unit boundaries shown on the overlay of Fig. 19 were the size and location of each unit and the soil series boundaries. The soil series associated with each unit is listed in Table 3.

Crops grown in the study area are hay, grain, pasture, and potatoes. Rate of evapotranspiration, ET', data for each crop were obtained from those published by Sutter and Corey (69). As the maximum ET' for all crops in the area occurs during the month of July, these data were used as the inputs for maximum system design specifications. A summary of maximum ET' and crop acreage data for each unit of Fig. 19 is listed in Table 4.

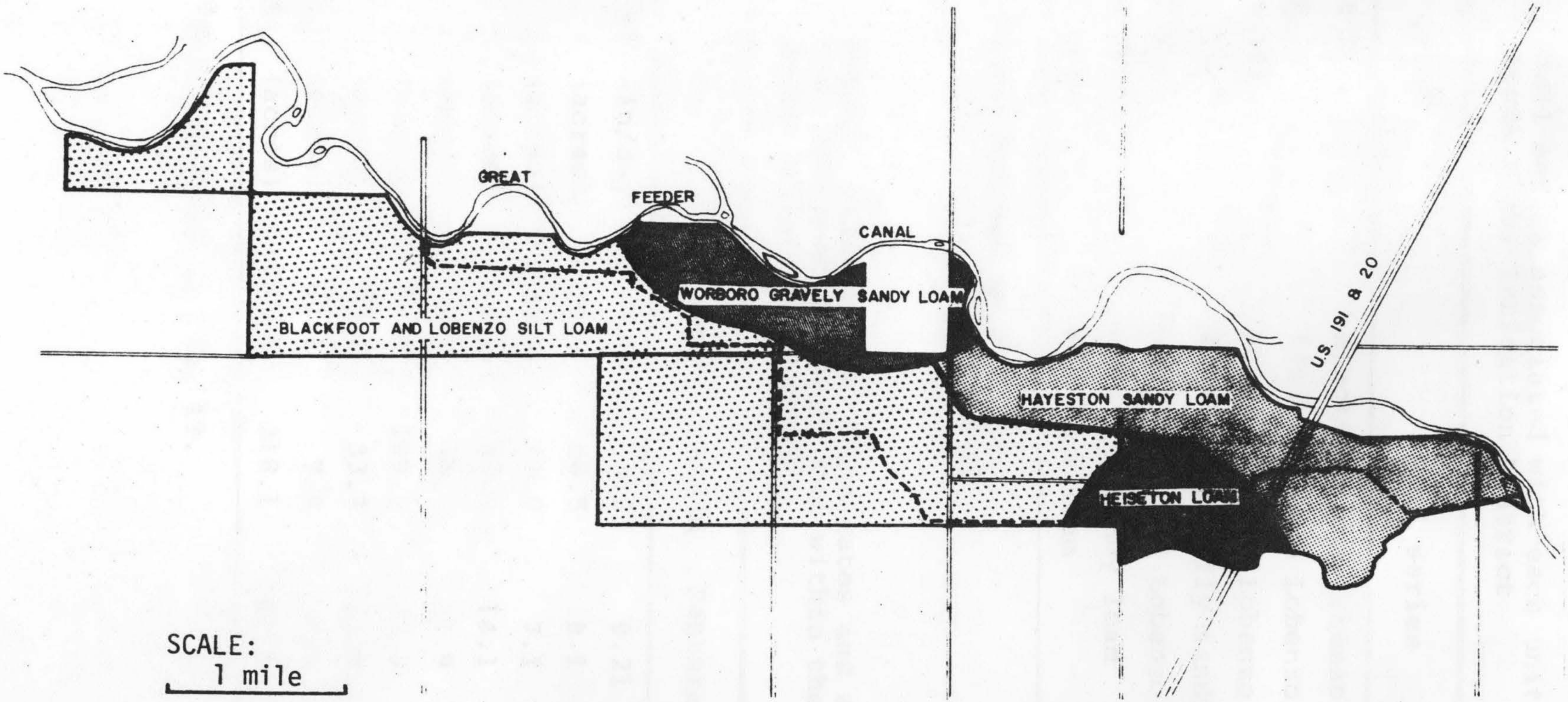


Fig. 19.--Soil series and units established within the North Rigby Irrigation District.

Table 3.--Soil series associated with each unit within the North Rigby Irrigation District

Unit[a]	Soil series
Unit I	Blackfoot and Lobenzo silt loam
Unit II	Blackfoot and Lobenzo silt loam
Unit III	Blackfoot and Lobenzo silt loam
Unit IV	Worboro gravelly sandy loam
Unit V	Blackfoot and Lobenzo silt loam
Unit VI	Hayeston sandy loam
Unit VII	Heiseton loam

[a]Units defined in Fig. 19.

Table 4.--Maximum evapotranspiration rates and a summary of crop acreages for each unit within the North Rigby Irrigation District

		Hay	Grain	Pasture	Potatoes
Maximum ET'	(in/day)	0.24	0.23	0.21	0.25
Unit I[a]	(acres)	26.1	66.5	9.1	10.0
Unit II	(acres)	20.2	10.0	7.1	33.9
Unit III	(acres)	13.6	42.4	14.1	52.2
Unit IV	(acres)	0.0	48.5	12.9	7.3
Unit V	(acres)	93.4	109.1	75.3	81.1
Unit VI	(acres)	87.2	33.7	45.9	21.5
Unit VII	(acres)	60.1	7.9	0.0	0.0
Total	(acres)	300.6	318.1	164.4	206.0

[a]Units defined in Fig. 19.

Distribution System Routes

The alternative distribution system routes chosen for consideration are shown in Fig. 20 and the associated overlays. The unlined channel route is the present route of the North Rigby Canal. This route was chosen so that the present system could be considered as a possible alternative system. The lined channel and gravity pipeline routes follow the unlined channel route very closely. Property boundaries, roads, and water diversion points in addition to topography were given consideration in route selection. The pressure pipeline route was chosen for minimum length and for supplying high pressure water to necessary locations.

As can be seen in Fig. 20, the junctions for various gravity pipe and channel sections lie at essentially the same points. By thus choosing the locations of section junction points, the possibility exists for joining dissimilar but compatible components at various points within the system. The fact that the pressure pipe section junction points are located by themselves is inconsequential as the pressure pipeline is not compatible with the other conveyance systems.

Section A for each system is that section through which the entire flow is conveyed to the rest of the system. The sections UCA, LCA, and GPA receive water at the present point of diversion located on the Great Feeder Canal. The

Table 5.--Surface application systems considered for the North Rigby Irrigation District

System type	Field length (feet)	Field width (feet)	General description
Unimproved gravity	1300	600	The system consists of poorly maintained earthen ditches with earthen and wooden structures and portable canvas dams used for water control. Maximum allowable length of irrigation run is 1300 feet.
	650	500	
	400	250	
Improved gravity	1300	600	The system consists of well maintained earthen ditches with concrete and metal structures used for water control. Maximum allowable length of irrigation run is 650 feet. A cross ditch is specified if the irrigation run is in excess of the 650 foot length.
	650	500	
	400	250	

Table 6.--Sprinkler application systems considered for the North Rigby Irrigation District

System type	Mainline length (feet)	Area served by mainline (acres)	Lateral length (feet)	General description
Hand-line sprinkler	2640	160	1300	The layout of the system consists of hand-carried laterals supplied by a permanent or semi-permanent mainline.
	2640	80	1300	
	1960	50	1300	
	1320	40	700	
Side-roll sprinkler	2640	160	1300	The layout of the system consists of mechanically moved laterals supplied by a permanent or semi-permanent mainline.
	2640	80	1300	
	1960	50	1300	
	1320	40	700	

The listing in Appendix C is the listing of data input into the routine APSYSCST described in Chapter 5 and listed in Appendix B.

The annual cost per acre and efficiency for each type of system listed in Tables 5 and 6 for each soil series was determined using the APSYSCST routine described in Chapter 5. The annual costs computed for application systems include the costs of applying water and conveying the water from a point of delivery to the point or points of application.

The following process was used to obtain the cost and efficiency data for a specific system type in a given unit of Fig. 19 with known soil series. Field size and crop distributions for each farm unit were first obtained from large-scale aerial photos. For gravity systems the field sizes for each crop were grouped into one of the size categories listed in Table 5. The cost and efficiency for a given crop was obtained from a weighted average considering the number of acres in each field size category. The average annual cost and efficiency for an entire unit were then computed as weighted averages considering the number of acres of each crop. For sprinkler systems, the farm size and layout were used in conjunction with crop acreage data to determine the overall annual costs per acre. Pumping costs were added to system costs for systems not receiving water from a high pressure distribution system.

The maximum required discharge was computed using Equation 4.1 utilizing system efficiency data for each unit and the maximum rate of evapotranspiration for each crop. Annual costs, water application efficiencies, and maximum required discharges for each application system considered in each unit are listed in Table 7.

Distribution Systems

The annual cost and water conveyance efficiency for each distribution system component shown in Fig. 20 and its overlays were determined using the routine SYSC0ST described in Chapter 5. All input data for the system components are listed in Appendix C.

Annual costs for each component were computed for a range of flow rates comparable to those expected in each component. A least-squares linear regression analysis was run to determine the best fit linear relationship between annual cost and maximum flow rate in order to get the relationship in the form of Equation 4.2, annual cost = cQ + d. The water conveyance efficiency for each open channel component was also determined. The results obtained for open channel and pipeline components are summarized in Table 8.

The high correlation coefficient, r, values for the estimated costs for all components listed in Table 8 indicate that the cost-discharge relationships are estimated quite well by a linear equation in the form of Equation 4.2.

Table 7.--Application system parameters for the North Rigby Irrigation District

System symbol	Unit[a]	System	Annual cost ($/acre)	Application efficiency (percent)	Maximum required discharge (cfs/acre)
UGI	I	Unimproved gravity	46.69	28.3	0.0342
IGI	I	Improved gravity	53.60	27.7	0.0357
HSI	I	Hand-line sprinkler	35.98	70.0	0.0139
RSI	I	Side-roll sprinkler	35.80	70.0	0.0139
HSPI	I	Hand-line sprinkler and pump	60.77	70.0	0.0139
RSPI	I	Side-roll sprinkler and pump	60.59	70.0	0.0139
UGII	II	Unimproved gravity	44.79	28.9	0.0351
IGII	II	Improved gravity	59.31	25.0	0.0412
HSII	II	Hand-line sprinkler	30.85	70.0	0.0144
RSII	II	Side-roll sprinkler	29.05	70.0	0.0144
HSPII	II	Hand-line sprinkler and pump	52.98	70.0	0.0144
RSPII	II	Side-roll sprinkler and pump	51.18	70.0	0.0144
UGIII	III	Unimproved gravity	50.60	28.8	0.0348
IGIII	III	Improved gravity	55.99	26.3	0.0388
HSIII	III	Hand-line sprinkler	37.68	70.0	0.0142
RSIII	III	Side-roll sprinkler	37.98	70.0	0.0142
HSPIII	III	Hand-line sprinkler and pump	61.47	70.0	0.0142
RSPIII	III	Side-roll sprinkler and pump	61.77	70.0	0.0142
UGIV	IV	Unimproved gravity	64.98	8.8	0.1109
IGIV	IV	Improved gravity	72.91	12.9	0.0779
HSIV	IV	Hand-line sprinkler	73.03	70.0	0.0137
RSIV	IV	Side-roll sprinkler	79.40	70.0	0.0137
HSPIV	IV	Hand-line sprinkler and pump	106.49	70.0	0.0137
RSPIV	IV	Side-roll sprinkler and pump	112.86	70.0	0.0137

Table 7.--Continued

System symbol	Unit[a]	System	Annual cost ($/acre)	Application efficiency (percent)	Maximum required discharge (cfs/acre)
UGV	V	Unimproved gravity	36.65	29.0	0.0338
IGV	V	Improved gravity	54.70	27.1	0.0367
HSV	V	Hand-line sprinkler	29.98	70.0	0.0140
RSV	V	Side-roll sprinkler	28.37	70.0	0.0140
HSPV	V	Hand-line sprinkler and pump	51.71	70.0	0.0140
RSPV	V	Side-roll sprinkler and pump	50.10	70.0	0.0140
UGVI	VI	Unimproved gravity	60.99	12.5	0.0799
IGVI	VI	Improved gravity	68.10	16.6	0.0618
HSVI	VI	Hand-line sprinkler	48.45	70.0	0.0139
RSVI	VI	Side-roll sprinkler	48.24	70.0	0.0139
HSPVI	VI	Hand-line sprinkler and pump	80.60	70.0	0.0139
RSPVI	VI	Side-roll sprinkler and pump	80.39	70.0	0.0139
UGVII	VII	Unimproved gravity	27.27	22.8	0.0448
IGVII	VII	Improved gravity	48.31	31.6	0.0321
HSVII	VII	Hand-line sprinkler	34.26	70.0	0.0143
RSVII	VII	Side-roll sprinkler	32.29	70.0	0.0143
HSPVII	VII	Hand-line sprinkler and pump	57.27	70.0	0.0143
RSPVII	VII	Side-roll sprinkler and pump	55.30	70.0	0.0143

[a] Units defined in Fig. 19.

Table 8.--Annual cost relationships and water conveyance efficiencies for distribution system components

System component[a]	c[b] ($/cfs)	d[b] ($)	r[c]	Water conveyance efficiency (percent)
UCA	4.91	293.55	0.989	98.5
UCB	18.91	719.18	0.949	95.5
UCC	18.71	723.47	0.973	95.2
UCD	18.56	693.39	0.976	92.5
UCE	15.09	635.01	0.982	92.3
UCF	17.19	492.50	0.966	95.7
UCG	11.07	162.36	0.983	95.0
UCH	11.27	504.39	0.962	96.8
LCA	9.22	604.73	0.987	100.0
LCB	19.87	1315.65	0.958	99.9
LCC	35.76	1578.13	0.973	99.8
LCD	31.34	1184.36	0.981	99.8
LCE	31.10	1260.82	0.962	99.8
LCF	43.30	1091.16	0.980	99.8
LCG	29.36	480.24	0.987	99.8
LCH	20.17	686.21	0.959	99.9
LCJ	21.80	523.99	0.980	99.9
GPA	58.22	1364.69	0.951	100.0
GPB	215.78	3472.96	0.961	100.0
GPC	291.35	3595.72	0.956	100.0
GPD	267.91	3400.86	0.968	100.0
GPE	168.12	1393.11	0.957	100.0
GPF	326.24	2198.57	0.948	100.0
GPH	111.40	1130.36	0.938	100.0
PPA	34.77	669.42	0.928	100.0
PPB	118.72	1925.69	0.951	100.0
PPC	289.44	4083.35	0.952	100.0
PPD	308.90	3800.91	0.964	100.0
PPE	204.71	1897.74	0.961	100.0
PPF	435.04	2964.29	0.953	100.0
PPH	180.92	1678.54	0.914	100.0

[a] Components shown in Fig. 20.

[b] Coefficients of Equation 4.2, annual cost = cQ + d.

[c] Correlation coefficient relating actual computed cost values with those estimated by Equation 4.2.

Annual cost versus discharge relationships were also computed for various types of pumping plants. Those types considered were pump-well systems and pumping plants receiving water from surface flows. Linear regression analyses were run for all data listed in Table 9; and, as can be seen, the correlation coefficients indicate good estimation by a linear equation. Pumping costs were computed for different groupings of units defined in Fig. 19 because of different cropping patterns and crop water requirements.

Operation and maintenance costs for distribution systems were computed from relationships developed by Brockway and Reese (11). These relationships can be expressed as:

$$COM_o = 96.3\ L^{0.663}\ CV^{0.774} \qquad (6.1)$$

$$COM_c = 89.5\ L^{1.072}\ CV^{0.351} \qquad (6.2)$$

where

COM_o = annual operation and maintenance for an open distribution system

COM_c = annual operation and maintenance cost for a closed distribution system

L = system length in miles

CV = average annual gross crop value in dollars per acre.

Table 9.--Annual cost relationships for various pumping plants operating at various efficiencies

Type of pumping plant	Area served[a]	Plant efficiency (percent)	c[b] ($/cfs)	d[b] ($)	r[c]
Pumping plant and inlet structure designed to receive surface flows and discharge water at a pressure of 80 psig	All units	65	807.86	800.25	1.000
		70	778.88	792.06	1.000
		75	753.79	783.33	1.000
	Units I-V	65	796.60	795.67	1.000
		70	768.43	787.74	1.000
		75	744.04	779.02	1.000
	Units VI-VII	65	819.04	805.96	1.000
		70	789.26	797.49	1.000
		75	763.47	788.64	1.000
Pumping plant and well lifting water 110 feet and discharging at 0 psig	All units	65	652.48	977.43	1.000
		70	633.80	967.04	1.000
		75	617.62	957.59	1.000
	Units I-V	65	652.48	977.43	1.000
		70	633.80	967.04	1.000
		75	617.62	957.59	1.000
	Units VI-VII	65	667.38	988.06	1.000
		70	647.60	978.52	1.000
		75	630.48	969.08	1.000

Table 9.--Continued

Type of pumping plant	Area served[a]	Plant efficiency (percent)	c[b] ($/cfs)	d[b] ($)	r[c]
Pumping plant and well lifting water 110 feet and discharging at 80 psig	All units	65	1120.52	858.11	0.997
		70	1080.85	841.50	0.997
		75	1046.29	826.94	0.997
	Units I-V	65	1104.56	851.80	0.997
		70	1065.87	835.21	0.997
		75	1032.21	820.53	0.997
	Units VI-VII	65	1136.20	866.58	0.997
		70	1095.75	849.38	0.997
		75	1060.60	834.12	0.997

[a] Units defined in Fig. 19.

[b] Coefficients of Equation 4.2, annual cost = cQ + d.

[c] Correlation coefficient relating actual computed cost values with those estimated by Equation 4.2.

Equations 6.1 and 6.2 were developed from data gathered from predominantly open or closed distribution systems. For varying combinations of open and closed systems the operation and maintenance costs were determined for both open and closed systems using the total length of the combination under consideration. The cost for the composite system was then computed as a weighted average of the individual costs of open and closed systems as:

$$COM_{total} = \frac{L_o COM_o}{L} + \frac{L_c COM_c}{L} \qquad (6.3)$$

where

COM_{total} = annual composite operation and maintenance cost

L_o = length of the open portion of the system

L_c = length of the closed portion of the system.

The crop value used in Equations 6.1 and 6.2 was $150 per acre. Operation and maintenance costs for a distirubtion system were assumed to be independent of the application systems served.

Distribution System Component Combinations

Three main categories of distribution and supply systems were considered for the North Rigby Irrigation District. Each supply system, gravity, pressure-pipe, and wells, was considered separately as the components of each are incompatible.

The gravity supply system components are all the unlined channel, lined channel, and gravity pipeline components shown in Fig. 20. These three different types of components are all compatible because all component node or junction points coincide, and the pressure head of water flowing in any component is near zero at all junction points.

The pressure-pipe system is incompatible with the gravity components because the pressure in the pipeline is great enough at all points to supply water directly to a sprinkler system without the need of a booster pump. Pressure is supplied by a pumping plant drawing water from the Great Feeder Canal and supplying it to section PPA shown in Fig. 18. The component junction points for the pressure-pipe system do not necessarily correspond to the gravity-system junction points.

Wells are assumed to supply water independently from any of the channel or pipeline systems. The pumping lift from all wells is considered to be 110 feet or less based on the findings of Brockway and deSonneville (10). Two different types of pumps are considered, low head supplying water at zero pressure and high head supplying water at 80 psi. The high-head pumps would be used only to supply water to sprinkler systems.

Pruning of Distribution System Component Combinations

For the gravity supply system there are three possible choices for each of seven sections, A-F, H, and two for section G. The resulting number of possible combinations is $3^7 \times 2 = 4374$ combinations. The dynamic-programming pruning technique described in Chapter 4 may be used to lessen the total number of combinations with assurance that only less-desirable combinations will be eliminated. In addition it is specified that section UCH (referring to Fig. 20) can receive water only from section UCB and that sections LCH, GPH, and LCJ can receive water only from sections LCB and GPB. Section LCJ is considered in conjunction with both sections LCH and GPH as stated previously.

The gravity supply system component combinations remaining after the pruning process are listed in Table 10. The result of specifying components for section H and pruning component combinations with higher costs and lower efficiencies than other combinations is a reduction of component combinations from 4374 to the 54 listed in Table 10.

No pruning is necessary for the other two types of supply systems, pressure pipe and wells. There are no alternative, compatible components specified for any section of the pressure-pipeline system. The same is true of the well-pump combinations.

Table 10.--Distribution system component configurations remaining after pruning

Component configuration name	Section[a]							
	A	B	C	D	E	F	G	H
AA	UC	UC	UC	UC	UC	UC	UC	UC
AB	UC	UC	UC	UC	UC	UC	LC	UC
AC	UC	UC	UC	UC	LC	UC	UC	UC
AD	UC	UC	UC	UC	LC	UC	LC	UC
AE	UC	UC	UC	UC	GP	UC	UC	UC
AF	UC	UC	UC	UC	GP	UC	LC	UC
AG	UC	UC	UC	LC	UC	UC	UC	UC
AH	UC	UC	UC	LC	UC	UC	LC	UC
AI	UC	UC	UC	LC	LC	UC	UC	UC
AJ	UC	UC	UC	LC	LC	UC	LC	UC
AK	UC	UC	UC	LC	GP	UC	UC	UC
AL	UC	UC	UC	LC	GP	UC	LC	UC
AM	UC	UC	LC	LC	LC	UC	LC	UC
AN	UC	LC	UC	UC	UC	UC	LC	LC
AO	UC	LC	UC	UC	LC	UC	LC	LC
AP	UC	LC	UC	LC	UC	UC	LC	LC
AQ	UC	LC	UC	LC	LC	UC	LC	LC
AR	UC	LC	UC	LC	LC	LC	LC	LC
AS	UC	LC	UC	LC	GP	UC	LC	LC
AT	UC	LC	UC	LC	GP	LC	LC	LC
AU	UC	LC	LC	LC	LC	UC	LC	LC
AV	UC	LC	LC	LC	LC	LC	LC	LC
AW	UC	LC	LC	LC	GP	LC	LC	LC
AX	LC	UC	UC	UC	UC	UC	UC	UC
AY	LC	UC	UC	LC	UC	UC	UC	UC
AZ	LC	UC	UC	LC	LC	UC	LC	UC
BA	LC	UC	UC	LC	GP	UC	LC	UC
BB	LC	UC	LC	LC	LC	UC	LC	UC
BC	LC	LC	UC	LC	LC	UC	LC	LC
BD	LC	LC	UC	LC	LC	UC	LC	GP
BE	LC	LC	UC	LC	LC	LC	LC	LC
BF	LC	LC	UC	LC	LC	LC	LC	GP
BG	LC	LC	UC	LC	GP	UC	LC	LC
BH	LC	LC	UC	LC	GP	UC	LC	GP
BI	LC	LC	UC	LC	GP	LC	LC	LC

Table 10.--Continued

Component configuration name	Section[a]							
	A	B	C	D	E	F	G	H
BJ	LC	LC	UC	LC	GP	LC	LC	GP
BK	LC	LC	LC	LC	LC	UC	LC	LC
BL	LC	LC	LC	LC	LC	UC	LC	GP
BM	LC	LC	LC	LC	LC	LC	LC	LC
BN	LC	LC	LC	LC	LC	LC	LC	GP
BO	LC	LC	LC	LC	GP	UC	LC	LC
BP	LC	LC	LC	LC	GP	UC	LC	GP
BQ	LC	LC	LC	LC	GP	LC	LC	LC
BR	LC	LC	LC	LC	GP	LC	LC	GP
BS	LC	LC	LC	LC	GP	GP	LC	LC
BT	LC	LC	LC	LC	GP	GP	LC	GP
BU	LC	LC	GP	LC	GP	GP	LC	LC
BV	LC	LC	GP	LC	GP	GP	LC	GP
BW	LC	LC	GP	GP	GP	GP	LC	LC
BX	LC	LC	GP	GP	GP	GP	LC	GP
BY	LC	GP	LC	LC	GP	LC	LC	GP
BZ	LC	GP	LC	LC	GP	GP	LC	GP
CA	LC	GP	GP	LC	GP	GP	LC	GP
CB	LC	GP	GP	GP	GP	GP	LC	GP

[a] Refers to sections in Fig. 20.

NOTE: UC refers to unlined channel; LC refers to lined channel; GP refers to gravity pipeline.

Linear-Programming Problem Formulation

The formulation of the linear-programming problem for the North Rigby Irrigation District is carried out in much the same manner as for the hypothetical model in Chapter 4. Unit costs for all application systems in each unit and for system components for a given distribution system configuration are combined to form a linear objective function. The objective function denoting total annual cost is then minimized subject to constraints. The constraints establish continuity in the model and establish the necessary relationships between the source(s) of supply (water into the system) and areas of demand (various application systems).

The linear-programming matrix shown in Fig. 21 is the complete matrix showing the objective and all constraints. The matrix is given in abbreviated form; that is, all numbers other than 1.000 are represented by letter symbols whose ranges of value are shown in Fig. 22. The application systems for all units represented in columns on the left-hand side of the matrix correspond to those symbols and systems of Table 7. All column headings ending in a number represent distribution system components. The number represents the type of component: 1 = unlined channel, 2 = lined channel, 3 = gravity pipe. The letter immediately preceding the number represents the section in which the component lies (referring to Fig. 20). The VON, VDP, and VSR columns represent the annual volumes of water diverted into the system, lost to deep percolation, and surface runoff, respectively, for the entire system. The summation of annual fixed specified costs for all distribution system components enters the objective in the CCON column, and annual operation and maintenance costs for the distribution system enter via the COM column.

```
                              R H                             R H                           C
                      R H     S S U I R H             R H     S S U I       C C C C C C C C C C
              R H     S S U I P P G G S S U I R H     S S U I P P G G       A A A A A A A A O O R R
              S S U I P P G G I I I I P P G G S S U I P P G G V V V V V V V T T T T T T T T N M H H
              P P G G I I I I I I I I I I I I P P G G V V V V I I I I D D S A B C D E F G H A A S S
              I I I I I I I I I I I I V V V V V V V V I I I I I I I I N P R 1 2 1 2 3 2 2 2 T T A B

OBJ       N   B B B B B B B B B B B B C C B B B B B B B B B B B B B B       A B B B C B B B D E
AREAI     E   1 1 1 1                                                                           C
AREAII    E           1 1 1 1                                                                   B
AREAIII   E                   1 1 1 1                                                           C
AREAIV    E                           1 1 1 1                                                   B
AREAV     E                                   1 1 1 1                                           C
AREAVI    E                                           1 1 1 1                                   C
AREAVII   E                                                   1 1 1 1                           B
LI        L   U U U U                                                                -T
LII       L           U U U U                                                          -T
LIII      L                   U U U U                                              -1 1 1
LIV       L                           U U T U                                    -T 1
LV        L                                   U U U U                          -T 1
LVI       L                                           U U U U                            -T
LVII      L                                                   U U U U        -T 1         1
LIIX      L                                                              -T 1
WTON      L                                                               1                   B 1
VOLON     E                                                        -V     1
DEPERC    E   T T T T T T T T T T T T T T A A T T T T T T A   T T A T  -1   A T A T   T T T
SUROFF    E       A A     A A     A A     A A     A A     A A     A A    -1
CONST     E                                                                               1   1
COEM      E                                                                                 1 1
CHON      N                                                           1
CHDP      N                                                             1
CHSR      N                                                               1
```

Fig. 21.--Linear-programming matrix for gravity supply to North Rigby Irrigation District.

```
                SUMMARY OF MATRIX

SYMBOL                   RANGE

  Z                 LESS THAN          .000001

  Y          .000001  THRU             .000009

  X          .000010                   .000099

  W          .000100                   .000999

  V          .001000                   .009999

  U          .010000                   .099999

  T          .100000                   .999999

  1         1.000000                  1.000000

  A         1.000001                 10.000000

  B        10.000001                100.000000

  C       100.000001              1,000.000000

  D     1,000.000001             10,000.000000

  E    10,000.000001            100,000.000000

  F   100,000.000001          1,000,000.000000

  G            GREATER THAN   1,000,000.000000
```

Fig. 22.--Summary of linear-programming matrix.

Rows of the matrix in Fig. 21 consist of the objective (OBJ) row, constraint rows, and change rows. The elements of the objective row are unit costs, the sum of which is minimized in the problem solution. Constraint rows assure continuity and establish necessary relationships. The AREA rows ensure that the entire area within each unit is supplied water by one or more of the alternative application systems considered for that unit. The "L" rows provide for the continuity of water flowing in the distribution system and for distribution of water to application systems at the proper place. For example, the components in the LIII row indicate that distribution section E3 must convey enough water, taking into account the water conveyance efficiency of that component, to supply the application systems of unit III in addition to the other components F2 and G2. Water entering the entire system is depicted and controlled by the elements of the WTON row. The change rows, whose names begin with the letter "CH," are rows whose elements are multiplied by some factor and added to another row in the process of parametric programming.

Right-hand-side, RHS, elements are the b's in the linear-programming constraints (Equation 3.2). These elements represent the limits placed on all constraints. The RHSB column is in effect a change column whose elements are multiplied by some factor in the process of parametric programming and added to another column that may include the right-hand side column.

The letter immediately to the right of each row name defines the type of row; i.e., the proper sign to be inserted between the row coefficients and the right-hand side. The symbols are defined as follows:

N	No constraint (change or objective row)
G	Greater than or equal to
E	Equality
L	Less than or equal to.

The linear-programming matrix shown in Fig. 23 contains elements representing application systems being supplied by wells. The column headings beginning with "WL" represent low head pumps pumping from wells and the "WH" letters on columns represent high head pumps. The low head pumps may supply water to any one of the surface systems or sprinkler systems with booster pumps in each unit. However, the high head wells are restricted to deliver water only to sprinkler systems. Although the low and high head wells are incompatible components, they may be considered in the same problem formulation because, as shown in Table 9, the annual fixed specified costs are very nearly the same for all well-pump combinations. The number of pumps and wells specified for each geographic unit and their estimated operating efficiencies are listed in Table 11. This is also the number of pumps required for sprinkler systems receiving water from gravity and low head well distribution systems.

Linear-Programming Solution and Post-Optimal Analysis

Optimal least-cost solutions for problems such as those represented in Figs. 21 and 23 can be obtained by use of a high-speed digital computer and a software package such as the MPS/360 routine furnished by the IBM Corporation. The routine, its capabilities and applications, are described in detail by the Programming User's Manual (53), Application

```
                                                                                                          C
                                                                                                          O
                                            R H                                             R H     F     N
                            R H     R H S S U I     R H             R H     R H S S U I L     S     W       W     W       W
                    R H     R H S S U I S S P P G G R H S S U I     R H     R H S S U I S S P P G G O     T   W L W   W L   W H W   W H R R
                R H S S U I S S P P G G I I I I I I S S P P G G R H S S U I S S P P G G V V V V V V W V V A W L I L W L V W H I H W H V H H
                S S P P G G I I I I I I I I I I I I I I I I I I S S P P G G V V V V V V I I I I I I O D S N L I I I L V I H I I I H V I S S
                I I I I I I I I I I I I I I I I I I V V V V V V V V V V V V I I I I I I I I I I I I N P R T I I I V V I I I I I V V I I A B

OBJ         N   B B B B B B B B B B B B B B B B B B B B C C B B B B B B B B B B B B B B B B B B B B       E C C C C C C C D D D D D D D
AREAI       E   1 1 1 1 1 1                                                                                                             C
AREAII      E               1 1 1 1 1 1                                                                                                 B
AREAIII     E                           1 1 1 1 1 1                                                                                     C
AREAIV      E                                       1 1 1 1 1 1                                                                         B
AREAV       E                                                   1 1 1 1 1 1                                                             C
AREAVI      E                                                               1 1 1 1 1 1                                                 C
AREAVII     E                                                                           1 1 1 1 1 1                                     B
LI          L       U U U U                                                                                -1
HI          L   U U                                                                                                      -1
LII         L                   U U U U                                                                      -1
HII         L               U U                                                                                             -1
LIII        L                               U U U U                                                            -1
HIII        L                           U U                                                                                   -1
LIV         L                                           U U T U                                                  -1
HIV         L                                       U U                                                                             -1
LV          L                                                       U U U U                                        -1
HV          L                                                   U U                                                                   -1
LVI         L                                                                   U U U U                              -1
HVI         L                                                               U U                                                         -1
LVII        L                                                                               U U U U                    -1
HVII        L                                                                           U U                                               -1
QON         L                                                                                       1                                   B 1
WTON        E                                                                                      -1       1 1 1 1 1 1 1 1 1 1 1 1 1 1
DEPERC      E   T T T T T T T T T T T T T T T T T T T T T T A A T T T T T T T T T T A A T T T T A T  -1
SUROFF      E           A A         A A         A A         A A         A A         A A         A A    -1
CONST       E                                                                                             1                             1
CHON        N
CHDP        N                                                                                         1
CHSR        N                                                                                           1
```

Fig. 23.--Linear-programming matrix for well supply to North Rigby Irrigation District.

Table 11.--Number of pumps and wells for each unit and estimated operating efficiencies

Unit[a]	Number of pumps[b]	Efficiency (percent)
I	2	70
II	1	70
III	2	70
IV	2	70
V	5	70
VI	5	70
VII	1	70

[a] Units outlined in Fig. 19.

[b] Refers both to the number of pumps and wells and booster pumps necessary for each unit.

Description Manual (54), and the Control Language User's Manual (55).

Nearly as important as the original solution are the variations in the solution caused by varying parameters within the original matrix. These parameter variations are referred to as parametric programming. Parametric programming can be used on the problem to determine the effects of varying numerous parameters including the availability of water, the cost of water flowing into the system, and the net value of water lost to deep percolation and surface runoff.

Linear-Programming Matrix Revision

After a set of optimal solutions are obtained for a linear programming problem by linear and parametric programming, the original problem can be revised. Problem revision means that one or more rows, columns, or individual elements in the original problem matrix are added, deleted, or replaced. The process of revision using IBM's MPS/360 is explained by Freeman and Lard (27) and IBM (53).

The linear-programming problem represented by the matrix in Fig. 21 may be revised to include elements representing various types of distribution system component combinations. To accomplish this revision, it is necessary to replace the columns representing distribution system components (those columns whose names end in a number) and the CCON and COM columns.

The MPS/360 control program used for problem solution, parametric programming, and problem revision is shown in Fig. 24. Descriptions of the various statements, routines, and their functions may be found in the IBM manuals (53, 54, 55) and the manual written by Freeman and Lard (27). The specific function of the program in Fig. 24 is to determine the optimal solutions for varying water prices from $0.00 to $12.00 per acre-foot for each of 19 different distribution system component configurations. The control program and input data can be altered to determine optimal solutions for a wide range of conditions which points to the flexibility of the procedure described.

```
          PROGRAM
          INITIALZ
          MACRO
          SOLVE(A,B,C,D)
          MOVE(XDATA,A)
          IF(IKT.GT.1,JMP)
          IKT=IKT+1
          MOVE(XPBNAME,B)
          MOVE(XOBJ,'OBJ')
          MOVE(XRHS,'RHSA')
          CONVERT('SUMMARY')
          BCDOUT
PRS       SETUP('MIN')
          PICTURE
          TRANCOL
          GOTO(PRI)
JMP       MOVE(XOLDNAME,D)
          MOVE(XPBNAME,B)
          REVISE('SUMMARY')
          SETUP('MIN')
PRI       PRIMAL
          SOLUTION
          MOVE(XOBJ,'OBJ')
          XPARAM=0.
          XPARMAX=12.
          XPARDELT=2.
          MOVE(XCHROW,'CHON')
          PARAOBJ
          SOLUTION
A         DC('ABC')
B         DC('EFG')
C         DC('HIJ')
D         DC('KLM')
IKT       DC(1)
          MEND
          SOLVE('SYSAA','AARUN','CAAA1','AARUN')
          SOLVE('SYSAB','ABRUN','CABA1','AARUN')
          SOLVE('SYSAC','ACRUN','CACA1','ABRUN')
          SOLVE('SYSAD','ADRUN','CADA1','ACRUN')
          SOLVE('SYSAE','AERUN','CAEA1','ADRUN')
          SOLVE('SYSAF','AFRUN','CAFA1','AERUN')
          SOLVE('SYSAG','AGRUN','CAGA1','AFRUN')
          SOLVE('SYSAH','AHRUN','CAHA1','AGRUN')
          SOLVE('SYSAI','AIRUN','CAIA1','AHRUN')
          SOLVE('SYSAJ','AJRUN','CAJA1','AIRUN')
          SOLVE('SYSAK','AKRUN','CAKA1','AJRUN')
          SOLVE('SYSAL','ALRUN','CALA1','AKRUN')
          SOLVE('SYSAM','AMRUN','CAMA1','ALRUN')
          SOLVE('SYSAN','ANRUN','CANA1','AMRUN')
          SOLVE('SYSAO','AORUN','CAOA1','ANRUN')
          SOLVE('SYSAP','APRUN','CAPA1','AORUN')
          SOLVE('SYSAQ','AQRUN','CAQA1','APRUN')
          SOLVE('SYSAR','ARRUN','CARA1','AQRUN')
          SOLVE('SYSAS','ASRUN','CASA1','ARRUN')
EPX       EXIT
          PEND
```

Fig. 24.--MPS/360 control program.

CHAPTER 7

RESULTS

The linear-programming problems for the distribution systems proposed for the North Rigby Irrigation District were formulated as described in Chapter 6. The optimal solutions obtained were the least cost combinations of distribution and application systems necessary to meet various specified conditions.

The specific conditions considered were the overall system efficiency, the price charged for water entering the system, and the price assessed against water lost to deep percolation. The specified overall system efficiency was computed for various flow rates of water allowed to enter the system as:

$$OAE = 100 \frac{QET}{Q_{in}} \tag{7.1}$$

where

OAE = overall system efficiency,

QET = flow rate required to satisfy maximum ET requirements,

Q_{in} = flow rate entering the system.

Variations in prices were obtained merely by changing the designated cost coefficients in the objective function.

The effects of various parameter changes were considered separately, and the results are described separately in the remainder of the chapter.

Effects of Changes in System Efficiency

The results of optimal solutions obtained for different types of distribution systems operating at various efficiencies are summarized in Tables 12, 13, and 14. The range of efficiencies for each type of system is the attainable range for that type.

The specified overall efficiency for the systems considered affects both the total annual cost and the configuration of the system. From Table 12 it can be seen that a system supplied by a gravity distribution system and operating at an efficiency of 17.1 percent has a total annual cost of $67,523 and requires a maximum flow rate of 56.9 cfs. All distribution system sections are unlined channels, and the application system in each unit is an unimproved gravity system. At a specified efficiency of 40 percent the total annual cost for the system is $76,826; and the maximum required flow rate is 24.3 cfs. Unlined channels are specified for distribution system sections A, B, C, F, G, and H. A lined channel is specified for section D and a gravity pipe for section E. Side-roll sprinklers are indicated for units I, II, and VI; hand-line sprinklers for units III and IV; and unimproved gravity for unit VII.

Table 12.--Total annual system costs for varying efficiencies for a gravity distribution system

System efficiency (%)	17.1	20	30	40	50	60	70
Total annual cost ($)	67,523	68,931	73,329	76,826	79,586	81,851	93,179
Max. flow rate (cfs)	56.9	48.7	32.4	24.3	19.5	16.2	13.9
Volume to DP (AF)	3326	2563	1409	944	844	721	399
Volume to SR (AF)	3554	3048	1816	1097	445	65	0
Distribution system							
Section A	UC[a]	UC	UC	UC	UC	UC	LC
B	UC	UC	UC	UC	UC	UC	GP
C	UC	UC	UC	UC	UC	UC	GP
D	UC	LC	LC	LC	LC	LC	GP
E	UC	UC	UC	GP	GP	GP	GP
F	UC	UC	UC	UC	UC	UC	GP
G	UC	UC	UC	UC	UC	UC	LC
H	UC	UC	UC	UC	UC	UC	GP
Application system							
Unit I	UG[b]	UG	UG	RSP	RSP	RSP	RSP
II	UG	RSP	RSP	RSP	RSP	RSP	RSP
III	UG	UG	HSP	HSP	HSP	HSP	HSP
IV	UG	IG	HSP(30%) IG(70%)	HSP	HSP	HSP	HSP
V	UG	UG	UG	RSP(17%) UG(83%)	RSP(79%) UG(11%)	RSP	RSP
VI	UG	RSP(15%) UG(85%)	RSP	RSP	RSP	RSP	RSP
VII	UG	UG	UG	UG	UG	RSP(70%) UG(30%)	RSP

[a] Distribution system components in Table 10.

[b] Application system symbols in Table 7.

Table 13.--Total annual system costs for varying efficiencies for a low head well supply

System efficiency (%)	38.4	40	50	60	70
Total annual cost ($)	86,738	86,785	87,007	87,165	87,739
Max. flow rate (cfs)	25.3	24.3	19.5	16.2	13.9
Volume to DP (AF)	523	520	505	501	399
Volume to SR (AF)	1618	1467	739	256	0
Application system					
Unit I	UG[a]	UG	UG	RSP(89%),UG(11%)	RSP
II	RSP	RSP	RSP	RSP	RSP
III	HSP	HSP	HSP	HSP	HSP
IV	HSP	HSP	HSP	HSP	HSP
V	UG	RSP(14%),UG(86%)	RSP(83%), UG(17%)	RSP	RSP
VI	RSP	RSP	RSP	RSP	RSP
VII	UG	UG	UG	UG	RSP

[a] Application system symbols in Table 7.

Table 14.--Total annual system costs for varying efficiencies for high pressure pipeline and high head well supplies

	Pressure pipeline	Wells with high head pumps
System efficiency (%)	70	70
Total annual cost ($)	75,121	68,769
Max. flow rate (cfs)	13.9	13.9
Volume to DP (AF)	399	399
Volume to SR (AF)	0	0
Application system		
Unit I	RS[a]	RS
II	RS	RS
III	HS	HS
IV	HS	HS
V	RS	RS
VI	RS	RS
VII	RS	RS

[a] Application system symbols in Table 7.

Unimproved gravity systems are specified for 83 percent and side-roll sprinklers for 17 percent of unit V.

An important relationship for each type of distribution system considered is that of how total costs vary with overall system efficiency for the different systems considered. These relationships for all systems are shown in Fig. 25. As can be seen, the lowest priced system is the gravity supply type operating at an overall system efficiency of 17.1 percent. The cost of this particular type of system increases almost linearly to the 60 percent figure.

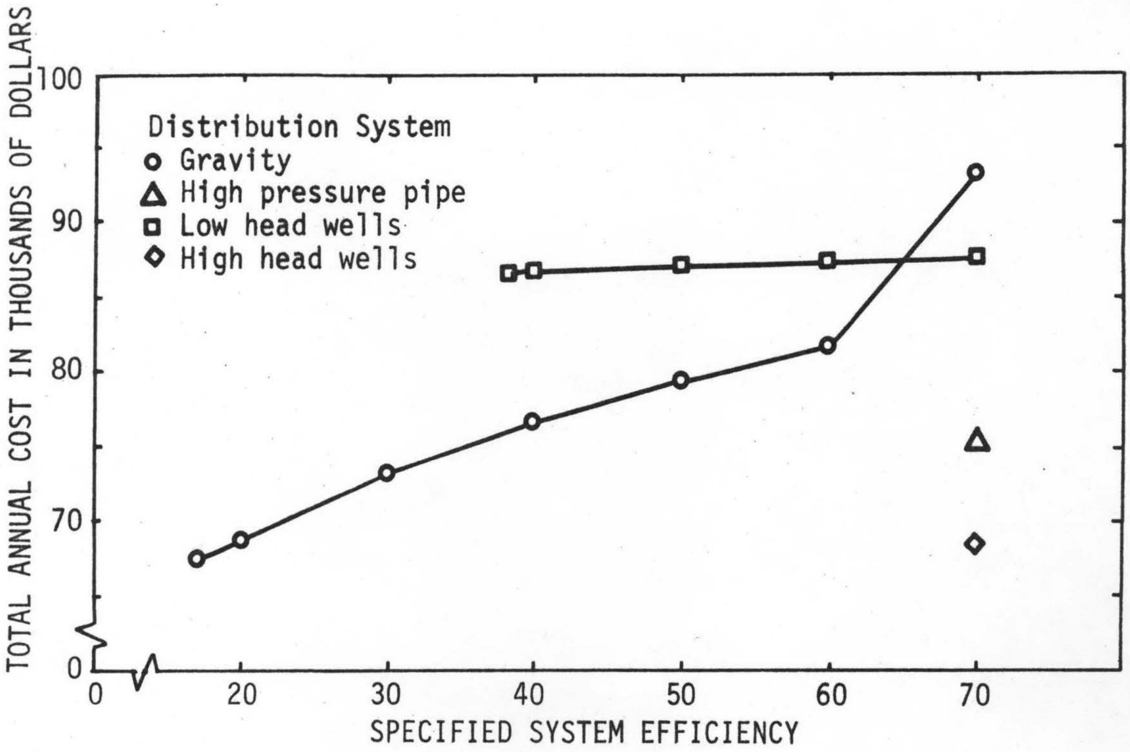


Fig. 25.--Total annual system costs for various specified system efficiencies.

However, costs rise quite sharply as the specified efficiency approaches the limit of 70 percent. This sharp increase is caused by increased distribution system costs. As can be seen in Table 12, the greatest changes in system configuration are with application systems and only at specified efficiencies greater than 60 percent is there any great change in distribution system configuration.

Total system costs for low head well supply systems remain nearly constant over the entire range of efficiencies.

The increase in costs for more efficient application systems is offset by savings in pumping costs.

The costs of high head supply systems are given only for an efficiency of 70 percent, the specified efficiency for the sprinkler systems supplied. These costs are much lower at that efficiency than the costs for either of the low head supplies considered. Comparing the data of Tables 12 and 14 reveals that the cost of supplying sprinkler systems from wells with high head pumps at a system efficiency of 70 percent is less than that of the gravity supply system operating at an efficiency of 20 percent.

Many other relationships could be established using the data in Tables 12, 13, and 14, depending upon needs. For instance, it would be possible to determine how sprinkler-irrigated acreage varies with system efficiency, cost, water lost to deep percolation, and/or surface runoff. Other relationships could also be established.

It should be emphasized that costs associated with different systems are somewhat of a different nature. For example, much of the annual cost associated with an unimproved gravity type distribution and application system is paid out for manual labor, management, and machine hire furnished by farmer irrigators. However, much of the annual cost associated with a side-roll sprinkler system supplied by a well with a high head pump is money required to repay a high initial capital investment.

Effects of Changes in Water Costs

Charges for water are often assessed for surface water delivered to an irrigation district by a feeder canal. The basis for charges can vary. A common basis is cost per unit volume, usually dollars per acre-foot.

The charge for surface water entering the North Rigby Irrigation District was allowed to vary from $0 per acre-foot to $12 per acre-foot. These charges were considered for both gravity and pressure distribution systems but not for wells as charges are seldom assessed against pumped groundwater. Results related to the various water costs are summarized in Tables 15 and 16.

The data in Table 15 indicate that the application system components are the first to change with increasing water cost as they were with increasing specified system efficiency. This fact indicates that the amount of water saved versus cost is generally greater for application system components than for distribution system components.

The relationships of system cost versus water cost for systems using surface water supply are shown by the data plotted in Fig. 26. The gravity supply system is cheaper when no charge is made for water entering the system. However, it is evident that the pressure pipe supply is the cheaper system for all water charges greater than or equal to $2.00 per acre-foot.

Table 15.--Total annual system costs for varying water costs for a gravity distribution system

Water cost (%/AF)	0	2	4	6	8	10	12
System cost ($)	67,523	84,318	92,718	98,394	103,537	108,509	113,480
System efficiency (%)	17.1	26.0	54.8	62.5	67.0	67.0	67.0
Max. flow rate (cfs)	56.9	37.0	17.8	15.6	14.5	14.5	14.5
Volume to DP (AF)	3326	1599	809	685	505	505	505
Volume to SR (AF)	3554	2294	219	0	0	0	0
Distribution system							
Section A	UC[a]	UC	UC	UC	LC	LC	LC
B	UC	UC	UC	UC	LC	LC	LC
C	UC	UC	UC	UC	UC	UC	UC
D	UC	LC	LC	LC	LC	LC	LC
E	UC	UC	GP	GP	GP	GP	GP
F	UC	UC	UC	UC	UC	UC	UC
G	UC	UC	UC	UC	LC	LC	LC
H	UC	UC	UC	UC	GP	GP	GP
Application system							
Unit I	UG[b]	UG	RSP	RSP	RSP	RSP	RSP
II	UG	RSP	RSP	RSP	RSP	RSP	RSP
III	UG	UG	HSP	HSP	HSP	HSP	HSP
IV	UG	IG	HSP	HSP	HSP	HSP	HSP
V	UG	UG	RSP	RSP	RSP	RSP	RSP
VI	UG	RSP	RSP	RSP	RSP	RSP	RSP
VII	UG	UG	UG	RSP	RSP	RSP	RSP

[a] Distribution system components in Table 10.

[b] Application system symbols in Table 7.

Table 16.--Total annual system costs for varying water costs for a high pressure pipeline system

Water cost ($/AF)	Overall annual system cost[a] Pressure pipeline ($)
0	75,121
2	79,881
4	84,641
6	89,401
8	94,161
10	98,921
12	103,681

[a] System configuration is identical to those in Table 14.

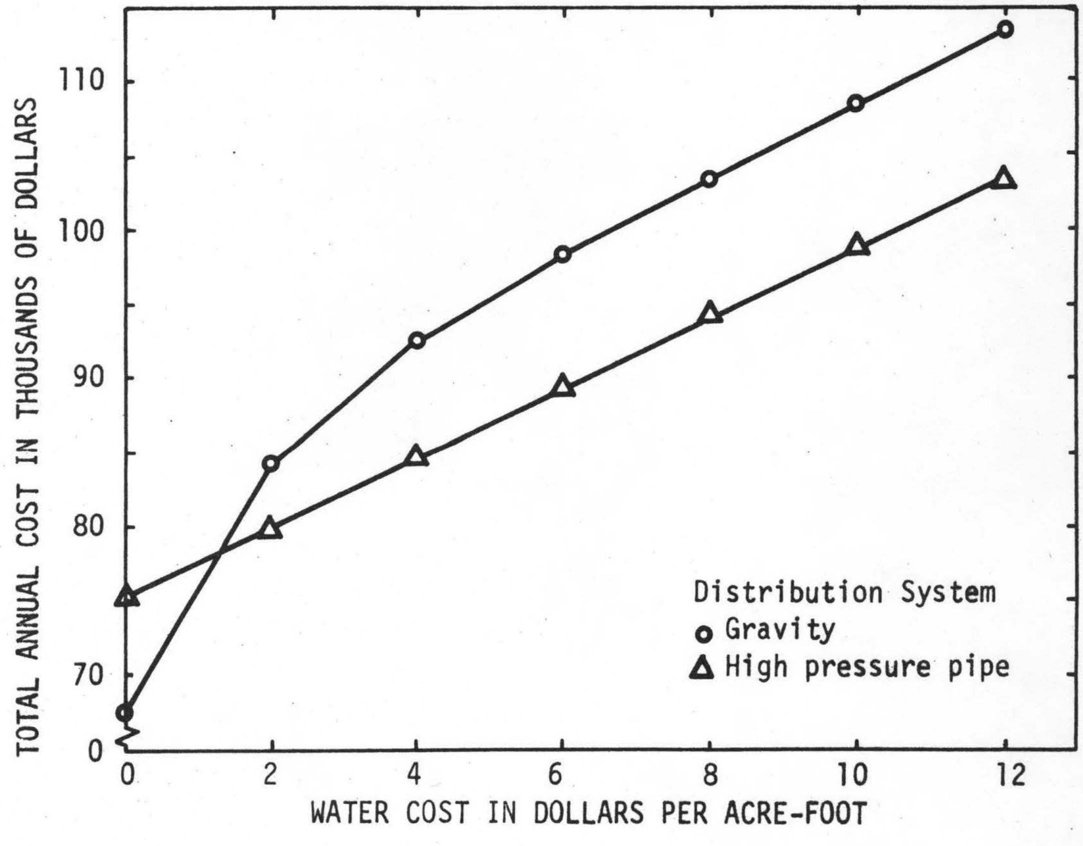


Fig. 26.--Total annual system costs for various water costs.

System efficiency is also affected by water costs as indicated by the data in Fig. 27. These data indicate that the overall system efficiency for the gravity distribution system asymtotically approaches the limit of 70 percent as water costs increase.

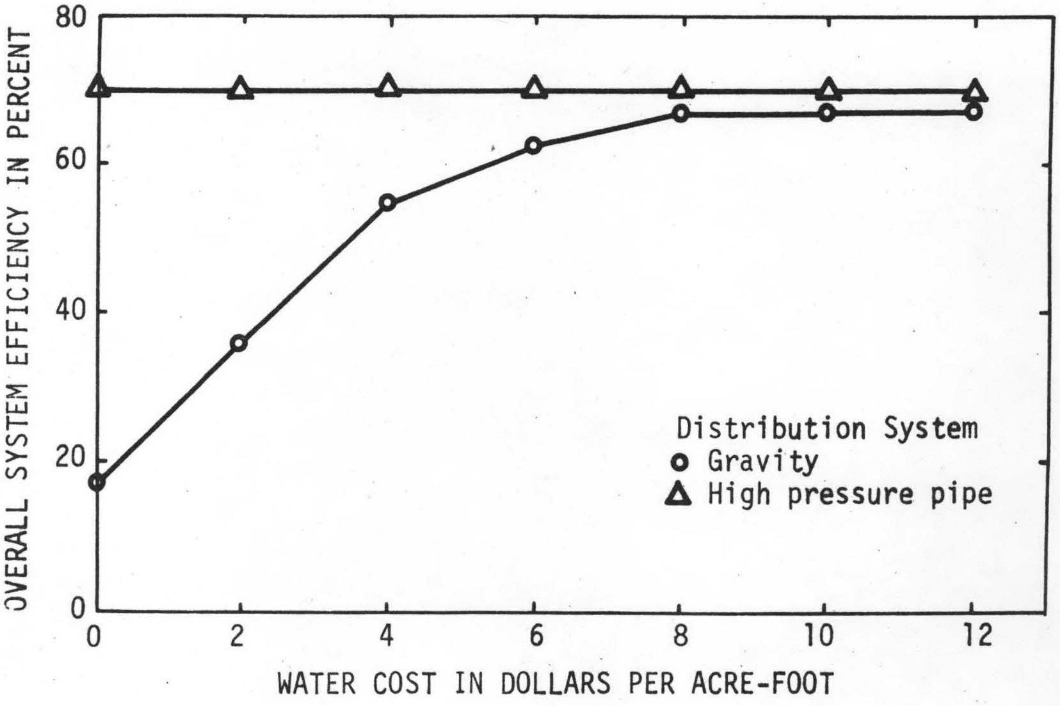


Fig. 27.--Overall system efficiency versus water cost.

Effects of Changes in Deep Percolation Charges

The area in which the North Rigby Irrigation District lies is plagued by high water tables as reported by Brockway and deSonneville (10). One possible solution for the high water table problem would be to charge a penalty for all water lost to deep percolation. A range of penalties from $0 to $2 per acre-foot was charged for all water lost to deep percolation. Results related to the various penalties are listed in Tables 17 and 18.

Distribution and application system configuration for gravity supply systems is little affected by the penalties within the specified range as indicated by the data in Table 17. Likewise, the overall system efficiency is also little affected by the charge for losses to deep percolation.

System costs versus deep percolation costs for the systems summarized in Tables 17 and 18 are shown in Fig. 28. The rate of cost increase for the gravity distribution system is greater than that for the pressure pipeline or wells with high head pumps. As a result, the gravity distribution system is more economical than high head wells only for charges of less than approximately $0.50 per acre-foot lost to deep percolation.

When comparing the data in Tables 12 and 17, several interesting facts become evident. First, the system cost in the 20 percent efficiency column of Table 12 is less than the system cost in the $0.50 column of Table 17, while at the same time the system efficiency is higher. In addition, less water is lost to deep percolation for the conditions of Table 12. Other similar comparisons can be made by comparing various columns in these two tables. As a result of

Table 17.--Total annual system costs for varying deep percolation charges for a gravity distribution system

Deep percolation penalty ($/AF)	0.00	0.50	1.00	1.50	2.00
System cost ($)	67,523	69,186	70,831	72,347	73,759
System efficiency (%)	17.1	17.1	17.6	17.6	18.5
Max. flow rate (cfs)	56.9	56.9	55.2	55.2	52.7
Volume to DP (AF)	3326	3326	3032	3032	2805
Volume to SR (AF)	3554	3554	3554	3554	3420
Distribution system					
Section A	UC[a]	UC	UC	UC	UC
B	UC	UC	UC	UC	UC
C	UC	UC	UC	UC	UC
D	UC	UC	LC	LC	LC
E	UC	UC	UC	UC	UC
F	UC	UC	UC	UC	UC
G	UC	UC	UC	UC	UC
H	UC	UC	UC	UC	UC
Application system					
Unit I	UG[b]	UG	UG	UG	UG
II	UG	UG	UG	UG	UG
III	UG	UG	UG	UG	UG
IV	UG	UG	UG	UG	IG
V	UG	UG	UG	UG	UG
VI	UG	UG	UG	UG	UG
VII	UG	UG	UG	UG	UG

[a] Distribution system components in Table 10.

[b] Application system symbols in Table 7.

Table 18.--Total annual system costs for varying deep percolation charges for high pressure pipeline and high head well supplies

Deep percolation penalty ($/AF)	Overall annual system cost[a]	
	Pressure pipeline ($)	Wells with high head pumps ($)
0.00	75,121	68,769
0.50	75,321	68,969
1.00	75,520	69,168
1.50	75,720	69,368
2.00	75,919	69,567

[a] System configuration is identical to those in Table 14.

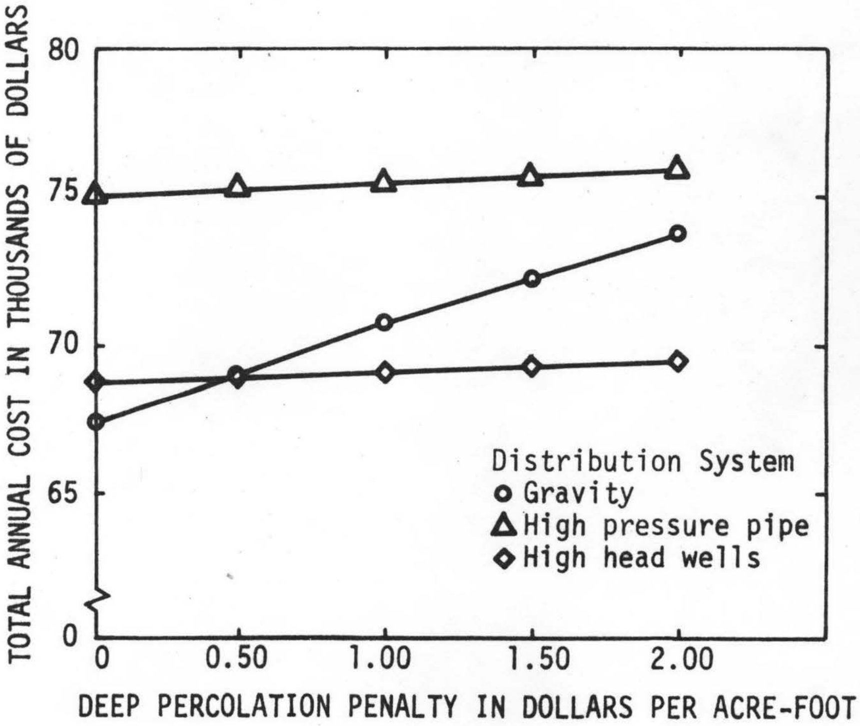


Fig. 28.--Total annual system costs for various deep percolation penalty charges.

these comparisons it may be concluded that for the case presented, more desirable results for the irrigation district are obtained by limiting the amount of water entering the system than by exacting a penalty upon water lost from the system unless the penalty charges were retained for use within the district. Such a comparison could prove to be quite valuable to policy-making groups seeking simultaneous solutions for problems such as overall system efficiency and excessive deep percolation losses.

Summary of Results

The results obtained and presented in this chapter are those obtained specifically for the North Rigby Irrigation District. Data describing the physical characteristics of the district and the systems presently in use were extended to predict the characteristics of proposed alternative systems. Annual costs were also obtained and extended for present and proposed systems. All prices and costs used were adjusted as closely as possible to third quarter 1973 prices and costs. The dollar values attached to many different items are of many different forms such as capital costs, labor costs, machine hire, management and operation costs, and many others including costs for some rather intangible items.

Meaningful relationships were obtained utilizing the methodology presented in Chapters 4 and 5. Relationships other than those shown in the figures of this chapter can be determined from the data presented in Tables 12-18. Specific water planning needs would dictate which relationships would be most meaningful when considering an irrigation district or districts.

Emphasis must be placed upon the fact that the methodology presented and the results obtained therefrom are intended to be used as planning tools and not as design tools. The physical values used are necessary input parameters if realistic results are to be obtained from the analytical model. The results indicate what types of system components would best meet a given set of conditions. These results should be used to develop specific designs for system components with the cost of the resultant design for the entire system being nearly the same as the cost obtained from the analytical model results.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Several conclusions can be drawn from the results of this study. First, a methodology was developed to obtain least cost irrigation system specifications; and secondly, least cost rehabilitation schemes subject to various constraints were determined for the North Rigby Irrigation District of Jefferson County, Idaho, using the methodology developed.

The components of an irrigation system can be classified as either distribution system or application system components. The components of the distribution system are arranged as to supply water both to one another and to application systems. Application systems are, in turn, used to apply water to cropland.

It is possible to attach monetary values to each of the system components considered. In addition, hard-to-define social values may also be estimated for the components. As a result, the cost of the entire system does represent its total cost. The merit in assigning dollar values to each component, especially when dealing with hard-to-define values, lies in the fact that these values are often better defined for smaller components than for larger conglomerations of the components. The result of summing individual values is then a more accurate representation of the true conglomerate value.

Monetary values of system components are related to various physical parameters describing the components. The cost of a specific type of application system can be expressed on a per-acre basis if the layout and use of the system is specified. Therefore, the total cost of an application system for a given area is linearly related to the number of acres served by the system. Costs of distribution system components can be related to the maximum flow of water that can be transmitted or controlled by that component. This cost-size relation for distribution system components can be accurately represented by a linear relationship.

All system components have costs that are linearly related to physical descriptors such as the number of acres and component capacities. These descriptors can be arranged to represent component relationships and interactions within an actual system. As a result, the component costs and physical system relationships can be represented by a set of linear equations that can be arranged to form a linear-programming problem. The linear-programming problem can then be solved using mathematically sound and efficient methods to obtain an optimal solution subject to specified constraints.

Dynamic programming can be used to eliminate higher cost, less efficient distribution system component combinations. Therefore, the number of linear-programming problem modifications required for different system combinations is greatly reduced.

The optimal solutions obtained for the North Rigby Irrigation District are minimum cost systems that conform to specified constraints. The constraints considered are overall system efficiency, water cost, and charges levied against water lost to deep percolation. System costs increase with specified efficiency and depend upon the type of distribution system used to convey and distribute the water. Based upon the results obtained and considering only the total annual cost, the most economical way to increase the overall irrigation efficiency of the given district is to abandon all present systems and to install wells from which water could be pumped to supply sprinkler systems. System costs increase quite drastically if a charge for water entering the system from a surface source is considered. However, an increasing water charge would also force system efficiency to increase quite drastically. If a charge is levied against deep percolation losses, the well-pump-sprinkler combination is again the most economical solution.

The least cost incentive for rehabilitation within the North Rigby Irrigation District would be to specify an overall system efficiency that must be attained. Charging for water and/or for deep percolation losses would add a cost requiring money to be spent outside the district.

Various other plans for rehabilitation could easily be considered for the given irrigation district as changes in constraints require minimal modification of the modeled problem. The number and type of modifications to be considered can be many and varied.

Therefore, it can be concluded that the analytical model developed and used is a powerful tool for determining least cost irrigation system specifications. The model is flexible in the fact that it can be adapted and applied to many different physical and socio-economic conditions. Although the model was applied to one rather small irrigation district, the same procedure can be applied to many different types and sizes of districts.

Recommendations

As concluded, the results obtained from the analytical model developed and used fulfill the objectives of the study. Several recommendations for more effective use of the model will be presented and discussed. The recommendations presented are from observations made while formulating the problem and obtaining the results presented in Chapter 7.

In determining costs and efficiencies for various types of application systems the following points may be incorporated. Provision may be made in the APSYSCST routine to incorporate cropping patterns along with farm layout for a given land unit. Such provision would allow application system costs, efficiencies, and required discharges such as listed in Table 7, to be calculated for multi-farm units using the digital computer. It would also be beneficial to analyze the size of geographical unit and the necessary application system detail required to maintain a specified level of model accuracy. Such an analysis would provide information pertaining to trade-offs between accuracy and required computing time.

More sophistication could be incorporated into the dynamic programming routine used to prune less desirable components from distribution systems. Provision should be made in the routine to include the costs associated with water lost to deep percolation and other operational waste. Operation and maintenance costs should also be criteria considered in the pruning process. The more considerations that are incorporated into the pruning process, the more accurate will be the results derived from it. Therefore, the component combinations considered in the linear-programming problem will be valid combinations for all governing criteria.

The number of separate linear-programming problems to be solved for any given problem is governed by the number of distribution system component combinations under consideration. Although IBM's MPS/360 routine is a very efficient routine for the solution, the output is very voluminous if many different combinations are under consideration. Effort should be extended to reduce the amount of output by either taking advantage of some of the routines available with the MPS/360 package or by interfacing the package with another language such as FORTRAN. The most desirable output would contain only the output from the linear-programming problems of the distribution system combinations providing overall optimal solutions for a given set of constraints.

In some areas, especially those with long growing seasons, the peak water demands by different crops will occur at different times. This variation of demand must be considered and incorporated into the model formulation if desirable results are to be obtained for such areas.

Careful planning and accurate input data are required in the formulation of the model if realistic and useful results are going to be obtained from it. If these requirements are met, the output generated will provide valid, factual information for planning purposes.

REFERENCES

1. Ackoff, R. L., and M. W. Sasieni. Fundamentals of Operation Research. John Wiley and Sons, Inc., New York, 1968.

2. Anderson, R. L., and A. Maass. "A Simulation of Irrigation Systems." USDA Economic Research Service Tech. Bull. No. 143, 1971.

3. Anderson, T. C. "Water Resource Planning to Satisfy Growing Demand in an Urbanizing Agricultural Region." Utah Water Research Laboratory, Utah State University, Logan, Utah, 1972.

4. Bellman, R. Dynamic Programming. Princeton University Press, Princeton, New Jersey, 1957.

5. Bellman, R., and S. Dreyfus. Applied Dynamic Programming. Princeton University Press, Princeton, New Jersey, 1962.

6. Beveridge, G. S. G., and R. S. Schechter. Optimization: Theory and Practice. McGraw-Hill, New York, 1970.

7. Bishop, A. A. "Consolidation of Irrigation Companies and Systems." Transactions of the ASAE, 1, 332-338, 1961.

8. Bishop, A. A., M. E. Jensen, and W. A. Hall. "Surface Irrigation Systems." Irrigation of Agricultural Lands, ed. Hagan, Haise, and Edminster, American Society of Agronomy, Madison, Wisconsin, 1967, pp. 865-884.

9. Brockway, C. E., and A. E. Herbig. "Operations and Maintenance Costs of Irrigation Distribution Systems." University of Idaho Engineering Experiment Station, Progress Report No. 1, Moscow, Idaho, 1970.

10. Brockway, C. E., and J. deSonneville. "Systems Analysis of Irrigation Water Management in Eastern Idaho." Research Technical Completion Report Project B-018-IDA, Water Resources Research Institute, University of Idaho, Moscow, Idaho, 1973.

11. Brockway, C. E., and D. L. Reese. "Operation and Maintenance Costs on Irrigation Distribution Systems." Final Report, College of Engineering, University of Idaho, Moscow, Idaho, 1973.

12. Buras, N. Scientific Allocation of Water Resources. American Elsevier, New York, 1972.

13. Carter, K. B., ed. Pioneer Irrigation--Upper Snake River Valley. Daughters of Utah Pioneers, Salt Lake City, Utah, 1955.

14. Cembrowicz, R. G., and J. J. Harrington. "Capital Cost Minimization of Hydraulic Network." Journal of the Hydraulics Division, ASCE, 99, 431-440, 1973.

15. Chow, V. T. Open-Channel Hydraulics. McGraw-Hill, New York, 1959.

16. Christiansen, J. E. "Hydraulics of Sprinkling Systems of Irrigation." Transactions of the ASCE, 107, 221-239, 1942.

17. Christiansen, J. E., and J. R. Davis. "Sprinkler Irrigation Systems." Irrigation of Agricultural Lands, ed. Hagan, Haise, Edminster, American Society of Agronomy, Madison, Wisconsin, 1967, pp. 885-904.

18. Clyde, C. G., A. B. King, and J. C. Anderson. "Application of Operations Research Techniques for Allocation of Water Resources in Utah." Utah Water Research Laboratory, Utah State University, Logan, Utah, 1971.

19. Corey, G. L., and D. W. Fitzsimmons. "Infiltration Patterns from Irrigation Furrows." Agricultural Experiment Station, University of Idaho, Res. Bull. 59, 1962.

20. Criddle, W. D., and C. Kalisvaart. "Subirrigation Systems." Irrigation of Agricultural Lands, ed. Hagan, Haise, Edminister, American Society of Agronomy, Madison, Wisconsin, 1967, pp. 905-921.

21. Dantzig, G. B. Linear Programming and Extensions. Princeton University Press, Princeton, New Jersey, 1963.

22. Davis, J. R. "Concepts on Design of Border Irrigation Systems." Proceedings of the ARS-SCS Workshop on Hydraulics of Surface Irrigation, Denver, Colorado, 1960, pp. 36-44.

23. Deb, A. K., and A. K. Sakar. "Optimization in Design of Hydraulic Network." Journal of the Sanitary Engineering Division, ASCE, 97, 141-159, 1971.

24. deNeufville, R., and J. H. Stafford. *Systems Analysis for Engineers and Managers*. McGraw-Hill, New York, 1971.

25. DeReemer, E. D. "New Findings on the Use of Trickle Irrigation Systems." *World Irrigation*, 20(6), 14-16, 1970.

26. Eyer, J. M. "Pumping Plant Operation and Maintenance Costs." *Journal of the Irrigation and Drainage Division, ASCE*, 91, 37-58, 1965.

27. Freeman, B. G., and C. F. Lard. "A Users Guide to Linear Programming and the IBM MPS-360 Computer Routine." Departmental Technical Report Number 70-2, Texas Agricultural Experiment Station, Texas A & M University, College Station, Texas, 1970.

28. Galinato, G. D. "Evaluation of Irrigation Systems in the Snake River Fan, Jefferson County, Idaho." Unpublished Master's Thesis, University of Idaho, Moscow, Idaho, 1974.

29. Gneiting, G. W. "An Economic History and Analysis of the Great Feeder Canal of Southeastern Idaho." Unpublished Master's Thesis, Utah State University, Logan, Utah, 1972.

30. Green, R. F. "Optimization by the Pattern Search Method." Research Paper No. 7, Division of Water Control Planning, TVA, Knoxville, Tennessee, 1970.

31. Hadley, G. *Linear Programming*. Addison-Wesley, Reading, Massachusetts, 1962.

32. Hadley, G. *Nonlinear and Dynamic Programming*. Addison-Wesley, Reading, Massachusetts, 1964.

33. Hall, W. A., and N. Buras. "Optimum Irrigated Practice under Conditions of Deficient Water Supply." *Transactions of the ASAE*, 4(1), 131-134, 1961.

34. Hall, W. A., and R. W. Shepard. "Optimum Operations for Planning for a Complex Water Resource System." University of California Water Resource Center Contribution No. 122, University of California (Los Angeles), 1967.

35. Hall, W. A., and W. S. Butcher. "Optimal Timing of Irrigation." *Journal of the Irrigation and Drainage Division, ASCE*, 94, 267-275, 1968.

36. Hall, W. A., and J. A. Dracup. Water Resources Systems Engineering. McGraw-Hill, New York, 1970.

37. Halter, A. N., and S. F. Miller. "River Basin Planning--A Simulation Approach." Agricultural Experiment Station Special Report 224, Oregon State University, Corvallis, Oregon, 1966.

38. Hansen, V. E. "Mathematical Relationships Expressing the Hydraulics of Surface Irrigation." Proceedings of the ARS-SCS Workshop on Hydraulics of Surface Irrigation, Denver, Colorado, 1960, pp. 29-35.

39. Horn, D. L. "Method for Determining Minimum-Cost Farm Irrigation Pipeline Design." Transactions of the ASAE, 10, 209-212, 1967.

40. Howe, C. W. Benefit-Cost Analysis for Water System Planning. American Geophysical Union, Washington, D. C., 1971.

41. Howell, T. A., and E. A. Hiler. "Trickle Irrigation System Design." ASAE Paper No. 72-221 presented at the 1972 Annual Meeting of ASAE, Hot Springs, Arkansas, June 27-30, 1972.

42. Hufschmidt, M. M. The Methodology of Water Resource Systems Design. University of Chicago Press, Chicago, Illinois, 1965.

43. Huszar, P. C., D. W. Seckler, and D. D. Rhody. "Economics of Irrigation System Consolidation." Colorado State University Experiment Station Tech. Bull. 105, Ft. Collins, Colorado, 1969.

44. Israelsen, O. W., and V. E. Hansen. Irrigation Principles and Practices. John Wiley and Sons, Inc., New York, 1962.

45. Jensen, M. E., J. L. Wright, and B. J. Pratt. "Estimating Soil Moisture Depletion from Climate, Crop, and Soil Data." Transactions of the ASAE, 14(5), 954-959, 1971.

46. Keller, J., and D. Karmeli. "Trickle Irrigation Design Parameters." ASAE Paper No. 73-234 presented at the 1973 Annual Meeting of ASAE, Lexington, Kentucky, June 17-20, 1973.

47. Linsley, R. K., and J. B. Franzini. Water Resources Engineering. McGraw-Hill, New York, 1972.

48. Luthin, J. N., ed. Drainage of Agricultural Lands. American Society of Agronomy, Madison, Wisconsin, 1957.

49. Maass, A., M. M. Hufschmidt, R. Dorfman, H. A. Thomas, Jr., S. A. Marglin, G. M. Fair, B. T. Bower, W. W. Reedy, D. F. Manzer, M. P. Barnett, M. B. Fiering, and P. Watermeyer. Design of Water Resource Systems. Harvard University Press, Cambridge, Massachusetts, 1962.

50. Maletic, J. T., and T. B. Hutchings. "Selection and Classification of Irrigable Land." Irrigation of Agricultural Lands, ed. Hagan, Haise, and Edminster, American Society of Agronomy, Madison, Wisconsin, 1967, pp. 125-173.

51. Mandry, J. E. "Design of Pipe Distribution Systems for Sprinkler Projects." Journal of the Irrigation and Drainage Division, ASCE, 93, 243-257, 1967.

52. Marr, P. D. "The Social Context of Irrigation." Irrigation of Agricultural Lands, ed. Hagan, Haise, and Edminster, American Society of Agronomy, Madison, Wisconsin, 1967, pp. 12-22.

53. "Mathematical Programming System/360, Version 2, Linear and Separable Programming--User's Manual." International Business Machines Corporation, White Plans, New York, 1969.

54. "Mathematical Programming System/360, Application Description Manual." International Business Machines Corporation, White Plains, New York, 1969.

55. "Mathematical Programming System/360, Version 2, Control Language User's Manual." International Business Machines Corporation, White Plains, New York, 1969.

56. Meier, W. L., A. O. Weiss, C. D. Puentes, and J. C. Moseley. "Sensitivity Analysis: A Necessity in Water Planning." Water Resources Bulletin, 7, 529-541, 1971.

57. Milligan, J. H. "General Theory of the Allocation Model." Appendix A, Application of Operations Research Techniques for Allocation of Water Resources in Utah, Utah Water Research Laboratory, Utah State University, Logan, Utah, 1971, pp. 63-66.

58. Myers, L. E., and D. A. Bucks. "Uniform Irrigation with Low-Pressure Trickle System." Journal of the Irrigation and Drainage Division, ASCE, 98, 341-346, 1972.

59. Pair, C. H., ed. Sprinkler Irrigation, third edition. Sprinkler Irrigation Association, Washington, D. C., 1969.

60. Pira, E. S., and K. S. Purohit. "Operating Characteristics and Design Criteria for the Chamber Method of Subsurface and Drip Irrigation Systems." ASAE Paper No. 72-226 presented at 1972 Annual Meeting of ASAE, Hot Springs, Arkansas, June 27-30, 1972.

61. Schmisseur, W. E., and F. S. Conklin. "The Economics of Water Conservation Investments and Practice: A General Methodology and Its Application to Selected Irrigation Units in Oregon." Department of Agric. Econ., Oregon State University, Corvallis, Oregon, 1973.

62. Schreiber, D. L. "Optimization Techniques for Water Resource Systems." Open-File Report No. 6, State of Washington Water Research Center, Washington State University, Pullman, Washington, 1968.

63. Shockley, D. G. "Present Procedures and Major Problems in Border Irrigation Design." Proceedings of the ARS-SCS Workshop on Hydraulics of Surface Irrigation, Denver, Colorado, 1960, pp. 1-6.

64. Simons, D. B. "Conveyance and Distribution Systems." Irrigation of Agricultural Lands, ed. Hagan, Haise, and Edminster, American Society of Agronomy, Madison, Wisconsin, 1967, pp. 786-827.

65. Smith, D. V. "Systems Analysis and Irrigation Planning." Journal of the Irrigation and Drainage Division, ASCE, 99, 89-107, 1973.

66. Stamm, G. G. "Problems and Procedures in Determining Water Supply Requirements for Irrigation Projects." Irrigation of Agricultural Lands, ed. Hagan, Haise, and Edminster, American Society of Agronomy, Madison, Wisconsin, 1967, pp. 771-785.

67. Stark, R. M., and R. M. Nicholls. Mathematical Foundations for Design: Civil Engineering Systems. McGraw-Hill, New York, 1972.

68. "The Story of the Columbia Basin Project." United States Department of the Interior, Bureau of Reclamation, Washington, D. C., 1964.

69. Sutter, R. J., and G. L. Corey. "Consumptive Irrigation Requirements for Crops in Idaho." College of Agriculture Bull. 516, University of Idaho, Moscow, Idaho, 1970.

70. "Water's Prime Consumer." The Farm Index, 12(1), 8-9, 1973.

71. Wiener, A. The Role of Water in Development. McGraw-Hill, New York, 1972.

72. Wiener, A. "The Development of Israel's Water Resources." American Scientist, 60, 466-473, 1972.

73. Willardson, L. S. "Attainable Irrigation Efficiencies." Journal of the Irrigation and Drainage Division, ASCE, 98, 239-246, 1972.

74. Windsor, J. S., and V. T. Chow. "A Programming Model for Farm Irrigation Systems." Hydraulic Engineering Series No. 23, Department of Civil Engineering, University of Illinois, Urbana, Illinois, 1970.

75. Windsor, J. S., and V. T. Chow. "Model for Farm Irrigation in Humid Areas." Journal of the Irrigation and Drainage Division, ASCE, 97, 369-385, 1971.

76. Young, R. A., and J. O. Bredehoeft. "Digital Computer Simulation for Solving Management Problems of Conjunctive Groundwater and Surface Water Systems." Water Resources Research, 8, 533-556, 1972.

APPENDIXES

APPENDIX A

DEFINITION OF TERMS

Term (Symbol)	Definition
Acre-foot (AF)	A volume of water equal to an acre covered to a depth of one foot, i.e., 43,560 cubic feet.
Application system	A system component within an irrigation system that is used to apply water to various areas of fields within a farm or other specified unit.
Capital-recovery factor	That factor, when specified for a given interest rate and period of time, by which a present amount of money is multiplied to express the amount as a series of uniform payments over the given time period.
Consumptive use (CU)	The sum of transpiration, water evaporated from the soil and exterior portions of plants, and water retained in plant tissue from a cropped area.
Consumptive use rate (CU rate)	The rate at which water is consumptively used from a cropped area.
Deep percolation (DP)	That water applied to the soil that percolates beneath the root zone where it is no longer available for plant use.

<u>Distribution system</u>.--A system component within an irrigation system that is used to convey water from a source of supply and distribute it for use by application systems.

<u>Evapotranspiration (ET)</u>.--The sum of transpiration and water evaporated from soil and plant surfaces from a cropped area.

<u>Evapotranspiration rate (ET rate)</u>.--The rate at which water is lost to evapotranspiration from a cropped area.

<u>Field capacity</u>.--The amount of water a soil profile will hold against drainage by gravity at a specified time (usually from 24 to 48 hours) after a thorough wetting.

<u>Matric tension</u>.--The tension of soil water resulting from the affinity of water to the whole matrix of the soil including its pores and particle surfaces together.

<u>Osmotic tension</u>.--The tension of soil water caused by the presence of solutes.

<u>Permanent wilting point</u>.--That soil moisture content at which plants permanently wilt.

<u>Uniform-series-compound-amount factor</u>.--That factor, when specified for a given interest rate and period of time, by which each payment of a uniform series of payments is multiplied to obtain the future sum of the end of the given time period.

APPENDIX B

DOCUMENTED LISTING OF COMPUTER PROGRAMS

Program	Page
APSYSCST ROUTINE	148
Subroutine SPNKLR	150
Subroutine SURFCE	156
SYSC0ST ROUTINE	163
Subroutine PIPCST	164
Subroutine DITCST	169
Subroutine PMPCST	178
Subroutine REGLIN	183
DYNAMIC PROGRAMMING PROGRAM	185

Note: All computer programs were written by the author as a part of the study reported in this dissertation. All programs utilize the subroutine INPUT supported as a library program by Computer Services, University of Idaho. The subroutine INPUT allows free-form input of numeric data. Only numeric data are read from data input cards. GET1(list), GET2(list),.....,GET15(list) are various entry points in the INPUT subroutine for reading in a list of a specified number of data pieces.

APSYSCST ROUTINE

```
C PROGRAM TO DETERMINE THE ANNUAL COSTS FOR VARIOUS IRRIGATION
C APPLICATION SYSTEMS ON A GIVEN FIELD OR AREA
C
C  USE FREE-FORM INPUT BY MEANS OF THE SUBROUTINE 'INPUT'
C
   REAL IRTOT
   COMMON  TRAMC(10), IRTOTC(10),  FREQC(10), ETTOTC(10), HEAD(6,20)
   KZZB = 0
C
C  READ IN THE NUMBER OF CROP-SOIL COMBINATIONS TO BE CONSIDERED
C  FOR EACH SOIL TYPE AND EACH IRRIGATION SYSTEM
C    NCMBF = NUMBER OF FURROW IRRIGATED CROPS CONSIDERED
C    NCMBB = NUMBER OF BORDER IRRIGATED CROPS CONSIDERED
C  NOTE:  DATA FOR BORDER IRRIGATED CROPS MUST BE ENTERED FIRST
  1 CALL GET2(NCMBB,NCMBF)
    NCMB = NCMBB + NCMBF
    IF(NCMB.EQ.0)  GO TO 10
C
    DO 90 IX = 1, NCMB
C
C  READ IN HEADING FOR EACH SOIL-CROP COMBINATION
    READ (1,100) (HEAD(IX,J),J=1,20)
 100 FORMAT (20A4)
C
C  READ IN CROP-SOIL-WATER PARAMETERS
C    WHC = WATER-HOLDING CAPACITY OF THE SOIL IN INCHES PER FOOT
C    RZD = ROOT ZONE DEPTH IN FEET
C    PCT = PERCENT OF TAM USEABLE AS TRAM
C    ETTOT = TOTAL ANNUAL ET REQUIREMENT IN INCHES
C    ETMAX = MAXIMUM ET RATE IN INCHES PER DAY
    CALL GET5(WHC,RZD,PCT,ETTOTC(IX),ETMAX)
C
```

```
C    COMPUTE TRAM  (TOTAL READILY AVAILABLE MOISTURE)
       TRAMC(IX) = RZD*WHC*PCT/100.
C
C    COMPUTE TOTAL NUMBER OF IRRIGATIONS PER YEAR ASSUMING
C    THAT THE TRAM IS SUPPLIED EACH IRRIGATION
       TOT = ETTOTC(IX)/TRAMC(IX) + 0.85
       IRTOTC(IX) = TOT
C
C    COMPUTE IRRIGATION FREQUENCY
       EFQ = TRAMC(IX)/ETMAX + 0.3
       IFQ = EFQ
       FREQC(IX) = IFQ
   90 CONTINUE
C
C    CALL INDIVIDUAL SUBROUTINES TO COMPUTE ANNUAL COSTS FOR
C    EACH TYPE OF APPLICATION SYSTEM UNDER CONSIDERATION
       CALL SURFCE (NCMBB,KZZB)
       CALL SURFCE (NCMBF,NCMBB)
       CALL SPNKLR(NCMB)
       GO TO 1
   10 CONTINUE
       STOP
       END
```

SUBROUTINE SPNKLR

```
C   SUBROUTINE SPNKLR WILL COMPUTE THE TOTAL ANNUAL COST FOR
C   A HAND-LINE PORTABLE SPRINKLER SYSTEM FOR THE SOILS AND
C   CROP DATA SUPPLIED
C
      SUBROUTINE SPNKLR (NCMB)
      REAL LLEN,LSPA,IRTOT
      COMMON  TRAMC(10), IRTOTC(10),  FREQC(10), ETTOTC(10), HEAD(6,20)
      DIMENSION SP(11),TSET(10)
      DIMENSION TITLE (20)
      DATA CON1,CON2/'READ','REWO'/
      WRITE (3,207)
      KZZ = 1
C
C   READ IN TITLE FOR GIVEN FIELD CONDITIONS
    3 READ (1,101) TITLE
  101 FORMAT (20A4)
C
C   READ IN LATERAL LENGTH AND LATERAL SPACING
C         LLEN = LENGTH OF LATERAL IN FEET
C         LSPA = LATERAL SPACING IN FEET
      CALL GET2(LLEN,LSPA)
C
C   READ IN AVERAGE TIME REQUIRED PER LATERAL MOVE AND
C   SET LENGTH TIME ALTERNATIVES
C         TMOV = TIME REQUIRED TO MOVE LATERAL IN MINUTES
C         TSET = TIMES FOR SET LENGTHS IN HOURS
C         NOTE:  TSET MAY CONTAIN UP TO 11 VALUES STARTING WITH
C                     THE SMALLEST VALUE
C                TSET MUST INCLUDE REQUIRED MOVING AND
C                     OTHER DOWN TIME
C                TMOVE MUST BE THE FIRST VALUE STORED ON THE CARD
C
```

```
      CALL INPUT(SP,N)
      TMOV = SP(1)
      DO 4 NK=2,N
      NK1=NK-1
    4 TSET(NK1) = SP(NK)
C
C   INPUT THE OVER-ALL EFFICIENCY OF THE SYSTEM AND THE
C   PERCENTAGE OF WATER LOST TO EVAPORATION BEFORE COMING
C   IN CONTACT WITH THE SOIL OR CROP CANOPY
C         OAEFF = OVER-ALL EFFICIENCY IN PERCENT
C         OLOSS = OTHER LOSSES IN PERCENT
      CALL GET2(OAEFF,OLOSS)
C
C   INPUT THE MAXIMUM ALLOWABLE INTAKE RATE FOR SPRINKLER IRRIGATION
C         RIMAX = MAXIMUM ALLOWABLE INTAKE RATE IN INCHES PER HOUR
      CALL GET1(RIMAX)
C
C   INPUT THE EXPECTED LIFE OF THE SYSTEM AND THE INTEREST RATE
C   AND OTHER EXPENSES SUCH AS TAXES AND INSURANCE
C         CNEW = ORIGINAL COST
C         TLIFE = LIFE OF SYSTEM IN YEARS
C         RINT = INTEREST RATE IN PERCENT
C         OEXP = OTHER EXPENSES IN PERCENT OF AVERAGE INVESTMENT
C         SVAL = SALVAGE VALUE AS A PERCENT OF ORIGINAL INVESTMENT
      CALL GET5(CNEW,TLIFE,RINT,OEXP,SVAL)
      RINT = RINT/100.
      OEXP = OEXP/100.
C
C   INPUT LABOR RATE FOR MOVING LATERALS AND TRANSPORT TIME
C   BETWEEN IRRIGATIONS
C         RLABOR = LABOR RATE IN $/HOUR
C         TTRAN  = TRANSPORT TIME IN HOURS
      CALL GET2(RLABOR,TTRAN)
C
C   INPUT THE COST OF WATER AT THE POINT OF DELIVERY AND THE
C   INPUT THE NET VALUE OF WATER LOST TO DEEP PERCOLATION
C         DPVAL = VALUE OF WATER TO DP IN $/ACRE-FOOT
```

```
      CALL GET1(DPVAL)
C
C   INPUT MAINLINE DATA
C         AML = AREA THE MAINLINE SERVES IN ACRES
C         CML = COST OF MAINLINE IN DOLLARS TOTAL OR DOLLARS PER FOOT
C         XML = LENGTH OF MAINLINE IN FEET
C         NOTE: IF THE COST IS GIVEN AS TOTAL COST THE VALUE FOR XML
C               MUST BE OMITTED
      CALL INPUT (SP,N)
      AML =SP(1)
      IF(N.EQ.2)SP(3)=1.
      CML = SP(2)*SP(3)
C
C   INPUT LIFE, INTEREST RATE AND SALVAGE VALUE FOR MAINLINE
C         TIML = EXPECTED LIFE IN YEARS
C         TINT = INTEREST RATE IN PERCENT
C         TSAL = SALVAGE VALUE AS PERCENT OF ORIGINAL INVESTMENT
C         TOEX = OTHER EXPENSES AS PERCENT OF AVERAGE INVESTMENT
      CALL GET4(TIML,TINT,TSAL,TOEX)
      TINT = TINT/100.
      TOEX = TOEX/100.
C
C   INPUT VALUE OF LAND LOST TO PRODUCTION FOR THE SYSTEM CONSIDERED
C         VLAND = ANNUAL VALUE OF PRODUCTICN LOST
      CALL GET1(VLAND)
   10 CONTINUE
C
      DO 98 IX = 1,NCMB
      TRAM = TRAMC(IX)
      IRTOT = IRTOTC(IX)
      FREQ = FREQC(IX)
      ETTOT = ETTCTC(IX)
C
C   DETERMINE APPLICATION RATES
      KT=1
   11 AR = TRAM/(TSET(KT)-TMOV/60.)
      IF(RIMAX-AR)12,14,14
```

```
   12 KT =KT+1
      IF(KT-N)11,13,13
   13 WRITE(3,201)
  201 FORMAT(3X,'APPLICATION RATE IS EXCESSIVE FOR ALLOWABLE TIMES')
      GO TO 99
C
C    DETERMINE AREA COVERED BY EACH SET
   14 AREA = LLEN*LSPA/43560.
C
C    DETERMINE TOTAL AREA COVERED BY EACH LATERAL IN ACRES
      TOTA = AREA*(24./TSET(KT))*(FREQ-TTRAN/24.)
C
C    DETERMINE LABOR REQUIREMENTS FOR LATERAL MOVING
      CLAB= IRTOT*(24./TSET(KT)*FREQ*(TMOV/60.)*RLABOR)
C
C    COMPUTE COSTS OF TRANSPORTING BETWEEN IRRIGATIONS
      CTRAN = IRTOT*(TTRAN*RLABOR)
C
C    COMPUTE DEPRECIATION AND INTEREST FOR LATERAL LINE
      ANDM = CNEW*(RINT*(1.+RINT)**TLIFE)/(((1.+RINT)**TLIFE)-1.)
     &-SVAL*0.01*CNEW*RINT/(((1.+RINT)**TLIFE)-1.)
C
C    COMPUTE TAXES AND INSURANCE
      COEXP=((CNEW-SVAL*0.01*CNEW)/2.+SVAL*0.01*CNEW)*OEXP
C
C    COMPUTE ANNUAL MAINTENANCE COSTS AS 3% OF TOTAL INVESTMENT
      CMAINT = 0.03*CNEW
C
C    COMPUTE THE VALUE OF WATER LOST TO DEEP PERCOLATION
      CDP = (ETTOT/12.)*(1-(OAEFF+OLOSS)/100.)*DPVAL
C
C    COMPUTE DEPRECIATION FOR MAINLINE
      AMLCST = CML*(TINT*(1.+TINT)**TIML)/(((1.+TINT)**TIML)-1.)
     &-TSAL*0.01*CML*TINT/(((1.+TINT)**TIML)-1.)
C
C    COMPUTE ANNUAL MAINTENANCE COST AS 3% OF ORIGINAL INVESTMENT
      TMAINT = 0.03*CML
```

```
C
C    COMPUTE TAXES AND INSURANCE
      TOTHER=((CML-0.01*TSAL*CML)/2.+0.01*TSAL*CML)*TOEX
C
C    COMPUTE TOTAL ANNUAL COST PER ACRE FCR THE SPRINKLER LATERAL
C    AND MAINLINE
C
      CANN = (CLAB+CTRAN+ANDM+COEXP+CMAINT+VLAND)/TOTA +CDP
     &     + (AMLCST+TMAINT+TOTHER)/AML
C
C    OUTPUT RESULTS
      WRITE(3,200)TRAM,IRTOT,FREQ,ETTOT,LLEN,LSPA,TMOV,TSET(KT),
     &OAEFF,OLOSS,RIMAX,TLIFE,CNEW,RINT,OEXP,SVAL,RLABOR,TTRAN,
     &DPVAL,WTRVAL,AML,CML,TIML,TINT,TSAL,TOEX,FREQ
C
      WRITE(3,200)TSET(KT),AR,AREA,TOTA,CLAB,CTRAN,ANDM,COEXP,
     &CMAINT,CDP,AMLCST,TMAINT,TOTHER,CANN,CWTR
C
  200 FORMAT(10(/,3(10XF15.5)))
C
      KZZ = KZZ + 1
      IF(KZZ.LT. 8) GO TO 88
      WRITE (3,207)
      KZZ = 1
  207 FORMAT ('1'///)
   88 CONTINUE
      WRITE (3,210) (HEAD(IX,J),J=1,20)
  210 FORMAT (///10X,20A4)
      WRITE (3,206) TITLE, CANN, OAEFF
  206 FORMAT (  /10X,20A4, //15X, 'ANNUAL COST PER ACRE = $',F6.2,/
     &15X,'WATER APPLICATION EFF = ',F4.1,'%' )
   98 CONTINUE
C
```

```
C   READ IN CONTROL TO TERMINATE SUBROUTINE OR TO REWORK FOR
C   ANOTHER SET OF DATA
C
C   IF THE WORD REWORK IS PUNCHED BEGINNING IN COLUMN 1 THE
C   SUBROUTINE WILL BE EXECUTED AGAIN; ANY OTHER WORD WILL
C   CAUSE THE SUBROUTINE TO TERMINATE
      READ(1,101)CN2
      IF(CN2.EQ.CON2)GO TO 3
   99 RETURN
      END
```

SUBROUTINE SURFCE

```
C   SUBROUTINE SURFCE WILL COMPUTE THE TOTAL ANNUAL COST ON A
C   PER-ACRE BASIS FOR A GRAVITY IRRIGATION SYSTEM (BORDER OR
C   FURROW)FROM THE CROP AND SOILS DATA SUPPLIED
C
C   READ IN DATA FOR ALL BORDER SYSTEMS TO BE CONSIDERED BEFORE
C   READING IN ANY DATA FOR FURROW SYSTEMS
C
      SUBROUTINE SURFCE (NCMB,KNZT)
      REAL IRTOT
      COMMON  TRAMC(10), IRTOTC(10),  FREQC(10), ETTOTC(10), HEAD(6,20)
      DIMENSION ARD(100),TA(50),TR(50),TAPP(50),DPTH(50),DPPH(50)
      DIMENSION TITLE (20)
      DATA CON1,CON2/'READ','REWO'/,BR1,BR2,BR3/'SET','EFF','WAT'/
      WRITE (3,207)
      KZZ = 1
C
C   READ IN TITLE FOR GIVEN FIELD CONDITIONS
    1 READ (1,101) TITLE
  101 FORMAT (20A4)
C
C   READ IN FIELD DIMENSIONS AND SET WIDTH
C         FLEN = FIELD LENGTH IN FEET
C         FWID = FIELD WIDTH IN FEET
C         SWID = SET WIDTH IN FEET
      CALL GET3(FLEN,FWID,SWID)
C
C   READ IN HYDRAULIC CHARACTERISTICS
C         QFT = FLOW RATE APPLIED IN CFS PER FOOT OF WIDTH
C         DK = MULTIPLIER IN THE EQUATION D = DK*T**TD
C         TD = EXPONENT IN THE EQUATION D = DK*T**TD
      CALL GET3(QFT,DK,TD)
C
```

```
C   READ IN ADVANCE AND RECESSION DATA AS DESCRIBED BY GALINATO (   )
C   READ IN MULTIPLIER AND EXPCNENT FOR EXPONENTIAL ADVANCE
C   AND RECESSION EQUATIONS -- DIST = A(R)K** T ** A(R)N
C     DIST = DISTANCE BETWEEN STATIONS IN FEET
      CALL GET5(DIST,AK,AN,RK,RN)
      STA = FLEN/DIST
      NSTA = STA
      STA = NSTA
      DREM = FLEN - STA * DIST
      DO 4 KX = 1,100
      X = KX
      NEND = KX
      DSTA = DIST*(X-1.)
      IF (DSTA.GE.FLEN) GO TO 5
      TA(KX) = (DSTA/AK)**(1./AN)
      TR(KX) = (DSTA/RK)**(1./RN)
    4 CONTINUE
    5 TA(NEND) = (FLEN/AK)**(1./AN)
      TR(NEND) = (FLEN/RK)**(1./RN)
C
C   READ IN THE LABOR REQUIRED PER SET, ANY ADDITIONAL LABOR PER
C   IRRIGATION AND THE LABOR RATE
C         SETL = LABOR REQUIRED PER SET IN HOURS
C         GRL = ADDITIONAL LABOR REQUIRED PER IRRIGATION IN HOURS
C         RATL = LABOR RATE IN $/HR
      CALL GET3(SETL,GRL,RATL)
C
C   READ IN EQUIPMENT COSTS, ASSOCIATED LIFE AND INTEREST RATE
C         ECST = CAPITAL COST OF IRRIGATION EQUIPMENT
C         LFC = MAJOR LAND FORMING COSTS
C         ELFE = EXPECTED LIFE OF IRRIGATION EQUIPMENT
C         SVAL = SALVAGE VALUE AS A PERCENTAGE OF CAPITAL COST
C         RINT = INTEREST RATE IN PERCENT
      CALL GET5(ECST,LFC,ELFE,SVAL,RINT)
      RINT=RINT/100.
C
C   READ IN LAND PREPARATION COSTS AND VALUE OF LAND LOST TO PRODUCTION
```

```
C   DUE TO DITCHES, ETC.
C         CPREP = COST OF LAND PREPARATICN IN $/ACRE
C         CLOST = TOTAL COST OF LAND LOST TO PRODUCTION
      CALL GET2(CPREP,CLOST)
C
C   READ IN TOTAL ANNUAL MAINTENANCE COST AND OTHER EXPENSE
C         CMAINT = ANNUAL MAINTENANCE COST IN DOLLARS
C         COEP = OTHER EXPENSE AS PERCENTAGE OF AVERAGE INVESTMENT
      CALL GET2(CMAINT,COEP)
      COEP = COEP/100.
C
C   INPUT VALUES OF WATER LOST TO SURFACE RUNOFF AND TO DEEP PERCOLATION
C         SRVAL = NET VALUE OF WATER TO SURFACE RUNOFF IN $/ACRE-FOOT
C         DPVAL = NET VALUE OF WATER TO DEEP PERC IN $/ACRE-FOOT
      CALL GET2(SRVAL,DPVAL)
C
C   BRANCH TO ONE OF THREE OPTIONS FROM THE HEADING PUNCHED ON THE
C   FOLLOWING CARD BEGINNING IN COLUMN 1:
C         SET-TIME OPTION
C         EFFICIENCY OPTION
C         WATER-RUNOFF OPTION
   10 READ(1,102)BRO
  102 FORMAT(A3)
C
      DO 98 IX = 1,NCMB
      IO = KNZT + IX
      TRAM = TRAMC(IO)
      IRTOT = IRTOTC(IO)
      FREQ = FREQC(IO)
      ETTOT = ETTOTC(IO)
C
      IF(BRO.EQ.BR1)GO TO 11
      IF(BRO.EQ.BR2)GO TO 12
C
C   COMPUTE SET-TIME AND EFFICIENCY FOR WATER-RUNOFF OPTION
C
      TSET = TA(NEND) -TR(NEND) + (TRAM/DK)**(1./TD)
```

```
   15 DO 13 KN=1,NEND
      DPPH(KN)=DK*((TSET-TA(KN)+TR(KN))**TD)
      DPTH(KN) = DPPH(KN) - TRAM
   13 IF(DPTH(KN).LT. 0. ) DPTH(KN) = 0.
C
C         DETERMINE VOLUME OF WATER LOST TO DP AND SR
      NEND1 = NEND-1
      VPP = 0.
      VDP = 0.
      DO 14 KN=2,NEND1
      VPP = VPP+ ((DPPH(KN-1)+DPPH(KN))/24.)*DIST
   14 VDP = VDP+ ((DPTH(KN-1)+DPTH(KN))/24.)*DIST
      VPP = VPP+ ((DPPH(NEND1)+DPPH(NEND))/24.)*DREM
      VDP = VDP+ ((DPTH(NEND1)+DPTH(NEND))/24.)*DREM
C         VOLUMES IN ACRE-FEET PER IRRIGATION
      VSR=((QFT * TSET*60.)-VPP)*FWID/43560.
      VDP = VDP * FWID/43560.
      VAPP = QFT*FWID*TSET*60./43560.
C         COMPUTE EFFICIENCY
      EFF = (VAPP-VSR-VDP)/VAPP
C
C NOTE: THIS IS THE POINT WHERE A PENALTY FOR NOT SUPPLYING TRAM IS NEEDED
C
      IF(BRO.EQ.BR2)GO TO 20
      GO TO 30
C
C   COMPUTE EFFICIENCY AND WATER VOLUMES FOR SET-TIME OPTION
C
C   READ IN TIME WATER IS APPLIED PER SET
C         TSET = TIME OF SET IN MINUTES
   11 CALL GET1(TSET)
      GO TO 15
C
C   COMPUTE SET-TIME FOR EFFICIENCY OPTION
C
C   READ IN THE SPECIFIED EFFICIENCY AND AN ESTIMATE OF THE SET TIME
C         ESPEC = SPECIFIED EFFICIENCY IN PERCENT
```

```
C                    REQUIRED TO OBTAIN THE SPECIFIED EFFICIENCY
C          TSET = TIME ESTIMATE IN MINUTES
   12 CALL GET2(ESPEC,TSET)
      ESPEC =ESPEC/100.
      KT = 1
   19 DELT =60.
      KON =1
      GO TO 15
   20 KON = KCN+1
      DIFE = ESPEC-EFF
      ADIF = ABS(DIFF)
      IF(ADIF.LE.0.001) GO TO 30
      IF(KON.GT.2) GO TO 25
      IF(ESPEC.GT.EFF.AND.TSET.LE.TA(NEND)) GO TO 22
      DIF2 = DIFE
      IF (DIFE)28,30,29
   22 WRITE(3,201)ESPEC,EFF,TSET,TA(NEND)
  201 FORMAT(5X,'SPECIFIED EFFICIENCY CANNOT BE MET',/5X,'ESPEC=',F7.3,
     &'EFF=',F7.3,'TSET=',F7.1,'TA(NEND)=',F7.1)
      ESPEC = ESPEC - 0.05
      GO TO 19
   25 PRD = DIFE*DIF2
      IF(KON.GT. 40) GO TO 31
      DIF2 = DIFE
      IF(PRD.LE.0) KT = 2
      IF(KT.LT.2) GO TO 24
      DELT = DELT/2.
   24 IF(PRD)26,30,27
   26 GO TO (29,28),KZ
   27 GO TO (28,29),KZ
   28 TSET = TSET +DELT
      KZ=1
      GO TO 15
   29 TSET = TSET -DELT
      KZ=2
      GO TO 15
C
```

```
   31 WRITE(3,202)KON,EFF,ESPEC
  202 FORMAT(5X,'KON=',I3,'EFF=',F7.4,'ESPEC=',F7.4)
C
C   COMPUTE WATER COSTS
   30 CWTR =IRTOT*(             VSR*SRVAL+VDP*DPVAL)
C
C   COMPUTE LABCR COSTS
      SET = FWID/SWID + 0.8
      NST = SET
      SET = NST
      CLAB = IRTOT*(SET*RATL*SETL+GRL*RATL)
C
C   COMPUTE EQUIPMENT COSTS
      BCST = ECST + LFC
      ANDM = BCST*(RINT*(1.+RINT)**ELFE)/(((1.+RINT)**ELFE)-1.)
     &-SVAL*0.01*ECST*RINT/(((1.+RINT)**ELFE)-1.)
C
C   COMPUTE OTHER EXPENSES SUCH AS TAXES AND INSURANCE
      COEXP =((ECST-SVAL*0.01*ECST)/2.+SVAL*0.01*ECST)*COEP
C
C   COMPUTE TOTAL ANNUAL COST ON A PER-ACRE BASIS
C
      TCANN =(COEXP+ ANDM+ CLAB+ CWTR+ CMAINT+        CLOST)/
     &(FLEN*FWID/43560.)+CPREP
C
C   WRITE OUT RESULTS
C
      ON = KON
      WRITE(3,205)TCANN,COEXP,ANDM,CLAB,CWTR,CMAINT,CPREP,CLOST,
     &VSR,VDP,VAPP,EFF,SET
     &,ON
C
  205 FORMAT(10(/,3(10XF15.5)))
C
C
      KZZ = KZZ + 1
      IF(KZZ.LT. 8) GO TO 88
```

```
      WRITE (3,207)
      KZZ = 1
  207 FORMAT ('1'///)
   88 EFF = EFF * 100.
      WRITE (3,210) (HEAD(IO,J),J=1,20)
  210 FORMAT (///10X,20A4)
      WRITE (3,206) TITLE, TCANN, EFF
  206 FORMAT (  /10X,20A4, //15X, 'ANNUAL COST PER ACRE = $',F6.2,/
     &15X,'WATER APPLICATION EFF = ',F4.1,'%' )
   98 CONTINUE
C
C    READ IN CCNTRCL TO TERMINATE SUBROUTINE OR TO REWORK FOR
C    ANOTHER SET OF DATA
C    IF THE WORD REWORK IS PUNCHED BEGINNING IN COLUMN 1, THE
C    SUBROUTINE WILL BE EXECUTED AGAIN; ANY OTHER WORD WILL CAUSE
C    THE SUBROUTINE TO TERMINATE
C
      READ(1,101)CN2
      IF(CN2.EQ.CON2) GO TO 1
   99 RETURN
      END
```

SYSCOST ROUTINE

```
C
C   MAIN PROGRAM TO CALCULATE COSTS OF DITCHES, PIPELINES, AND PUMPS
C
C   THE MAIN PROGRAM CALLS THE SUBROUTINES IN THE PROPER SEQUENCE
C
C   ALL INPUT DATA ARE READ DIRECTLY INTO THE SUBROUTINES, AND ALL
C   OUTPUT DATA ARE OUTPUT DIRECTLY BY THE SUBROUTINES
C
C   USE FREE-FORM INPUT BY MEANS OF SUBROUTINE 'INPUT'
C
      WRITE (3,200)
  200 FORMAT(////////////////)
C
      CALL PIPCST
      CALL PIPCST
      CALL DITCST
      CALL DITCST
      CALL PMPCST
      CALL PMPCST
      CALL PMPCST
      CALL PMPCST
      CALL PMPCST
      CALL PMPCST
      CALL PMPCST
      CALL PMPCST
      CALL PMPCST
      STOP
      END
```

SUBROUTINE PIPCST

```
C     SUBROUTINE PIPCST CALCULATES THE ANNUAL COST OF A PIPELINE
C     IN RELATION TO THE FLOW RATE OF WATER CONVEYED
C
      SUBROUTINE PIPCST
C
      DIMENSION A(50),SZE(50),CPIP(50),CLAY(50),CTRN(50),CVLV(50),
     &CTO(50),CMET(50), CREG(50),TAC(50),QT(50)
      DIMENSION TITLE (18)
      DATA CN1, CN2/'END ','SKIP'/
      WRITE(3,255)
      KXQ = 0
C
C     READ IN CONTROL FOR PROPER BRANCHING AND A TITLE
C     IF THE WORD BEGINNING IN COLUMN 1 IS:
C           'READ'  CONTROL IS SHIFTED TO STATEMENT 5
C           'SKIP'  CONTROL IS SHIFTED TO STATEMENT 3
C           'END'  CONTROL IS SHIFTED TO STATEMENT 98
C            NOTE:  THE SKIP CONTROL IS USED TO MINIMIZE THE ENTRY OF
C                   REDUNDANT DATA.  STATEMENT 3 IS A 'CONTINUE'
C                   STATEMENT THAT MAY BE MOVED IF DESIRED.
C     THE TITLE BEGINS IN COLUMN 8
    1 READ (1,150) CON, TITLE
  150 FORMAT (A4,3X,18A4)
      IF (CON.EQ.CN1) GO TO 98
      IF (CON.EQ.CN2) GO TO 3
    5 CONTINUE
C
C     READ IN THE PIPE ROUGHNESS COEFFICIENT FOR USE IN THE
C     HAZEN-WILLIAMS FORMULA
C           CF = FRICTION COEFFICIENT
      CALL GET1(CF)
C
```

```
C   READ IN THE LIST OF STANDARD PIPE DIAMETERS TO BE CONSIDERED
C   IN SIZE SELECTIONS FROM SMALLEST TO LARGEST
C         SZE = PIPE DIAMETER IN INCHES
      CALL INPUT(A,N)
      DO 6 K=1,N
    6 SZE(K)=A(K)
C
C   ENTER COST DATA FOR ALL PIPE DIAMETERS TO BE CONSIDERED
C         CPIP = COST OF PIPE IN $/FT
C         CLAY = COST OF LAYING PIPE IN $/FT
C         CTRN = COST OF TRENCHING AND BACKFILLING IN $/FT
C         CVLV = COST OF VALVES IN $
C         CTO  = COST OF TURNOUTS IN $
C         CMET = COST OF METERS IN $
C         CREG = COST OF PRESSURE REGULATORS IN $
C   THE ORDER OF DATA IS:  SZE, CPIP, CLAY, CTRN, CVLV, CTO, CMET, CREG
      DO 7 K=1,N
      CALL INPUT (A,NQ)
      CPIP (K) = A(2)
      CLAY (K) = A(3)
      CTRN (K) = A(4)
      CVLV (K) = A(5)
      CTO  (K) = A(6)
      CMET (K) = A(7)
      CREG (K) = A(8)
    7 CONTINUE
C
C   READ IN RIGHT-OF-WAY WIDTH AND COST
C         RWID = RIGHT-OF-WAY WIDTH IN FEET
C         RVAL = COST OF RIGHT-OF-WAY IN $/ACRE
      CALL GET2(RWID,RVAL)
C
C   READ IN LIFE OF SYSTEM COMPONENTS ANNUAL INTEREST RATE & SALVAGE VALUE
C         TLFE = LIFE OF SYSTEM COMPONENTS IN YEARS
C         RINT = ANNUAL INTEREST RATE IN PERCENT
C         SVAL = SALVAGE VALUE AS PERCENTAGE OF ORIGINAL COST
      CALL GET3(TLFE,RINT,SVAL)
```

```
      RINT = RINT/100.
C
C     READ IN OTHER EXPENSE VALUES
C           OEXP = ANNUAL VALUE FOR TAXES AND INSURANCE
C                  AS A PERCENTAGE OF THE AVERAGE INVESTMENT
C           PVAL = OTHER NET PUBLIC VALUES IN $/YEAR
      CALL GET2(OEXP,PVAL)
      OEXP = OEXP/100.
C
    3 CONTINUE
C     READ IN SECTION LENGTH AND THE ELEVATION AND HYDRAULIC
C     HEAD AT THE SECTION OUTLET AND INLET
C           SLEN = LENGTH OF SECTION IN FEET
C           ELO = ELEVATION IN FEET AT PIPE OUTLET
C           ELI = ELEVATION IN FEET AT PIPE INLET
C           HDO = MAXIMUM HEAD IN FEET AT PIPE OUTLET
C           HDI = MINIMUM HEAD IN FEET AT PIPE INLET
      CALL GET5(SLEN,ELO,ELI,HDO,HDI)
C
C     READ IN THE NUMBER OF VALVES, TURNOUTS, METERS AND REGULATORS
C     REQUIRED FOR THE SECTION
C           XVLV = NUMBER OF VALVES REQUIRED
C           XTO  = NUMBER OF TUNOUTS
C           XMET = NUMBER OF METERS OR WEIRS
C           XREG = NUMBER OF PRESSURE REGULATORS
      CALL GET4(XVLV,XTO,XMET,XREG)
C
C     READ IN THE RANGE OF DISCHARGES UNDER CONSIDERATION AND
C     THE INCREMENTAL STEP SIZE
C           MINQ = MINIMUM DISCHARGE IN CFS
C           MAXQ = MAXIMUM DISCHARGE IN CFS
C           KNTQ = STEP SIZE IN CFS
      CALL GET3(MINQ,MAXQ,KNTQ)
C
C       DETERMINE COSTS FOR A RANGE OF DISCHARGES
      NQ=0
      DO 49 KQ=MINQ,MAXQ,KNTQ
```

```
      NQ = NQ + 1
      Q=KQ
C    DETERMINE MAXIMUM HYDRAULIC GRADIENT
      DH = ELI+HDI - (ELO+HDO)
      SLP = DH/SLEN
C    DETERMINE THE DIAMETER OF PIPE FROM HAZEN-WILLIAMS EQN
      DIA = 16.5*(Q/(CF*(SLP**0.54)))**0.3802
      DO 10 NK=1,N
      IF(DIA.GT.SZE(NK))GO TO 9
      IF(NK.EQ.1)GO TO 12
      BP = SZE(NK-1) + 0.3*(SZE(NK)-SZE(NK-1))
      IF(DIA-BP)11,12,12
   11 IDA = NK - 1
      GO TO 20
   12 IDA = NK
      GO TO 20
    9 IF(NK.EQ.N)GO TO 50
   10 CONTINUE
C    DETERMINE COSTS
   20 CST = SLEN*(CPIP(IDA)+CLAY(IDA)+CTRN(IDA)) +XVLV*CVLV(IDA)
     &+ XTO*CTO(IDA) + XMET*CMET(IDA) + XREG*CREG(IDA)
C    COMPUTE ANNUAL COST FOR CAPITAL OUTLAY DEPRECIATICN
      CANN = CST*(RINT*(1.+RINT)**TLFE)/(((1.+RINT)**TLFE)-1.)
     & - SVAL*0.01*(CST-SLEN*(CLAY(IDA)-CTRN(IDA)))* RINT/
     &(((1.+RINT)**TLFE)-1.)
C    COMPUTE TAXES AND INSURANCE
      COEXP = OEXP* (CST + SVAL*0.01*(CST-SLEN*(CLAY(IDA)+CTRN(IDA))))/
     & 2.
C
C    COMPUTE TOTAL ANNUAL COST
      TAC(NQ)=CANN+COEXP       - PVAL+SLEN*RWID*RVAL/43560.*RINT
      QT(NQ) = Q
C    WRITE OUT RESULTS
      XNK = NK
   49 CONTINUE
      GO TO 57
   50 CONTINUE
```

```
      IF (NQ.LE.1) GO TO 96
      NQ = NQ - 1
C
   57 KXQ = KXQ + 1
      IF (KXQ.LT.7) GO TO 70
      KXQ = 0
      WRITE (3,255)
  255 FORMAT('1',////)
   70 WRITE(3,260) TITLE
  260 FORMAT(    ///,10X,18A4)
C
C    DETERMINE LINEAR REGRESSION COEFFICIENTS FOR THE DATA OBTAINED
C
   55 CALL REGLIN (QT,TAC,NQ)
      GO TO 99
   96 WRITE(3,201)DIA,SZE(NK)
  201 FORMAT(10X,'DIA =',F10.3,'SZE =',F10.3)
   99 CONTINUE
      GO TO 1
   98 RETURN
      END
```

SUBROUTINE DITCST

```
C
C   SUBROUTINE DITCST CALCULATES THE ANNUAL COST CF AN OPEN CHANNEL
C   IN RELATION TO THE FLOW RATE OF WATER CONVEYED
C
      SUBROUTINE DITCST
C
      DIMENSION CTO(50),CDRP(50),CCMB(50),A(50),CWER(50),STO(50),
     &SDRP(50),SCMB(50),SWER(50),SBRD(50),CBRD(50),CTANN(50),QX(50)
      DIMENSION TITLE (18), SBFD (50), CBFD(50)
      DATA CN1, CN2/'END ','SKIP'/
      KXQ = 0
      NNT = 0
      WRITE(3,255)
C
C   READ IN CONTRCL FOR PROPER BRANCHING AND A TITLE
C   IF THE WORD BEGINNING IN COLUMN 1 IS:
C        'READ'  CONTROL IS SHIFTED TO STATEMENT 5
C        'SKIP'  CONTROL IS SHIFTED TO STATEMENT 3
C        'END'  CONTROL IS SHIFTED TO STATEMENT 98
C         NOTE:  THE SKIP CONTROL IS USED TO MINIMIZE THE ENTRY OF
C                REDUNDANT DATA.  STATEMENT 3 IS A 'CONTINUE'
C                STATEMENT THAT MAY BE MOVED IF DESIRED.
C   THE TITLE BEGINS IN COLUMN 8
    1 READ (1,150) CON, TITLE
  150 FORMAT (A4,3X,18A4)
      IF (CON.EQ.CN1) GO TO 98
      IF (CON.EQ.CN2) GO TO 3
C
C   READ IN COST DATA FOR DIFFERENT SIZES AND TYPES OF STRUCTURES
C   BY READING THE MAXIMUM ALLOWABLE DISCHARGE THROUGH THE STRUCTURE
C   AND THE COST OF THE STRUCTURE
C
```

```
C     --READ IN COST DATA FOR TURNOUT STRUCTURES
C          STO = MAX ALLOWABLE DISCHARGE FOR EACH TURNOUT
C          CTO = COST OF TURNOUT IN $
    5 CALL INPUT(A,NT)
      DO 7 K=2,NT,2
      STO(K/2)= A(K-1)
    7 CTO(K/2)= A(K)
      NT = NT/2
C     --READ IN DATA FOR DROP STRUCTURES
C          SDRP = MAX ALLOWABLE DISCHARGE THROUGH EACH STRUCTURE
C          CDRP = COST OF DROP STRUCTURE IN $
      CALL INPUT(A,ND)
      DO 8 K=2,ND,2
      SDRP(K/2) = A(K-1)
    8 CDRP(K/2) = A(K)
      ND = ND/2
C     --READ IN DATA FOR COMBINATION DROP-TURNOUT STRUCTURES
C          SCMB = MAX ALLOWABLE DISCHARGE THROUGH EACH STRUCTURE
C          CCMB = COST OF COMBINATION STRUCTURE IN $
      CALL INPUT(A,NC)
      DO 9 K=2,NC,2
      SCMB(K/2)= A(K-1)
    9 CCMB(K/2)= A(K)
      NC = NC/2
C     --READ IN DATA FOR WEIRS
C          SWER = MAX ALLOWABLE DISCHARGE THROUGH EACH WEIR
C          CWER = COST OF EACH WEIR IN $
      CALL INPUT(A,NW)
      DO 10 K=2,NW,2
      SWER(K/2) = A(K-1)
   10 CWER(K/2) = A(K)
      NW =NW/2
C
C    READ IN COST DATA FOR HIGHWAY BRIDGES
C          SBRD = BRIDGE SPAN IN FEET
C          CBRD = BRIDGE COST IN $
      CALL INPUT(A,NB)
```

```
      DO 90 K=2,NB,2
      SBRD(K/2)=A(K-1)
   90 CBRD(K/2)=A(K)
      NB = NB/2
C
C    READ IN COST DATA FOR FARM BRIDGES
C          SBFD = BRIDGE SPAN IN FEET
C          CBFD = BRIDGE COST IN $
      CALL INPUT(A,NF)
      DO 91 K=2,NF,2
      SBFD(K/2)=A(K-1)
   91 CBFD(K/2)=A(K)
      NF = NF/2
C
C    READ IN COST OF EXCAVATION, AND IF LINING IS INCLUDED READ IN
C    LINING THICKNESS IN INCHES AND COST PER SQ.YD. OF LINING MTL
C          CEX = COST OF EXCAVATION IN $/CU.YD.
C          CLN = COST OF LINING MTL IN $/SQ.YD.
C          THLN = LINING THICKNESS IN INCHES
      THLN = 0.
      CALL INPUT(A,NO)
      CEX= A(1)
      IF(NO.EQ.1)GO TO 4
      CLN =A(2)
      THLN=A(3)
C
C    READ IN CHANNEL PROPERTIES
C          Z = SIDE-SLOPE OF CHANNEL
C          BH = BASE WIDTH-WATER DEPTH RATIO
C          RN = MANNINGS ROUGHNESS COEFFICIENT
C          VMX = MAXIMUM ALLOWABLE VELOCITY
C          YMN = MINIMUM CHANNEL DEPTH IN FEET
    4 CALL GET5(Z,BH,RN,VMX,YMN)
C
C    READ IN DATA PERTAINING TO OPERATIONAL WASTE
C          DPV = VALUE OF WATER LOST FROM CANAL SECTION IN $/ACRE-FOOT
C          DPT = NUMBER OF DAYS CANAL IS CARRYING 75% OF PEAK DEMAND
```

```
C               (BASED ON BUREAU GUIDELINE OF CAP = 120-150% AVE DEMAND)
      CALL GET2(DPV,DPT)
C
C   READ IN THE LIFE, ANNUAL INTEREST RATE AND SALVAGE VALUE OF
C   SYSTEM COMPONENTS
C         TLFE = LIFE OF SYSTEM COMPONENTS IN YEARS
C         RINT = ANNUAL INTEREST RATE IN PERCENT
C         SVAL = SALVAGE VALUE AS PERCENTAGE OF ORIGINAL COST
      CALL GET3(TLFE,RINT,SVAL)
      RINT = RINT/100.
C
C   READ IN OTHER EXPENSE VALUES
C         OEXP = ANNUAL VALUE FOR TAXES AND INSURANCE AS A
C                PERCENTAGE OF THE AVERAGE INVESTMENT
      CALL GET1(OEXP)
      OEXP = OEXP/100.
C
C   READ IN RIGHT-OF-WAY WIDTH IN ADDITICN TC CANAL TOP WIDTH AND COST
C         RWID = ADDITIONAL RIGHT-OF-WAY WIDTH IN FEET
C         RVAL = VALUE OF RIGHT-OF-WAY IN $/ACRE
      CALL GET2(RWID,RVAL)
C
    3 CONTINUE
C
C   READ IN PUBLIC VALUES AND SEEPAGE RATE FOR OPERATIONAL WASTE
C         CMZ = SEEPAGE RATE IN CFS/SQFT/DAY USED IN MORITZ FORMULA
C         PVAL = NET PUBLIC VALUE IN $/YEAR
      CALL GET2(CMZ,PVAL)
C
C   READ IN SECTION LENGTH AND ELEVATION OF SECTION OUTLET AND INLET
C         SLEN = SECTION LENGTH IN FEET
C         ELO = ELEVATION AT OUTLET IN FEET
C         ELI = ELEVATION AT INLET IN FEET
      CALL GET3(SLEN,ELO,ELI)
C
C   READ IN THE NUMBER OF EACH TYPE OF STRUCTURE REQUIRED FOR
C   THE SECTION
```

```
C          XTO  = NUMBER OF TURNOUTS
C          XDRP = NUMBER OF DROP STRUCTURES
C          XCMB = NUMBER OF COMBINATION DROP-TURNOUT STRUCTURES
C          XWER = NUMBER OF WEIRS
C          XBRD = NUMBER OF HIGHWAY BRIDGES
C          XBFD = NUMBER OF FARM BRIDGES
      CALL GET6(XTO,XDRP,XCMB,XWER,XBRD,XBFD)
C
C    READ IN THE RANGE OF DISCHARGES UNDER CONSIDERATION AND THE
C    INCREMENTAL STEP SIZE
C          MINQ = MIN DISCHARGE IN CFS
C          MAXQ = MAX DISCHARGE IN CFS
C          KNTQ = STEP SIZE IN CFS
      CALL GET3(MINQ,MAXQ,KNTQ)
C
C    COMPUTE COSTS FOR A RANGE OF DISCHARGES
C
      KX = 0
      DO 49 KQ=MINQ,MAXQ,KNTQ
      KX = KX + 1
      Q = KQ
      CTL = 0.
C    DETERMINE HYDRAULIC GRADIENT
   11 SLP =(ELI-ELO)/SLEN
      IF(SLP.LE.0.)GO TO 98
C    DETERMINE BOTTOM WIDTH AND WATER DEPTH FOR GIVEN B:H RATIO
      Y=((Q*RN/(1.49*(SLP**0.5)))**0.375)*((2*(1.+Z*Z)**0.5+BH)**0.25)/
     &((Z+BH)**0.625)
      YS = Y
      IF(Y.LT.YMN) YS=YMN
      BW = BH*YS
C
C    CHECK VELOCITY AGAINST MAX ALLOWABLE VELOCITY
      V =(1.49/RN)*((Z*Y*Y+BW*Y)/(BW+2*Y*((1.+Z*Z)**0.5)))**0.66667
     &   *(SLP**0.5)
      IF(V.LE.VMX) GO TO 32
C    INSERT DROP OR COMBINATION STRUCTURE IF VELOCITY > VMX
```

```
      IF(XTO.EQ.0..AND.XDRP.EQ.0.) XDRP = 1.
      IF(XTO.GT.0..AND.XCMB.EQ.0.)GOTO8
      GO TO 9
    8 XCMB = 1.
      XTO = XTO - 1.
    9 ELO = ELO +1.
      GO TO 11
C
C   COMPUTE FREEBOARD
C      NOTE: VARIABLE FREEBOARD INPUT MAY BE DESIRED AT THIS POINT
   32 IF(Q-10)12,12,13
   12 YFB = Y+ 0.2 + 0.1*Q
      GO TO 14
   13 YFB = Y+ 1.1 + 0.01*Q
   14 IF(YFB.LT.YMN)  YFB = YMN
C
C   CALCULATE PROPER SIZES OF STRUCTURES TO BE INCLUDED
      NNT = 1
      NNC = 1
      NND = 1
      NNW = 1
      NNB = 1
      NNF = 1
C    --TURNOUT STRUCTURES
      IF(XTO) 41,41,40
   40 DO 16 K=1,NT
   17 NNT = K
      IF(STO(K).GE.Q)GO TO 41
   16 CONTINUE
C    --DROP STRUCTURES
   41 IF(XDRP) 43,43,42
   42 DO 18 K=1,ND
   19 NND = K
      IF(SDRP(K).GE.Q)GO TO 43
   18 CONTINUE
C    --COMBINATION STRUCTURES
   43 IF(XCMB) 45,45,44
```

```
   44 DO 20 K=1,NC
   21 NNC = K
      IF(SCMB(K).GE.Q)GO TO 45
   20 CONTINUE
C      --WEIRS
   45 IF(XWER)  47,47,46
   46 DO 22 K=1,NW
   23 NNW = K
      IF(SWER(K).GE.Q)GO TO 47
   22 CONTINUE
C      --HIGHWAY BRIDGES
   47 TWID = BW + 2*YFB*Z
      IF(XBRD)449,449,48
   48 DO 25 K=1,NB
   26 NNB= K
      IF(SBRD(K).GE.TWID)GOTO449
   25 CONTINUE
C      --FARM BRIDGES
  449 IF(XBFD) 35,35,33
   33 DO 34 K = 1,NF
      NNF = K
      IF (SBFD(K).GE.TWID) GO TO 35
   34 CONTINUE
   35 CONTINUE
C
C     CALCULATE CROSS-SECTIONAL AREA OF EXCAVATION
      AREA = YFB*(BW + Z*YFB)
C
C     COMPUTE COSTS
C      --EXCAVATION COSTS
      CTX = ((AREA*SLEN)/27.)*CEX
C      --LINING COSTS
      CTL = 0.
      IF(THLN.EQ.0.) GO TO 30
      YLN = Y+0.5
      DELY = YFB -Y
      IF(DELY.LT.0.5.OR.Y.LT.YMN)  YLN = YFB
```

```
      WP =(2*YLN*(1.+Z*Z)**0.5)+ BW
      CTL = (WP*SLEN/9.)* CLN
C    --STRUCTURE COSTS
   30 CTS = XTO*CTO(NNT) + XDRP*CDRP(NND) + XCMB*CCMB(NNC)
     &     +XWER*CWER(NNW)+XBRD*CBRD(NNB) + XBFD*CBFD(NNF)
C
C   COMPUTE DEPRECIATION
      CANN =(CTX+CTL+CTS)*(RINT*(1.+RINT)**TLFE)/(((1.+RINT)**TLFE)-1.)
     &      -SVAL*0.01*(CTL+CTS)*RINT/(((RINT+1.)**TLFE)-1.)
C
C   COMPUTE TAXES AND INSURANCE
      COEXP = OEXP*(CTX+CTL +CTS+SVAL*0.01*(CTL+CTS))/2.
C
C   COMPUTE VALUE OF WATER LOST TO OPERATIONAL WASTE
      DPVOL =(0.2*CMZ*((Q/V)**0.5)*1.98*SLEN/5280.)*DPT
      CTDP = DPVOL*DPV
      EFF = (Q - (0.2*CMZ*((Q/V)**0.5)*SLEN/5280.))*100./Q
C
C   COMPUTE LAND VALUES FOR RIGHT-OF-WAY
      CTRW =((TWID+RWID)*SLEN/43560.)*RVAL*RINT
C
C   COMPUTE TOTAL ANNUAL COST
      QX(KX) =  KQ
      CTANN(KX) = CANN + COEXP + CTDP        + CTRW - PVAL
C
C   WRITE OUT RESULTS
C
   49 CONTINUE
      KXQ = KXQ + 1
      IF (KXQ.LT.6) GO TO 70
      KXQ = 0
```

```
      WRITE (3,255)
  255 FORMAT('1',///)
   70 WRITE(3,260) TITLE, EFF
  260 FORMAT(    ///,10X,18A4,//10X,'EFFICIENCY =' ,F5.1,'%')
C
C    DETERMINE LENEAR REGRESSION COEFFICIENTS FOR THE DATA OBTAINED
      CALL REGLIN (QX,CTANN,KX)
      GO TO 1
   98 RETURN
      END
```

SUBROUTINE PMPCST

```
C
C   SUBROUTINE PMPCST COMPUTES THE ANNUAL COST OF A PUMPING PLANT
C   FOR THE DATA GIVEN
C
      SUBROUTINE PMPCST
      DIMENSION A(75),PMQ(50),PMC(50), QMX(50),CQX(50),WRQ(12),CTANN(50)
      DIMENSION TITLE (18),PMX(50)
      DATA CN1, CN2/'END ','SKIP'/
      KXQ = 0
      WRITE(3,255)
C
C   READ IN CONTROL FOR PROPER BRANCHING AND A TITLE
C   IF THE WORD BEGINNING IN COLUMN 1 IS:
C        'READ'  CONTROL IS SHIFTED TO STATEMENT 5
C        'SKIP'  CONTROL IS SHIFTED TO STATEMENT 3
C        'END'  CONTROL IS SHIFTED TO STATEMENT 98
C         NOTE:  THE SKIP CONTROL IS USED TO MINIMIZE THE ENTRY OF
C                REDUNDANT DATA.  STATEMENT 3 IS A 'CONTINUE'
C                STATEMENT THAT MAY BE MOVED IF DESIRED.
C   THE TITLE BEGINS IN COLUMN 8
    1 READ(1,150) CON, TITLE
  150 FORMAT (A4,3X,18A4)
      IF (CON.EQ.CN1) GO TO 98
      IF (CON.EQ.CN2) GO TO 3
C
C   READ IN THE TOTAL DYNAMIC HEAD AND THE COSTS OF PUMPS OF VARYING
C   DISCHARGE PUMPING AGAINST THAT HEAD
C         TDH = TOTAL DYNAMIC HEAD IN FEET
C         PMQ = PUMP DISCHARGE IN GALLONS/MIN
C         PMC = PUMPING PLANT COST IN DOLLARS
C               NOTE:  PUMPING PLANT COST MUST INCLUDE THE PUMP,
C                      MOTOR AND ALL CONTROLS
```

```
C   THE ORDER OF THE DATA IS:  TDH,PMQ(1),PMC(1),PMQ(2),PMC(2),......
    5 CALL INPUT(A,NO)
      TDH = A(1)
      N1 = NO - 1
      NO = (NO-1)/2
      DO 10 KN=2,N1,2
      PMQ(KN/2) = A(KN)
   10 PMC(KN/2) = A(KN+1)
C
C   READ IN PARAMETERS NECESSARY FOR CCMPUTING O&M COSTS ACCORDING
C   TO EYER(1967)
C         A = PLANT AGE IN YEARS
C         R = RATIO OF CURRENT PRICE LEVEL TO 1962 PRICE LEVEL
C         T = LENTGH OF OPERATING SEASON IN WEEKS
C         WM = HOURLY WAGE RATE FOR MECHANICS
C         WO = HOURLY WAGE RATE FOR PUMPING PLANT OPERATORS
C
      CALL GET5(A,R,T,WM,WO)
C
C   READ IN THE COST OF ALL STRUCTURES AND FITTINGS (INCLUDING
C   WELLS) AND THE MAXIMUM DISCHARGE ALLOWED FOR EACH
C         QMX = DISCHARGE IN GPM
C         CQX = COST FOR SPECIFIED DISCHARGE
C   THE ORDER OF THE DATA IS:  QMX(1),CQX(1),QMX(2),CQX(2),......
      CALL INPUT (A,NQ)
      DO 12 K=2,NQ,2
      QMX(K/2) = A(K-1)
   12 CQX(K/2) = A(K)
C
C   READ IN THE EXPECTED LIFE, INTEREST RATE AND SALVAGE VALUE
C         TLFE = EXPECTED LIFE IN YEARS FOR STRUCTURES AND FITTINGS
C         RINT = INTEREST RATE IN PERCENT
C         SVAL = SALVAGE VALUE IN PERCENT OF ORIGINAL INVESTMENT
      CALL GET3(TLFE,RINT,SVAL)
      RINT = RINT/100.
C
C   READ IN OTHER EXPENSE AND PUBLIC VALUES
```

```
C         OEXP = OTHER EXPENSE AS A PERCENTAGE OF AVERAGE INVESTMENT
C         PVAL = ANNUAL NET PUBLIC VALUE IN DOLLARS
      CALL GET2(OEXP,PVAL)
      OEXP = OEXP/100.
C
C   READ IN AVARAGE MONTHLY IRRIGATION REQUIREMENTS FOR CROPS
C   SUPPLIED BY THE PUMP
C         WRQ = WEIGHTED MONTHLY IRRIGATION REQUIREMENT IN INCHES
      CALL INPUT(A,NW)
      DO 14 KW=1,NW
   14 WRQ(KW) = A(KW)
C
C   SORT WRQ AND DETERMINE THE PROPORTION OF WATER VOLUME PUMPED EACH
C   MONTH TO THE WATER VOLUME PUMPED THE MONTH OF PEAK DEMAND
      RAT = WRQ(1)
      DO 15 KW = 2,NW
      KW1 = KW-1
      IF(WRQ(KW).GT.WRQ(KW1))RAT = WRQ(KW)
   15 CONTINUE
C
    3 CONTINUE
C   READ IN EXPECTED EFFICIENCY
C         EFF = EFFICIENCY IN PERCENT
      CALL GET1(EFF)
      EFF = EFF/100.
C
C   COMPUTE ANNUAL EXPENSE FOR EACH PUMP FOR WHICH DATA ARE ENTERED
C
      DO 49 LP=1,NO
C   COMPUTE HORSEPOWER
      HP = PMQ(LP)*TDH/(3960.*EFF)
C   DETERMINE PUMP LIFE (AFTER EYER(   ))
      PLF = 100.
      IF(HP.GT.750.) PLF = 50.
C   DETERMINE PUMP DEPRECIATION COST
      PCOST = PMC(LP)*(RINT*(1.+RINT)**PLF )/(((1.+RINT)**PLF )-1.)
     &-SVAL*0.01*PMC(LP)*RINT/(((1.+RINT)**PLF)-1.)
```

```
C     DETERMINE DEPRECIATION COST FOR STRUCTURES AND FITTINGS
      NQ = NQ/2
      DO 18 KQ = 1,NQ
      IF(PMQ(LP).LE.QMX(KQ)) GO TO 19
   18 CONTINUE
   19 CQS = CQX(KQ)
      SCOST = CQS     *(RINT*(1.+RINT)**TLFE)/(((1.+RINT)**TLFE)-1.)
     &-SVAL*0.01*CQS     *RINT/(((1.+RINT)**TLFE)-1.)
C
C     DETERMINE OTHER EXPENSE SUCH AS TAXES AND INSURANCE
      COEX =(CQS+PMC(LP))*(1.+SVAL*0.01)*OEXP/2.
C
C     DETERMINE OPERATION COSTS ASSUMING A NON-ATTENDED PLANT
C     AS DESCRIBED BY EYER (   )
      COP = 1.8*((PMQ(LP)/449.)**0.47)*(TDH**0.26)*(1.2*WO + R)
     &*(T**0.34)
C
C     DETERMINE MAINTENANCE COSTS
      CMN=4.04 *((PMQ(LP)/449.)**0.84)*(TDH**0.40)*(0.485*WM + R)
C
C     DETERMINE POWER COSTS
C       --- THE FOLLOWING POWER RATES ARE THOSE SUPPLIED BY UTAH POWER & LIGHT
      CPWR = 0.
      IF (HP - 100.) 20,20,21
   20 DPWR = HP * 1.77
      GO TO 22
   21 DPWR = 1.16 * (HP - 100.) + 177.0
   22 DO 30 KM = 1,NW
      HKWR =  HP*24.*30.4*.746*WRQ(KM)/RAT
      IF (HKWR.GT. 25100.) GO TO 27
      IF (HKWR.GT. 5100.) GO TO 26
      IF (HKWR.GT. 100.) GO TO 25
      CPWR = CPWR + 0.0172 * HKWR +DPWR
      GO TO 30
   25 CPWR = CPWR + 1.72 + 0.0104*(HKWR - 100.) + DPWR
      GO TO 30
   26 CPWR = CPWR + 53.72 + 0.007 * (HKWR - 5100.) + DPWR
```

```
      GO TO 30
   27 CPWR = CPWR + 193.72 + 0.0047 * (HKWR - 25100.) + DPWR
   30 CONTINUE
C
      CTANN(LP) = PCOST + SCOST + COEX + COP + CMN + CPWR - PVAL
C
C    WRITE OUT RESULTS
      PMX(LP) = PMQ(LP)/449.
   49 CONTINUE
      KXQ = KXQ + 1
      IF (KXQ.LT.7) GO TO 70
      KXQ = 0
      WRITE (3,255)
  255 FORMAT('1',///)
   70 WRITE(3,260) TITLE
  260 FORMAT(   ///,10X,20A4)
C
C    DETERMINE LENEAR REGRESSION COEFFICIENTS FOR THE DATA OBTAINED
      CALL REGLIN (PMX,CTANN,NO)
      GO TO 1
   98 RETURN
      END
```

SUBROUTINE REGLIN

```
      SUBROUTINE REGLIN (X,Y,N)
C
C    SUBROUTINE REGLIN DETERMINES LINEAR REGRESSION COEFFICIENTS FOR
C    A GIVEN SET OF DATA
C          X = INDEPENDENT VARIABLE
C          Y = DEPENDENT VARIABLE
C
      DIMENSICN X(100), Y(100), YE(110)
C
      XN = N
      SX = 0.
      SY = 0.
      SX2 = 0.
      SY2 = 0.
      SXY = 0.
      SYE  =0.
      SYE2 =0.
      SYYE =0.
C
      DO 10 K=1,N
      SX = SX + X(K)
      SY = SY + Y(K)
      SX2 = SX2 + X(K)*X(K)
      SY2 = SY2 + Y(K)*Y(K)
      SXY = SXY + Y(K)*X(K)
   10 CONTINUE
      SSX = SX2 - (SX*SX/XN)
      SSY = SY2 - (SY*SY/XN)
      SSXY = SXY - (SX*SY/XN)
      XM = SX/XN
      YM = SY/XN
C
```

```
      B= SSXY/SSX
      A = YM - B*XM
C
      SDYX = B*SSXY
      RESS = (SSY-SDYX)/(XN-2.)
      SB = RESS/SSX
      T = B/SB
C
C    DETERMINE CORRELATION COEFFICIENT RELATING ESTIMATED VALUES
C    TO ACTUAL VALUES
C
      DO 15 K = 1,N
      YE(K) = A + B * X(K)
      SYE = SYE + YE (K)
      SYE2 = SYE2 + YE(K)*YE(K)
   15 SYYE = SYYE + YE(K)*Y(K)
      SSYE = SYE2 - (SYE*SYE/XN)
      R = (SYYE-(SYE*SY /XN))/((SSYE*SSY)**0.5)
      WRITE(3,200) A,B,R
  200 FORMAT(  /13X,'A = ',F12.3,/13X,'B = ',F12.3,/13X,'R = ',F12.3)
      RETURN
      END
```

DYNAMIC PROGRAMMING PROGRAM

```
C   DYNAMIC PROGRAMMING PROGRAM FOR PRUNING LESS-DESIRABLE
C   DISTRIBUTION SYSTEM COMPONENT COMBINATIONS
C
      DIMENSION  AXZN(12)
      DIMENSION EI(1200),BI(1200),AI(1200),E(10),A(10),B(10),
     &EE(2400),AE(2400),BE(2400),R(1200),LAB(2400)
      DIMENSION TITLE(19)
      DATA SP / 'STO'/
      DATA  CON,ST / 'PUN','STA'/
C
C   INITIALIZE
      WRITE (3,202)
  202 FORMAT (//////'DYNAMIC OUTPUT'///'1')
   50 CONTINUE
      DO 2 N=1,2400
    2 LAB(N) = 0
      KLINE = 0
      I = 0
      KNT1 = 1
      WRITE (3,203)
C
C   READ IN THE NUMBER OF STARTING NODES
C       KNT = NUMBER OF NODES
      CALL GET1(KNT)
      IF (KNT-1) 3,3,4
C
C   READ IN VALUES FOR STARTING NODES.  IF THE STARTING NODE IS 0 OR 1
C   NO DATA CAN BE ENTERED.
C       EE,AE, AND BE ARE ARE THE COMPOSITE EFFICIENCY AND COST
C       FUNCTION TERMS AT NODES 1-KNT
    4 DO 6 KE = 1,KNT
    6 CALL GET3(EE(KE ),AE(KE ),BE(KE))
```

```
      KNT = KNT + 1
      I = I+ 1
    3 I = I + 1
C
C   READ IN CONTROLS AND TITLE
C       J = NUMBER OF ALTERNATIVE BRANCHES
C      CNT = PUNCH CONTROL--
C             IF 'PUN' IS PUNCHED IN COLUMNS 2-4 THE OUTPUT FOR THE
C             PARTICULAR SECTION WILL BE PUNCHED ON CARDS BY FORMAT 205
C             IF 'START' IS PUNCHED IN COLUMNS 2-6 THE ENTIRE ROUTINE
C             IS REINITIALIZED BY TRANSFERRING CONTROL TO STATEMENT 50
C             IF 'STOP' IS PUNCHED IN COLUMNS 2-5 THE ROUTINE IS
C             TERMINATED
C       TITLE = DESCRIPTION OF SECTION UNDER CONSIDERATION PUNCHED IN
C               COLUMNS 5-80
      READ (1,100) J, CNT, TITLE
  100 FORMAT (I1,A3,19A4)
      IF (CNT.EQ.ST) GO TO 50
      IF (CNT.EQ.SP)  GO TO 88
      N = J - 1
      LB = J
C
C   READ IN THE MAXIMUM DISCHARGE TO BE CONSIDERED IN THE REACH
C       QMX = MAXIMUM DISCHARGE IN CFS
      CALL GET1(QMX)
C
C   READ IN THE EFFICIENCY, A AND B FOR EACH OF J SYSTEMS IN THE
C   PRESENT REACH
C       E = EFFICICY IN PERCENT
C       A = Y-INTERCEPT OF COST FUNCTION
C       B = SLOPE OF COST FUNCTION
C
      DO 5 K=1,J
      CALL GET4(E(K),A(K),B(K),REG)
    5 CONTINUE
      IF(I.EQ.1) GO TO 9
C
```

```
C    MULTIPLY EFFICIENCY WITH EXISTING EFFICIENCY FOR PROPER
C    RETURN FUNCTION AND ADD COST FUNCTION COMPONENTS TO
C    EXISTING COMPONENTS FOR COMPOSITE COST FUNCTION
C
      KLT = KNT - 1
      DO 8 KB = KNT1,KLT
      DO 8 KBB = 1,J
      LB = (KB-KNT1)*J + KBB
      EI(LB) = E(KBB) * EE(KB)
      AI(LB) = A(KBB) + AE(KB)
      BI(LB) = B(KBB) + BE(KB)
    8 CONTINUE
      N = LB - 1
      GO TO 10
    9 DO 7 K = 1,J
      EI(K) = E(K)
      AI(K) = A(K)
    7 BI(K) = B(K)
C
C    COMPARE EFFICIENCIES AND COSTS AT THE SECTION UNDER CONSIDERATION
C
   10 DO 1 JZ=1,1200
    1 R(JZ) = 1.
      DO 20 KC = 1,N
      ND = N-KC+1
      DO 20 L = 1,ND
      KL = KC + L
      AMXC = AI(KC) + BI(KC) * QMX
      AMXL = AI(KL) + BI(KL) * QMX
      IF(EI(KC).GE.EI(KL).AND.AI(KC).LT.AI(KL).AND.AMXC.LT.AMXL)
     &  R(KL) = 0.
      IF(EI(KL).GE.EI(KC).AND.AI(KL).LT.AI(KC).AND.AMXL.LT.AMXC)
     &  R(KC) = 0.
   20 CONTINUE
C
C    WRITE TITLE
C
```

```
      KDIF = KNT - KLINE
      IF (KDIF-30) 18,19,19
   19 KLINE = KNT
      WRITE (3,203)
  203 FORMAT ('1'//)
   18 WRITE (3,201) TITLE
  201 FORMAT(//,15X,19A4,/)
C
C    GIVE ALL NON-ZERO ELEMENTS THE PROPER LABEL AND STORE THEM IN
C    1-D ARRAYS
C
      KN1 = KNT1
      KNT1 = KNT
      NR = 0
      DO 30 KD = 1,LB
      IF (NR.LT.J) GO TO 25
      KN1 = KN1 + 1
      NR = 0
   25 NR = NR + 1
      IF (R(KD)) 21,21,22
   21 KNT = KNT-1
      GO TO 30
C
   22 LAB(KNT) =(LAB(KN1)*10) + NR
      IF(I.EQ.1) LAB(KNT) = NR
      EE(KNT) = EI(KD)
      AE(KNT) = AI(KD)
      BE(KNT) = BI(KD)
C
```

```
C   WRITE OUT RESULTS
C
      WRITE(3,200) LAB(KNT),EE(KNT),AE(KNT),BE(KNT)
  200 FORMAT(15X,I10,3F20.5)
      IF (CNT.EQ.CON) WRITE(2,205) LAB(KNT),EE(KNT),AE(KNT),BE(KNT)
  205 FORMAT(I8,2X,'EFF',F7.4,2X,'AE',F10.2,2X,'BE',F9.2)
   30 KNT = KNT + 1
      GO TO 3
   88 STOP
      END
```

APPENDIX C

INPUT DATA FOR MODEL FORMULATION

Input data for: Page

APSYSCST ROUTINE 191
SYSCØST ROUTINE 207
DYNAMIC PROGRAMMING PROGRAM 214

```
  NCMBR  3      NCMBF  1
BLACKFOOT (LOBENZO) SILT LOAM  --  HAY
  1.8   4.   50.   18.7   .25
BLACKFOOT (LOBENZO) SILT LOAM  --  GRAIN
1.8   2.5   50.   15.   .25
BLACKFOOT (LOBENZO) SILT LOAM  --  PASTURE
  1.8   2.   50.   14.9   .2
BLACKFOOT (LOBENZO) SILT LOAM  --  POTATOES
  1.8   3.   40.   18.6   .25
UNIMPROVED BORDER SYSTEM ON BLACKFOOT SILT LOAM   L = 1300   W = 600
FLEN  1300.   FWID  600.   SWID  65.
QFT  .026  DK  .26  TD  .56
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL  .8  GRL  1.5  RATL  5.
ECST  200.  LFC  0.  ELFE  15.  SVAL  0.  RINT  7.5
CPREP  2.4  CLOST  30.
CMAINT  50.  COEP  2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED BORDER SYSTEM ON BLACKFOOT SILT LOAM   L = 650  W = 500
FLEN  650.  FWID  500.  SWID  65.
QFT  .026  DK  .26  TD  .56
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL .75   GRL 1.5   RATL 5.
ECST  50.   LFC 0.0   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 2.4   CLOST 40.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED BORDER SYSTEM ON BLACKFOOT SILT LOAM   L = 400   W = 250
FLEN  400.   FWID 250.   SWID 65.
QFT  .026  DK  .26  TD  .56
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL .65   GRL 1.2   RATL 5.
ECST 40.   LFC 0.0   ELFE 15.0   SVAL 0.0   RINT 7.5
CPRIP 2.4   CLOST 30.
CMAINT 70.   COEP 2.
SRVAL   0.0   DPVAL   0.0
WATER RUNOFF OPTION
REWORK
IMPROVED BORDER SYSTEM ON BLACKFOOT SILT LOAM    L = 1300   W = 600
FLEN  650.   FWID  1200.   SWID  65.
QFT  .026  DK  .26  TD  .56
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL  .65  GRL  1.5  RATL  5.
FCST  1500.  LFC  0.0  ELFE  15.   SVAL  15.   RINT  7.5
CPREP  2.4  CLOST  50.
CMAINT  100.  COEP  2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED BORDER SYSTEM ON BLACKFOOT SILT LOAM   L= 650   W = 500
FLEN 650.   FWID 500.   SWID 97.
QFT  .026  DK  .26  TD  .56
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL .6   GRL 1.   RATL 5.
ECST  1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  2.4   CLOST 30.
CMAINT 70.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED BORDER SYSTEM ON BLACKFOOT SILT LOAM  L = 400   W = 250
FLEN 400.   FWID 250.   SWID 97.
QFT  .026  DK  .26  TD  .56
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL .6   GRL 1.   RATL 5.
ECST  1000.   LFC  0.0   ELFE  15.   SVAL  15.   RINT  7.5
CPREP 2.4   CLOST 20.
CMAINT 60.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
DO NOT REWORK
```

```
UNIMPROVED FURROW SYSTEM ON BLACKFOOT SILT LOAM   L = 1300   W = 600
FLEN 1300.   FWID 600.   SWID 180.
QFT  .022  DK   .13  TD  .55
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL 3.2   GRL 1.5   RATL 5.
ECST 200.   LFC 0.0   ELFE  15.   SVAL 0.0   RINT 7.5
CPREP 3.   CLOST 30.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED FURROW SYSTEM ON BLACKFOOT SILT LOAM   L = 650   W = 500
FLEN  650.   FWID  500.   SWID  180.
QFT  .022  DK   .13  TD  .55
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL 2.7   GRL 1.5   RATL 5.
ECST 150.   LFC 0.   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 3.   CLOST  30.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED FURROW SYSTEM ON BLACKFOOT SILT LOAM   L = 400   W = 250
FLEN  400.   FWID  250.   SWID  180.
QFT  .022  DK   .13  TD  .55
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL 2.5   GRL 1.5   RATL 5.
ECST 130.   LFC   0.0   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 3.0   CLOST 25.
CMAINT 40. COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON BLACKFOOT SILT LOAM   L = 1300   W = 600
FLEN 650.   FWID 1200.   SWID 180.
QFT  .022  DK   .13  TD  .55
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL 2.   GRL 1.5   RATL 5.
ECST 1500.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  3.   CLOST  30.
CMAINT 100.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON BLACKFOOT SILT LOAM   L = 650   W = 500
FLEN 650.   FWID 500.   SWID 240.
QFT  .022  DK   .13  TD  .55
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL 2.   GRL 1.2   RATL 5.
ECST 1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPRIP 3.   CLOST 25.
CMAINT 80.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON BLACKFOOT SILT LOAM   L = 400   W = 250
FLEN  400.   FWID  250.   SWID  240.
QFT  .022  DK   .13  TD  .55
DSTA  50.  AK  61.9  AN  .684  RK  100000.    RN  1.
SETL 1.8   GRL 1.5   RATL 5.
ECST 1000. LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  3.   CLOST  20.
CMAINT 80.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
DO NOT REWORK
```

```
HAND LINE SPRINKLER ON BLACKFOOT SILT LOAM   LLEN = 1300   AML = 160
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  .6
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 160.   CML 2.5   XML 2640.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON BLACKFOOT SILT LOAM   LLEN = 1300   AML = 80
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
RIMAX  .6
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 80.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON BLACKFOOT SILT LOAM   LLEN = 1300   AML = 50
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
RIMAX  .6
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 50.   CML 2.   XML 1960.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON BLACKFOOT SILT LOAM   LLEN = 700   AML = 40
LLEN  700.   LSPA 50.
TMOV 60.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
IMAX  .6
CNEW 700.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.5
 DPVAL   0.0
AML 40.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
```

```
SIDE ROLL SPRINKLER ON BLACKFOOT SILT LOAM   LLEN = 1300   AML = 160
LLEN 1300.   LSPA 50.
TMOV. 30.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
IMAX  .6
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 160.   CML 2.5   XML 2640.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER ON BLACKFOOT SILT LOAM   LLEN = 1300   AML = 80
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
IMAX  .6
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 80.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL,SPRINKLER ON BLACKFOOT SILT LOAM   LLEN = 1300   AML = 50
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
IMAX  .6
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 50.   CML 2.   XML 1960.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER ON BLACKFOOT SILT LOAM   LLEN = 700   AML = 40
LLEN  700.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
IMAX  .6
CNEW 3200.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 40.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
DO NOT REWORK
```

```
  NCMBB  3     NCMBF  1
HEISETON LOAM  --  HAY
 1.5  4.   50.   18.7   .25 .
HEISETON LOAM  --  GRAIN
 1.5  2.5  50.   15.   .25
HEISETON LOAM  --  PASTURE
1.5   2.   50.   14.9   .2
HEISETON LOAM  --  PCTATOES
1.5   3.   40.   18.6   .25
UNIMPROVED BORDER SYSTEM ON HEISETON LOAM  L = 1300  W = 600
FLEN  1300.   FWID  600.   SWID  65.
QFT  .028   DK  .42   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL  .8  GRL  1.5  RATL  5.
ECST  200.  LFC  0.  ELFE  15.  SVAL  0.  RINT  7.5
CPREP  2.4  CLOST  30.
CMAINT  50.  CCEP  2.
SRVAL   0.0   DPVAL  0.0
WATER RUNCFF OPTICN
REWORK
UNIMPROVED BORDER SYSTEM ON HEISETON LOAM  L = 650  W = 500
FLFN  650.  FWID  500.   SWID  65.
QFT  .028   DK  .42   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL .75   GRL 1.5   RATL 5.
ECST  50.   LFC 0.0   ELFE 15.   SVAL 0.C   RINT 7.5
CPREP 2.4   CLOST 40.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNCFF OPTICN
REWORK
UNIMPROVED BORDER SYSTEM ON HEISETON LOAM  L = 400  W = 250
FLEN  400.   FWID 250.   SWID 65.
QFT  .028   DK  .42   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL .65   GRL 1.2   RATL 5.
ECST 40.   LFC 0.0   ELFE 15.0   SVAL 0.0   RINT 7.5
CPREP  2.4   CLOST  30.
CMAINT 70.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPROVED BORDER SYSTEM CN HEISETON LOAM  L = 1300  W = 600
FLEN  650.   FWID  1200.   SWID  65.
QFT  .028   DK  .42   TC  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL  .65  GRL  1.5  RATL  5.
EXCST  1500.  LFC  0.0  ELFE  15.  SVAL  15.  RINT  7.5
CPREP  2.4  CLOST  50.
CMAINT  100.  COEP  2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPROVED BORDER SYSTEM CN HEISETON LOAM  L = 650  W = 500
FLEN 650.   FWID 500.   SWID 97.
QFT  .028   DK  .42   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL .6   GRL 1.   RATL 5.
ECST  1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  2.4   CLOST 30.
CMAINT 70.   CCEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPROVED BORDER SYSTEM CN HEISETON LOAM  L = 400  W = 250
FLEN 400.   FWID 250.   SWID 97.
QFT  .028   DK  .42   TC  .65
DSTA  50.  AK  65.2  AN  .681  RK  100C00.   RN 1.
SETL .6   GRL 1.   RATL 5.
ECST  1000.   LFC  0.0   ELFE  15.   SVAL  15.   RINT  7.5
CPREP 2.4   CLOST 20.
CMAINT 60.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
DO NCT REWORK
```

```
UNIMPROVED FURROW SYSTEM ON HEISETON LOAM  L = 1300  W = 600
FLEN  1300.   FWID  600.  SWID  180.
QFT  .024   DK  .21   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL 3.2   GRL 1.5   RATL 5.
ECST 200.   LFC 0.0   ELFE  15.   SVAL 0.0   RINT 7.5
CPREP 3.   CLOST 30.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED FURROW SYSTEM ON HEISETON LOAM  L = 650  W = 500
FLEN  650.  FWID  500.   SWID  180.
QFT  .024   DK  .21   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL 2.7   GRL 1.5   RATL 5.
ECST 150.   LFC 0.   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 3.   CLOST  30.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED FURROW SYSTEM ON HEISETON LOAM  L = 400  W = 250
FLWEN 400.   FWID 250.   SWID 180.
QFT  .024   DK  .21   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL 2.5   GRL 1.5   RATL 5.
ECST 130.   LFC   0.0   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 3.0   CLOST 25.
CMAINT 40. COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON HEISETON LOAM  L = 1300  W = 600
FLEN 650.   FWID 1200.   SWID 180.
QFT  .024   DK  .21   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL 2.   GRL 1.5   RATL 5.
ECST 1500.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  3.   CLOST  30.
CMAINT 100.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON HEISETON LOAM  L = 650  W = 500
FLEN 650.   FWID 500.   SWID 240.
QFT  .024   DK  .21   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL 2.   GRL 1.2   RATL 5.
ECST 1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  3.   CLOST  25.
CMAINT 80.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON HEISETON LOAM  L = 400  W = 250
FLEN  400.   FWID  250.   SWID  240.
QFT  .024   DK  .21   TD  .65
DSTA  50.  AK  65.2  AN  .681  RK  100000.   RN 1.
SETL 1.8   GRL 1.5   RATL 5.
ECST 1000. LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  3.   CLOST  20.
CMAINT 80.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
DO NOT REWORK
```

```
HAND LINE SPRINKLER CN HEISETON LOAM  LLEN = 1300  AML = 160
LLEN 1300.   LSPA 50.
TMOV· 75.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
IMAX  .8
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 160.   CML 2.5   XML 2640.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER CN HEISETON LOAM  LLEN = 1300  AML = 80
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
IMAX  .8
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 80.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON HEISETON LOAM  LLEN = 1300  AML = 50
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
IMAX  .8
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 50.   CML 2.   XML 1960.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON HEISETON LOAM  LLEN = 700  AML = 40
LLEN  700.   LSPA 50.
TMOV 60.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
IMAX  .8
CNEW 700.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.5
 DPVAL   0.0
AML 40.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
```

```
SIDE ROLL SPRINKLER CN HEISETON LOAM  LLEN = 1300  AML = 160
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
CAEFF 70.   OLCSS 10.
RIMAX  .8
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 160.   CML 2.5   XML 2640.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER CN HEISETON LOAM  LLEN = 1300  AML = 80
LLEN 1300.   LSPA 50.
TMCV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  .8
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 80.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER CN HEISETON LOAM  LLEN = 1300  AML = 50
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
RIMAX  .8
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 50.   CML 2.   XML 1960.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER CN HEISETON LOAM  LLEN = 700  AML = 40
LLEN  700.   LSPA 50.
TMCV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  .8
CNEW 3200.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 40.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
DO NOT REWORK
```

```
  NCMBB  3      NCMBF  1
HAYESTON SANDY LOAM  --  HAY
1.25  4.   50.   18.7   .25
HAYESTON SANDY LOAM  --  GRAIN
1.25   2.5  50.   15.   .25
HAYESTON SANDY LOAM  --  PASTURE
1.25  2.   50.   14.9   .2
HAYESTON SANDY LOAM  --  POTATOES
1.25  3.   40.   18.6   .25
UNIMPROVED BORDER SYSTEM ON HAYESTON SANDY LCAM  L = 1300  W = 600
FLEN  1300.   FWIC  600.   SWID  65.
QFT  .067   DK  .23   TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL  .8  GRL  1.5  RATL  5.
ECST  200.  LFC  0.  ELFE  15.  SVAL  0.  RINT  7.5
CPREP  2.4  CLOST  30.
CMAINT  50.  COEP  2.
SRVAL   0.0   DPVAL  0.0
WATER RUNCFF OPTICN
REWORK
UNIMPROVED BORDER SYSTEM ON HAYESTON SANDY LOAM  L = 650  W = 500
FLEN  650.  FWID  500.   SEID  65.
QFT  .067   DK  .23   TC  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL .75   GRL 1.5   RATL 5.
ECST  50.   LFC 0.0   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 2.4   CLOST 40.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNCFF OPTICN
REWORK
UNIMPROVED BORCER SYSTEM ON HAYESTON SANDY LOAM  L = 400  W = 250
FLEN  400.   FWID 250.   SWID 65.
CFT  .067   DK  .23   TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL .65   GRL 1.2   RATL 5.
ECST 40.   LFC 0.0   ELFE 15.0   SVAL 0.0   RINT 7.5
CPREP 2.4   CLOST 30.
CMAINT 70.   COEP 2.
SRVAL   0.0   CPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPROVED BORDER SYSTEM CN HAYESTON SANDY LOAM  L = 1300  W = 600
FLEN  650.   FWID  1200.   SWID  65.
CFT  .067   DK  .23   TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL  .65  GRL  1.5  RATL  5.
FXCST  1500.  LFC  0.0  ELFE  15.  SVAL  15.  RINT  7.5
CPREP  2.4  CLOST  50.
CMAINT  100.  COEP  2.
SRVAL   0.0   CPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPROVED BORDER SYSTEM ON HAYESTON SANDY LOAM  L = 650  W = 500
FLEN 650.   FWID 500.   SWID 97.
CFT  .067   DK  .23   TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL .6   GRL 1.   RATL 5.
ECST  1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  2.4   CLOST 30.
CMAINT 70.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPROVED BORDER SYSTEM CN HAYESTON SANCY LCAM  L = 400  W = 250
FLEN 400.   FWID 250.   SWID 97.
QFT  .067   DK  .23   TC  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL .6   GRL 1.   RATL 5.
ECST 1000.   LFC 0.0   ELFE 15.   SVAL 15.   RING 7.5
CPREP 2.4   CLOST 20.
CMAINT 50.   CCEP 2.
SRVAL   0.0   CPVAL  0.0
WATER RUNCFF OPTICN
CO NCT REWCRK
```

```
UNIMPROVED FURROW SYSTEM ON HAYESTON SANDY LOAM  L = 1300  W = 600
FLEN 1300.   FWID 600.   SWID 180.
QFT .037   DK  .12  TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL 3.2   GRL 1.5   RATL 5.
ECST 200.   LFC 0.0   ELFE  15.   SVAL 0.0   RINT 7.5
CPREP 3.   CLOST 30.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED FURROW SYSTEM ON HAYESTON SANDY LOAM  L = 650  W = 500
FLEN  650.   FWID  500.   SWID  180.
QFT  .037   DK  .12  TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL 2.7   GRL 1.5   RATL 5.
ECST 150.   LFC 0.   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 3.   CLOST  30.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED FURROW SYSTEM ON BLACKFOOT SILT LOAM   L = 400   W = 250
FLEN  400.   FWID  250.  SWID  180.
QFT  .037   DK  .12  TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL 2.5   GRL 1.5   RATL 5.
ECST 130.   LFC   0.0   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 3.0   CLOST 25.
CMAINT 40. COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON HAYESTON SANDY LOAM  L = 1300  W = 600
FLEN 650.   FWID 1200.   SWID 180.
QFT  .037   DK  .12  TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL 2.  GRL 1.5  RATL 5.
ECST 1500.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  3.   CLOST  30.
CMAINT 100.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON HAYESTON SANDY LOAM  L = 650  W = 500
FLEN 650.   FWID 500.   SWID 240.
QFT  .037   DK  .12  TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL 2.  GRL 1.2  RATL 5.
ECST 1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP 3.   CLOST 25.
CMAINT 80.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED FURROW SYSTEM ON HAYESTON SANDY LOAM  L = 400  W = 250
FLEN  400.   FWID  250.  SWID  240.
QFT  .037   DK  .12  TD  .86
DSTA  50.  AK  19.6  AN  .815   RK  100000.  RN  1.
SETL 1.8   GRL 1.5   RATL 5.
ECST 1000. LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPRIP 3.   CLOST 20.
CMAINT 80.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
DO NOT REWORK
```

```
HAND LINE SPRINKLER ON HAYESTON SANDY LOAM  LLEN = 1300  AML = 160
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  1.3
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 160.   CML 2.5   XML 2640.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON HAYESTON SANDY LOAM  LLEN = 1300  AML = 80
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  1.3
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 80.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON HAYESTON SANDY LOAM  LLEN = 1300  AML = 50
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  1.3
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 50.   CML 2.   XML 1960.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON HAYESTON SANDY LOAM  LLEN = 700  AML = 40
LLEN  700.   LSPA 50.
TMOV 60.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  1.3
CNEW 700.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.5
 DPVAL   0.0
AML 40.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
```

```
SIDE ROLL SPRINKLER ON HAYESTON SANDY LOAM  LLEN = 1300  AML = 160
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  1.3
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 160.   CML 2.5   XML 2640.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER ON HAYESTON SANDY LOAM  LLEN = 1300  AML = 80
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  1.3
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 80.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER ON HAYESTON SANDY LOAM  LLEN = 1300  AML = 50
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  1.3
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 50.   CML 2.   XML 1960.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER ON HAYESTON SANDY LOAM  LLEN = 700  AML = 40
LLEN  700.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX  1.3
CNEW 3200.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 40.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
DO NOT REWORK
```

```
  NCMBB  3     NCMBF  1
WORBORO GRAVELLY LOAM  --  HAY
 1. . 4.   60.   18.7   .25
WORBORO GRAVELLY LOAM  --  GRAIN
  1.   2.5   50.   15.   .25
WORBORO GRAVELLY LOAM  --  PASTURE
1.   2.   50.   14.9   .2
WORBORO GRAVELLY LOAM  --  POTATOES
1.   3.   50.   18.6   .25
UNIMPROVED BORDER SYSTEM ON WORBORO GRAVELLY LOAM  L = 1300  W = 600
FLEN  1300.   FWID  600.   SWID  65.
QFT .127   DK .36  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL  .8  GRL  1.5  RATL  5.
ECST  200.  LFC  0.  ELFE  15.  SVAL  0.  RINT  7.5
CPREP  2.4  CLOST  30.
CMAINT  50.  COEP  2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED BORDER SYSTEM ON WORBORO GRAVELLY LOAM  L = 650  W = 500
FLEN  650.   FWID  500.  SWID  65.
QFT .127   DK .36  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL .75    GRL 1.5    RATL 5.
ECST  50.   LFC 0.0   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 2.4   CLOST 40.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
UNIMPROVED BORDER SYSTEM ON WORBORO GRAVELLY LOAM  L = 400  W = 250
FLEN  400.   FWID 250.   SWID 65.
QFT .127   DK .36  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL .65   GRL 1.2   RATL 5.
ECST 40.   LFC 0.0   ELFE 15.0   SVAL 0.0   RINT 7.5
CPREP  2.4   CLOST  30.
CMAINT 70.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED BORDER SYSTEM ON WORBORO GRAVELLY LOAM  L = 1300  W = 600
FLEN  650.   FWID  1200.   SWID  65.
QFT .127   DK .36  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL  .65  GRL  1.5  RATL  5.
EXCST  1500.  LFC  0.0  ELFE  15.  SVAL  15.  RINT  7.5
CPREP  2.4  CLOST  50.
CMAINT  100.  COEP  2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED BORDER SYSTEM ON WORBORO GRAVELLY LOAM  L = 650  W = 500
FLEN 650.   FWID 500.   SWID 97.
QFT .127   DK .36  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL .6   GRL 1.   RATL 5.
ECST  1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  2.4   CLOST 30.
CMAINT 70.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
REWORK
IMPROVED BORDER SYSTEM ON WORBORO GRAVELLY LOAM  L = 400  W = 250
FLEN 400.   FWID 250.   SWID 97.
QFT .127   DK .36  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL .6   GRL 1.   RATL 5.
ECST 1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP 2.4   CLOST 20.
CMAINT 60.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTION
DO NOT REWORK
```

```
UNIMPROVED FURROW SYSTEM CN WORBORO GRAVELLY LOAM  L = 1300  W = 600
FLEN  1300.   FWID  600.   SWID  180.
QFT  .048   DK  .18  TC  .83.
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL 3.2   GRL 1.5   RATL 5.
ECST 200.   LFC 0.0   ELFE  15.   SVAL 0.0   RINT 7.5
CPREP 3.   CLOST 30.
CMAINT 50.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
REWCRK
UNIMPROVED FURROW SYSTEM ON BLACKFOOT SILT LCAM   L = 650   W = 500
FLFN  650.   FWID  500.   SWID  180.
QFT  .048   DK  .18  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL 2.7   GRL 1.5   RATL 5.
ECST 150.   LFC 0.   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 3.   CLUST  30.
CMAINT 50.   CCEP 2.
SRVAL   0.0   CPVAL  0.0
WATER RUNOFF CPTICN
REWORK
UNIMPROVED FURROW SYSTEM CN WORBORO GRAVELLY LCAM  L = 400  W = 250
FLEN  400.   FWID  250.   SWID  180.
QFT  .048   DK  .18  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL 2.5   GRL 1.5   RATL 5.
ECST 130.   LFC   0.0   ELFE 15.   SVAL 0.0   RINT 7.5
CPREP 3.0   CLOST 25.
CMAINT 40. COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPROVED FURROW SYSTEM CN WCRBORO GRAVELLY LOAM  L = 1300  W = 600
FLEN 650.   FWID 1200.   SWID 180.
QFT  .048   DK  .18  TD  .83
CSTA  50.  AK  61.2  AN  .637  RK  100C00.  RN  1.
SETL 2.   GRL 1.5   RATL 5.
ECST 1500.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP 3.   CLOST 30.
CMAINT 100.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPRCVED FURRCW SYSTEM CN WCRBORO GRAVELLY LOAM  L = 650  W = 500
FLEN 650.   FWID 500.   SWID 240.
QFT  .048   DK  .18  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL 2.   GRL 1.2   RATL 5.
ECST 1000.   LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  3.   CLOST  25.
CMAINT 80.   COEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
REWORK
IMPRCVED FURROW SYSTEM CN WCRBORO GRAVELLY LOAM  L = 400  W = 250
FLEN  400.   FWID  250.   SWID  240.
QFT  .048   DK  .18  TD  .83
DSTA  50.  AK  61.2  AN  .637  RK  100000.  RN  1.
SETL 1.8   GRL 1.5   RATL 5.
ECST 1000. LFC 0.0   ELFE 15.   SVAL 15.   RINT 7.5
CPREP  3.   CLOST  20.
CMAINT 80.   CCEP 2.
SRVAL   0.0   DPVAL  0.0
WATER RUNOFF OPTICN
DO NOT REWORK
```

```
HAND LINE SPRINKLER ON WCRBORO GRAVELLY LOAM  LLEN = 1300  AML = 160
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
RIMAX   1.8
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 160.   CML 2.5   XML 2640.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON WCRBORO GRAVELLY LOAM  LLEN = 1300  AML = 80
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
RIMAX   1.8
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 80.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON WCRBORO GRAVELLY LOAM  LLEN = 1300  AML = 50
LLEN 1300.   LSPA 50.
TMOV 75.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX   1.8
CNEW 1100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 2.5
 DPVAL   0.0
AML 50.   CML 2.   XML 1960.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
HAND LINE SPRINKLER ON WCRBORO GRAVELLY LOAM  LLEN = 700  AML = 40
LLEN  700.   LSPA 50.
TMOV 60.   TSTET 8,12,16,24,36
CAEFF 70.   OLOSS 10.
RIMAX   1.8
CNEW 700.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.5
 DPVAL   0.0
AML 40.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
```

```
SIDE ROLL SPRINKLER ON WORBORO GRAVELLY LOAM  LLEN = 1300  AML = 160
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX   1.8
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 160.   CML 2.5   XML 2640.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER ON WORBORO GRAVELLY LOAM  LLEN = 1300  AML = 80
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX   1.8
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 80.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER ON WORBORO GRAVELLY LOAM  LLEN = 1300  AML = 50
LLEN 1300.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX   1.8
CNEW 4100.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 50.   CML 2.   XML 1960.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
REWORK
SIDE ROLL SPRINKLER ON WORBORO GRAVELLY LOAM  LLEN = 700  AML = 40
LLEN  700.   LSPA 50.
TMOV 30.   TSTET 8,12,16,24,36
OAEFF 70.   OLOSS 10.
RIMAX   1.8
CNEW 3200.   TLIFE 15.   RINT 7.5   OEXP 3.   SVAL 10.
RLABOR 3.00   TTRAN 1.
 DPVAL   0.0
AML 40.   CML 2.   XML 1320.
TIML 20.   TINT 7.5   TSAL 5.   TOEX 3.
VLAND 25.
DO NOT REWORK
STP   0  0
```

```
READ   GRAVITY PIPE -- SECTION GPA
CF  100.0
PIPE SIZES   6.   8.   10.  12.  15.  18.  24.  30.  36.  42.  48.
SZE   6. CPIP  2.24 CLAY 0.  CTRN 1.00  CVLV  266.96  CTO 700. CMET 0.  CREG 0.
SZE   8. CPIP  2.97 CLAY 0.  CTRN 1.00  CVLV  334.50  CTO 700. CMET 0.  CREG 0.
SZE  10. CPIP  3.84 CLAY 0.  CTRN 1.00  CVLV  432.34  CTO 700. CMET 0.  CREG 0.
SZE  12. CPIP  4.49 CLAY 0.  CTRN 1.00  CVLV  526.73  CTO 700. CMET 0.  CREG 0.
SZE  15. CPIP  6.33 CLAY 0.  CTRN 1.00  CVLV  966.04  CTO 700. CMET 0.  CREG 0.
SZE  18. CPIP  7.93 CLAY 0.  CTRN 1.33  CVLV 1395.98  CTO 700. CMET 0.  CREG 0.
SZE  24. CPIP 11.23 CLAY 0.  CTRN 1.66  CVLV 1850.00  CTO 700. CMET 0.  CREG 0.
SZE  30. CPIP 14.95 CLAY 0.  CTRN 2.00  CVLV 2415.00  CTO 700. CMET 0.  CREG 0.
SZE  36. CPIP 19.99 CLAY 0.  CTRN 2.32  CVLV 3280.00  CTO 700. CMET 0.  CREG 0.
SZE  42. CPIP 23.33 CLAY 0.  CTRN 2.67  CVLV 3942.00  CTO 800. CMET 0.  CREG 0.
SZE  48. CPIP 27.67 CLAY 0.  CTRN 3.00  CVLV 4817.00  CTO 800. CMET 0.  CREG 0.
RWID   8.0     RVAL 250.00
TLFE  100.0     RINT  6.5     SVAL  0.0
OEXP  3.0     PVAL   0.0
SLEN  1831.0      ELO     65.0      ELI     70.0     HDO     5.0     HDI     5.0
XVLV  0.      XTO  1.      XMET  0.      XREG  0.
MINQ    1     MAXQ   52     KNTQ     3
SKIP   GRAVITY PIPE -- SECTION GPB
SLEN  5153.0      ELO     53.0      ELI     65.0     HDO     5.0     HDI     5.0
XVLV  1.      XTO  1.      XMET  0.      XREG  0.
MINQ    1     MAXQ   42     KNTQ     3
SKIP   GRAVITY PIPE -- SECTION GPC
SLEN  5831.0      ELO     42.0      ELI     53.0     HDO     5.0     HDI     5.0
XVLV  1.      XTO  1.      XMET  0.      XREG  0.
MINQ    1     MAXQ   33     KNTQ     2
SKIP   GRAVITY PIPE -- SECTION GPD
SLEN  5153.0      ELO     33.5      ELI     42.0     HDO     5.0     HDI     5.0
XVLV  2.      XTO  1.      XMET  0.      XREG  0.
MINQ    1     MAXQ   33     KNTQ     2
SKIP   GRAVITY PIPE -- SECTION GPE
SLEN  2712.0      ELO     28.0      ELI     33.5     HDO     5.0     HDI     5.0
XVLV  1.      XTO  2.      XMET  0.      XREG  0.
MINQ    1     MAXQ   21     KNTQ     2
SKIP   GRAVITY PIPE -- SECTION GPF
SLEN  4238.0      ELO     23.0      ELI     28.0     HDO     5.0     HDI     5.0
XVLV  0.      XTO  2.      XMET  0.      XREG  0.
MINQ    1     MAXQ   15     KNTQ     1
SKIP   GRAVITY PIPE -- SECTION GPH
SLEN  1898.0      ELO     60.0      ELI     59.0     HDO     3.0     HDI     7.0
XVLV  0.      XTO  1.      XMET  0.      XREG  0.
MINQ    1     MAXQ   20     KNTQ     2
END    DATA
```

```
READ   PRESSURE PIPE -- SECTION PPA
CF  130.0
PIPE SIZES   6.   8.  10.  12.  15.  18.  24.  30.  36.  42.  48.
SZE   6. CPIP  3.36 CLAY 0.  CTRN 1.00  CVLV  355.95  CTO 700. CMET 0.  CREG 0.
SZE   8. CPIP  4.45 CLAY 0.  CTRN 1.00  CVLV  446.00  CTO 700. CMET 0.  CREG 0.
SZE  10. CPIP  5.76 CLAY 0.  CTRN 1.00  CVLV  576.45  CTO 700. CMET 0.  CREG 0.
SZE  12. CPIP  6.73 CLAY 0.  CTRN 1.00  CVLV  702.30  CTO 700. CMET 0.  CREG 0.
SZE  15. CPIP  9.49 CLAY 0.  CTRN 1.00  CVLV 1288.05  CTO 700. CMET 0.  CREG 0.
SZE  18. CPIP 11.90 CLAY 0.  CTRN 1.33  CVLV 1861.30  CTO 700. CMET 0.  CREG 0.
SZE  24. CPIP 16.85 CLAY 0.  CTRN 1.66  CVLV 3220.00  CTO 700. CMET 0.  CREG 0.
SZE  30. CPIP 22.43 CLAY 0.  CTRN 2.00  CVLV 4630.00  CTO 700. CMET 0.  CREG 0.
SZE  36. CPIP 29.98 CLAY 0.  CTRN 2.32  CVLV 6100.00  CTO 800. CMET 0.  CREG 0.
SZE  42. CPIP 35.00 CLAY 0.  CTRN 2.67  CVLV 7650.00  CTO 850. CMET 0.  CREG 0.
SZE  48. CPIP 41.50 CLAY 0.  CTRN 3.00  CVLV 9500.00  CTO 900. CMET 0.  CREG 0.
RWID   8.0     RVAL  20.00
TLFE  100.0     RINT  6.5      SVAL  0.0
OEXP  4.0     PVAL   0.0
SLEN   644.0      ELO     60.0      ELI     60.0      HDO  180.0      HDI  185.0
XVLV  2.      XTO  0.      XMET  0.      XREG  0.
MINQ    1      MAXQ   52      KNTQ     3
SKIP   PRESSURE PIPE -- SECTION PPB
SLEN  2610.0      ELO     53.5      ELI     60.0      HDO  175.0      HDI  180.0
XVLV  0.      XTO  1.      XMET  0.      XREG  0.
MINQ    1      MAXQ   40      KNTQ     3
SKIP   PRESSURE PIPE -- SECTION PPC
SLEN  5288.0      ELO     42.0      ELI     53.5      HDO  170.0      HDI  175.0
XVLV  0.      XTO  3.      XMET  0.      XREG  0.
MINQ    1      MAXQ   37      KNTQ     3
SKIP   PRESSURE PIPE -- SECTION PPD
SLEN  4542.0      ELO     33.0      ELI     42.0      HDO  170.0      HDI  170.0
XVLV  1.      XTO  3.      XMET  0.      XREG  0.
MINQ    1      MAXQ   33      KNTQ     2
SKIP   PRESSURE PIPE -- SECTION PPE
SLEN  2644.0      ELO     28.0      ELI     33.0      HDO  170.0      HDI  170.0
XVLV  0.      XTO  2.      XMET  0.      XREG  0.
MINQ    1      MAXQ   21      KNTQ     2
SKIP   PRESSURE PIPE -- SECTION PPF
SLEN  4238.0      ELO     23.0      ELI     28.0      HDO  170.0      HDI  170.0
XVLV  0.      XTO  2.      XMET  0.      XREG  0.
MINQ    1      MAXQ   15      KNTQ     1
SKIP   PRESSURE PIPE -- SECTION PPH
SLEN  2373.0      ELO     65.0      ELI     60.0      HDO  170.0      HDI  180.0
XVLV  0.      XTO  2.      XMET  0.      XREG  0.
MINQ    1      MAXQ   15      KNTQ     1
END    DATA
```

```
READ   LINED CHANNEL -- SECTION LCA
STO,CTO,...  55., 704.
SDRP,CDRP,...  10., 452.  15., 510.  21., 638.  28., 890.  35.,1119.  42.,1294.,
  52.,1410.
SCMB,CCMB,...  10.,1052.  15.,1110.  21.,1238.  28.,1490.  35.,1719.  42.,1894.,
  52.,2010.
SWER,CWER,...  55.,2310.
SBRD,CBRD,...   4.,2180.   6.,2442.   8.,2910.  10.,2435.  11.,3830.  12.,4500.,
  14.,4650.  16.,4900.  18.,5125.  20.,5400.  22.,5800.  24.,6100.  26.,6400.
  30.,7650.
SBFD,CBFD,...   4.,1631.   6.,1762.   8.,1947.  10.,2175.  12.,2387.  14.,2675.,
  16.,2918.  18.,3310.  20.,3415.  22.,3550.  24.,3905.  26.,4135.
CEX 0.70     CLN  3.38     THLN 2.00
Z  1.0     BH  1.33     RN  0.014     VMX  8.     YMN  1.0
DPV  0.0       DPT  120.
TLFE  100.0      RINT  6.5      SVAL 10.0
DEXP  3.0
RWID  10.0      RVAL  500.0
CMZ  0.10      PVAL -30.00
SLEN  1763.0      ELO     65.0     ELI     70.0
XTO  1.      XDRP  0.      XCMB  1.      XWER  0.      XBRD  0.      XBFD  1.
MINQ     1     MAXQ    52     KNTQ     3
SKIP   LINED CHANNEL -- SECTION LCB
CMZ  0.10      PVAL -20.00
SLEN  4407.0      ELO     53.5     ELI     65.0
XTO  1.      XDRP  0.      XCMB  1.      XWER  0.      XBRD  2.      XBFD  0.
MINQ     1     MAXQ    43     KNTQ     3
SKIP   LINED CHANNEL -- SECTION LCC
CMZ  0.10      PVAL -20.00
SLEN  6475.0      ELO     42.0     ELI     53.5
XTO  2.      XDRP  0.      XCMB  2.      XWER  0.      XBRD  1.      XBFD  0.
MINQ     1     MAXQ    34     KNTQ     3
SKIP   LINED CHANNEL -- SECTION LCD
CMZ  0.10      PVAL -15.00
SLEN  4002.0      ELO     36.5     ELI     42.0
XTO  1.      XDRP  0.      XCMB  2.      XWER  0.      XBRD  1.      XBFD  1.
MINQ     1     MAXQ    25     KNTQ     2
SKIP   LINED CHANNEL -- SECTION LCE
CMZ  0.10      PVAL -15.00
SLEN  4475.0      ELO     28.0     ELI     36.5
XTO  2.      XDRP  0.      XCMB  2.      XWER  0.      XBRD  0.      XBFD  2.
MINQ     1     MAXQ    21     KNTQ     2
SKIP   LINED CHANNEL -- SECTION LCF
CMZ  0.10      PVAL -10.00
SLEN  4339.0      ELO     23.0     ELI     28.0
XTO  1.      XDRP  0.      XCMB  0.      XWER  0.      XBRD  0.      XBFD  3.
MINQ     1     MAXQ    15     KNTQ     1
SKIP   LINED CHANNEL -- SECTION LCG
CMZ  0.10      PVAL  -5.00
SLEN  2305.0      ELO     27.0     ELI     28.0
XTO  0.      XDRP  0.      XCMB  0.      XWER  0.      XBRD  0.      XBFD  1.
MINQ     1     MAXQ    15     KNTQ     1
SKIP   LINED CHANNEL -- SECTION LCH
CMZ  0.10      PVAL -15.00
SLEN  2780.0      ELO     60.0     ELI     65.0
XTO  1.      XDRP  0.      XCMB  0.      XWER  0.      XBRD  1.      XBFD  0.
MINQ     1     MAXQ    21     KNTQ     2
SKIP   LINED CHANNEL -- SECTION LCK
CMZ  0.10      PVAL  -5.00
SLEN  1695.0      ELO     53.0     ELI     54.0
XTO  0.      XDRP  0.      XCMB  0.      XWER  0.      XBRD  0.      XBFD  2.
MINQ     1     MAXQ    15     KNTQ     1
END    DATA
```

```
READ   UNLINED CHANNEL -- SECTION UCA
STO,CTO,...  55., 704.
SDRP,CDRP,...  10., 452.  15., 510.  21., 638.  28., 890.  35.,1119.  42.,1294.,
  52.,1410.
SCMB,CCMB,...  10.,1052.  15.,1110.  21.,1238.  28.,1490.  35.,1719.  42.,1894.,
  52.,2010.
SWER,CWER,...  55.,2310.
SBRD,CBRD,...   4.,2180.   6.,2442.   8.,2910.  10.,2435.  11.,3830.  12.,4500.,
  14.,4650.  16.,4900.  18.,5125.  20.,5400.  22.,5800.  24.,6100.  26.,6400.
  30.,7650.
SBFD,CBFD,...   4.,1631.   6.,1762.   8.,1947.  10.,2175.  12.,2387.  14.,2675.,
  16.,2918.  18.,3310.  20.,3415.  22.,3550.  24.,3905.  26.,4135.
CEX 0.20     CLN  0.0      THLN 0.0
Z  1.5     BH  1.33     RN  0.035     VMX  4.     YMN  1.0
DPV  0.0      DPT  120.
TLFE  100.0     RINT  6.5     SVAL  5.0
OEXP  3.0
RWID  10.0     RVAL  500.0
CMZ  2.60     PVAL  25.00
SLEN  1831.0     ELO    65.0     ELI     69.0
XTO  1.     XDRP  0.     XCMB  1.     XWER  0.     XBRD  0.     XBFD  1.
MINQ    1     MAXQ   52     KNTQ    3
SKIP   UNLINED CHANNEL -- SECTION UCB
CMZ  2.20     PVAL -20.00
SLEN  5356.0     ELO    53.5     ELI     65.0
XTO  1.     XDRP  0.     XCMB  2.     XWER  0.     XBRD  2.     XBFD  0.
MINQ    1     MAXQ   40     KNTQ    3
SKIP   UNLINED CHANNEL -- SECTION UCC
CMZ  1.70     PVAL  10.00
SLEN  5831.0     ELO    42.0     ELI     53.5
XTO  3.     XDRP  0.     XCMB  2.     XWER  0.     XBRD  1.     XBFD  1.
MINQ    1     MAXQ   30     KNTQ    3
SKIP   UNLINED CHANNEL -- SECTION UCD
CMZ  2.80     PVAL   0.0
SLEN  5119.0     ELO    35.0     ELI     42.0
XTO  2.     XDRP  0.     XCMB  2.     XWER  0.     XBRD  1.     XBFD  1.
MINQ    1     MAXQ   30     KNTQ    3
SKIP   UNLINED CHANNEL -- SECTION UCE
CMZ  2.60     PVAL  10.00
SLEN  3593.0     ELO    28.0     ELI     35.0
XTO  3.     XDRP  0.     XCMB  2.     XWER  0.     XBRD  0.     XBFD  2.
MINQ    1     MAXQ   12     KNTQ    1
SKIP   UNLINED CHANNEL -- SECTION UCF
CMZ  1.70     PVAL  15.00
SLEN  3322.0     ELO    23.0     ELI     28.0
XTO  1.     XDRP  0.     XCMB  0.     XWER  0.     XBRD  0.     XBFD  3.
MINQ    1     MAXQ   15     KNTQ    1
SKIP   UNLINED CHANNEL -- SECTION UCG
CMZ  1.70     PVAL   0.0
SLEN  2359.0     ELO    27.0     ELI     28.0
XTO  0.     XDRP  0.     XCMB  0.     XWER  0.     XBRD  0.     XBFD  1.
MINQ    1     MAXQ   10     KNTQ    1
SKIP   UNLINED CHANNEL -- SECTION UCH
CMZ  2.70     PVAL -10.00
SLEN  2805.0     ELO    54.0     ELI     62.0
XTO  2.     XDRP  0.     XCMB  0.     XWER  0.     XBRD  1.     XBFD  1.
MINQ    1     MAXQ   31     KNTQ    3
END    DATA
```

```
READ    PUMP COST DATA FOR ALL UNITS    EFF = 55%
TDH 180.    PMQ,PMC       0.,  1644.    200.,  1644.    400.,  3289.    800.,  6578. ,
  1600., 13155.  3200., 26311.  6400., 52622. 12800.,105244. 25600.,210489.
A  30.   R  1.65    T  16.   WM  5.00   WO  4.00
QMX,CQX,... 30000.,       0.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0      PVAL -200.00
WRQ  1.63  4.68  7.07  4.62  1.93
EFF  55.0
SKIP    PUMP COST DATA FOR ALL UNITS    EFF = 60%
EFF  60.0
SKIP    PUMP COST DATA FOR ALL UNITS    EFF = 65%
EFF  65.0
SKIP    PUMP COST DATA FOR ALL UNITS    EFF = 70%
EFF  70.0
SKIP    PUMP COST DATA FOR ALL UNITS    EFF = 75%
EFF  75.0
SKIP    PUMP COST DATA FOR ALL UNITS    EFF = 80%
EFF  80.0
END     DATA
READ    PUMP COST DATA FOR UNITS I-V    EFF = 55%
TDH 180.    PMQ,PMC       0.,  1644.    200.,  1644.    400.,  3289.    800.,  6578. ,
  1600., 13155.  3200., 26311.  6400., 52622. 12800.,105244. 25600.,210489.
A  30.   R  1.65    T  16.   WM  5.00   WO  4.00
QMX,CQX,... 30000.,       0.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0      PVAL -200.00
WRQ  1.57  4.63  7.13  4.03  1.73
EFF  55.0
SKIP    PUMP COST DATA FOR UNITS I-V    EFF = 60%
EFF  60.0
SKIP    PUMP COST DATA FOR UNITS I-V    EFF = 65%
EFF  65.0
SKIP    PUMP COST DATA FOR UNITS I-V    EFF = 70%
EFF  70.0
SKIP    PUMP COST DATA FOR UNITS I-V    EFF = 75%
EFF  75.0
SKIP    PUMP COST DATA FOR UNITS I-V    EFF = 80%
EFF  80.0
END     DATA
READ    PUMP COST DATA FOR UNITS VI-VII    EFF = 55%
TDH 180.    PMQ,PMC       0.,  1644.    200.,  1644.    400.,  3289.    800.,  6578. ,
  1600., 13155.  3200., 26311.  6400., 52622. 12800.,105244. 25600.,210489.
A  30.   R  1.65    T  16.   WM  5.00   WO  4.00
QMX,CQX,... 30000.,       0.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0      PVAL -200.00
OEXP  3.0      PVAL-200.00
WRQ  1.76  4.78  6.96  4.77  2.33
EFF  55.0
SKIP    PUMP COST DATA FOR UNITS VI-VII    EFF = 60%
EFF  60.0
SKIP    PUMP COST DATA FOR UNITS VI-VII    EFF = 65%
EFF  65.0
SKIP    PUMP COST DATA FOR UNITS VI-VII    EFF = 70%
EFF  70.0
SKIP    PUMP COST DATA FOR UNITS VI-VII    EFF = 75%
EFF  75.0
SKIP    PUMP COST DATA FOR UNITS VI-VII    EFF = 80%
EFF  80.0
END     DATA
```

```
READ   LOW HEAD WELL & PUMP COST DATA FOR ALL UNITS   EFF = 55%
TDH 120.   PMQ,PMC      0.,  1644.   200.,  1644.   400.,  3289.   800.,  6578. ,
 1600., 13155.  3200., 26311.  6400., 52622. 12800.,105244. 25600.,210489.
A  30.   R  1.65   T  16.   WM  5.00   WO  4.00
QMX,CQX,...    900.,  3400.  1900.,  4605.  3000.,  5640.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0     PVAL -200.00
WRQ  1.57  4.63  7.13  4.03  1.73
EFF  55.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR ALL UNITS   EFF = 60%
EFF  60.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR ALL UNITS   EFF = 65%
EFF  65.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR ALL UNITS   EFF = 70%
EFF  70.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR ALL UNITS   EFF = 75%
EFF  75.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR ALL UNITS   EFF = 80%
EFF  80.0
END    DATA
READ   LOW HEAD WELL & PUMP COST DATA FOR UNITS I-V    EFF = 55%
TDH 120.   PMQ,PMC      0.,  1644.   200.,  1644.   400.,  3289.   800.,  6578. ,
 1600., 13155.  3200., 26311.  6400., 52622. 12800.,105244. 25600.,210489.
A  30.   R  1.65   T  16.   WM  5.00   WO  4.00
QMX,CQX,...    900.,  3400.  1900.,  4605.  3000.,  5640.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0     PVAL -200.00
WRQ  1.57  4.63  7.13  4.03  1.73
EFF  55.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS I-V    EFF = 60%
EFF  60.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS I-V    EFF = 65%
EFF  65.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS I-V    EFF = 70%
EFF  70.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS I-V    EFF = 75%
EFF  75.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS I-V    EFF = 80%
EFF  80.0
END    DATA
READ   LOW HEAD WELL & PUMP COST DATA FOR UNITS VI-VII    EFF = 55%
TDH 120.   PMQ,PMC      0.,  1644.   200.,  1644.   400.,  3289.   800.,  6578. ,
 1600., 13155.  3200., 26311.  6400., 52622. 12800.,105244. 25600.,210489.
A  30.   R  1.65   T  16.   WM  5.00   WO  4.00
QMX,CQX,...    900.,  3400.  1900.,  4605.  3000.,  5640.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0     PVAL -200.00
WRQ  1.76  4.78  6.96  4.77  2.33
EFF  55.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS VI-VII    EFF = 60%
EFF  60.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS VI-VII    EFF = 65%
EFF  65.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS VI-VII    EFF = 70%
EFF  70.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS VI-VII    EFF = 75%
EFF  75.0
SKIP   LOW HEAD WELL & PUMP COST DATA FOR UNITS VI-VII    EFF = 80%
EFF  80.0
END    DATA
```

```
READ   WELL & PUMP COST CATA FOR ALL UNITS   EFF = 55%
TDH 260.   PMQ,PMC      0.,  1500.   200., 1500.   400.,  3000.   600.,  4500. ,
   800.,  6000.  1000.,  7500.  1200.,  9000.  1400., 10500.  1600., 12000.
  1800., 13500.  2000., 15000.  2400., 17000.
A  30.   R  1.65   T  16.   WM  5.00   WO  4.00
QMX,CQX,...    900.,  3400.  1900.,  4605.  3000.,  5640.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0      PVAL -200.00
WRO  1.63  4.68  7.07  4.62  1.93
EFF  55.0
SKIP   WELL & PUMP COST DATA FOR ALL UNITS   EFF = 60%
EFF  60.0
SKIP   WELL & PUMP COST DATA FOR ALL UNITS   EFF = 65%
EFF  65.0
SKIP   WELL & PUMP CCST DATA FOR ALL UNITS   EFF = 70%
EFF  70.0
SKIP   WELL & PUMP COST DATA FOR ALL UNITS   EFF = 75%
EFF  75.0
SKIP   WELL & PUMP COST DATA FOR ALL UNITS   EFF = 80%
EFF  80.0
END    DATA
READ   WELL & PUMP COST CATA FOR UNITS I-V   EFF = 55%
TDH 260.   PMQ,PMC      0.,  1500.   200., 1500.   400.,  3000.   600.,  4500. ,
   800.,  6000.  1000.,  7500.  1200.,  9000.  1400., 10500.  1600., 12000.
  1800., 13500.  2000., 15000.  2400., 17000.
A  30.   R  1.65   T  16.   WM  5.00   WO  4.00
QMX,CQX,...    900.,  3400.  1900.,  4605.  3000.,  5640.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0      PVAL -200.00
WRQ  1.57  4.63  7.13  4.03  1.73
EFF  55.0
SKIP   WELL & PUMP COST CATA FOR UNITS I-V   EFF = 60%
EFF  60.0
SKIP   WELL & PUMP COST DATA FOR UNITS I-V   EFF = 65%
EFF  65.0
SKIP   WELL & PUMP COST DATA FOR UNITS I-V   EFF = 70%
EFF  70.0
SKIP   WELL & PUMP COST DATA FOR UNITS I-V   EFF = 75%
EFF  75.0
SKIP   WELL & PUMP COST DATA FOR UNITS I-V   EFF = 80%
EFF  80.0
END    DATA
READ   WELL & PUMP COST CATA FOR UNITS VI-VII   EFF = 55%
TDH 260.   PMQ,PMC      0.,  1500.   200., 1500.   400.,  3000.   600.,  4500. ,
   800.,  6000.  1000.,  7500.  1200.,  9000.  1400., 10500.  1600., 12000.
  1800., 13500.  2000., 15000.  2400., 17000.
A  30.   R  1.65   T  16.   WM  5.00   WO  4.00
QMX,CQX,...    900.,  3400.  1900.,  4605.  3000.,  5640.
TLFE  100.0      RINT  6.5      SVAL 10.0
OEXP  3.0      PVAL -200.00
WRQ  1.76  4.78  6.96  4.77  2.33
EFF  55.0
SKIP   WELL & PUMP COST CATA FOR UNITS VI-VII   EFF = 60%
EFF  60.0
SKIP   WELL & PUMP COST DATA FOR UNITS VI-VII   EFF = 65%
EFF  65.0
SKIP   WELL & PUMP COST DATA FOR UNITS VI-VII   EFF = 70%
EFF  70.0
SKIP   WELL & PUMP COST DATA FOR UNITS VI-VII   EFF = 75%
EFF  75.0
SKIP   WELL & PUMP COST CATA FOR UNITS VI-VII   EFF = 80
EFF  80.0
END    DATA
```

```
KNT  1
3   SECTION A  --  MAIN STEM
SEC A  QMX 60.
ON U      EFF  0.985     A   293.55     B      4.91      R 0.989
 LCA      EFF  1.000     A   604.73     B      9.22      R 0.987
GPA       EFF  1.000     A  1364.69     B     58.22      R 0.951
3   SECTION B  --  MAIN STEM
SEC B  QMX 60.
ON U      EFF  0.955     A   719.18     B     18.90      R 0.949
 LCB      EFF  0.999     A  1315.65     B     19.87      R 0.958
GPB       EFF  1.000     A  3472.96     B    215.78      R 0.961
3   SECTION C  --  MAIN STEM
SEC C  QMX  55.
ON U      EFF  0.952     A   723.47     B     18.71      R 0.973
 LCC      EFF  0.998     A  1578.13     B     35.76      R 0.973
GPC       EFF  1.000     A  3595.72     B    291.35      R 0.956
3   SECTION D  --  MAIN STEM
SEC D  QMX  50.
ON U      EFF  0.925     A   693.39     B     18.56      R 0.976
 LCD      EFF  0.998     A  1184.36     B     31.34      R 0.981
GPD       EFF  1.000     A  3400.86     B    267.90      R 0.968
3   SECTION E  --  MAIN STEM
SEC E  QMX  45.
ON U      EFF  0.923     A   635.01     B     15.09      R 0.982
 LCE      EFF  0.998     A  1260.82     B     31.10      R 0.962
GPE       EFF  1.000     A  1393.11     B    168.12      R 0.957
3   SECTION F  --  MAIN STEM
SEC F  QMX  15.
ON U      EFF  0.957     A   492.50     B     17.19      R 0.966
 LCF      EFF  0.998     A  1091.16     B     43.30      R 0.980
GPF       EFF  1.000     A  2198.57     B    326.24      R 0.948
 START
KNT  1
3   SECTION A  --  BRANCH I
SEC A  QMX 60.
UCA       EFF  0.985     A   293.55     B      4.91      R 0.989
 LCA      EFF  1.000     A   604.73     B      9.22      R 0.987
GPA       EFF  1.000     A  1364.69     B     58.22      R 0.951
2   SECTION B  --  BRANCH I
SEC B  QMX 60.
LCA DUMMY  EFF  0.0001   A  9999999.    B  9999999.       R  0.98
 LCB      EFF  0.999     A  1315.65     B     19.87      R 0.958
3   SECTION H  --  BRANCH I
SEC H  QMX  25.
LCA DUMMY  EFF  0.0001   A  9999999.    B  9999999.       R  0.98
LCH      KEFF  0.999     A  1210.20     B     41.97      R 0.97
GPH       EFF  1.000     A  1654.35     B    132.20      R 0.95
 START
KNT  1
3   SECTION A  --  BRANCH II
SEC A  QMX 60.
UCA       EFF  0.985     A   293.55     B      4.91      R 0.989
 LCA      EFF  1.000     A   604.73     B      9.22      R 0.987
GPA       EFF  1.000     A  1364.69     B     58.22      R 0.951
3   SECTION B  --  BRANCH II
SEC B  QMX 60.
UCB       EFF  0.955     A   719.18     B     18.90      R 0.949
 LCB      EFF  0.999     A  1315.65     B     19.87      R 0.958
GPB       EFF  1.000     A  3472.96     B    215.78      R 0.961
3   SECTION C  --  BRANCH II
SEC C  QMX  55.
UCC       EFF  0.952     A   723.47     B     18.71      R 0.973
 LCC      EFF  0.998     A  1578.13     B     35.76      R 0.973
GPC       EFF  1.000     A  3595.72     B    291.35      R 0.956
3   SECTION D  --  BRANCH II
SEC D  QMX  50.
UCD       EFF  0.925     A   693.39     B     18.56      R 0.976
 LCD      EFF  0.998     A  1184.36     B     31.34      R 0.981
GPD       EFF  1.000     A  3400.86     B    267.90      R 0.968
3   SECTION E  --  BRANCH II
SEC E  QMX  45.
UCEU      EFF  0.923     A   635.01     B     15.09      R 0.982
 LCE      EFF  0.998     A  1260.82     B     31.10      R 0.962
GPE       EFF  1.000     A  1393.11     B    168.12      R 0.957
2   SECTION G  --  BRANCH II
SEC G  QMX  10.
ON U      EFF  0.950     A   162.36     B     11.07      R 0.983
 LCG      EFF  0.998     A   480.24     B     29.36      R 0.987
 STOP
```