Research Technical Completion Report
Project B-041-IDA

OPTIMAL PLANNING OF IRRIGATION DISTRIBUTION AND APPLICATION SYSTEMS FOR A LARGE IRRIGATED AREA

by
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PROJECT SUMMARY

The research conducted on OWRT Project B-041-IDA entitled, "Optimizing Project Systems for Distributing and Applying Irrigation Water" has involved various aspects of irrigation systems evaluation and planning. This report describes the major thrust and findings of the project. In addition, there have been two partial technical completion reports, two M.S. Thesis, one Ph.D. Dissertation and five technical papers resulting from the project. Summaries of studies related to this report are contained in Appendix F. A list of all project publications is shown below.

Additional Publications Under Project B-041-IDA

Busch, J.R. and K.H. Yoo. 1981. Optimal multistage decisions using dynamic programming. Paper presented at the 1981 Summer Meeting, American Society of Agricultural Engineers, Orlando, Florida, Paper No. 81-5013.

Khanjani, M.J. 1980. Methodology for optimization of an irrigation system with storage reservoirs. Unpublished Ph.D. Dissertation. Department of Agricultural Engineering, University of Idaho, Moscow, Idaho.

Khanjani, M.J. and J.R. Busch. 1981. Optimal irrigation water use from probability cost-benefit analysis. TRANSACTIONS of the American Society of Agricultural Engineers. (Accepted for publication).

Khanjani, M.J. and J.R. Busch. 1981. Optimal irrigation distribution systems with internal storage. TRANSACTIONS of the American Society of Agricultural Engineers. (Submitted for publication).

Kim, S. 1981. Analyzing and predicting irrigation diversions in southeastern Idaho. Unpublished M.S. Thesis, Department of Agricultural Engineering, University of Idaho, Moscow, Idaho.

Netz, K.E. 1980. Evaluation of canal seepage in the Snake River Fan, Bonneville and Bingham Counties, Idaho. Unpublished M.S. Thesis, Department of Agricultural Engineering, University of Idaho, Moscow, Idaho.

Additional Publications Under Project B-041-IDA (continued)

Yoo, K.H. and J.R. Busch. 1980. User's guide to UIMIP and MTRX: Mixed Integer-Linear Programming and Matrix Generating Program Packages. Partial Research Technical Completion Report, Project B-041-IDA, Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho.

Yoo, K.H. and J.R. Busch. 1981. Soil water intake rates and surface irrigation system characteristics by soil series in southeastern Idaho. Partial Research Technical Completion Report, Project B-041-IDA, Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho.

Yoo, K.H. and J.R. Busch. 1981. Mixed integer-linear programming for Agricultural Engineering problems. Paper presented at the 1981 Summer Meeting, American Society of Agricultural Engineers, Orlando, Florida, Paper No. 81-5007.

Yoo, K.H. and J.R. Busch. 1981. Low level aerial infrared images for inventory of an irrigated area. TRANSACTIONS of the American Society of Agricultural Engineering. (Accepted for publication).

ABSTRACT

The purpose of the research reported was to develop and apply techniques to obtain optimal solutions for multi-objective planning of a large irrigated area. Techniques were developed to effectively inventory a large area, determine the costs and operating characteristics of irrigation system components and obtain optimal system plans using mathematical programming. These techniques were applied to a large irrigated area located near Idaho Falls, Idaho.

All sources of data pertinent to irrigation in the study area were collected, and low level infrared pictures were taken over the area. Files of data from all sources were stored in a digital computer so that they could be easily accessed to obtain information about irrigation practices and systems located in any small subarea within the study area. These data files were also used to obtain detailed computer-drawn maps of the area.

Costs and operating characteristics of all irrigation system components were determined using computerized routines. Annual costs on a per acre basis were computed for on-farm application systems as well as application efficiencies. For conveyance sections annual costs were based on the design flow rate, and conveyance efficiencies were computed to account for conveyance losses. Costs of pumping plants were also based upon the design discharge and were adjusted to account for inflationary trends in energy cost.

Optimal plans of the least cost arrangement of distribution and application system components were obtained using linear programming and mixed integer-linear programming models. Linear programming models were

used when only one type of distribution system was considered such as for the analysis of existing irrigation district distribution systems. Developing rehabilitation plans that considered several alternative types of distribution system components for any one section required the use of mixed integer-linear programming models. Using this type of model assured that one and only one component was selected for any one section. Also, this type of model could incorporate cost functions with step functions.

Using the procedures developed, optimal irrigation system plans were obtained for the study area. These plans were based upon different specified constraints such as overall system efficiency, cost of water delivered to the system at the project headgate and the cost of water diverted from the distribution system to on-farm application systems. The results obtained were useful in determining the costs and configurations necessary to meet specified efficiency levels. When charging for water, it was found that the variation of water cost over a rather narrow range was effective in increasing overall efficiency to a point, and additional charges had little effect. Consolidation plans for the two irrigation districts in the study area showed that it would be most economical to use a high pressure supply and sprinkler application system to attain an overall efficiency greater than 70%.

The planning procedures developed proved to be effective and flexible in producing optimal irrigation system plans for a large area. Results produced were descriptive scenarios that would assist planners, irrigators and other interested parties in making multiple objective planning decisions.

CHAPTER I

INTRODUCTION

Irrigated agriculture on the Snake River plain of southeastern Idaho was first developed in the late 1800's. In early days, the irrigators found plenty of water to irrigate their farmland and had minimal interest in the most efficient water use. Since that time extensive areas have been developed for irrigated agriculture. When drought hit the area in 1977, the flows in the Snake River could not meet the water rights along the river. This lack of water coupled with inefficient irrigation systems resulted in massive crop damage on many farms. In the United States, irrigated agriculture is the largest consumer of water and is often a culprit of non-point water pollution. To save and keep clean the nation's precious water resources, especially in water short western states, it is necessary that irrigation systems be designed for efficient use of water.

Throughout an irrigation project there are many things that must be considered to maintain an efficient system. Ideally water should be diverted from the source as it is needed, delivered to downstream without loss and applied only to satisfy the amount of water needed for crop growth. However, it is not possible to construct and manage an irrigation system that would operate in this manner as there are water losses due to both physical and management limitations. It is necessary that these limitations be objectively assessed and losses minimized in the most economical way.

Demands on water resources have increased the need to evaluate alternatives in order to achieve better water management for new irrigation projects and for rehabilitation of older irrigation systems. Often, criteria governing water management such as water and energy availability, quantity and quality of drainage water and acceptable irrigation practices are unknown. The requirements for evaluating many alternatives in multi-objective planning as directed by the U.S. Water Resources Council's proposed Principles and Standards (Principles and Standards for Planning Water and Related Land Resources, Federal Register Vol. 38, No. 174, Part III, September 10, 1973) places heavy burdens on planners using conventional evaluation procedures. An optimizing technique to assist planning engineers in designing project systems to distribute and apply irrigation water and meet specific water management objectives is a necessity. Specifically, the U.S. Bureau of Reclamation in their Westwide Water Management Study (Critical Water Problems Facing the Eleven Western States, U.S. Bureau of Reclamation, April, 1975) has expressed the need for this type of planning tool to assist in achieving the goals of that study.

A computerized irrigation planning model and methodology that conjunctively considers the distribution and application of irrigation water has been developed at the University of Idaho (Busch, 1974). The model was updated by the addition of U.S. Bureau of Reclamation's irrigation system planning routines (Galinato and others, 1977) and other refinements (Allen and others, 1978). This procedure enables systems planners to evaluate many alternative irrigation system plans for use in an initial design or for planning rehabilitation and consolidation of existing irrigation systems. The optimization techniques used in the procedure provide the ability to obtain the best combinations of conveyance and on-farm application systems subject to legal, physical, social and resource constraints over the entire system.

The original methodology was successfully applied to two relatively small irrigation projects; one in eastern Idaho (Busch, 1974) and one in central Washington (Galinato and others, 1977). This procedure was also used to obtain optimal irrigation system rehabilitation plans for a portion of the Teton flood plain inundated by the flood which took place when the nearly completed Teton dam in eastern Idaho failed (Allen and others, 1977 and Brockway and Allen, 1979). These studies indicated that the analytical model used is a valid and useful tool for determining rapid, least cost irrigation system specifications.

CHAPTER II

OBJECTIVES

The major objective of this study was to develop and apply techniques to obtain optimal solutions for multi-objective planning of a large scale irrigation system.

The specific objectives are:

1. To identify and determine the influence of various criteria on the level of water management within irrigation projects. Specific criteria will include physical, social, economic and legal aspects.
2. To develop techniques for determining optimum designs and management plans for large scale irrigation systems to meet specified water management criteria.
3. To apply the techniques developed in specifying optimum rehabilitation schemes for a large irrigated area. Application will include evaluation of numerous water management criteria including the consolidation of existing irrigation district systems.

CHAPTER III

OPTIMIZATION TECHNIQUES USED IN IRRIGATION SYSTEMS PLANNING

In irrigation systems planning many factors must be considered. There are several alternatives of system components that can be used to deliver and apply water to different crop fields through different irrigation conveyance and application systems. Also considered must be many influences and constraints associated with the physical, social, legal and economic aspects of an irrigation project. In order to specify the best combination of system components and management practices so that minimum system design cost is achieved, some type of systematic decision process should be used.

At the University of Idaho several studies have been conducted to develop a means of obtaining optimal (least cost) irrigation system plans that comply with both physical and institutional constraints. Each of these studies used a two-stage dynamic-linear programming approach. Dynamic programming is the optimization procedure first used to select discrete components for the best possible conveyance system combinations to be used in supplying water to application systems. The linear programming then uses the dynamic programming output to select optimal application and distribution combinations. More details of this procedure are described by Busch (1974), Galinato and others (1977) and Allen and others (1978).

The two-stage dynamic-linear programming approach is best used for small scale problems (1000 - 3000 acres). The diversity of an area increases as the size increases and the irrigation distribution system becomes more complex with many branching pipelines and/or canals. This complexity greatly increases the size and difficulty of the dynamic programming problem (Allen and others, 1978 and Busch and Yoo, 1981). The problem of obtaining an optimal solution involving discrete components can be solved by another type of linear programming, mixed integer-linear programming (MIP).

MIXED INTEGER-LINEAR PROGRAMMING (MIP)

In operations research linear programming (LP) is widely used because of its simple form and a thoroughly explored solution algorithm (Hammer and others, 1979). An LP problem consists of a linear objective function to be optimized (i.e., either maximized or minimized) subject to linear equality or inequality constraints. Linear programming also requires that the decision variables be nonnegative and continuous. LP models have proven to be a powerful tool in the area of water resources research because of the relative ease of solution using readily available computer packages (IBM, 1974 and CDC, 1979). The simplex method is the basis for the solution of any LP problem in which the decision variables must be nonnegative and continuous.

In many real world problems the continuous solution of a problem may not be desirable because of the interpretation given to the solution. The requirement of integer values only for certain decision variables may arise in a linear programming problem where nonbreakable items are modeled. These problems can be formulated as LP problems with the additional restriction that some or all of the decision variables can assume only discrete values. Because of this additional constraint an LP problem becomes non-linear (discrete) and cannot be solved by the simplex method. This type of problem is called pure integer or mixed integer-linear programming problems. The solution of these problems requires special algorithms. Details of these algorithms are beyond the purpose of this paper and are well described by Gomory (1963), Geoffrin and Marsten (1972), Murty (1976) and Land and Powell (1979).

FORMULATION OF A MIXED INTEGER-LINEAR PROGRAMMING (MIP) PROBLEM

The general mixed integer-linear programming (MIP) problem is formulated as:

$$\text{Minimize:} \quad z = \sum_{i=1}^{m} c_i x_i + \sum_{i=m+1}^{n} c_i y_i \tag{3-1}$$

$$\text{Subject to:} \quad \sum_{i=1}^{m} a_{ij} x_i + \sum_{i=m+1}^{n} a_{ij} y_i \ (\leq = \geq)\ d_j \tag{3-2}$$

for all $j = 1, 2, --- p$

$x_i \geq 0$ for $i = 1, 2, --- m$

$y_i \geq 0$, integer only for $i = m+1, m+2, --- n$

where n is the total number of decision variables, m is the number of continuous variables, and p is the number of constraints. The c_i's, a_{ij}'s and d_j's are known constants and x_i and y_i are the decision variables. If all the decision variables are restricted to assume only integer values, the problem becomes a pure integer programming problem.

In many real world problems the integer decision variables are often restricted to "0 or 1" in the pure-integer or mixed integer-linear programming problems. This type of "0 or 1" restriction is necessary to solve problems that have variables with step functions as shown in Figure III-1. The function shown may represent the cost of an irrigation system component.

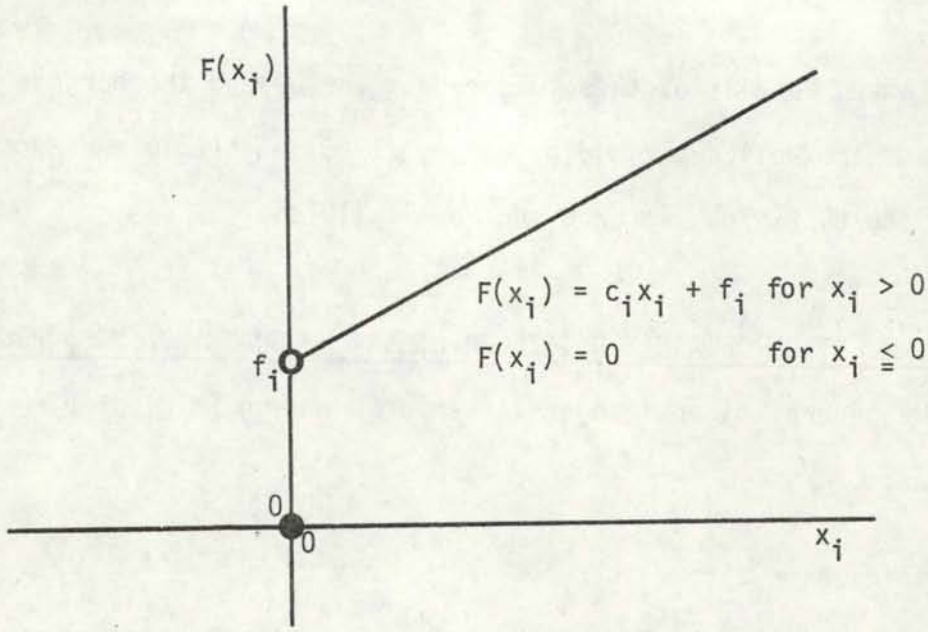


Figure III-1. Linear Function with Fixed Cost

where,

$F(x_i)$ = component cost,

c_i = variable cost of decision variable i,

x_i = decision variable i, and

f_i = fixed charge of decision variable i.

As shown in this figure, the cost of performing the activity x_i is 0 if $x_i \leq 0$ and is $c_i x_i + f_i$ if $x_i > 0$. An MIP model which includes variables both with and without fixed costs is formulated as:

$$\text{Minimize: } a = \sum_{i=1}^{m} c_i x_i + \sum_{i=m+1}^{n} (c_i x_i + f_i y_i) \quad (3\text{-}3)$$

$$\text{Subject to: } \sum_{i=1}^{n} a_{ij} x_i \ (< \ = \ >) d_j \text{ for all } j = 1, 2, \text{---} p \quad (3\text{-}4)$$

$$x_i - \alpha_i y_i \leq 0 \text{ for all } i = m+1, m+2, \text{---} n$$

$$x_i \geq 0 \text{ for } i = 1, 2, \text{---} n$$

$$\alpha_i \geq x_i$$

$$y_i = 0 \text{ or } 1 \text{ for } i = m+1, m+2, \text{---} n$$

Where,

n = number of decision variables,

m = number of decision variables included in the function that are purely linear without fixed costs,

p = number of constraints related to the continuous variables, and

α = upper bound of decision variables x_i for $i = m+1, m+2, \text{---} n$

The first set of constraints are general linear programming constraints which may be included in the model for all x_i ($i = 1, 2, \text{---} n$). The second set indicates that when $y_i = 0$, x_i must equal to 0 and alternatively y_i is forced to 1 when $x_i > 0$. Therefore, y_i have values of 0 or 1 dependent upon whether or not x_i are included in the solution.

Furthermore, if there is more than one alternative for the variables $x_{m+1}, x_{m+2}, \text{---} x_n$ which include fixed charges, and one and only one variable must be selected for the final decision, the problem becomes a multiple choice problem with a fixed charge linear function. To solve this problem the mixed integer-linear programming formulation equation (3-2) requires additional constraints to specify that exactly one activity be performed as denoted by the following constraints.

$$\text{Subject to: } \sum_{k=1}^{q} y_{ik} = 1 \text{ for all } i = m+1, m+2, \text{---} n \qquad (3\text{-}5)$$

Where, q = number of alternatives for decision variables y_i

Use of an MIP model such as in equation (3-2) allows the incorporation of functions with steps and also assures that discrete components can be selected in the optimal solution by using the constraints of equations (3-3). This and other applications of MIP models are described by Yoo and Busch, (1981).

SOLUTION ALGORITHMS FOR PURE INTEGER AND MIXED INTEGER-LINEAR PROGRAMMING PROBLEMS

There is no single method such as the simplex method for solving pure integer or mixed integer-linear programming problems. Since Dantzig discovered the simplex method in 1949 there have been several attempts made to solve these problems. The earliest applicable algorithm was a cutting plane method developed by Gomory (1958). Land and Doig (1960) developed an enumerative technique (branch-and-bound algorithm) to solve general pure integer and mixed integer-linear programming problems. The cutting plane and branch-and-bound algorithms are the most widely used methods to solve these problems. These two methods will be briefly discussed in the following sections.

GOMORY'S CUTTING PLANE METHOD

The cutting plane method is a technique which squeezes down or cuts the feasible region of a solution of pure integer or mixed integer-linear programming problems ignoring the integer constraints. The cuts are achieved by sequentially introducing new constraints to the original constraints set of the problem. Each step in the solution reduces the feasible region at the expense of analyzing the problem by adding one constraint. Each solution is then obtained by the simplex method. The solution will terminate when an optimal feasible solution of the original problem is reached. The main problem associated with this method is deciding how to construct the new constraints. Discussion of this problem is beyond the purpose of this report and is well described by Gomory (1963) and others (Jeroslow, 1974; Owen, 1973; and Murty (1976)).

LAND AND DOIG'S BRANCH-AND-BOUND METHOD

The branch-and-bound method is a solution strategy that has been used as one of the major practical tools for the solution of pure integer and mixed integer-linear programming problems. If the total number of feasible integer solutions is small the best optimal feasible solution can be obtained by comparing all individual solutions using a total enumerative method. However, in most real world problems this approach is not practical as the number of solutions required often increases dramatically as the number of integer variables increases.

The branch-and-bound method provides a methodology to search for an optimum feasible solution by doing only a partial enumeration. The initial optimal solution of pure integer and mixed integer-linear programming problems is first obtained by neglecting the integer restriction. The space of all feasible solutions is repeatedly partitioned into smaller subsets (branching) as a better bound of a most promising subset (lower bound for a minimization and higher bound for a maximization problem) is calculated within the subset (bounding). The initial solution and each solution of the partitioned subsets are obtained by the simplex method. In each stage the subsets with feasible integer solutions are temporarily maintained or fathomed to check optimality or to improve the current solution. Those subsets with a bound which exceeds the known feasible integer solution are then excluded from all further partitioning. Therefore, a large number of subsets may be excluded from bounding without being explored.

The advantage of this method over the cutting plane method is that the branch-and-bound method generates all intermediate feasible integer solutions before the optimal feasible integer solution is reached. The details of this method are discussed by Murty (1976) and Balas and Guignard (1979).

COMPUTER PROGRAM PACKAGES FOR MIXED INTEGER-LINEAR PROGRAMMING SOLUTIONS

There are several computer programs available which deal with pure integer and mixed integer-linear programming problems. These programs are in two categories, commercial and non-commercial programs. The commercial program codes are those developed by major computer manufacturers and are all based on revised simplex and branch-and-bound methods. These codes include mixed integer-linear programming as well as linear programming. The most popular codes are listed in Table III-1. They are available by monthly lease with the cost usually being quite expensive.

Table III-1. Commercial Codes for Mathematical Programming

Code	Vendor	Computer
APEX III	Control Data Corporation	Cyber 70 series Cyber 170,760 CDC 6000
MPSX/370-MIP	International Business Machines	IBM 370
FMPS	Sperry Univac	Univac 1100 series

Non-commercial codes are those which are less powerful than the commercial codes and are usually developed for academic purposes. They are slow in solution time and can handle only small to medium size (less than 150 x 150 matrix) problems within reasonable computing time. For large problems the solution time is usually beyond reason, and a large computer memory is required. Land and Powell (1979) surveyed and described the non-commercial codes. According to their survey most of them are available to any users without charge or with minimum charges.

One of the non-commercial codes was developed by Yoo and Busch (1980). The program, UIMIP can solve medium sized pure integer and mixed integer-linear programming problems (up to 250 x 250 matrix) as well as linear programming problems. It is based on the simplex algorithm and branch-and-bound method. It also uses some heuristic methods to obtain intermediate feasible integer solutions and approximate the optimal solution to save computing time.

The manual of the UIMIP (Yoo and Busch, 1980) describes the program package and example solutions and is available along with the source programs from the Agricultural Engineering Department of the University of Idaho with minimum charge. Also available is a matrix generating program, which generates input data for the UIMIP in MPS standard format.

APPLICATION OF MIXED INTEGER-LINEAR PROGRAMMING TO IRRIGATION SYSTEMS PLANNING

Consider the example irrigation system in Figure III-2 which includes two separate cropped areas, subarea A (α acres) and subarea B (β acres). There are several types of crops grown in each subarea. The irrigation water may be delivered to subareas A and B by unlined or lined open channel or by gravity pipe system. Water is supplied to subarea A at point a and to subarea B at point b and flows further downstream. Point c is the water source of the conveyance system; in this case it is

a diversion point from a river. The alternative application systems to be considered for each subarea are unimproved gravity, improved gravity and sprinkler irrigation application systems. The maximum flow rates (or design flow rates) of the application systems for each area are obtained from the weighted average of maximum daily evapotranspiration, ET, required by crops grown and application efficiencies of the irrigation application systems in each subarea.

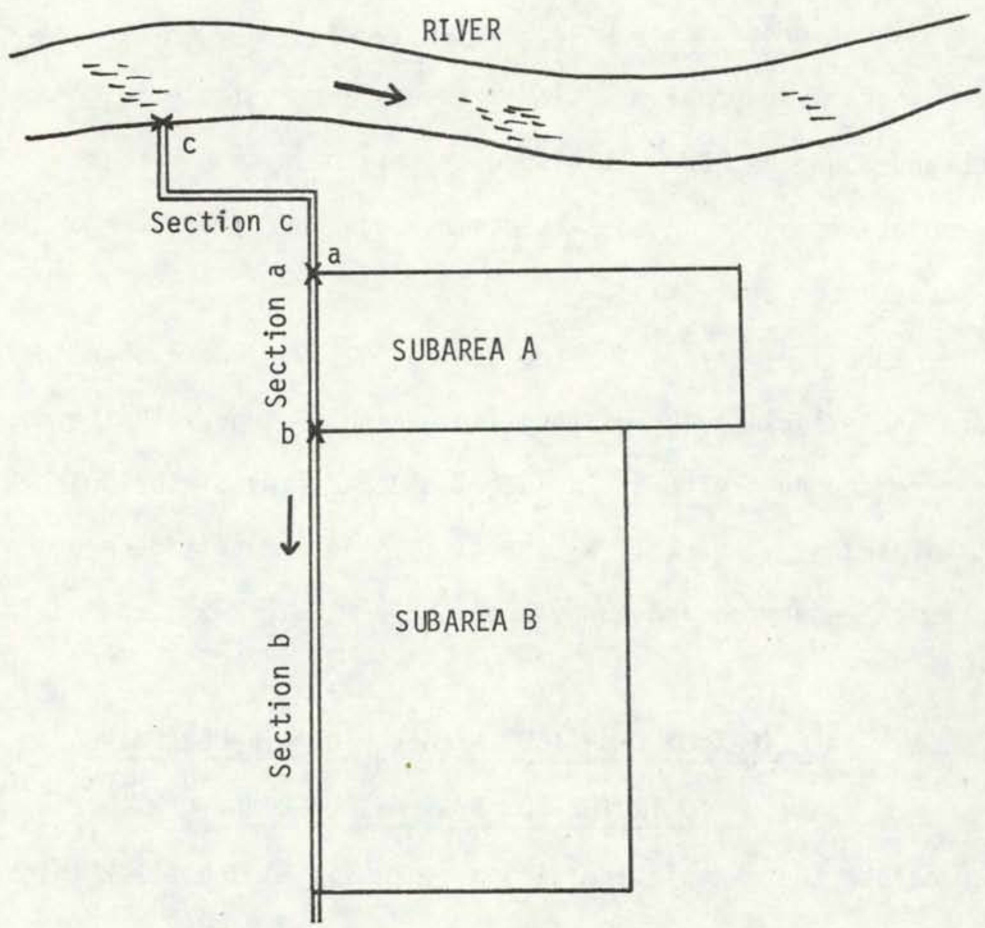


Figure III-2. Schematic Diagram of a Hypothetical Irrigation System Showing Conveyance Sections and Service Area of Each Section

$$Q_{max} = \frac{1}{23.8} \left(\frac{ET'_{max}}{EFF}\right) \qquad (3\text{-}6)$$

where,

Q_{max} = maximum required flow rate of an application system for each area in cfs per acre,

ET'_{max} = weighted average of maximum daily ET of crops grown in each area in inches per day, and

EFF = application system efficiency expressed as a decimal.

The annual costs for an application system are best expressed on a per acre basis and for a conveyance system as a function of peak design flow rate with a fixed charge. The details of obtaining the system annual costs are discussed later in Chapter V. The alternative systems under consideration and the annual costs, system efficiencies and other coefficients associated with each alternative are given in symbol form in Tables III-2 and III-3.

The mixed integer-linear programming problem matrix of the hypothetical irrigation system is shown in Figure III-3. The sum of the elements in the OBJ row, each multiplied by the value of its proper variable as selected in the optimal solution, is the total annual cost of operating and maintaining the entire system. The water cost for water entering the system is related to the total diversion at point c, VON (acre-feet) multiplied by the cost factor, CVON ($/acre-feet) shown in the OBJ row. The operation and maintenance costs of the conveyance systems are computed as a function of canal length in miles as developed by Brockway and Reese (1973). Operation and maintenance costs are further discussed in Chapter VI.

Table III-2. Coefficient Symbols for Irrigation Application Systems in the Hypothetical Model

Subarea	System	Cost per acre	Application Efficiency (decimal)	Flow Rate (cfs/acre) at peak use
	UGA	CUA	EUA	QUA
A	IGA	CIA	EIA	QIA
	SPA	CSA	ESA	QSA
	UGB	CUB	EUB	QUB
B	IGB	CIB	EIB	QIB
	SPB	CSB	ESB	QSB

Note: UG - Unimproved gravity irrigation system
IG - Improved gravity irrigation system
SP - Sprinkler irrigation system

Table III-3. Coefficient Symbols for Distribution Systems in the Hypothetical Model

System	Canal Length (miles)	Cost Per Unit Flow Rate ($/CFS)	Fixed Cost ($)	Delivery Efficiency (decimal)
a1	La1	Ca1	Fa1	Ea1
a2	La2	Ca2	Fa2	Ea2
a3	La3	Ca3	Fa3	Ea3
b1	Lb1	Cb1	Fb1	Eb1
b2	Lb2	Cb2	Fb2	Eb2
b3	Lb3	Cb3	Fb3	Eb3
c1*	Lc1	Cc1	Fc1	Ec1

Note: a - Canal Section a
b - Canal Section b
c - Canal Section c
1 - Unlined open channel system
2 - Lined open channel system
3 - Gravity pipe system

*Unlined open channel only is considered for section c.

	UGA	IGA	SPA	UGB	IGB	SPB	Qa1	Ya1	Qa2	Ya2	Qa3	Ya3	Qb1	Yb1	Qb2	Yb2	Qb3	Yb3	Qc1	Yc1	OMO	OMC	VON	RMS
OBJ	CUA	CIA	CSA	CUB	CIB	CSB	Ca1	Fa1	Ca2	Fa2	Ca3	Fa3	Cb1	Fb1	Cb2	Fb2	Cb3	Fb3	Cc1	Fc1	COMO	COMC	CVON	
AREAA	1	1	1																					= α
AREAB				1	1	1																		= β
SYSa	ZAU	ZAI	ZAS				-Ea1		-Ea2		-Ea3		1		1		1							<= 0
SYSb				ZBU	ZBI	ZBS							-Eb1		-Eb2		-Eb3							<= 0
SYSc							1		1		1								-Ec1					<= 0
BETAa								1		1		1												= 1
BETAb														1		1		1						= 1
BETAc																				1				= 1
ALPAa1							1	-qa1																<= 0
ALPAa2									1	-qa2														<= 0
ALPAa3											1	-qa3												<= 0
ALPAb1													1	-qb1										<= 0
ALPAb2															1	-qb2								<= 0
ALPAb3																	1	-qb3						<= 0
ALPAc1																			1	-qc1				<= 0
SYSOP								La1		La2				Lb1		Lb2				Lc1	-1			= 0
SYSCL												La3						Lb3				-1		= 0
WTON																			1					<=Qspec
VOLON																			-1				ζ	= 0

CVON - Water cost charged at headgate diversion point, $/acre-feet
COMO - O&M cost of open channel system, $/mile
COMC - O&M cost of pipe system, $/mile
Qspec - Specified diversion flow to the system, cfs
WTON - Total inflow rate delivered to point c, cfs
ζ - Conversion factor of cfs to acre-feet
Q.. - Design flow rate of distribution system, cfs
Y.. - 0 or 1 integer variables
q.. - Flow rate of distribution system which must be greater than or equal to the maximum design flow rate, cfs.
z.. - Maximum flow rate requirement of application system, cfs/acre

* For other symbols refer to Tables III-2 and III-3.

Figure III-3. Mixed Integer-Linear Programming Problem Matrix Model of the hypothetical Irrigation System

The solution of the problem will give the minimum cost for the objective subject to the constraints given in the rows below the OBJ row. These constraints include size of each subarea, amount of water available to the system and other computational constraints. The BETA constraints are used to force the solution select one and only one system type for a conveyance section by satisfying the following conditions.

$$\sum_{i=1}^{n} BETA_i = 1 \text{ for } n = \text{number of system types of a conveyance system} \quad (3\text{-}7)$$

The ALPA constraints are used to force the solution to take zero flow rate for a system type of a conveyance section when a decision variable Y is selected zero by satisfying the following conditions.

$$Q - q\,Y \leq 0 \text{ for each conveyance system component in each section.} \quad (3\text{-}8)$$

where,

Q = the flow rate in the section,

$q \geq$ maximum design flow rate for the section, and

Y = 0 or 1 integer values.

The COMO and COMC are the operation and maintenance costs associated with open channel and pipe systems, respectively. These terms are considered to be dependent upon the distribution system (canal length) 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 water use, subareas A and B. The AREAA row simply indicates that the acreage irrigated by the three irrigation systems must total α acres. The same concept holds true for the AREAB row. The supply system which connects points c and a must supply any losses along the section, the maximum irrigation requirements imposed by the irrigation systems in subarea A(ZA.) and those from point B indicated by the coefficients of row SYSa. The efficiency figures, Ea, signify that the flow rate of water entering the conveyance system at point c must include conveyance losses in each system type of the section. In the SYSb row it can be seen that the supply section b must supply water to the irrigation systems in subarea B and downstream need and any losses along the section. This example does not consider any excess or waste water flow from the conveyance system. The water supply entering the entire system must not exceed the specified value of Q_{spec}, which represents total system flow rate requirement during periods of peak water use at a set project overall efficiency. The value Q_{spec} may also represent the maximum legal water right of an irrigation system.

An optimal (least cost) solution can be obtained for the problem described by using mixed integer-linear programming techniques and associated computer package. The results would indicate how the limited resource, water, would be conveyed through the canal sections to supply water to the irrigation systems in the two service areas and how many acres would be served by each type of application system in each service area. The effects of variations in water availability and cost could be incorporated into the same problem by altering specified parameters within the matrix.

CHAPTER IV

DESCRIPTION OF THE STUDY AREA

The Snake River originates in Yellowstone and Teton National Parks of western Wyoming. It flows into Jackson Reservoir and then westward through Palisades Reservoir into Idaho. The river continues north and west to reach the Upper Snake River Plain where it turns southward. The study area for this project is located along the east side of the Snake River near the city of Idaho Falls (Figure IV-1). The area was first brought under irrigation in the late 1880's. Roughly 46,000 acres of the study area are irrigated with water diverted form the Snake River, of which 29,000 acres[1/] are under Idaho Irrigation District and 17,000 acres[1/] under Snake River Valley Irrigation District. Both districts divert water mainly from the Snake River, and both receive some waste or excess water from upstream irrigation districts.

TOPOGRAPHY

The topography of the study area is markedly flat, with an average slope of 0.002 ft/ft to 0.004 ft/ft. It is suitable for irrigation by both sprinkler and gravity methods. Sand dunes exist along Sand Creek, a natural channel, on the eastern part of the area. These dunes are hilly and usually lie idle or are cultivated with extensive land leveling and irrigated by sprinkler systems only.

1/ These figures include only irrigated agricultural land of each district obtained from aerial infrared photography taken in August, 1978. It does not include roads, canals, residential areas and wasteland.

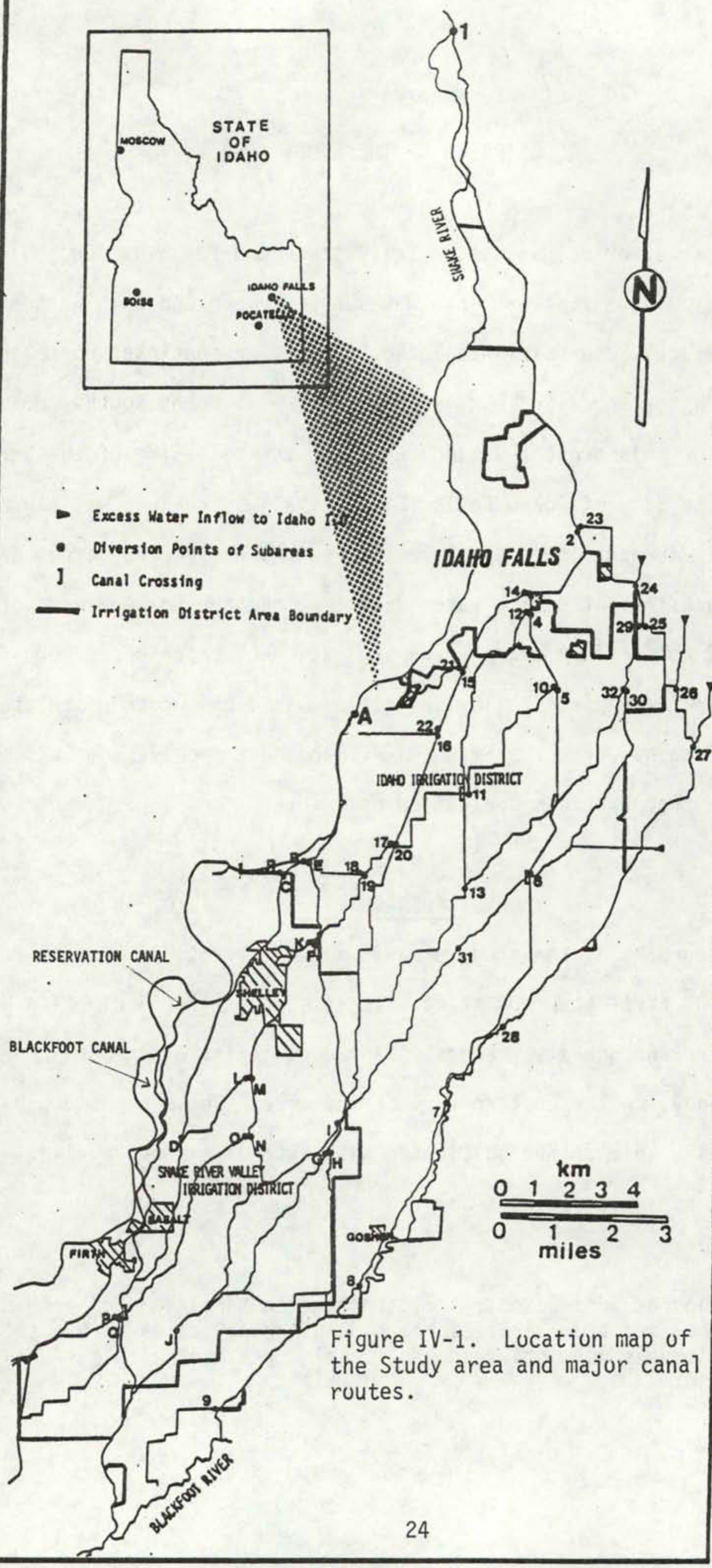


Figure IV-1. Location map of the Study area and major canal routes.

CLIMATE

The area is semi-arid with 11 to 13 inches of annual precipitation of which about 5 inches occur during the May through August growing season. The peak irrigation demand of the area occurs in July. However, the month of July supplies only 0.7 inches of precipitation on the average. Pan evaporation is 40.5 inches per year and lake evaporation is 29.2 inches per year, and the minimum daily relative humidity remains near 45 percent during the growing season. The area is around 4500 to 4800 feet in elevation above sea level. Temperatures range from 32°F and 100°F during the growing season with generally severe winter temperatures. The growing season is approxiamtely 110 days between freezes.

Consumptive irrigation requirements for crops in the study area were obtained from data in the University of Idaho Agricultural Experiment Station Bulletin No. 516 (Sutter and Corey, 1970) and the Soil Conservation Service Irrigation Guide for Southern and Southeastern Idaho (Soil Conservation Service, USDA, 1970). The monthly ET and maximum daily ET of each crop in the area are shown in Table IV-1.

FARM CHARACTERISTICS

The on-farm irrigation systems used in the area are border, furrow, hand-move sprinkler, side-roll sprinkler and center-pivot sprinkler systems. A very small area is under drip irrigation, and no subsurface irrigation is practiced in the area. The major crops raised are potatoes, small grain, alfalfa hay and pasture for forage and grazing. The cropping and on-farm irrigation system patterns of the area in the 1978 crop year are shown in Table IV-2.

Table IV-1. Monthly and daily maximum consumptive irrigation requirement of each crop grown in the study area in inches

	Alfalfa	Grain	Pasture	Potatoes
April	0.0	1.04	0.0	0.0
May	1.13	1.60	1.00	0.55
June	5.06	5.68	4.26	3.3
July	7.27	8.51	6.21	8.43
August	5.74	3.13	4.46	7.44
September	2.28	0.0	1.08	2.27
Total (inches)	21.48	19.96	17.0	21.99
Daily Max. (inches)	0.3	0.25	0.22	0.28

Table IV-2. Distribution pattern of crops, irrigation systems and land ownership in the study area in 1978 crop year

Cropping Pattern

	Area Irrigated (acres)	Potatoes (%)	Grain (%)	Alfalfa (%)	Pasture (%)
IID 1/	28,577	27.11	40.12	18.85	13.82
SRVID 2/	17,177	26.38	39.90	23.21	10.51
Study Area	45,754	27.07	39.92	20.55	12.46

1/ IID - Idaho Irrigation District
2/ SRVID- Snake River Valley Irrigation District

Irrigation Systems Pattern

Application System Type	Border (%)	Furrow (%)	HMS 1/ (%)	SRS 2/ (%)	CPS 3/ (%)
IID	52.71	10.5	26.16	9.0	1.63
SRVID	49.54	5.80	31.00	12.00	1.66
Study Area	51.50	8.79	27.88	10.19	1.64

1/ HMS - Hand-Move Sprinkler system
2/ SRS - Side-Roll Sprinkler system
3/ CPS - Center-Pivot Sprinkler system

Land Ownership Pattern

Range of ownership size (acres)	<30	31-50	51-70	71-100	101-140	141-210	211-280	>281
IID	19 1/	72	20	154	51	43	21	6
SRVID	7	62	13	94	24	23	8	3
Study Area	26	134	33	248	75	66	29	9

1/ Numbers indicate the number of land ownerships in each size range.

Border irrigation system is the most dominant irrigation practice followed by hand-move sprinkler irrigation systems. There is insignificant area supplied by center-pivot sprinkler systems. These data were obtained from low level aerial infrared images taken over the study area in August, 1978. More details of these photographs will be discussed later.

The U.S. Department of the Interior Bureau of Reclamation provided the land ownership pattern of the study area. Data in Table IV-2 show the summary of this information. The average size of land ownership in the area is about 80 acres and the maximum single ownership was found to be 960 acres.

SOIL TYPES

The soils of the study area are composed of silt loam, loam and sandy loam textures for the A horizon with gravelly sand and loam in the B horizon. The soils are excessively well drained with high porosity and permeability. The major soil series of the area are Ammon silt loam (Am), Bannock loam and gravelly loam (Ba), Bock loam (Bo), Hayeston (Ht) and Heiston (He) sandy loam, Paesl silt loam (Pe), Stan (St) and Sasser (Sa) fine sandy loam, and Wolverine sand (Wo). With the exception of Ammon and Paesl silt loam series all of these soils have very gravelly and sandy soils in the B horizon. A brief description of each soil type is contained in Appendix A. Soil maps obtained from the U.S. Department of Agriculture Soil Conservation Service were used to locate the soil series on the study area map developed from the aerial infrared photographs. The resulting study area map showing soil series is shown in Figure IV-2.

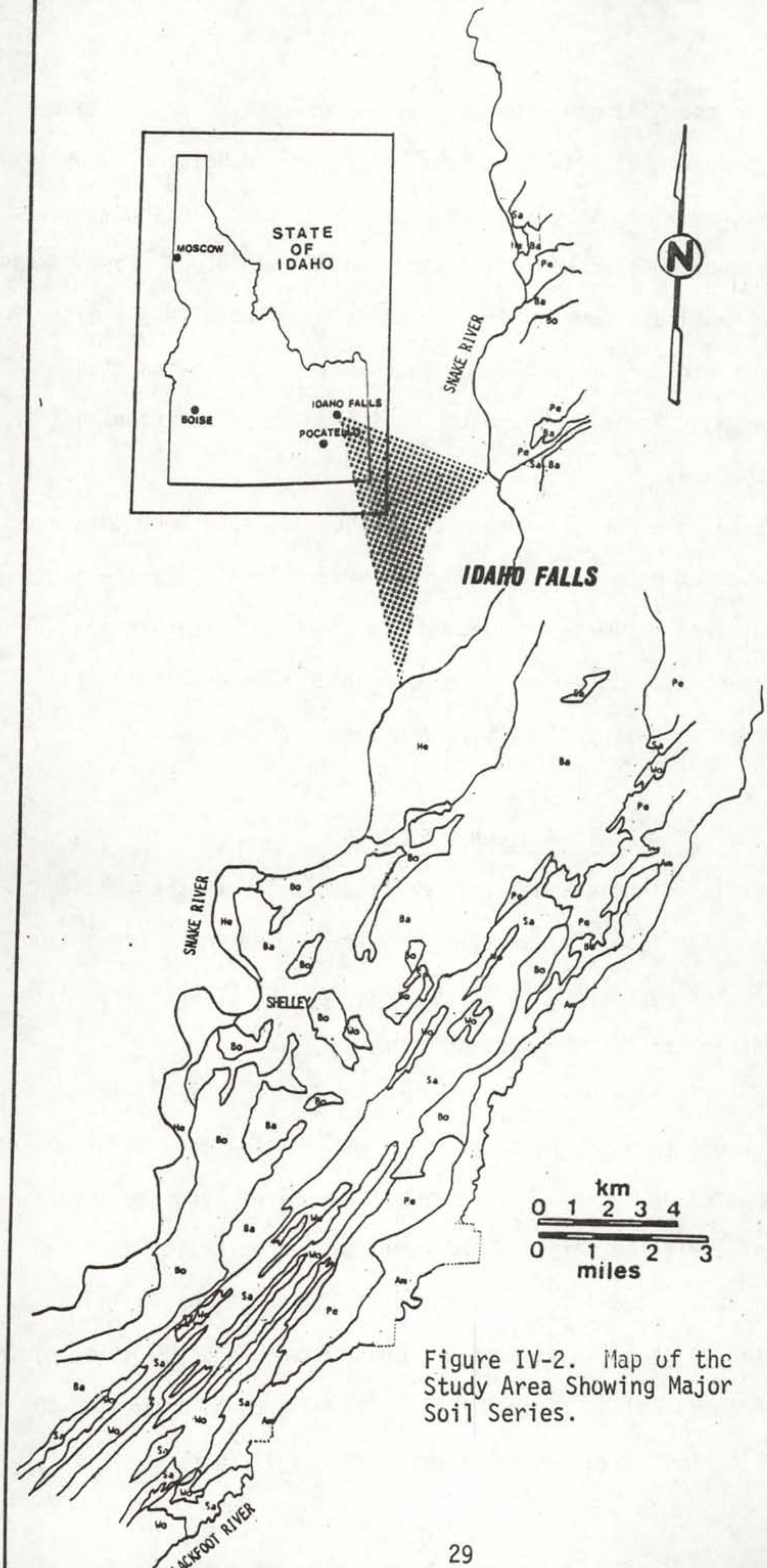


Figure IV-2. Map of the Study Area Showing Major Soil Series.

As shown in the soil map Bannock loam and gravelly loam and Bock loam are the dominant soils in the area. Hayeston and Heiston sandy loam soils are stretched along the Sand Creek on the east of the study area where several sand dunes of Wolverine sand (Wo) are located. East of the Sand Creek are Paesl and Ammon silt loam soils. In Table IV-3 are the distribution pattern and properties of each soil series in the study area. Also shown in Table IV-4 are the soil-crop-water relationships for each soil in the area.

Water intake rate for all soil except Wolverine sand were obtained from field tests for each crop in the study area. These data are necessary to evaluate and estimate irrigation practices and efficiencies. The details of these tests and results are described in a separate partial completion report of this project (Yoo and Busch, 1981b).

IRRIGAITON DISTRICTS

Two irrigation districts deliver irrigation water to the area and operate and maintain separate conveyance systems. The Idaho Irrigation District serves the northern part of the area and the Snake River Valley Irrigation District serves the south (Figure IV-1).

The Idaho Irrigation District was first served with water in the late 1880's. Since then the district has grown in size and in the amount of irrigation water delivered. At present it supplies water to about 29,000 acres of irrigated farmland and operates and maintains over 100 miles of major canals and laterals. The inlet headgate for the main canal is located on the east side of the Snake River about 10 miles north of the city of Idaho Falls (Figure IV-1). The main canal flows for 40 miles to the Blackfoot River where excess water is discharged. The

Table IV-3. Distribution pattern and properties of the soil series in the study area

	Distribution (%)	P (in/hr)	AWC (in/in)	FAM	Average Slope (ft/ft)	T Depth (ft)
Am	8.8	0.6	0.21	0.5	0.0027	3.75
Ba	32.1	1.3	0.15	1.5	0.0025	3.0
Bo	13.8	1.0	0.17	1.0	0.0032	3.8
He 1/	10.1	2.0	0.13	2.0	0.0030	2.5
Pe	10.4	0.6	0.20	0.5	0.0016	2.25
Sa 2/	16.0	2.0	0.13	2.0	0.0026	4.17
Wo	8.8	3.0	0.10	3.0	0.0050	3.0

Note: P = permeability
AWC = available water holding capacity
FAM = SCS intake family
T Depth = top soil depth
1/ = includes He and Ht soil series
2/ = includes Sa and St soil series

Table IV-4. Soil-crop-water relationships of the soils in the study area

Soil Series	Potato	Alfalfa	Grain	Pasture
Am				
RZD (ft)	2.5	4.0	3.5	2.5
TAM (in)	6.3	10.1	8.8	6.3
RAM (in)	2.52	5.04	4.41	3.15
Ba				
RZD (ft)	2.5	3.5	3.5	2.5
TAM (in)	4.5	6.3	6.3	4.5
RAM (in)	1.8	3.78	3.15	2.25
Bo				
RZD (ft)	2.5	4.0	3.5	2.5
TAM (in)	5.1	8.2	2.1	5.1
RAM (in)	2.04	4.9	3.57	2.55
He				
RZD (ft)	2.5	3.0	3.0	2.5
TAM (in)	3.9	4.7	4.7	3.9
RAM (in)	1.56	2.81	2.81	1.95
Pe				
RZD (ft)	2.0	3.0	2.5	2.5
TAM (in)	4.8	7.2	6.0	6.0
RAM (in)	1.92	3.6	3.0	3.0
Sa				
RZD (ft)	2.5	4.0	3.5	2.5
TAM (in)	3.9	6.2	5.5	3.9
RAM (in)	1.56	3.74	2.73	1.95
Wo				
RZD (ft)	2.5	4.0	3.5	2.5
TAM (in)	3.0	4.8	4.2	3.0
RAM (in)	1.2	2.88	2.1	1.5

Note: RZD = Root zone depth
TAM = Total available water holding capacity, TAM=RZDxAWC
RAM = Readily available moisture replaced in an irrigation

elevation at the inlet headgate is 4,755 feet and at the outlet is 4,575 feet above sea level. The total amount of water diverted to the district through the main canal in 1978 was 272,789 acre-feet, and the maximum flow rate in the canal was 1500 cfs. A natural stream, Sand Creek, flows north to south in the eastern portion of the district. Some reaches of this creek are used to convey irrigation water and others serve as drainage ways.

In addition to diversions from the Snake River, the district receives excess water from upstream districts. This water is not significant and dependable enough as an irrigation source and is often a hindrance as large excess flows often enter the district for short periods of time causing water regulation problems in the canal network. Most excess water from the district flows into the Snake River Valley Irrigation District except that from the main canal which flows into the Blackfoot River.

Irrigation started in the Snake River Valley Irrigation District in the late 1890's. The diversion headgate is located at a point on the east side of the Snake River about 3 miles south of the city of Idaho Falls (Figure IV-1). Since the first service the district has grown in size, and it presently serves about 17,000 acres of irrigated agricultural land. The total diverted water from the Snake River directly to the district in 1978 irrigation season was 166,616 acre-feet with a maximum flow rate of 850 cfs. This district also receives excess water from the upstream Idaho Irrigation District. This excess water is not regular enough as a dependable irrigation water source.

A network of over 50 miles of canals and laterals are used to convey and distribute water in the district. The main canal inlet is located at

4,647 feet above sea level and the outlet of the West Branch of the canal is at 4,555 feet. It is nearly 20 miles from the inlet point to the end of the West Branch of the Snake River Valley canal. The excess water from this district flows into the Reservation and Blackfoot Canals.

The main distribution canals and laterals were originally constructed along property lines and natural contours to minimize excavation as all work was done by men and animals. Since then some improvements have been made, but the major systems are unlined canals and follow basically the original established routes. Because of the highly permeable soils with gravelly sandy subsoils in the area, high canal seepage losses occur as the bottoms of the canals are often found to lie in the gravelly subsoils.

It is necessary to have the conveyance efficiency of each canal system to evaluate and determine project efficiency. Canal seepage of the area was studied and seepage rates were determined as a separate study of this project (Netz, 1980). As expected the seepage rates of most of the canal sections are significantly high and accordingly cause low conveyance efficiencies. Those canal sections located in the east of the study area have relatively low seepage loss. This area has deeper top soils of loam and silt loam. The total seepage rates of the two irrigation districts are an average of 312 cfs at a peak diversion rate of 1500 cfs for the Idaho Irrigation District and an average of 179 cfs at a peak diversion rate of 850 cfs for the Snake River Valley Irrigation District. The data used in this study are based on the 1978 and 1979 irrigation seasons. Seepage rates for individual canal sections are listed in Table VII-1, and additional details are reported by Netz (1980).

Along with the water delivered from the Snake River each district receives excess water from upstream irrigation district(s) and dumps waste water to downstream districts. As a part of its "Water Use Supply" study the U.S. Department of the Interior Bureau of Reclamation in Boise, Idaho measured excess water flows in and out of the two studied districts. The schematic diagram of the excess water delivery systems are shown in Figure IV-3, and Table IV-5 contains the results of the 1978 irrigation season. As shown in the table, Sand Creek (Site 3), Little Sand Creek (Site 1) and Henry's Creek (Site 4) deliver most of the excess water into the study area. These waterways are not only used for irrigation but used for drainage in the area. The excess waters from sites 1, 2, 3 and 4 dump into Idaho Irrigation District, and the water at sites 6, 7, 8, 9 and 10 is waste from the Idaho Irrigation District flowing into the Snake River Valley Irrigation District. The excess water from the other sites shown in the figure is lost out of the study area. Most of it is reused in downstream areas.

There was a total of 28,894 acre-feet of excess water delivered into the Idaho Irrigation District and a total of 36,870 acre-feet of waste water left the district in 1978 irrigation season. For the Snake River Valley Irrigation District in 1978 irrigation season, 27,707 acre-feet of excess water received from Idaho Irrigation District and 60,850 acre-feet of waste water was lost. Overall, the study area received 28,804 acre-feet of waste water and directly wasted 70,013 acre-feet in 1978 irrigation season. The large amount of water lost from the area is not a good source of irrigation water for downstream use since this excess water flow is not regular and does not necessarily occur at the time of irrigation water use in the area downstream. The total diverted inflows

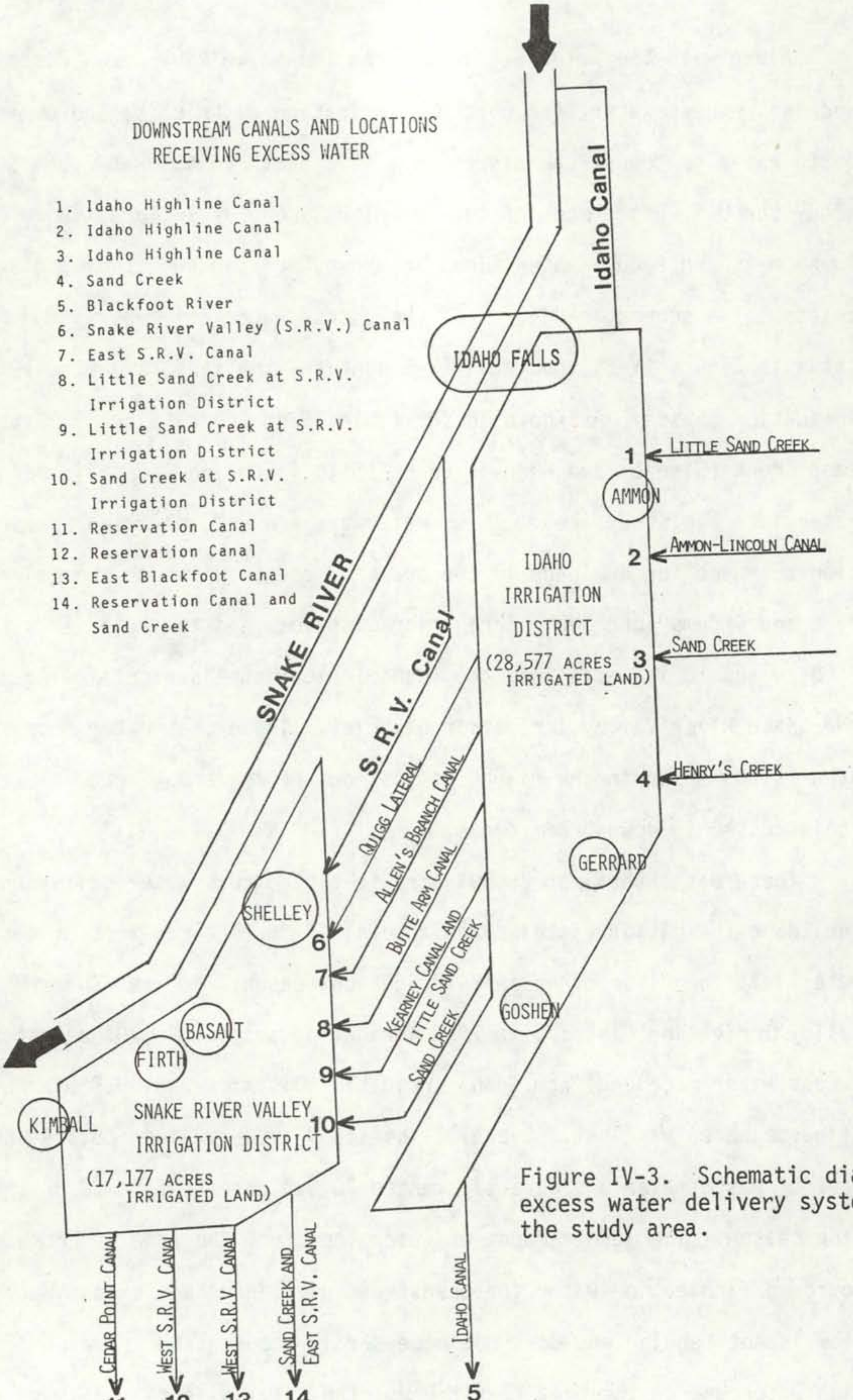


Figure IV-3. Schematic diagram of excess water delivery systems in the study area.

Table IV-5. Excess water flows of the study area in the 1978 irrigation season (From U.S. Department of the Interior Bureau of Reclamation, Boise, Idaho)

Site No. 1/	Total Flow acre-feet	Average 2/ cfs	Flow Rate maximum cfs	Flow Rate maximum date	Flow Rate minimum cfs	Flow Rate minimum date
1	17920	97.7	440	8/14	0.1	7/26
2	3500	19.0	31.3	8/3	0.2	9/19
3	7384	40.0	62.2	8/20	0.1	10/12
4	6680	36.0	64.5	9/9	10.6	8/4
5	9163	50.0	119.7	7/31	0.0	10/7
6	trace	--	--	--	--	--
7	3745	20.0	88.4	8/6	0.0	10/31
8	2350	12.8	22.6	7/9	1.3	9/26
9	trace	--	--	--	--	--
10	21612	117.8	234.4	9/21	1.1	7/25
11	1854	10.1	20.0	8/13	0.0	10/3
12	trace	--	--	--	--	--
13	53390	291.0	744.0	8/14	23.7	6/30
14	5606	30.0	35.0	11/5	0.0	8/31

1/ Record site shown in Figure IV-3
2/ Converted from acre-feet to cfs using conversion factor 0.00545 assuming 92 days of canal flow over 75% of maximum flow.

directly from the Snake River to the districts were 272,789 acre-feet for the Idaho Irrigation District and 166,616 acre-feet for the Snake River Valley Irrigation District in 1978 irrigation season.

LOW LEVEL AERIAL INFRARED IMAGES FOR INVENTORY OF THE STUDY AREA

It is necessary to accurately inventory existing irrigation systems, crops and waterways in an irrigated area in the process of developing rehabilitation plans. However, detailed site investigation is highly time and labor consuming for this purpose and important information may be easily overlooked in a cursory on-site survey. In this project low level aerial infrared images were taken over the study area in 1978 irrigation season. The images provided a great deal of information of the area, and the information was accurate enough to be used for the planning study.

INFRARED FILM AND ITS IMAGES

Many uses of KODAK AEROCHROME infrared film, type 2443, often called false-color film, have been found in forestry, geology, archeology, medical science, and crop and soil studies. (American Society of Photogrammetry, 1960). The film is sensitive to wavelengths from 360 to 900 nanometers which includes the visible component (400 to 700 nanometers). As a result, this film produces characteristic colors from the reflecting objects. It is the infrared component (700 to 900 nanometers), however, that produces the modified color rendition to the film.

The film is exposed with a yellow filter, Wratten #12, which attentuates wavelength shorter than about 500 nanometers. As a result the scattered blue and other shorter wavelengths are filtered out, and only the reflected green, red and infrared wavelengths reach the emulsion layers of the color infrared film.

The sensitivity of the film to infrared radiation reflected from vegetation and the high absorption of infrared energy by water bodies can be applied to identify and inventory irrigated agricultural land. The relationship between the colors taken and those resulting in the film is that the sequence of the reproduced colors is in the order of blue, green and red as it is in the spectrum, but the correspondence to the colors being detected is one block toward longer wavelengths, green, red and near infrared.

An object that reflects only infrared energy will expose the cyan layer in the film emulsion to form a red image in the resulting color transparency. Plant foliage reflects a significant amount of energy in the green color spectrum, and a large amount in the infrared spectrum. Thus, the resulting color of green vegetation varies from magenta to red. Deviations from the red color of plant foliage in an infrared image are not always caused by a change in infrared reflectance, but in many cases are caused by changes in visible energy (Knipling, 1973).

APPLICATION

Aerial photographs of the study area were taken on August 10, 1978. The KA-2 9-inch camera used was equipped with a 12-inch lens. A Wratten #12 yellow filter was used to eliminate scattered blue and shorter wavelengths in exposing the KODAK AEROCHROME infrared film, Type 2443 Estar base. The airplane was flying at 12,600 feet to 12,800 feet above sea level, approxiamtely 8,000 feet above ground level of the area. The scale of the resulting image was 1:8,000 (7.9 inches per mile). It took about 4 hours to cover the 50,000 acres area with 60 percent overlap for stereo images. An aerial exposure of 1/500 secong at f/5.6 was used. The total amount of film used was three 125-foot rolls. The film was developed to obtain color infrared transparencies.

After developing, the color positive infrared images of the study area were analyzed to iventory irrigation system components, crops and other details. The procedures used in analyzing the infrared transparencies are shown in Figure IV-4. Coordinates of all crop fields, canals, roads and other features such as residential areas were obtained from each transparency using an X-Y digitizer. These data were then refined by a digital computer by applying proper scaling factors and incorporating any needed corrections. The output consisted of a detailed printout and a composite computer drawn map of the entire area using a CALCOMP plotter.

When digitizing the coordinates of each field boundary, data describing the crops grown and types of irrigation application systems used in the area were also obtained from the color infrared transparencies and entered into the computer. These data were used to obtain distribution patterns of each crop and irrigation system type. There were four major crops (potatoes, alfalfa, grain and pastureland) and five irrigation application system types (furrow, border and hand-move, side-roll and center pivot sprinklers) in the study area. To simplify the analysis in the planning procedure, small areas of other crops were combined with one of the four major crops. For example, small areas of corn were grouped with potatoes as they are both row crops. With the exception of small laterals, the length and width of each irrigation canal were also

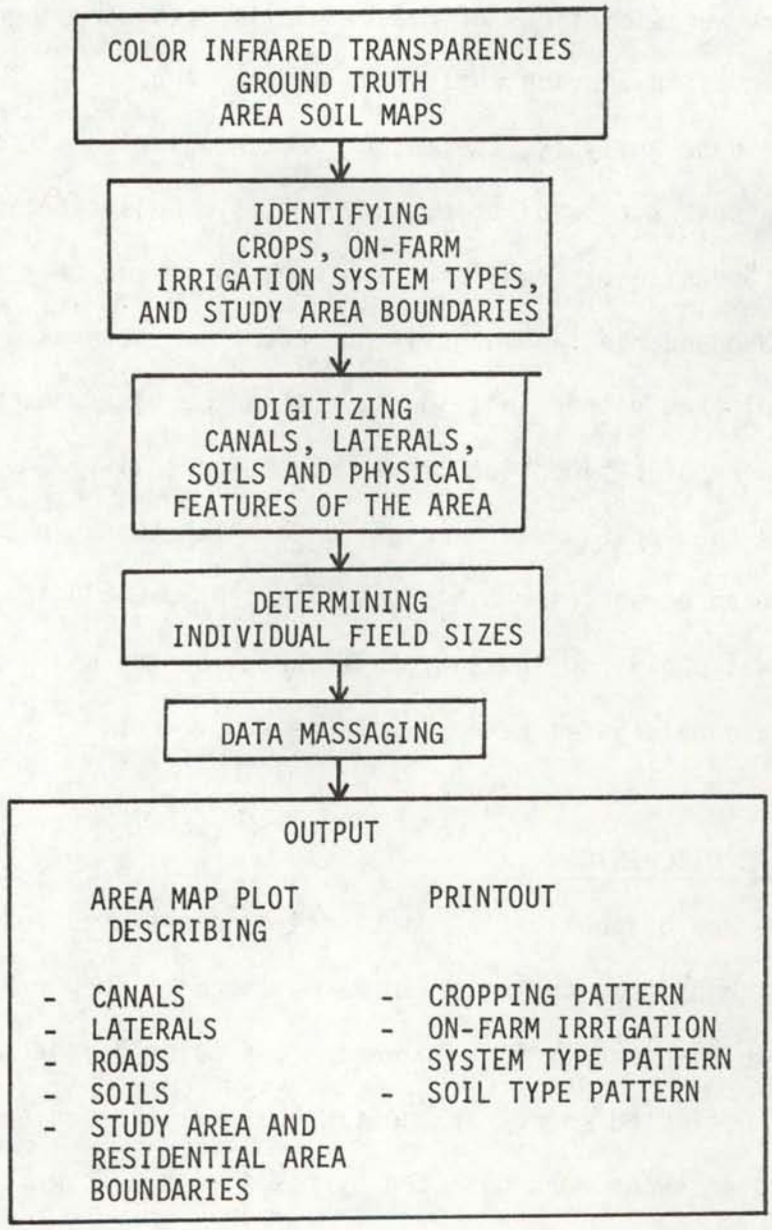


Figure IV-4. Flow chart of the procedures used in analyzing the infrared photographs.

obtained as were locations of roads. Soils data were input by digitizing Soil Conservation Service soils maps of the area.

After data analysis, the output obtained included crop distribution, irrigation system type distribution, soil type distribution, and canal locations and sizes. Computer drawn maps consisted of a base map showing study area boundaries and canals and laterals. Several overlay maps could be plotted either individually or on the base map. Individual overlays were of residential areas, roads and soils. The map in Figure IV-1 shows the locations of irrigation canal networks obtained from the infrared transparencies. Since the latest U.S. Geological Service map of the area was published in 1948, this map gives the most updated information about canal system networks of the study area.

RESULTS AND DISCUSSION

There are basically five distinctive colors used for identifying different crops from the color infrared images. They are red, magenta, greenish, bluish, and yellow colors. Each color is characterized by the amount of reflected energy of the visible and infrared spectrums. Irrigation system types were detected by physical characteristics recorded from each type, and not by typical colors obtained. Canals, laterals and even small farm ditches were well defined by their black to dark blue color caused by the high infrared absorption of water. Ground truth data were collected and used as base information for the analyses.

The information in Table IV-6 describes how the infrared images were analyzed to identify crops, on-farm irrigation systems and other objects in this study. The data obtained from the pictures include cropping pattern, canal length, width and route, irrigation system type pattern and other necessary information to inventory the area. More details of this part of the study are described by the authors (Yoo and Busch, 1980a).

Table IV-6. Resolution used to identify crops, irrigation application system types and other objects from the study area

Object	Resolution for Identification
CROPS	
-- Grain	Unharvested field -yellow (mixture of high visible and high IR reflectance) and bluish green (high visible and low IR relectance)
	Harvested field - yellow strips between bluish colors
-- Potatoes	Red to magneta with row marks which are well shown on field ends where crop cover is poor. Potatoes were the only major row crop in the area.
-- Alfalfa	Unharvested field - red to bright red
	Harvested field - narrow yellow strips between green or scattered red marks. Hay bales are occasionally found on ground.
-- Pasture	Dark red with large dark and blue spots (water pondage or wet bare soil).
IRRIGATION SYSTEMS	
-- Furrow	Row marks on field without any sprinkler marks. In most cases head and tail ends have poor crop cover and large dark area on tail end (wet bare soil or water pondage).
-- Border	No row marks or sprinkler marks on fields. Some fields show border dikes. Most fields have poor crop cover on tail and head ends, and large dark spots are often vivid on tail ends (wet bare soil or water pondage).
-- Hand-move Sprinkler	This system can be easily detected from the picture when it is operating. Otherwise, it is difficult to identify. Other systems must be first described.
-- Side-roll Sprinkler	Side-roll wheel marks are vividly shown in the picture with or without the system operating. The side-roll driver is a good identification mark of this system.
-- Center-Pivot Sprinkler	This system is easly detected by circular shaped wheel marks with or without a corner system.
OTHER	
-- Idle land	Greenish blue and very light color (dry bare soil) with or without tillage marks.
-- Canals & Laterals	Black and dark blue with white sparkles from water spray and waves which indicate the direction of water flow.
-- Roads	Grey to black for unpaved or paved roads.

CHAPTER V

IRRIGATION SYSTEMS COST ESTIMATION FOR THE STUDY AREA

The optimization technique requires the representation of physical and economic features and values in numerical terms for all irrigation system components. Although the system costs and efficiencies are the major input parameters to the optimization problem matrix, there are many factors which are included in formulating these parameters. The reliability of the results of this study is somewhat dependent upon the accuracy of these parameters. However, the evaluation and comparison of alternative irrigation system plans obtained are rather relative in a decision-making process.

COMPUTER PROGRAMMING ROUTINES FOR COST ESTIMATION

Computer programs have been developed to generate numerical values of costs and operating characteristics of physical features of on-farm irrigation systems (Galinato and others, 1977 and Allen and others, 1978). These values are used to formulate mixed integer-linear programming problem matrix for the optimization procedures in this study. The details of the computer programs and their usages are well described by Allen and others (1978). These computer routines have been continuously revised to improve the accuracy and to obtain practical values and are available to any potential users.

The computer routines are composed of four submodels: APSYS, PUMP, CANAL and PIPE. Each subsystem is summarized in Table V-1. The details of input parameters and formats, and sample outputs of the routines are listed in Appendices C and D. The APSYS routine includes two parts,

Table V-1. Synopsis of the computerized planning and cost estimation routines used to determine annual costs of irrigation systems (After Allen and others, 1978).

APSYS	This routine determines the annual costs of owning and operating irrigation application systems including land forming costs. Water application and distribution efficiencies are evaluated for each system design and on-farm managment practice. Specific application methods evaluated are furrow and border surface systems and hand-line, side-roll solid-set, and center pivot sprinkler systems.
CANAL	Annual ownership costs and conveyance efficiencies of open channel conveyance systems are estimated in this routine. The planned system may be lined or unlined and construction costs may be estimated for new or rehabilitated systems. Procedures used in this routine estimate costs of earthwork, canal lining and shaping, lateral turn-outs, and flow control structures.
PIPE	This computer routine estimates costs of constructing a gravity or high pressure pipeline system through undisturbed terrain or along an unlined channel route for a rehabilitation project. Pipe costs can be estimated for concrete, steel, or PVC pipe, and turnout costs can be estimated for high or low pressure operation.
PUMP	Annual ownership, operation, and electrical power costs of large pumping plants and small on-farm pumping units are estimated in this computerized procedure. Provision has been made to estimate escalation of power costs over the system life. On-farm units can be of centrifugal or turbine type, and costs of deep or shallow wells can also be estiamted. USBR planning specifications and procedures are used in the estimation of annual costs for large pumping systems.

SPNKLR and SURFCE. The first part is designed to deal with hand-move, side-roll and center-pivot sprinkler irrigation systems and the second part does the necessary computations for furrow and border gravity irrigation systems. These routines estimate annual system cost, gross system water requirement, water application efficiency and water lost to surface runoff and deep percolation. Procedures developed by the U.S. Department of Agriculture Soil Conservation Service are used for furrow irrigation system evaluation and design (UDSA, 1979). The main method of border irrigation system design and evaluation is from the border irrigation system zero-inertia model developed by Katopodes and Strelkoff (1977). This model uses zero-inertia, open channel flow, continuity and momentum theories. The main APSYS routine reads information for a specific soil-type, and a CROP subroutine inputs soil-plant-water relation data for each crop and soil type. These data and information generated are then utilized by SPNKLR and SURFCE subroutines to calculate the final desired information.

The PUMP routine is used to calculate annual pump and power costs for large pumping plants operating from rivers, canals, or reservoirs and smaller stations designed for on-farm operations. Total construction and power costs associated with each system are calcualted in relation to the design flow capacity of a pump station. Operation and maintenance costs of the pumping station are also estimated by the routine.

The distribution system costs are estimated for open channel and pipe (gravity and pressurized) system components by the computer routines, CANAL and PIPE, respectively. Many of the design procedures and routines have been obtained from the U.S. Department of the Interior Bureau of Reclamation (Galinato and others, 1977). These routines are used to provide cost estimation for conveyance system rehabilitation over existing systems or for new system development. The routine finally develops a relationship between annual system cost and design flow rate, and calculates canal conveyance efficiency for canal sections. The annual system costs for each section are computed for a range of design flow rates comparable to those expected in each section, and a linear cost function with a fixed cost (e.g. Figure III-1) is developed with this restriction. These functions have been found very suitable with a highly significant (95%) coefficient of determination (R^2) value (Busch, 1974, Galinato and others, 1977 and Allen and others, 1978).

APPLICATION OF THE COST ESTIMATION ROUTINES TO THE STUDY AREA

The cost estimation routines were applied to the study area with the data obtained from the 1978 crop year. As mentioned in the previous chapter the infrared images of the area taken by low level aerial photographs were used to obtain existing crop and irrigation system patterns of the study rea. Soil type patterns were obtained from Soil Conservation Service soil maps of the study area. The Bureau of Reclamation in Boise, Idaho provided land ownership descriptions of the area.

The base data of the cost estimation routines were obtained from numerous current publications including Gray (1981), Linderborg and others (1979), Gossett and others (1976), Willett (1976) and Pair and others (1975). A 12% annual interest rate, 20-30 year system life and 12% energy escalation rate were used in computing annual costs as well as cost indices used by the Bureau of Reclamation.

Application of the cost routines to the large study area required several assumptions to keep computing time within reasonable limits. The assumptions in Table V-2 were used for surface irrigation systems cost estimation. Sprinkler systems were assumed to require two pump units for fields of 240 acres or larger and one unit for smaller fields. A 150-foot total dynamic head (TDH) farm pump for hand-move and side-roll sprinkler irrigation systems and 175-foot TDH farm pump for center-pivot systems were assumed. Land ownership sizes of 40 acres and 160 acres in the area with sandy soils were considered suitable for center-pivot sprinkler systems. In the study area the subareas 9 and 31 in Idaho ID and J, R, and S in Snake River Valley ID (Figure VI-2) are compatible for center-pivot sprinkler systems due to their sandy soil and land ownership sizes. For other sprinkler systems field sizes from 20 acres to 320 acres in all subareas were considered suitable. System dimensions and descriptions of each sprinkler irrigation system considered in the study area are described in Table V-3.

The APSYS cost estimation routine was run for combinations of four crops, seven soil types, and different run lengths for gravity systems and different land ownership sizes for sprinkler systems. The outputs obtained include annual system cost ($/acre), deep percolation and surface runoff losses (acre-feet/acre) and system application efficiency (%)1/. The PUMP routine was run to obtain power and pump costs for each sprinkler irrigation system for different field sizes. An annual energy inflation rate of 12% was used in computing power costs.

1/ Application efficiency is defined as the ratios of the water stored in the root zone to the amount of water applied to a field.

Table V-2. Design assumptions to calculate costs and efficiencies for gravity irrigation systems

Improved Gravity	Unimproved Gravity
1. Lined concrete ditch	1. No ditch lining
2. Well maintained concrete and metal structures for stream control and measurement.	2. Minimum stream control and measurement device
3. Extensive land leveling and operating and irrigation scheduling management	3. Minimum land leveling
4. Irrigation set time adjusted for maximum efficiency	4. Longer set time and run lengths than the improved system
5. Siphon tube used for distributing water	5. More labor time and land lost to production required than for the improved system.

Soil 1/	Irrigation run lengths and widths considered for each soil (feet)			
	Improved Gravity		Unimproved Gravity	
	length	width	length	width
Am	860	860	1300	1300
Ba	650	650	650	860
Bo	860	860	1300	1300
He	650	650	650	860
Pe	860	860	1300	1300
Sa	320	650	320	650
Wo	320	650	320	650

1/ Soil series discussed in Chapter IV and Appendix A

Table V-3. System dimensions and descriptions of the sprinkler irrigation systems

Sprinkler System	Field Size (acres)	Lateral Length (feet)	Description
Hand-Move Sprinkler	20 40 60 80 120 160 240 320	1300 1300 1950 1300 & 2600 2600 2600 2600 2600	The layout of this system consists of hand-carried laterals supplied by a buried main-line. Lateral spacing is 60 feet. The overall application efficiency is 75% with 8% evaporation loss. The system life is 15 years for laterals and 20 years for mainlines. The labor rate over this life time is $4.50 per hour.
Side-roll Wheel line sprinkler	20 40 60 120 160 240 320	1300 1300 1950 1300 & 2600 2600 2600 2600	The layout of this system consists of mechanically moved laterlas supplied by a buried main-line. Lateral spacing is 60 feet. The overall application efficiency is 78% with 8% evaporation loss. The system life is 15 years for laterals and 20 years for mainlines. The labor rate over the lifetime is $6.50 per hour.
Center-pivot	40 160		This system consists of a mechanically moved lateral which rotates about a center pivot point. Water is applied by a permanently buried mainline. The lateral includes an attached corner system. The overall application efficiency of the system is 85% with 10% evaporation loss. The life is 15 years for laterals and 20 years for mainlines. Minimum labor is involved for operation of the system.

Since the mixed integer-linear programming formulation requires information for each subarea supplied by a conveyance section, the weighted averages of the data generated by the cost estimation routines were computed for obtaining site-specific data for each subarea. Weighted averages of the data were obtained from the routines based on crops, soil types and land ownership patterns of each subarea.

For developing rehabilitation and consolidation plans for the irrigation districts in the study area, costs and conveyance efficiencies were obtained for all conveyance system sections using the CANAL and PIPE routines. Annual costs were in the form of, Annual Cost = AQ + B where Q is the design flow rate.

CHAPTER VI

ANALYSIS OF EXISTING IRRIGATION DISTRICT SYSTEMS WITH ALTERNATIVE IRRIGATION APPLICATION SYSTEMS

Much of the water diverted into the irrigation systems in the study area is lost due to inefficiencies in the systems. The average diversion exceeds 10 acre-feet/acre whereas crop water requirements seldom exceed 2.5 acre-feet/acre. High canal seepage and operational losses and low on-farm application efficiencies cause this low overall project efficiency.

An analysis and evaluation of the irrigation systems including the cost and availability of water can be used to provide valuable information for comprehensive future planning of efficient systems. In this chapter the status of the existing systems is presented along with a series of planning scenarios for future changes. The changes are considered for on-farm irrigation system alternatives served by the existing conveyance systems in the area. Therefore, no system costs are involved for conveyance systems except operation and maintenance (O & M) costs as no alternatives are considered. Evaluation of an existing system can be formulated as a linear programming problem which does not require any discrete solution since all cost functions are linear with no step functions.

CONVEYANCE SYSTEM PARAMETERS

The existing conveyance system routes of the study area are shown in Figure VI-1. The canal routes shown are those of existing unlined systems of the two irrigation districts studied. Through the years, portions of the systems have been improved to straighten and realign canal sections. Also, some wooden structures have been replaced with concrete or steel. However, the entire system still does not efficiently deliver water. As discussed in Chapter IV most of the canal bottoms are exposed to gravelly subsoil, and the results of a canal seepage study done by Netz (1980) show extremely high seepage losses from the canal systems. The seepage rates of the two irrigation districts are an average of 312 cfs at a peak diversion of 1500 cfs for the Idaho Irrigation District and an average of 179 cfs at a peak diversion of 850 cfs for the Snake River Valley Irrigation District.

A total of 32 and 18 conveyance sections were defined for the Idaho and Snake River Valley Irrigation Districts, respectively (Figure VI-1). Some sections are designated to deliver water only to downstream section(s) only while others deliver irrigation water to a farm subarea (subarea will be discussed later) as well as downstream section(s). The locations of sections and diversion points of the sections are shown in Figure VI-1. The dentritic nature of the canal sections is shown in the schematic diagram of the study area's water deliver system in Figure VI-2. The first section of each district is that section through which the entire diverted water from the Snake River is conveyed to meet water requirement of the area. Information for each conveyance section is shown in Table VI-1. These data include seepage rate, length and average width of canal sections, and service area of each canal section and cumulated total service area downstream of each section.

Operation and maintenance (O & M) costs for distribution systems of the existing systems were computed from a relationship obtained by Allen and Brockway (1979). They found O & M costs to be a function of total water delivered to a district. The relationship is:

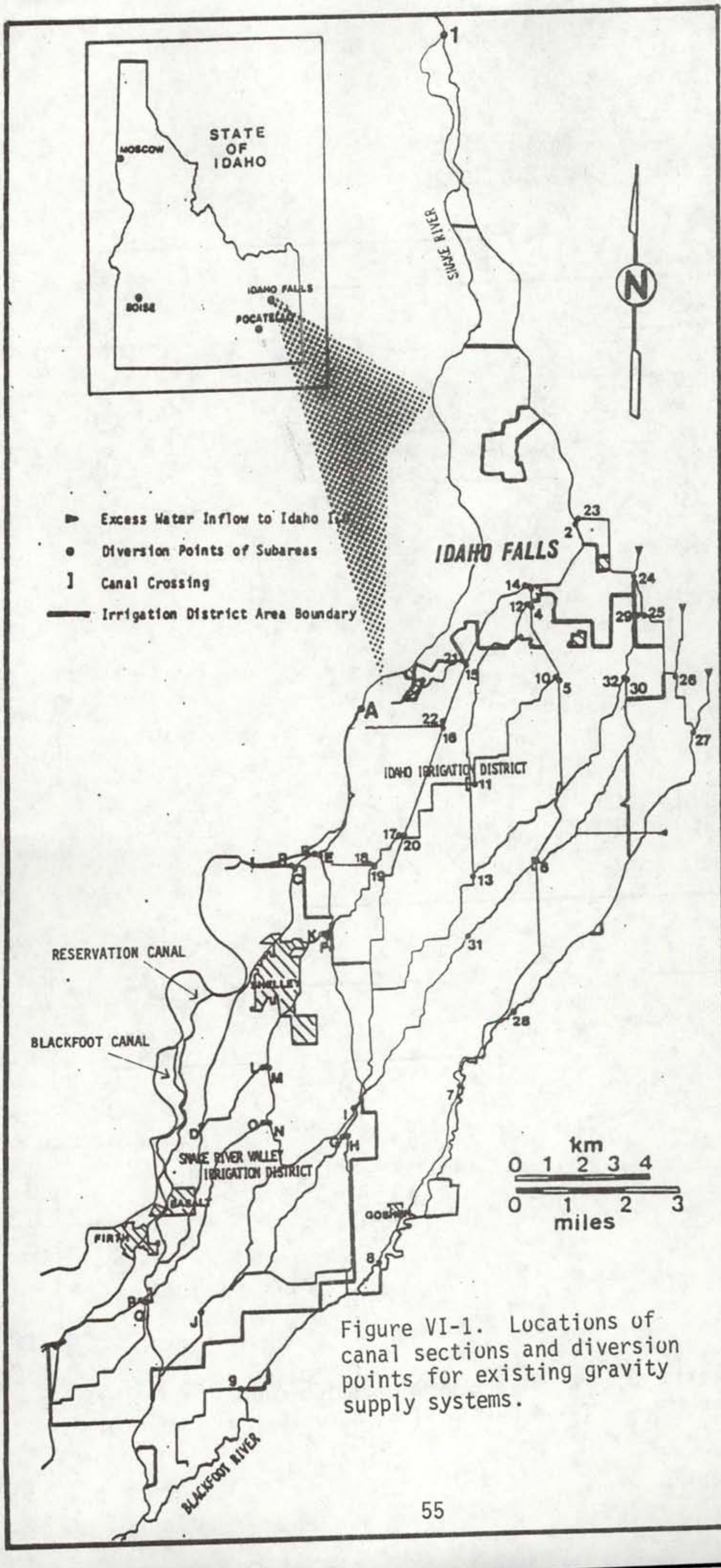
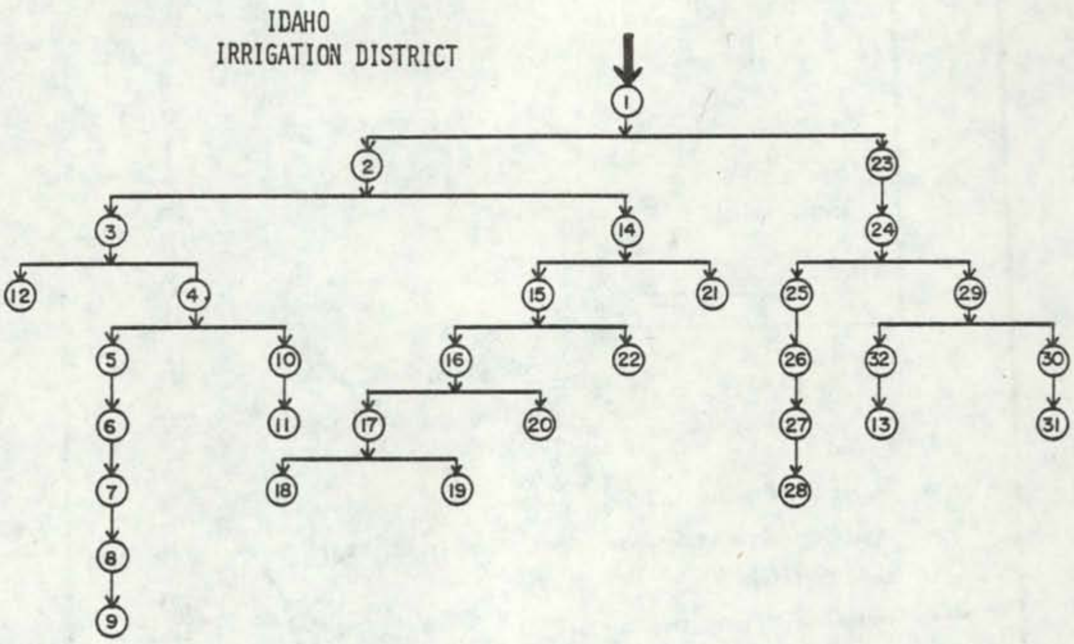


Figure VI-1. Locations of canal sections and diversion points for existing gravity supply systems.



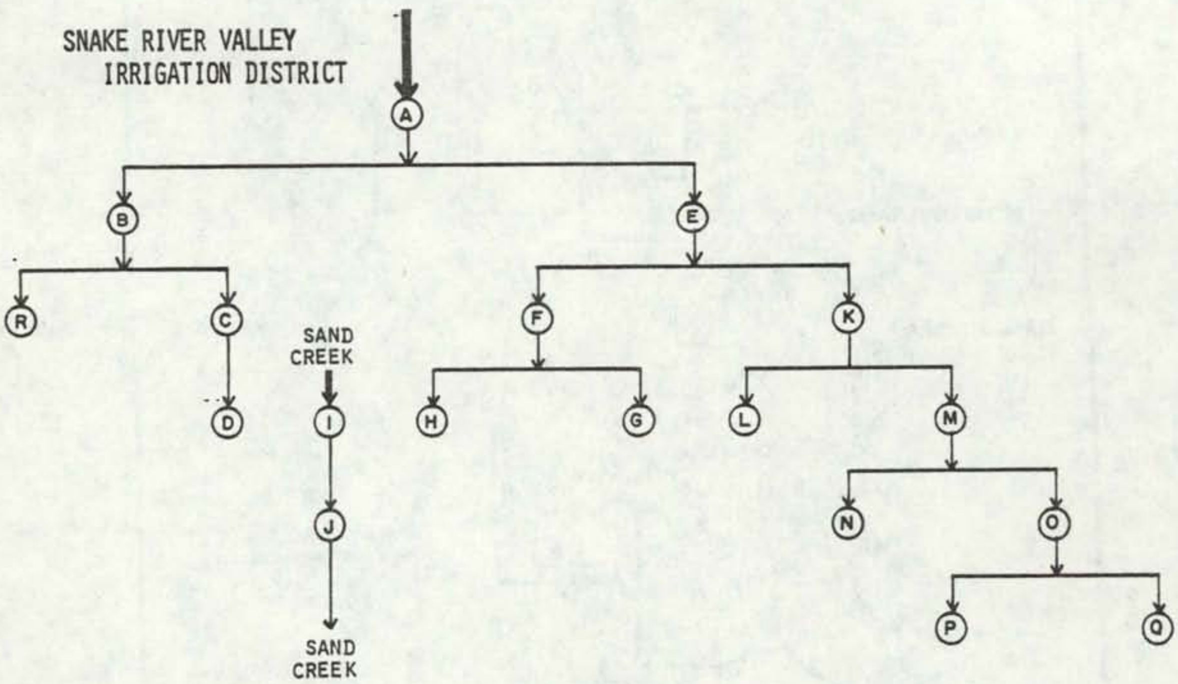


Figure VI-2. Schematic diagram of the canal section routes of the existing system and diversion points of subarea in the study area.

Table VI-1. Conveyance system data for the existing irrigation conveyance system sections

Section No.	Subarea Served (acres)	Total Downstream Area Served (acres)	Length Miles	Average Top Width Feet	Canal Seepage $Ft^3/Ft^2/Day$
1	1,248	28,577	10.38	67.84	2.68
2	0	20,463	1.94	49.98	2.31
3	0	15,230	0.32	35.70	2.31
4	1,219	12,330	1.55	35.70	1.31
5	1,592	8,856	3.83	29.63	1.05
6	1,969	7,264	5.29	23.57	0.60
7	2,474	5,295	3.99	18.21	0.60
8	1,435	2,821	4.56	14.28	0.60
9	1,386	1,386	2.83	19.28	0.60
10	1,164	2,255	3.27	10.71	1.31
11	1,091	1,091	2.45	7.85	1.31
12	1,385	2,900	6.42	11.78	1.05
13	1,515	1,515	3.45	28.56	1.05
14	189	5,233	2.04	28.56	2.31
15	478	4,417	1.87	24.99	2.31
16	0	2,273	2.36	22.14	2.31
17	363	1,630	0.93	11.43	1.81
18	374	374	1.25	3.57	2.31
19	893	893	2.24	12.14	1.81
20	643	643	2.72	5.0	1.81
21	627	627	1.41	4.28	3.74
22	1,666	1,666	1.95	4.28	3.74
23	0	6,866	2.05	21.42	1.31
24	0	6,866	0.85	33.20	2.40
25	508	2,548	1.67	14.28	1.00
26	351	2,040	1.54	14.28	1.00
27	1,073	1,689	7.10	13.57	0.60
28	616	616	8.33	10.71	0.60
29	435	4,318	1.34	60.69	1.05
30	1,288	2,760	5.23	28.56	2.40
31	1,472	1,472	4.14	28.56	2.40
32	1,123	1,123	5.36	26.78	1.05
A	0	15,036 1/	3.24	46.41	3.61
B	0	5,074	0.50	34.27	3.74
C	1,914	3,159	5.70	22.49	3.74
D	1,245	1,245	3.06	17.85	2.53
E	0	9,962	1.68	46.41	3.61
F	2,061	4,685	4.25	24.28	1.48
G	718	718	3.44	13.57	1.94
H	1,906	1,906	5.50	17.14	1.04
I	1,678	2,141 2/	4.99	31.07	2.40
J	463	463	1.25	33.92	2.40
K	522	5,277	2.99	22.14	1.31
L	541	541	2.08	8.93	1.40
M	553	4,214	1.24	27.85	1.31
N	599	599	1.10	12.14	1.31
O	1,218	3,062	4.51	18.92	1.31
P	265	265	2.22	7.14	2.53
Q	1,579	1,579	3.33	5.36	2.53
R	1,915	1,915	1.49	14.28	3.74

1/ Total area served by water diverted from Snake River
2/ Total area served by water from Sand Creek

$$COMO = 0.413\ AF$$

where,

COMO = annual operation and maintenance cost for an open channel system.

AF = total water delivered to a district in acre-feet.

This relationship was developed from data obtained from Idaho Irrigation District. Since the existing distribution systems of the study area are completely open channel systems, the above function can be directly used to obtain O & M costs for the Snake River Valley Irrigation District.

SUBAREA SELECTION AND APPLICATION SYSTEM PARAMETERS

Each conveyance section delivers water to a defined subarea as well as any conveyance sections located downstream. The selected subareas served by the existing unlined gravity canal system are shown in Figure VI-3. The numbers and letters both identify the subareas and indicate the conveyance sections shown in Figures VI-1 and VI-2 that serve the subareas. One requirement of a gravity irrigated subarea selection is that it must be located at a lower elevation than the supply point. Small head ditches and sublaterals in a subarea used to deliver and distribute irrigation water to individual fields are considered as part of the on-farm application systems. Subareas can be designated independently of soil type and land use. However, subarea boundaries are defined wherever possible so that there is a homogeneous soil type in the area to reduce the complexity of evaluation. One of the main purposes of each subarea selection is to determine the design flow rate required in each conveyance section so that water can be adequately delivered throughout the system. Another purpose is to obtain more detailed information of

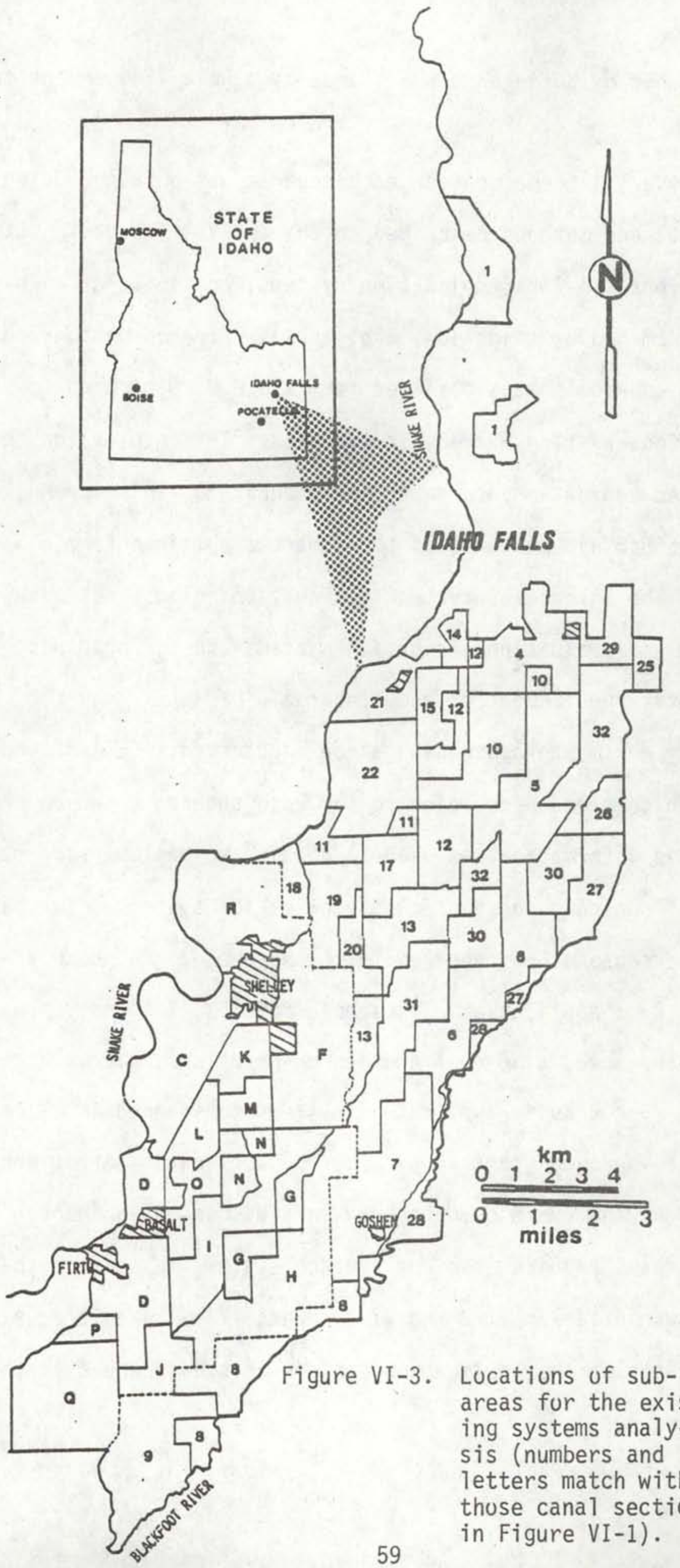


Figure VI-3. Locations of sub-areas for the existing systems analysis (numbers and letters match with those canal section in Figure VI-1).

each subarea unit by defining a small area as a unit independent from other units.

All necessary information for each subarea was obtained using the background data and methods described in Chapter V. The distribution patterns of crops, on-farm application systems, and soils of each subarea were determined by using low level aerial infrared photographs taken over the area and soils maps obtained form the U.S. Department of Agriculture Soil Conservation Service in the area. The results for the existing system evaluation are shown in Appendix B. This appendix also includes the ownership patterns of the subareas obtained from U.S. Department of the Interior Bureau of Reclamation. These data are vital for analyzing and evaluating irrigation systems and for obtaining for the irrigation water requirement of each subarea.

The daily maximum evapotranspiration requirements (ET) of the major crops grown in the area were weighted for each subarea based on cropping patterns. This information was used to obtain the maximum flow rate requirement of subareas for different application systems. The daily maximum ET and seasonal ET required for each subarea are shown in Table B-1 (Appendix B). Application efficiencies of 75%, 78% and 85% were assumed for hand-move, side-roll and center-pivot sprinkler systems, respectively. For gravity application systems considered in this study, unimproved and improved gravity systems, the application efficiencies were computed by the APSYS computer routines discussed in Chapter V. The maximum flow rates required for application systems in each of the subareas are shown in Tables VI-2 and VI-3. These flow rates are used as design flow rates of the application systems of the subareas in the optimization procedures.

Table VI-2. Gravity irrigation application systems data of annual operation for the evaluation under existing canal systems

Subarea	Improved Gravity Irrigation (IG)					Unimproved Gravity Irrigation (UG)				
No. 1/	Q_{max} 2/ Cfs/Acre	EFF 3/ %	Annual Cost $/Acre	DP 4/ AF/Acre	EP 5/ AF/Acre	Q_{max} Cfs/Acre	EFF %	Annual Cost $/Acre	DP AF/Acre	SR AF/Acre
1	0.0204	53.1	85	0.196	1.521	0.0321	33.7	59	1.015	2.853
4	0.019	57.2	89	0.283	1.178	0.0313	35.6	68	1.063	2.095
5	0.0207	51.5	82	0.202	1.410	0.0361	29.5	57	1.067	3.055
6	0.0190	58.2	90	0.136	1.373	0.0275	40.2	63	0.887	2.003
7	0.0194	59.1	80	0.093	1.574	0.0287	39.9	51	0.832	2.183
8	0.0188	59.9	90	0.089	1.370	0.272	41.5	63	0.780	1.975
9	0.0195	58.3	135	0.259	1.217	0.0273	41.6	121	0.990	1.835
10	0.0203	55.4	90	0.301	1.264	0.0321	35.0	69	1.096	2.242
11	0.0213	52.9	93	0.468	1.322	0.0304	37.1	74	1.346	1.734
12	0.0200	54.6	87	0.279	1.300	0.0337	32.5	65	1.132	2.667
13	0.0203	54.7	112	0.329	1.393	0.0300	37.0	94	1.090	2.240
14	0.0202	53.5	86	0.276	1.393	0.0380	28.5	62	1.247	3.374
15	0.0195	55.5	84	0.216	1.302	0.0372	29.1	59	1.173	3.188
18	0.0195	56.4	88	0.308	1.209	0.0304	36.3	66	1.124	2.003
19	0.0202	55.2	93	0.415	1.226	0.0301	37.1	76	1.203	1.789
20	0.0204	54.9	93	0.394	1.253	0.0308	36.4	74	1.191	1.925
21	0.0213	53.7	89	0.347	1.272	0.0369	31.0	68	1.290	2.625
22	0.0208	53.8	92	0.428	1.238	0.0327	34.3	74	1.286	2.172
25	0.0179	57.1	78	0.076	1.298	0.0283	36.0	49	0.776	2.311
26	0.0204	56.6	78	0.086	1.796	0.0304	37.9	50	0.804	2.428
27	0.0202	56.1	77	0.110	1.693	0.0288	37.2	50	0.854	2.118
28	0.0227	50.1	79	0.130	2.253	0.0321	36.4	52	0.884	2.523
29	0.0185	58.4	82	0.146	1.437	0.0291	37.6	56	0.843	2.178
30	0.0192	56.8	93	0.149	1.453	0.0276	39.5	67	0.878	2.189
31	0.0190	57.0	105	0.164	1.316	0.0255	42.5	79	0.893	2.362
32	0.0193	55.6	83	0.130	1.421	0.0313	34.3	57	0.928	2.813
C	0.0196	56.0	87	0.322	1.198	0.0313	35.0	65	1.186	2.189
D	0.0204	55.4	95	0.229	0.290	0.0332	34.2	62	1.217	2.406
F	0.0196	56.5	95	0.278	1.222	0.0304	36.5	73	1.072	2.113
G	0.0194	58.8	140	0.251	1.122	0.0271	42.2	125	0.954	1.658
H	0.0192	60.3	96	0.104	1.293	0.0288	40.2	71	0.832	2.111
I	0.0199	55.4	110	0.227	1.355	0.0274	40.1	88	0.988	2.399
J	0.0195	58.1	118	0.197	1.313	0.0272	41.7	99	0.937	2.210
K	0.0193	58.2	85	0.248	1.165	0.0302	37.3	61	1.072	1.933
L	0.0201	57.5	83	0.266	1.234	0.0304	38.2	57	1.212	1.333
M	0.0180	60.5	85	0.214	1.036	0.0298	36.6	62	0.982	1.926
N	0.0189	59.2	87	0.198	1.125	0.0305	36.8	63	0.983	2.046
O	0.0193	59.0	97	0.203	1.161	0.0288	39.4	73	1.020	1.879
P	0.0183	63.6	76	0.027	1.023	0.0306	38.0	46	0.849	2.117
Q	0.0192	56.7	115	0.330	1.256	0.0282	38.5	98	1.089	2.102
R	0.0197	56.7	80	0.307	1.179	0.315	35.4	66	1.142	2.099

1/ Subareas are shown in Figure VI-3
2/ Maximum flow rate required
3/ Application system efficiency
4/ Deep percolation loss
5/ Surface runoff loss

Table VI-3. Sprinkler irrigation application systems data of annual operation for the evaluation under existing canal systems

Subarea	Hand-Movement Sprinkler (HMS)					Side-Roll Sprinkler (SPS)				
No. 1/	Q_{max} 2/	Annual Cost ($/Acre)			DP 4/	Q_{max}	Annual Cost ($/Acre)			DP
	Cfs/Acre	Total 3/	Pump	Power	AF/Acre	Cfs/Acre	Total	Pump	Power	AF/Acre
1	0.0144	89	36	16	0.4058	0.0139	99	17	33	0.3571
4	0.0149	97	40	18	0.4195	0.0143	104	19	36	0.3691
5	0.0142	89	37	15	0.3911	0.0137	99	14	34	0.3442
6	0.0147	89	34	19	0.4155	0.0142	99	18	32	0.3656
7	0.0153	90	34	19	0.4272	0.0147	100	18	32	0.3670
8	0.0150	82	34	14	0.4197	0.0145	92	14	32	0.3694
9	0.0151	88	34	12	0.4255	0.0134	97	10	31	0.3744
10	0.0150	95	41	15	0.4212	0.0144	104	15	37	0.3707
11	0.0150	95	37	18	0.4324	0.0144	101	13	33	0.3805
12	0.0146	93	39	14	0.4110	0.0140	105	14	36	0.3617
13	0.0148	93	38	15	0.4211	0.0142	102	14	35	0.3705
14	0.0144	100	36	24	0.4054	0.0139	108	24	35	0.3567
15	0.0144	84	32	14	0.4045	0.0139	96	13	30	0.3560
18	0.0147	92	37	16	0.4183	0.0141	101	16	34	0.3681
19	0.0149	101	40	17	0.4269	0.0143	110	17	37	0.3757
20	0.0149	95	38	18	0.4260	0.0143	101	18	34	0.3749
21	0.0152	87	33	14	0.4245	0.0146	95	12	30	0.3735
22	0.0149	94	38	15	0.4241	0.0143	103	15	34	0.3732
25	0.0136	85	34	16	0.3846	0.0131	97	16	32	0.2385
26	0.0154	87	36	15	0.4289	0.0148	102	15	34	0.3774
27	0.0151	84	36	14	0.4227	0.0145	96	14	33	0.3720
28	0.0152	82	34	12	0.4309	0.0146	93	13	31	0.3792
29	0.0144	98	35	25	0.4084	0.0138	106	25	32	0.3593
30	0.0145	86	33	17	0.4107	0.0140	96	16	31	0.3614
31	0.0145	89	34	18	0.4056	0.0139	96	17	32	0.3569
32	0.0143	87	35	16	0.3990	0.0138	97	15	33	0.3511
C	0.0146	89	15	35	0.4151	0.0140	98	14	32	0.3653
D	0.0151	92	19	36	0.4229	0.0145	99	18	33	0.3782
F	0.0148	96	17	39	0.4180	0.0142	106	15	36	0.3478
G	0.0152	99	17	39	0.4282	0.0147	108	16	36	0.3769
H	0.0154	87	14	37	0.4260	0.0148	98	13	35	0.3748
I	0.0147	95	20	36	0.4125	0.0141	102	19	33	0.3630
J	0.0152	93	16	36	0.4206	0.0146	104	10	33	0.3701
K	0.0150	90	15	38	0.4227	0.0144	97	15	34	0.3720
L	0.0154	83	13	33	0.4341	0.0149	93	13	30	0.3820
M	0.0145	94	18	39	0.4117	0.0140	103	19	35	0.3623
N	0.0149	97	20	39	0.4179	0.0144	104	19	36	0.3677
O	0.0151	90	17	36	0.4243	0.0146	98	17	33	0.3734
P	0.0155	86	18	37	0.4219	0.0149	91	17	34	0.3713
Q	0.0147	97	19	37	0.4178	0.0139	103	20	33	0.3676
R	0.0149	91	17	37	0.4200	0.0143	99	16	34	0.3700

Subarea	Center-Pivot Sprinkler (CPS)				
No 1/	Q_{max} 2/	Annual Cost ($/Acre)			DP 4/
	Cfs/Acre	Total 3/	Pump	Power	AF/Acre
9	0.0134	129	13	30	0.2533
31	0.0128	165	20	30	0.2433
J	0.0134	164	19	32	0.2523
Q	0.0128	154	16	30	0.2397
R	0.0131	109	8	29	0.2477

1/ Subareas are shown in Figure VI-3

2/ Maximum flow rate required

3/ Total cost includes pump and power cuts

4/ Deep percolation loss

Cost and efficiency data for alternative application systems were also computed and are shown in Tables VI-2 and VI-3. The weighted average of annual cost ($/acre), deep percolation loss (acre-feet/acre) and runoff loss (acre-feet/acre) of the application systems for each subarea were obtained based on the distribution patterns of crops, soils and land ownerships. The system cost data includes capital, operating and maintenance costs. For sprinkler irrigation systems it was assumed that deep percolation is the only source of water loss with no surface runoff, and that each system is operated at the given application efficiency level. Total annual cost of sprinkler system includes pump and power costs. The five subarea units 9 and 31 in Idaho ID and J, Q anr R in Snake River Valley ID were considered suitable for center-pivot irrigation systems due to their sandy top soils and large land ownerships. In general, the application system costs are in descending order for center-pivot, side-roll, hand-move, improved and unimproved gravity irrigation systems. However, some subareas such as units 9 and 31 have lower cost for sprinkler systems than for gravity systems. This fact is due to the high labor cost involved in operating gravity systems on soils with high water intake rates.

INPUT DATA FORMULATION OF THE LINEAR PROGRAMMING PROBLEM FOR THE EXISTING SYSTEMS EVALUATION

The data in Tables VI-1, VI-2 and VI-3 are used to develop a linear programming (LP) model of each irrigation district in the study area. Optimum values obtained were least cost systems as the objective function denoting total annual cost is minimized subject to constraints. Constraints establish continuity in the model and contain necessary relationships between the source(s) of supply and areas of demand (various application systems).

A linear programming formulation of analyzing an existing irrigation system contains the following equality and inequality functions:

Minimize objective function OBJ (OBJ = $\sum_{i=1}^{N} C_i X_i$, N = number of decision variables, C = unit cost of a variable and X = value of a decision variable) subject to:

a) Area constraints:

$$\sum_{i=1}^{m} AREA_{ij} = ACRE; \text{ for all } j \qquad (6\text{-}2)$$

where

$AREA_{ij}$ = size of a field in subarea j which is irrigated by application system i,

$ACRE_j$ = total acreage of subarea j,

m = number of application systems alternative considered in a subarea

b) System continuity constraints: (6-3)

$$Q_k - \sum_{i=1}^{m} Q_{ik} - \sum_{j=1}^{n} Q_{jk} \geq Seepage_k, \text{ for all } k$$

where

Q_k = design flow rate of canal section k which supplies water to application systems in a subarea and/or canal section(s) downstream,

Q_{ik} = flow rate required by application system i supplied by canal section k,

Q_{jk} = design flow rate in canal section j supplied by canal section k,

m = number of application system alternatives which are supplied by canal section k,

n = number of canal sections downstream directly supplied by canal section k, and

$Seepage_k$ = seepage rate of canal section k.

c) Resource constraints

$$Q_{head} \leq Q_{spec} \tag{6-4}$$

where

Q_{head} = flow rate required at headgate of a district, and

Q_{spec} = specified or available flow rate entering a system.

d) Flow-rate-to-volume conversion constraints: (6-5)

$$\S \cdot WN - Q_{head} = 0.$$

where

§ = conversion factor of cfs to acre-feet, 0.00545

WN = delivered inflow at headgate in acre-feet, and

Q_{head} = delivered inflow at headgate in cfs.

e) Deep percolation constraints:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} DP_{ij}\ AREA_{ij} = VDP \tag{6-6}$$

where

DP_{ij} = deep percolation loss in acre-feet/acre from application system j in subarea i,

$AREA_{ij}$ = area irrigated by system j in subarea i,

m = number of subareas,

n = number of application systems alternatives, and

VDP = total deep percolation loss.

f) Surface runoff constraint:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} SR_{ij} \, AREA_{ij} = VSR \qquad (6\text{-}7)$$

where

SR_{ij} = surface runoff loss in acre-feet/acre from system j in subarea i (no surface runoff is considered for sprinkler application systems),

$Area_{ij}$ = area irrigated by application system in subarea i,

m = number of subareas,

n = number of application systems alternatives, and

VSR = total surface runoff loss.

These relationships are the rows in the linear programming matrix map shown in Figure VI-4 for an example system. This matrix map represents a small irrigation system starting at diversion point B of the Snake River Valley Irrigation District. The system includes subareas C, D and R which are supplied through canal sections B, C, D and R. The matrix map is given in abbreviated form; that is, all numbers other than 1.0 are represented by letter symbols whose ranges of value are also shown in the figure. The application systems for all units represented in columns of the matrix correspond to those symbols and systems UG, IG, HMS, SRS and

		SRC	HMC	UGC	IGC	SRD	HMD	UGD	IGD	SRR	HMR	UGR	IGR	WN	VDP	VSR	SECB	SECC	SECD	SECR	OMU	RHS
OBJ	N	B	B	B	B	B	B	B	B	B	B	B	B									
AREAC	E	1	1	1	1																	D
AREAD	E					1	1	1	1													D
AREAR	E									1	1	1	1									D
SYSB	L																-1	1		1		-A
SYSC	L	U	U	U	U													-1	1			-B
SYSD	L					U	U	U	U										-1			-A
SYSR	L									U	U	U	U							-1		-A
WTON	L																1					C
WON	E													V			-1					
DP	E	-T	-T	-A	-T	-T	-T	-A	-T	-T	-T	-A	-T		1							
SR	E			-A	-A			-A	-A			-A	-A			1						
SYSU	E																1	1	1	1	-V	
CHON	N													1							T	
CNDP	N														1							
CHSR	N															1						

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

Figure VI-4. Linear programming matrix for optimum planning of an example irrigation distribution and application systems.

CPS) listed in Tables VI-2 and VI-3. All column headings beginning with "SEC" represent distribution system component sections.

The WN, VDP and VSR columns in the matrix represent annual volumes of water (acre-feet) diverted into the system at the headgate, deep percolation loss and surface runoff loss, respectively, for the entire system. Annual operation and maintenance cost for the distribution system appears in the OMU column.

Rows of the matrix in Figure VI-4 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 each subarea receives irrigation water via one or more of the listed application system alternatives. Total acreages of each of these rows must equal to the total land area of the subarea listed in the RHS column. The "SYS" rows provide for continuity of water flowing through the distribution system and for distribution of water to application systems from the proper section. For example, the coefficients in the SYSC row indicate that distribution section SECC must convey enough water, considering the seepage loss of that section, to supply the application systems selected for subarea C in addition to section SECD. The total flow rate of water entering the entire system is depicted and controlled by elements of the WTON row. The coefficient in the RHS column of this row is the Q_{spec} value. The WON row is necessary to convert the total system flow rate (cfs) to a total annual volume (acre-feet). The coefficient necessary for this conversion entered in the WN column has been set equal to 0.00545 CFS/AF for this particular example. This coefficient was estimated, using a seasonal ET curve for the area, by setting the maximum flow rate required by the system equal to the peak of the seasonal ET curve and integrating under the curve over the total length of the irrigation season.

The DP and SR rows are necessary for calculation of deep total percolation and surface runoff losses of program-selected application system alternatives. Coefficients entered into these rows are obtained from output of the APSYS application system evaluation computer routine described in Chapter V and listed in Tables VI-2 and VI-3. The change rows, whose names begin with the letters "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 represent the limits placed on all constraints.

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

SYSTEMS ANALYSIS OF EXISTING IRRIGATION SYSTEMS

The purpose of the systems analysis for the irrigation systems was to obtain the "optimal" (lease cost) system plans for a specified set of conditions. To accomplish this purpose, relations present in the existing conveyance systems and alternative on-farm irrigation application systems were formulated into linear programming models for the two studied irrigation districts. The problem matrix of each irrigation district is similar to the one in Figure VI-4. The solutions and analysis were obtained using the MPS/360 Version 2 computer routine by International Business Machines, Inc.. The method of data formatting and control programs are discussed in detail in the MPS/360 Version 2 User's Manual (International Business Machines, 1974). The control program was used for program solution, parametric programming, and problem revision of the linear programming matrix representing the irrigation distribution and application systems.

The specific conditions considered in the evaluation for optimum planning of the existing irrigation systems of the study area were the overall project irrigation system efficiency and the water cost charged to water users for water entering a system at the headgate. Since no alternatives of the conveyance systems were considered, only those combinations of application systems which achieve these conditions at minimum cost were obtained in the existing systems analysis. The two studied irrigation districts were tested and will be discussed separately.

The specified overall irrigation efficiency during the peak ET period was computed for various flows entered to the systems as:

$$OSE = \frac{Q_{ET}}{Q_{IN}} (100) \qquad (6\text{-}8)$$

where,

OSE = overall system efficiency (%)

Q_{ET} = flow rate required to satisfy maximum ET requirement

Q_{IN} = flow rate entering a system at headgate

Efficiency levels were specified by adjusting the value of Q_{IN} in the linear programming matrix (Q_{spec} in RHS column of Figure VI-4), representing the maximum flow rate allowed to enter the system. Variations in prices for water diverted into each irrigation district were obtained by changing the coefficients in the objective function of WN column. These changes were accomplished by using parametric programming available in the MPS/360 routine. More details on the use and interpretation of parametric programming are described in the IBM manual and by Allen and others (1980).

IDAHO IRRIGATION DISTRICT RESULTS

During the 1978 irrigation season, 272,787 acre-feet of water was diverted from the Snake River District. The excess water received from upstream irrigation districts was 28,804 acre-feet and the excess water outflow from the district was 36,870 acre-feet. Hence, the water used in the district, which includes crop ET, deep percolation, canal seepage and other minor losses was 264,721 acre-feet. The approximate canal seepage loss measured by Netz (1980) was 52,477 acre-feet during the season. Based on the crop distribution pattern presented in Chatper IV, the crop ET requirement of this district was 57,431 acre-feet. Therefore, the overall system efficiency (OSE) of the existing system was:

$$OSE = \frac{\text{Crop ET Requirement}}{\text{Total Water Entered - Excess Water Outflow}} (100)$$

$$= \frac{57,431}{272,787 + 28,804 - 36,870} (100) = 21.7\% \qquad (6\text{-}9)$$

The on-farm application efficiency was:

$$E_{app} = \frac{\text{Crop ET Requirement}}{\text{Total Water Delivered to Farm}} (100)$$

$$= \frac{57,431}{272,787 + 28,805 - 36,870 - 52,477} (100) = 27.1\% \qquad (6\text{-}10)$$

The excess water inflow from upstream districts and natural streams were not considered as suitable sources of irrigation water. The excess water inflows are usually high when the irrigation demand is low when the demand is high. Therefore, they are not suitable and dependable sources for irrigation.

OVERALL SYSTEM EFFICIENCY CONSTRAINTS

Different levels of overall system efficiencies may be imposed by limiting the flow rate entering the district in the LP model. The optimal linear programming solutions for various efficiencies are summarized in Table VI-4 and Figure VI-6. The table includes the optimal combination of the application systems at each efficiency level. It can be seen that by increasing the efficiency, more sprinkler irrigation systems are included in the optimal combination. In most cases each subarea is assigned one application system, except a few subareas which share two application systems.

Annual system costs are itemized as distribution and application system costs on a total area and also unit area basis ($/acre). The distribution system costs include only canal operation and maintenance costs. The application system costs include capital, operation and maintenance costs. The project overall system and application efficiency, total water required in the district, water lost to deep percolation and surface runoff are also shown in the Table VI-4.

Table VI-4. Total annual system costs and descriptions of optimal irrigation systems with existing conveyance systems at various overall system efficiencies, Idaho Irrigation District

	Overall System Efficiency (%)					
	27.8	30.0	35.0	40.0	45.0	45.5
Total annual cost ($)	1,961,406	2,038,253	2,244,877	2,435,824	2,771,553	3,914,704
App. sys. cost ($)	1,876,301	1,959,190	2,177,109	2,376,527	2,718,845	2,862,569
Dist. sys. cost - O&M ($)	85,105	79,063	67,768	59,297	52,708	52,135
Total annual cost ($/AC)	68.6	71.3	78.6	85.2	97.0	102.0
App. sys. cost ($/AC)	65.6	68.5	76.2	83.1	95.2	100.2
Dist. sys. cost - O&M($/AC)	3.0	2.8	2.4	2.1	1.8	1.8
Inflow rate (cfs)	1123	1043	894	782	696	688
Overall eff. (%)	27.8	30.0	35.0	40.0	45.0	45.5
App. sys. eff. (%)	37.4	41.3	51.5	63.1	76.3	77.9
Vol. of D.P. (AF)	27,303	23,749	17,955	13,933	10,799	10,137
Vol. of S.R. (AF)	61,021	49,638	28,980	12,376	0	0
Total vol. used (AF)	206,066	191,437	164,089	143,577	127,624	126,236
Total vol. used (AF/AC)	7.2	6.7	5.7	5.0	4.5	4.4
Section no.	Optimal Application System Combination					
1	UG	UG	UG	HM	HM	SR
4	UG	UG	UG	HM	HM	SR
5	UG	UG	HM	HM	HM	SR
6	UG	UG	UG	HM	HM	SR
7	UG	UG	UG	UG	SR (85%) HM (15%)	SR
8	UG	UG	HM	HM	HM	SR
9	CP	CP	CP	CP	CP	CP
10	UG	UG	HM	HM	SR	SR
11	UG	UG	HM	HM	SR	SR
12	UG	UG	HM (20%) UG (80%)	HM	HM	SR
13	UG	HM	HM	HM	SR	SR
14	UG	UG	IG	IG	SR	SR
15	UG	HM (80%) UG (20%)	HM	HM	HM	SR
17	UG	UG	UG	HM	SR	SR
18	UG	UG	UG	HM	SR	SR
19	UG	UG	HM	HM	SR	SR
20	UG	UG	HM	HM	SR	SR
21	UG	HM	HM	HM	SR	SR
22	UG	HM	HM	HM	SR	SR
25	UG	UG	UG	UG	HM	SR
26	UG	UG	UG	UG	HM	SR
27	UG	UG	UG	UG	HM	SR
28	UG	UG	UG	HM	HM	SR
29	UG	UG	UG	UG	SR	SR
30	UG	UG	HM	HM	HM	SR
31	UG	HM	HM	HM	CP	CP
32	UG	UG	UG	HM	HM	SR

The minimum overall system efficiency obtained from the LP model of the existing system was 27.8% and the application effficiency was 37.4%. These efficiencies were obtained with all unimproved gravity application systems except in subarea 9 where center-pivot sprinkler systems were specified. (The application system in subarea 9 were restricted to be center-pivot sprinkler due to its sandy soil.) These efficiencies from the model are higher than those obtained from the observed data considering the fact that sprinkler systems are currently used to irrigate about 37% or 10,500 acres in the district.

Several reasons for this discrepancy could be presented. Some of them are:

1) No excess water outflow from the district due to operational waste was considered;
2) The design parameters of each on-farm application system are not same as those of existing systems, especially the management aspects;
3) Errors in determining canal seepage loss and excess water inflow and outflow measurements; and
4) The conversion factor used to convert peak flow rate in cfs to annual volume in acre-feet.

Most of these factors cannot be easily identified and corrected. However, for planning purposes it is not uncommon to accept a certain level of error in initial measurements and data preparation.

As the system efficiency is increased the irrigation systems used change from gravity to sprinkler systems. The maximum overall system efficiency attainable is 45.5% with an application efficiency of 77.9%.

To achieve this efficiency, all subareas must be irrigated by sprinkler irrigation systems.

The results increasing system efficiencies are summarized in Figure VI-5. This figure illustrates the relationships of total system cost, total water used and application efficiency associated with the overall efficiencies considered. As expected, Figure VI-5 shows that the total system cost increases as the system efficiency is improved. It can be noted that the rate at which system costs increase is nearly constant for system efficiencies less than 40%, but becomes markedly greater for higher efficiencies.

The low overall system efficiency even with the high application efficiency is caused by high canal seepage losses that would be expected from the existing conveyance system. Since the size of canal sections remain unchanged with different flow rates required for different overall efficiencies, canal seepage loss was assumed constant for all flow rates tested in this study.

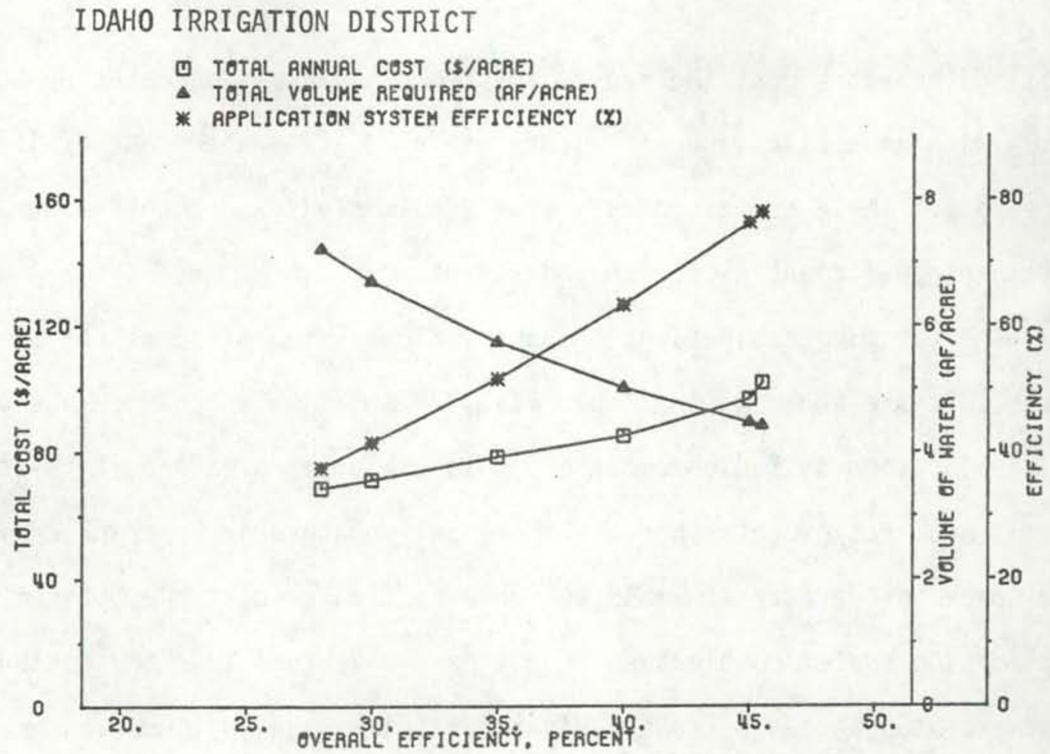
WATER COST CHARGED AT HEADGATE

To evaluate the effect of water cost on the system, water entering the district was charged from $0 to $15 per acre-foot at $3 per acre-foot increments. The optimization results related to this test are shown in Table VI-5 and Figure VI-5. The table includes the optimal combinations of the application irrigation systems for each water charge. Annual system costs are itemized as distribution and application system costs on a total area and also unit area basis ($/acre). The table also includes the total annual system costs with water cost. With no-charge the overall system efficiency is 27.8%, the application efficiency is 37.4%. By

Table VI-5. Total annual system costs and descriptions of optimal irrigation systems with existing conveyance systems at various water costs charged at headgate, Idaho Irrigation District

	Water Cost at Headgate ($/AF)					
	0	3	6	9	12	15
Total annual cost ($)	1,961,406	1,974,600	2,179,823	2,450,551	2,527,109	2,623,227
App. sys. cost ($)	1,876,301	1,890,729	2,108,726	2,391,943	2,470,936	2,569,659
Dist. sys. cost - O&M ($)	85,105	83,871	71,097	58,608	56,173	53,568
Water cost ($)	0	609,237	1,032,900	1,277,181	1,632,156	1,945,575
Total annual cost ($/AC)	68.6	69.0	76.3	85.8	88.5	91.8
App. sys. cost ($/AC)	65.6	66.1	73.8	83.7	86.5	89.9
Dist. sys. cost - O&M($/AC)	3.0	2.9	2.5	2.8	2.0	1.9
Water cost ($/AC)	0	21.4	36.2	44.7	57.1	68.0
Inflow rate (cfs)	1123	1106	938	773	741	707
Overall eff. (%)	27.8	28.3	33.3	40.4	42.2	44.3
App. sys. eff. (%)	37.4	38.2	48.0	64.3	68.8	74.3
Vol. of D.P. (AF)	27,303	26,586	19,835	13,620	12,523	11,546
Vol. of S.R. (AF)	61,021	57,544	34,589	10,910	6,289	625
Total vol. used (AF)	206,066	203,079	172,150	141,909	136,013	129,705
Total vol. used (AF/AC)	7.2	7.1	6.0	5.0	4.8	4.5

Section no.	Optimal Application System Combination					
1	UG	UG	UG	HM	HM	HM
4	UG	UG	UG	HM	HM	HM
5	UG	UG	HM	HM	HM	HM
6	UG	UG	UG	HM	HM	HM
7	UG	UG	UG	UG	UG	HM
8	UG	UG	HM	HM	HM	HM
9	CP	CP	CP	CP	CP	CP
10	UG	UG	UG	HM	HM	HM
11	UG	UG	HM	HM	HM	HM
12	UG	UG	UG	HM	HM	HM
13	UG	HM	HM	HM	HM	HM
14	UG	UG	IG	IG	IG	HM
15	UG	UG	HM	HM	HM	HM
17	UG	UG	UG	HM	HM	HM
18	UG	UG	UG	HM	HM	HM
19	UG	UG	UG	HM	HM	HM
20	UG	UG	HM	HM	HM	HM
21	UG	UG	HM	HM	HM	HM
22	UG	UG	HM	HM	HM	HM
25	UG	UG	UG	UG	HM	HM
26	UG	UG	UG	UG	HM	HM
27	UG	UG	UG	HM	HM	HM
28	UG	UG	UG	HM	HM	HM
29	UG	UG	UG	UG	IG	IG
30	UG	UG	HM	HM	HM	HM
31	UG	HM	HM	HM	HM	HM
32	UG	UG	UG	HM	HM	HM



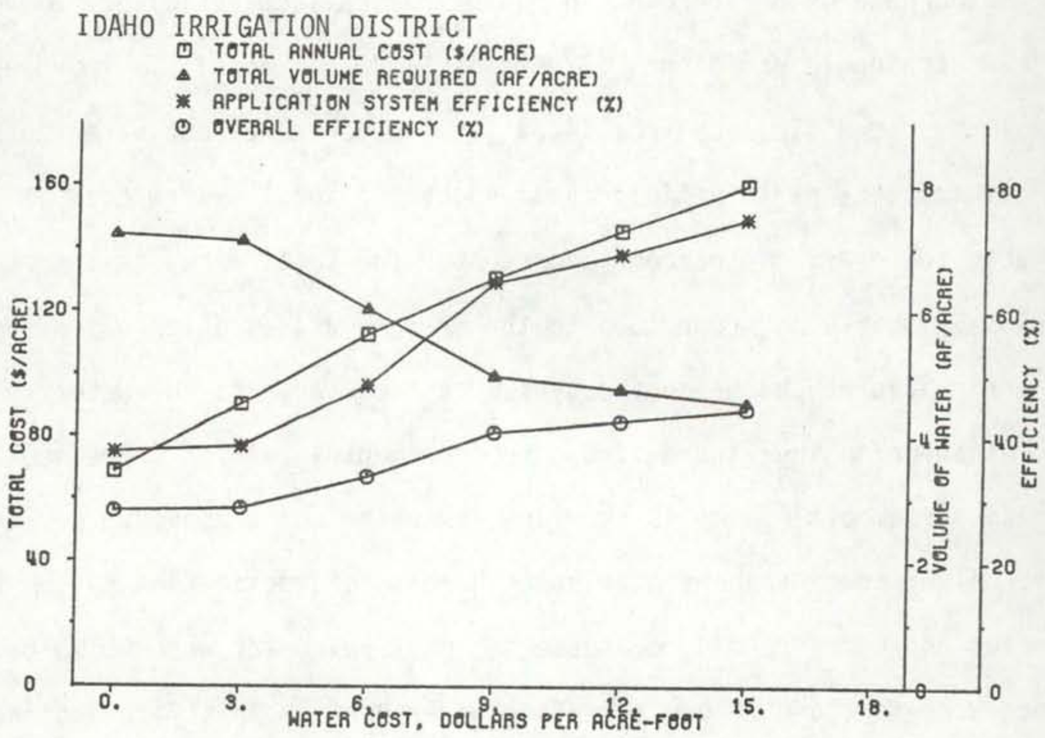


Figure VI-5. Results obtained for optimum system planning in the Idaho Irrigation District with existing conveyance systems.

raising the water cost the overall system efficiency increases up to 44.3% with an application efficiency at 74.3% at a water cost of $15 per acre-foot. These efficiencies are only slightly lower than the maximum attainable efficiencies for this district.

The optimum combinations of application system alternatives at each water cost are shown in the Table VI-5. With no water charge, the optimal application system combination is to use unimproved gravity systems at all subareas except subarea 9 where only center-pivot sprinkler systems are considered. At a $15 per acre-foot water cost the optimum application system combination is all hand-move sprinkler irrigation systems except subareas 9 (center-pivot sprinkler) and 29 (improved gravity). As illustrated in the Table VI-5, the average system cost required for an increase of one percent in the overall system efficiency above the minimum attainable efficiency (27.8%) is $1.40 per acre. To improve the overall system efficiency from 44.3% (at $15 per acre-foot water cost) to the maximum attainable efficiency of 45.5% the total system cost is $7 per acre for every one percent increment. The total annual system costs increase linearly in proportion to the charges assessed for water due to the insignificant change in the system cost compared to the water cost.

As shown in the Figure VI-6, the incremental rate of increase in overall system efficiency is very low for water costs above $9 per acre-foot. Also shown is the significant increase of application system efficiencies and corresponding decrease in total volume of water used between $6 per acre-foot and $9 per acre-foot water costs. This fact indicates that a water cost greater than $9 per acre-foot is not a good incentive to the efficiency of this system.

SNAKE RIVER VALLEY IRRIGATION DISTRICT RESULTS

During the 1978 irrigation season, the Snake River Valley Irrigation District diverted 166,616 acre-feet of water from the Snake River and received 27,707 acre-feet as excess water from Idaho Irrigation District. The excess water outflow from this district was 60,850 acre-feet during the same season. Hence, this district used 133,473 acre-feet which includes crop ET requirements, deep percolation losses, canal seepage losses and other minor losses. The canal seepage losses measured were 33,944 acre-feet during the crop year. Based on the crop distribution pattern presented in Chapter IV, the crop ET requirements of this district in 1978 crop year were 35,412 acre-feet. Therefore, the overall system efficiency (OSE) of the existing system was:

$$OSE = \frac{\text{Crop ET Requirement}}{\text{Total Water Entered - Excess Water Outflow}} (100)$$

$$= \frac{35,412}{166,616 + 27.707 - 60,850} (100) = 26.5\% \qquad (6\text{-}11)$$

The on-farm application efficiency was:

$$Eapp = \frac{\text{Crop ET Requirement}}{\text{Total Water Delivered to Farm}} (100)$$

$$= \frac{35,412}{166,616 + 27,707 - 60,850 - 33.944} (100) = 35.6\% \qquad (6\text{-}12)$$

The excess water entering this district from Idaho Irrigation District was not considered in this analysis. This inflow is not stable and not dependable as irrigation water source.

OVERALL SYSTEM EFFICIENCY CONSTRAINTS

The effects of different levels of overall system efficiency on system configuration and total annual cost were obtained by constraining the available inflow rate entering the district, Q_{spec} in the linear programming model. The results are summarized in Table VI-6 which shows the optimal combination of the application systems at each efficiency level. All costs involved in the optimal system configurations are also shown.

With no restriction on water entering the district, the overall system efficiency is 29.0% and the application efficiency is 40.2%. These efficiencies are somewhat greater than the measured system efficiencies even though about 40% of the existing application systems in the district are sprinkler systems. Sevral possible reasons for this difference are presented in the previous section for the Idaho Irrigation District. Results in Table VI-6 show that at the lowest irrigation efficiency all application systems are unimproved gravity systems and as efficiency increase more sprinkler systems are selected for use.

The results are also illustrated in Figure VI-6 which shows the overall efficiency versus total annual system cost, total water diverted and application efficiency. As in the case of the Idaho Irrigation District incremental rate increases markedly as overall efficiency exceeds 40% thus pointing to the need of reducing canal seepage losses in the existing canal system.

WATER COST CHARGED AT HEADGATE

To evaluate the effect of water cost on system configuration and total annual cost the water entering the district was charged varying rates from $0 to $15 per acre-foot at $3 per acre-foot increments. The

Table VI-6. Total annual system costs and descriptions of optimal irrigation systems with existing conveyance systems at various overall system efficiencies, Snake River Valley Irrigation District

	Overall System Efficiency (%)				
	29.0	30.0	35.0	40.0	45.0
Total annual cost ($)	1,301,320	1,312,413	1,427,575	1,528,520	1,813,500
App. sys. cost ($)	1,250,877	1,263,662	1,385,789	1,491,597	1,780,900
Dist. sys. cost - O&M ($)	50,443	48,751	41,786	36,563	32,600
Total annual cost ($/AC)	75.7	76.4	83.1	89.0	105.6
App. sys. cost ($/AC)	72.8	73.6	80.7	86.9	103.7
Dist. sys. cost - O&M($/AC)	2.9	2.8	2.4	2.1	1.9
Inflow rate (cfs)	665.6	643.3	551.4	482.5	430.2
Overall eff. (%)	29.0	30.0	35.0	40.0	45.0
App. sys. eff. (%)	40.2	42.1	52.7	64.9	78.7
Vol. of D.P. (AF)	16,574	15,570	11,852	8,875	6,208
Vol. of S.R. (AF)	31,684	27,459	14,278	5,277	0
Total vol. used (AF)	122,140	118,042	101,179	88,532	78,933
Total vol. used (AF/AC)	7.1	6.9	5.9	5.2	4.6
Section no.	Optimal Application System Combination				
C	UG	UG	HM	HM	SR
D	UG	UG	UG	HM(86%) UG(14%)	SR
F	UG	UG	HM(45%) UG(55%)	HM	SR
G	HM	HM	HM	HM	SR
H	UG	UG	HM	HM	SR
I	UG	HM	HM	HM	SR
J	HM	HM	HM	HM	CP
K	UG	UG	UG	UG	SR
L	UG	UG	UG	UG	SR
M	UG	UG	UG	UG	SR
N	UG	UG	UG	UG	SR
O	UG	UG	HM	HM	SR
P	UG	UG	UG	UG	SR
Q	UG	HM(20%) UG(80%)	HM	HM	CP
R	UG	UG	UG	UG	SR

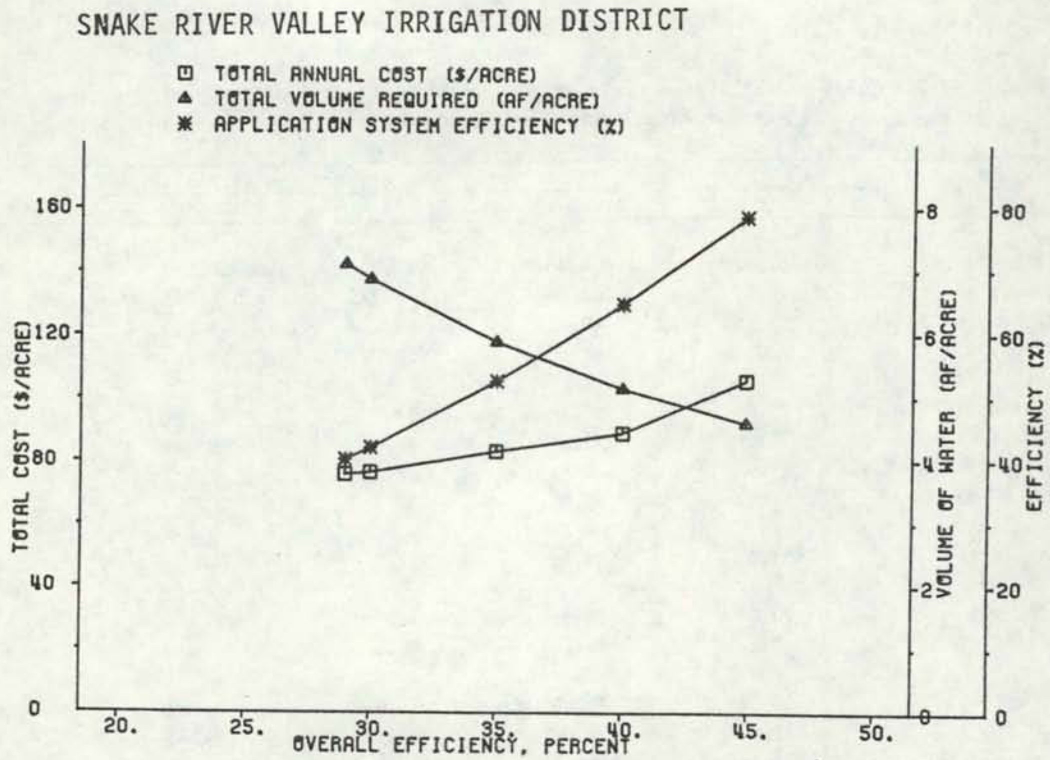
optimization results related to this test are shown in Table VI-7 and Figure VI-6. With no water charge, the system has an overall efficiency of 29.0% and an application efficiency of 40.2%. By increasing the water cost to $15 per acre-foot the district could obtain system efficiencies of up to 45% for the overall efficiency and 78.7% for the application efficiency. These efficiencies are slightly lower than the maximum attainable efficiencies of the district. It should be noted that a charge of over $30 per acre-foot water cost would be required to obtain the maximum efficiencies. At the maximum charge, all application systems except for subarea P are hand-move sprinkler irrigation systems. The table shows annual cost, application and distribution system costs, and water cost for the entire system and per unit area. It can also be seen that increases in the system costs are not significant compared to those for water costs. This fact is shown as a linear increment of total annual cost vs. water cost in Figure VI-6. The comparative large increase in application system efficiency and the consequent reduction of total volume required between $6 and $9 per acre-foot of water costs indicate that the most effective water cost for reducing water use is located between these two water costs.

The results obtained from the evaluation of irrigation application systems show that the overall effects of rehabilitation are severely limited as long as existing irrigation district systems remain unchanged. Not only is the possible improvement in irrigation efficiency limited, but the cost of rehabilitating application systems only may be greater than the cost of upgrading at least a portion of the distribution system. It is necessary that both application and distribution system components be conjunctively considered in the planning process for rehabilitation and consolidation of the system.

Table VI-7. Total annual system costs and descriptions of optimal irrigation systems with existing conveyance systems at various water costs charged at headgate, Snake River Valley Irrigation District

	Water Cost at Headgate ($/AF)					
	0	3	6	9	12	15
Total annual cost ($)	1,301,320	1,666,101	2,022,017	2,326,520	2,612,676	2,856,518
App. sys. cost ($)	1,250,877	1,262,630	1,318,723	1,524,043	1,601,154	1,605,985
Dist. sys. cost - O&M ($)	50,443	48,823	45,292	35,209	33,654	33,508
Water cost ($)	0	354,648	658,002	767,268	977,868	1,217,025
Total annual cost ($/AC)	75.8	97.1	117.7	135.5	152.1	166.4
App. sys. cost ($/AC)	72.9	73.5	76.8	88.8	93.2	93.5
Dist. sys. cost - O&M($/AC)	2.9	2.8	2.6	2.0	2.0	1.9
Water cost ($/AC)	0	20.6	38.3	44.7	56.9	71.0
Inflow rate (cfs)	665.6	644.3	597.7	464.6	444.1	442.2
Overall eff. (%)	29.0	30.0	32.3	41.5	43.4	43.6
App. sys. eff. (%)	40.2	42.0	46.8	69.0	74.5	75.0
Vol. of D.P. (AF)	16,574	15,608	13,929	7,889	6,994	7,103
Vol. of S.R. (AF)	31,684	27,656	20,409	3,368	844	271
Total vol. used (AF)	122,140	118,216	109,667	85,252	81,489	81,135
Total vol. used (AF/AC)	7.1	6.9	6.4	5.0	4.7	4.7

Section no.	Optimal Application System Combination					
C	UG	UG	UG	HM	HM	HM
D	UG	UG	UG	HM	HM	HM
F	UG	UG	UG	HM	HM	HM
G	HM	HM	HM	HM	HM	HM
H	UG	UG	HM	HM	HM	HM
I	UG	HM	HM	HM	HM	HM
J	HM	HM	HM	HM	HM	HM
K	UG	UG	UG	UG	HM	HM
L	UG	UG	UG	HM	HM	HM
M	UG	UG	UG	IG	IG	HM
N	UG	UG	UG	UG	HM	HM
O	UG	UG	HM	HM	HM	HM
P	UG	UG	UG	UG	IG	IG
Q	UG	UG	HM	HM	HM	HM
R	UG	UG	UG	HM	HM	HM



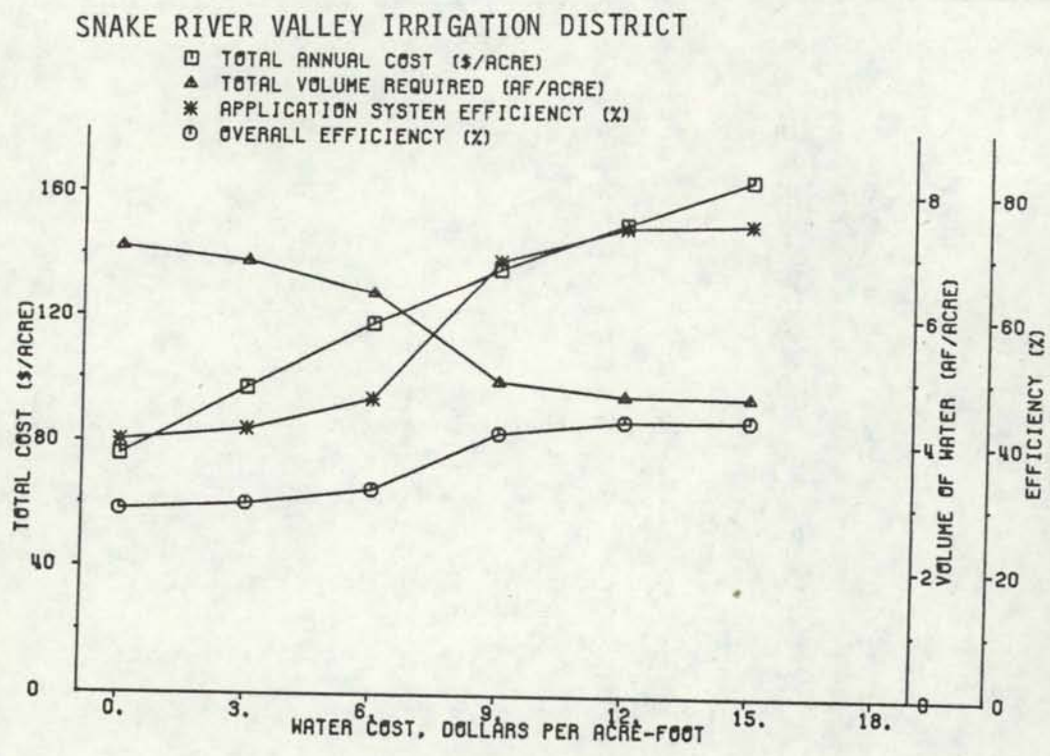


Figure VI-6. Results obtained for optimum system planning in the Snake River Valley Irrigation District with existing conveyance systems.

CHAPTER VII

REHABILITATION AND CONSOLIDATION PLANS FOR THE STUDY AREA

Rehabilitation or consolidation of the studied irrigation district(s) is necessary to improve overall system efficiency. As discussed in the previous chapter the existing system of the study area could increase its overall system efficiency by only 15% (from 30% to 45%) even though the application system efficiency was improved by 40% (from 35% to 75%). This discrepancy is all due to the low conveyance efficiency of the existing canal systems of the area. In order to improve the overall system efficiency it would be necessary to rehabilitate or even to consolidate the conveyance systems of the two irrigation districts.

In this chapter, rehabilitation plans for each irrigation district using a gravity water delivery system using canals and/or low head gravity pipe systems and consolidation plans for the two districts using a high pressure pipe systems to test the effects of water availability and water charge on overall system efficiency and system configuration. The water charges were imposed both at headgate diversion and at each subarea diversion point, and different overall system efficiencies were attained by restricting the inflow rate available to the districts. Those combinations of conveyance and applicaton systems which achieved these conditions at minimum cost are the results presented in this chapter.

Mixed integer-linear programming (MIP) was required to develop the rehabilitation plans by selecting the optimal (least cost) combination of conveyance and application systems for a specified set of boundary conditions. The MIP problems were solved by the APEX III mathematical programming package (Control Data Corporation, 1979) supported on the Bureau of Reclamation's CDC CYBER computer system in Denver, Colorado. For the consolidation plans, linear programming was used since only one conveyance system (high pressure pipe system) was considered for the plan. The linear programming (LP) problems were solved by MPS/360 mathematical programming (International Business Machines, 1969). Input data and problem pictures of example matrices (smaller than real problems used in this study) for the mixed integer-linear programming and linear programming problems are contained in Appendix E. The MIP and LP problem matrices used to model problems presented in this chapter have same formats as the examples given in Chapters III and VI but only expanded for the larger problems. The example control programs to solve the mixed integer-linear programming and the linear programming problems of the rehabilitation and consolidation plans are also listed in Appendix E.

REHABILITATION PLANS WITH GRAVITY SUPPLY SYSTEMS

Minimum changes of existing conveyance system routes were considered for the rehabilitation of the gravity supply systems in the two irrigation districts. One major change is that the Sand Creek would be used strictly as a drainage system and not convey any irrigation water. To achieve this change, some subarea diversion points were relocated. The altered system of canal routes and subarea diversion points for the rehabilitation plan are shown on the map in Figure VII-1 and by the schematic diagrams in Figure VII-2. The subarea of each new diversion point for the rehabilitation plan was analyzed to obtain necessary data as described for the existing system evaluation in Chapter VI. As shown in Figure VII-3 the new subarea boundaries were relocated to coincide with the canal diversion points in the rehabilitation plan.

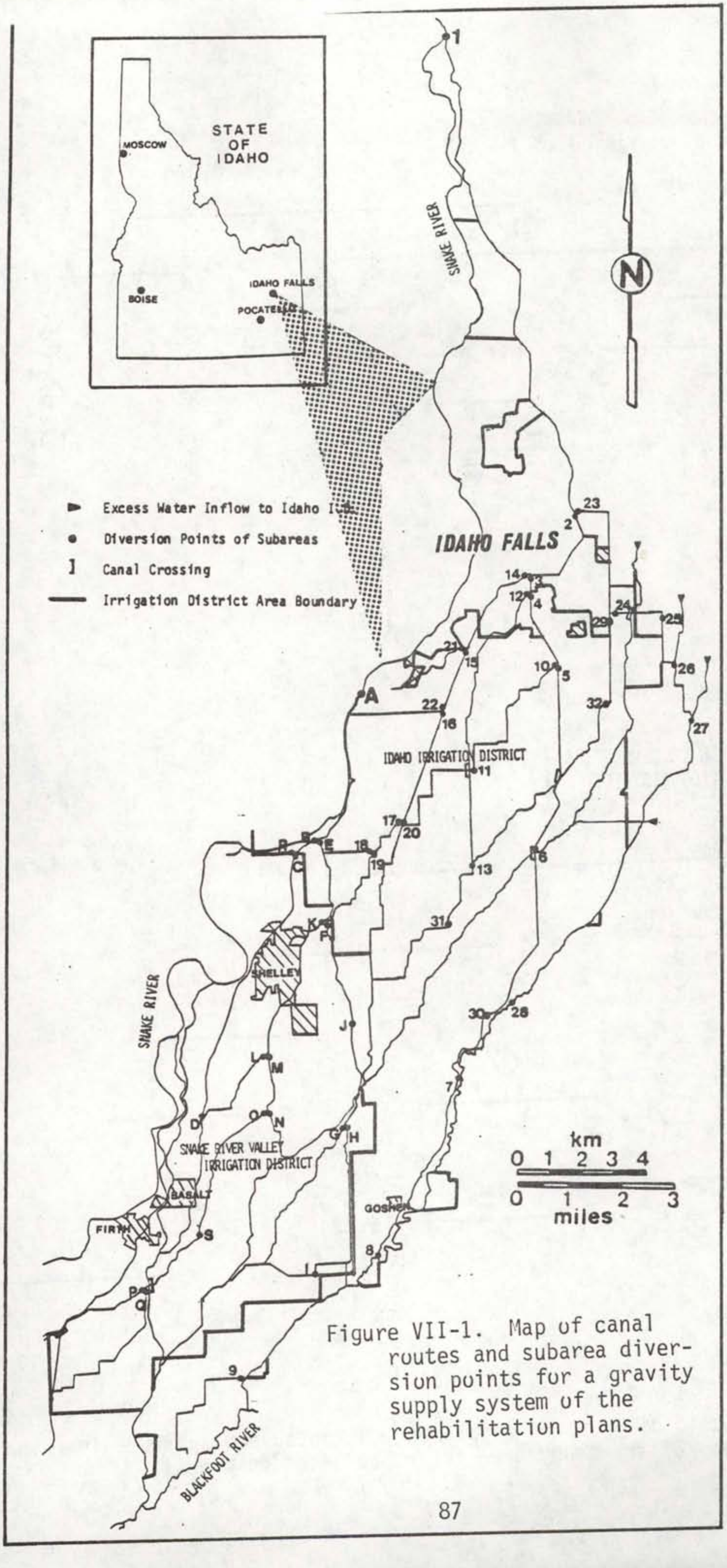


Figure VII-1. Map of canal routes and subarea diversion points for a gravity supply system of the rehabilitation plans.

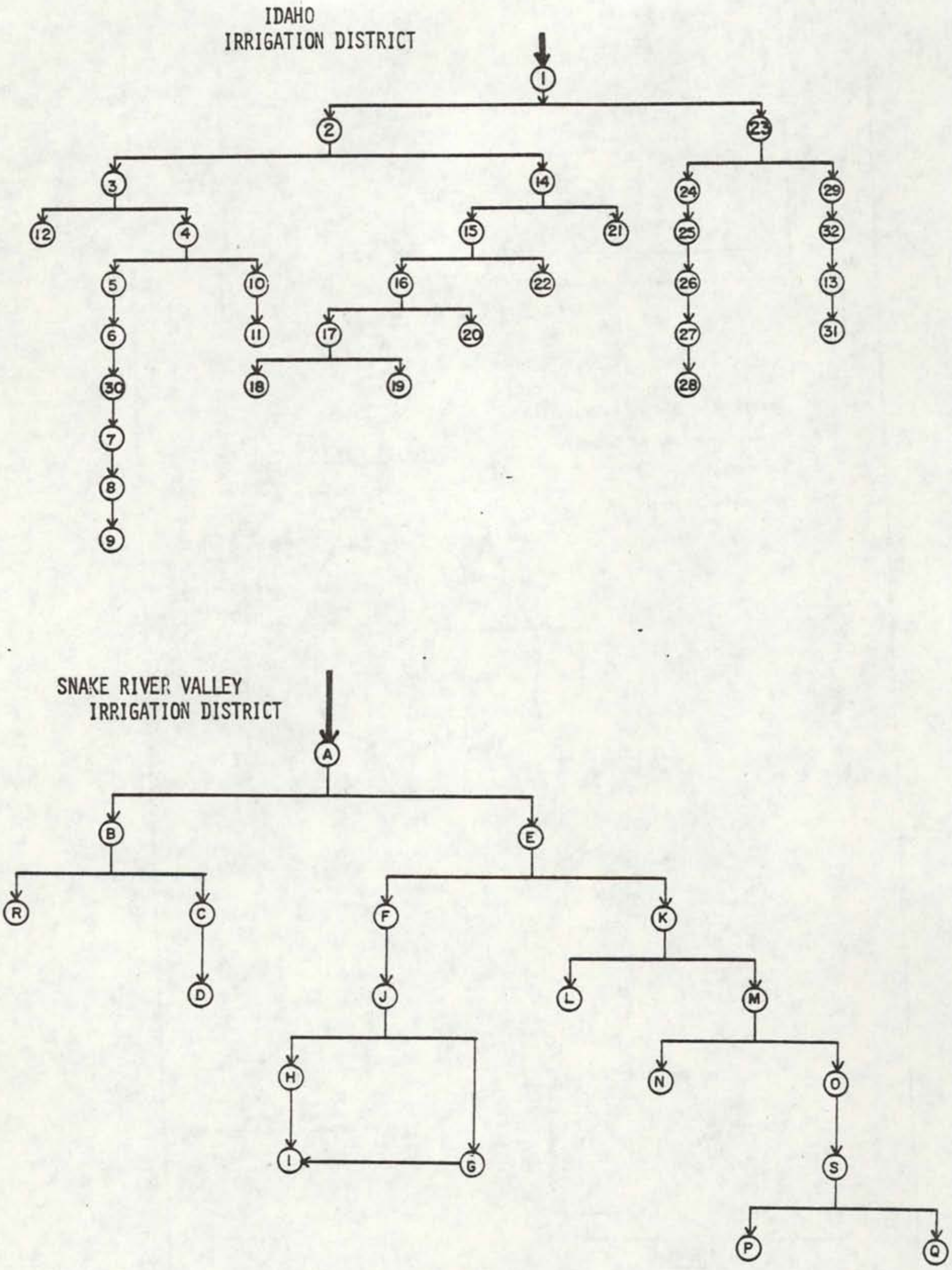
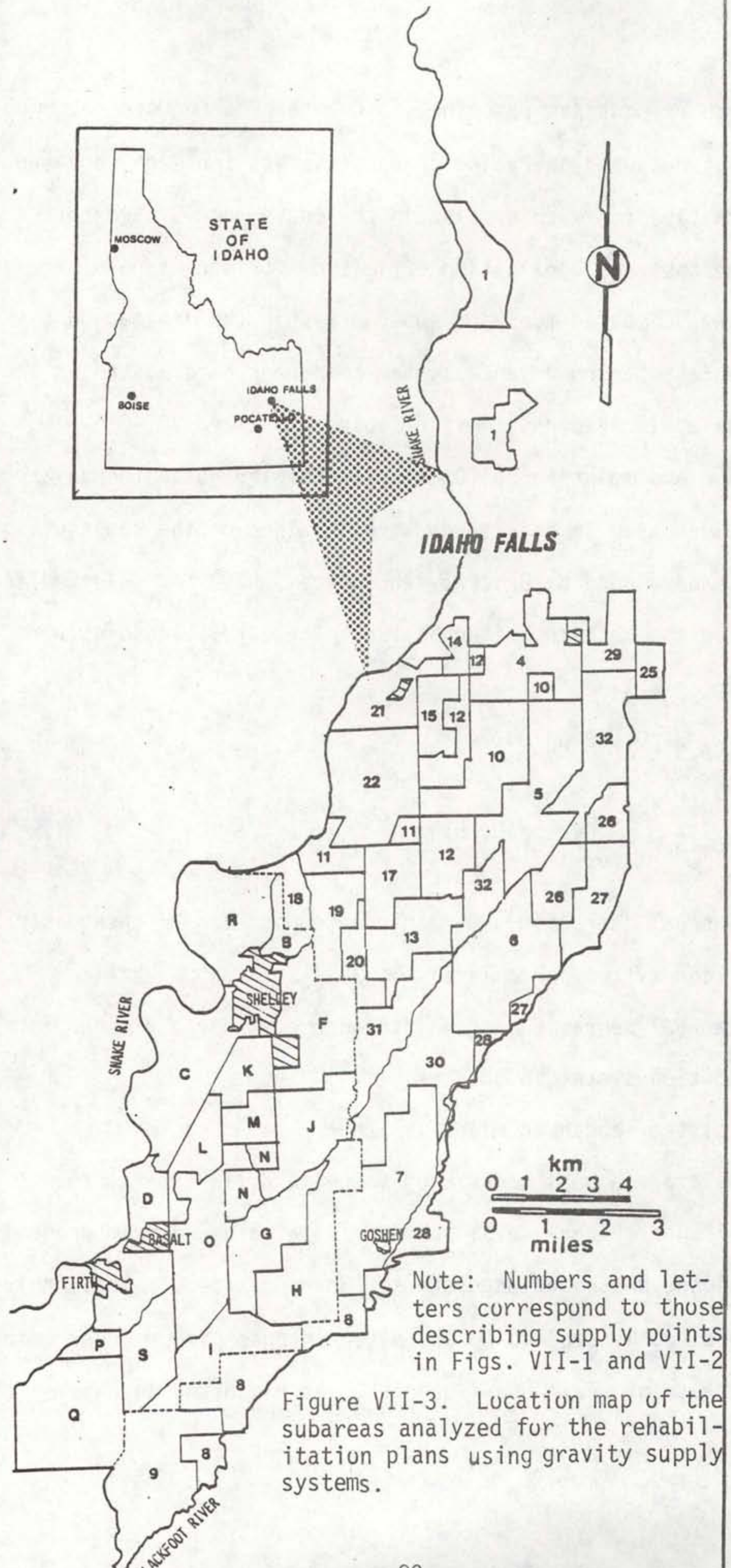


Figure VII-2. Schematic diagrams of canal section routes and subarea diversion points of the study area for rehabilitation plans.



Note: Numbers and letters correspond to those describing supply points in Figs. VII-1 and VII-2

Figure VII-3. Location map of the subareas analyzed for the rehabilitation plans using gravity supply systems.

The computer routines described in Chapter V were used to compute necessary cost data and operating characteristics for each conveyance system alternative for each section in the conveyance system route. Likewise, the cost and application efficiency for each type of application system was computed for each subarea within the irrigation districts. The data for conveyance system components are listed in Table VII-1 and for application systems in Tables VII-2 and VII-3.

Operation and maintenance (O&M) costs for irrigation conveyance system alternatives used in this study were obtained on the basis of the relationships developed by Brockway and Reese (1973) for selected irrigated areas in the Western United States. These relationships were expressed as:

$$COM_o = 96.3\ L^{0.663}\ CV^{0.774} \qquad (7\text{-}1)$$

and

$$COM_c = 89.5\ L^{1.072}\ CV^{0.351} \qquad (7\text{-}2)$$

where

COM_o = annual operation and maintenance cost for an open distribution system in dollars

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

L = system length in miles

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

Equations 7-1 and 7-2 were developed from data gathered from predominantly open or closed distribution systems. However, these relationships could not be directly applied to the mixed integer-linear programming procedure because of their non-linearity. As discussed in Chapter II a

Table VII-1. Conveyance systems data and annual costs for rehabilitation plan using gravity delivery system.

Section	Subarea	Total Downstream Area Served	Length	Canal 1/ Seepage	Cost 2/ Unlined a	Unlined b	Lined c	Lined d	Gravity Pipe e	Gravity Pipe f
no.	(Acres)	(Acres)	(Miles)	ft^3/ft^2/day	$/CFS	Fixed ($)	$/CFS	Fixed ($)	$/CFS	Fixed ($)
1	1,248	28,577	10.38	2.68	0	40,086	344.8	505,547	-	-
2	0	20,491	1.94	2.31	-3/	-	-	-	296.9	93,187
3	0	15,258	0.32	2.31	-	-	23.5	12,355	38.9	12,321
4	1,219	13,873	1.55	1.31	-	-	58.2	64,526	376.1	65,181
5	1,592	19,399	3.83	1.05	0	7,579	615.2	51,133	609.7	145,608
6	1,848	8,807	3.53	0.6	0	16,268	213.7	106,936	766.8	141,948
7	2,474	5,295	3.99	0.6	0	9,237	256.9	55,392	1,218.3	111,006
8	1,435	2,821	4.56	0.6	0	3,866	192.5	42,698	974.9	77,486
9	1,386	1,386	2.83	9.6	0	1,909	233.0	14,336	742.4	41,351
10	1,164	2,255	3.27	1.31	0	3,119	196.1	24,041	832.8	53,262
11	1,091	1,091	1.45	1.31	0	2,129	306.5	8,866	884.7	31,811
12	1,385	1,385	6.42	1.05	0	4,249	548	33,379	2,121.0	86,874
13	1,051	1,961	1.50	1.05	0	2,482	151.7	9,565	427.1	31,386
14	189	5,233	2.04	2.31	-	-	322.6	12,118	294.7	44,767
15	478	4,417	1.87	2.31	0	2,132	75.6	21,179	552.9	52,071
16	0	2,273	2.36	2.31	0	5,512	217.9	15,408	610.6	39,351
17	363	1,630	0.93	1.81	0	1,521	98.2	6,423	350.2	16,906
18	374	374	1.25	2.31	0	839	111.4	5,220	800.0	10,896
19	893	893	2.24	1.81	0	2,055	142.9	11,246	692.6	31,386
20	643	643	2.72	1.81	0	1,341	216.0	12,284	1,123.7	27,647
21	627	627	1.41	3.74	0	1,055	155.7	5,093	613.8	17,496
22	1,666	1,666	1.95	3.74	0	1,362	103.3	9,319	606.8	27,644
23	0	6,838	2.70	1.31	11.4	15,211	57.6	35,288	418.7	80,231
24	0	3,169	0.95	2.4	30.8	1,731	46.7	5,116	-	-
25	508	3,169	1.42	1.0	0	1,023	126.7	6,639	-	-
26	972	2,661	1.54	1.0	0	1,600	166.4	7,126	-	-
27	1,073	1,689	7.10	0.6	0	1,641	-	-	-	-
28	616	616	8.33	0.6	0	1,519	-	-	-	-
29	435	3,669	2.40	1.05	59.7	5,554	94.9	13,766	943.4	56,687
30	1,664	6,959	1.76	0.6	0	1,487	76.6	24,773	340.1	42,063
31	910	910	1.95	1.05	0	1,959	244.5	11,224	637.4	29,757
32	1,273	3,234	4.36	0.6	0	3,303	218.4	40,865	893.4	79,573

1/ Total service area located below each section.

2/ Conveyance system cost = ax + b

where, a = Variable cost, $/CFS

b = Fixed cost, $

x = Design flow rate, CFS

3/ These conveyance systems are not considered for the sections.

Table VII-1. (continued)

Section	Subarea	Total Downstream Area Served	Length	Canal 1/ Seepage	Cost 2/ Unlined a		Lined c		Gravity Pipe e	
					a	b	c	d	e	f
no.	(Acres)	(Acres)	(Miles)	$ft^3/ft^2/day$	$/CFS	Fixed ($)	$/CFS	Fixed ($)	$/CFS	Fixed ($)
A	0	17,177	3.24	3.61	0	0	135.6	83,516	-	-
B	359	4,833	0.50	3.74	0	667	23.3	8,860	-	-
C	1,914	3,079	5.70	3.74	0	4,764	347.6	35,752	1,395.6	135,854
D	1,165	1,165	3.06	1.53	0	1,952	245.0	22,686	1,391.6	50,794
E	0	12,343	1.68	3.61	0	0	96.7	38,300	-	-
F	1,257	5,392	1.95	1.48	0	3,323	71.6	23,681	576.7	60,638
G	1,058	1,058	3.44	1.94	0	2,863	198.6	20,926	1,166.0	47,916
H	1,497	2,346	3.70	1.04	0	3,737	171.0	28,061	973.7	65,502
I	849	849	1.80	1.04	0	1,587	201.3	9,546	888.8	26,972
J	1,331	4,735	2.30	1.48	0	9,532	134.1	28,285	481.6	54,140
K	522	6,351	2.99	1.31	0	3,684	168.3	34,195	697.1	79,630
L	541	541	2.08	1.40	0	1,292	103.3	9,605	1,032.9	20,724
M	553	5,288	1.24	1.31	0	1,388	48.5	16,855	264.0	31,823
N	599	599	1.10	1.31	0	1,036	43.1	9,164	537.0	16,691
O	1,477	3,320	3.01	1.31	0	3,434	126.9	21,927	639.4	70,362
P	265	265	2.22	2.53	0	985	242.9	10,276	1,831.4	22,392
Q	1,578	1,578	3.33	2.53	0	1,875	302.5	13,087	1,089.1	53,453
R	1,395	1,395	1.49	3.74	0	1,487	96.9	7,574	454.9	26,080
S	816	2,659	1.50	1.31	0	6,603	113.4	1,326	381.2	32,336

1/ Total service area located below each section.

2/ Conveyance system cost = ax + b

where, a = Variable cost, $/CFS

b = Fixed cost, $

x = Design flow rate, CFS

3/ These conveyance systems are not considered for the sections

Table VII-2. Gravity irrigation application systems data and annual costs for rehabilitation plans using gravity delivery systems.

Section	Improved Gravity Irrigation					Unimproved Gravity Irrigation				
	Q max 1/	EFF 2/	Cost	DP 3/	SR 4/	Q max	EFF	Cost	DP	SR
No.	CFS/Acre	%	$/Acre	AF/Acre	AF/Acre	CFS/Acre	%	$/Acre	AF/Acre	AF/Acre
1	0.0204	53.0	85	0.196	1.520	0.0318	34.1	59	1.039	2.472
4	0.0203	54.9	85	0.272	1.130	0.0304	36.6	65	1.122	1.801
5	0.0207	51.4	82	0.202	1.410	0.0315	33.8	57	0.978	2.283
6	0.0182	56.6	83	0.102	1.128	0.0286	36.2	57	0.911	1.906
7	0.0193	59.1	80	0.093	1.574	0.0298	38.3	51	0.992	2.457
8	0.0188	59.9	90	0.089	1.370	0.0286	39.4	63	0.903	2.131
9	0.0195	58.3	135	0.259	1.217	0.0300	37.9	121	1.205	1.940
10	0.0201	56.3	91	0.305	1.224	0.0302	37.5	70	1.231	1.944
11	0.0204	54.6	92	0.373	1.271	0.0307	36.3	73	1.390	1.989
12	0.0200	54.7	87	0.279	1.300	0.0301	36.4	65	1.137	2.073
13	0.0207	54.1	101	0.365	1.338	0.0312	35.8	82	1.394	2.069
14	0.0202	53.5	86	0.276	1.393	0.0302	35.8	62	1.097	2.201
15	0.0195	55.5	84	0.216	1.302	0.0291	37.2	59	0.996	2.069
17	0.0220	51.4	95	0.522	1.367	0.0334	33.9	78	1.882	1.990
18	0.0196	56.7	88	0.313	1.219	0.0297	37.4	67	1.329	1.926
19	0.0202	55.3	93	0.415	1.226	0.0302	37.0	76	1.508	1,873
20	0.0204	54.9	93	0.394	1.253	0.0306	36.5	74	1.460	1.941
21	0.0213	53.7	89	0.347	1.272	0.0319	35.7	68	1.288	2.000
22	0.0202	54.6	89	0.358	1.232	0.0305	36.2	68	1.329	1.945
25	0.0179	57.1	78	0.076	1.298	0.0276	36.9	49	0.778	2.179
26	0.0204	54.7	80	0.124	1.899	0.0309	36.1	53	1.043	2.816
27	0.0201	56.4	78	0.110	1.704	0.0302	37.4	50	1.061	2.455
28	0.0227	50.1	79	0.130	2.253	0.0339	33.5	52	1.161	3.037
29	0.0184	58.4	82	0.146	1.437	0.0274	39.3	56	0.942	2.220
30	0.0195	56.4	108	0.180	1.394	0.0302	36.5	84	1.073	2.218
31	0.0194	55.6	104	0.189	1.366	0.0298	36.1	79	0.987	2.255
32	0.0192	55.8	86	0.141	1.427	0.0300	35.8	60	0.910	2.408
B	0.0210	53.1	94	0.428	1.325	0.0316	35.2	76	1.510	2.048
C	0.0196	56.7	87	0.307	1.172	0.0300	37.1	65	1.326	1.873
D	0.0207	54.7	86	0.290	1.327	0.0328	34.6	62	1.318	2.209
F	0.0205	54.3	97	0.395	1.283	0.0311	35.8	79	1.479	1.996
G	0.0194	57.8	129	0.238	1.223	0.0298	37.6	112	1.136	1.974
H	0.0191	59.5	98	0.117	1.339	0.0298	38.1	73	0.944	2.229
I	0.0189	62.3	99	0.090	1.138	0.0295	39.9	75	0.892	1.972
J	0.0190	58.1	91	0.158	1.189	0.0289	38.2	65	0.944	1.951
K	0.0193	58.2	85	0.248	1.165	0.0297	37.9	61	1.241	1.900
L	0.0201	57.5	83	0.266	1.234	0.0323	35.9	57	1.516	2.029
M	0.0180	60.5	85	0.214	1.036	0.0269	40.5	62	1.036	1.676
N	0.0189	59.2	87	0.198	1.125	0.0287	39.0	63	1.047	1.840
O	0.0202	55.4	103	0.270	1.310	0.0320	35.0	81	1.348	2.134
P	0.0183	63.6	76	0.027	1.023	0.0292	39.8	46	0.808	1.948
Q	0.0192	56.8	109	0.229	1.317	0.0294	37.0	89	1.074	2.160
R	0.0194	56.3	87	0.302	1.192	0.0293	37.3	65	1.245	1.896
S	0.0188	61.2	109	0.140	1.085	0.0288	39.9	85	0.977	1.803

1/ maximum flow rate required for subarea
2/ application system efficiency
3/ deep percolation loss
4/ surface runoff loss

Table VII-3. Sprinkler irrigation application systems data and annual costs for rehabilitation plans using a gravity delivery system.

Section No.	Hand-Move Sprinkler (HMS) Q max 1/ CFS/Acre	Cost ($/Acre) Total 2/	Pump	Power	DP 3/ AF/Acre	Side-Roll Sprinkler (SRS) Q max CFS/Acre	Cost ($/Acre) Total	Pump	Power	DP AF/Acre
1	0.0144	89	15	36	0.4055	0.0139	99	15	33	0.3568
4	0.0149	93	16	38	0.4024	0.0143	100	16	35	0.3541
5	0.0142	89	14	37	0.3911	0.0137	100	14	34	0.3441
6	0.0138	82	16	32	0.3865	0.0132	91	16	30	0.3401
7	0.0152	90	18	34	0.4272	0.0147	100	17	32	0.3759
8	0.0150	82	13	34	0.4197	0.0144	92	13	32	0.3693
9	0.0151	88	10	34	0.4255	0.0146	97	10	31	0.3744
10	0.0151	95	14	41	0.4253	0.0145	103	13	38	0.3742
11	0.0148	96	17	39	0.4228	0.0143	104	17	35	0.3720
12	0.0146	93	14	39	0.4110	0.0140	105	13	36	0.3617
13	0.0149	96	16	39	0.4250	0.0143	105	16	36	0.3740
14	0.0144	100	22	36	0.4053	0.0139	108	23	35	0.3567
15	0.0144	84	13	32	0.4045	0.0139	96	12	30	0.3559
17	0.0151	96	16	37	0.4357	0.0145	104	16	34	0.3834
18	0.0148	92	15	37	0.4210	0.0142	102	15	34	0.3705
19	0.0149	101	17	40	0.4269	0.0143	110	16	37	0.3756
20	0.0149	95	17	38	0.4260	0.0143	101	17	34	0.3749
21	0.0152	87	12	33	0.4244	0.0146	95	11	30	0.3735
22	0.0147	90	13	36	0.4164	0.0142	99	13	33	0.3664
25	0.0136	85	15	34	0.3846	0.0131	97	14	32	0.3384
26	0.0149	85	13	34	0.4211	0.0143	99	13	32	0.3706
27	0.0151	84	13	36	0.4253	0.0145	97	13	34	0.3743
28	0.0151	82	11	34	0.4309	0.0146	93	11	31	0.3791
29	0.0143	98	24	35	0.4083	0.0138	106	24	32	0.3593
30	0.0147	88	15	35	0.4151	0.0141	98	14	33	0.3653
31	0.0144	87	14	35	0.4038	0.0138	93	14	32	0.3553
32	0.0143	88	18	34	0.4005	0.0138	97	17	32	0.3524
B	0.0148	98	17	40	0.4249	0.0143	107	17	36	0.3739
C	0.0149	89	14	36	0.4200	0.0143	98	13	33	0.3696
D	0.0151	91	18	35	0.4218	0.0145	98	17	33	0.3712
F	0.0149	98	17	39	0.4242	0.0143	107	16	36	0.3733
G	0.0150	99	17	38	0.4209	0.0144	109	16	35	0.3704
H	0.0151	87	12	37	0.4211	0.0146	100	12	34	0.3705
I	0.0157	86	13	37	0.4287	0.0151	96	13	35	0.3773
J	0.0147	88	12	39	0.4110	0.0142	97	12	36	0.3616
K	0.0150	90	15	38	0.4227	0.0144	97	14	34	0.3719
L	0.0154	83	12	33	0.4341	0.0148	93	12	30	0.3820
M	0.0145	94	18	39	0.4117	0.0140	103	17	35	0.3623
N	0.0149	97	19	39	0.4178	0.0143	104	19	36	0.3677
O	0.0149	94	19	36	0.4220	0.0143	101	18	33	0.3714
P	0.0155	86	17	37	0.4219	0.0149	91	16	34	0.3712
Q	0.0145	92	17	36	0.4086	0.0139	98	17	32	0.3596
R	0.0146	89	15	36	0.4132	0.0140	97	15	33	0.3636
S	0.0153	91	16	37	0.4246	0.0147	99	15	34	0.3736

Table VII-3. (continued)

		Center-Pivot Sprinkler (CPS)			
Section	Q max		Cost ($/Acre)		DP AF/Acre
No.	CFS/Acre	Total	Pump	Power	
9	0.0134	122	11	30	0.2553
30	0.0128	161	18	31	0.2491
31	0.0127	161	18	30	0.2423
G	0.0132	165	19	32	0.2525
H	0.0134	158	18	32	0.2526
I	0.0138	147	16	32	0.2572
Q	0.0128	154	17	30	0.2452
S	0.0135	157	18	32	0.2547

1 maximum flow rate required for subarea with application efficiencies:
75% for hand-made sprinkler
78% for side-roll sprinkler
85% for center-pivot sprinkler

2/ includes on-farm irrigation system and pump system costs

3/ seep percolation loss

linear programming requires that objective functions be linear. To approximate the non-linearity of the O&M cost to linear function annual total O&M costs of all canal systems of the districts were computed using total canal lengths and weighted crop values per unit area of each district. The crop values and canal lengths used are:

	Weighted Crop Values ($/Acre)	Total Canal Length (miles)
Idaho ID	254.0	95.0
Snake River Valley, ID	305.0	46.0

The linear functions to estimate the operation and maintenance costs of open channel and closed conduit are expressed as:

For Idaho ID

$$COM_O = 1506\ L_O \qquad (7\text{-}3)$$

$$COM_C = 869\ L_C \qquad (7\text{-}4)$$

For Snake River Valley, ID

$$COM_O = 2123\ L_O \qquad (7\text{-}5)$$

$$COM_C = 887\ L_C \qquad (7\text{-}6)$$

where

L_O = system length of a open channel canal subsection in miles

L_C = system length of a closed conduit canal subsection in miles.

For varying combinations of open and closed systems, the operation and maintenance costs are determined for both open and closed systems using the total length of the combination under consideration. The O&M cost for the composite system is then computed as:

$$COM_{total} = \sum_{all\ n} COM_o + \sum_{all\ m} COM_c \qquad (7\text{-}7)$$

where

COM_{total} = annual composite O&M cost of an irrigation distribution system.

n = number of open channel subsections selected.

m = number of closed ocnduit subsections selected.

OVERALL SYSTEM EFFICIENCY CONSTRAINTS

The results of optimal mixed integer-linear programming solutions obtained for the combination of conveyance and application systems at various imposed overall efficiencies are shown in Table VII-4 for the Idaho Irrigation District (IID) and in Table VII-5 for the Snake River Valley Irrigation District (SRVID). In the Tables annual system costs have been itemized as distribution system and application system costs on a total area and unit area basis. On-farm pumping costs are included in the application system costs of sprinkler systems.

With an unlimited water supply, the districts would have an overall efficiency of about 30%. In this case the conveyance system sections are composed of almost all unlined canals which supply unimproved gravity application systems in each subarea. For the IID canal system, in consideration of safety, high seepage losses and an aesthetic point of view, section 2 of the delivery system is constrained to be a gravity pipe system, and section 3, 4 and 14 to be lined canal or gravity pipe system alternatives. Other constraints for delivery system sections are no gravity pipe systems for sections 1, 24, 25 and 26 in the IID and for sections A, B and E in the SRVID, and unlined canals only for sections 27 and 28 in the IDD.

Table VII-4. Annual system costs and descriptions of optimal irrigation systems configuration for rehabilitation plans at various overall system efficiencies, Idaho Irrigation District

	Overall System Efficiency (%)							
	31.7	40.0	45.0	50.0	55.0	60.0	70.0	76.6
Total system cost ($)	2,627,397	2,758,055	2,858,767	2,950,392	3,044,157	3,132,286	3,999,575	6,025,756
Application system cost ($)	1,799,204	2,063,347	2,164,059	2,255,684	2,349,449	2,437,578	2,670,992	2,926,144
Conveyance System cost ($)	828,193	694,708	694,708	694,708	694,708	694,708	1,328,583	3,099,612
Total system cost ($/AC)	92.0	96.5	100.0	103.2	106.5	109.6	140.0	210.8
Application system cost ($/AC)	63.0	71.3	75.7	79.6	83.0	86.6	93.5	102.4
Conveyance system cost ($/AC)	29.0	24.3	24.3	24.3	24.3	24.3	46.5	108.4
Inflow rate (cfs)	989	789	701	631	574	526	451	412
Overall eff. (%)	31.7	40	45	50	55	60	70	76.6
Vol. of D.P. (AF/year)	29,824	21,143	18,140	15,881	13,962	12,410	10,971	10,139
Vol. of S.R. (AF/year)	55,746	35,135	25,201	17,105	9,332	2,730	0	0
Total vol. diverted (AF/year)	181,431	144,770	128,678	115,816	105,284	96,513	82,733	75,596
Total vol. diverted (AF/AC/yr)	6.35	5.07	4.50	4.05	3.68	3.38	2.90	2.65

Section no.	Optimal Conveyance System Combination							
	32.0	40.0	45.0	50.0	55.0	60.0	70.0	76.6
1	U 1/	U	U	U	U	U	L	L
2	G	G	G	G	G	G	G	G
3	L	G	G	G	G	G	G	G
4	L	L	L	L	L	L	L	L
5	U	U	U	U	U	U	U	G
6	U	U	U	U	U	U	U	G
7	U	U	U	U	U	U	U	G
8	U	U	U	U	U	U	U	G
9	U	U	U	U	U	U	U	G
10	U	U	U	U	U	U	U	G
11	U	U	U	U	U	U	U	G
12	U	U	U	U	U	U	U	G
13	U	U	U	U	U	U	U	G
14	L	L	L	L	L	L	L	G
15	U	U	U	U	U	U	U	G
16	U	U	U	U	U	U	L	G
17	U	U	U	U	U	U	U	G
18	U	U	U	U	U	U	U	G
19	U	U	U	U	U	U	L	G
20	U	U	U	U	U	U	U	G
21	U	U	U	U	U	U	L	G
22	U	U	U	U	U	U	U	G
23	U	U	U	U	U	U	U	G
24	U	U	U	U	U	U	L	L
25	U	U	U	U	U	U	U	L
26	U	U	U	U	U	U	U	L
27	U	U	U	U	U	U	U	U
28	U	U	U	U	U	U	U	U
29	U	U	U	U	U	U	L	G
30	U	U	U	U	U	U	U	G
31	U	U	U	U	U	U	L	L
32	U	U	U	U	U	U	U	G

1/ Symbols for conveyance system sections are described in Table VII-1.
2/ Symbols for application systems are described in tables VII-2 and VII-3.
3/ No subarea supplied by canal section.

Table VII-4. (continued)

Section no.	Optimal Application System Combination							
	32.0	40.0	45.0	50.0	55.0	60.0	70.0	76.6
1	UG 2/	UG	UG	UG	HM	HM	HM	SR
2	– 3/	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	UG	UG	UG	HM	HM	HM	SR	SR
5	UG	UG	UG (20%) HM (80%)	HM	HM	HM	HM	SR
6	UG	UG	HM	HM	HM	HM	SR	SR
7	UG	UG	UG	UG	UG	UG (93%) HM (7%)	HM	SR
8	UG	HM	HM	HM	HM	HM	SR	SR
9	HM	HM	HM	HM	HM	HM	SR	CP
10	UG (42%) HM (38%)	HM	HM	HM	HM	HM	SR	SR
11	UG	HM	HM	HM	HM	HM	SR	SR
12	UG	UG	HM	HM	HM	HM	HM	SR
13	UG	HM	HM	HM	HM	HM	SR	SR
14	UG	UG	UG	UG	HM	HM	SR	SR
15	UG	HM	HM	HM	HM	HM	HM	SR
16	–	–	–	–	–	–	–	–
17	UG	HM	HM	HM	HM	HM	SR	SR
18	UG	HM	HM	HM	HM	HM	SR	SR
19	UG	HM	HM	HM	HM	HM	SR	SR
20	UG	HM	HM	HM	HM	HM	SR	SR
21	UG	HM	HM	HM	HM	HM	SR	SR
22	UG	HM	HM	HM	HM	HM	HM (61%) SR (39%)	SR
23	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–
25	UG	UG	UG	UG	UG	UG	HM	SR
26	UG	UG	UG	UG	HM	HM	HM	SR
27	UG	UG	UG	UG	UG (45%) HM (55%)	HM	HM	SR
28	UG	UG	HM	HM	HM	HM	HM	SR
29	UG	UG	UG	UG	UG	UG	SR	SR
30	HM	HM	HM	HM	HM	HM	SR	SR
31	UG	HM	HM	HM	HM	HM	SR	SR (1%) CP (99%)
32	UG	UG	UG	UG (3%) HM (97%)	HM	HM	SR	SR

1/ Symbols for conveyance system sections are described in Table VII-1.
2/ Symbols for application systems are described in tables VII-2 and VII-3.
3/ No subarea supplied by canal section.

Table VII-5. Annual system costs and descriptions of optimal irrigation systems configuration for rehabilitation plans at various overall system efficiencies, Snake River Valley Irrigation District

	Overall System Efficiency (%)							
	30.5	40.0	45.0	50.0	55.0	60.0	70.0	78.6
Total system cost ($)	1,401,690	1,496,402	1,556,059	1,611,280	1,661,488	1,741,348	2,139,905	3,463,124
Application system cost ($)	1,254,583	1,349,194	1,408,851	1,464,071	1,514,280	1,546,144	1,675,748	2,035,593
Conveyance System cost ($)	147,107	147,208	147,208	147,208	147,208	195,204	464,157	1,427,581
Total system cost ($/AC)	81.6	87.1	90.6	93.8	96.7	101.4	124.6	201.6
Application system cost ($/AC)	73.0	78.5	82.0	85.2	88.1	90.0	97.6	118.5
Conveyance system cost ($/AC)	8.6	8.6	8.6	8.6	8.6	11.4	27.0	83.1
Inflow rate (cfs)	632	480	426	384	349	320	274	245
Overall system eff. (%)	30.5	40.0	45.0	50.0	55.0	60.0	70.0	78.6
Vol. of D.P. (AF/year)	19,450	14,267	11,620	9,464	8,151	7,431	6,526	5,669
Vol. of S.R. (AF/year)	32,323	16,528	11,274	6,816	3,065	1,269	0	0
Total vol. diverted (AF/year)	115,971	88,036	78,256	70,422	64,018	58,678	50,293	45,045
Total vol. diverted (AF/AC/yr)	6.75	6.13	4.56	4.10	3.73	3.42	2.93	2.62

Section no.	Optimal Conveyance System Combination							
	30.3	40.0	45.0	50.0	55.0	60.0	70.0	78.2
A	U 1/	U	U	U	U	U	L	L
B	U	U	U	U	U	U	U	L
C	U	U	U	U	U	L	L	G
D	U	U	U	U	U	U	L	G
E	U	U	U	U	U	U	L	L
F	U	U	U	U	U	U	U	G
G	U	U	U	U	U	U	L	G
H	U	U	U	U	U	U	U	G
I	U	U	U	U	U	U	L	G
J	U	U	U	U	U	U	U	G
K	U	U	U	U	U	U	U	G
L	U	U	U	U	U	U	U	G
M	U	U	U	U	U	U	U	G
N	U	U	U	U	U	U	U	G
O	U	U	U	U	U	U	U	G
P	U	U	U	U	U	U	L	G
Q	U	U	U	U	U	U	L	G
R	U	U	U	U	U	U	L	G
S	U	L	L	L	L	L	L	G

1/ Symbols for conveyance system sections are described in Table VII-1.
2/ Symbols for application systems are described in tables VII-2 and VII-3.
* No subarea supplied by canal section.

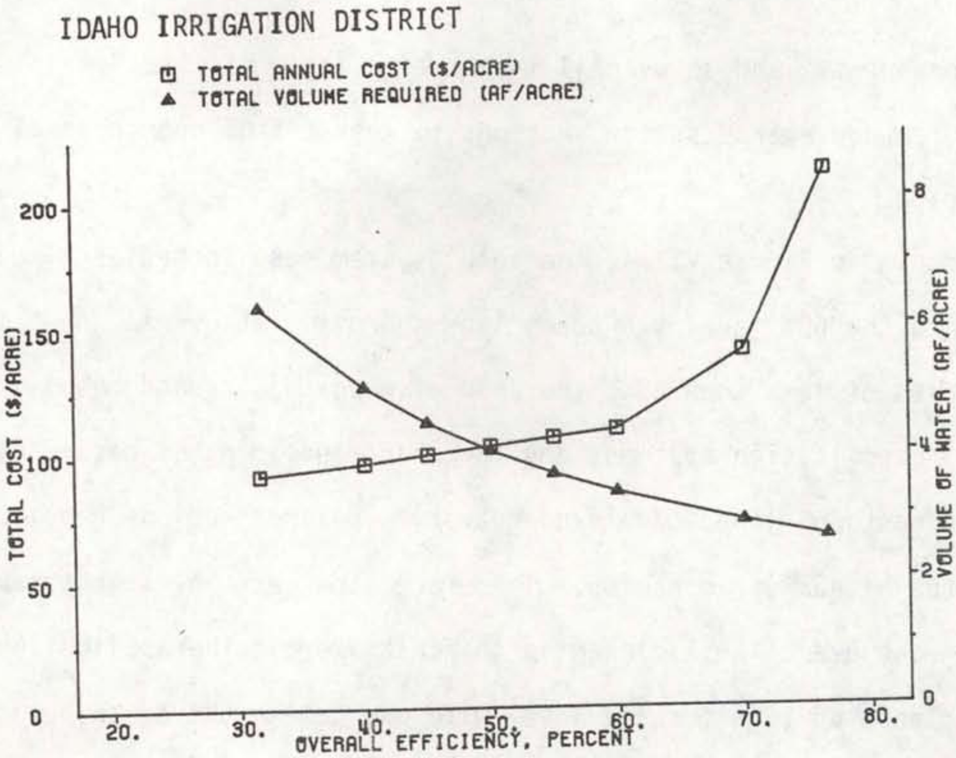
Table VII-5. (continued)

Section no.	Optimal Application System Combination							
	30.3	40.0	45.0	50.0	55.0	60.0	70.0	78.2
A	- *	-	-	-	-	-	-	-
B	UG 2/	UG	UG	HM	HM	HM	HM (76%) SR (24%)	SR
C	UG	UG	UG (18%) HM (82%)	HM	HM	HM	SR	SR
D	UG	HM	HM	HM	HM	HM	SR	SR
E	-	-	-	-	-	-	-	-
F	UG	UG (93%) HM (7%)	HM	HM	HM	HM	SR	SR
G	UG	HM	HM	HM	HM	HM	SR	CP
H	UG	HM	HM	HM	HM	HM	HM	CP
I	UG	HM	HM	HM	HM	HM	SR	CP
J	UG	UG	UG	UG	HM	HM	HM	SR
K	UG	UG	UG	UG	UG (77%) HM (23%)	HM	SR	SR
L	UG	UG	UG	HM	HM	HM	SR	SR
M	UG	UG	UG	UG	UG	UG	HM	SR
N	UG	UG	UG	UG	UG	IG (11%) HM (89%)	SR	SR
O	UG	HM	HM	HM	HM	HM	SR	SR
P	UG	UG	UG	UG	IG	IG	SR	SR
Q	UG	HM	HM	HM	HM	HM	SR	CP
R	UG	UG	UG	UG (26%) HM (74%)	HM	HM	SR	SR
S	UG	HM	HM	HM	HM	HM	SR	SR (6%) CP (94%)

1/ Symbols for conveyance system sections are described in Table VII-1.
2/ Symbols for application systems are described in tables VII-2 and VII-3.
* No subarea supplied by canal section.

The maximum attainable overall efficiencies are 76.6% and 78.6% for Idaho and Snake River Valley Irrigation Districts, respectively. These figures are almost 30% higher than the maximum attainable with existing distribution systems analyzed in Chapter VI. The effects of overall efficiency on total annual cost and total volume of water required for the optimal rehabilitation plans of the two irrigation districts are shown in Figure VII-4.

The specified overall efficiency for the systems considered affects both the total annual cost and the configuration of the system. From Tables VII-4 and VII-5 it can be seen that with unlimited water supply the IID would require a maximum diversion rate of 989 cfs to operate at an overall efficiency of 31.7% with a total annual cost of $2,627,397, and the SRVID would require a maximum flow rate of 632 cfs supplied by gravity distribution system and operate at an overall efficiency of 30.5% with a total annual cost of $1,401,690. Almost all conveyance system components are unlined canals, except for those which are constrained otherwise, and the application systems are unimproved gravity systems except for subareas 9 in the IID. This subarea has hand-move sprinkler application systems due to the dominant sandy soil of the area which causes gravity systems more costly than sprinkler systems. At a specified overall efficiency of 60%, the total annual cost for the system is $3,132,286 and the maximum required flow rate is 526 cfs for the IID, and $1,741,348 and 320 cfs for the SRVID. At an efficiency of 60%, the nearly all conveyance system sections remain as unlined open channel with a few lined sections, but the application systems for nearly all subareas are hand-move sprinkler systems. It is not until the overall system efficiency reaches 70% that there is much of a change in distribution



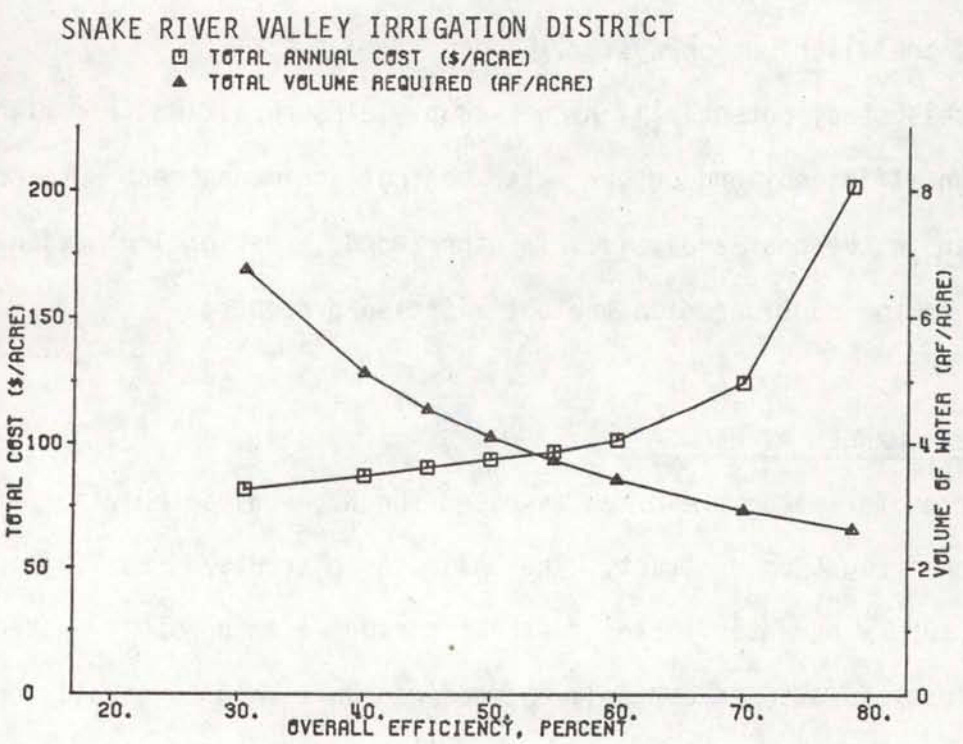


Figure VII-4. Results obtained for optimum rehabilitation plans at various overall system efficiencies.

system components, and an overall system efficiency of over 75% is required for conveyance system sections to change from open channel to gravity pipe.

As shown in Figure VII-4, the total system cost increases almost linearly to the 60% level and then rises sharply. At overall system efficiencies of less than 60%, the change in cost is caused mostly by changes in application systems, and the sharp increment is caused by the increased costs of lined canal and gravity pipeline sections required to achieve the higher efficiencies. Therefore, the best investment for improving the overall efficiency is to first improve the application system efficiency up to a certain level with changes in the distribution system only in those sections with high conveyance losses. To achieve the highest possible efficiencies, it would also be necessary to radically change the distribution system.

In this study potentially higher crop yields resulting from higher irrigation efficiency and better water control and management were not considered in the cost analysis. In other words, cost of irrigation is the only factor considered in the optimization procedure.

WATER COST CHARGED AT HEADGATE

Charges for water are often assessed for water diverted at a headgate to an irrigation district. The basis for charge can result from costs of supplying water to the district through a main supply system, and the cost of water is commonly charged per unit volume, usually dollars per acre-foot.

The charges for surface water entering the two studied irrigation districts were allowed to vary from \$0 to \$30 per acre-foot. Optimal results related to the various water charges summarized in Tables VII-6

Table VII-6. Annual system costs and descriptions of optimal irrigation systems configuration for rehabilitation plans at various water costs charged at the headgate, Idaho Irrigation District

	Water Cost ($/AF)						
	0.0	5.0	8.0	10.0	15.0	20.0	30.0
Total cost ($)	2,627.308	3,479,142	3,879,059	4,096,422	4,569,365	5,035,001	5,962,887
Total system cost ($)	2,627,397	2,882,450	2,917,243	3,060,172	3,170,045	3,176,861	3,191,217
Application system cost ($)	1,799,204	2,155,780	2,245,217	2,388,146	2,498,019	2,504,835	2,521,192
Conveyance system cost ($)	828,193	726,670	672,026	672,026	672,026	672,026	669,998
Water cost ($)	0	596,692	961,816	1,036,250	1,399,320	1,858,140	2,771,670
Total cost ($/AC)	92.0	121.7	135.7	143.3	159.9	176.2	208.6
Total system cost ($/AC)	92.0	100.9	102.1	107.1	110.9	111.2	111.7
Application system cost ($/AC)	63.0	75.4	78.5	83.6	87.4	87.7	88.2
Conveyance system cost ($/AC)	29.0	25.5	23.5	23.5	23.5	23.5	23.5
Water cost ($/AC)	0	20.8	33.6	36.2	49.0	65.0	96.9
Inflow rate (CFS)	989	813	655	565	508	506	503
Overall system eff. (%)	31.7	38.5	47.8	55.4	61.6	61.8	62.2
Volume of D.P. (AF/year)	29,824	21,969	16,513	13,656	11,713	11,827	11,827
Volume of S.R. (AF/year)	55,746	37,434	20,089	8,151	625	0	0
Total volume diverted (AF/year)	181,431	149,173	120,227	103,625	93,288	92,907	92,389
Total volume diverted (AF/AC/yr)	6.35	5.22	4.21	3.63	3.26	3.25	3.23

Section no.	Optimal Conveyance System Combination						
	0.0 1/	5.0	8.0	10.0	15.0	20.0	30.0
1	U	U	U	U	U	U	U
2	G	G	G	G	G	G	G
3	L	G	G	G	G	G	G
4	L	L	L	L	L	L	L
5	U	U	U	U	U	U	U
6	U	U	U	U	U	U	U
7	U	U	U	U	U	U	U
8	U	U	U	U	U	U	U
9	U	U	U	U	U	U	U
10	U	U	U	U	U	U	U
11	U	U	U	U	U	U	U
12	U	U	U	U	U	U	U
13	U	U	U	U	U	U	U
14	L	U	L	L	L	L	L
15	U	U	U	U	U	U	U
16	U	U	U	U	U	U	U
17	U	U	U	U	U	U	U
18	U	U	U	U	U	U	U
19	U	U	U	U	U	U	U
20	U	U	U	U	U	U	U
21	U	U	U	U	U	U	U
22	U	U	U	U	U	U	U
23	U	U	U	U	U	U	U
24	U	U	U	U	U	U	L
25	U	U	U	U	U	U	U
26	U	U	U	U	U	U	U
27	U	U	U	U	U	U	U
28	U	U	U	U	U	U	U
29	U	U	U	U	U	U	U
30	U	U	U	U	U	U	U
31	U	U	U	U	U	U	U
32	U	U	U	U	U	U	U

1/ Symbols for conveyance system sections are described in Table VII-1.
2/ Symbols for application systems are described in tables VII-2 and VII-3.
* No subarea supplied by canal section.

Table VII-6. (continued)

Section no.	Optimal Application System Combination						
	0.0	5.0	8.0	10.0	15.0	20.0	30.0
1	UG 2/ *	UG	UG	HM	HM	HM	HM
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	UG	UG	HM	HM	HM	HM	HM
5	UG	UG	HM	HM	HM	HM	HM
6	UG	UG	HM	HM	HM	HM	HM
7	UG	UG	UG	UG	HM	HM	HM
8	UG	HM	HM	HM	HM	HM	HM
9	HM	HM	HM	HM	HM	HM	HM
10	UG	UG	HM	HM	HM	HM	HM
11	UG	HM	HM	HM	HM	HM	HM
12	UG	UG	HM	HM	HM	HM	HM
13	UG	HM	HM	HM	HM	HM	HM
14	UG	UG	UG	HM	HM	HM	HM
15	UG	HM	HM	HM	HM	HM	HM
16	-	-	-	-	-	-	-
17	UG	HM	HM	HM	HM	HM	HM
18	UG	HM	HM	HM	HM	HM	HM
19	UG	HM	HM	HM	HM	HM	HM
20	UG	HM	HM	HM	HM	HM	HM
21	UG	HM	HM	HM	HM	HM	HM
22	UG	HM	HM	HM	HM	HM	HM
23	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-
25	UG	UG	UG	UG	HM	HM	HM
26	UG	UG	UG	HM	HM	HM	HM
27	UG	UG	UG	HM	HM	HM	HM
28	UG	UG	HM	HM	HM	HM	HM
29	UG	UG	UG	UG	IG	HM	HM
30	HM	HM	HM	HM	HM	HM	HM
31	UG	HM	HM	HM	HM	HM	HM
32	UG	UG	UG	HM	HM	HM	HM

1/ Symbols for conveyance system sections are described in Table VII-1.
2/ Symbols for application systems are described in tables VII-2 and VII-3.
* No subarea supplied by canal section.

Table VII-7. Annual system costs and descriptions of optimal irrigation systems configuration for rehabilitation plans at various water costs charged at the headgate, Snake River Irrigation District

	Water Cost ($/AF)						
	0.0	5.0	8.0	10.0	15.0	20.0	30.0
Total cost ($)	1,401,690	1,932,850	2,172,585	2,301,021	2,602,615	2,898,896	3,469,509
Total system cost ($)	1,401,690	1,460,920	1,650,537	1,673,181	1,713,775	1,713,775	1,771,627
Application system cost ($)	1,254,583	1,313,712	1,503,329	1,525,973	1,566,567	1,566,567	1,568,475
Conveyance system cost ($)	147,107	147,208	147,208	147,208	147,208	147,208	203,154
Water cost ($)	0	471,930	522,048	627,840	888,840	1,185,120	1,697,880
Total cost ($/AC)	81.5	112.5	126.5	134.0	151.5	168.8	202.0
Total system cost ($/AC)	81.5	85.1	96.1	97.4	99.8	99.8	103.1
Application system cost ($/AC)	73.0	76.5	87.5	88.8	91.2	91.2	91.3
Conveyance system cost ($/AC)	8.5	8.6	8.6	8.6	8.6	8.6	11.8
Water cost ($/AC)	0	27.4	30.4	36.6	51.7	69.0	98.9
Inflow rate (CFS)	632	514	356	342	323	323	308
Overall system eff. (%)	30.5	37.5	54.3	56.4	59.8	59.8	62.6
Volume of D.P. (AF/year)	19,450	15,405	8,455	7,821	7,204	7,204	7,190
Volume of S.R. (AF/year)	32,323	19,280	3,537	2,300	0	0	0
Total volume diverted (AF/year)	115,971	94,386	65,256	62,784	59,256	59,256	56,596
Total volume diverted (AF/AC/yr)	6.75	5.50	3.80	3.66	3.45	3.45	3.30

Section no.	Optimal Conveyance System Combination						
	0.0	5.0	8.0	10.0	15.0	20.0	30.0
A	U 1/	U	U	U	U	U	U
B	U	U	U	U	U	U	U
C	U	U	U	U	U	U	L
D	U	U	U	U	U	U	U
E	U	U	U	U	U	U	U
F	U	U	U	U	U	U	U
G	U	U	U	U	U	U	U
H	U	U	U	U	U	U	U
I	U	U	U	U	U	U	U
J	U	U	U	U	U	U	U
K	U	U	U	U	U	U	U
L	U	U	U	U	U	U	U
M	U	U	U	U	U	U	U
N	U	U	U	U	U	U	U
O	U	U	U	U	U	U	U
P	U	U	U	U	U	U	U
Q	U	U	U	U	U	U	U
R	U	U	U	U	U	U	L
S	U	L	L	L	L	L	L

* No subarea supplied by canal section.
1/ Symbols for conveyance system sections are described in Table VII-1.
2/ Symbols for application systems are described in tables VII-2 and VII-3.

Table VII-7. (continued)

Section no.	Optimal Application System Combination						
	0.0	5.0	8.0	10.0	15.0	20.0	30.0
A	-	-	-	-	-	-	-
B	UG 2/	UG	HM	HM	HM	HM	HM
C	UG	UG	HM	HM	HM	HM	HM
D	UG	UG	HM	HM	HM	HM	HM
E	-	-	-	-	-	-	-
F	UG	UG	HM	HM	HM	HM	HM
G	UG	HM	HM	HM	HM	HM	HM
H	UG	HM	HM	HM	HM	HM	HM
I	UG	HM	HM	HM	HM	HM	HM
J	UG	UG	HM	HM	HM	HM	HM
K	UG	UG	UG	HM	HM	HM	HM
L	UG	UG	HM	HM	HM	HM	HM
M	UG	UG	UG	UG	HM	HM	HM
N	UG	UG	UG	UG	HM	HM	HM
O	UG	HM	HM	HM	HM	HM	HM
P	UG	UG	UG	IG	HM	HM	SR
Q	UG	HM	HM	HM	HM	HM	HM
R	UG	UG	HM	HM	HM	HM	HM
S	UG	HM	HM	HM	HM	HM	HM

* No subarea supplied by canal section.

1/ Symbols for conveyance system sections are described in Table VII-1.

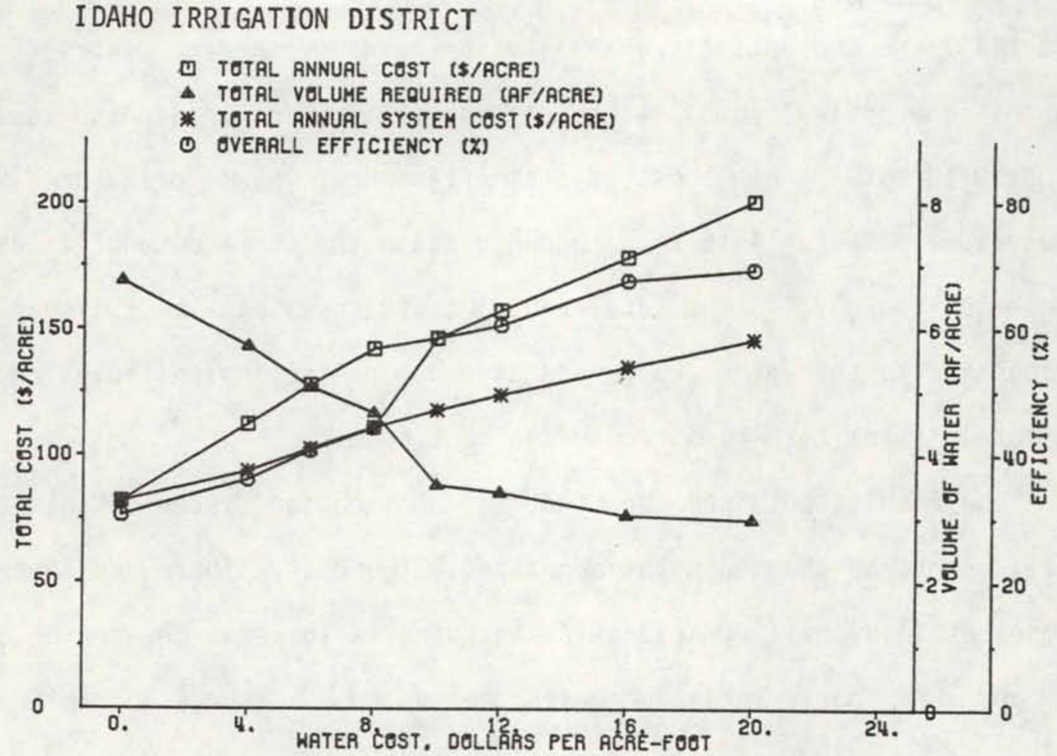
2/ Symbols for application systems are described in tables VII-2 and VII-3.

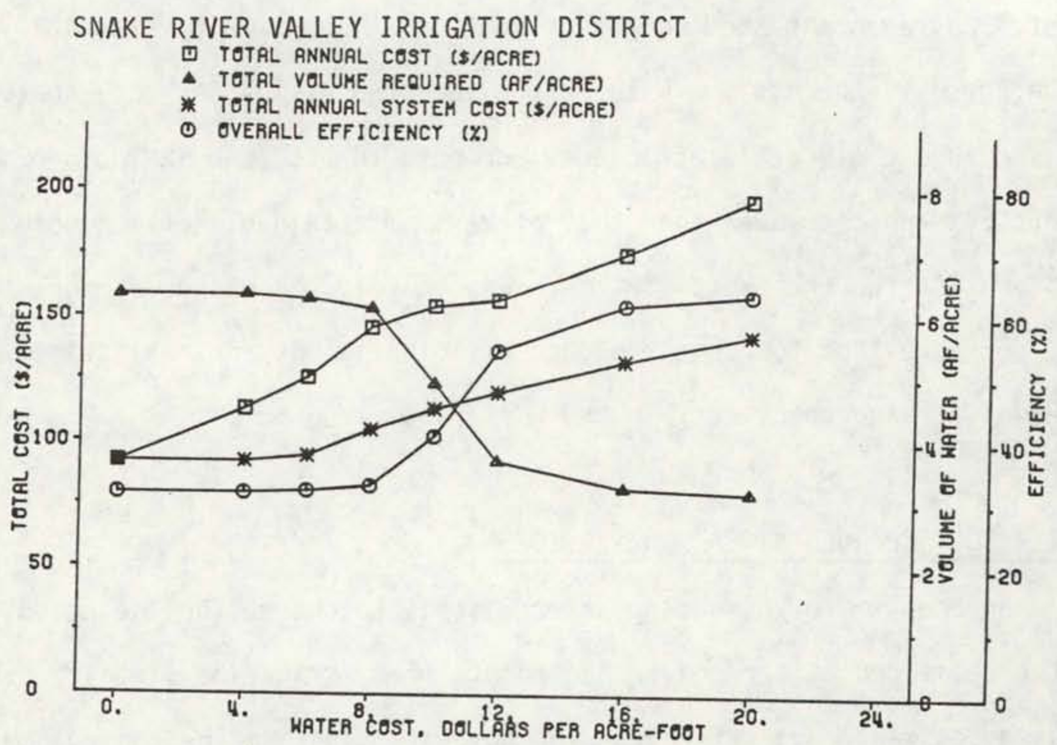
and VII-7 are the optimal rehabilitation plans of the two districts. The tables show optimal combinations of distribution and application systems along with total annual cost, system efficiency, volume of water diverted and volume of water lost to deep percolation and surface runoff. As shown in Figure VII-5 the total annual cost increases almost linearly in proportion to the water charge assessed due to the insignificant changes in total system cost compared to the cost of water.

The results obtained show that the application system components are the first to be changed with increasing water cost. There are sharp increases in overall efficiency as water costs increase between \$5 and \$10 per acre-foot. These increases are caused by changes in application systems from predominately unimproved gravity systems at a charge of \$5 per acre-foot to nearly all sprinkler systems at \$8 and \$10 per acre-foot. Conveyance system component configurations remain essentially unchanged up to the maximum with charge invested at \$30 per acre-foot. At this charge the overall efficiency for both the IID and SRVID is 62%, about 14% and 16% lower than that of maximum attainable efficiencies of 76% and 78% for the two districts, respectively. A charge of more than \$30 per acre-foot to achieve higher efficiencies is not realistic under present farming practices.

WATER COST CHARGED AT FARM DIVERSIONS

Another way of assessing water cost is to charge for the amount of water delivered at farm diversion points from irrigation district canals. This assessment does not charge for any water lost in the conveyance system between the headgate and farm diversion points. The basis of the charge is cost per unit volume diverted or dollars per acre-foot diverted





Note: Total annual cost = total annual system cost + annual water cost

Figure VII-5. Results obtained for optimum rehabilitation plans for various water costs charged at the headgate.

from canal to farm field. However, because of difficulties in formulating the mixed integer-linear programming problem matrix, this charge method could not be directly applied as dollars per acre-foot. Water cost must be converted to dollars per acre of land in the subarea where the water is delivered. The maximum irrigation flow rate requirement (cfs/acre) for each irrigation application system in each subarea was converted to the seasonal volume requirement (acre-feet per acre) by using the cfs-to-acre-feet conversion factor. The water charge in dollars per acre-foot is then converted for the seasonal volume requirement in dollars per acre.

Because the irrigation requirement of a subarea is influenced by application system efficiency the water cost in dollars per acre will be low for a application system with a high application efficiency and high for a system with low application efficiency. For example, a \$1 per acre-foot water charge for an unimproved gravity application system in subarea 30 of the Idaho Irrigation District is converted as follows:

Irrigation requirement rate = 0.0302 cfs/acre

$$\text{Seasonal Volume Requirement} = \frac{0.0302 \text{ cfs/acre}}{0.00545 \text{ cfs/acre-foot/year}} = 5.54 \text{ acre-feet/acre/year}$$

$$\text{Seasonal Water Charge} = 5.54 \text{ acre-feet/acre/year} \times 1.0 \text{ \$/acre-foot} = 5.54 \text{ \$/acre/year}$$

Using the same procedure the water costs in dollars per acre could be obtained for all application systems in the subareas shown in Figure VII-3.

The charges at farm diversion points were allowed to vary from \$0 to \$20 per acre-foot. The total assessed revenue for water is constrained to be less than or equal to the total conveyance system cost including operation and maintenance costs. With this constraint the conveyance system cost is equal to the total water cost as long as the water cost is greater than or equal to the minimum conveyance system cost since the objective of the problem is to find the mimimum total cost.

The optimal results related to various water costs charged at the farm deliveries are shown in Tables VII-8 and VII-9 and in Figure VII-6. The tables include data for total annual cost, overall system efficiency, water diverted at the headgate, water lost to deep percolation and surface runoff and optimal combinations of distribution and application systems for each level of water cost. The total system cost for this case does not include the water cost as the objective of this particular model is to minimize total system cost subject to the constraint described in the preceding paragraph. The results listed in the tables show that a water cost of $6 per acre-foot is necessary to meet the minimum distribution system costs ($888,656) for the IID whereas a cost of $4 per acre-foot is necessary for the SRVID ($319,576). The graphs in Figure VII-6 show that the greatest increase in overall efficiency for both districts occur at water charges of $12 per acre-foot or less.

At a $20 per acre-foot cost, the optimal systems would have overall efficiencies of 63.4% and 69.3% for the Idaho and Snake River Valley Irrigation Districts, respectively. These numbers are higher than those for the $20 per acre-foot water cost charged at the headgate diversions for the two districts. In comparing both types of water charge, it can be seen that the application system combinations are not much different from each other. However, try constraining the distribution system cost greater than or equal to the water costs charged at farm diversion points

Table VII-8. Annual system costs and description of optimal irrigation systems configuration for rehabilitation plans at various water costs at farm diversion Idaho Irrigation District

	Water Cost ($/AF)							
	0	4.0	6.0	8.0	10.0	12.0	16.0	20.0
Total system cost ($)	2,627,397	2,627,397	2,691,332	2,993,357	3,228,593	3,417,031	3,774,802	4,070,629
Total system cost + water cost ($)	2,627,397	3,225,984	3,579,988	4,159,338	4,408,065	4,477,961	5,004,160	5,608,547
Application system cost ($)	1,799,204	1,799,204	1,802,676	1,827,376	2,048,721	2,356,101	2,545,444	2,532,711
Conveyance system cost ($)	828,193	828,193	888,656	1,165,981	1,179,672	1,060,930	1,229,358	1,537,918
Water cost ($)	0	598,587	888,656	1,165,981	1,179,672	1,060,930	1,229,358	1,537,918
Total system cost ($/AC)	92.0	92.0	94.2	104.7	113.0	119.6	132.1	142.4
Total system cost + water cost ($)	92.0	112.9	125.3	145.5	154.2	156.7	175.1	196.2
Application system cost ($/AC)	63.0	63.0	63.1	63.9	71.7	82.4	89.1	88.6
Conveyance system cost ($/AC)	29.0	29.0	31.1	40.8	41.3	37.2	43.0	53.8
Total inflow rate (CFS)	989	989	978	954	767	574	507	493
Overall system eff. (%)	31.7	31.7	32.0	32.8	40.8	54.5	61.8	63.4
Volume of D.P. (AF/Year)	29,824	29,824	29,566	29,060	21,656	14,230	11,772	11,801
Volume of S.R. (AF/Year)	55,746	55,746	54,750	52,415	32,344	10,280	0	0
Total volume used (AF/Year)	181,431	181,431	179,418	175,095	140,656	105,356	92,976	90,536
Total volume used (AF/AC/Year)	6.35	6.35	6.28	6.13	4.92	3.69	3.25	3.17

Table VII-8. (continued)

SECTION NO.	Optimal Conveyance System Combination Water Cost at Farm Diversion ($/Acre-Foot)							
	0	4	6	8	10	12	16	20
1	U[1/]	U	U	U	U	U	U	U
2	G	G	G	G	G	G	G	G
3	L	L	L	L	L	L	L	L
4	L	L	L	G	L	G	L	L
5	U	U	U	L	L	U	L	L
6	U	U	U	U	U	U	G	U
7	U	U	U	U	U	L	U	U
8	U	U	U	U	U	U	U	G
9	U	U	U	U	U	G	U	U
10	U	U	U	U	L	U	L	L
11	U	U	U	U	U	U	L	U
12	U	U	U	U	U	U	U	G
13	U	U	U	U	U	G	U	U
14	L	L	L	L	L	L	L	L
15	U	U	L	L	L	L	L	L
16	U	U	U	U	U	U	U	U
17	U	U	U	U	U	U	U	U
18	U	U	U	U	U	G	G	G
19	U	U	U	U	U	U	G	U
20	U	U	U	U	U	U	U	U
21	U	U	U	U	U	U	U	U
22	U	U	U	U	U	U	U	U
23	U	U	L	U	U	U	U	G
24	U	U	U	U	U	U	U	U
25	U	U	U	U	U	L	L	L
26	U	U	U	U	U	U	U	U
27	U	U	U	U	U	U	U	U
28	U	U	U	U	U	U	U	U
29	U	U	U	U	U	U	U	G
30	U	U	U	U	U	G	U	G
31	U	U	U	U	U	U	U	G
32	U	U	U	U	U	U	U	G

1/ Symbols for conveyance system sections are described in Table VII-1.

Table VII-8. (continued)

SECTION NO.	Optimal Application System Combination Water Cost at Farm Delivery ($/Acre-Foot)							
	0	4	6	8	10	12	16	20
1	UG	UG 2/	UG	UG	HM	HM	HM	HM
2	--	-- 3/	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--
4	UG	UG	UG	UG	UG	HM	HM	HM
5	UG	UG	UG	UG	UG	HM	HM	HM
6	UG	UG	UG	UG	HM	HM	HM	HM
7	UG	UG	UG	UG	UG	UG	HM	HM
8	UG	UG	UG	HM	HM	HM	HM	HM
9	UG	UG	UG	HM	HM	HM	HM	HM
10	UG	UG	UG	UG	HM	HM	HM	HM
11	UG	UG	UG	UG	UG	HM	HM	HM
12	UG	UG	UG	UG	HM	HM	HM	HM
13	UG	UG	UG	UG	UG	UG	HM	HM
14	UG	UG	UG	UG	UG	HM	HM	HM
15	--	--	--	--	--	--	--	--
16	UG	UG	UG	UG	HM	HM	HM	HM
17	UG	UG	UG	UG	UG	HM	HM	HM
18	UG	UG	UG	UG	UG	HM	HM	HM
19	UG	UG	UG	UG	UG(1%)	HM	HM	HM
20	UG	UG	UG	UG	HM(99%)	HM	HM	HM
21	UG	UG	UG	UG	HM	HM	HM	HM
22	UG	UG	UG	UG	UG	HM	HM	HM
23	--	--	--	--	--	--	--	--
24	--	--	--	--	--	--	--	--
25	UG	UG	UG	UG	UG	UG	HM	HM
26	UG	UG	UG	UG	UG	HM	HM	HM
27	UG	UG	UG	UG	UG	UG(65%) HM(35%)	HM	HM
28	UG	UG	UG	UG	HM	HM	HM	HM
29	UG	UG	UG	UG	UG	UG	HM	HM
30	HM	HM	HM	HM	HM	HM	HM(80%) CP(20%)	HM(90%) CP(10%)
31	UG	UG	UG(51%) HM(49%)	UG(87%) HM(23%)	HM	HM	HM	HM
32	UG	UG	UG	UG	UG	HM	HM	HM

2/ Symbols for application systems are described in Tables VII-2 and VII-3.

3/ No subarea is supplied by canal section.

Table VII-9. Annual system costs and description of optimal irrigation systems configuration for rehabilitation plans at various water costs at farm diversion, Snake River Valley Irrigation District

	Water Cost ($/AF)							
	0	4.0	6.0	8.0	10.0	12.0	16.0	20.0
Total system cost ($)	1,401,690	1,605,740	1,759,793	1,903,026	2,020,950	2,126,676	2,316,983	2,504,942
Total system cost + water cost ($)	1,401,690	1,925,316	2,193,461	2,440,202	2,513,800	2,700,952	3,060,471	3,446,142
Application system cost ($)	1,254,583	1,286,164	1,326,125	1,365,850	1,528,100	1,552,400	1,573,435	1,563,742
Conveyance system cost ($)	147,107	319,576	433,668	537,176	492,850	574,276	743,488	941,200
Water cost ($)	0	310.576	433.668	537.176	402.95-	574.276	743,488	941,200
Total system cost ($/AC)	81.6	93.5	102.5	110.8	117.7	123.8	134.9	146.4
Total system cost + water cost ($)	81.6	112.1	127.7	142.1	146.3	157.2	178.2	200.6
Application system cost ($/AC)	73.0	74.9	77.2	79.5	89.0	90.4	91.6	91.6
Conveyance system cost ($/AC)	8.6	18.6	25.3	31.3	28.7	33.4	43.4	54.8
Total inflow rate (CFS)	632	535	474	436	330	318	285	278
Overall system eff. (%)	30.5	36.1	40.7	44.3	58.5	60.6	67.6	69.3
Volume of D.P. (AF/Year)	19,450	17,224	15,414	13,462	8,299	7,216	7,126	7,128
Volume of S.R. (AF/Year)	32,323	25,774	19,317	15,610	3,172	980	202	195
Total volume used (AF/Year)	151,971	98,208	87,098	79,956	60,529	58,400	52,421	51,112
Total volume used (AF/AC/Year)	6.75	5.72	5.07	4.66	3.52	3.40	3.05	2.98

Table VII-9. (continued)

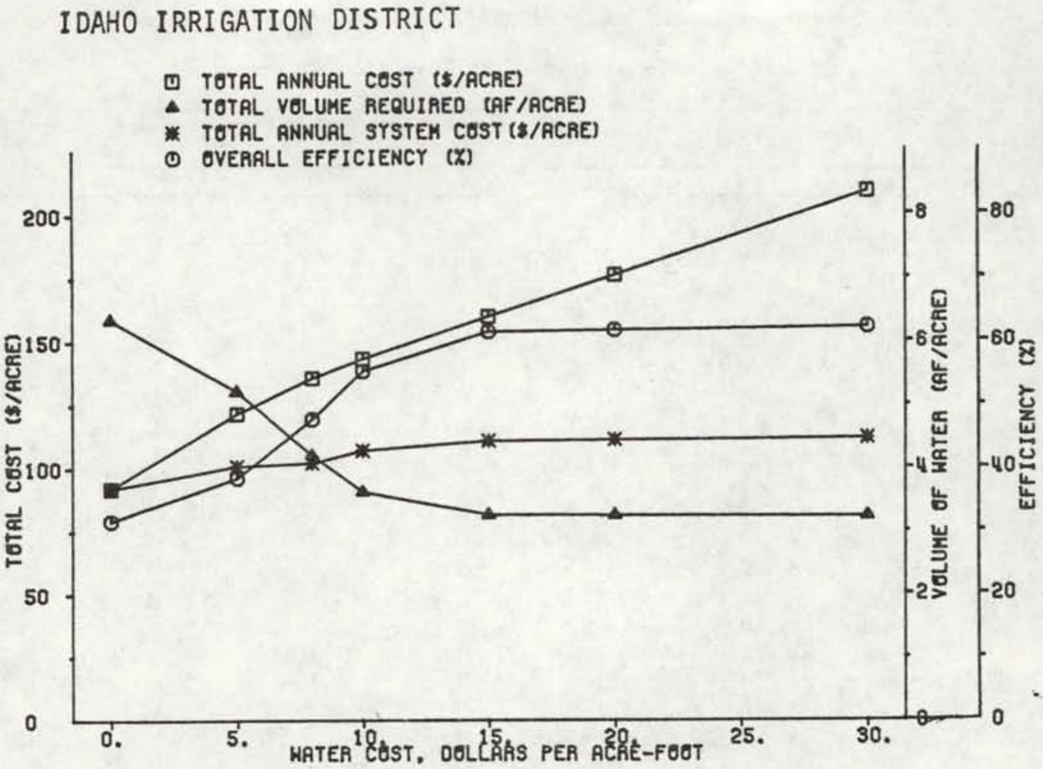
Water Cost at Farm Diversion ($/Acre-Foot)

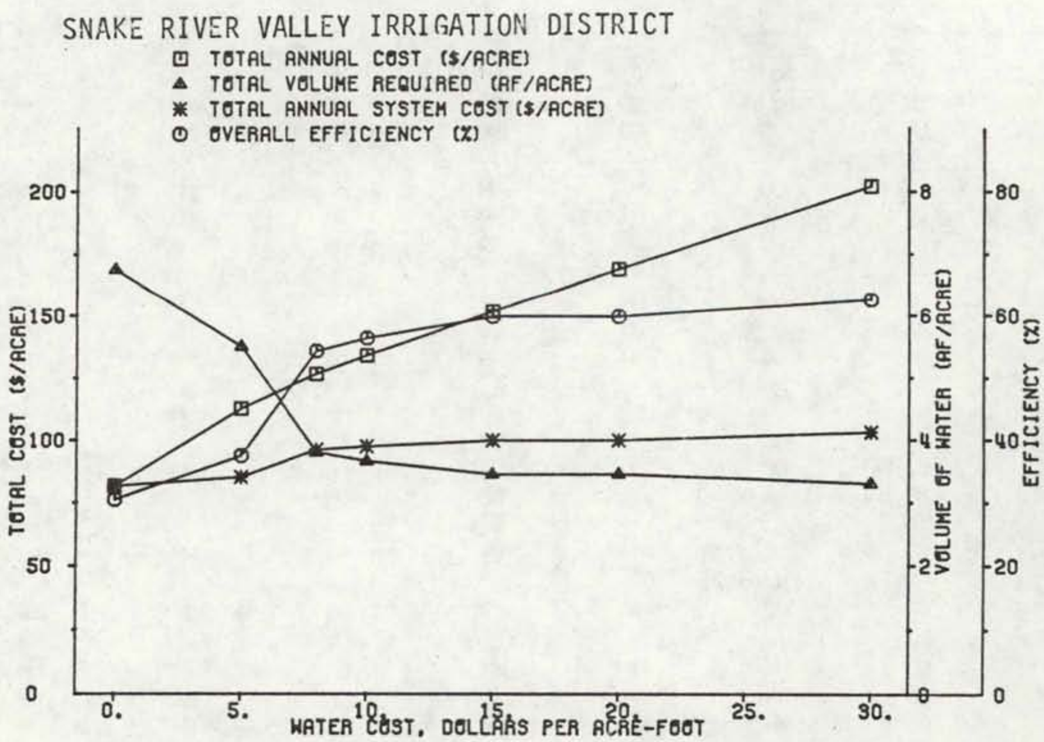
SECTION NO.	0	4	6	8	10	12	16	20
	Optimal Conveyance System Combination							
A	U 1/	U	U	U	U	U	L	L
B	U	L	U	U	U	U	U	U
C	U	L	L	L	L	U	L	L
D	U	U	G	U	U	U	U	L
E	U	U	U	L	U	U	U	U
F	U	U	U	U	U	U	U	G
G	U	U	U	U	U	U	U	G
H	U	U	U	L	G	L	G	G
I	U	G	U	U	U	U	U	G
J	Y	Y	Y	G	G	G	G	G
K	U	U	U	U	U	G	G	L
L	U	U	U	U	U	G	U	U
M	U	U	U	U	L	U	G	L
N	U	U	U	U	U	G	G	U
O	U	U	G	G	G	G	U	G
P	U	U	U	G	U	U	U	U
Q	U	L	U	L	L	L	L	L
R	U	G	U	U	U	U	G	U
S	U	L	U	U	L	U	L	G
	Optimal Application System Combination							
A	-- 3/	--	--	--	--	--	--	--
B	UG 2/	UG	UG	HM	HM	HM	HM	HM
C	UG	UG	UG	UG	HM	HM	HM	HM
D	UG	UG	UG	UG	HM	HM	HM	HM
E	--	--	--	--	--	--	--	--
F	UG	UG	UG	HM	HM	HM	HM	HM
G	UG	HM	HM	HM	HM	HM	HM	HM
H	UG	UG	UG(1%) HM(99%)	HM	HM	HM	HM	HM
I	UG	UG	HM	HM	HM	HM	HM	HM
J	UG	UG	UG	UG	HM	HM	HM	HM
K	UG	UG	UG	UG	UG(63%) HM(37%)	HM	HM	HM
L	UG	UG	UG	UG(61%) HM(39%)	HM	HM	HM	HM
M	UG	UG	UG	UG	UG	HM	HM	HM
N	UG	UG	UG	UG	UG	IG(69%) HM(31%)	HM	HM
O	UG	UG(47%) HM(53%)	HM	HM	HM	HM	HM	HM
P	UG	UG	UG	UG	UG	UG	IG(74%) HM(26%)	IG(72%) HM(28%)
Q	UG	HM	HM	HM	HM	HM	HM	HM
R	UG	UG	UG	UG	HM	HM	HM	HM
S	UG	HM	HM	HM	HM	HM	HM	HM

1/ Symbols for conveyance system sections are described in Table VII-1.

2/ Symbols for application systems are described in Tables VII-2 and VII-3.

3/ No subarea is supplied by canal section.





Note: Total annual cost = total annual system cost + annual water cost

Figure VII-6. Results obtained for optimum rehabilitation plans for various water costs charged at farm delivery.

the model to select more efficient distribution systems such as gravity pipe systems to achieve a higher overall system efficiency.

CONSOLIDATION PLANS WITH HIGH PRESSURE PIPE SUPPLY SYSTEM

Two types of consolidation plans are considered for the study area. The first plan, Plan A, is to install two river pump stations to supply water to two areas determined on the basis of present irrigation district boundaries. The first river pump is located in about 5 miles south of the present diversion point of the Idaho Irrigation District (IID). This system, called the North District would supply most of the present area of the IID except for the narrow band south of the town of Goshen (Figure VI-2). The second river pump is installed about 3 miles south of the existing diversion point of the Snake River Valley Irrigation District (SRVID). This system, called the South District, would supply the SRVID and the area in the IID not supplied by the North District system. The cost of energy is considered to increase by 12% per year for all pumping costs.

The high pressure pipe systems routing and subarea supplied by the pipe sections are shown in Figures VII-7 and VII-8, respectively. Routes for the high pressure pipe delivery systems are determined by considering present canal system routes, land ownership, and the locations of roads and railroads. The main pipe system of the North District follows the existing main Idaho canal system and the South District's main pipe system follows the East Branch of the Snake River Valley canal system. The purpose of Sand Creek is limited for drainage and flood control in the area. Lateral pipe systems are located almost every mile along east-west county road systems and sublateral pipes are considered for the areas

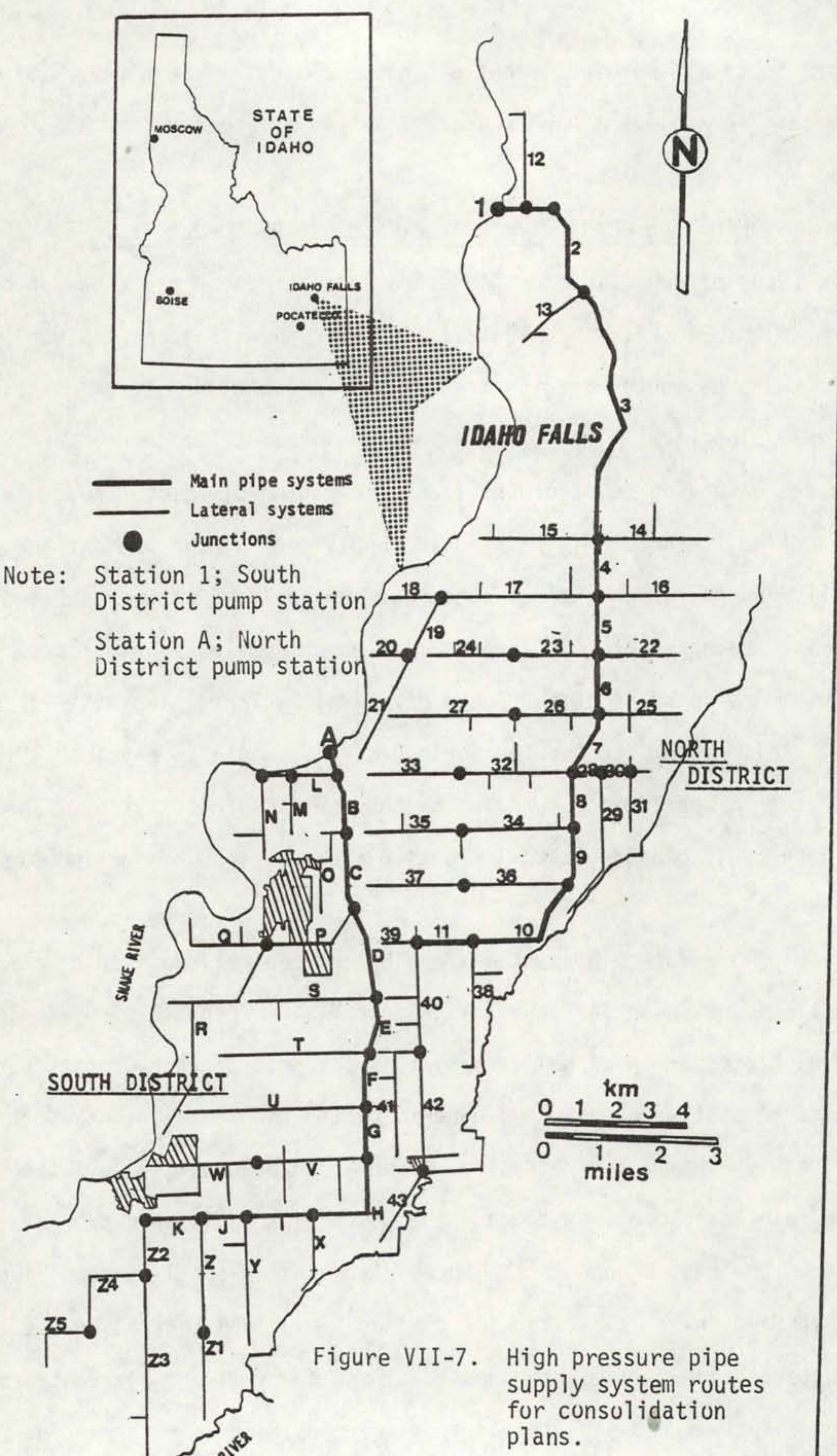


Figure VII-7. High pressure pipe supply system routes for consolidation plans.

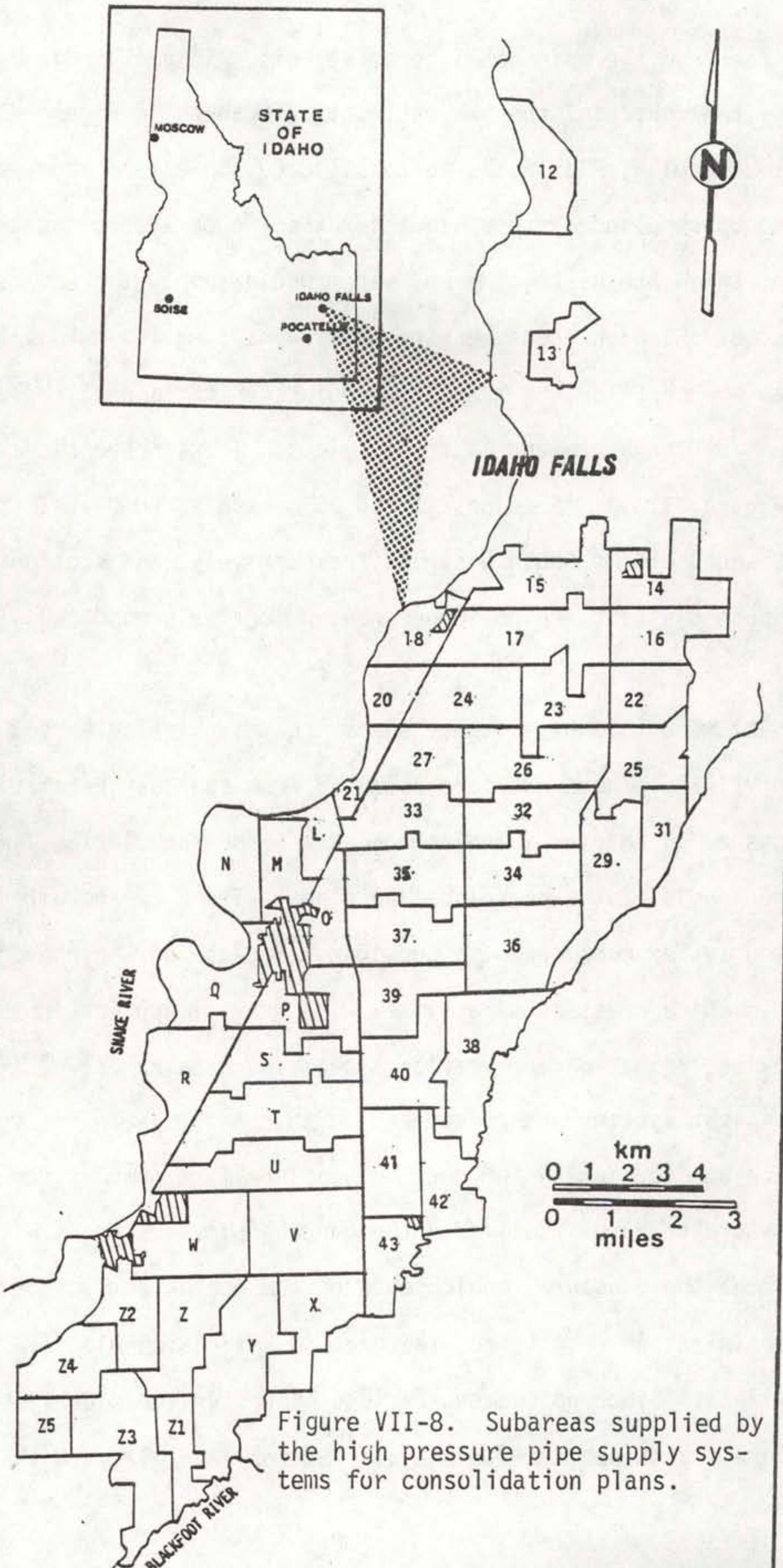


Figure VII-8. Subareas supplied by the high pressure pipe supply systems for consolidation plans.

which are far from the main and lateral systems. Schematic diagrams of the pipe system routes of the two districts are shown in Figure VII-9.

The second plan, Plan B, is to consolidate the entire study area under one pump-supplied system. In this case a pump system located at the site of the North District pump system would supply the entire study area. Most of the high pressure pipe delivery system lay-out is the same as for Plan A except for the transition points which connect the original main systems of the North and South Districts. These connections are shown in Figure VII-10. Sections 33 and 35 of the North District supply sections L and C of the South District, respectively, and sections A and B of the South District are no longer needed for the second consolidation plan.

The data used to analyze these plans are shown in Tables VII-10, VII-11 and VII-12. These data are obtained from the cost estimation programs discussed in Chapter V and are necessary for formulating linear programming models of the consolidation plans. There are no alternative distribution system components to consider. Because of the non-compatibility of the high pressure pipe system with gravity application systems only sprinkler irrigation application systems such as handmove, side-roll and center-pivot systems are considered in this analysis. The system cost of each application system does not include farm pump system costs as the pressure of 75 psi delivered through the pipe system is high enough to meet the pressure requirements of the sprinkler systems.

The optimization results for the each consolidation plan are shown in Table VII-13. Since no conveyance loss occurs in the pipe system, the minimum overall attainable efficiency is 75% for each plan. With this

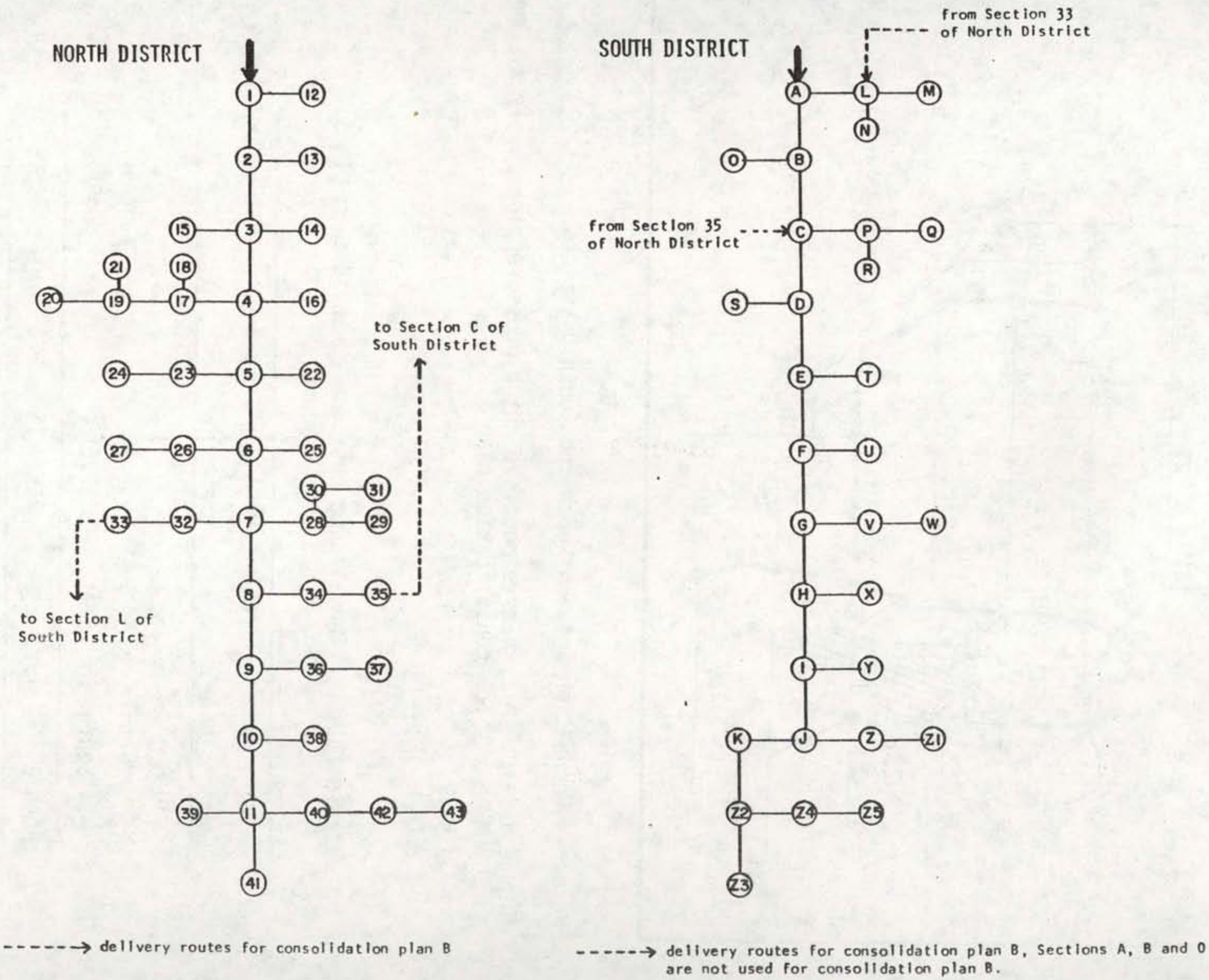
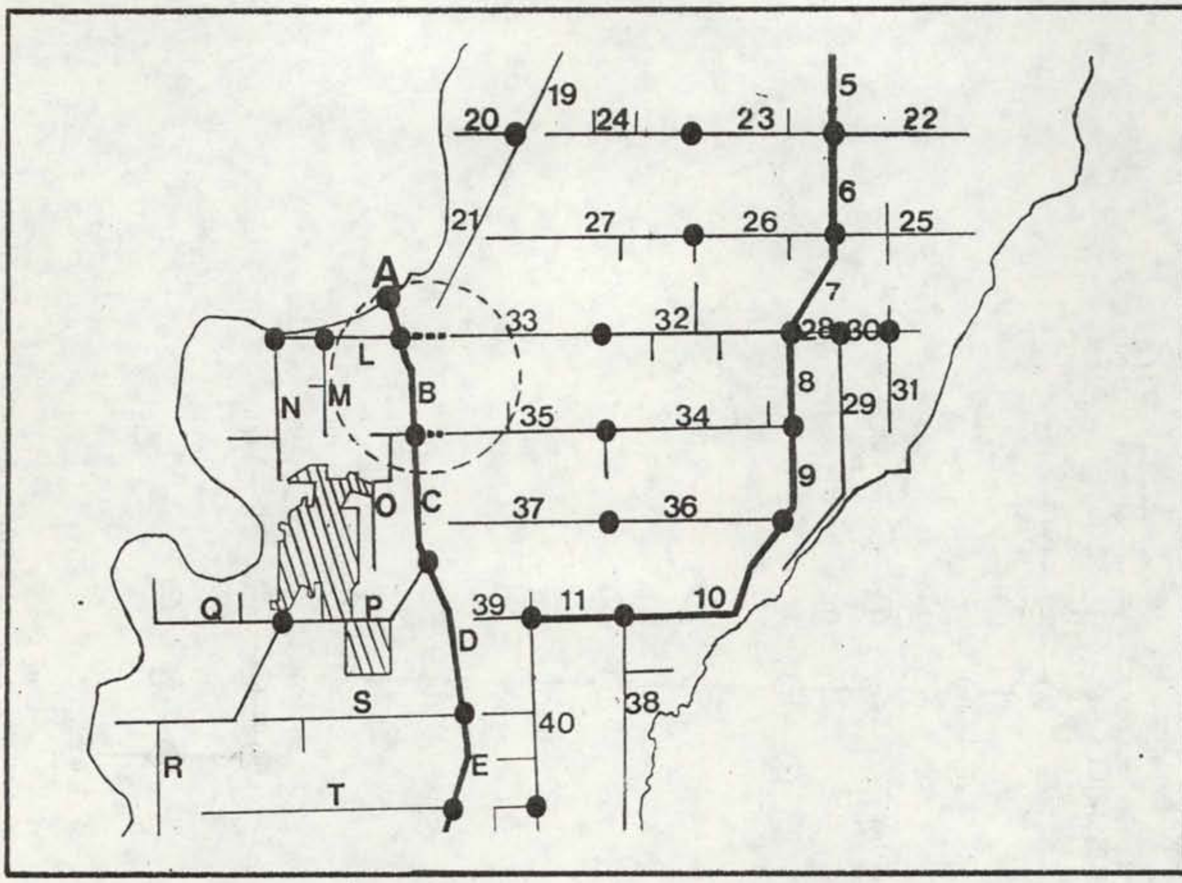


Figure VII-9. Schematic diagram of the high pressure pipe system routes for the consolidation plans.



Note; -- Connection between North and South Districts

Figure VII-10. Alternative routes of high pressure pipe supply systems for consolidation plan B.

Table VII-10. Annual pump cost for consolidation plans.

	Variable $ /cfs	Fixed $
PLAN A		
North	455.4	973407
South	537.5	848877
PLAN B	455.4	856806

Annual Pump Cost = Variable cost X Flow rate + Fixed cost

Table VII-11. High pressure pipe conveyance system data and annual cost for consolidation plan

Section no.	Subarea Served (Acres)	Total Downstream Area Served (Acres)	Length (Miles)	Annual cost 1/ a $/CFS	Annual cost 1/ b Fixed ($)
1	0	26,636	0.517	665.4	14,391
2	0	25,809	2.177	653.2	210,693
3	0	25,339	4.731	646.7	481,096
4	0	23,430	1.020	619.3	34,551
5	0	19,547	1.063	562.3	21,571
6	0	16,905	1.048	522.9	44,164
7	0	14,241	1.173	484.5	52,875
8	0	10,210	0.980	393.7	38,228
9	0	8,098	1.037	119.8	33,931
10	0	5,783	2.333	85.9	84,257
11	0	4,487	1.034	66.3	10,567
12	827	827	1.687	12.2	42,393
13	470	470	1.337	6.5	26,619
14	1,016	1,016	1.728	14.3	41,470
15	893	893	2.137	13.1	52,943
16	857	857	1.864	12.2	37,396
17	1,486	3,026	2.844	44.9	69,542
18	516	516	0.939	7.8	13,718
19	0	1,024	1.139	15.4	20,639
20	743	743	0.735	11.0	18,374
21	281	281	2.369	4.4	24,323
22	794	794	1.442	11.8	30,320
23	867	1,848	1.525	27.5	27,156
24	981	981	1.865	14.8	41,559
25	743	743	1.551	11.1	29,787
26	1,093	1,921	2.559	27.4	49,031
27	828	828	1.293	12.1	32,012
28	0	1,959	0.517	29.2	2,903
29	1,320	1,320	3.008	19.4	45,710
30	0	639	0.517	9.8	2,414
31	639	639	1.088	9.8	21,588
32	994	2,072	2.027	61.6	47,845
33	1,078	1,078	1.878	47.3	39,272
34	924	2,112	1.973	274.0	61,144
35	1,188	1,188	1.945	260.8	51,983
36	1,278	2,315	1.932	33.9	72,016
37	1,037	1,037	1.905	15.2	48,242
38	1,296	1,296	2.286	19.6	46,596
39	772	772	0.762	11.3	28,524
40	1,026	3,715	1.972	55.0	55,222
41	1,050	1,050	2.327	15.3	45,248
42	907	1,639	1.864	24.9	25,269
43	732	732	1.746	11.1	44,521

Table VII-11. (continued)

Section no.	Subarea Served (Acres)	Total Downstream Area Served (Acres)	Length (Miles)	Annual cost 1/ a $/CFS	b Fixed ($)
A	0	19,118	0.748	274.4	39,650
B	0	16,873	1.210	243.2	76,951
C	0	16,346	0.780	235.3	48,015
D	0	13,611	1.840	194.9	80,252
E	0	12,702	1.150	181.2	47,897
F	0	11,080	1.050	158.9	30,144
G	0	9,741	0.966	140.3	39,549
H	0	7,205	1.877	105.1	15,811
I	0	6,046	1.224	89.0	15,699
J	0	4,481	0.775	66.8	8,693
K	0	3,191	1.006	47.1	8,472
L	434	2,245	0.885	31.2	23,637
M	702	702	0.993	10.2	26,249
N	1,109	1,109	1.608	14.6	27,902
O	527	527	1.306	7.9	20,816
P	727	2,735	2.215	40.4	43,645
Q	831	831	1.360	12.2	34,260
R	1,177	1,177	4.567	17.5	67,812
S	909	909	2.122	13.6	42,061
T	1,622	1,622	2.612	22.4	53,443
U	1,339	1,339	3.225	18.6	59,560
V	1,303	2,536	1.904	35.2	68,961
W	1,233	1,233	2.341	17.0	59,916
X	1,159	1,159	1.219	16.2	38,142
Y	1,565	1,565	2.571	22.1	40,170
Z	865	1,290	1.918	20.0	22,226
Z1	425	425	1.387	6.5	15,196
Z2	763	3,191	0.939	47.1	35,750
Z3	1,066	1,066	3.306	15.8	49,176
Z4	918	1,362	2.000	19.9	28,432
Z5	444	444	1.334	6.3	22,288

1/ Conveyance System Cost, Cost = ax + b

where, a = Variable cost, $/CFS
b = Fixed cost, $
x = Design flow rate, CFS

Table VII-12. Sprinkler irrigation application system data and annual cost for consolidation plan of high pressure pipe conveyance system.

	Hand-move Sprinkler (HMS)			Side-roll Sprinkler (SRS)			Center-pivot Sprinkler(CPS)		
SUBAREA NO.	Q max 1/ CFS/Acre	Cost 2/ $/Acre	DP 3/ AF/Acre	Q max CFS/Acre	Cost $/Acre	DP AF/Acre	Q max CFS/Acre	Cost $/Acre	DP AF/Acre
12	0.0147	39	0.4154	0.0141	52	0.3656	0.0130	106	0.2490
13	0.0138	24	0.3867	0.0133	45	0.3403	0.0122	111	0.2320
14	0.0141	35	0.4021	0.0136	48	0.3539	0.0125	101	0.2412
15	0.0147	39	0.4156	0.0142	49	0.3657	0.0130	110	0.2493
16	0.0142	35	0.4000	0.0136	50	0.3517	0.0125	113	0.2397
17	0.0146	38	0.4137	0.0140	50	0.3640	0.0129	108	0.2481
18	0.0151	41	0.4254	0.0145	51	0.3744	0.0133	72	0.2552
20	0.0148	40	0.4237	0.0143	53	0.3728	0.0131	92	0.2542
21	0.0156	43	0.4444	0.0150	53	0.3910	0.0137	115	0.2666
22	0.0149	36	0.4123	0.0143	48	0.3628	0.0131	105	0.2473
23	0.0146	40	0.4150	0.0141	54	0.3652	0.0129	105	0.2490
24	0.0151	39	0.4221	0.0145	54	0.3715	0.0133	110	0.2532
25	0.0149	38	0.4203	0.0143	53	0.3698	0.0124	111	0.2521
26	0.0140	39	0.3982	0.0135	54	0.3504	0.0124	114	0.2389
27	0.0146	38	0.4138	0.0141	52	0.3641	0.0129	107	0.2482
29	0.0147	36	0.4169	0.0141	50	0.3669	0.0130	99	0.2520
31	0.0153	34	0.4290	0.0147	50	0.3775	0.0135	115	0.2574
32	0.0144	35	0.4059	0.0138	48	0.3572	0.0127	117	0.2435
33	0.0149	43	0.4288	0.0144	53	0.3773	0.0132	104	0.2573
34	0.0143	39	0.4080	0.0138	51	0.3591	0.0126	102	0.2443
35	0.0148	40	0.4254	0.0143	53	0.3743	0.0131	110	0.2551
36	0.0146	34	0.4067	0.0140	44	0.3579	0.0128	116	0.2440
37	0.0147	40	0.4229	0.0142	52	0.3722	0.0130	113	0.2537
38	0.0151	38	0.4316	0.0145	52	0.3798	0.0133	96	0.2589
39	0.0146	38	0.4146	0.0141	49	0.3649	0.0129	100	0.2487
40	0.0144	39	0.4061	0.0138	50	0.3574	0.0127	103	0.2436
41	0.0146	37	0.4086	0.0140	51	0.3596	0.0129	107	0.2451
42	0.0153	35	0.4308	0.0147	49	0.3791	0.0135	86	0.2585
43	0.0151	36	0.4273	0.0145	50	0.3760	0.0133	99	0.2563
L	0.0148	38	0.4235	0.0142	49	0.3726	0.0131	116	0.2540
M	0.0145	38	0.4146	0.0140	51	0.3649	0.0128	122	0.2487
N	0.0146	38	0.4136	0.0140	47	0.3640	0.0128	80	0.2481
O	0.0149	44	0.4482	0.0143	58	0.3944	0.0131	115	0.2561
P	0.0147	37	0.4145	0.0141	50	0.3548	0.0129	117	0.2487
Q	0.0147	38	0.4190	0.0141	52	0.3687	0.0129	108	0.2514
R	0.0149	39	0.4217	0.0144	50	0.3711	0.0132	110	0.2530
S	0.0150	35	0.4182	0.0144	47	0.3680	0.0132	105	0.2509
T	0.0147	36	0.4160	0.0142	49	0.3661	0.0130	108	0.2496
U	0.0150	40	0.4242	0.0144	51	0.3733	0.0132	109	0.2544
V	0.0151	39	0.4220	0.0146	53	0.3714	0.0134	113	0.2533
W	0.0150	36	0.4211	0.0144	46	0.3706	0.0132	113	0.2526
X	0.0153	33	0.4229	0.0147	47	0.3721	0.0135	95	0.2537
Y	0.0151	36	0.4230	0.0145	47	0.3725	0.0133	82	0.2537
Z	0.0152	43	0.4274	0.0147	60	0.3761	0.0134	112	0.2564
Z1	0.0154	45	0.4375	0.0148	59	0.3850	0.0136	72	0.2625
Z2	0.0150	35	0.4210	0.0145	43	0.3705	0.0133	108	0.2525
Z3	0.0148	39	0.4112	0.0142	58	0.3618	0.0130	82	0.2466
Z4	0.0148	40	0.4204	0.0142	49	0.3700	0.0130	99	0.2522
Z5	0.0142	38	0.4012	0.0137	49	0.3530	0.0125	108	0.2387

1/ maximum flow rate required for subarea with application efficiencies of
- 75% for hand-move sprinkler
- 78% for side-roll sprinkler
- 85% for center-pivot sprinkler

2/ no pump cost included

3/ deep percolation loss

Table VII-13. Total annual system costs and descriptions of optimal irrigation systems for the consolidation plans

	PLAN A		PLAN B
	North District	South District	
Total cost ($)	5060213	3397038	7857636
Application system cost ($)	1184386	845965	2000730
Conveyance system cost ($)	3875827	2551073	5856906
Total cost ($/AC)	186.5	182.4	171.7
Applicatioan system cost ($/AC)	43.6	45.4	43.7
Conveyance system cost ($/AC)	142.9	137.0	128.0
Total inflow rate (CFS)	391.0	274.0	665.0
Overall system eff. (%)	75.0	75.0	75.0
Volume of D.P. (AF)	11071	7740	18811
Volume of S.R. (AF)	0	0	0
Total volume used (AF)	71747	50344	122091
Total volume used (AF/AC)	2.64	2.70	2.67

efficiency the volumes required are 391 cfs and 274 cfs for the North District and South District of consolidation plan A, and 665 cfs for the total area of consolidation plan B. The annual water volume required for the total area of the consolidation plan B (122,091 acre-feet) is far below the water actually diverted to the area from the Snake River in 1978 irrigation season (439,403 acre-feet).

Hand-move sprinkler systems are selected for the entire area in the optimal plans. The increased costs associated with side-roll and center pivot systems would be greater than the potential savings from reduced pumping costs and smaller distribution systems. From the results of a parametric programming analysis, more than $30 per acre-foot would have to be charged at the farm diversions to cause the application systems to be changed from hand-move to the other systems with higher efficiencies.

The annual cost of Plan B is about $13 per acre less than that of Plan A. However, the merits of one large pumping plant and the more complex pipe system of Plan B including operational characteristics would have to be studied more closely in comparison with the smaller systems of Plan A. The costs of the pressure pipe systems and associated sprinkler application systems are quite similar to the costs of a gravity distribution system consisting of gravity pipes supplying sprinkler systems at an overall efficiency of 75% (Tables VII-4 and VII-5).

CHAPTER VIII

SUMMARY AND DISCUSSION

A systems planning method was applied to evaluate a large irrigated agricultural area under existing conveyance system conditions. Also the same method was used to develop a scenario of conveyance and application systems combinations under specific conditions for obtaining optimum planning of rehabilitation and consolidation plans of the area. The methodology used in this study is based upon a methodology first developed by Busch (1974) and updated and revised by Galinato and others (1977) and Allen and others (1978). The methodology is composed of two main procedures, cost estimation and mathematical programming. The cost estimation procedures are computer routines used to determine the operating characteristics and costs of irrigation water distribution systems and pumping plant components, and to compute costs and application efficiencies of on-farm irrigation application systems. On-farm irrigation application systems evaluated by the computer routines include improved and unimproved gravity systems and hand-move, side-roll wheel-line and center-pivot sprinkler systems. The irrigation water application efficienies and costs are estimated for specific soil types, field lengths and slopes, and crops grown by modelling the hydraulics of these systems. The irrigation conveyance systems considered in the computer routines are lined and unlined canals and gravity and high pressure pipe systems. Water conveyance efficiencies and costs are estimated for all components. A routine also estimates the costs of wells, pumping plants, and electric power if water is to be pumped from underground or surface supplies or pressurized for sprinkler system operation.

The second procedure uses linear programming (LP) and mixed integer-linear programming (MIP) techniques to obtain the least cost combination of system components for a specified set of conditions. Lienar programming can be used to evaluate a systemn when only one type of distribution system is under consideration such as existing unlined canal systems or high pressure pipe systems since no alternative distribution systems are considered in either case. Developing rehabilitation plans when alternatives for both conveyance and application systems are considered requires that mixed integer-linear programming be used. In an MIP model constraints can specify that one and only one type of conveyance system is selected for each canal section, and the component cost functions can include both fixed and variable costs.

An MIP computer program package for solving small to medium sized problems was developed as part of this project (Yoo and Busch, 1980). However, it was found that a commercial APEX III MIP package maintained on the CDC CYBER computer of U.S. Department of the Interior Bureau of Reclamation in Denver was necessary to solve large MIP problems used in this study. The package was efficient and easy to use for the irrigation systems planning study.

Figure VIII-1 is a schematic diagram of the methodology for developing optimal system plans as used in this study. The discussion that follows is a summary of the optimal planning procedure as applied to a large irrigated area.

The area analyzed in this study consists of the Idaho Irrigation District (IID) and the Snake River Valley Irrigation District (SRVID) located near Idaho Falls, Idaho. Irrigation water diverted from the

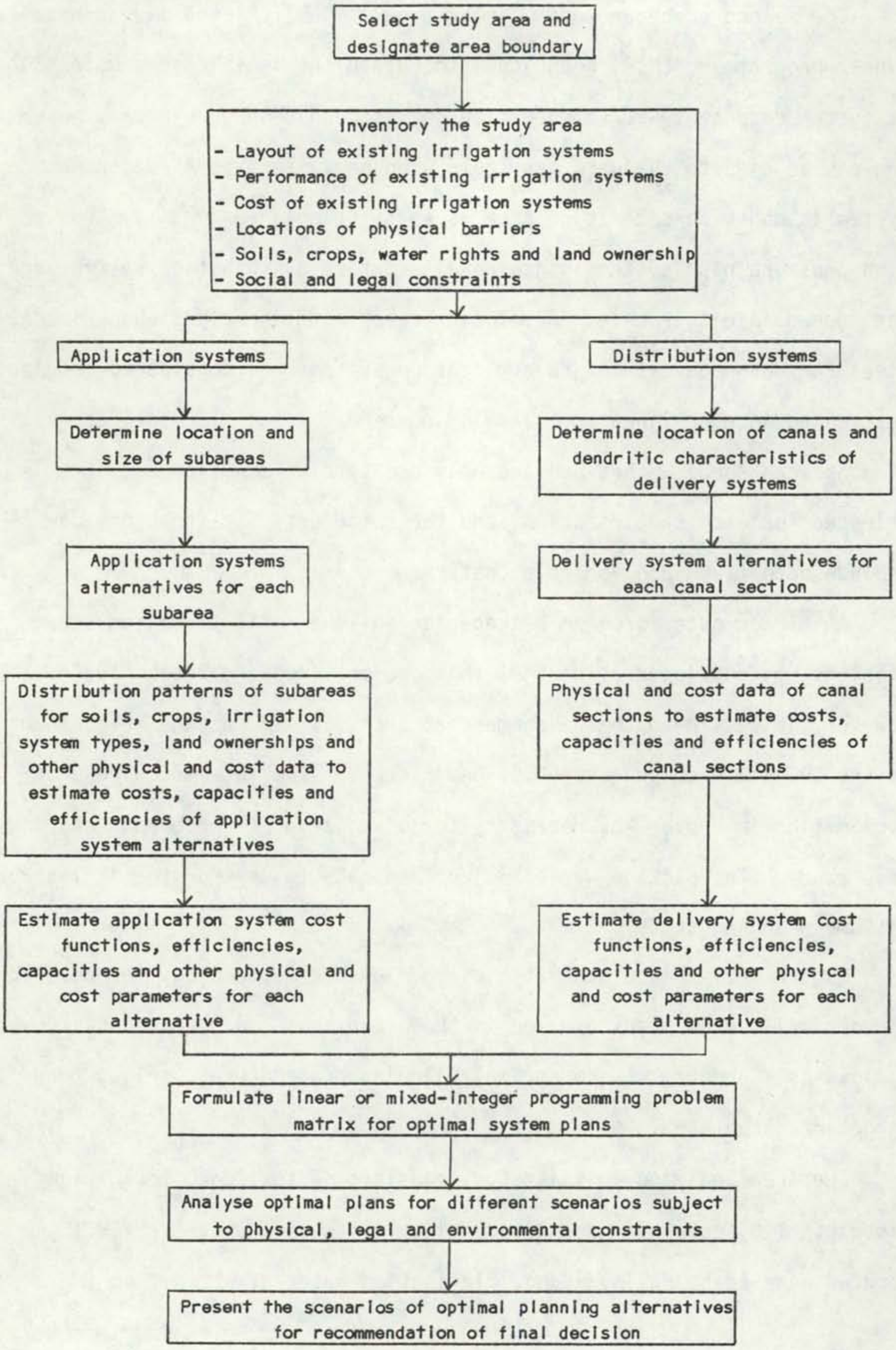


Figure VIII-1. Schematic diagram of the optimal planning procedure of an irrigated agricultural area.

Snake River is presently used to irrigate 46,000 acres of land in the study area of which 29,000 acres are in the IID and 17,000 acres are in the SRVID. The area also receives some excess water from upstream irrigation districts and natural streams. However, this excess water is not a dependable source of irrigation water, and the amount available is minor compared to the total diversion from the Snake River. The total amount of diverted water in the 1978 irrigation season was 440,000 acre-feet or 9.5 acre-feet per acre.

In August 1978, low level aerial infrared pictures were taken over the study area to obtain information on crops, irrigation systems, canals and other necessary physical data. These data were used to adequately inventory the area and to estimate the costs and efficiencies of irrigation water distribution and application system alternatives considered in this study. Soil series in the area and their locations were obtained from Soil Conservation Service soils maps. In addition, field experiments were conducted and irrigation system operating characteristics on each soil type in the study area.

Unit costs of the irrigation systems considered in this study were obtained from the State Agricultural Extension Service Bulletins of Idaho, Washington and Oregon, and irrigation equipment and construction companies of the area. Cost indices from U.S. Department of the Interior Bureau of Reclamation were used for estimating many system components to compensate for differences in construction or operating costs of systems in various geographical regions, or to increase the cost estimates due to inflationary trends.

Optimal system plans were first developed for the existing distribution systems in the IID and SRVID. Since no alternative conveyance systems were considered the problem could be solved by linear programming. The results showed that if there are no constraints on the availability or cost of water, the overall system efficiency would be about 30% with an application efficiency of about 40%. For this case, all unimproved gravity irrigation application systems are selected as the least cost system configuration. The efficiencies are higher than those of the present irrigation systems and practices in the area. One of the reasons is that system operation losses were not considered when computing efficiencies.

Restricting the water supply and charging for water required some changes in the application systems. The maximum application efficiencies of 78% were obtained by system combinations of side-roll sprinkler irrigation systems supplied by the existing unlined canal systems. A much lower overall system efficiency of 45% was due to the high seepage losses occurred in the existing delivery systems. Therefore, without improvement of the delivery systems for overall system efficiency could not be increased further.

By charging for water diverted at the system headgate the optimal plans developed showed that the area should improve system efficiencies to minimize costs. With a $15 per acre-foot water cost, the plans showed application system efficiency with overall system efficiency of 75%. It was also found that a water cost between $6 and $9 per acre-foot was the most effective water cost which caused the greatest increase in efficiency per unit of water cost, and there was a minimal effect on optimal system plans with charges over $15 per acre-foot. To achieve the highest attainable efficiency would require more than $30 per acre-foot to be charged, an unrealistic charge for the agricultural practices of the area.

Rehabilitation and consolidation plans for the irrigation districts in the study area were developed to determine the effects of various factors on overall system efficiency and cost. The initial plans developed using the existing canal systems showed that the low conveyance efficiency resulted in a low overall system efficiency. Mixed integer-linear programming was necessary to obtain the rehabilitation plans since it was required to consider several delivery system alternatives. Three parameters were tested to obtain scenarios of optimal rehabilitation plans. They were: 1) overall system efficiency, 2) water cost charged at the headgate, and 3) water cost charged at subarea diversion points. Each parameter was allowed to vary over a certain range to determine the effects on the total annual system cost and system efficiency, and to obtain the optimal combinations of distribution and application system combinations.

The minimum overall system efficiency obtained with the rehabilitation plan was 31% with no restrictions on water supply or water cost. The optimal systems consisted of unlined canal systems supplying unimproved gravity irrigation application systems. This efficiency is a bit higher than the one obtained under present conveyance system conditions and is due to the changes of canal sizes as the flow rate requirements are decreased. By reducing the available inflow rate to increase overall efficiency, the application systems of each subarea generally change first to more efficient systems followed by changes in distribution system components. The maximum attainable overall system efficiency was 77% and the system configuration consisted of side-roll sprinkler applicaton systems supplied by gravity pipe systems.

Charging for water diverted at the headgate also forces the optimal system plans to consist of more efficient distribution and application systems. The most effective water cost which increased the system efficiency the greatest amount per unit of water cost was between $5 and $10 per acre-foot. With a $30 per acre-foot water cost the optimal overall efficiency was 62% which is 15% lower than the maximum attainable efficiency. Also, the $30 per acre-foot water cost is not realistic considering the agricultural practices in the area.

Another way of assessing water cost is to charge for the amount of water delivered at farm diversion points from canals. In this way, there is no charge for any water lost in conveyance systems. With this method of charge the optimal system plans would result in a system with an overall efficiency of 65% at a $20 per acre-foot water cost. The water cost was most effective in increasing system efficiency between $8 and $12 per acre-foot. In the mixed integer-linear programming formulation the total conveyance system cost charged thus assuring that the total charge for water delivered would be spent on the conveyance system. This constraint caused the actual system costs (distribution and application system costs only) to be greater for farm diversion charges than for either efficiency constraints or water charges at the headgate.

Two types of consolidation plans were considered for the study area. One plan was to install two river pump stations to supply irrigation water to two separate areas. The second plan was to install one pump station which would supply the entire study area. Since only a high pressure pipe system was considered there were no conveyance losses and the overall system efficiency was always same as the application system efficiency. For both plans, an overall system efficiency of 75% could be attained with minimum system cost by hand-move sprinkler irrigation systems in all subareas. With this efficiency the area required a maximum flow rate of 665 cfs and an annual diversion of 122,000 acre-feet. This figure is far below the annual volume of water diverted to the area (440,000 acre-feet). With such a system, about 7.0 acre-feet per acre of water could be saved annually and left in the Snake River for other uses. The second plan costs about $600,000 per year or $13 per acre per year less than the first plan but would involve more complicated operational practices due to the larger size of the system.

A great deal of information can be obtained from the results of analysis of existing systems and the rehabilitation and consolidation plans. The results of the existing systems analysis show that radical improvement of the application efficiency results in only a moderate increase in overall system efficiency if there is no improvement in distribution system efficiency. Optimal system configurations obtained in the rehabilitation plans required that nearly all application systems be improved along with those sections in the existing distribution systems with high seepage losses to achieve moderate overall system efficiencies. To attain maximum overall system efficiencies required extensive changes in the distribution systems with greatly increased costs. An increase in overall system efficiency for a gravity supply system from 70% to 77% resulted in a cost increase from $134 per acre to $207 per acre over the entire study area with a resulting water savings of less than 0.3 acre-feet per acre. Consolidating the existing irrigation districts under a high pressure supply system would be a less costly venture to attain an overall efficiency of 75% as the resulting cost would be $171 per acre.

The procedures developed for this project made it possible to generate numerous optimal system plans subject to various constraints. By thoroughly inventorying the study area and storing pertinent data as digital data in a computer allowed the large irrigated area to be carefully analyzed. Detailed information for subareas within the study area could be obtained for different configurations of subareas by merely defining their boundaries. This versatility combined with the versatility of the linear programming and mixed integer-linear programming models was very beneficial in developing the various rehabilitation and consolidation plans. The summary of systems evaluation with the existing unlined conveyance system is shown in Table VII-1. Table VII-2 illustrates the summarized scenarios of optimal rehabilitation plans of the study area using three gravity conveyance systems alternatives. Consolidation plans with high pressure pipe delivery system are shown in Table VII-13 in Chapter VII.

The plans developed would allow planners, irrigators and other interested parties to evaluate the effects of various proposed changes to the studied irrigation districts. Decisions could then be made based upon the plans developed considering the many factors involved. For example, if more efficient irrigation systems are used, the value of water remaining in the river for downstream uses resulting from reduced diversion rates may justify the cost of system rehabilitation and consolidation. If necessary additional plans could be generated from the same data base considering different constraints with minimum effort. Results from the optimal plans would also be suitable as input data for more detailed economic studies of various benefits and trade-offs.

Table VIII-1 Summary of systems evaluation with the existing unlined conveyance systems of the study area - annual cost and water use.

		Idaho Irrigation District						Snake River Valley Irrigation District					
		Total System Cost ($/AC)	Application System Cost ($/AC)	Conveyance System Cost ($/AC)	Inflow Rate Required (CFS)	Total Volume Diverted (AF/AC)	Overall System Efficiency (%)	Total System Cost ($/AC)	Application System Cost ($/AC)	Conveyance System Cost ($/AC)	Inflow Rate Required (CFS)	Total Volume Diverted (AF/AC)	Overall System Efficiency (%)
Overall sys. Efficiency (%)	27.8 (29.0)*	68.6	65.6	3.0	1,123	7.2	27.8	75.8	72.8	2.9	665.6	7.1	29.0
	30.0	71.3	68.5	2.8	1,043	6.7	30.0	76.4	73.6	2.8	643.3	6.9	30.0
	35.0	78.6	76.2	2.4	894	5.7	35.0	83.1	80.7	2.4	551.4	5.9	35.0
	40.0	85.2	83.1	2.1	782	5.0	40.0	89.0	86.9	2.1	482.5	5.2	40.0
	45.0	97.0	95.2	1.8	696	4.5	45.0	105.6	103.7	1.9	430.2	4.6	45.0
	45.5	102.0	100.2	1.8	688	4.4	45.5						
Water charge at head gate ($/AF)	0.0	68.6	65.6	3.0	1,123	7.2	27.8	75.8	72.9	2.9	665.6	7.1	29.0
	3.0	69.0	66.1	2.9	1,106	7.1	28.3	76.3	73.5	2.8	644.3	6.9	30.0
	6.0	76.3	73.8	2.5	938	6.0	33.3	79.4	76.8	2.6	597.7	6.4	32.3
	9.0	85.8	83.7	2.8	773	5.0	40.4	90.8	88.8	2.0	464.6	5.0	41.5
	12.0	88.5	86.5	2.0	741	4.8	42.2	95.2	93.2	2.0	444.1	4.7	43.4
	15.0	91.8	89.9	1.9	707	4.5	44.3	95.4	93.5	1.9	442.2	4.7	43.6

*Numbers in parentheses are for Snake Rivery Valley Irrigation District.

Table VIII-2. Summary of optimal rehabilitation plans using three gravity conveyance systems (unlined, lined, and gravity pipe) of the study area - annual cost and water use.

		Idaho Irrigation District						Snake River Valley Irrigation District					
		Total System Cost ($/AC)	Application System Cost ($/AC)	Conveyance System Cost ($/AC)	Inflow Rate Required (CFS)	Total Volume Diverted (AF/AC)	Overall System Efficiency (%)	Total System Cost ($/AC)	Application System Cost ($/AC)	Conveyance System Cost ($/AC)	Inflow Rate Required (CFS)	Total Volume Diverted (AF/AC)	Overall System Efficiency (%)
Overall sys. efficiency (%)	31.7 (30.5)*	92.0	63.0	29.0	989	6.35	31.7	81.6	78.0	8.6	632	6.75	30.5
	42.0	96.5	71.3	24.3	789	5.07	40.0	87.1	78.5	8.6	480	5.13	40.0
	45.0	100.0	75.7	24.3	701	4.50	45.0	90.6	82.0	8.6	426	4.56	45.5
	50.0	103.2	79.6	24.3	631	4.25	50.0	93.8	85.2	8.6	384	4.10	50.0
	55.0	106.5	83.0	24.3	574	3.68	55.0	96.7	88.1	8.6	349	3.73	55.5
	60.0	109.6	86.6	24.3	526	3.38	60.0	101.4	90.0	11.4	320	3.42	60.0
	70.0	140.0	93.5	46.5	451	2.90	70.0	124.6	97.6	27.0	274	2.93	70.0
	76.6 (78.6)*	210.8	102.4	108.4	412	2.65	76.6	201.6	118.5	83.1	245	2.62	78.6
Water charge at head gate ($/AF)	0.0	92.0	63.0	29.0	989	6.35	31.7	81.5	73.0	8.5	632	6.75	30.5
	5.0	100.9	75.4	25.5	813	5.22	38.5	85.1	76.5	8.6	514	5.50	37.5
	8.0	102.1	78.5	23.5	655	4.21	47.8	96.1	87.5	8.6	356	3.80	54.3
	10.0	107.1	83.6	23.5	565	3.63	55.4	97.4	88.8	8.6	342	3.66	56.4
	15.0	110.9	87.4	23.5	508	3.26	61.6	99.8	91.2	8.6	323	3.45	59.8
	20.0	111.2	87.7	23.5	506	3.25	61.8	99.8	91.2	8.6	323	3.45	59.8
	30.0	111.7	88.2	23.5	503	3.23	62.2	103.1	91.3	11.8	308	3.30	62.6
Water charge at farm diversion ($/AF)	0.0	92.0	63.0	29.0	989	6.35	31.7	81.6	73.0	8.6	632	6.75	30.5
	4.0	92.0	63.0	29.0	989	6.35	31.7	112.1	74.9	18.6	535	5.72	36.1
	6.0	94.2	63.1	31.1	978	6.28	32.0	127.7	77.2	25.3	474	5.07	40.7
	8.0	104.7	63.9	40.8	954	6.13	32.8	142.1	79.5	31.3	436	4.66	44.3
	10.0	113.0	71.7	41.3	767	4.92	40.8	146.3	89.0	28.7	330	3.52	58.5
	12.0	119.6	82.4	37.2	574	3.69	54.5	157.2	90.4	33.4	318	3.40	60.6
	16.0	132.1	89.1	43.0	507	3.25	61.8	178.2	91.6	43.3	285	3.05	67.6
	20.0	142.4	88.6	53.8	493	3.17	63.4	200.6	91.6	54.8	278	2.98	69.3

*Numbers in parenthesis are for Snake River Valley Irrigation District.

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APPENDIX A

DESCRIPTIONS OF THE SOIL SERIES IN THE STUDY AREA

1. Ammon
2. Bannock
3. Bock
4. Hayeston
5. Heiseton
6. Paesl
7. Sasser
8. Stan
9. Wapello
10. Wolverine

AMMON SERIES[1/]

The Ammon series consists of well drained, nearly level to gently sloping soils that are more than 60 inches deep. These soils formed under bunchgrass and big sagebrush on alluvial fans that consist of outwash from loessal uplands. They are associated with Newdale and Paesl soils.

Elevations range from 4400 to 4800 feet. The annual precipitation is about 11 to 13 inches. The mean annual air temperature is 43° to 45°F, and the frost-free period is 110 to 126 days.

In a representative profile the surface layer is grayish-brown silt loam 10 inches thick. The underlying layers are light brown-gray silt loam that extends to a depth of more than 60 inches. The soils are limy throughout. The permeability is 0.63 to 2.0 inches per hour. The available water holding capacity is 0.19 to 0.21 inches per inch over this soil layer.

Ammon soils are used mainly for irrigated crops.

1/ These descriptions were obtained from "Soil Survey of Bingham Area, Idaho" by Soil Conservation Service, USDA and the Agricultural Experiment Station, University of Idhao, Moscow, 1973.

BANNOCK SERIES

The Bannock series consists of well drained, nearly level to moderately sloping soils that are 20 to 40 inches deep to very gravelly sands. These soils formed under big sagebrush and bunchgrass in alluvium on high river terraces. These soils are associated with Bock, Polatis, Hayeston, and Packham soils.

Elevations range from 4200 to 4600 feet. The annual precipitation is 11 to 13 inches. The mean annual air temperature is 42° to 45°F, and the frost-free perod is 110 to 126 days.

In a representative profile the surface layer is grayish-brown loam that is slightly gravelly and 6 inches thick. The subsoil is grayish-brown and light brownish-gray loam that is slightly gravelly and extends to a depth of 16 inches. The substratum, in the upper part, is pale brown and light brownish-gray, strongly calcareous stratified loam, gravelly loam, and very gravelly sandy loam. This is underlain by very gravelly coarse sand at a depth of 36 inches. The profile is limy throughout. The permeability is 0.63 to 2.0 inches per hour. The available water holding capacity is 0.14 to 0.16 inches per inch of top soil and 0.04 to 0.06 inches per inch for subsoil layer.

Bannock soils are used for irrigated hay, pasture, small grains, beets, and potatoes.

BOCK SERIES

The Bock series consists of deep, well drained, loamy soils more than 60 inches deep that formed on nearly level to very gently sloping high terraces. The vegetation is mainly big sagebrush and bunchgrass. These soils are associated with Bannock, Packham, Hayeston, and Stan Soils.

Elevations range from 4200 to 4500 feet. The annual precipitaton is 11 to 13 inches. The mean annual air temperature is 42° to 45°F, and the frost-free period is 110 to 126 days.

In a representative profile the surface layer is grayish brown loam about 10 inches thick. The subsoil is brown loam that extends to a depth of 15 inches. The substratum is light brownish-gray and light-gray, stratified alluvium that is mainly loam and fine sandy loam to a depth of 47 inches. Below 47 inches is very gravelly coarse sand. These soils have a limy substratum.

The permeability is 0.63 to 2.0 inches per hour. Available water holding capacity is 0.16 to 0.18 inches per inch of top soil depth and very low (0.03 to 0.06 inches per inch of soil) for subsoil (0.03 to 0.05 inches per inch).

Bock soils are used mainly fo irrigated hay, small grains, pasture, potatoes, and sugarbeets.

HAYESTON SERIES

The Hayeston series consists of well drained, nearly level to very gently sloping soils that are less than 40 inche sthick over sand and gravel. These soils formed under big sagebrush and bunchgrass in alluvium. They are on river terraces. Hayeston soils are associated with soils of the Heiseton, Bannock, Blackfoot, and Wardboro series.

Elevations range from 4200 to 4600 feet. The annual precipitation is 11 to 13 inches. The mean annual air temperature is 42° to 45°F, and the frost-free period is 110 to 126 days.

In a representative profile the surface layer is grayish-brown sandy loam that contains a little gravel and is 9 inches thick. The underlying material is light brownish-gray, calcareous sandy loam that extends to a depth of 30 inches. Below this is light brownish-gray very gravelly coarse sand. These soils are limy throughout.

The permeability is 2.0 to 6.3 inches per hour. The available water holding capacity is 0.11 to 0.13 inches per inch of top soil and 0.03 to 0.05 inches per inch of subsoil layer.

Hayeston soils are used primarily for irrigated hay, pasture, small grains, and potatoes.

PAESL SERIES

The Paesl series consists of well drained, nearly level soils overlying sand and gravel at depths ranging from 20 to 40 inches. These soils formed in mixed alluvium. They are on flood plains and terraces. Nearly all the areas are cultivated. In uncultivated areas the vegetation is big sagebrush, three-tip sagebrush, and bunchgrass. These soils are associated with Ammon, Stan, and Wapello soils.

Elevations range from 4600 to 4800 feet. The mean annual precipitation ranges from 11 to 13 inches. The mean annual air temperature ranges from 42° to 45°F, and the frost-free season is 110 to 130 days.

In a representative profile the surface layer is grayish-brown silt loam 9 inches thick. The subsoil is brown and light-brown silt loam. The substratum is pinkish-gray loam to a depth of 27 inches. It is underlain by light brownish-gray very gravelly loamy coarse sand that extends to a depth of more than 50 inches. The soil is limy throughout, but is more limy in the lower part of the subsoil and substratum than in the surface layer.

The permeability is 0.63 yo 2.0 inches per hour. The available water holding capacity is 0.19 to 0.21 inches per inch of top soil and 0.04 to 0.06 inches per inch of subsoil.

Paesl soils are used for irrigated potatoes, sugarbeets, small grains, alfalfa, and pasture.

SASSER SERIES

The Sasser series consists of well drained, nearly level to gently sloping soils that are about 38 inches deep to sand and gravel. These soils formed under grasses and shrubs in fine sandy alluvium. They are on river terraces. Sasser soils are associated with soils of the Bannock, Bock, and Stan series.

Elevations range from 4200 to 4600 feet. The mean annual precipitation is 11 to 13 inches. The mean annual air temperature is 39° to 45°F, and the frost-free period is 110 to 130 days.

In a representative profile the surface layer is grayish-brown sandy loam 6 inches thick. The subsoil is light brownish-gray and pale-brown fine sandy loam 8 inches thick. The substratum is light-gray find sandy loam that contains as much as 15 percent gravel. It extends to a depth of 38 inches. It is underlain by sand and waterworn gravel. These soils are limy throughout but have lime accumulations in the substratum.

The permeability is 2.0 to 6.3 inches per hour. The available water holding capacity is 0.11 to 0.13 inches per inch of top soil and 0.04 to 0.06 inches per inch of subsoil layer.

Sasser soils are used mainly for irrigated hay, pasture, and small grain.

STAN SERIES

The Stan series consists of well drained soils that formed in sandy alluvium on river terraces. The slope is 0-4 percent. These soils are fine sandy loam in texture. The vegetation is mainly big sagebrush and bunchgrass. Stan soils are associated with soils of the Sasser, Bannock, and Paesl series.

Elevations range from 4200 to 5500 feet. The mean annual precipitation is 11 to 13 inches. The mean annual air temperature is 39° to 45°F, and the frost-free period is 110 to 125 days.

In a representative profile, the surface layer is grayish-brown and brown fine sandy loam 16 inches thick. The subsoil is pale-brown fine sandy loam 13 inches thick. The substratum is light gray fine sandy loam to a depth of 50 inches. It is underlain by light-gray, very gravelly light-sandy loam. These soils are limy throughout but are mostly limy in the substratum.

The permeability is 2.0 to 6.3 inches per hour. The available water holding capacity is 0.13 to 0.15 inches per inch of top soil and low in subsoil layer (0.07 to 0.09 inches per inch).

Stan soils are used to irrigated hay, pasture, small grains, and potatoes.

WAPELLO SERIES

The Wapello series consists of well drained, nearly level and very gently sloping soils that are 20 to 30 inches deep over silt loam or loam. These soils are fine sandy loam in texture. They formed on stream terraces under big sagebrush and bunchgrass. Wapello soils are associated with Wolverine, Preston, and Firth soils.

Elevations range from 4200 to 4600 feet. The annual precipitation is 11 to 13 inches. The mean annual air temperature is 42° to 45°F, and the frost-free season is 110 to 125 days.

In a representative profile the surface layer is grayish-brown fine sandy loam 8 inches thick. The underlying material is light brownish-gray and light-gray fine sandy loam. It is underlain at a depth of 29 inches by stratified layers of light-gray silt loam and loamy alluvium. These soils are limy throughout.

This soil has high permeability for top soil (over 20 inches per hour) and decreased to 2.0 to 6.3 inches per hour of subsoil. Top soil has very low available water holding capacity (0.02 to 0.04 inches per inch) and moderate in subsoil (2.0 to 6.3 inches per inch).

Wapello soils are used mainly for irrigated hay, small grain, and for pasture.

WOLVERINE SERIES

The Wolverine series consists of excessively drained, nearly level to moderately steep, sandy soils that formed in colian sands. These soils are on terraces. Roots can penetrate to a depth of 60 inches or more. The vegetation consists mainly of bunchgrass and big sagebrush. Wolverine soils are associated with Weeding, Wapello, Firth, and Presto soils.

Elevations range from 4400 to 4600 feet. The annual precipitation is 11 to 13 inches. The mean annual air temperature is 40° to 45°F, and the frost-free period is 110 to 126 days.

In a representative profile, the soil is limy, light brownish-gray sand to a depth of 60 inches or more.

This soil has very high permeability (over 20 inches per hour) and low available water holding capacity (0.06 to 0.08 inches per inch of soil).

Wolverine soils are used for range.

APPENDIX B

SEASONAL, MONTHLY AND MAXIMUM DAILY ET REQUIREMENT OF SUBAREAS AND DISTRIBUTION PATTERNS FOR CROPS, APPLICATION SYSTEMS, SOILS AND LAND OWNERSHIPS

B-1. For existing systems analysis

B-2. For rehabilitation plans

B-3. For consolidation plans

Table B-1. For existing systems analysis

SUBAREA NO.	ET max IN/DAY	Seasonal ET		Monthly ET Distribution (%)1/					
		INCHES	AF/ACRE	April	May	June	July	Aug.	Sept.
1	0.257	19.67	1.63	1.07	5.43	23.27	37.40	25.74	7.05
4	0.265	20.62	1.71	2.38	5.68	23.19	39.41	23.87	5.44
5	0.253	19.46	1.62	1.52	5.86	24.26	37.91	24.33	6.09
6	0.262	20.40	1.70	2.28	5.72	23.36	39.26	23.90	5.45
7	0.272	20.78	1.73	2.36	5.76	23.47	39.11	23.64	5.63
8	0.268	20.57	1.71	2.10	5.78	23.70	38.59	23.84	5.97
9	0.270	20.76	1.73	1.65	5.22	22.26	38.36	25.64	6.85
10	0.267	20.60	1.71	1.87	5.40	22.68	38.69	24.99	6.32
11	0.267	21.15	1.76	1.90	4.55	20.04	39.87	27.09	6.51
12	0.260	20.16	1.68	2.15	5.80	23.69	38.99	23.83	5.51
13	0.264	20.55	1.71	1.93	5.22	22.09	38.91	25.41	6.13
14	0.257	19.98	1.66	2.62	6.30	24.91	39.38	22.19	4.57
15	0.257	20.00	1.66	2.93	6.55	25.50	39.66	21.27	4.05
17	0.267	21.15	1.76	1.90	4.55	20.04	39.87	27.09	6.51
18	0.262	20.56	1.71	2.38	5.49	22.60	39.78	24.38	5.35
19	0.265	20.99	1.74	2.38	5.07	21.31	40.22	25.40	5.59
20	0.266	20.89	1.74	2.12	5.06	21.45	39.68	25.65	6.01
21	0.271	20.75	1.72	1.84	5.55	23.18	38.24	24.61	6.56
22	0.266	20.76	1.73	1.96	5.13	21.79	39.26	25.61	6.23
25	0.242	18.73	1.56	1.48	6.06	24.88	38.05	24.00	5.51
26	0.274	20.94	1.74	1.72	5.36	22.66	38.17	25.17	6.89
27	0.269	20.88	1.74	2.25	5.49	22.70	39.25	24.43	5.86
28	0.270	20.94	1.74	1.23	4.53	20.43	38.43	27.72	7.63
29	0.256	20.30	1.69	3.48	6.38	24.59	41.07	21.24	3.22
30	0.259	20.19	1.68	2.23	5.75	23.49	39.24	23.89	5.37
31	0.257	19.90	1.65	2.19	6.07	24.51	38.80	23.13	5.26
32	0.255	19.42	1.61	1.38	5.98	24.75	37.38	24.12	6.35
C	0.260	20.64	1.72	2.33	5.59	22.96	39.43	24.13	5.53
D	0.269	20.60	1.71	1.49	5.31	22.64	37.94	25.55	7.04
F	0.263	20.51	1.70	2.17	5.54	22.90	39.24	24.42	5.70
G	0.272	20.92	1.74	1.66	5.12	21.97	38.44	25.85	6.94
H	0.275	20.71	1.72	1.33	5.53	23.45	37.07	25.08	7.50
I	0.261	20.14	1.67	1.73	5.57	23.26	38.39	24.77	6.24
J	0.270	20.47	1.70	1.40	5.53	23.38	37.44	25.07	7.15
K	0.268	20.75	1.72	2.25	5.60	23.03	39.16	24.16	5.77
L	0.275	21.18	1.76	1.61	4.98	21.58	38.40	26.20	7.20
M	0.259	20.44	1.70	3.34	6.34	24.56	40.71	21.43	3.60
N	0.266	20.56	1.71	2.45	5.97	24.04	39.13	23.06	5.31
O	0.270	20.57	1.71	1.87	5.45	22.83	38.50	24.86	6.47
P	0.276	20.64	1.72	1.89	6.28	25.40	37.16	22.69	6.55
Q	0.258	20.09	1.67	2.39	6.00	24.15	39.55	23.14	5.03
R	0.265	20.42	1.70	2.45	5.65	23.02	39.79	23.94	5.12

1/ % of Seasonal ET

Table B-1. (continued)

SERVICE AREA	Crop (%)2/				Application System (%)2/				
	POT	GRA	ALF	PAS	BOR	FUR	HMS	SRS	CPS
1	18.38	20.41	25.83	35.38	75.83	9.44	14.74	0	0
4	29.41	47.29	16.93	6.37	63.92	25.63	10.45	0	0
5	12.49	28.60	22.17	36.74	75.69	12.49	11.82	0	0
6	27.02	44.82	16.39	11.77	51.82	5.89	26.99	15.31	0
7	25.84	47.28	25.45	2.43	34.07	4.85	42.46	18.62	0
8	21.14	41.58	28.88	8.40	44.06	1.30	37.05	6.78	10.82
9	32.54	32.96	26.06	8.44	45.61	4.41	27.19	5.87	16.92
10	32.04	39.55	23.16	5.25	49.57	22.68	27.77	0	0
11	41.67	40.23	9.84	8.27	42.89	15.39	12.79	28.93	0
12	22.66	41.82	17.79	17.73	64.12	15.59	20.30	0	0
13	37.46	38.30	12.36	11.88	42.88	11.58	37.17	8.37	0
14	14.23	50.43	17.38	17.96	85.77	14.23	0	0	0
15	10.68	56.41	17.85	15.06	65.26	3.54	26.17	5.04	0
17	65.67	33.19	0	1.14	1.14	6.73	3.00	89.13	0
18	36.69	47.08	8.35	8.48	31.48	6.27	62.27	0	0
19	50.09	48.12	1.51	0.28	6.76	4.70	70.83	17.71	0
20	46.06	42.62	7.43	3.89	17.73	6.01	53.22	23.04	0
21	24.13	36.75	32.71	6.41	29.72	2.70	34.96	32.61	0
22	28.64	45.51	15.34	10.51	43.56	11.16	40.22	5.06	0
25	7.86	26.73	12.41	53.00	93.39	6.61	0	0	0
26	28.50	34.78	33.43	3.29	71.51	28.50	0	0	0
27	33.27	45.23	19.86	1.64	62.22	28.53	4.51	4.74	0
28	48.97	24.86	17.02	9.15	45.07	19.95	22.60	0	12.38
29	25.00	68.03	1.00	5.98	27.18	3.60	69.23	0	0
30	25.57	43.39	14.18	16.86	74.43	15.36	2.40	7.81	0
31	14.86	42.08	20.51	22.55	63.87	0.74	29.00	6.40	0
32	6.21	25.86	30.03	37.90	93.80	6.21	0	0	0
C	31.53	46.35	15.62	6.50	49.93	10.40	30.55	9.13	0
D	27.13	29.67	30.72	12.48	58.89	9.82	31.30	0	0
F	30.96	42.97	15.46	10.62	49.36	9.03	29.12	12.49	0
G	35.74	33.44	25.67	5.15	41.15	0	30.38	28.48	0
H	16.22	26.53	47.47	9.77	70.03	4.88	20.99	4.11	0
I	23.44	33.64	21.96	20.96	56.22	3.31	29.32	11.16	0
J	18.33	27.74	38.89	15.04	79.04	8.73	12.23	0	0
K	29.81	45.07	20.90	4.22	22.91	3.73	61.69	11.66	0
L	39.32	32.91	27.77	0	7.93	0	92.09	0	0
M	23.74	65.79	7.01	3.46	22.48	0	43.79	33.74	0
N	20.77	48.64	24.27	6.32	44.37	3.10	5.57	46.96	0
O	28.15	37.02	27.90	6.93	43.77	9.09	36.47	0	10.68
P	0	37.54	56.53	5.92	100.00	0	0	0	0
Q	20.40	46.13	15.91	17.56	59.26	4.06	26.82	0	9.86
R	32.32	48.31	8.64	10.73	30.12	4.55	32.51	32.83	0

Crops

POT--potatoes
GRA--grain
ALF--alfalfa-hay
PAS--pasture land

Irrigation Systems

BOR--border
FUR--furrow
HMS--hand-move sprinkler
SRS--side-roll sprinkler
CPS--center-pivot sprinkler

2/ % of irrigated subarea

Table B-1. (continued)

SERVICE AREA	Soil Series (%)3/ Am	Ba	Bo	He	Pc	Sa	Wo
1	0	43.20	5.23	6.71	35.47	9.39	0
4	0	92.30	0	1.16	0	2.49	0
5	0	90.25	0	0	3.77	1.37	2.56
6	27.97	0	34.96	0	11.98	25.36	0
7	38.28	0	18.60	0	41.04	1.77	0.31
8	61.74	0	0	0	5.70	25.56	7.00
9	6.26	0	0	0	0	36.37	57.37
10	0	96.27	0	0.09	0	3.73	0
11	0	85.72	12.57	0	0	1.71	0
12	0	73.02	0	23.97	0.51	2.49	0
13	0	59.42	11.09	0	2.58	23.12	3.79
14	0	0	0	100.00	0	0	0
15	0	4.45	0	95.55	0	0	0
17	0	46.95	44.92	8.14	0	0	0
18	0	69.61	30.39	0	0	0	0
19	0	78.94	21.06	0	0	0	0
20	0	80.99	18.44	0	0	0.57	0
21	0	0	0	100.00	0	0	0
22	0	9.11	16.55	74.34	0	0	0
25	0	17.87	0	0	81.24	0	0.89
26	35.29	0	0	0	64.71	0	0
27	78.73	0	19.22	0	2.05	0	0
28	98.05	0	1.95	0	0	0	0
29	0	42.29	0	0	57.71	0	0
30	5.30	3.14	21.90	0	38.01	26.88	4.60
31	0	1.47	8.76	0	9.16	67.42	13.19
32	0	41.79	2.57	0	36.61	6.70	12.33
C	0	27.28	36.90	35.82	0	0	0
D	0	8.18	47.82	43.30	0	0.30	0.39
F	0	67.94	15.66	0	0	11.56	4.83
G	0	0	0	0	0	56.89	43.02
H	3.66	0	0	0	45.17	29.24	21.94
I	0	20.37	10.22	0	0.96	53.94	14.51
J	0	0	0	0	0	51.42	48.58
K	0	61.20	38.80	0	0	0	0
L	0	16.05	83.95	0	0	0	0
M	0	90.01	9.99	0	0	0	0
N	0	79.09	11.03	0	0	8.18	1.70
O	0	18.68	48.40	0	0	24.81	8.11
P	0	48.68	48.39	0	0	2.93	0
Q	0	35.07	0	0	0	30.57	34.36
R	0	53.82	22.55	23.63	0	0	0

3/ % of total subarea

Table B-1. (continued)

Service area	# of Land Ownership (range in acres) 30	31-50	51-70	71-100	101-140	141-210	211-280	281
1	0	6	1	9	4	1	0	0
4	2	3	1	6	3	2	1	0
5	0	2	1	20	0	3	0	0
6	3	8	1	13	4	2	1	0
7	6	2	3	3	3	3	5	1
8	0	4	0	2	1	6	3	1
9	0	0	0	1	1	4	4	1
10	0	1	0	7	1	3	1	0
11	0	3	0	3	1	0	0	0
12	0	0	0	13	2	1	0	0
13	0	5	0	8	2	4	0	0
14	2	4	0	0	1	0	0	0
15	0	0	0	9	1	1	1	0
17	0	2	1	3	1	0	0	0
18	0	1	0	3	0	0	1	0
19	2	0	2	7	3	0	0	0
20	0	3	1	1	2	0	0	0
21	0	0	0	2	1	0	1	1
22	0	1	3	10	6	2	0	0
25	0	1	0	2	1	0	0	0
26	0	0	1	5	0	0	0	0
27	0	1	0	6	2	3	0	0
28	0	1	0	0	4	2	1	0
29	3	4	0	0	1	0	0	0
30	0	8	1	7	0	1	1	2
31	1	7	3	4	3	3	1	0
32	0	5	1	10	3	2	0	0
C	0	1	6	13	3	3	1	0
D	1	9	2	5	3	0	0	0
F	0	8	0	18	1	2	0	0
G	1	3	0	5	2	3	0	0
H	0	2	0	10	4	7	0	0
I	3	9	1	5	2	0	1	1
J	0	1	0	4	0	0	0	1
K	0	1	1	2	1	1	0	0
L	0	0	0	2	0	0	1	1
M	0	4	0	6	0	0	0	0
N	1	3	1	5	0	0	0	0
O	0	7	0	8	3	1	2	0
P	0	2	0	0	2	0	0	0
Q	1	6	2	2	1	3	2	0
R	0	6	0	9	2	3	1	0

Table B-2. For rehabilitation plan

SUBAREA NO.	ET max IN/DAY	Seasonal ET		Monthly ET Distribution (%)1/					
		INCHES	AF/ACRE	April	May	June	July	Aug.	Sept.
1	0.257	19.67	1.63	1.07	5.43	23.27	37.40	25.74	7.05
4	0.265	20.62	1.71	2.38	5.68	23.19	39.41	23.87	5.44
5	0.253	19.46	1.62	1.52	5.86	24.26	37.91	24.33	6.09
6	0.246	19.00	1.58	2.38	6.05	24.33	39.06	22.97	5.17
7	0.272	20.99	1.74	2.34	5.76	23.47	39.06	23.67	5.68
8	0.268	20.57	1.71	2.10	5.78	23.70	38.59	23.84	5.97
9	0.270	20.76	1.73	1.65	5.22	22.26	38.36	25.64	6.85
10	0.269	20.80	1.73	1.97	5.39	22.58	38.81	24.92	6.30
11	0.264	20.71	1.72	2.01	5.14	21.77	39.42	25.55	6.08
12	0.260	20.16	1.68	2.15	5.80	23.69	38.99	23.83	5.51
13	0.265	20.80	1.73	1.93	4.99	21.36	39.42	25.99	6.27
14	0.257	19.98	1.66	2.62	6.30	24.91	39.38	22.19	4.57
15	0.257	20.00	1.66	2.93	6.55	25.50	39.66	21.27	4.05
17	0.269	21.25	1.77	1.62	4.24	19.28	39.65	28.10	7.06
18	0.264	20.70	1.72	2.36	5.47	22.55	39.77	24.44	5.38
19	0.265	20.99	1.74	2.38	5.07	21.31	40.22	25.40	5.59
20	0.266	20.89	1.74	2.12	5.06	21.45	39.68	25.65	6.01
21	0.271	20.75	1.72	1.84	5.55	23.18	38.24	24.61	6.56
22	0.263	20.46	1.70	2.31	5.68	23.23	39.36	23.96	5.44
25	0.242	18.73	1.56	1.48	6.06	24.88	38.05	24.00	5.51
26	0.266	20.81	1.73	2.59	5.62	22.86	39.89	23.84	5.18
27	0.269	20.88	1.74	2.25	5.49	22.70	39.25	24.43	5.86
28	0.270	20.94	1.74	1.23	4.53	20.43	38.43	27.72	7.63
29	0.256	20.30	1.69	3.48	6.38	24.59	41.07	21.24	3.22
30	0.262	20.30	1.69	1.87	5.49	22.95	38.73	24.83	6.11
31	0.256	19.80	1.65	2.10	6.04	24.47	38.71	23.31	5.34
32	0.255	19.53	1.62	1.59	5.97	24.57	37.82	23.96	6.05
B	0.265	20.77	1.73	1.79	4.84	20.99	39.36	26.51	6.49
C	0.265	20.64	1.72	2.33	5.59	22.96	39.43	24.13	5.53
D	0.269	20.52	1.71	1.34	5.28	22.67	37.68	25.75	7.25
F	0.265	20.75	1.72	1.90	4.97	21.33	39.40	26.07	6.30
G	0.267	20.59	1.71	1.88	5.43	22.77	38.67	24.91	6.31
H	0.270	20.56	1.71	1.73	5.67	23.62	37.90	24.41	6.64
I	0.280	20.81	1.73	1.10	5.60	23.83	36.35	25.05	8.03
J	0.262	20.17	1.68	2.21	6.09	24.56	38.61	23.02	5.48
K	0.268	20.75	1.72	2.25	5.60	23.03	39.16	24.16	5.77
L	0.275	21.18	1.76	1.61	4.98	21.58	38.40	26.20	7.20
M	0.259	20.44	1.70	3.34	6.34	24.56	40.71	21.43	3.60
N	0.266	20.56	1.71	2.45	5.97	24.04	39.13	23.06	5.31
O	0.266	20.53	1.71	1.36	4.99	21.73	38.23	26.51	7.15
P	0.276	20.64	1.72	1.89	6.28	25.40	37.16	22.69	6.55
Q	0.258	20.09	1.67	2.38	5.99	24.11	39.27	23.17	5.05
R	0.259	20.35	1.69	2.56	5.79	23.39	39.84	23.50	4.89
S	0.273	20.74	1.72	1.76	5.70	23.69	37.80	24.29	6.74

1/ % of Seasonal ET

Table B-2. (continued)

SERVICE AREA	Crop (%)2/				Application System (%)2/				
	POT	GRA	ALF	PAS	BOR	FUR	HMS	SRS	CPS
1	18.38	20.41	25.83	35.38	75.83	9.44	14.74	0	0
4	29.41	47.29	16.93	6.37	63.92	25.63	10.45	0	0
5	12.49	28.60	22.17	36.74	75.69	12.49	11.82	0	0
6	16.69	43.68	20.17	19.46	64.98	2.15	25.13	7.74	0
7	25.84	47.28	25.45	2.43	34.07	4.85	42.46	18.62	0
8	21.14	41.58	28.88	8.40	44.06	1.30	37.50	6.78	10.82
9	32.54	32.96	26.06	8.44	45.61	4.41	27.19	5.87	16.92
10	32.04	39.55	23.16	5.25	49.57	22.68	27.77	0	0
11	41.67	40.23	9.84	8.27	42.89	15.39	12.79	28.93	0
12	22.66	41.82	17.79	17.73	64.12	15.59	20.30	0	0
13	45.38	38.78	8.74	7.10	34.68	10.93	43.55	10.84	0
14	14.23	50.43	17.38	17.96	85.77	14.23	0	0	0
15	10.68	56.41	17.85	15.06	65.26	3.54	26.17	5.04	0
17	65.67	33.19	0	1.14	1.14	6.73	3.60	89.07	0
18	36.69	47.08	8.35	8.48	31.48	6.27	62.27	0	0
19	50.09	48.12	1.51	0.28	6.76	4.70	70.83	17.71	0
20	46.06	42.62	7.43	3.89	17.73	6.01	53.22	23.04	0
21	24.13	36.75	32.71	6.41	29.72	2.70	34.96	32.61	0
22	28.64	45.51	15.34	10.51	43.56	11.16	40.22	5.06	0
25	7.86	26.73	12.41	53.00	93.39	6.61	0	0	0
26	34.84	51.89	12.08	1.19	65.15	23.17	11.68	0	0
27	33.27	45.23	19.86	1.64	62.22	28.53	4.51	4.74	0
28	48.97	24.86	17.02	9.15	45.07	19.95	22.60	0	12.38
29	25.00	68.03	1.00	5.98	27.18	3.60	69.23	0	0
30	27.79	36.52	18.75	16.94	51.60	6.98	24.66	16.77	0
31	14.67	40.11	19.68	25.54	67.91	6.19	25.90	0	0
32	9.67	30.02	26.05	34.26	90.33	9.40	0.27	0	0
B	48.21	35.82	6.79	9.18	32.30	11.62	56.08	0	0
C	31.53	46.35	15.62	6.50	49.93	10.40	30.55	9.13	0
D	25.51	26.55	32.69	15.25	64.52	11.87	23.61	0	0
F	45.39	38.01	8.22	8.38	32.47	9.45	37.61	20.47	0
G	29.44	37.37	22.76	10.43	43.40	0.53	36.75	19.32	0
H	18.58	34.30	36.31	10.81	63.48	3.13	28.16	5.23	0
I	9.60	22.20	59.74	8.46	77.01	9.60	13.39	0	0
J	13.71	42.97	27.21	16.11	73.34	8.38	9.85	8.43	0
K	29.81	45.07	20.90	4.22	22.91	3.73	61.69	11.66	0
L	39.32	32.91	27.77	0	7.93	0	92.09	0	0
M	23.74	65.79	7.01	3.46	22.48	0	43.79	33.74	0
N	20.77	48.64	24.27	6.32	44.37	3.10	5.57	46.96	0
O	36.08	26.98	15.96	50.83	5.30	38.79	5.08	0	10.68
P	0	37.54	56.53	5.92	100.00	0	0	0	0
Q	20.40	46.13	15.91	17.56	59.26	4.06	26.82	0	9.86
R	29.35	50.15	9.09	11.41	30.75	3.37	27.23	38.65	0
S	17.70	35.18	40.72	6.40	55.63	8.10	20.34	0	15.93

Crops

POT--potatoes
GRA--grain
ALF--alfalfa-hay
PAS--pasture land

Irrigation Systems

BOR--border
FUR--furrow
HMS--hand-move sprinkler
SRS--side-roll sprinkler
CPS--center-pivot sprinkler

2/ % of irrigated subarea

Table B-2. (continued)

SUBAREA NO.	Soil Series (%)1/						
	AM	BA	BO	HE	PE	SA	WO
1	0	43.20	5.23	6.71	35.47	9.39	0
4	0	92.30	0	1.16	0	2.49	0
5	0	90.25	0	0	3.77	1.37	2.56
6	14.63	0	40.62	0	13.88	29.51	1.36
7	38.28	0	18.60	0	41.04	1.77	0.31
8	61.74	0	0	0	5.70	25.56	7.0
9	6.26	0	0	0	0	36.37	57.37
10	0	96.28	0	0.09	0	3.73	0
11	0	85.72	12.57	0	0	1.71	0
12	0	73.03	0	23.97	0.51	2.49	0
13	0	67.13	11.89	0	4.22	16.65	0.11
14	0	0	0	100.0	0	0	0
15	0	4.45	0	95.55	0	0	0
17	0	46.95	44.91	8.14	0	0	0
18	0	69.61	30.39	0	0	0	0
19	0	78.94	21.06	0	0	0	0
20	0	80.99	18.44	0	0	0.57	0
21	0	0	0	100.0	0	0	0
22	0	9.11	16.55	74.34	0	0	0
25	0	17.87	0	0	81.24	0	0.89
26	21.43	3.86	8.53	0	65.52	0.35	0
27	78.73	0	19.22	0	2.05	0	0
28	98.05	0	1.95	0	0	0	0
29	0	42.29	0	0	57.71	0	0
30	18.23	0	14.32	0	6.51	52.78	8.16
31	0	18.31	4.71	0	3.23	59.89	13.86
32	0	32.47	2.39	0	38.48	14.36	12.28
B	0	84.82	15.18	0	0	0	0
C	0	27.28	36.90	35.82	0	0	0
D	0	9.82	42.50	45.71	0	1.51	0.46
G	0	5.61	0	0	0	56.57	37.82
H	4.57	0	0	0	43.54	31.53	20.36
I	0	0	0	0	23.30	37.65	39.05
J	0	60.47	4.04	0	0	34.76	0.73
K	0	61.20	38.80	0	0	0	0
L	0	16.05	83.95	0	0	0	0
M	0	90.01	9.99	0	0	0	0
N	0	79.09	11.03	0	0	8.18	1.70
O	0	17.03	46.78	0	0	28.92	7.28
P	0	48.68	48.39	0	0	2.93	0
Q	0	35.07	0	0	0	30.57	34.36
R	0	48.70	23.14	28.16	0	0	0
S	0	10.36	7.97	0	0	56.81	24.86

1/% of total subarea

Table B-2. (continued)

SUBAREA No.	No. of Ownership (Range in Acres) <30	31-50	51-70	71-100	101-140	141-210	211-280	>281
1	0	6	1	9	4	1	0	0
4	2	3	1	6	3	2	0	0
5	0	2	1	20	0	2	0	0
6	2	12	1	13	2	2	1	0
7	6	2	3	3	3	3	5	1
8	0	4	0	2	1	6	3	1
9	0	0	0	1	1	4	4	1
10	0	1	0	7	1	3	1	0
11	0	3	0	3	1	0	0	0
12	0	0	0	13	2	1	0	0
13	0	4	0	8	1	1	0	0
14	2	4	0	0	1	0	0	0
15	0	0	0	9	1	1	1	0
17	0	2	1	3	1	0	0	0
18	0	1	0	3	0	0	1	0
19	2	0	2	7	3	0	0	0
20	0	3	1	1	2	0	0	0
21	0	0	0	2	1	0	1	1
22	0	1	3	10	6	2	0	0
25	0	1	0	2	1	0	0	0
26	0	0	1	7	1	0	0	1
27	0	1	0	6	2	3	0	0
28	0	1	0	0	4	2	1	0
29	3	4	0	0	1	0	0	0
30	0	5	0	8	2	3	1	0
31	0	2	3	0	3	2	0	0
32	0	6	2	5	0	0	0	0
B	0	2	0	4	0	0	0	0
C	0	1	6	13	3	3	1	0
D	1	8	2	2	3	1	1	0
F	0	7	0	14	1	0	0	0
G	2	3	0	9	1	3	0	0
H	0	0	0	11	2	5	0	0
I	0	2	0	3	1	4	0	1
J	0	0	0	4	2	3	0	0
K	0	1	1	2	1	1	0	0
L	0	0	0	2	0	0	1	1
M	0	4	0	6	0	0	0	0
N	1	3	1	5	0	0	0	0
O	4	16	0	9	3	1	2	1
P	0	2	0	0	2	0	0	0
Q	1	6	2	2	0	3	2	0
R	0	4	0	5	2	2	1	0
S	0	3	0	4	0	1	1	1

Table B-3. For Consolidation Plan

SUBAREA NO.	ET max IN/DAY	Seasonal ET		Monthly ET Distribution (%)1/					
		INCHES	AF/ACRE	April	May	June	July	Aug.	Sept.
12	0.263	20.12	1.67	0.99	5.08	22.24	37.49	26.64	7.52
13	0.246	18.79	1.56	1.24	6.18	25.43	37.21	23.85	6.06
14	0.253	19.83	1.65	2.69	6.18	24.50	39.86	22.46	4.27
15	0.264	20.47	1.70	2.55	5.98	24.01	39.41	22.97	5.05
16	0.254	19.58	1.63	2.04	6.13	24.78	38.58	23.16	5.28
17	0.261	20.39	1.69	2.67	5.95	23.83	39.79	22.97	4.76
18	0.270	20.84	1.73	2.04	5.50	22.88	38.76	24.56	6.22
20	0.265	20.77	1.73	2.08	5.16	21.77	39.51	25.45	6.00
21	0.278	21.37	1.78	0.19	3.62	18.34	37.23	30.84	9.75
22	0.266	20.05	1.67	1.33	5.80	24.27	37.07	24.49	7.00
23	0.262	20.22	1.68	1.49	5.26	22.48	38.29	25.75	6.70
24	0.269	20.54	1.71	1.36	5.29	22.66	37.71	25.72	7.23
25	0.267	20.56	1.71	1.91	5.52	23.01	38.60	24.68	6.25
26	0.251	19.38	1.61	1.38	5.62	23.64	38.03	25.06	6.24
27	0.261	20.32	1.69	2.26	5.77	23.53	39.19	23.80	5.43
29	0.263	20.71	1.72	2.70	5.59	22.69	40.28	23.84	4.88
31	0.273	21.00	1.75	1.95	5.41	22.68	38.58	24.84	6.52
32	0.257	19.86	1.65	1.91	5.82	23.90	38.59	24.04	5.71
33	0.267	21.02	1.75	2.09	4.92	21.04	39.77	26.02	6.14
34	0.256	19.86	1.65	1.60	5.48	23.06	38.45	25.17	6.22
35	0.265	20.85	1.73	2.12	5.05	21.41	39.74	25.68	5.97
36	0.260	20.06	1.67	2.69	6.53	25.59	39.09	21.51	4.56
37	0.264	20.73	1.72	2.09	5.09	21.55	39.67	25.63	5.95
38	0.270	21.02	1.75	1.48	4.66	20.67	38.75	27.16	7.25
39	0.262	20.35	1.69	2.22	5.71	23.39	39.16	23.97	5.52
40	0.257	19.97	1.66	2.38	6.06	24.34	39.23	23.00	4.95
41	0.261	20.23	1.68	3.04	6.60	25.58	39.67	21.02	4.06
42	0.274	20.98	1.74	1.47	5.05	21.87	38.07	26.17	7.33
43	0.270	20.93	1.74	2.05	5.29	22.21	39.10	25.09	6.23
L	0.265	20.85	1.73	2.55	5.43	22.32	40.09	24.34	5.25
M	0.259	20.47	1.70	2.79	5.81	23.29	40.30	23.24	4.54
N	0.260	20.31	1.69	2.29	5.67	23.22	39.42	24.02	5.35
O	0.266	20.78	1.73	1.41	4.55	20.34	38.94	27.57	7.16
P	0.262	20.43	1.70	2.62	5.97	23.92	39.61	22.96	4.89
Q	0.263	20.63	1.71	2.55	5.68	23.07	39.81	23.74	5.12
R	0.267	20.63	1.71	1.89	5.40	22.65	38.72	25.00	6.32
S	0.267	20.62	1.71	2.68	6.21	24.64	39.20	22.24	5.00
T	0.263	20.46	1.70	2.39	5.81	23.58	39.32	23.56	5.31
U	0.267	20.79	1.73	2.09	5.36	22.41	39.16	24.90	6.05
V	0.271	20.58	1.71	1.55	5.55	23.36	37.67	24.88	6.97
W	0.269	20.47	1.70	1.27	5.27	22.68	37.56	25.85	7.34
X	0.273	20.66	1.72	1.77	5.85	24.14	37.61	23.9 1	6.69
Y	0.270	20.66	1.72	1.73	5.56	23.26	38.04	24.69	6.68
Z	0.273	20.72	1.72	1.03	4.98	21.94	37.32	26.76	7.95
Z1	0.275	21.25	1.77	1.17	4.45	20.22	38.22	27.94	7.97
Z2	0.269	20.54	1.71	1.65	5.54	23.25	37.95	24.83	6.74
Z3	0.264	20.21	1.68	2.34	6.36	25.31	38.44	22.20	5.31
Z4	0.265	20.58	1.71	1.97	5.32	22.36	39.08	25.14	6.10
Z5	0.254	19.74	1.64	2.83	6.64	25.83	39.47	21.17	4.02

1/ % of seasonal ET

Table B-3. (continued)

SUBAREA NO.	Crop (%)2/			
	POT	GRA	ALF	PAS
12	27.73	19.34	26.12	26.81
13	0.00	22.52	25.25	52.23
14	19.67	51.43	7.41	21.49
15	22.32	50.37	19.39	7.92
16	11.36	38.54	19.60	30.50
17	25.50	52.40	12.83	9.27
18	29.29	41.06	26.11	3.54
20	42.20	41.63	9.60	6.57
21	62.47	4.02	25.34	8.17
22	8.93	25.67	41.28	24.12
23	29.57	29.05	19.76	21.62
24	25.76	26.98	32.58	14.66
25	27.05	37.83	24.51	10.61
26	17.90	25.78	16.29	40.03
27	25.17	44.26	16.86	13.71
29	37.94	53.85	5.14	3.07
31	30.36	39.44	29.50	0.70
32	18.80	36.54	18.87	25.79
33	50.37	42.32	5.74	1.57
34	215.05	30.63	15.83	28.49
35	46.65	42.71	5.96	4.68
36	7.32	52.01	25.83	14.84
37	44.75	41.69	5.95	7.61
38	48.60	30.06	15.90	5.44
39	26.23	43.46	16.89	13.42
40	18.24	45.88	15.72	20.16
41	10.19	59.19	21.67	8.95
42	34.89	29.75	30.53	4.83
43	36.77	41.48	19.62	2.13
L	40.49	51.19	7.19	1.13
M	32.54	55.11	4.89	7.46
N	28.82	44.79	12.40	13.99
O	51.77	28.25	8.13	11.84
P	23.97	51.49	15.92	8.62
Q	32.35	50.67	11.71	5.27
R	30.77	37.54	22.04	9.65
S	16.12	53.21	27.88	2.78
T	25.47	47.07	17.79	9.67
U	35.17	41.89	17.81	5.14
V	19.72	30.72	37.76	11.80
W	24.82	25.06	33.31	16.81
X	12.87	35.18	44.17	7.78
Y	22.37	34.55	33.98	9.10
Z	30.32	20.64	35.85	13.19
Z1	50.47	23.96	22.83	2.74
Z2	21.91	32.65	33.17	12.27
Z3	6.65	45.66	34.09	13.60
Z4	34.89	39.13	15.41	10.57
Z5	7.03	53.88	17.79	21.30

2/ % of irrigated subarea

Table B-3. (continued)

SUBAREA NO.	Soil Series (%)1/						
	Am	Ba	Bo	He	Pe	Sa	Wo
12	0	46.71	7.95	10.21	25.01	10.12	0
13	0	36.62	0	0	55.53	7.85	0
14	0	45.89	0	0	53.66	0.45	0
15	0	65.47	0	33.20	0	1.33	0
16	0	46.90	0	0	50.76	1.84	0.50
17	0	57.19	0	39.18	0	3.63	0
18	0	0	0	100.00	0	0	0
20	0	2.30	15.25	82.45	0	0	0
21	0	5.65	37.44	56.91	0	0	0
22	0	65.21	0	0	15.02	1.09	18.68
23	0	100.00	0	0	0	0	0
24	0	28.55	0	71.45	0	0	0
25	15.72	27.32	0.29	0	51.79	0	4.87
26	0	93.67	0	0	0	2.57	3.75
27	0	30.77	43.83	25.40	0	0	0
29	41.29	3.50	24.73	0	28.15	1.60	0
31	82.66	0	13.92	0	3.42	0	0
32	0	54.11	16.48	0	14.24	15.00	0.16
33	0	82.63	17.37	0	0	0	0
34	0	20.91	21.20	0	12.12	39.07	6.90
35	0	82.23	15.37	0	0.93	1.48	0
36	8.11	0	30.17	0	17.39	41.66	2.67
37	0	61.53	12.99	0	1.50	23.47	0.51
38	43.59	0	27.86	0	8.06	20.48	0
39	0	50.47	6.52	0	4.73	23.23	15.06
40	0	7.51	16.29	0	2.81	62.98	10.41
41	15.31	0	6.93	0	43.05	22.48	12.22
42	69.17	0	2.26	0	28.57	0	0
43	88.64	0	0	0	11.36	0	0
L	0	70.47	29.53	0	0	0	0
M	0	58.61	41.39	0	0	0	0
N	0	40.48	11.78	47.73	0	0	0
O	0	98.51	6.49	0	0	0	0
P	0	48.25	45.03	0	0	0	6.71
Q	0	35.56	21.90	42.54	0	0	0
R	0	12.20	40.50	47.30	0	0	0
S	0	71.41	27.84	0	0	0.75	0
T	0	42.66	38.78	1.99	0	16.36	0.20
U	0	33.31	20.67	0	0.54	29.08	16.41
V	0.38	3.50	0	0	29.21	41.03	25.83
W	0	19.04	53.10	6.07	0	19.37	2.42
X	38.48	0	0	0	54.53	5.06	1.93
Y	27.56	0	0	0	3.46	44.18	24.88
Z	0	4.08	0	0	0	55.56	40.37
Z1	8.97	0	0	0	0	32.44	58.59
Z2	0	20.93	29.70	16.14	0	28.19	5.04
Z3	0	0	0	0	0	34.32	65.68
Z4	0	60.82	8.05	0	0	16.80	14.32
Z5	0	11.83	0	0	0	39.46	49.09

1/ % of total subarea

Table B-3. (continued)

SUBAREA NO.	# of Land Ownership (range in acres)							
	30	31-50	51-70	71-100	101-140	141-210	211-280	281
12	0	2	1	6	4	0	0	0
13	0	2	3	2	1	1	0	0
14	0	3	0	4	2	2	1	0
15	4	5	1	3	2	2	1	0
16	0	2	0	8	0	2	0	0
17	0	4	0	9	2	3	0	0
18	0	0	0	0	1	0	1	1
20	0	0	0	2	1	2	0	0
21	0	2	3	1	1	0	0	0
22	0	2	0	4	1	2	0	0
23	0	0	0	6	1	1	1	0
24	0	0	0	10	0	2	1	0
25	0	2	3	1	1	0	0	0
26	0	1	0	14	1	2	0	0
27	0	0	1	6	2	1	0	0
29	0	1	0	5	2	1	0	2
31	0	1	0	5	0	1	0	0
32	0	4	0	5	0	1	0	0
33	2	1	1	3	2	1	1	0
34	1	1	1	3	2	1	1	0
35	0	4	1	8	3	1	0	0
36	2	14	2	6	1	2	0	0
37	0	5	1	7	3	0	0	0
38	1	0	1	6	4	4	1	0
39	0	2	0	3	1	3	0	0
40	1	2	1	4	2	0	3	0
41	3	1	0	5	1	2	1	0
42	0	1	0	1	1	1	2	1
43	2	2	0	3	2	3	1	0
L	0	3	1	3	0	0	1	0
M	0	3	0	7	0	0	0	0
N	0	1	0	0	2	2	1	0
O	0	2	0	4	1	0	0	0
P	0	3	1	6	1	0	0	0
Q	0	0	1	7	0	3	0	0
R	0	4	5	8	4	0	1	0
S	0	2	0	6	1	3	0	0
T	0	4	0	9	2	2	0	1
U	2	7	1	5	3	2	0	0
V	1	3	0	14	1	3	0	0
W	2	10	1	5	3	0	1	0
X	0	2	0	3	3	2	1	0
Y	0	2	0	0	2	4	2	0
Z	1	3	0	4	0	0	0	2
Z1	0	0	0	0	0	2	0	1
Z2	0	7	0	1	1	1	1	0
Z3	0	0	0	2	1	1	4	2
Z4	1	4	0	1	2	1	2	0
Z5	0	1	2	2	0	2	0	0

APPENDIX C

INPUT PARAMETERS AND FORMATS OF THE COST ESTIMATION COMPUTER PROGRAMS

C-1. Gravity irrigation application system

C-2. Sprinkler irrigation application system

C-3. Canal conveyance system

C-4. Pipe conveyance system

C-5. Pump system - Farm pump

C-6. Pump system - River pump

C-1. INPUT DATA FOR PROGRAM APSYS (GRAVITY IRRIGATION SYSTEM)

Card No. 1

Number of soil types or land class to be processed

Card No. 2

Farm and soil data

1 - Average farm size, acres
2 - Average field slope, ft/ft
3 - Intake family, SCS classification

Card No. 3

Total number of crops to be processed

Card No. 4i; i = 1 - - - n, n = number of crops

Name of crop number i

Card No. 5i; i = 1 - - - n, n = number of crops

Information for Crop number i

1 - Water holding capacity, in/ft

2 - Root zone depth, ft
3 - Percent readly available moisture to total available moisture
4 - Total annual ET requirement, inches
5 - Maximum daily ET requirement in/day
6 - Percentage of crop grown

Card No. 6i; i = 1 - - - n, n = number of crops

Manning's surface roughness coefficient SCS values are as follows:

0.04 --- bare earth
0.10 --- small grain-drilled
0.15 --- alfalfa, small grain-broadcast
0.25 --- dense sod, small grain-drilled across border
0.0 --- may be used if border irrigation is not considered for this crop

*Note: Cards No. 4, 5 and 6 are repeated up to the total number of crops considered.

Card No. 7

Irrigation system code
Input one of the following codes

'GRAVITY' --- furrow or border irrigation
'HAND MOVE' --- hand move sprinkler system
'SIDE ROLL' --- wheel move sprinkler system
'CENTER PIVOT' --- center pivot sprinkler system
'SOLID SET' --- solid set sprinkler system

If a sprinkler system is selected data entries are discussed on the following section, "Input Data per Sprinkler System".

Care No. 8

Average field lengths for furrow and border fields as pair, Enter as many pairs of run lengths as desired for computation of efficiency (i.e. 1300.0, 1300.0, 1000.0, 800.0, 800.0, 600.0 . . .)

Card No. 9

Information on gravity system for each crop

1 - Gravity system code
  '1.0' --- furrow irrigation
  '2.0' --- border irrigation
2 - Average inflow rate, GPM for furrow and CFS for border; If not known enter '0.0'.
3 - Furrow spacing (inches) or border width (feet).
4 - Average time of inflow, minutes, If not known type '0.0'.

*Note: Enter '0.0' for both of inflow rate and time of inflow in order finding maximum efficiency of furrow irrigation

*Note: Card No. 9 is repeated up to the total number of crops considered

Card No. 10

Labor rate

1 - Irrigation labor for furrow hr/irrig/acre/1000 ft run
2 - Irrigation labor for border hr/irrig/acre/1000 ft run
3 - Additional labor for furrow if any, hr/irrig/acre
4 - Additional labor for border if any, hr/irrig/acre
5 - Rate of labor, $/hr

Card No. 11

Irrigation cost data

1 - Cost of constructing open ditch and drain $/ft
2 - Cost of lining farm ditches, $/ft
3 - Cost of irrigation structure for furrow, $/acre
4 - Cost of irrigation structure for border, $/acre
5 - Cost of miscellaneous irrigation equipment for furrow, $/acre
6 - Cost of miscellaneous irrigation equipment for border, $/acre
7 - Cost of leveling, smoothing, or grading for furrow fields, $/acre
8 - Cost of leveling, smoothing, or grading for border fields, $/acre

Card No. 12

Amortizaton Data

1 - Life of irrigation equiment for furrow, years
2 - Life of irrigation equipment for border, years
3 - Salvage value, percent of total capital cost
4 - Rat of interest, percent

Card No. 13

Land cost data

1 - Cost of annual land preparation (planning), $/acre
2 - Value of land lost to production, $/acre

Card No. 14

Operation and maintenance cost data

1 - Annual operation and maintenance costs, percent of total investment
2 - Annual tax and insurance, percent of average investment

Card No. 15

Value of Water

1 - Value of water lost to surface runoff, $/acre-feet
2 - Value of water lost to deep percolation, $/acre-feet

*Note: If no water value is considered at this point, enter '0.0' for both of them. These values can be entered later in the optimization procedure.

Card No. 16

Sub-surface drainage code

If sub-surface drainage is considered, enter 'YES'.
If not, enter 'NO'.

**If 'YES' has been entered on Card No. 16, enter data card Nos. 16a, 16b and 16c, otherwise skip these cards.

Card No. 16a

Sub-surface drainage data

1 - Drain depth, ft
2 - Distance between drain and barrier, ft
3 - Permeability, between drain and barrier, ft/day
4 - Maximum permissible water table height above drain, ft
5 - Slope of lateral drain, ft/ft

Card No. 16b

Cost and laying of drain pipe for the following pipe sizes

1 - 4 inch pipe, $/ft
2 - 6 inch pipe, $/ft
3 - 8 inch pipe, $/ft

Card No. 16c

Cost of earthwork

1 - Unit cost of excavation $/CY
2 - Unit cost of backfill, $/CY
3 - Unit cost of gravel envelope, $/CY
4 - Percent contingency cost, pipe trench

Card No. 17

Code for border irrigation

If advance and recesion and intake rate curves are available for border irrigation enter 'YES'.
If not, enter 'NO'.

**If 'YES' has been entered in Card No. 17, enter Card No. 17a, otherwise skip this card.

Card No. 17a

Curve coefficients of the general equations of advance, recession and intake rate curves

1 - Multiplier and exponent of intake rate
2 - Multiplier and exponent of advance
3 - Multiplier and exponent of recession

Card No. 18

Options for efficiency calculation for border

Enter

'1.0' --- If the flow rate and set length are to be adjusted to increase efficiency
'2.0' --- If only the set length is to be adjusted
'3.0' --- If neither flow rate nor set length are to be adjusted

Card No. 19

Border irrigation data

1 - Lag time for graded border irrigation (Table 4-6, Reference 1)
2 - Assumed graded irrigation efficiency (Table 4-12, Reference 1)

*Note: The referenced tables are in Appendix E.

*Note: If more than one run length are to be processed repeat Cards No. 9 and 17 (and 17a if necessary) after Card No. 19.

*Note: If application time is greater than 0.0 then skip this card.

Card No. 20

End of data code

Enter one of the following codes

If, there is an additional system to be processed
'GRAVITY' --- furrow or border irrigation
'HAND MOVE' --- hand move sprinkler system
'SIDE ROLL' --- wheel move sprinkler system
'CENTER PIVOT' --- center pivot sprinkler system
'SOLID SET' --- solid set sprinkler system
'REWORK' --- If there are no more irrigation systems to be processed but data on another soil type or land class are considered; Data entries are then repeated starting with Card No. 2
'END DATA' --- If it is the end of a job.

If 'GRAVITY' system is selected, data entries are repeated starting with Card No. 8

If a sprinkler system is selected, data entries are discussed on the following section, Input Data for Sprinkler System.

C-2. INPUT DATA FOR PROGRAM APSYS (SPRINKLER IRRIGATION SYSTEM)

Cards No. 1-7

Same as for Gravity Irrigation System

Card No. 8

Lateral line data

1 - Length of lateral, ft
For a center pivot with a corner system, enter radius
2 - Lateral spacing, Enter '0.0' for center pivot sprinkler system
3 - No. of corner systems irrigated for center pivot, 0.0 for other systems

Card No. 9

Lateral setting

1 - Time required to move lateral, min.
2 - Time allowed for set length, hrs: up to 11 values: i.e., 8.0, 12.0, 24.0, 36.0. This value must include the required moving and down time.

Card No. 10

Efficiency data

1 - Overall efficiency of system, percent
2 - Other losses, percent (losses to evaporation and leaks, etc.)

Card No. 11

Maximum allowable intake rate of soil, inches/hour

Card No. 12

Lateral line cost and expenses

1 - Original cost of one lateral, $ (cost includes pipe, sprinkler heads, riser, etc.)
2 - Life of system, years
3 - Interest rate, percent
4 - Tax and insurance expenses, percent of average investment
5 - Salvage value, percent of original investment
6 - Maintenance cost, percent of total investment
7 - Contingency cost, percent

Card No. 13

Labor data

1 - Labor rate for moving lateral lines, $/hr
2 - Transport time between irrigation, hour

Card No. 14

Value of water lost to deep percolation, $/acre

Card No. 15

Mainline Data

1 - Pipe size, inches
2 - Length of pipe with this size on entire field
3 - Cost of mainline (pipe and accessory) $/ft

*Note: Enter as many sizes as needed.

Card No. 16

Mainline code

If mainline is buried --- 'YES'.
If not --- 'NO'.

If 'YES' on Card No. 16, enter the following on Card No. 16a

Card No. 16a

Unit costs of following

1 - Mainline excavation, $/CY
2 - Mainline backfill $/CY

Card No. 17

Mainline amortization and expenses

1 - Life of equipment, years
2 - Interest rate, percent
3 - Salvage value, percent of original investment
4 - Annual tax and insurance, percent of average investment
5 - Annual maintenance cost, percent of original investment

Card No. 18

Value of land lost to production, $/acre

Card No. 19

End of data code, See Card No. 20 on Gravity Irrigation System Section

C-3. INPUT DATA FOR PROGRAM XCANAL (CANAL CONVEYANCE SYSTEM)

Card No. 1 - 3

Unite prices for each of the following items

1 - Excavation, common, canal, $/CY	)	
2 - Excavation, common, structures, $/CY	)	
3 - Excavation, common, siphons, $/CY	)	
4 - Excavation, common, pipe trenches, $/CY	)	#1
5 - Excavation, rock, canals, $/CY	)	
6 - Excavation, rock, structures $/CY	)	
7 - Excavation, rock, siphons, $/CY	)	
8 - Excavation, rock, pipe trenches, $/CY	)	
1 - Backfill, canal, $/CY	)	
2 - Backfill, structures $/CY	)	
3 - Backfill, siphons, $/CY	)	
4 - Backfill, pipe trenches, $/CY	)	#2
5 - Bed preparation, canal lining, $/CY	)	
6 - Compacting embankment, $/CY	)	
7 - Compacting backfill, $/CY	)	
8 - Overhaul, $/YD-MI	)	
1 - Concrete in canal lining, $/CY	)	
2 - Concrete in structures, $/CY	)	
3 - Concrete in siphons, $/CY	)	#3
4 - Steel, $/LB		
5 - Cement, $/CWT		

Card No. 4

Hourly Wages and indices

1 - Hourly wage rate for pipe layers, $/HR
2 - Equipment index, base year is 1976
3 - Area factor index
4 - Haul distance of pipe for up to 150 ft head class, ft
5 - Haul distance of pipe over 150 ft head class, ft
6 - Hourly wage rate for miner, $/HR
7 - Structural steel index, base year is 1976
8 - Cement index, base year is 1976

Card No. 5

Rehabilitation code

Enter '1.0' --- If the program is to estimate costs of rehabilitating an existing channel

'0.0' --- To estimate costs of excavating a channel on natural terrain

Card No. 6

System code

Enter 'READ---LINED CANAL', then reach identifier if the reach being processed is a lined canal or
'READ---UNLINED CANAL', then reach identifier if the reach being processed is an unlined canal

Card No. 7

Contingencies, lining materials

1 - Percent contingency cost, canal or lateral structures
2 - Percent contingency cost, earthwork
3 - Percent contingency cost, right-of-way (R-O-W)
4 - Percent contingency cost, canal lining
5 - Canal structures cost index, base year is 1976
6 - Code for canal lining (5 options): Enter one of the following codes

'0.0' --- no lining
'1.0' --- unreinforced portland cement
'2.0' --- reinforced portland cement
'3.0' --- asphaltic concrete
'4.0' --- shortcrete

Card No. 8

Design channel properties

1 - Design side slope of canal
2 - Side slope of outside of new, design canal
3 - Manning's roughness coefficient
4 - Minimum allowable velocity, ft/sec
5 - Maximum allowable velocity, ft/sec
6 - Minimum channel depth, ft

Card No. 9

Bridge data

1 - Width of county bridge, ft
2 - Unit cost for county bridge, $/sq ft
3 - Width of farm bridge, ft
4 - Unit cost for farm bridge, $/sq ft

Card No. 10

Amortization

1 - Life of project, years
2 - Annual interest rate, percent
3 - Salvage value as a percent of original cost

Card No. 11

Water losses

1 - Value of water lost from canal reach, $/AF
2 - Number of days canal is operating 75 percent of peak flow
3 - Other operational losses as a percent of flow rate, Q

Card No. 12

Seepage coefficient and right-of-way

1 - Seepage coefficient, Moritz equation, cu ft/sq ft/day
2 - Present right-of-way (ROW), ft
3 - Value of ROW, $/acre
4 - Area for severance, acre
5 - Unit costs for sevrance pay, $/acre
6 - Distance to borrow area (common), miles

Card No. 13

Canal length and elevation

1 - Length of reach, ft
2 - Elevation of canal bottom at outlet, ft
3 - Elevation of canal bottom at inlet, ft
4 - Required minimum water elevation at outlet for turnout operation, ft

Card No. 14

Farm turnout

1 - Number of farm turnouts
2 - Size of farm turnouts, cfs

*Note: If there are more than one size of farm turnouts, the entries are repeated on the same card. If no turnout, enter '0.0, 0.0'

Card No. 15

Drainage crossings

1 - Number of crossings
2 - Diameter of crossings, inches
3 - Approximate capacity, cfs

*Note: If no drainage, enter '0.0, 0.0, 0.0'.

Card No. 16

Number of structures to be included in reach

1 - Rectangular inclined drop
2 - concrete check without apron
3 - Modified Parshall flume
4 - County bridge
5 - Farm bridge
6 - Siphon
7 - Tunnel

If siphon is present enter the following Card No. 16a, otherwise, skip it

Card No. 16a

Siphon data

1 - Head loss desired in pipe or barrel, ft/1,000 ft
2 - Maximum velocity in pipe, fps
3 - Length of pipe, upstream slope, ft
4 - Length of pipe, bottom slope, ft
5 - Length of pipe, downstream slope, ft

6 - Transition loss coefficient in inlet
7 - Pipe slope, upstream, vertical/horizontal, ft/ft
8 - Pipe slope, bottom, ft/ft
9 - Pipe slope, downstream ft/ft
10 - Width of R-O-W, ft

If Tunnel is present enter the following Card No. 16b, otherwise, skip it

No. 16b

Tunnel data

1 - Head loss desired, ft/1,000 ft
2 - Desired velocity in tunnel, fps
3 - Elevation of tunnel, ft
4 - Length of tunnel, ft
5 - Number of headings to be used

Card No. 17

Prism data of old canal

1 - Base width of old channel, ft
2 - Side slope (average) of inside of old channel
3 - Average relative height of berms above old channel bottom, ft
4 - Average top width of old berm on left side (facing upstream)
5 - Average top width of old berm on right side of channel
6 - Side slope of outside face of left channel berm
7 - Side slope of outside face of right channel berm
8 - Elevation of natural terrain to left of channel at inlet
9 - Elevation of natural terrain to right of channel at inlet
10 - Elevation of natural terrain to left of channel at outlet
11 - Elevation of natural terrain to right of channel at outlet

Card No. 18

Flow rate data

1 - Minimum Q, cfs
2 - Maximum Q, cfs
3 - Q interval, cfs

*Note: There must be a minimum of three steps

Card No. 19

End of data code

Enter

'END DATA'--- If end of data
'SKIP---LINED CHANNEL'--- If there is another reach of lined canal to be processed
'SKIP---UNLINED CHANNEL'--- If there is another reach of unlined canal to be processed

*Note: For more run of lined or unlined canal reach the data entries are repeated starting with Card No. 12.

C-4. INPUT DATA FOR PROGRAM XPIPE (PIPE CONVEYANCE SYSTEM)

Card No. 1

System planning code

Enter

'0.0' --- If pipe is to be placed in natural, undisturbed terrain
'1.0' --- If pipe is to replace an existing unlined channel (i.e.) pipe will be placed directly in old channel, along with the required excavation and backfill.

Card No. 2

Unit cost of excavation

1 - Common, canal, $/CY
2 - Common, structure, $/CY
3 - Common, siphon, $/CY
4 - Pipe trench, $/CY
5 - Rock, canal, $/CY
6 - Rock, structure, $/CY
7 - Rock, siphon, $/CY
8 - Rock, pipe trench, $/CY

Card No. 3

Backfill and compaction

1 - Backfill, canal (compacted bottom fill for rehabilitation of canal to pipe system), $/CY
2 - Backfill, structure, $/CY
3 - Backfill, siphon, $/CY
4 - Backfill, pipe trench, $/CY
5 - Bed preparation, canal lining, $/CY
6 - Compacting embankment, $/CY
7 - Compacting backfill, $/CY
8 - Overhaul, $/YD-MI

Card No. 4

Concrete and steel cost

1 - Concrete in canal lining, $/CY
2 - Concrete in structure, $/CY
3 - Concrete in siphon, $/CY
4 - Steel, $/#

Card No. 5

System code

Enter one of the following codes
'READ---GRAVITY PIPE', then reach identifier or
'READ---HIGH PRESSURE PIPE', then reach identifier

Card No. 6

Hourly wages and indices

1 - Wage rate for pipe layer
2 - Equipment index, base is 1976
3 - Area factor
4 - Haul distance of pipe for up to 150 ft head
5 - Haul distance of pipe over 150 ft head
6 - Code for type of cover
    '1.0' --- A cover (5 ft)
    '2.0' --- B cover (10 ft)
    '3.0' --- C cover (15 ft)
    '4.0' --- D cover (20 ft)
7 - Cost index for pipe system
8 - Depth of backfill over top of pipe, ft
9 - Head class (ft) of concrete pipe

Card No. 7

Contingency cost

1 - Contingency cost for earthwork, percent
2 - Contingency cost for steel reservoir, percent
3 - Contingency cost for R.O.W., percent
4 - Concrete pipe contingency cost for pipes valves, etc., percent
5 - PVC pipe contingency cost for pipes, valves, etc. percent
7 - Head class desired for PVC pipe, enter one of the following codes
    '1.0' --- for 63 psi bell end
    '2.0' --- for 125 psi bell end
    '3.0' --- for 160 psi end

Card No. 8

Amortization

1 - Type of project, years
2 - Interest rate, percent of total investment
3 - Salvage value, percent of initial investment

Card No. 9

Elevated tank

1 - Tower height, ft
2 - Minimum flow rate to tank, cfs
3 - Maximum flow rate to tank, cfs
4 - Flow rate interval

*Note: There must be a minimum three steps. If no tank is desired, enter 0.0, 0.0, 0.0.

Card No. 10

Length and elevation

1 - Length of reach
2 - Hydraulic grade line elevation at pipe outlet, ft
3 - Elevation of pipe outlet, ft
4 - Hydraulic grade line elevation at pipe inlet, ft
5 - Elevation of pipe inlet, ft

Card No. 11

Type of pipe for this reach

1.0 - for concrete
2.0 - for steel (AWWA tar coat)
3.0 - for PVC (4 to 14 inches diameter)
4.0 - Program will select the least cost ppe type (1, 2, or 3)

Card No. 12

Water Hammer Factor for Head Class Selection

Enter

'1.0' --- when no head class increase is desired
'2.0' --- when 50 percent head class increase is desired
'3.0' --- when 100 percent head class increase is desired

Card No. 13

Easement excavation

1 - Width of easement, ft
2 - Value of easement for cropped land $/acre
3 - Value of easement for other land, $/acre
4 - Length of easement for other purposes, percent of total length
5 - Rock excavation, percent of total excavation
6 - Distance to borrow area (common), miles

Card No. 14

Farm turnout code and misc. cost

1 - Enter one of the following codes

'0.0' --- If no pressure regulating valves for turnouts are desired
'1.0' --- If pressure regulating valves are desired

2 - Miscellaneous cost for additional turnout items

Card No. 15

Farm turnouts

1 - Number of farm turnouts
2 - Size of farm turnouts, inches

*Note: If there are more than one size of farm turnouts the entries are repeated on the same card, if no turnout enter, 0.0, 0.0.

Card No. 16

Type data for old channel prism

Data are to be representative of the entire reach:

1 - Base width of old channel
2 - Inside side slope (ave) of old channel
3 - Average relative height of berms above old channel bottom
4 - Average top width of berm on left side of channel (facing upstream)
5 - Average top width of berm on right side of channel
6 - Average sideslope of outside of left side berm
7 - Average sideslope of outside of right side berm
8 - Elev of natural terrain to left of reach inlet
9 - Elev of natural terrain to right of reach inlet
10 - Elev of natural terrain to left of reach outlet
11 - Elev of natural terrain to right of reach outlet
12 - Width of present right of way
13 - Elev of old channel bottom at inlet
14 - Elev of old channel bottom at outlet

Card No. 17

Flow rate

1 - Minimum flow rate, cfs
2 - Maximum flow rate, cfs
3 - Flow rate interval, cfs

Card No. 18

End of data code

Enter one of the following codes

'END DATA'	--- If end of data
'SKIP---GRAVITY'	--- If there is another reach of gravity pipe system to be processed
'SKIP---HIGH PRESSURE PIPE'	--- If there is another reach of high pressure pipe system to be processed

C-5 INPUT DATA FOR PROGRAM XPUMP (FARM PUMP)

Card No. 1

Type of pump to process

Enter one of the following codes

'READ---RIVER PUMP', if river pump or relift pumps is desired
'READ---FARM PUMP', if on-farm pump (centrifugal or turbine for deep well) is desired

Card No. 2

Farm pump data

1 - Total dynamic head, ft
2 - Cost index for pump facilities, base year is 1976
3 - Code for the type of pumping unit
    Enter one of the following codes
    '1.0' --- for centrifugal
    '2.0' --- for vertical turbine
4 - Efficiency of pumping unit, percent
5 - Miscellaneous costs (sump, discharge lines, etc.), percent
6 - Contingency cost, percent of field cost
7 - Indirect engineering costs, percent of field costs.

Card No. 3

Amortization

1 - Service life of pumping unit, years
2 - Interest rate, percent
3 - Salvage value, percent of original investment
4 - Other expenses, percent of original investment
5 - Average escalation of energy, percent per year
6 - Percent of time pump is operated during peak month (normally 100%)

Card No. 4

Water requirement

1 - Energy monthly irrigation requirement for the season as percent of total annual requirement

*Note: Enter as many months as necessary.

Card No. 5

Operation and maintenance and insurance data

1 - Annual O & M cost, percent of total investment
2 - Taxes and insurance, percent of average investment

Card No. 6

Deep well data

1 - Life of well, years
2 - Interest rate, percent

3 - Salvage value of well, percent of original investment
4 - Type of well
    Enter '1.0' --- well in alluvium
          '2.0' --- well in hard rock
5 - Miscellaneous costs (discharge lines, housing, etc), percent of pumping unit cost
6 - Contingency cost, percent of field cost
7 - Depth of well, ft

*Note: If deep well is not used enter, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0.

Card No. 7

Number of pump units and type

1 - Number of pump units in station
2 - Type of pump
    Enter one of the following information
    a) Horsepower size of smallest pumping unit proposed
    b) Ratio of size of smallest pumping unit relative to total HP of plant (decimal)

Enter 0.0 for default
Default is

cfs range	No. units
<1.0	1
1.0 - 3.0	2
3.0 - 6.0	3
6.0 - 20.0	4
>20.0	5

Default ratio of size of smallest unit relative to total HP of plant is

1.0/(Q + 2.0) , Q < 8.0 cfs
and 1.0/10.0 , Q >=8.0 cfs

*Note: Number of units and smallest size are necessary to estimate monthly power demands and changes for private utility.

Card No. 8

Flow rate data

1 - Minimum flow rate, gpm
2 - Maximum flow rate, gpm
3 - Flow rae interval, gpm

*Note: There must be a minimum of three steps.

Card No. 9

Code for demand rate

Enter 'YES'--- if demand is based on flat rate for certain range of HP, i.e. for HP 0-3, $5.00/KW/month
'NO'--- otherwise

Card No. 10

Demand rate schedule

If the monthly demand charge is based on HP, enter data with the following format:

xxx.x $/KW, FIRST xxx.x KW
xxx.x $/KW, SECOND xxx.x KW

(i.e., 2.53,100.0, 1.66, 101.0)

Card No. 11

Energy rate schedule

Enter data with the following format,

xx.x CENT, FIRST xx.x KWH, CODE
xx.x CENT, SECOND xx.x KWH, CODE

Code used '1.0' --- When energy rate is per KW
'2.0' --- When energy rate is not based on KW

Card No. 12

Fixed charge for energy cost - if no fixed charge enter 0.0.

Card No. 13

End of data code

Enter

'END OF DATA' --- if end of data
'READ---RIVER PUMP' --- if river pump is to be processed
'READ---FARM PUMP' --- if on-farm pump is to be processed

C-6. INPUT DATA FOR PROGRAM XPUMP (RIVER PUMP)

Card No. 1

Same as Card No. 1 in Farm Pump

Card No. 2

River Pump data

1 - Type of pumping units
 Enter, '1.0' --- for vertical pump
 '2.0' --- for horizontal pump
2 - Total dynamic head, ft
3 - Month of estimate, enter number of month, e.c., February 2.0
4 - Year of estimate, enter last two numbers, i.e., 78.0

Card No. 3

Miscellaneous pumping plant data

1 - Contingency cost for pumping plant, percent
2 - Code for structures, improvements and waterways
 Enter 1.0 --- no major difficulty
 2.0 --- major difficulty
 3.0 --- booster pump
3 - Cost of power, cents per KWH
4 - General cost index, base year is 1976
5 - Code for type of pumping plant (according to Gyer)
 Enter '1.0' --- unattended plant
 '2.0' --- semi-attended plant
 '3.0' --- attended plant
6 - Sediment code - for water allowance computation
 Enter '1.0' --- clear water
 '2.0' --- light sediment load
 '3.0' --- medium sediment load
 '4.0' --- heavy sediment load
7 - Average efficiency of pumping station (wire to water) express as percent
8 - Indirect engineering costs above normal engineering costs (already included in cost equations)

Card No. 4

Same as Card No. 7 of Farm Pump

Card No. 5

Transmission line data and cost indices

1 - Actual length of transmission line, miles
2 - Code for terrain condition
 Enter '0.0' --- flat terrain
 '1.0' --- swampy or mountainous terrain
3 - Code for foundation
 Enter '0.0' --- average condition
 '1.0' --- swampy or rock foundation

4 - Contingency cost for transmission line, percent
5 - Cost index, transmission line, base is 1976
6 - Cost index, irrigation O & M, base is 1976

Card No. 6

Switching bay data

1 - Contingency cost for switching bay
2 - Cost index, switching bay, base is 1976

Card No. 7

Amortization data, transmission line

1 - Service life of transmission line and switching bay, years
2 - Salvage value, percent of initial investment

Card No. 8

Amortization data, pumping unit

1 - Life of pumping unit, years
2 - Interest rate, percent
3 - Salvage value of the unit, percent of original investment
4 - Average escalation of energy, percent per year

Card No. 9

Water requirement

Enter monthly irrigation requirement for the season --- percent of annual total requirement for each month.

Card No. 10

O&M Data for pump

1 - Length of operating season, weeks
2 - Hourly wage rate for mechanic
3 - Hourly wage rate for pumping plant operator
4 - Percent of time station is operated during peak month (normally 100%) --- (assumed at full discharge)

Card No. 11

Flow rate data

1 - Minimum flow rate, cfs
2 - Maximum flow rate, cfs
3 - Flow rate interval, cfs

Card No. 12

Code for demand rate

Same as Card No. 9 of Farm Pump

Card No. 13

Demand rate schedule
Same as Card No. 10 of Farm Pump

Card No. 14

Energy rate schedule
Same as Card No. 11 of Farm Pump

Card No. 15

Same as Card No. 12 of Farm Pump

Card No. 16

End of data code
Same as Card No. 13 of Farm Pump

APPENDIX D

SAMPLE OUTPUTS OF THE COST ESTIMATION COMPUTER PROGRAMS

D-1. ON-FARM IRRIGATION APPLICATION SYSTEMS SUBPROGRAMS

a. Unimproved gravity irrigation application system

b. Improved gravity irrigation application system

c. Hand-move sprinkler irrigation application system

d. Side-roll wheel line sprinkler irrigation application system

e. Center-pivot sprinkler irrigation application system.

D-2. CONVEYANCE SYSTEMS SUBPROGRAMS

a. Unlined canal system

b. Lined canal system

c. Gravity pipe system

d. High pressure pipe system

D-3. PUMP SYSTEMS SUBPROGRAMS

a. Farm pump system

b. River pump system

Table D-1. On-farm irrigation application systems subprograms

ANNUAL COST OF IRRIGATION--------GRAVITY SYSTEM (UNIMPROVED) AMMON
SOIL TYPE NUMBER----- 1

	ALFALFA	GRAIN
FIELD LENGTH, FT	1300.	1300.
LABOR REQUIRED, HR/AC/IRR	0.50	0.50
ADDITIONAL LABOR, HR/AC/IRR	0.20	0.20
LABOR RATE, $/HR	4.50	4.50
COST OF CONST. FARM DITCH, $/FT	0.45	0.45
COST OF FARM DITCH LINING, $/FT	0.0	0.0
COST OF IRRIGATION STRUC., $/AC	5.00	5.00
COST OF MISC. EQUIPT., $/AC,	0.0	0.0
COST OF LEVELING, GRADING, $/AC	100.00	100.00
COST OF LAND PREPARATION, $/AC	10.00	10.00
COST OF LAND LOST TO PRODUCTION, $/AC	250.00	250.00
NUMBER OF IRRIG./SEASON	4.	5.
DEPLETED RAM BETWEEN IRRIGATIONS, INCHES	6.05	4.41
FREQUENCY OF IRRIGATION AT PEAK USE, DAYS	20.	17.
FARM SIZE, ACRE	80.	80.
FIELD SIZE FOR THIS CROP, AC	20.	20.
TOTAL INVESTMENT, $/AC	120.	120.
OWNERSHIP COST ($/AC)		
DEPRECIATION (SINKING FUND)	0.28	0.28
INTEREST ON INITIAL INVESTMENT	14.41	14.41
OPERATION AND MAINTENANCE COST ($/AC)		
LABOR COST	10.52	13.15
MAINTENANCE AND REPAIR	10.10	10.10
TAXES AND INSURANCE	0.20	0.20
SUB TOTAL	35.51	38.14
COST OF LAND LOST TO PRODUCTION	5.77	5.77
COST OF WATER LOST	0.0	0.0
COST OF SUB-SURFACE DRAIN ($/AC)	0.0	0.0
TOTAL ANNUAL COST ($/AC/YR)...	41.28	43.91

BORDER IRRIGATION EFFICIENCY ESTIMATES

	ALFALFA	GRAIN
LENGTH OF IRRIGATION RUN, FT	1300.	1300.
DEPTH OF WATER APPLIED AT FIELD HEAD, IN	8.13	5.90
DEPTH OF WATER APPLIED AT FIELD END , IN	7.42	5.42
UNIT STREAM SIZE, CFS/FT	0.0270	0.0308
BORDER WIDTH, FT	50.	50.
FIELD SLOPE, FT/FT	0.0027	0.0027
TIME OF APPLICATION, MIN	867.	554.
APPLICATION EFFICIENCY, PERCENT	45.	45.
DISTRIBUTION EFFICIENCY, PERCENT	94.	94.
VOLUME OF DEEP PERC, AC-FT/AC/YR	0.68	0.62
VOLUME OF RUNOFF, AC-FT/AC/YR	1.69	1.54

ANNUAL COST OF IRRIGATION--------GRAVITY SYSTEM (UNIMPROVED) AMMON
SOIL TYPE NUMBER----- 1

PASTURE

FIELD LENGTH, FT	1300.
LABOR REQUIRED, HR/AC/IRR	0.50
ADDITIONAL LABOR, HR/AC/IRR	0.20
LABOR RATE, $/HR	4.50
COST OF CONST. FARM DITCH, $/FT	0.45
COST OF FARM DITCH LINING, $/FT	0.0
COST OF IRRIGATION STRUC., $/AC	5.00
COST OF MISC. EQUIPT., $/AC,	0.0
COST OF LEVELING, GRADING, $/AC	100.00
COST OF LAND PREPARATION, $/AC	10.00
COST OF LAND LOST TO PRODUCTION, $/AC	250.00
NUMBER OF IRRIG./SEASON	6.
DEPLETED RAM BETWEEN IRRIGATIONS,INCHES	3.15
FREQUENCY OF IRRIGATION AT PEAK USE,DAYS	14.
FARM SIZE, ACRE	80.
FIELD SIZE FOR THIS CROP, AC	20.
TOTAL INVESTMENT, $/AC	120.

OWNERSHIP COST ($/AC)

DEPRECIATION (SINKING FUND)	0.28
INTEREST ON INITIAL INVESTMENT	14.41

OPERATION AND MAINTENANCE COST ($/AC)

LABOR COST	15.78
MAINTENANCE AND REPAIR	10.10
TAXES AND INSURANCE	0.20
SUB TOTAL	40.77
COST OF LAND LOST TO PRODUCTION	5.77
COST OF WATER LOST	0.0
COST OF SUB-SURFACE DRAIN ($/AC)	0.0

TOTAL ANNUAL COST ($/AC/YR)... 46.54

BORDER IRRIGATION EFFICIENCY ESTIMATES

LENGTH OF IRRIGATION RUN, FT	1300.
DEPTH OF WATER APPLIED AT FIELD HEAD, IN	4.47
DEPTH OF WATER APPLIED AT FIELD END , IN	4.29
UNIT STREAM SIZE, CFS/FT	0.0396
BORDER WIDTH, FT	50.
FIELD SLOPE, FT/FT	0.0027
TIME OF APPLICATION, MIN	372.
APPLICATION EFFICIENCY, PERCENT	37.
DISTRIBUTION EFFICIENCY, PERCENT	98.
VOLUME OF DEEP PERC, AC-FT/AC/YR	0.68
VOLUME OF RUNOFF, AC-FT/AC/YR	1.89

POTATOES

FIELD LENGTH, FT	1300.
LABOR REQUIRED, HR/AC/IRR	0.70
ADDITIONAL LABOR, HR/AC/IRR	0.20
LABOR RATE, $/HR	4.50
COST OF CONST. FARM DITCH, $/FT	0.45
COST OF FARM DITCH LINING, $/FT	0.0
COST OF IRRIGATION STRUC., $/AC	10.00
COST OF MISC. EQUIPT., $/AC,	0.0
COST OF LEVELING, GRADING, $/AC	100.00
COST OF LAND PREPARATION, $/AC	10.00
COST OF LAND LOST TO PRODUCTION, $/AC	250.00
NUMBER OF IRRIG./SEASON	9.
DEPLETED RAM BETWEEN IRRIGATIONS,INCHES	2.52
FREQUENCY OF IRRIGATION AT PEAK USE,DAYS	9.
FARM SIZE, ACRE	80.
FIELD SIZE FOR THIS CROP, AC	20.
TOTAL INVESTMENT, $/AC	125.

OWNERSHIP COST ($/AC)

DEPRECIATION (SINKING FUND)	0.35
INTEREST ON INITIAL INVESTMENT	15.01

OPERATION AND MAINTENANCE COST ($/AC)

LABOR COST	29.91
MAINTENANCE AND REPAIR	10.13
TAXES AND INSURANCE	0.25
SUB TOTAL	55.64
COST OF LAND LOST TO PRODUCTION	5.77
COST OF WATER LOST	0.0
COST OF SUB-SURFACE DRAIN ($/AC)	0.0

TOTAL ANNUAL COST ($/AC/YR)... 61.41

LENGTH OF IRRIGATION RUN,FT	1300.
TOTAL DEPTH OF WATER APPLIED, IN	8.61
DEPTH OF WATER APPLIED AT FIELD HEAD	4.21
DEPTH OF WATER APPLIED AT FIELD END	3.57
FURROW STREAM SIZE,GPM	25.
FURROW SPACING,IN	36.
FIELD SLOPE, FT/FT	.00270
TIME OF APPLICATION,MIN	837.
ADVANCED TIME TO FIELD END	171.
INTAKE FAMILY BASED ON SCS	0.5

A COEF=0.0471 B COEF=0.7475 C COEF=0.2750

APPLICATION EFFICIENCY, PERCENT	29.
VOLUME OF DEEP PERC, AC-FT/AC/YR	1.11
VOLUME OF RUNOFF, AC-FT/AC/YR	3.46

SOIL TYPE NUMBER------ 1

WEIGHTED COST FOR THIS SOIL TYPE AND IRRIGAT TION SYSTEM ALTERNATIVE---->>>	48.29	DOLLARS PER ACRE
WEIGHTED WATER APPLICATION EFFICIENCY-----------	39.09	PERCENT
WEIGHTED VOLUME OF DEEP PERCOLATION ------------	0.7725	AC-FT PER AC PER YR
WEIGHTED VOLUME OF SURFACE RUNOFF ------------	2.1459	AC-FT PER AC PER YR

ANNUAL COST CF IRRIGATION--------GRAVITY SYSTEM (IMPROVED) AMMON
SOIL TYPE NUMBER----- 1

	ALFALFA	GRAIN
FIELD LENGTH, FT	1300.	1300.
LABOR REQUIRED, HR/AC/IRR	0.35	0.35
ADDITICNAL LABOR, HR/AC/IRR	0.0	0.0
LABOR RATE, $/HR	4.50	4.50
COST CF CONST. FARM DITCH, $/FT	0.45	0.45
COST OF FARM DITCH LINING, $/FT	2.80	2.80
COST OF IRRIGATION STRUC., $/AC	10.00	10.00
COST OF MISC. EQUIPT., $/AC,	5.00	5.00
COST OF LEVELING, GRADING, $/AC	150.00	150.00
COST OF LAND PREPARATICN, $/AC	15.00	15.00
COST OF LAND LOST TO PRCDUCTION, $/AC	150.00	150.00
NUMBER OF IRRIG./SEASON	4.	5.
DEPLETED RAM BETWEEN IRRIGATIONS, INCHES	6.05	4.41
FREQUENCY OF IRRIGATION AT PEAK USE, DAYS	20.	17.
FARM SIZE, ACRE	80.	80.
FIELD SIZE FOR THIS CROP, AC	20.	20.
TOTAL INVESTMENT, $/AC	274.	274.
CWNERSHIP COST ($/AC)		
DEPRECIATICN (SINKING FUND)	1.72	1.72
INTEREST ON INITIAL INVESTMENT	32.87	32.87
OPERATION AND MAINTENANCE COST ($/AC)		
LABCR COST	4.85	6.06
MAINTENANCE AND REPAIR	15.62	15.62
TAXES AND INSURANCE	1.24	1.24
SUB TOTAL	56.29	57.50
COST OF LAND LOST TO PRODUCTION	3.46	3.46
COST OF WATER LOST	0.0	0.0
COST OF SUB-SURFACE DRAIN ($/AC)	0.0	0.0
TOTAL ANNUAL COST ($/AC/YR)...	59.75	60.97

BORDER IRRIGATION EFFICIENCY ESTIMATES

	ALFALFA	GRAIN
LENGTH OF IRRIGATION RUN, FT	1300.	1300.
DEPTH OF WATER APPLIED AT FIELD HEAD, IN	6.05	4.41
DEPTH OF WATER APPLIED AT FIELD END , IN	5.20	3.83
UNIT STREAM SIZE, CFS/FT	0.0270	0.0308
BORDER WIDTH, FT	50.	50.
FIELD SLOPE, FT/FT	0.0027	0.0027
TIME OF APPLICATION, MIN	578.	369.
APPLICATION EFFICIENCY, PERCENT	67.	67.
DISTRIBUTION EFFICIENCY, PERCENT	90.	90.
VOLUME OF DEEP PERC, AC-FT/AC/YR	0.0	0.0
VOLUME OF RUNOFF, AC-FT/AC/YR	0.95	0.86

ANNUAL COST OF IRRIGATION--------GRAVITY SYSTEM (IMPROVED) AMMON
SOIL TYPE NUMBER------ 1

PASTURE	
FIELD LENGTH, FT	1300.
LABOR REQUIRED, HR/AC/IRR	0.35
ADDITIONAL LABOR, HR/AC/IRR	0.0
LABOR RATE, $/HR	4.50
COST OF CONST. FARM DITCH, $/FT	0.45
COST OF FARM DITCH LINING, $/FT	2.80
COST OF IRRIGATION STRUC., $/AC	10.00
COST OF MISC. EQUIPT., $/AC,	5.00
COST OF LEVELING, GRADING, $/AC	150.00
COST OF LAND PREPARATION, $/AC	15.00
COST OF LAND LOST TO PRODUCTION, $/AC	150.00
NUMBER OF IRRIG./SEASON	6.
DEPLETED RAM BETWEEN IRRIGATIONS, INCHES	3.15
FREQUENCY OF IRRIGATION AT PEAK USE, DAYS	14.
FARM SIZE, ACRE	80.
FIELD SIZE FOR THIS CROP, AC	20.
TOTAL INVESTMENT, $/AC	274.
OWNERSHIP COST ($/AC)	
DEPRECIATION (SINKING FUND)	1.72
INTEREST ON INITIAL INVESTMENT	32.87
OPERATION AND MAINTENANCE COST ($/AC)	
LABOR COST	7.27
MAINTENANCE AND REPAIR	15.62
TAXES AND INSURANCE	1.24
SUB TOTAL	58.72
COST OF LAND LOST TO PRODUCTION	3.46
COST OF WATER LOST	0.0
COST OF SUB-SURFACE DRAIN ($/AC)	0.0
TOTAL ANNUAL COST ($/AC/YR)...	62.18

BORDER IRRIGATION EFFICIENCY ESTIMATES

LENGTH OF IRRIGATION RUN, FT	1300.
DEPTH OF WATER APPLIED AT FIELD HEAD, IN	3.36
DEPTH OF WATER APPLIED AT FIELD END, IN	3.02
UNIT STREAM SIZE, CFS/FT	0.0396
BORDER WIDTH, FT	50.
FIELD SLOPE, FT/FT	0.0027
TIME OF APPLICATION, MIN	248.
APPLICATION EFFICIENCY, PERCENT	57.
DISTRIBUTION EFFICIENCY, PERCENT	94.
VOLUME OF DEEP PERC, AC-FT/AC/YR	0.04
VOLUME OF RUNOFF, AC-FT/AC/YR	1.12

POTATOES	
FIELD LENGTH, FT	1300.
LABOR REQUIRED, HR/AC/IRR	0.50
ADDITIONAL LABOR, HR/AC/IRR	0.0
LABOR RATE, $/HR	4.50
COST OF CONST. FARM DITCH, $/FT	0.45
COST OF FARM DITCH LINING, $/FT	2.80
COST OF IRRIGATION STRUC., $/AC	20.00
COST OF MISC. EQUIPT., $/AC,	10.00
COST OF LEVELING, GRADING, $/AC	100.00
COST OF LAND PREPARATION, $/AC	15.00
COST OF LAND LOST TO PRODUCTION, $/AC	150.00
NUMBER OF IRRIG./SEASON	9.
DEPLETED RAM BETWEEN IRRIGATIONS, INCHES	2.52
FREQUENCY OF IRRIGATION AT PEAK USE, DAYS	9.
FARM SIZE, ACRE	80.
FIELD SIZE FOR THIS CROP, AC	20.
TOTAL INVESTMENT, $/AC	239.
OWNERSHIP COST ($/AC)	
DEPRECIATION (SINKING FUND)	1.93
INTEREST ON INITIAL INVESTMENT	28.67
OPERATION AND MAINTENANCE COST ($/AC)	
LABOR COST	15.58
MAINTENANCE AND REPAIR	15.69
TAXES AND INSURANCE	1.39
SUB TOTAL	63.26
COST OF LAND LOST TO PRODUCTION	3.46
COST OF WATER LOST	0.0
COST OF SUB-SURFACE DRAIN ($/AC)	0.0
TOTAL ANNUAL COST ($/AC/YR)...	66.72

LENGTH OF IRRIGATION RUN, FT	1300.
TOTAL DEPTH OF WATER APPLIED, IN	7.18
DEPTH OF WATER APPLIED AT FIELD HEAD	3.47
DEPTH OF WATER APPLIED AT FIELD END	2.52
FURROW STREAM SIZE, GPM	25.
FURROW SPACING, IN	36.
FIELD SLOPE, FT/FT	.00270
TIME OF APPLICATION, MIN	698.
ADVANCED TIME TO FIELD END	253.
INTAKE FAMILY BASED ON SCS	0.5

A COEF=0.0471 B COEF=0.7475 C COEF=0.2750

APPLICATION EFFICIENCY, PERCENT	35.
VOLUME OF DEEP PERC, AC-FT/AC/YR	0.50
VOLUME OF RUNOFF, AC-FT/AC/YR	3.00

SOIL TYPE NUMBER------ 1

WEIGHTED COST FOR THIS SOIL TYPE AND IRRIGAT TION SYSTEM ALTERNATIVE---->>>	62.40	DOLLARS PER ACRE
WEIGHTED WATER APPLICATION EFFICIENCY-----------	56.61	PERCENT
WEIGHTED VOLUME OF DEEP PERCOLATION ------------	0.1353	AC-FT PER AC PER YR
WEIGHTED VOLUME OF SURFACE RUNOFF ------------	1.4825	AC-FT PER AC PER YR

ANNUAL COST OF IRRIGATION-------HAND MOVE (AMMON) 40 ACRES
SOIL TYPE NUMBER----- 2

ALFALFA

FARM DATA:

FIELD LENGTH, FT	1300.
FARM SIZE, ACRES	40.
NO. OF IRRIGATION	4.
FREQUENCY OF IRRIGATION, DAYS	20.
GPM/LATERAL	474.
LABOR RATE, $/HR	4.50
NUMBER OF LATERALS / FARM	0.7
LENGTH OF LATERAL, FEET	1300.
LATERAL SPACING, FEET	50.
TIME TO MOVE LATERAL, MIN/SET	30.
TIME OF SETTING, HRS	12.
TRANSPORT TIME PER ROTATION,HRS	1.
AREA COVERED BY EACH LATERAL, ACRES	59.56
COST PER LATERAL LINE, $	1980.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	1.
DEEP PERCOLATION,AF/ACRE	0.4475
APPLICATION EFFICIENCY,PERCENT	75.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	1300.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	1300.	2.65

TOTAL COST OF MAINLINE, $	3789.
TOTAL INVESTMENT ($/AC)	128.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	0.80
MAINLINE	1.20
INTEREST ON INVESTMENT	
LATERAL	3.99
MAINLINE	11.37
LABOR COST	6.35
MAINTENANCE COST	3.84
TAXES AND INSURANCE	1.40
TOTAL	28.94

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

GRAIN

FARM DATA:

FIELD LENGTH, FT	1300.
FARM SIZE, ACRES	40.
NO. OF IRRIGATION	5.
FREQUENCY OF IRRIGATION, DAYS	17.
GPM/LATERAL	529.
LABOR RATE, $/HR	4.50
NUMBER OF LATERALS / FARM	0.5
LENGTH OF LATERAL, FEET	1300.
LATERAL SPACING, FEET	50.
TIME TO MOVE LATERAL, MIN/SET	30.
TIME OF SETTING, HRS	8.
TRANSPORT TIME PER ROTATION,HRS	1.
AREA COVERED BY EACH LATERAL, ACRES	75.92
COST PER LATERAL LINE, $	1980.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	2.
DEEP PERCOLATION,AF/ACRE	0.3942
APPLICATION EFFICIENCY,PERCENT	75.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	1300.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	1300.	2.65

TOTAL COST OF MAINLINE, $	3789.
TOTAL INVESTMENT ($/AC)	121.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	0.63
MAINLINE	1.20
INTEREST ON INVESTMENT	
LATERAL	3.13
MAINLINE	11.37
LABOR COST	7.85
MAINTENANCE COST	3.62
TAXES AND INSURANCE	1.32
TOTAL	29.12

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

ANNUAL COST OF IRRIGATION-------HAND MOVE (AMMON) 40 ACRES
SOIL TYPE NUMBER----- 2

PASTURE

FARM DATA:

FIELD LENGTH, FT	1300.
FARM SIZE, ACRES	40.
NO. OF IRRIGATION	6.
FREQUENCY OF IRRIGATION, DAYS	14.
GPM/LATERAL	516.
LABOR RATE, $/HR	4.50
NUMBER OF LATERALS / FARM	0.5
LENGTH OF LATERAL, FEET	1300.
LATERAL SPACING, FEET	50.
TIME TO MOVE LATERAL, MIN/SET	30.
TIME OF SETTING, HRS	6.
TRANSPORT TIME PER ROTATION, HRS	1.
AREA COVERED BY EACH LATERAL, ACRES	83.31
COST PER LATERAL LINE, $	1980.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	2.
DEEP PERCOLATION, AF/ACRE	0.3542
APPLICATION EFFICIENCY, PERCENT	75.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	1300.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	1300.	2.65

TOTAL COST OF MAINLINE, $	3789.
TOTAL INVESTMENT ($/AC)	119.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	0.57
MAINLINE	1.20
INTEREST ON INVESTMENT	
LATERAL	2.85
MAINLINE	11.37
LABOR COST	9.40
MAINTENANCE COST	3.56
TAXES AND INSURANCE	1.29
T O T A L	30.24

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

POTATOES

FARM DATA:

FIELD LENGTH, FT	1300.
FARM SIZE, ACRES	40.
NO. OF IRRIGATION	9.
FREQUENCY OF IRRIGATION, DAYS	9.
GPM/LATERAL	413.
LABOR RATE, $/HR	4.50
NUMBER OF LATERALS / FARM	0.7
LENGTH OF LATERAL, FEET	1300.
LATERAL SPACING, FEET	50.
TIME TO MOVE LATERAL, MIN/SET	30.
TIME OF SETTING, HRS	6.
TRANSPORT TIME PER ROTATION, HRS	1.
AREA COVERED BY EACH LATERAL, ACRES	53.47
COST PER LATERAL LINE, $	1980.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	3.
DEEP PERCOLATION, AF/ACRE	0.4581
APPLICATION EFFICIENCY, PERCENT	75.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	1300.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	1300.	2.65

TOTAL COST OF MAINLINE, $	3789.
TOTAL INVESTMENT ($/AC)	132.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	0.89
MAINLINE	1.20
INTEREST ON INVESTMENT	
LATERAL	4.44
MAINLINE	11.37
LABOR COST	14.39
MAINTENANCE COST	3.95
TAXES AND INSURANCE	1.44
T O T A L	37.69

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

SOIL TYPE NUMBER------ 2

WEIGHTED COST FOR THIS SOIL TYPE AND IRRIGAT TION SYSTEM ALTERNATIVE---->>>	31.50	DOLLARS PER ACRE
WEIGHTED WATER APPLICATION EFFICIENCY-----------	75.00	PERCENT
WEIGHTED VOLUME OF DEEP PERCOLATION ------------	0.4135	AC-FT PER AC PER YR
WEIGHTED VOLUME OF SURFACE RUNOFF ------------	0.0	AC-FT PER AC PER YR

ANNUAL COST OF IRRIGATION--------SIDE ROLL (AMMON) 40 ACRES
SOIL TYPE NUMBER----- 2

ALFALFA

FARM DATA:

FIELD LENGTH, FT	1300.
FARM SIZE, ACRES	40.
NO. OF IRRIGATION	4.
FREQUENCY OF IRRIGATION, DAYS	20.
GPM/LATERAL	446.
LABOR RATE, $/HR	6.50
NUMBER OF LATERALS / FARM	0.7
LENGTH OF LATERAL, FEET	1300.
LATERAL SPACING, FEET	50.
TIME TO MOVE LATERAL, MIN/SET	15.
TIME OF SETTING, HRS	12.
TRANSPORT TIME PER ROTATION, HRS	0.
AREA COVERED BY EACH LATERAL, ACRES	59.63
COST PER LATERAL LINE, $	6600.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	1.
DEEP PERCOLATION, AF/ACRE	0.3938
APPLICATION EFFICIENCY, PERCENT	78.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	1300.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	1300.	2.65

TOTAL COST OF MAINLINE, $	3789.
TOTAL INVESTMENT ($/AC)	205.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	2.67
MAINLINE	1.20
INTEREST ON INVESTMENT	
LATERAL	13.28
MAINLINE	11.37
LABOR COST	4.58
MAINTENANCE COST	6.16
TAXES AND INSURANCE	2.25
TOTAL	41.51

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

GRAIN

FARM DATA:

FIELD LENGTH, FT	1300.
FARM SIZE, ACRES	40.
NO. OF IRRIGATION	5.
FREQUENCY OF IRRIGATION, DAYS	17.
GPM/LATERAL	493.
LABOR RATE, $/HR	6.50
NUMBER OF LATERALS / FARM	0.5
LENGTH OF LATERAL, FEET	1300.
LATERAL SPACING, FEET	50.
TIME TO MOVE LATERAL, MIN/SET	15.
TIME OF SETTING, HRS	8.
TRANSPORT TIME PER ROTATION, HRS	0.
AREA COVERED BY EACH LATERAL, ACRES	76.01
COST PER LATERAL LINE, $	6600.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	1.
DEEP PERCOLATION, AF/ACRE	0.3469
APPLICATION EFFICIENCY, PERCENT	78.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	1300.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	1300.	2.65

TOTAL COST OF MAINLINE, $	3789.
TOTAL INVESTMENT ($/AC)	182.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	2.10
MAINLINE	1.20
INTEREST ON INVESTMENT	
LATERAL	10.42
MAINLINE	11.37
LABOR COST	5.67
MAINTENANCE COST	5.45
TAXES AND INSURANCE	1.99
TOTAL	38.18

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

ANNUAL COST OF IRRIGATION-------SIDE ROLL (AMMON) 40 ACRES
SOIL TYPE NUMBER----- 2

PASTURE			PUTATOES		
FARM DATA:			FARM DATA:		
FIELD LENGTH, FT		1300.	FIELD LENGTH, FT		1300.
FARM SIZE, ACRES		40.	FARM SIZE, ACRES		40.
NO. OF IRRIGATION		6.	NO. OF IRRIGATION		9.
FREQUENCY OF IRRIGATION, DAYS		14.	FREQUENCY OF IRRIGATION, DAYS		9.
GPM/LATERAL		474.	GPM/LATERAL		379.
LABOR RATE, $/HR		6.50	LABOR RATE, $/HR		6.50
NUMBER OF LATERALS / FARM		0.5	NUMBER OF LATERALS / FARM		0.7
LENGTH OF LATERAL, FEET		1300.	LENGTH OF LATERAL, FEET		1300.
LATERAL SPACING, FEET		50.	LATERAL SPACING, FEET		50.
TIME TO MOVE LATERAL, MIN/SET		15.	TIME TO MOVE LATERAL, MIN/SET		15.
TIME OF SETTING, HRS		6.	TIME OF SETTING, HRS		6.
TRANSPORT TIME PER ROTATION,HRS		0.	TRANSPORT TIME PER ROTATION,HRS		0.
AREA COVERED BY EACH LATERAL, ACRES		83.44	AREA COVERED BY EACH LATERAL, ACRES		53.59
COST PER LATERAL LINE, $		6600.	COST PER LATERAL LINE, $		6600.
ALLOWABLE INTAKE RATE, IN/HR		0.60	ALLOWABLE INTAKE RATE, IN/HR		0.60
TOTAL LABOR, HR/AC/YR		1.	TOTAL LABOR, HR/AC/YR		2.
DEEP PERCOLATION,AF/ACRE		0.3117	DEEP PERCOLATION,AF/ACRE		0.4031
APPLICATION EFFICIENCY,PERCENT		78.00	APPLICATION EFFICIENCY,PERCENT		78.00
MAINLINE DATA:			MAINLINE DATA:		
TOTAL AREA SERVED BY MAINLINE, ACRES		40.	TOTAL AREA SERVED BY MAINLINE, ACRES		40.
TOTAL LENGTH OF MAINLINE, FEET		1300.	TOTAL LENGTH OF MAINLINE, FEET		1300.
DIAMETER(IN)	LENGTH(FT)	COST ($/FT)	DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	1300.	2.65	5.	1300.	2.65
TOTAL COST OF MAINLINE, $		3789.	TOTAL COST OF MAINLINE, $		3789.
TOTAL INVESTMENT ($/AC)		174.	TOTAL INVESTMENT ($/AC)		218.
ANNUAL COST:		$/AC	ANNUAL COST:		$/AC
DEPRECIATION			DEPRECIATION		
LATERAL		1.91	LATERAL		2.97
MAINLINE		1.20	MAINLINE		1.20
INTEREST ON INVESTMENT			INTEREST ON INVESTMENT		
LATERAL		9.49	LATERAL		14.78
MAINLINE		11.37	MAINLINE		11.37
LABOR COST		6.78	LABOR COST		10.37
MAINTENANCE COST		5.22	MAINTENANCE COST		6.54
TAXES AND INSURANCE		1.90	TAXES AND INSURANCE		2.39
TOTAL		37.86	TOTAL		49.61

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

SOIL TYPE NUMBER------ 2

WEIGHTED COST FOR THIS SOIL TYPE AND IRRIGAT TION SYSTEM ALTERNATIVE---->>>	41.79	DOLLARS PER ACRE
WEIGHTED WATER APPLICATION EFFICIENCY-----------	78.00	PERCENT
WEIGHTED VOLUME OF DEEP PERCOLATION ------------	0.3639	AC-FT PER AC PER YR
WEIGHTED VOLUME OF SURFACE RUNOFF ------------	0.0	AC-FT PER AC PER YR

ANNUAL COST OF IRRIGATION-------CENTER PIVOT (AMMON) 40.0 ACRES
SOIL TYPE NUMBER----- 2

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FARM DATA:

FIELD LENGTH, FT	650.
FARM SIZE, ACRES	40.
NO. OF IRRIGATION	4.
FREQUENCY OF IRRIGATION, DAYS	20.
GPM/LATERAL	260.
LABOR RATE, $/HR	7.50
NUMBER OF LATERALS / FARM	1.0
LENGTH OF LATERAL, FEET	650.
LATERAL SPACING, FEET	0.
TIME TO MOVE LATERAL, MIN/SET	0.
TIME OF SETTING, HRS	6.
TRANSPORT TIME PER ROTATION,HRS	0.
AREA COVERED BY EACH LATERAL, ACRES	38.81
COST PER LATERAL LINE, $	22000.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	2.
DEEP PERCOLATION,AF/ACRE	0.2685
APPLICATION EFFICIENCY,PERCENT	85.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	650.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	650.	2.65

TOTAL COST OF MAINLINE, $	1895.
TOTAL INVESTMENT ($/AC)	614.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	29.07
MAINLINE	0.66
INTEREST ON INVESTMENT	
LATERAL	68.02
MAINLINE	5.68
LABOR COST	0.0
MAINTENANCE COST	11.81
TAXES AND INSURANCE	6.71
T O T A L	121.95

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

GRAIN

FARM DATA:

FIELD LENGTH, FT	650.
FARM SIZE, ACRES	40.
NO. OF IRRIGATION	5.
FREQUENCY OF IRRIGATION, DAYS	17.
GPM/LATERAL	223.
LABOR RATE, $/HR	7.50
NUMBER OF LATERALS / FARM	1.0
LENGTH OF LATERAL, FEET	650.
LATERAL SPACING, FEET	0.
TIME TO MOVE LATERAL, MIN/SET	0.
TIME OF SETTING, HRS	6.
TRANSPORT TIME PER ROTATION,HRS	0.
AREA COVERED BY EACH LATERAL, ACRES	38.81
COST PER LATERAL LINE, $	22000.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	2.
DEEP PERCOLATION,AF/ACRE	0.2365
APPLICATION EFFICIENCY,PERCENT	85.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	650.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	650.	2.65

TOTAL COST OF MAINLINE, $	1895.
TOTAL INVESTMENT ($/AC)	614.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	29.07
MAINLINE	0.66
INTEREST ON INVESTMENT	
LATERAL	68.02
MAINLINE	5.68
LABOR COST	0.0
MAINTENANCE COST	11.81
TAXES AND INSURANCE	6.71
T O T A L	121.95

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

ANNUAL COST OF IRRIGATION--------CENTER PIVOT (AMMON) 40.0 ACRES
SOIL TYPE NUMBER----- 2

PASTURE

FARM DATA:

FIELD LENGTH, FT	650.
FARM SIZE, ACRES	40.
NC. OF IRRIGATION	6.
FREQUENCY OF IRRIGATION, DAYS	14.
GPM/LATERAL	194.
LABOR RATE, $/HR	7.50
NUMBER OF LATERALS / FARM	1.0
LENGTH OF LATERAL, FEET	650.
LATERAL SPACING, FEET	0.
TIME TO MOVE LATERAL, MIN/SET	0.
TIME OF SETTING, HRS	6.
TRANSPORT TIME PER ROTATION,HRS	0.
AREA COVERED BY EACH LATERAL, ACRES	38.81
COST PER LATERAL LINE, $	22000.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	2.
DEEP PERCOLATION,AF/ACRE	0.2125
APPLICATICN EFFICIENCY,PERCENT	85.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	650.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	650.	2.65

TOTAL COST OF MAINLINE, $	1895.
TOTAL INVESTMENT ($/AC)	614.

ANNUAL COST:	$/AC
DEPRECIATION	
LATERAL	29.07
MAINLINE	0.66
INTEREST CN INVESTMENT	
LATERAL	68.02
MAINLINE	5.68
LABOR COST	0.0
MAINTENANCE COST	11.81
TAXES AND INSURANCE	6.71
T O T A L	121.95

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

POTATOES

FARM DATA:

FIELD LENGTH, FT	650.
FARM SIZE, ACRES	40.
NC. OF IRRIGATION	9.
FREQUENCY OF IRRIGATION, DAYS	9.
GPM/LATERAL	241.
LABOR RATE, $/HR	7.50
NUMBER OF LATERALS / FARM	1.0
LENGTH OF LATERAL, FEET	650.
LATERAL SPACING, FEET	0.
TIME TO MOVE LATERAL, MIN/SET	0.
TIME OF SETTING, HRS	6.
TRANSPORT TIME PER ROTATION,HRS	0.
AREA COVERED BY EACH LATERAL, ACRES	38.81
COST PER LATERAL LINE, $	22000.
ALLOWABLE INTAKE RATE, IN/HR	0.60
TOTAL LABOR, HR/AC/YR	2.
DEEP PERCOLATION,AF/ACRE	0.2749
APPLICATION EFFICIENCY,PERCENT	85.00

MAINLINE DATA:

TOTAL AREA SERVED BY MAINLINE, ACRES	40.
TOTAL LENGTH OF MAINLINE, FEET	650.

DIAMETER(IN)	LENGTH(FT)	COST ($/FT)
5.	650.	2.65

TOTAL CCST OF MAINLINE, $	1895.
TOTAL INVESTMENT ($/AC)	614.

ANNUAL COST:	$/AC
DEPRECIATICN	
LATERAL	29.07
MAINLINE	0.66
INTEREST CN INVESTMENT	
LATERAL	68.02
MAINLINE	5.68
LABOR COST	0.0
MAINTENANCE COST	11.81
TAXES AND INSURANCE	6.71
T O T A L	121.95

NOTE: TOTAL ANNUAL COST DOES NOT INCLUDE PUMP UNIT AND RESERVOIRS

SOIL TYPE NUMBER------ 2

WEIGHTED COST FOR THIS SOIL TYPE AND IRRIGAT TION SYSTEM ALTERNATIVE---->>>	121.95	DOLLARS PER ACRE
WEIGHTED WATER APPLICATION EFFICIENCY-----------	85.00	PERCENT
WEIGHTED VOLUME OF DEEP PERCOLATION ------------	0.2481	AC-FT PER AC PER YR
WEIGHTED VOLUME OF SURFACE RUNOFF ------------	0.0	AC-FT PER AC PER YR

UNLINED CANAL---REACH NUMBER ID24

Q (CFS)	COST OF STRUCTURE	COST OF EARTHWORK	COST OF LINING	COST OF RIGHT OF/WAY	TOTAL CONST. COST	ANNUAL EQUI COST	VEL FPS	CONV EFF.
40.	0.	18185.	0.	2180.	20365.	2528.	1.5	95.8
48.	0.	25535.	0.	2480.	28014.	3478.	1.8	96.3
56.	0.	25865.	0.	2488.	28354.	3520.	1.8	96.5
64.	0.	28224.	0.	2572.	30796.	3823.	1.9	96.7
72.	0.	29742.	0.	2626.	32368.	4018.	1.9	96.9
80.	0.	31344.	0.	2682.	34026.	4224.	1.9	97.0
88.	0.	33021.	0.	2734.	35755.	4439.	2.0	97.1
96.	0.	35403.	0.	2792.	38195.	4742.	2.0	97.2
104.	0.	37191.	0.	2841.	40032.	4970.	2.0	97.3
112.	0.	38546.	0.	2884.	41430.	5143.	2.1	97.4

UNLINED CANAL---REACH NUMBER ID24

>>>>>> EARTHWORK COMPUTATION FOR THIS REACH <<<<<<<<

Q = 120

STATION	X SLOPE	TOTAL CUT	ROCK CUT	COMMON EXCAV STA-STA	COMMON EXCAV ACCUMUL	ROCK EXCAV STA-STA	ROCK EXCAV ACCUMUL	COMPACT. STA-STA	EMBANK. ACCUMUL	FILL BANK STA-STA	FILL BANK ACCUMUL	BALANCE STA-STA	BALANCE ACCUMUL	ROW
				0.		0.		0.		0.		0.		
0+ 0	99.99	3.1	0.0		0.		0.		0.		0.		0.	50.8
				4387.		0.		0.		4025.		-242.		
25+ 0	59.99	3.1	0.0		4387.		0.		0.		4025.		-242.	50.8
				4415.		0.		0.		4051.		-243.		
50+16	99.99	3.1	0.0		8802.		0.		0.		8075.		-485.	50.8

>>>>>> SUMMARY OF EARTHWORK FOR THIS REACH <<<<<<

Q = 120 CFS

COMMON EXCAVATION TOTAL	8802. CU YD
ROCK EXCAVATION TOTAL	0. CU YD
BACKFILL TOTAL	8075. CU YD
COMPACTING BACKFILL TOTAL	0. CU YD
AVERAGE R-O-W	51. FT

UNLINED CANAL---REACH NUMBER ID24

ESTIMATED COST OF STRUCTURES

Q = 120 CFS

ESTIMATED COST OF SIPHON..........................	0.
ESTIMATED COST OF TUNNEL..........................	0.
ESTIMATED COST OF DROPS...........................	0.
ESTIMATED COST OF CONCRETE CHECKS.................	0.
ESTIMATED COST OF MODIFIED P. FLUME...............	0.
ESTIMATED COST OF TURNOUTS........................	0.
ESTIMATED COST OF COUNTY BRIDGE...................	0.
ESTIMATED COST OF FARM BRIDGE.....................	0.
ESTIMATED COST OF DRAINAGE CROSSINGS..............	0.
CONTINGENCIES (10)......................	0.
TOTAL COST OF STRUCTURES FOR THIS REACH...........	0.

COST SUMMARY FOR THIS #Q#

Q (CFS)	COST OF STRUCTURE	COST OF EARTHWORK	COST OF LINING	COST OF RIGHT OF/WAY	TOTAL CONST. COST	ANNUAL EQUI COST	VEL FPS	CONV EFF.
120.	0.	39804.	0.	2923.	42728.	5304.	2.1	97.4

INLET ELEV, FT4720.0 OUTLET ELEV, FT4718.0 ORIGINAL OUTLET ELEV, FT4718.0

CONVEYANCE EFFICIENCY = 97.4

AVERAGE CANAL SEEPAGE (AF-FT/CFS OF FLOW) = 6.3189

A = 1731.
B = 30.9
R = 0.978

LINED CANAL---REACH NUMBER SRVB

Q (CFS)	COST OF STRUCTURE	COST OF EARTHWORK	COST OF LINING	COST OF RIGHT OF/WAY	TOTAL CONST. COST	ANNUAL EQUI COST	CONVEYANCE EFFICIENCY
50.	5402.	53400.	20289.	0.	79092.	9818.7	98.8
60.	5402.	54871.	21601.	0.	81874.	10164.1	98.9
70.	5402.	56247.	22784.	0.	84433.	10481.8	98.9
80.	5402.	57547.	23866.	0.	86814.	10777.5	98.9
90.	5402.	58783.	24867.	0.	89053.	11055.3	98.9
100.	5402.	59565.	25802.	0.	91169.	11318.1	98.9
110.	5402.	60597.	26681.	0.	93079.	11555.2	98.9
120.	5402.	61927.	27511.	0.	94840.	11773.7	98.9
130.	5402.	62707.	28300.	0.	96409.	11968.5	98.9
140.	5402.	63443.	29052.	0.	97857.	12153.2	98.9
150.	5402.	64133.	29771.	0.	99306.	12328.2	98.9
160.	5402.	64787.	30462.	0.	100651.	12495.1	98.9

***** SUMMARY OF EARTHWORK FOR REHABILAIATION OF THIS REACH *****

Q = 170 CFS

COMMON EXCAVATION TOTAL	22034. CU YD
FILL FROM CHANNEL EXCAVATION	17627. CU YD
CHANNEL COMPACTED BACKFILL TOTAL	7533. CU YD
COMPACTED EMBANKMENT TOTAL	13268. CU YD
FILL FROM ADJACENT EXCAVATION	0. CU YD
OVERHALL	0. CU YD
AVERAGE MINIMUM RIGHT OF WAY	7. FEET

OLD INLET AND OUTLET ELEV	4635.0	4633.0 FEET
DESIGN INLET AND OUTLET ELEV	4635.0	4633.0 FEET

DESIGN DEPTH OF CHANNEL	5.2 FEET
DESIGN WIDTH OF CHANNEL	8.6 FEET
LENGTH OF REACH	2640. FEET

LINED CANAL---REACH NUMBER SRVB

ESTIMATED COST OF STRUCTURES

Q = 170 CFS

ESTIMATED COST OF SIPHON..........................	0.
ESTIMATED COST OF TUNNEL..........................	0.
ESTIMATED COST OF DROPS...........................	0.
ESTIMATED COST OF CONCRETE CHECKS.................	0.
ESTIMATED COST OF MODIFIED P. FLUME...............	0.
ESTIMATED COST OF TURNOUTS........................	4911.
ESTIMATED COST OF COUNTY BRIDGE...................	0.
ESTIMATED COST OF FARM BRIDGE.....................	0.
ESTIMATED COST OF DRAINAGE CROSSINGS..............	0.
CONTINGENCIES (10)......................	491.
TOTAL COST OF STRUCTURES FOR THIS REACH...........	5402.

COST SUMMARY FOR THIS #Q#

Q (CFS)	COST OF STRUCTURE	COST OF EARTHWORK	COST OF LINING	COST OF RIGHT OF/WAY	TOTAL CONST. COST	ANNUAL EQUI COST	CONVEYANCE EFFICIENCY
170.	5402.	65409.	31126.	0.	101937.	12654.8	98.9

CONVEYANCE EFFICIENCY = 98.9

AVERAGE CANAL SEEPAGE (AF-FT/CFS OF FLOW) = 0.2992

A = 8860.
B = 23.3
R = 0.992

GRAVITY PIPE---REACH NUMBER SRVB

Q (CFS)	DIAMETER (IN)	LENGTH (FT)	PIPE COST 1/ ($)	TURNOUTS 2/ ($)	RIGHT OF WAY ($)	EARTHWORK 3/ ($)	TOTAL COST ($)	ANNUAL COST ($)	PIPE TYPE
50.	50.	2640.	114048.	14792.	1061.	54578.	184478.	22875.	CONCRETE
60.	54.	2640.	123552.	14792.	1061.	54619.	194024.	24058.	CONCRETE
70.	56.	2640.	136224.	14792.	1061.	54634.	206711.	25631.	CONCRETE
80.	60.	2640.	145728.	14792.	1061.	54653.	216233.	26811.	CONCRETE
90.	62.	2640.	158400.	14792.	1061.	54656.	228908.	28382.	CONCRETE
100.	66.	2640.	171072.	14792.	1061.	54651.	241575.	29951.	CONCRETE
110.	68.	2640.	183744.	14792.	1061.	54643.	254239.	31521.	CONCRETE
120.	70.	2640.	196416.	14792.	1061.	54630.	266899.	33090.	CONCRETE
130.	72.	2640.	196416.	14792.	1061.	54614.	266882.	33088.	CONCRETE
140.	74.	2640.	224928.	14792.	1061.	54594.	295374.	36619.	CONCRETE
150.	76.	2640.	224928.	14792.	1061.	54570.	295350.	36616.	CONCRETE
160.	78.	2640.	224928.	14792.	1061.	54542.	295322.	36613.	CONCRETE

NOTE:

1/PIPE COST INCLUDES COST OF PIPE,LAYING OF PIPE,COST OF FITTINGS,VALVES,BLOCKING,ETC.
2/TURNOUT COST INCLUDES GATE VALVE,LINE METER,PRESSURE REDUCING VALVE,CONCRETE PIPE,STEEL PIPE DELIVERY,ETC
3/EARTHWORK COST INCLUDES TRENCHING, BACKFILLING AND COMPACTING BACKFILL

PIPE EARTHWORK FOR THE ABOVE REACH OF INFLOW Q = 170 CFS

P I P E V O L U M E

REHABILITATION PLAN---LAYING PIPE IN OLD CHANNEL

TOTAL EXCAVATION = 586. CUBIC YARDS

TOTAL COMPACTED BACKFILL= 1436. CUBIC YARDS

TOTAL BACKFILL (OLD CHAN)= 0.CUBIC YARDS

TOTAL OVERHAUL = 0.CUBIC YARDS

SUBSTITUTE EXCAVATION FROM AREA ADJACENT TO PIPELINE
IN PLACE OF OVERHAUL FROM OUTSIDE AREA.

ADJACENT EXCAVATION = 41831. CUBIC YARDS
TOTAL BACKFILL = 2708. CUBIC YARDS

Q (CFS)	DIAMETER (IN)	LENGTH (FT)	PIPE COST 1/ ($)	TURNOUTS 2/ ($)	RIGHT OF WAY ($)	EARTHWORK 3/ ($)	TOTAL COST ($)	ANNUAL COST ($)	PIPE TYPE
170.	80.	2640.	256608.	14792.	1061.	54510.	326971.	40535.	CONCRETE

***** SUMMARY FOR THIS REACH *****

COST INDEX FOR PIPE SYSTEM(B=1976)= 1.
LENGTH OF REACH IN FEET = 2640.
ELEVATION OF PIPE OUTLET, FEET = 4633.
ELEVATION OF PIPE INLET, FEET = 4635.
H.G.L. REQ. AT PIPE OUTLET,FEET = 4638.
H.G.L. REQ. AT PIPE INLET, FEET = 4640.
WIDTH OF EASEMENT, FEET = 35.
VALUE OF EASEMENT FOR CROPPED LAND= 500.
VALUE OF EASEMENT FOR OTHER LAND = 100.
PERCENT LENGTH OF OTHER EASEMENT = 0.
NUMBER OF TURNOUTS:

NUMBER= 6. SIZE (IN)= 12.

CHECK DATA FOR .....Q = 170. CFS
CAPACITY,CFS = 170.
DIAMETER,INCHES (ROUNDED) = 80.
AVERAGE HEAD CLASS, FEET = 25.
TYPE OF COVER =
PIPE COST, $/FT = 81.00
MISC COST, (DOLLARS) = 0.0

A = 15824.
B = 139.9
R = 0.991

HIGH PRESSURE PIPE---REACH NUMBER SRVB

Q (CFS)	DIAMETER (IN)	LENGTH (FT)	PIPE COST 1/ ($)	TURNOUTS 2/ ($)	RIGHT OF WAY ($)	EARTHWORK 3/ ($)	TOTAL COST ($)	ANNUAL COST ($)	PIPE TYPE
200.	44.	6389.	324260.	0.	2200.	544859.	871318.	104914.	STEEL
207.	46.	6389.	339230.	0.	2200.	545906.	887336.	106843.	STEEL
214.	46.	6389.	339230.	0.	2200.	545906.	887336.	106843.	STEEL
221.	46.	6389.	339230.	0.	2200.	545906.	887336.	106843.	STEEL
228.	46.	6389.	339230.	0.	2200.	545906.	887336.	106843.	STEEL
235.	48.	6389.	353946.	0.	2200.	546937.	903083.	108739.	STEEL
242.	48.	6389.	353946.	0.	2200.	546937.	903083.	108739.	STEEL
249.	48.	6389.	353946.	0.	2200.	546937.	903083.	108739.	STEEL
256.	48.	6389.	353946.	0.	2200.	546937.	903083.	108739.	STEEL
263.	50.	6389.	414007.	0.	2200.	527284.	943491.	113603.	CONCRETE

NOTE:

1/PIPE COST INCLUDES COST OF PIPE,LAYING OF PIPE,COST OF FITTINGS,VALVES,BLOCKING,ETC.
2/TURNOUT COST INCLUDES GATE VALVE,LINE METER,PRESSURE REDUCING VALVE,CONCRETE PIPE,STEEL PIPE DELIVERY,ETC
3/EARTHWORK COST INCLUDES TRENCHING, BACKFILLING AND COMPACTING BACKFILL

PIPE EARTHWORK FOR THE ABOVE REACH OF INFLOW Q = -270 CFS

P I P E   V O L U M E

REHABILITATION PLAN---LAYING PIPE IN OLD CHANNEL

TOTAL EXCAVATION = 0. CUBIC YARDS

TOTAL COMPACTED BACKFILL= 26282. CUBIC YARDS

TOTAL BACKFILL (OLD CHAN)= 0.CUBIC YARDS

TOTAL OVERHAUL = 0.CUBIC YARDS

SUBSTITUTE EXCAVATION FROM AREA ADJACENT TO PIPELINE
IN PLACE OF OVERHAUL FROM OUTSIDE AREA.

ADJACENT EXCAVATION = 200974. CUBIC YARDS
TOTAL BACKFILL = 58469. CUBIC YARDS

Q (CFS)	DIAMETER (IN)	LENGTH (FT)	PIPE COST 1/ ($)	TURNOUTS 2/ ($)	RIGHT OF WAY ($)	EARTHWORK 3/ ($)	TOTAL COST ($)	ANNUAL COST ($)	PIPE TYPE
270.	52.	6389.	452341.	0.	2200.	527344.	981885.	118226.	CONCRETE

***** SUMMARY FOR THIS REACH *****

COST INDEX FOR PIPE SYSTEM(B=1976)= 1.
LENGTH OF REACH IN FEET = 6389.
ELEVATION OF PIPE OUTLET, FEET = 4640.
ELEVATION OF PIPE INLET, FEET = 4648.
H.G.L. REQ. AT PIPE OUTLET,FEET = 4780.
H.G.L. REQ. AT PIPE INLET, FEET = 4907.
WIDTH OF EASEMENT, FEET = 30.
VALUE OF EASEMENT FOR CROPPED LAND= 500.
VALUE OF EASEMENT FOR OTHER LAND = 100.
PERCENT LENGTH OF OTHER EASEMENT = 0.
NUMBER OF TURNOUTS:

NUMBER= 0. SIZE (IN)= 0.
NUMBER= 0. SIZE (IN)= 0.

CHECK DATA FOR .....Q = 270. CFS
CAPACITY,CFS = 270.
DIAMETER,INCHES (ROUNDED) = 52.
AVERAGE HEAD CLASS, FEET = 300.
TYPE OF COVER =
PIPE COST, $/FT = 59.00
MISC COST, (DOLLARS) = 0.0

A = 76951.
B = 136.4
R = 0.841

Table D-3. Pump systems subprograms.

FARM PUMP---CANAL TO SPRINKLER FOR 1978, 175 FEET TDH 1 UNIT

Q (GPM)	DESIGN MOTOR HP 1/	MAXIMUM ENERGY DEMAND (KW) 2/	SEASONAL ENERGY USE (KWH) 3/	TOTAL CAPITAL COST ($) 4/	ANNUAL CAPITAL COST ($/YR)	ANNUAL O & M COST ($/YR) 5/	ANNUAL TAXES & INS ($/YR)	ANNUAL POWER COST ($/YR) 6/	WELL COST ($) 7/	ANNUAL WELL COST ($/YR)	TOTAL ANNUAL COST ($/YR) 8/
100.	10.	5.	7290.	3328.	469.	100.	55.	640.	0.	0.	1264.
140.	10.	7.	10206.	3751.	529.	113.	62.	827.	0.	0.	1530.
180.	15.	8.	13122.	4101.	578.	123.	68.	1013.	0.	0.	1782.
220.	15.	10.	16037.	4405.	621.	132.	73.	1200.	0.	0.	2026.
260.	20.	12.	18953.	4674.	659.	140.	77.	1386.	0.	0.	2263.
300.	20.	14.	21869.	4918.	694.	148.	81.	1573.	0.	0.	2495.
340.	25.	16.	24785.	5142.	725.	154.	85.	1759.	0.	0.	2724.
380.	25.	18.	27701.	5349.	754.	160.	88.	1946.	0.	0.	2949.
420.	30.	20.	30617.	5542.	782.	166.	91.	2132.	0.	0.	3172.
460.	30.	22.	33533.	5725.	807.	172.	94.	2319.	0.	0.	3392.
500.	35.	24.	36449.	5897.	832.	177.	97.	2505.	0.	0.	3611.
540.	35.	25.	39365.	6060.	855.	182.	100.	2692.	0.	0.	3828.
580.	40.	27.	42281.	6216.	877.	186.	103.	2878.	0.	0.	4044.
620.	40.	29.	45197.	6365.	898.	191.	105.	3065.	0.	0.	4259.
660.	45.	31.	48112.	6508.	918.	195.	107.	3251.	0.	0.	4472.
700.	45.	33.	51028.	6646.	937.	199.	110.	3438.	0.	0.	4684.
740.	50.	35.	53944.	6778.	956.	203.	112.	3624.	0.	0.	4896.
780.	50.	37.	56860.	6906.	974.	207.	114.	3811.	0.	0.	5106.
820.	55.	39.	59776.	7030.	992.	211.	116.	3997.	0.	0.	5316.
860.	55.	41.	62692.	7150.	1009.	215.	118.	4184.	0.	0.	5525.
900.	60.	42.	65608.	7267.	1025.	218.	120.	4370.	0.	0.	5733.
940.	60.	44.	68524.	7380.	1041.	221.	122.	4557.	0.	0.	5941.
980.	65.	46.	71440.	7490.	1056.	225.	124.	4743.	0.	0.	6148.

NOTE:

1/ HP WAS ROUNDED TO NEAREST 5 HORSEPOWER AND CALCULATED USING A MOTOR EFFICIENCY OF 90 %. (TOTAL PLANT HP)
2/ MAXIMUM MONTHLY DEMAND OF SERVICE LINE
3/ ENERGY USE CALCULATED USING ADJUSTED (LOWERED) EFFICIENCIES FOR NONPEAK MONTHS.
AND CALCULATED ASSUMING PUMP OPERATES 80. % OF TIME DURING PEAK USE MONTH
4/ PUMP COST INCLUDES HOUSING,DISCHARGE FACILITIES, SUMP, ELEC. CONTR, GEAR, WIRING, AND SHORT INTAKE INSTALLED
5/ O & M INCLUDES MINOR REPLACEMENT COST
6/ POWER COST IS ESCALATED VALUE COMPUTED WITH AN EQUIVALENT COST FACTOR FOR ESCALATION OF **** PERCENT
7/ WELL COST INCLUDES DRILLING, CASING, TESTING, SCREEN ASSEMBLY, ETC.
8/ ANNUAL PUMPING COST INCLUDES AMORTIZATION OF PUMP UNIT AND WELL, O & M, TAXES & INS. AND ESCALATED POWER COST

TOTAL ANNUAL DEMAND COST AT PRESENT PRICES.. 1541.
TOTAL ANNUAL ENERGY COST AT PRESENT PRICES.. 1100.
TOTAL ANNUAL POWER COST AT PRESENT PRICES.. 2641.
TOTAL ANNUAL POWER COST AT ENERGY INFLATION RATE OF 10.00 PERCENT
OVER PROJECT LIFE... 4743.

TOTAL DYNAMIC HEAD, FEET.......... 175.
PUMP-MOTOR EFF, PERCENT.......... 70.
SERVICE LIFE OF PUMPING UNIT...... 16.
NUMBER OF UNITS................... 1.
DEMAND OF SMALLEST UNIT, KW....... 46.
INTEREST RATE, PERCENT............ 12.
COST INDEX, BASE=1976............. 1.17

FOR DESIGN FLOW RATE OF 980. GPM:
SALVAGE VALUE OF PUMP (10. %) 749.
MISC. COSTS (SUMP,DISCHARGE,ETC) (5. %) 326.
ENGINEERING COSTS (INDIRECT) (0. %) 0.
CONTINGENCY FOR FIELD COSTS (15. %) 1124.
OTHER EXPENSES (0. % OF INITIAL INVEST.) 0.
ANNUAL O & M COSTS (3. % OF INITIAL INVEST.) 225.
ANNUAL TAXES & INS (3. % OF INITIAL INVEST.) 124.

FARM PUMP---CANAL TO SPRINKLER FOR 1978, 175 FEET TDH 1 UNIT

A = 824.
B = 5.5
R = 1.000

RIVER PUMP--- IDAHO CANAL ID

Q (CFS) 1/	MAXIMUM ENERGY DEMAND (KW) 2/	SEASONAL ENERGY USE (KWH) 3/	DESIGN MOTOR HP 4/	ESTIMATED CAPTIAL COST ($)	ANNUAL EQUIVALENT COST ($/YR) 5/	ANNUAL OPERATION COST ($/YR)	ANNUAL MAINT. COST ($/YR)	ANNUAL REPLACEMENT COST ($/YR)	ANNUAL POWER COST ($/YR) 6/	TOTAL ANNUAL PUMPING COST ($/YR) 7/
100.	4681.	0.90E 07	5645.	549567.	66593.	22428.	16961.	---8/	744912.	850894.
105.	4868.	0.94E 07	5870.	572901.	69420.	22483.	17413.	---8/	774577.	883894.
110.	5059.	0.98E 07	6150.	596011.	72220.	22536.	17856.	---8/	811363.	923975.
115.	5330.	0.10E 08	6430.	619120.	75021.	22586.	15547.	191.	848149.	961492.
120.	5561.	0.11E 08	6710.	642079.	77803.	22634.	15908.	198.	884534.	1001477.
125.	5793.	0.11E 08	6990.	664889.	80567.	22680.	16263.	206.	891495.	1011210.
130.	6024.	0.12E 08	7270.	687548.	83312.	22725.	16611.	213.	891495.	1014356.
135.	6255.	0.12E 08	7550.	710132.	86049.	22768.	16953.	221.	891495.	1017485.
140.	6486.	0.13E 08	7830.	732642.	88776.	22809.	17289.	228.	891495.	1020598.
145.	6721.	0.13E 08	8105.	755054.	91492.	22849.	17620.	236.	891495.	1023692.
150.	6953.	0.13E 08	8385.	777254.	94182.	22888.	17945.	243.	891495.	1026753.
155.	7184.	0.14E 08	8665.	799304.	96854.	22925.	18266.	250.	891495.	1029790.
160.	7415.	0.14E 08	8945.	821354.	99526.	22962.	18582.	258.	891495.	1032822.
165.	7646.	0.15E 08	9225.	843179.	102171.	22997.	18893.	265.	891495.	1035820.
170.	7878.	0.15E 08	9505.	864929.	104806.	23031.	19200.	272.	891495.	1038804.
175.	8109.	0.16E 08	9785.	886604.	107433.	23065.	19503.	279.	891495.	1041774.
180.	8340.	0.16E 08	10065.	908054.	110032.	23097.	19802.	286.	891495.	1044712.
185.	8572.	0.17E 08	10345.	929579.	112640.	23129.	20097.	293.	891495.	1047654.
190.	8807.	0.17E 08	10625.	950804.	115212.	23160.	20389.	300.	891495.	1050554.
195.	9038.	0.17E 08	10900.	972029.	117784.	23190.	20677.	306.	891495.	1053451.
200.	9269.	0.18E 08	11180.	992954.	120319.	23219.	20961.	313.	891495.	1056307.

NOTE:

1/ WEAR ALLOWANCE WAS INCLUDED FOR SEDIMENT-LADEN WATER.
2/ MAXIMUM DEMAND OF SERVICE LINE (KW) = (PEAK Q * (1.+ %WEAR)) * TDH/(EFF*8.8)*0.746
3/ CALCULATED WITH ADJUSTED EFFICIENCIES FOR NONPEAK MONTHS
AND CALCULATED ASSUMING PLANT OPERATES 100. % OF THE PEAK USE MONTH
4/ DESIGN HORSEPOWER OF MOTOR. ROUNDED TO NEAREST 5 HP. ASSUMED MOTOR EFFICIENCY = 0.90
5/ INCLUDES CONTINGENCIES
6/ POWER COST IS ESCALATED VALUE COMPUTED WITH AN EQUIVALENT COST FACTOR FOR ESCALATION OF **** PERCENT
INCLUDES TRANSMISSION LINE AND SWITCHING BAY COST IF APPLICABLE (PRIVATE LINE)
7/ ANNUAL PUMPING COST INCLUDES ANNUAL EQUIV. COST OF PUMPING PLANT, OM AND R, AND POWER COST.

SUMMARY OF PUMPING PLANT DATA:

TYPE OF PUMPING UNIT----VERTICAL PUMP	
DATE OF ESTIMATE	6/78
INTEREST RATE, PERCENT	12.0
ESTIMATED SYSTEM LIFE, YEARS	40.

COST SUMMARY FOR THE LAST 'Q' CONSIDERED:

PLANT CAPACITY, CFS	200.
TOTAL DYNAMIC HEAD, FEET	350.
NUMBER OF PUMPING UNITS	5.
DEMAND OF SMALLEST UNIT, KW	927.
EFFICIENCY (WIRE TO WATER)-PERCENT	65.
WEAR ALLOWANCE FOR SEDIMENT, PERCENT	1.
STRUCTURES, IMPROVEMENTS AND WATERWAYS	126881.
PUMPS AND MOTORS	468944.
ELECTRICAL ACCESSORIES AND SWITCHGEAR	149194.
INTAKE AND DISCHARGE LINES (MANIFOLDS)	82444.
SUBTOTAL OF PUMPING PLANT	827462.
CONTINGENCY COST (20.0 %)	165492.
EXTRA INDIRECT COSTS(0.0 %)	0.
SALVAGE COSTS (10.0 %)	99295.
PUMP TOTAL CONSTRUCTION COSTS	992954.
ANNUAL EQUIVALENT PLANT COST	120319.

TRANSMISSION LINE COST	187849.
ADD 50 PERCENT FOR MOUNTAINOUS TERRAIN	0.
ADD 50 PERCENT FOR ROCKY/SWAMPY FOUND.	0.
ADD 100 PERCENT FOR LINE UNDER 5 MILES	187849.
ADD 50 PERCENT FOR LINE 5 TO 20 MILES	0.
SUBTOTAL	375698.
SWITCHING BAY COST	721847.
CONTINGENCIES (TL AND SB)	109754.
TOTAL FIELD COSTS	1207299.
INDIRECT COST	382581.
SERVICE LIFE OF TRANS. LINE & SW BAY	35.
SALVAGE VALUE OF LINE AND BAY (20.%)	317976.
TOTAL POWER LINE CONSTRUCTION COSTS	1589880.

SEASONAL DEMAND CHARGE FOR PRVT UTILITY	221794.
SEASONAL ENERGY CHARGE FOR PRVT UTILITY	251596.
TOT. POWER COST, PRVT UTILITY, CURRT RATE	473390.

	CURRENT RATE	ESCALATED RATE
ANNUAL POWER COST---OPT 1 F.RATE,OWN LINE	661974.	2062164.
ANNUAL POWER COST---OPT 2 WHEELING CHARGE	286178.	891495.
ANNUAL POWER COST---OPT 3 PRIVATE UTILITY	473390.	1474690.

RIVER PUMP--- IDAHO CANAL ID

A =	782303.
B =	1504.5
R =	0.830

APPENDIX E

CONTROL PROGRAMS, INPUT DATA AND MATRIX PICTURES OF THE MATHEMATICAL PROGRAMMING PROBLEMS

E-1. Mixed integer-linear programming (MIP) problem for Rehabilitation plan with gravity supply systems

E-2. Linear programming (LP) problem for Consolidation plan with high pressure pipe system

Figure E-1. Mixed integer-linear programming (MIP) problem for rehabilitation plan with gravity supply systems

Control program for mixed integer-linear programming of APEX III (Reference: Control Data Corporation, 1979).

```
MIP,CM100000,T30.
USER(PNLSNGI,A)
CHARGE,103000,0019.
ATTACH(APEX=APEXIII/UN=LIBRARY)
GET,TAPE1=OIDAHO.
PURGE,TAPE5/NA.
PURGE, TAPE 12/NA.
DEFINE, TAPE5.
DEFINE, TAPE12.
RFL,700C).
REDUCE,-.
APEX(SOLVE,MIN,MIP,SV,RANGE)
GOTO,IA.
EXIT.
IA.,RETURN,TAPE12.
RETURN,TAPE5.
REWIND,OUTPUT.
COPYEI,OUTPUT,WIDAHO5.
REWIND,OUTPUT.
DAYFILE,WIDAHO5.
PACK,WIDAHO5.
REPLACE,WIDAHO5.
```

```
NAME          SRVSYS3
ROWS
 G  SRVK
 G  SRVL
 G  SRVM
 G  SRVN
 G  SRVO
 G  SRVP
 G  SRVQ
 G  SRVS
 L  SYSA
 L  SYSE
 L  SYSK
 L  SYSL
 L  SYSM
 L  SYSN
 L  SYSO
 L  SYSP
 L  SYSQ
 L  SYSS
 E  BETAA
 E  BETAE
 E  BETAK
 E  BETAL
 E  BETAM
 E  BETAN
 E  BETAO
 E  BETAP
 E  BETAQ
 E  BETAS
 L  ALPHAA1
 L  ALPHAA2
 L  ALPHAE1
 L  ALPHAE2
 L  ALPHAK1
 L  ALPHAK2
 L  ALPHAK3
 L  ALPHAL1
 L  ALPHAL2
 L  ALPHAL3
 L  ALPHAM1
 L  ALPHAM2
 L  ALPHAM3
 L  ALPHAN1
 L  ALPHAN2
 L  ALPHAN3
 L  ALPHAO1
 L  ALPHAO2
 L  ALPHAO3
 L  ALPHAP1
 L  ALPHAP2
 L  ALPHAP3
 L  ALPHAQ1
 L  ALPHAQ2
 L  ALPHAQ3
 L  ALPHAS1
 L  ALPHAS2
 L  ALPHAS3
 E  SYSOP
 E  SYSCL
 L  WION
 E  VOLON
 E  DEPERC
 E  SEEP
 E  RUNOFF
 E  WCOST
 L  SYSCOST
 N  OBJ
COLUMNS
    UGK       OBJ            61.00000   SRVK           1.00000
    UGK       SYSK            0.02970   DEPERC        -1.24100
    UGK       RUNOFF         -1.90000
    UGK       WCOST          -5.44
    IGK       OBJ            85.00000   SRVK           1.00000
    IGK       SYSK            0.01930   DEPERC        -0.24800
    IGK       RUNOFF         -1.16500
    IGK       WCOST          -3.53
    HMK       OBJ            90.00000   SRVK           1.00000
    HMK       SYSK            0.01500   DEPERC        -0.42270
    HMK       WCOST          -2.75
    SRK       OBJ            97.00000   SRVK           1.00000
    SRK       SYSK            0.01440   DEPERC        -0.37900
    SRK       WCOST          -2.64
    UGL       OBJ            57.00000   SRVL           1.00000
    UGL       SYSL            0.03230   DEPERC        -1.51600
    UGL       RUNOFF         -2.02900
    UGL       WCOST          -5.91
    IGL       OBJ            83.00000   SRVL           1.00000
    IGL       SYSL            0.02010   DEPERC        -0.26600
    IGL       RUNOFF         -1.23400
    IGL       WCOST          -3.68
    HML       OBJ            83.00000   SRVL           1.00000
    HML       SYSL            0.01540   DEPERC        -0.43410
    HML       WCOST          -2.82
    SRL       OBJ            93.00000   SRVL           1.00000
    SRL       SYSL            0.01480   DEPERC        -0.38200
    SRL       WCOST          -2.71
    UGM       OBJ            62.00000   SRVM           1.00000
    UGM       SYSM            0.02690   DEPERC        -1.03600
    UGM       RUNOFF         -1.67600
    UGM       WCOST          -4.92
    IGM       OBJ            85.00000   SRVM           1.00000
    IGM       SYSM            0.01800   DEPERC        -0.21400
    IGM       RUNOFF         -1.03600
    IGM       WCOST          -3.29
    HMM       OBJ            94.00000   SRVM           1.00000
    HMM       SYSM            0.01450   DEPERC        -0.41170
    HMM       WCOST          -2.65
    SRM       OBJ           103.00000   SRVM           1.00000
    SRM       SYSM            0.01400   DEPERC        -0.36230
    SRM       WCOST          -2.56
    UGN       OBJ            63.00000   SRVN           1.00000
    UGN       SYSN            0.02870   DEPERC        -1.04700
    UGN       RUNOFF         -1.84000
    UGN       WCOST          -5.25
    IGN       OBJ            87.00000   SRVN           1.00000
    IGN       SYSN            0.01890   DEPERC        -0.19800
    IGN       RUNOFF         -1.12500
    IGN       WCOST          -3.46
    HMN       OBJ            97.00000   SRVN           1.00000
    HMN       SYSN            0.01490   DEPERC        -0.41780
    HMN       WCOST          -2.73
    SRN       OBJ           104.00000   SRVN           1.00000
    SRN       SYSN            0.01430   DEPERC        -0.36770
    SRN       WCOST          -2.62
    UGO       OBJ            81.00000   SRVO           1.00000
    UGO       SYSO            0.03200   DEPERC        -1.34800
    UGO       RUNOFF         -2.13400
    UGO       WCOST          -5.86
```

IGO	OBJ	103.00000	SRVO	1.00000
IGO	SYSO	0.02020	DEPERC	-0.27000
IGO	RUNOFF	-1.31000		
IGO	WCOST	-3.70		
HMO	OBJ	94.00000	SRVO	1.00000
HMO	SYSO	0.01490	DEPERC	-0.42200
HMO	WCOST	-2.73		
SRO	OBJ	101.00000	SRVO	1.00000
SRO	SYSO	0.01430	DEPERC	-0.37140
SRO	WCOST	-2.62		
UGP	OBJ	46.00000	SRVP	1.00000
UGP	SYSP	0.02920	DEPERC	-0.80800
UGP	RUNOFF	-1.94800		
UGP	WCOST	-5.34		
IGP	OBJ	76.00000	SRVP	1.00000
IGP	SYSP	0.01830	DEPERC	-0.02700
IGP	RUNOFF	-1.02300		
IGP	WCOST	-3.34		
HMP	OBJ	86.00000	SRVP	1.00000
HMP	SYSP	0.01550	DEPERC	-0.42190
HMP	WCOST	-2.84		
SRP	OBJ	91.00000	SRVP	1.00000
SRP	SYSP	0.01490	DEPERC	-0.37120
SRP	WCOST	-2.73		
UGQ	OBJ	89.00000	SRVQ	1.00000
UGQ	SYSQ	0.02940	DEPERC	-1.07400
UGQ	RUNOFF	-2.16000		
UGQ	WCOST	-5.38		
IGQ	OBJ	109.00000	SRVQ	1.00000
IGQ	SYSQ	0.01920	DEPERC	-0.22900
IGQ	RUNOFF	-1.31700		
IGQ	WCOST	-3.51		
HMQ	OBJ	92.00000	SRVQ	1.00000
HMQ	SYSQ	0.01450	DEPERC	-0.40860
HMQ	WCOST	-2.65		
SRQ	OBJ	98.00000	SRVQ	1.00000
SRQ	SYSQ	0.01390	DEPERC	-0.35960
SRQ	WCOST	-2.54		
CPQ	OBJ	153.59999	SRVQ	1.00000
CPQ	SYSQ	0.01279	DEPERC	-0.24520
CPQ	WCOST	-2.34		
UGS	OBJ	85.00000	SRVS	1.00000
UGS	SYSS	0.02880	DEPERC	-0.97700
UGS	RUNOFF	-1.80300		
UGS	WCOST	-5.27		
IGS	OBJ	109.00000	SRVS	1.00000
IGS	SYSS	0.01880	DEPERC	-0.14000
IGS	RUNOFF	-1.08500		
IGS	WCOST	-3.44		
HMS	OBJ	91.00000	SRVS	1.00000
HMS	SYSS	0.01530	DEPERC	-0.42460
HMS	WCOST	-2.80		
SRS	OBJ	99.00000	SRVS	1.00000
SRS	SYSS	0.01470	DEPERC	-0.37360
SRS	WCOST	-2.69		
CPS	OBJ	156.79999	SRVS	1.00000
CPS	SYSS	0.01353	DEPERC	-0.25470
CPS	WCOST	-2.47		
XA1	SYSA	-0.95000	ALPHAA1	1.00000
XA1	WTON	1.00000	VOLON	-1.00000
XA1	SEEP	-11.76000		
YA1	BETAA	1.00000	ALPHAA1	-650.00000
YA1	SYSOP	-3.24000		
XA2	SYSCOST	-135.59999	SYSA	-0.98800
XA2	ALPHAA2	1.00000	WTON	1.00000
XA2	VOLON	-1.00000	SEEP	-0.91880

XA2	OBJ	135.6		
YA2	SYSCOST	-83516.00000	BETAA	1.00000
YA2	ALPHAA2	-650.00000	SYSOP	-3.24000
YA2	OBJ	83516.0		
XE1	SYSA	1.00000	SYSE	-0.96100
XE1	ALPHAE1	1.00000	SEEP	-8.53000
YE1	BETAE	1.00000	ALPHAE1	-420.00000
YE1	SYSOP	-1.68000		
XE2	SYSCOST	-96.70000	SYSA	1.00000
XE2	SYSE	-0.98800	ALPHAE2	1.00000
XE2	SEEP	-0.70050		
XE2	OBJ	96.7		
YE2	SYSCOST	-38300.00000	BETAE	1.00000
YE2	ALPHAE2	-420.00000	SYSOP	-1.68000
YE2	OBJ	38300.0		
XK1	SYSE	1.00000	SYSK	-0.96500
XK1	ALPHAK1	1.00000	SEEP	-7.39000
YK1	SYSCOST	-3684.39990	BETAK	1.00000
YK1	ALPHAK1	-230.00000	SYSOP	-2.30000
YK1	OBJ	3684.4		
XK2	SYSCOST	-168.29999	SYSE	1.00000
XK2	SYSK	-0.98700	ALPHAK2	1.00000
XK2	SEEP	-1.45330		
XK2	OBJ	168.3		
YK2	SYSCOST	-34195.00000	BETAK	1.00000
YK2	ALPHAK2	-230.00000	SYSOP	-2.30000
YK2	OBJ	34195.0		
XK3	SYSCOST	-697.09985	SYSE	1.00000
XK3	SYSK	-1.00000	ALPHAK3	1.00000
XK3	OBJ	697.1		
YK3	SYSCOST	-79630.00000	BETAK	1.00000
YK3	ALPHAK3	-230.00000	SYSCL	-2.30000
YK3	OBJ	79630.0		
XL1	SYSK	1.00000	SYSL	-0.93700
XL1	ALPHAL1	1.00000	SEEP	-15.87000
YL1	SYSCOST	-1292.39990	BETAL	1.00000
YL1	ALPHAL1	-25.00000	SYSOP	-2.08000
YL1	OBJ	1292.4		
XL2	SYSCOST	-103.29999	SYSK	1.00000
XL2	SYSL	-0.98100	ALPHAL2	1.00000
XL2	SEEP	-4.01560		
XL2	OBJ	103.3		
YL2	SYSCOST	-9605.00000	BETAL	1.00000
YL2	ALPHAL2	-25.00000	SYSOP	-2.08000
YL2	OBJ	9605.0		
XL3	SYSCOST	-1032.89990	SYSK	1.00000
XL3	SYSL	-1.00000	ALPHAL3	1.00000
XL3	OBJ	1032.9		
YL3	SYSCOST	-20724.00000	BETAL	1.00000
YL3	ALPHAL3	-25.00000	SYSCL	-2.08000
YL3	OBJ	20724.0		
XM1	SYSK	1.00000	SYSM	-0.97900
XM1	ALPHAM1	1.00000	SEEP	-3.20000
YM1	SYSCOST	-1388.59985	BETAM	1.00000
YM1	ALPHAM1	-180.00000	SYSOP	-1.24000
YM1	OBJ	1388.6		
XM2	SYSCOST	-48.49998	SYSK	1.00000
XM2	SYSM	-0.98800	ALPHAM2	1.00000
XM2	SEEP	-0.64910		
XM2	OBJ	48.5		
YM2	SYSCOST	-16855.00000	BETAM	1.00000
YM2	ALPHAM2	-180.00000	SYSOP	-1.24000
YM2	OBJ	16855.0		
XM3	SYSCOST	-264.00000	SYSK	1.00000
XM3	SYSM	-1.00000	ALPHAM3	1.00000
XM3	OBJ	264.0		

```
YM3        SYSCOST    -31823.00000   BETAM          1.00000      YQ2      SYSCOST    -13087.00000   BETAQ          1.00000
YM3        ALPHAM3      -180.00000   SYSCL         -1.24000      YQ2      ALPHAQ2       -55.00000   SYSOP         -3.33000
YM3        OBJ         31823.0                                   YQ2      OBJ         13087.0
XN1        SYSM            1.00000   SYSN          -0.95300      XQ3      SYSCOST     -1089.09985   SYSQ          -1.00000
XN1        ALPHAN1         1.00000   SEEP         -10.91000      XQ3      SYSS            1.00000   ALPHAQ3        1.00000
YN1        SYSCOST     -1035.79980   BETAN          1.00000      XQ3      OBJ          1089.1
YN1        ALPHAN1       -20.00000   SYSOP         -1.10000      YQ3      SYSCOST    -53453.00000   BETAQ          1.00000
YN1        OBJ          1035.8                                   YQ3      ALPHAQ3       -55.00000   SYSCL         -3.33000
XN2        SYSCOST       -43.09999   SYSM           1.00000      YQ3      OBJ         53453.0
XN2        SYSN           -0.98400   ALPHAN2        1.00000      XS1      SYSO            1.00000   SYSS          -0.97200
XN2        SEEP           -2.52290                               XS1      ALPHAS1         1.00000   SEEP          -5.26000
XN2        OBJ            43.1                                   YS1      SYSCOST     -6603.00000   BETAS          1.00000
YN2        SYSCOST     -9164.00000   BETAN          1.00000      YS1      ALPHAS1       -90.00000   SYSOP         -1.50000
YN2        ALPHAN2       -20.00000   SYSOP         -1.10000      YS1      OBJ          6603.0
YN2        OBJ          9164.0                                   XS2      SYSCOST      -113.39999   SYSO           1.00000
XN3        SYSCOST      -537.00000   SYSM           1.00000      XS2      SYSS           -0.98900   ALPHAS2        1.00000
XN3        SYSN           -1.00000   ALPHAN3        1.00000      XS2      SEEP           -0.36080
XN3        OBJ           537.0                                   XS2      OBJ           113.4
YN3        SYSCOST    -16691.00000   BETAN          1.00000      YS2      SYSCOST     -1326.00000   BETAS          1.00000
YN3        ALPHAN3       -20.00000   SYSCL         -1.10000      YS2      ALPHAS2       -90.00000   SYSOP         -1.50000
YN3        OBJ         16691.0                                   YS2      OBJ          1326.0
XO1        SYSM            1.00000   SYSO          -0.96100      XS3      SYSCOST      -381.19995   SYSO           1.00000
XO1        ALPHAO1         1.00000   SEEP          -8.55000      XS3      SYSS           -1.00000   ALPHAS3        1.00000
YO1        BETAO           1.00000   ALPHAO1     -140.00000      XS3      OBJ           381.2
YO1        SYSOP          -3.01000                               YS3      SYSCOST    -32336.00000   BETAS          1.00000
YO1        SYSCOST     -3434.00000   OBJ         3434.0          YS3      ALPHAS3       -90.00000   SYSCL         -1.50000
XO2        SYSCOST      -126.89999   SYSM           1.00000      YS3      OBJ         32336.0
XO2        SYSO           -0.98500   ALPHAO2        1.00000      COMO     SYSCOST     -2123.00000   SYSOP          1.00000
XO2        SEEP           -2.04140                               COMO     OBJ          2123.0
XO2        OBJ           126.9                                   COMC     SYSCOST      -887.00000   SYSCL          1.00000
YO2        SYSCOST    -21927.00000   BETAO          1.00000      COMC     OBJ           887.0
YO2        ALPHAO2      -140.00000   SYSOP         -3.01000      VON      VOLON           0.00545
YO2        OBJ         21927.0                                   VDP      DEPERC          1.00000
XO3        SYSCOST      -639.39990   SYSM           1.00000      VSEEP    SEEP            1.00000
XO3        SYSO           -1.00000   ALPHAO3        1.00000      VSR      RUNOFF          1.00000
XO3        OBJ           639.4                                   WCST     WCOST           1.0       SYSCOST        1.0
YO3        SYSCOST    -70362.00000   BETAO          1.00000   RHS
YO3        ALPHAO3      -140.00000   SYSCL         -3.01000      RHS      SRVK          522.00000   SRVL         541.00000
YO3        OBJ         70362.0                                   RHS      SRVM          553.00000   SRVN         599.00000
XP1        SYSP           -0.74000   SYSS           1.00000      RHS      SRVO         1477.00000   SRVP         265.00000
XP1        ALPHAP1         1.00000   SEEP         -74.37997      RHS      SRVQ         1578.00000
YP1        SYSCOST      -984.49976   BETAP          1.00000      RHS      SRVS          816.00000   BETAA          1.0
YP1        ALPHAP1       -15.00000   SYSOP         -2.22000      RHS      BETAE           1.0
YP1        OBJ           984.5                                   RHS      BETAK           1.0
XP2        SYSCOST      -242.89999   SYSP          -0.97300      RHS      BETAL           1.0       BETAM          1.0
XP2        SYSS            1.00000   ALPHAP2        1.00000      RHS      BETAN           1.0       BETAO          1.0
XP2        SEEP           -7.71040                               RHS      BETAP           1.0       BETAQ          1.0
XP2        OBJ           242.9                                   RHS      BETAS           1.0
YP2        SYSCOST    -10276.00000   BETAP          1.00000      RHS      WTON           94.60
YP2        ALPHAP2       -15.00000   SYSOP         -2.22000   BOUNDS
YP2        OBJ         10276.0                                  BV BINARY    YA1
XP3        SYSCOST     -1831.39990   SYSP          -1.00000     BV BINARY    YE1
XP3        SYSS            1.00000   ALPHAP3        1.00000     BV BINARY    YK1
XP3        OBJ          1831.4                                  BV BINARY    YK2
YP3        SYSCOST    -22392.00000   BETAP          1.00000     BV BINARY    YL1
YP3        ALPHAP3       -15.00000   SYSCL         -2.22000     BV BINARY    YL2
YP3        OBJ         22392.0                                  BV BINARY    YM1
XQ1        SYSQ           -0.95500   SYSS           1.00000     BV BINARY    YM2
XQ1        ALPHAQ1         1.00000   SEEP         -10.41000     BV BINARY    YN1
YQ1        SYSCOST     -1875.59985   BETAQ          1.00000     BV BINARY    YN2
YQ1        ALPHAQ1       -55.00000   SYSOP         -3.33000     BV BINARY    YO1
YQ1        OBJ          1875.6                                  BV BINARY    YO2
XQ2        SYSCOST      -302.49976   SYSQ          -0.98200     BV BINARY    YP1
XQ2        SYSS            1.00000   ALPHAQ2        1.00000     BV BINARY    YP2
XQ2        SEEP           -3.67220                              BV BINARY    YQ1
XQ2        OBJ           302.5                                  BV BINARY    YQ2
                                                                BV BINARY    YS1
                                                                BV BINARY    YS2
                                                             ENDATA
```

* COLUMNS

ROWS		UGK	IGK	HMK	SRK	UGL	IGL	HML	SRL	UGM	IGM	HMM	SRM	UGN	IGN	HMN	SRN	UGO	IGO	HMO	SRO	UGP	IGP	HMP	SRP	UGQ	IGQ	HMQ	SRQ	CPQ	UGS	IGS	HMS	SRS	CPS	XA1	YA1	XA2	YA2	XE1	YE1	XE2	YE2	XK1	YK1	XK2	YK2	XK3	YK3	XL1	YL1	XL2	YL2	XL3	YL3	XM1	YM1	XM2	YM2	XM3	YM3	XN1	YN1	XN2	YN2	XN3	YN3	XO1	YO1	XO2	YO2	XO3	YO3	XP1	YP1	XP2	YP2	XP3	YP3	XQ1	YQ1	XQ2	YQ2	XQ3	YQ3	XS1	YS1	XS2	YS2	XS3	YS3	COMO	COMC	VON	VDP	VSEEP	VSR	*CST	RHS
SRVK	GE	1	1	1	1																																																																																													C
SRVL	GE					1	1	1	1																																																																																										C
SRVM	GE									1	1	1	1																																																																																						C
SRVN	GE													1	1	1	1																																																																																		C
SRVO	GE																	1	1	1	1																																																																												D
SRVP	GE																					1	1	1	1																																																																									C
SRVQ	GE																									1	1	1	1	1																																																																		D
SRVS	GE																														1	1	1	1	1																																																																		C
SYSA	LE																																			-T		-T		1		1																																																									
SYSE	LE																																							-T		-T		1		1		1																																																
SYSK	LE	U	U	U	U																																							-T		-T		-1		1		1		1		1		1		1																																									
SYSL	LE					U	U	U	U																																									-T		-T		-1																																																	
SYSM	LE									U	U	U	U																																											-T		-T		-1		1		1		1		1		1		1																											
SYSN	LE													U	U	U	U																																													-T		-T		-1																																	
SYSO	LE																	U	U	U	U																																															-T		-T		-1													1		1		1									
SYSP	LE																					U	U	U	U																																																		-T		-T		-1																				
SYSQ	LE																									U	U	U	U	U																																																				-T		-T		-1														
SYSS	LE																														U	U	U	U	U																																									1		1		1		1		1		1		-T		-T		-1									
BETAA	EQ																																				1		1																																																																		1
BETAE	EQ																																								1		1																																																												1
BETAK	EQ																																												1		1		1																																																						1
BETAL	EQ																																																		1		1		1																																																1
BETAM	EQ																																																								1		1		1																																										1
BETAN	EQ																																																														1		1		1																																				1
BETAO	EQ																																																																				1		1		1																											1
BETAP	EQ																																																																										1		1		1																				1
BETAQ	EQ																																																																																		1		1		1														1
BETAS	EQ																																																																																										1		1		1								1
ALPHAA1	LE																																			1	-C																																																																
ALPHAA2	LE																																					1	-C																																																													
ALPHAE1	LE																																							1	-C																																																										
ALPHAE2	LE																																									1	-C																																																							
ALPHAK1	LE																																											1	-C																																																				
ALPHAK2	LE																																													1	-C																																																			
ALPHAK3	LE																																															1	-C																																																
ALPHAL1	LE																																																	1	-B																																														
ALPHAL2	LE																																																			1	-B																																												
ALPHAL3	LE																																																					1	-B																																											
ALPHAM1	LE																																																							1	-C																																									
ALPHAM2	LE																																																									1	-C																																						
ALPHAM3	LE																																																											1	-C																																				
ALPHAN1	LE																																																													1	-B																																		
ALPHAN2	LE																																																															1	-B																																
ALPHAN3	LE																																																																	1	-B																														
ALPHAO1	LE																																																																			1	-C																												
ALPHAO2	LE																																																																					1	-C																										
ALPHAO3	LE																																																																							1	-C																								
ALPHAP1	LE																																																																									1	-B																						
ALPHAP2	LE																																																																											1	-B																				
ALPHAP3	LE																																																																													1	-B																		
ALPHAQ1	LE																																																																															1	-B																
ALPHAQ2	LE																																																																																	1	-B														
ALPHAQ3	LE																																																																																			1	-B													
ALPHAS1	LE																																																																																					1	-B											
ALPHAS2	LE																																																																																							1	-B									
ALPHAS3	LE																																																																																								1	-B								
SYSOP	EQ																																				-A		-A		-A		-A		-A		-A				-A		-A				-A		-A				-A		-A				-A		-A				-A		-A				-A		-A				-A		-A			1							
SYSCL	EQ																																																-A						-A						-A						-A						-A						-A						-A						-A		1						
WTON	LE																																			1		1																																																																		B
VOLON	EQ																																			-1		-1																																																											V					
DEPERC	EQ	-A	-T	-T	-T	-A	-T	-T	-T	-A	-T	-T	-T	-A	-T	-T	-T	-A	-T	-T	-T	-T	-U	-T	-T	-A	-T	-T	-T	-T	-T	-T	-T	-T	-T																																																															1				
SEEP	EQ																																			-B		-T		-A		-T		-A		-A				-B		-A				-A		-T				-H		-A				-A		-A				-B		-A				-B		-A				-A		-T								1			
RUNOFF	EQ	-A	-A			-A	-A			-A	-A			-A	-A			-A	-A			-A	-A			-A	-A				-A	-A																																																																					1		
WCOST	EQ	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A	-A																																																																							1	
SYSCOST	LE																																					-C	-E			-B	-E		-D	-C	-E	-C	-E	-D		-C	-D	-D	-E		-D	-B	-E	-C	-E		-D	-B	-D	-C	-E		-D	-C	-E	-C	-E		-C	-C	-E	-D	-E		-D	-C	-E	-D	-E		-D	-C	-D	-C	-E	-D	-C					1	
OBJ	FR	B	B	B	B	B	B	B	B	B	B	B	C	B	B	B	C	B	C	B	C	B	B	B	B	B	C	B	B	C	B	C	B	B	C			C	E			B	E		D	C	E	C	E	D		C	D	D	E		D	B	E	C	E		D	B	D	C	E		D	C	E	C	E		C	C	E	D	E		D	C	E	D	E		D	C	D	C	E	D	C						

Figure E-2. Linear programming (LP) problem for consolidation plan with high pressure pipe system

Control of IBM MPS/360

```
PROGRAM
INITIALZ
MOVE(XDATA,'HPSRV')
MOVE(XPBNAME,'OLDSYS')
MOVE(XOBJ,'OBJ')
MOVE(XRHS,'RHSA')
CONVERT('SUMMARY')
BODOUT
SETUP('MIN')
PICTURE
PRIMAL
SOLUTION
MOVE(XOBJ,'OBJ')
XPARAM=0.0
XPARMAX=15.0
XPARDELT=3.0
MOVE(XCHROW,'CHVON')
PARAOBJ('CONT')
SOLUTION
EXIT
PEND
```

```
          EXECUTOR.    MPS/360 V2-M10

NAME      HPSRV
ROWS
 G  AREAL
 G  AREAM
 G  AREAN
 G  AREAO
 G  AREAP
 G  AREAQ
 G  AREAR
 G  AREAS
 G  AREAT
 G  AREAU
 G  AREAV
 G  AREAW
 G  AREAX
 G  AREAY
 G  AREAZ
 G  AREAZ1
 G  AREAZ2
 G  AREAZ3
 G  AREAZ4
 G  AREAZ5
 E  SYSA
 E  SYSB
 E  SYSC
 E  SYSD
 E  SYSE
 E  SYSF
 E  SYSG
 E  SYSH
 E  SYSI
 E  SYSJ
 E  SYSK
 E  SYSL
 E  SYSM
 E  SYSN
 E  SYSO
 E  SYSP
 E  SYSQ
 E  SYSR
 E  SYSS
 E  SYST
 E  SYSU
 E  SYSV
 E  SYSW
 E  SYSX
 E  SYSY
 E  SYSZ
 E  SYSZ1
 E  SYSZ2
 E  SYSZ3
 E  SYSZ4
 E  SYSZ5
 E  CONST

          EXECUTOR.    MPS/360 V2-M10

 E  SYSOL
 E  WCOST
 L  WTON
 E  VOLON
 E  DEPERC
 G  SYSCOST
 E  CONFMP
 N  OBJ
 N  CHVON
 N  CHOP
COLUMNS
    HML       AREAL         1.00000   SYSL        .01480
    HML       WCOST         2.71000   DEPERC      .42340
    HML       OBJ          33.00000
    SRL       AREAL         1.00000   SYSL        .01420
    SRL       WCOST         2.61000   DEPERC      .37260
    SRL       OBJ          49.00000
    CPL       AREAL         1.00000   SYSL        .01310
    CPL       WCOST         2.40000   DEPERC      .25400
    CPL       OBJ         115.70000
    HMM       AREAM         1.00000   SYSM        .01450
    HMM       WCOST         2.65000   DEPERC      .41460
    HMM       OBJ          38.00000
    SRM       AREAM         1.00000   SYSM        .01400
    SRM       WCOST         2.55000   DEPERC      .36480
    SRM       OBJ          51.00000
    CPM       AREAM         1.00000   SYSM        .01280
    CPM       WCOST         2.34000   DEPERC      .24870
    CPM       OBJ         122.00000
    HMN       AREAN         1.00000   SYSN        .01460
    HMN       WCOST         2.67000   DEPERC      .41350
    HMN       OBJ          38.00000
    SRN       AREAN         1.00000   SYSN        .01400
    SRN       WCOST         2.57000   DEPERC      .36390
    SRN       OBJ          47.00000
    CPN       AREAN         1.00000   SYSN        .01280
    CPN       WCOST         2.36000   DEPERC      .24810
    CPN       OBJ          80.29999
    HMO       AREAO         1.00000   SYSO        .01490
    HMO       WCOST         2.73000   DEPERC      .44810
    HMO       OBJ          44.00000
    SRO       AREAO         1.00000   SYSO        .01430
    SRO       WCOST         2.63000   DEPERC      .39430
    SRO       OBJ          58.00000
    CPO       AREAO         1.00000   SYSO        .01310
    CPO       WCOST         2.41000   DEPERC      .25610
    CPO       OBJ         114.79999
    HMP       AREAP         1.00000   SYSP        .01470
    HMP       WCOST         2.69000   DEPERC      .41450
    HMP       OBJ          37.00000
    SRP       AREAP         1.00000   SYSP        .01410
    SRP       WCOST         2.55000   DEPERC      .36470
    SRP       OBJ          50.00000
    CPP       AREAP         1.00000   SYSP        .01290
```

EXECUTOR. MPS/360 V2-M10

CPP	WCOST	2.39000	DEPERC	.24970
CPP	OBJ	117.39999		
HMQ	AREAQ	1.00000	SYSQ	.01470
HMQ	WCOST	2.69000	DEPERC	.41900
HMQ	OBJ	33.00000		
SRQ	AREAQ	1.00000	SYSQ	.01420
SRQ	WCOST	2.59000	DEPERC	.36870
SRQ	OBJ	52.00000		
CPQ	AREAQ	1.00000	SYSQ	.01300
CPQ	WCOST	2.38000	DEPERC	.25140
CPQ	OBJ	108.29999		
HMR	AREAR	1.00000	SYSR	.01490
HMR	WCOST	2.73000	DEPERC	.42170
HMR	OBJ	39.00000		
SRR	AREAR	1.00000	SYSR	.01440
SRR	WCOST	2.63000	DEPERC	.37110
SRR	OBJ	50.00000		
CPR	AREAR	1.00000	SYSR	.01320
CPR	WCOST	2.58000	DEPERC	.25300
CPR	OBJ	110.59999		
HMS	AREAS	1.00000	SYSS	.01500
HMS	WCOST	2.75000	DEPERC	.41820
HMS	OBJ	35.00000		
SRS	AREAS	1.00000	SYSS	.01440
SRS	WCOST	2.64000	DEPERC	.36800
SRS	OBJ	47.00000		
CPS	AREAS	1.00000	SYSS	.01320
CPS	WCOST	2.42000	DEPERC	.25090
CPS	OBJ	105.29999		
HMT	AREAT	1.00000	SYST	.01470
HMT	WCOST	2.69000	DEPERC	.41600
HMT	OBJ	35.00000		
SRT	AREAT	1.00000	SYST	.01420
SRT	WCOST	2.59000	DEPERC	.36610
SRT	OBJ	49.00000		
CPT	AREAT	1.00000	SYST	.01300
CPT	WCOST	2.38000	DEPERC	.24960
CPT	OBJ	108.09999		
HMU	AREAU	1.00000	SYSU	.01500
HMU	WCOST	2.73000	DEPERC	.42410
HMU	OBJ	40.00000		
SRU	AREAU	1.00000	SYSU	.01440
SRU	WCOST	2.63000	DEPERC	.37320
SRU	OBJ	51.00000		
CPU	AREAU	1.00000	SYSU	.01320
CPU	WCOST	2.41000	DEPERC	.25440
CPU	OBJ	109.49998		
HMV	AREAV	1.00000	SYSV	.01510
HMV	WCOST	2.76000	DEPERC	.42190
HMV	OBJ	33.00000		
SRV	AREAV	1.00000	SYSV	.01460
SRV	WCOST	2.65000	DEPERC	.37130
SRV	OBJ	53.00000		
CPV	AREAV	1.00000	SYSV	.01340

EXECUTOR. MPS/360 V2-M10

CPV	WCOST	2.43000	DEPERC	.25330
CPV	OBJ	112.89999		
HMW	AREAW	1.00000	SYSW	.01500
HMW	WCOST	2.75000	DEPERC	.42100
HMW	OBJ	36.00000		
SRW	AREAW	1.00000	SYSW	.01440
SRW	WCOST	2.64000	DEPERC	.37050
SRW	OBJ	46.00000		
CPW	AREAW	1.00000	SYSW	.01320
CPW	WCOST	2.42000	DEPERC	.25260
CPW	OBJ	112.89999		
HMX	AREAX	1.00000	SYSX	.01530
HMX	WCOST	2.80000	DEPERC	.42280
HMX	OBJ	33.00000		
SRX	AREAX	1.00000	SYSX	.01470
SRX	WCOST	2.69000	DEPERC	.37210
SRX	OBJ	47.00000		
CPX	AREAX	1.00000	SYSX	.01350
CPX	WCOST	2.47000	DEPERC	.25370
CPX	OBJ	94.70000		
HMY	AREAY	1.00000	SYSY	.01510
HMY	WCOST	2.76000	DEPERC	.42300
HMY	OBJ	36.00000		
SRY	AREAY	1.00000	SYSY	.01450
SRY	WCOST	2.65000	DEPERC	.37250
SRY	OBJ	47.00000		
CPY	AREAY	1.00000	SYSY	.01330
CPY	WCOST	2.43000	DEPERC	.25380
CPY	OBJ	82.00000		
HMZ	AREAZ	1.00000	SYSZ	.01520
HMZ	WCOST	2.78000	DEPERC	.42740
HMZ	OBJ	43.00000		
SRZ	AREAZ	1.00000	SYSZ	.01470
SRZ	WCOST	2.67000	DEPERC	.37610
SRZ	OBJ	60.00000		
CPZ	AREAZ	1.00000	SYSZ	.01340
CPZ	WCOST	2.45000	DEPERC	.25640
CPZ	OBJ	112.00000		
HMZ1	AREAZ1	1.00000	SYSZ1	.01540
HMZ1	WCOST	2.82000	DEPERC	.43750
HMZ1	OBJ	45.00000		
SRZ1	AREAZ1	1.00000	SYSZ1	.01480
SRZ1	WCOST	2.71000	DEPERC	.38500
SRZ1	OBJ	59.00000		
CPZ1	AREAZ1	1.00000	SYSZ1	.01360
CPZ1	WCOST	2.49000	DEPERC	.26250
CPZ1	OBJ	72.00000		
HMZ2	AREAZ2	1.00000	SYSZ2	.01500
HMZ2	WCOST	2.75000	DEPERC	.42090
HMZ2	OBJ	35.00000		
SRZ2	AREAZ2	1.00000	SYSZ2	.01450
SRZ2	WCOST	2.64000	DEPERC	.37040
SRZ2	OBJ	43.00000		
CPZ2	AREAZ2	1.00000	SYSZ2	.01330

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CPZ2	WCOST	2.42000	DEPERC		.25250
CPZ2	CBJ	103.29999			
HMZ3	AREAZ3	1.00000	SYSZ3		.01480
HMZ3	WCOST	2.71000	DEPERC		.41110
HMZ3	CBJ	39.00000			
SRZ3	AREAZ3	1.00000	SYSZ3		.01420
SRZ3	WCOST	2.61000	DEPERC		.36180
SRZ3	CBJ	59.00000			
CPZ3	AREAZ3	1.00000	SYSZ3		.01300
CPZ3	WCOST	3.40000	DEPERC		.24660
CPZ3	CBJ	82.00000			
HMZ4	AREAZ4	1.00000	SYSZ4		.01480
HMZ4	WCOST	2.71000	DEPERC		.42040
HMZ4	CBJ	40.00000			
SRZ4	AREAZ4	1.00000	SYSZ4		.01420
SRZ4	WCOST	2.61000	DEPERC		.36990
SRZ4	CBJ	49.00000			
CPZ4	AREAZ4	1.00000	SYSZ4		.01300
CPZ4	WCOST	2.40000	DEPERC		.25220
CPZ4	CBJ	99.20000			
HMZ5	AREAZ5	1.00000	SYSZ5		.01420
HMZ5	WCOST	2.60000	DEPERC		.40110
HMZ5	CBJ	38.00000			
SRZ5	AREAZ5	1.00000	SYSZ5		.01370
SRZ5	WCOST	2.50000	DEPERC		.35300
SRZ5	CBJ	49.00000			
CPZ5	AREAZ5	1.00000	SYSZ5		.01250
CPZ5	WCOST	2.29000	DEPERC		.23970
CPZ5	CBJ	107.70000			
SYSA4	SYSA	- 1.00000	SYSCOST		100.89999
SYSA4	CONPMP	1.00000	CBJ		100.89999
SYSB4	SYSA	1.00000	SYSB	-	1.00000
SYSB4	SYSCOST	136.39999	CBJ		136.39999
SYSC4	SYSB	1.00000	SYSC	-	1.00000
SYSC4	SYSCOST	119.39999	CBJ		119.39999
SYSD4	SYSC	1.00000	SYSD	-	1.00000
SYSD4	SYSCOST	132.70000	CBJ		132.70000
SYSE4	SYSD	1.00000	SYSE	-	1.00000
SYSE4	SYSCOST	93.20000	CBJ		93.20000
SYSF4	SYSE	1.00000	SYSF	-	1.00000
SYSF4	SYSCOST	164.00000	CBJ		164.00000
SYSG4	SYSF	1.00000	SYSG	-	1.00000
SYSG4	SYSCOST	96.49998	CBJ		96.49998
SYSH4	SYSG	1.00000	SYSH	-	1.00000
SYSH4	SYSCOST	382.09985	CBJ		382.09985
SYSI4	SYSH	1.00000	SYSI	-	1.00000
SYSI4	SYSCOST	106.89999	CBJ		106.89999
SYSJ4	SYSI	1.00000	SYSJ	-	1.00000
SYSJ4	SYSCOST	87.20000	CBJ		87.20000
SYSK4	SYSJ	1.00000	SYSK	-	1.00000
SYSK4	SYSCOST	173.00000	CBJ		173.00000
SYSL4	SYSA	1.00000	SYSL	-	1.00000
SYSL4	SYSCOST	226.79999	CBJ		226.79999
SYSM4	SYSL	1.00000	SYSM	-	1.00000

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SYSM4	SYSCOST	225.09999	CBJ		225.09999
SYSN4	SYSL	1.00000	SYSN	-	1.00000
SYSN4	SYSCOST	318.00000	CBJ		318.00000
SYSO4	SYSB	1.00000	SYSO	-	1.00000
SYSO4	SYSCOST	551.00000	CBJ		551.00000
SYSP4	SYSO	1.00000	SYSP	-	1.00000
SYSP4	SYSCOST	380.79980	CBJ		380.79980
SYSQ4	SYSP	1.00000	SYSQ	-	1.00000
SYSQ4	SYSCOST	308.29980	CBJ		308.29980
SYSR4	SYSP	1.00000	SYSR	-	1.00000
SYSR4	SYSCOST	1635.49976	CBJ		1635.49976
SYSS4	SYSD	1.00000	SYSS	-	1.00000
SYSS4	SYSCOST	419.69995	CBJ		419.69995
SYST4	SYSE	1.00000	SYST	-	1.00000
SYST4	SYSCOST	935.29980	CBJ		935.29980
SYSU4	SYSF	1.00000	SYSU	-	1.00000
SYSU4	SYSCOST	1154.89990	CBJ		1154.89990
SYSV4	SYSG	1.00000	SYSV	-	1.00000
SYSV4	SYSCOST	327.29980	CBJ		327.29980
SYSW4	SYSV	1.00000	SYSW	-	1.00000
SYSW4	SYSCOST	838.29980	CBJ		838.29980
SYSX4	SYSH	1.00000	SYSX	-	1.00000
SYSX4	SYSCOST	241.09999	CBJ		241.09999
SYSY4	SYSI	1.00000	SYSY	-	1.00000
SYSY4	SYSCOST	920.69995	CBJ		920.69995
SYSZ4	SYSJ	1.00000	SYSZ	-	1.00000
SYSZ4	SYSCOST	1058.69995	CBJ		1058.69995
SYSZ14	SYSZ	1.00000	SYSZ1	-	1.00000
SYSZ14	SYSCOST	585.19995	CBJ		585.19995
SYSZ24	SYSK	1.00000	SYSZ2	-	1.00000
SYSZ24	SYSCOST	161.49998	CBJ		161.49998
SYSZ34	SYSZ2	1.00000	SYSZ3	-	1.00000
SYSZ34	SYSCOST	653.89990	CBJ		653.89990
SYSZ44	SYSZ2	1.00000	SYSZ4	-	1.00000
SYSZ44	SYSCOST	1104.00000	CBJ		1104.00000
SYSZ54	SYSZ4	1.00000	SYSZ5	-	1.00000
SYSZ54	SYSCOST	562.89990	CBJ		562.89990
FIX	CONST	1.00000	SYSCOST		2039652.000
FIX	CBJ	2039652.000			
COMC	SYSCL	1.00000	SYSCOST		44032.00000
COMC	CBJ	44032.00000			
WCST	WCOST	- 1.00000	SYSCOST	-	1.00000
VCN	VOLCN	- .00545	CHVCN		1.00000
VDP	CHDP	1.00000	DEPERC	-	1.00000
EMP	WTCN	1.00000	VOLUN		1.00000
EMP	CONPMP	- 1.00000	CBJ		537.49976

RHS

RHSA	AREAL	434.00000	AREAM	702.00000
RHSA	AREAN	1000.00000	AREAO	527.00000
RHSA	AREAP	727.00000	AREAQ	831.00000
RHSA	AREAR	1177.00000	AREAS	909.00000
RHSA	AREAT	1522.00000	AREAU	1239.00000
RHSA	AREAV	1203.00000	AREAW	1133.00000
RHSA	AREAX	1059.00000	AREAY	1465.00000

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    RHSA        AREAZ          863.00000   AREAZ1        425.00000
    RHSA        AREAZ2         763.00000   AREAZ3       1366.00000
    RHSA        AREAZ4         913.00000   AREAZ5        444.00000
    RHSA        CONST            1.00000   WTON          280.00000
    RHSA        SYSCL            1.00000
    RHSB        WTON             1.00000
    RHSC        WCOST            1.00000
ENDATA
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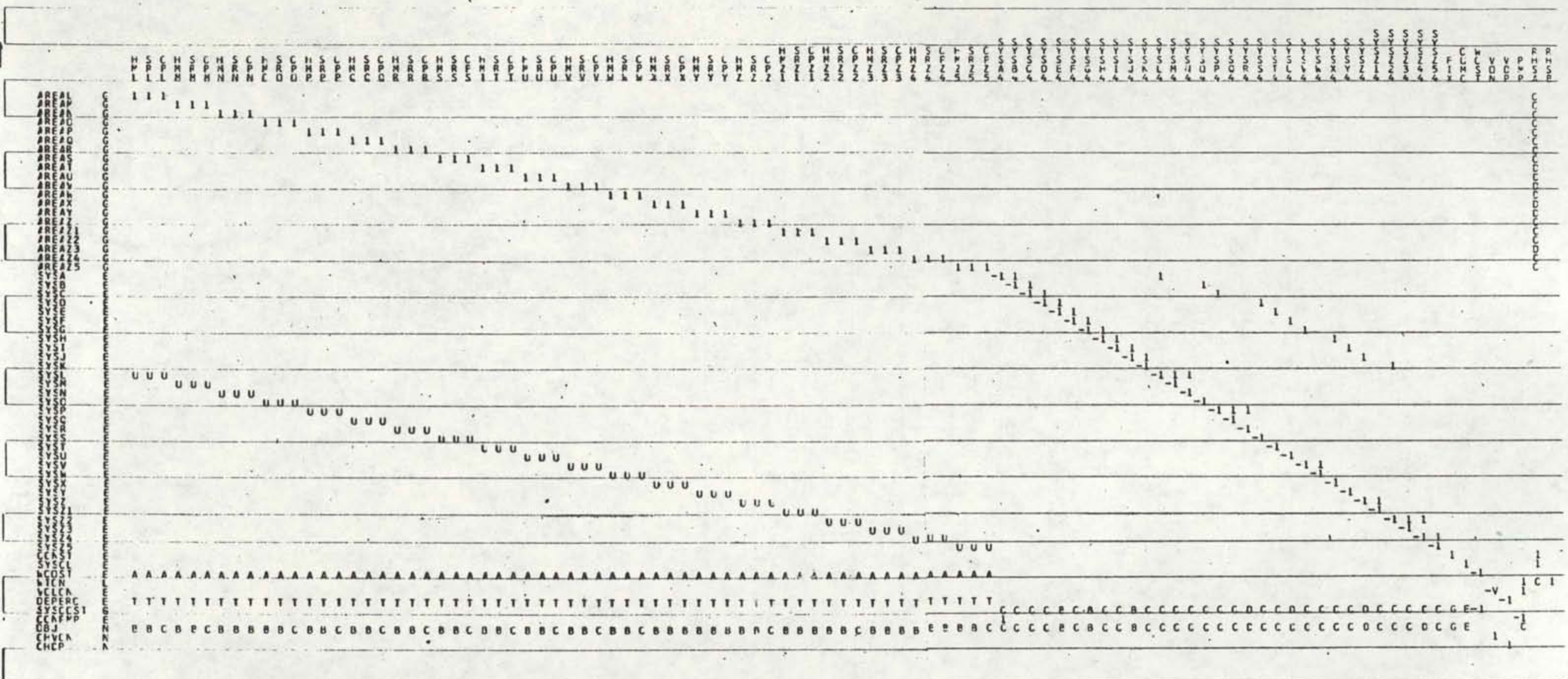

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SUMMARY OF MATRIX

SYMBOL	RANGE		COUNT (INCL.RHS)
Z	LESS THAN	.000001	
Y	.000001 THRU	.000009	
X	.000010	.000099	
W	.000100	.000999	
V	.001000	.009999	1
U	.010000	.099999	60
T	.100000	.999999	60
1	1.000000	1.000000	136
A	1.000001	10.000000	60
B	10.000001	100.000000	52
C	100.000001	1,000.000000	76
D	1,000.000001	10,000.000000	16
E	10,000.000001	100,000.000000	2
F	100,000.000001	1,000,000.000000	
G	GREATER THAN	1,000,000.000000	2

APPENDIX F

SUMMARIES OF RELATED STUDIES UNDER THIS PROJECT, PROJECT NO. B-041-IDA

1. Soil water intake rates and surface irrigation system characteristics by soil series in Southeastern Idaho, by Kyung H. Yoo and J.R. Busch, 1981.

2. Evaluation of canal seepage in the Snake River Fan, Bonneville and Bingham Counties, Idaho, by Kenneth E. Netz, 1980.

3. Methodology for optimization of an irrigation system with storage reservoirs, by Mohammad J. Khanjani, 1980.

4. Analyzing and predicting irrigation diversions in Southeastern Idaho, by Sung Kim, 1981.

1. SOIL WATER INTAKE RATES AND SURFACE IRRIGATION SYSTEM CHARACTERISTICS BY SOIL SERIES IN SOUTHEASTERN IDAHO, By Kyung H. Yoo and J.R. Busch, 1981.

Seven major soil series found in the study area (shown in Figure IV-2) were evaluated to obtain soil wtaer intake rates. They range in texture from silt loam to gravelly loam. Three crop fields (hay, grain and potatoes) were selected for this study. Soil survey maps from local Soil Conservation Service were used to locate each soil series of the area. It was difficult to select representative sampling sites in any field. Therefore, it was necessary to test several different sites to obtain average results.

The infiltrometer ring test method was used for border irrigated fields, and the inflow-outflow method for furrow fields. There were different intake rates for fields of different crops on the same soil. Generally potato fields had lower intake rates than the other crops when tested by the ring method. There were also differences between the intake rates obtained by the ring test and the inflow-outflow method for furrow irrigated potato fields. The inflow-outflow method has been known as the most dependable method of obtaining furrow intake rate. However, under some conditions, the ring test is simpler and easier than the inflow-outflow method. The coefficients used in a water intake rate formula $I = at^b$ (where, I = intake rate, t = intake opportunity time and a and b are coefficients) were found different from soil types and crop fields. Figure F-1 shows the relationships of these coefficients to crop fields and the relationships to soil types are shown in Figure F-2. All three soils shown have the largest intercept value (coefficient a for

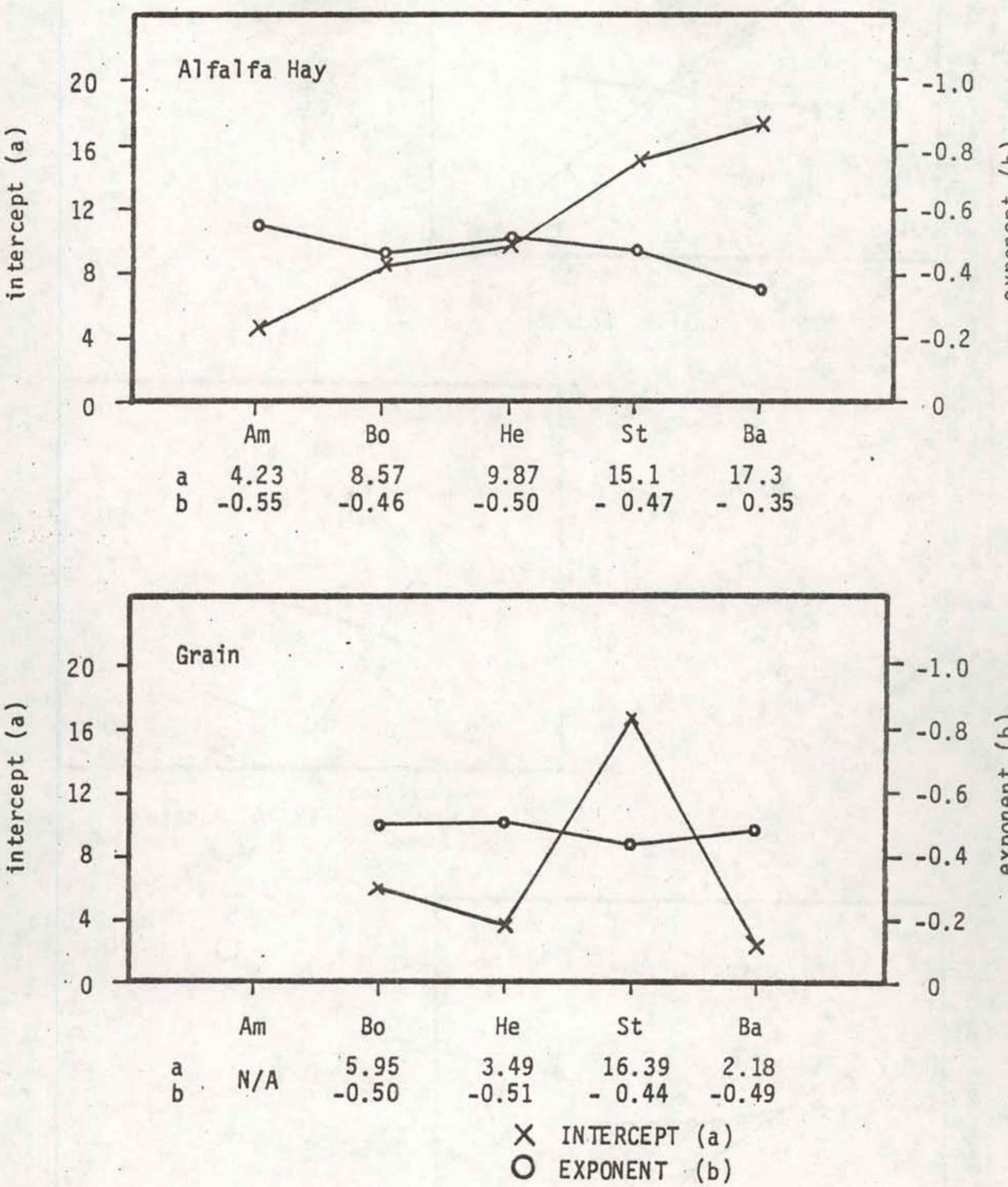


Figure F-1. Graphical comparison of coefficients of intake rate equations among soils (potato fields tested by infiltrometer ring).

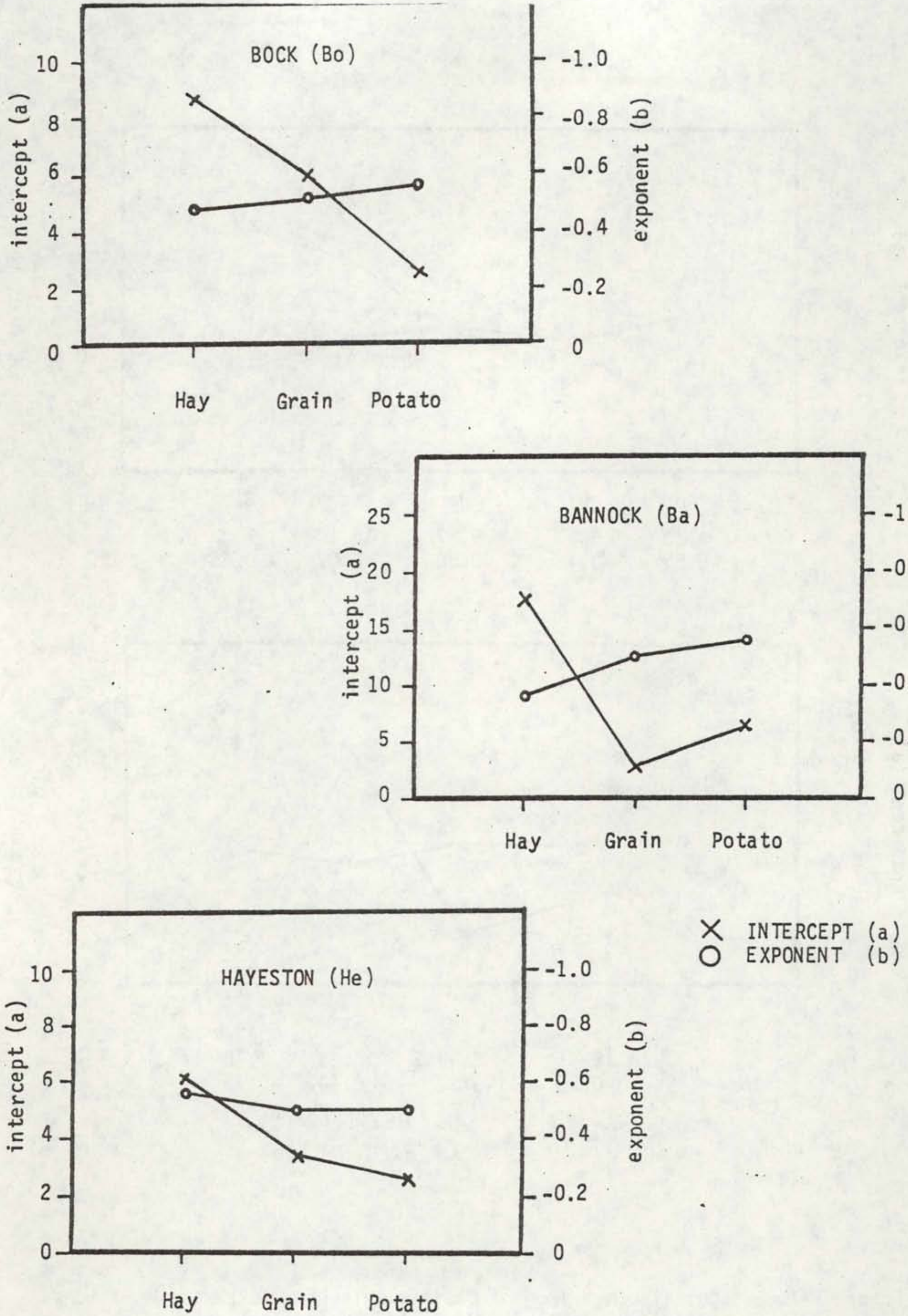


Figure F-2. Graphical comparison of coefficients of intake rate equations among crops (potato fields tested by infiltrometer ring).

hay, intermediate for grain and lowest for potatoes except for Bannock soil. For the exponents (coefficient b) Bock and Hayeston soils have almost constant values while that of Bannock shows a decreasing value in the order of hay, grain and potatoes. Generally, hay has the highest intake rate and potatoes have the lowest among the three crops. From Figure 2, the intercept values for the alfalfa field increase from silt loam (Ammon) to gravelly loam (Bannock) and the exponents decrease slightly in same order. for the same order, the exponents are nearly constant, but the wide variation in intercept values are shown. For these two tests the number of data were not enough to statistically test and find any relationships between the two methods in this study, which would be useful for field application.

The irrigation practices on two furrow fields were evaluated usign the data obtained in this study. The results showed that improved water management practices are needed to obtain higher application efficiencies on both fields. One field had excess irrigation with high runoff loss and the other field had a lack of irrigation with high runoff loss. The irrigators could increase the efficiency by using a cut back stream and/or a return flow recovery system.

Publication:

Yoo, Kyung H. and J.R. Busch, 1981. Soil water intake rates and surface irrigation system characteristics by soil series in southeastern Idaho, Resarch Technical Partial Completion Report, Idaho Water Resources Research Institute, University of Idaho, Moscow.

2. EVALUATION OF CANAL SEEPAGE IN THE SNAKE RIVER FAN, BONNEVILLE AND BINGHAM COUNTIES, IDAHO, By Kenneth E. Netz, 1980.

The canal networks of the irrigation projects of the study area (Figure IV-1) are a means of water management that supply water for agricultural use in the area. The effectiveness of these canals for this use is of concern to the farmers and community. Efficient delivery of water for irrigation is a special concern during drought year. Thus, the canal companies must be able to deliver water to the farmer in a way that allows the most effective application of water to crops. Canal seepage is of concern because it represents a loss in water that could otherwise be available to the crops.

The study showed that rates of seepage ranged from 0.5 to 3.7 cubic feet per square foot per day on two major projects. High loss areas were usually located in the large canals that were distributing large amounts of water.

The inflow-outflow method used in determining the seepage from a canal showed that very accurate water measurements were needed to measure seepage rates in canals. Statistical Analysis Procedures used to evaluate the loss rates showed that the inflow-outflow method was ineffective during mid-season, high flow periods. This was undoubtedly due to the inherent errors of measuring water in an open channel. Measurements made at very low flows during the very early spring and late fall, before and after farmers were diverting water for crop use, provided to the acceptable seepage loss measurements.

The General Linear models Procedure indicated that the variation in seepage measured at individual stations was too great even during the spring and fall to attribute the seepage to the soil type or canal bottom type. Based on the measurements taken using the inflow-outflow method a prediction cannot be made with adequate accuracy on prospective new canals using soil type and canal bottom type as indicators.

The procedure showed that actual measurements made at low flows do indeed indicate that some canals have higher loss rates than others. The results from this study are shown in Table F-1. The table contains the seepage rate, total loss rate for a canal and conveyance efficiency of each canal. Canals with high losses were Main Snake River Valley Canal, Main Idaho Canal, Cedar Point Canal, Sand Creek, and Butte Arm Canal. Canals with a medium loss were East Branch of Snake River Valley Canal and West Branch of Snake River Valley Canal. Low loss rates were found in the lower end of the Main Idaho Canal, Highline Canal, and Little Sand Creek and Kearney Canal.

In summary, the study was successful in estimating seepage loss and determining where high and low losses could be expected. The study has been shown to benefit the planner who wishes to preserve water and put Idaho's water to its most beneficial use.

Publication:

Netz, Kenneth E., 1980. Evaluation of canal seepage in the Snake River Fan, Bonneville and Bingham Counties, Idaho, Unpublished M.S. Thesis, Department of Agricultural Engineering, University of Idaho, Moscow, Idaho.

Table F-1. Canal seepage rates and conveyance efficiency of the study area

Canal Name	Wetted Perimeter ft	Seepage Rate, ft/day	Water Loss Rate, cfs	Conveyance Efficient, %
Idaho Main	75.5	2.68	102.0	93.1
Butte Arm	17.1	2.31	19.9	96.1
Little Sand Creek	31.4	0.62	9.8	90.2
Sand Creek	19.2	2.40	23.2	89.6
Highline Creek	3.5	0.60	1.0	98.7
Snake River Valley Main	20.0	3.61	36.2	95.6
Cedar Point	18.5	3.74	34.8	91.5
West Branch SRV	29.8	1.31	19.7	92.1
East Branch SRV	18.8	1.48	14.0	94.2

3. METHODOLOGY FOR OPTIMIZATION OF AN IRRIGATION SYSTEM WITH STORAGE RESERVOIRS, By Mohammad J. Khanjani, 1980.

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

To achieve the objective, an area of approximately 1,965 ha in the Snake River Valley Irrigation District was selected as a study area for application of the proposed model. The study area was divided into 24 farm units. Cropping pattern, soil type, quantity and quality of irrigation water and existing irrigation application systems were considered and necessary data collected.

Daily evapotranspiration values for 25 years (1952-1976) were estimated, and frequency distribution of evapotranspiration for 1 to 30 days and seasonal duration were estimated. A log-normal probability distribution was found to best fit the data. Daily actual evapotranspiration of pasture, wheat, alfalfa and potatoes were computed. Frequency distributions of these crops for 1 to 30 days and for seasonal use were estimated. A log-normal probability distribution was again found to best fit the estimated actual evapotranspiration of the four crops. Mathematical probability equations for the prediction of actual evapotranspiration for different duration were developed. Figure F-3 shows the log-normal

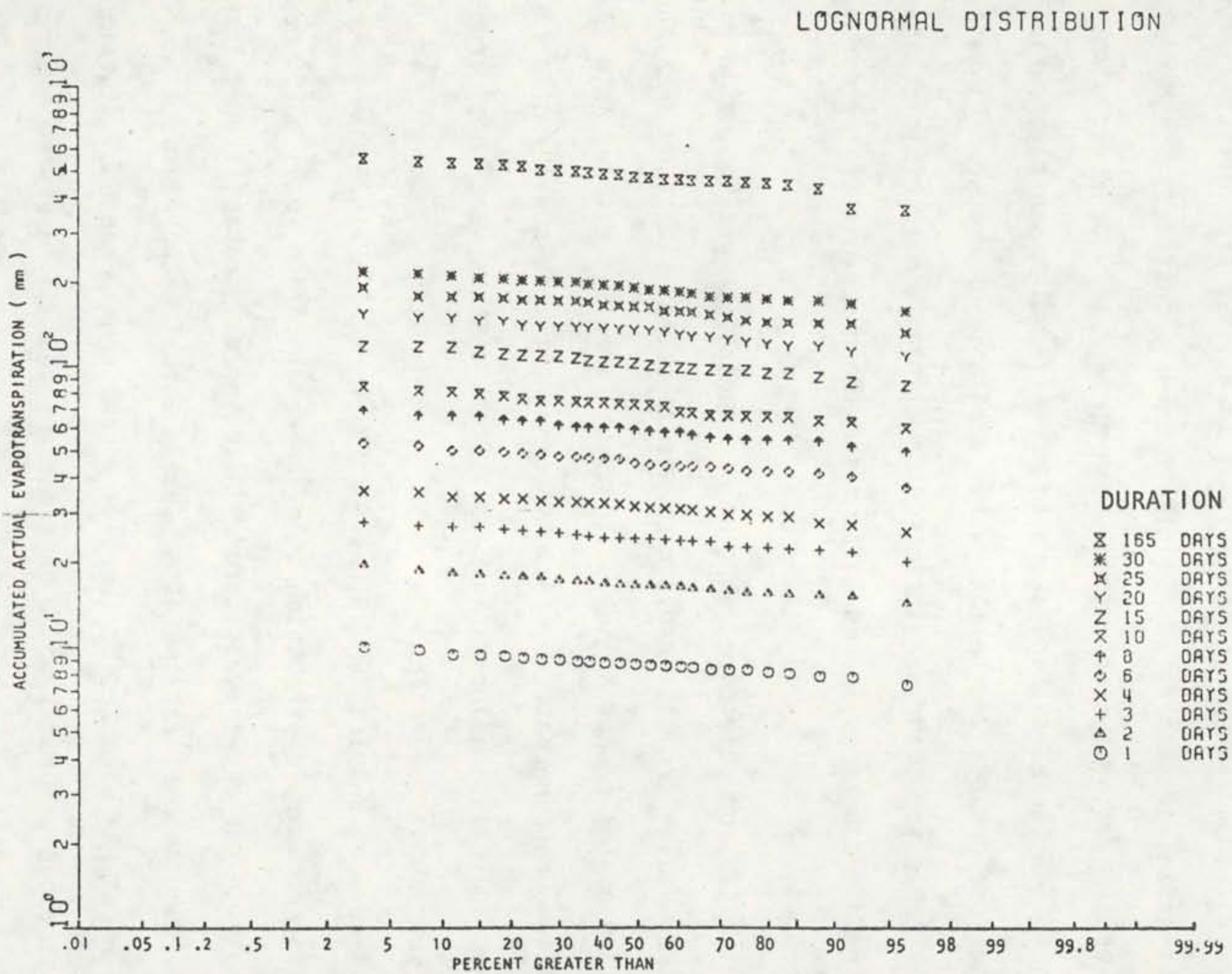


Figure F-3. Log-normal probability distribution of actual evapotranspiration of potatoes for different durations in the study area.

distribution of actual ET for a crop of the study area in different durations.

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

Annual costs of irrigation application subsystems for each soil type and crop, for different amounts of applied water, were estimated. Annual costs were also estimated for canal rehabilitation and farm service reservoirs. Benefits of various levels of irrigation for each crop were estimated by dimensionless crop yield-water use functions and unit prices of crops, and by incorporating the level of risk in satisfying actual evapotranspiration requirements. The relationships of benefit and cost to applied irrigation water for a crop and irrigation application system are shown in Figure F-4. By estimating the annual costs of irrigation application subsystems and benefits from different amounts of applied water, and by using a marginal cost-benefit analysis, the most economical irrigation interval for each crop on a particular soil was computed for a particular irrigation application subsystem. The peak actually water required for each different crop-soil-irrigation application system were then determined. The time of occurrence of maximum actual evapotranspiration for each crop in the study area follows a log-normal distribution, and the mathematical probability equations were defined.

The peak water requirement of each farm unit was computed as a function of cropping pattern, soil type, and irrigation application subsystem.

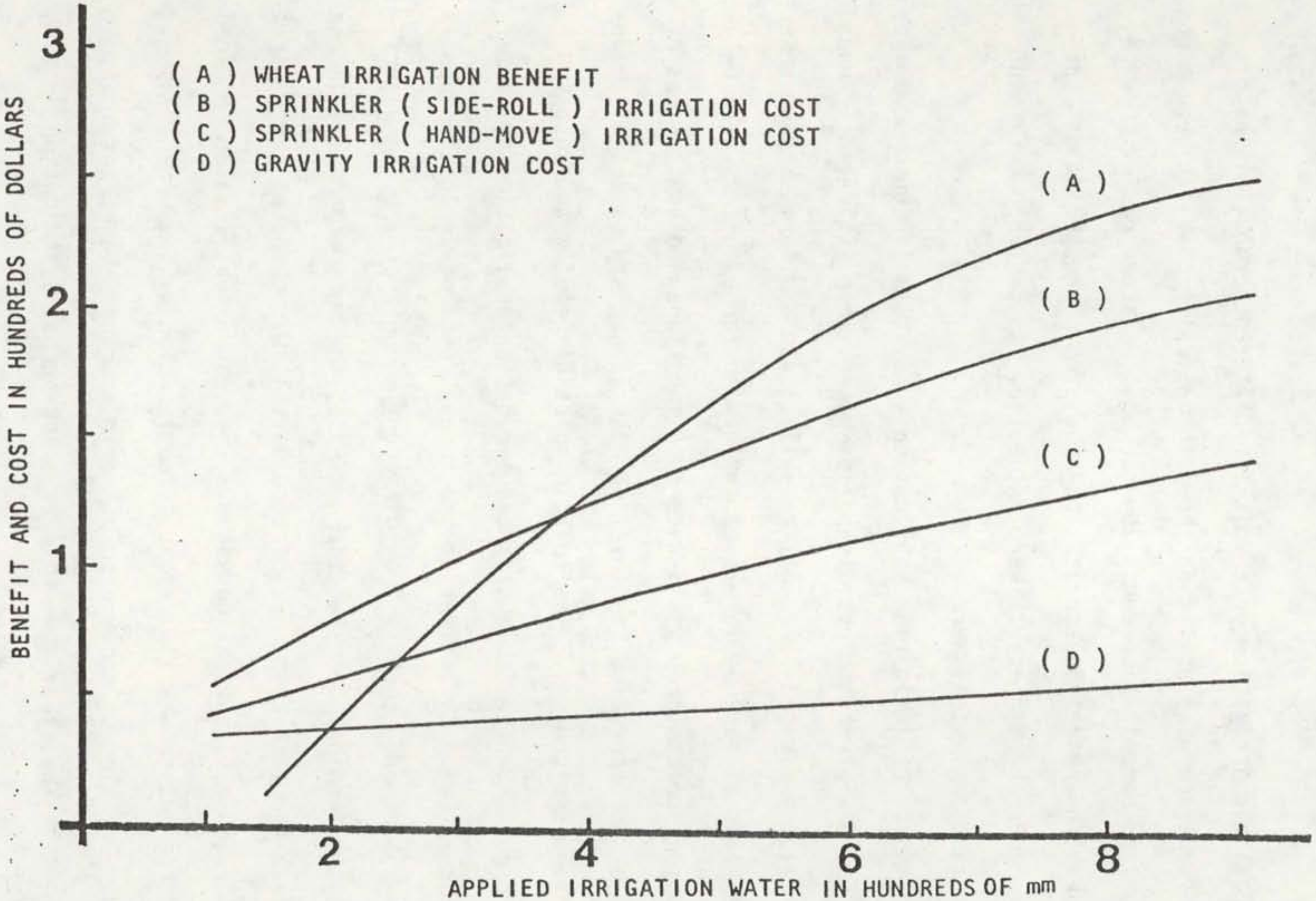


Figure F-4. Cost and benefit of wheat irrigation on Bannock soil by different irrigation application subsystems.

It was found that although there were a variety of cropping patterns, soil types, and irrigation application subsystems, the peak water requirement of all farm units occurred in July.

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

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

The effect of water cost on system configuration was examined by parametric programming for different water costs ($0-$12.15/1,000 m^3).

By increasing the cost of inflow water to \$.81/1,000 m^3 it was found that it would be better to collect and reuse all the runoff water from fields. Further cost increases showed no effect on the configuration of the system without the specified range.

Publication:

Khanjani, M.J., 1980. Methodology for optimization of an irrigation system with storage reservoirs. Unpublished Ph.D. Dissertation, Department of Agricultural Enginereing, University of Idaho, Moscow.

Khanjani, M.J. and J.R. Busch, 1982. Optimal irrigation water use from probability cost-benefit analysis. TRANSACTIONS of the American Society of Agricultural Engineers. (accepted for publication).

Khanjani, M.J. and J.R. Busch, 1982. Optimal irrigation distribution systems with internal storage. TRANSACTIONS of the American Society of Agricultural Engineers. (submitted for publication).

4. ANALYZING AND PREDICTING IRRIGATION DIVERSINS IN SOUTHEASTERN IDAHO, By Sung Kim, 1981.

The daily water flow data and crop consumptive water use data for the 1978, 1979, and 1980 irrigation seasons were analyzed to determine the relationships among them for the Idaho Irrigation District (IID) and the Snake River Valley Irrigation District (SRVID). A methodology for predicting daily water diversions was developed for an irrigation district and was applied to the two irrigation districts.

Seasonal irrigation water uses were different from year to year for the districts, but the seasonal water use patterns were similar among the districts. Approximately 90 and 80 percent of total inflows were directly diverted from the Snake River with additional water received from upper irrigation district(s) as wastewater. Total outflows were about 20 to 27 percent of the total inflows for the IID and SRVID, respectively.

Statistical analyses using linear correlation were used to determine relationships among inflow, outflow, evapotranspiration and precipitation. The results showed that outflow fluctuated more frequently than inflow did. A slight change of evapotranspiration resulted in a rather large change of inflow, and inflow was also highly related to precipitation. Generally, negative correlations existed between inflow and outflow, and between outflow and evapotranspiration on the same day. As expected, a positive correlation existed between inflow and evapotranspiration on the same day.

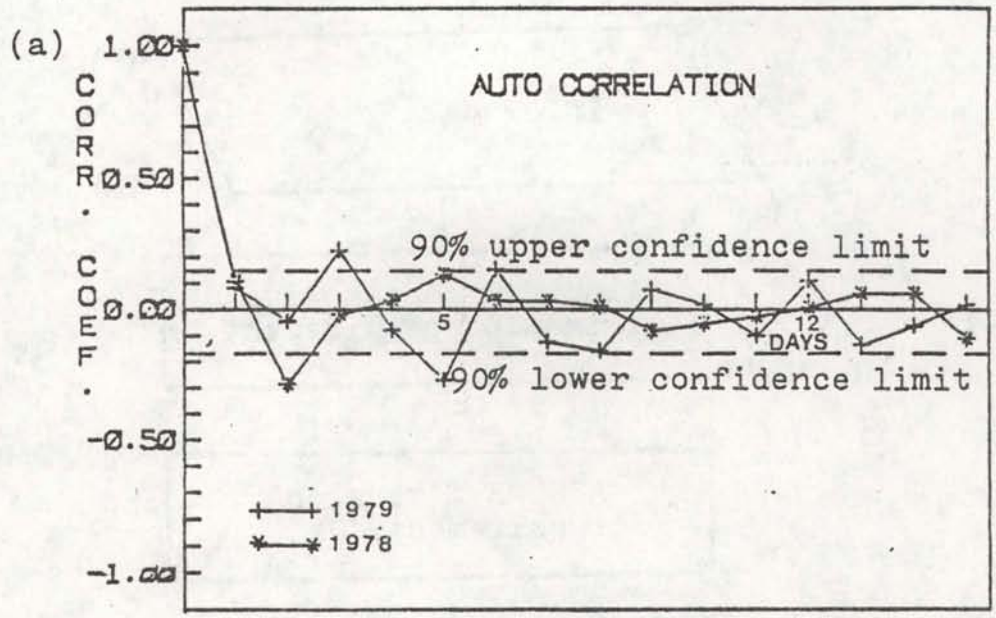
Autocorrelation methods were used to determine frequencies within the inflow and outflow of the irrigation water from the districts studied. Weekly cycles were found within outflows, but not found within inflows. This trend could illustrate that present irrigation schedules of diversions for the IID and SRVID can be adjusted to more precisely meet demand with weekly cycles. Figure F-5 shows the autocorrelation of the inflow and outflow in the IID. Most of the points (correlation coefficients of event time inflows) are between the upper and lower confidence limits for autocorrelogram of the inflow. This result illustrates that they are not different and no particular frequencies exist. Points in the outflow diagram for 7 day and 14 day intervals are located outside of the confidence limits. This means that on a weekly cycle the outflows are different from those of other days.

Relationships between diversion times and requirements were established. Based on the time effects, proper consumptive irrigation requirements were estimated at the district level for each district. Multiple linear regression equations were also developed to estimate total water losses due to management, seepage, and deep percolation.

A computer program was developed for predicting water diversions for the districts. Figure F-6 is a schematic flow chart of the program to determine irrigation diversion requirement. The predicted values appeared to be more closely related to the consumptive irrigation requirements than did the actual inflows. It must be noted that the predicted values are not necessarily close to the measured inflow of the districts. The predicted inflow is the one which the district should divert to meet its requirement effectively sould the prediction be reasonable. However, the measured inflow is that the district actually diverted, which may or may not be based on actual requirements.

Publication:

Kim, S., 1981. Analyzing and predicting irrigation diversions in southeastern Idaho. Unpublished M.S. Thesis, Department of Agricultural Engineering, University of Idaho, Moscow, Idaho.



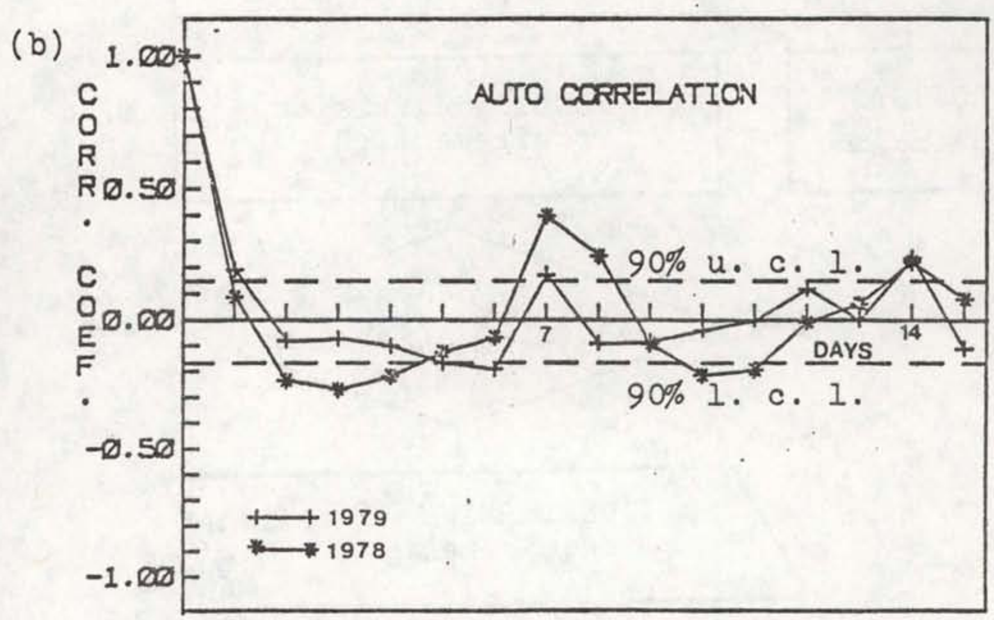


Figure F-5. Autocorrelograms of inflow and outflow in the Idaho Irrigation District. (a) inflow, (b) outflow.

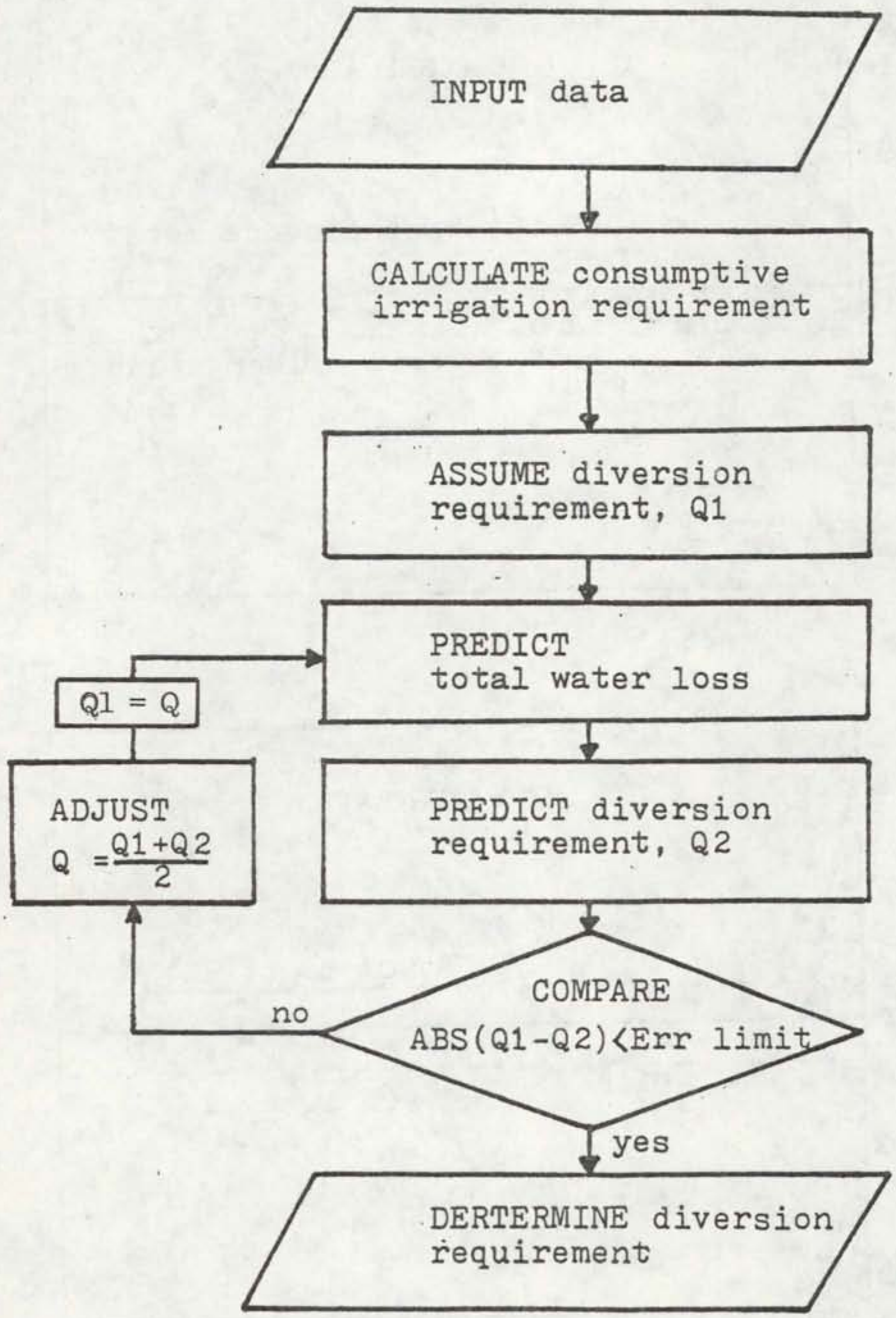


Figure F-6. Flow chart for determining diversion requirements.

SELECTED WATER RESOURCES ABSTRACT

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OPTIMAL PLANNING OF IRRIGATION DISTRIBUTION AND APPLICATION SYSTEMS FOR A LARGE IRRIGATED AREA

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16. *Abstract* The purpose of the research was to develop and apply techniques to obtain optimal solutions for multi-objective planning of a large irrigated area. Techniques were developed to effectively inventory a large area, determine the costs and operating characteristics of irrigation system components and obtain optimal system plans using mathematical programming. These techniques were applied to a large irrigated area located near Idaho Falls, Idaho.

All sources of data pertinent to irrigation in the study area were collected, and low level infrared pictures were taken over the area. Files of data from all sources were stored in a digital computer so that they could be easily accessed to obtain information about irrigation practice and systems located in any small subarea within the study area. These data files were also used to obtain detailed computer-drawn maps of the area.

Using the procedures developed, optimal irrigation system plans were obtained for the study area. These plans were based upon different specified constraints such as overall system efficiency, cost of water delivered to the system at the project headgate and the cost of water diverted to the distribution system to on-farm application systems. The results obtained were useful in determining the costs and configurations necessary to meet specified efficiency levels. When charging for water, it was found that the variation of water cost over a rather narrow range was effective in increasing overall efficiency to a point, and additional charges had little effect. Consolidation plans for the two irrigation districts in the study area showed that it would be most economical to use a high pressure supply and sprinkler application system to attain an overall efficiency greater than 70%.

17a. *Descriptors*

Planning of Large Irrigated Areas

Consolidation plans for irrigation districts

17c. *COWRR Field & Group*

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