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Implementation of Agricultural Salinity Control Technology in Grand Valley

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IMPLEMENTATION OF AGRICULTURAL SALINITY CONTROL TECHNOLOGY IN GRAND VALLEY

by

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DISCLAIMER

FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C. Galegar

William C. Galegar
Director
Robert S. Kerr Environmental
Research Laboratory

PREFACE

This report is the first in a series of three reports resulting from U.S. Environmental Protection Agency Grant No. S-802985 entitled, "Implementation of Agricultural Salinity Control Technology in Grand Valley." This report details the experimental design and procedures used to collect data on several types of on-farm improvements, field drainage, canal and lateral linings and irrigation management practices (such as irrigation scheduling) as salinity control measures. The second report in this series is entitled, "Evaluation of Irrigation Methods for Salinity Control in Grand Valley" and is concerned with the evaluation of furrow, border, sprinkler, and trickle irrigation as individual salinity control measures. The third report of this series "Best Management Practices for Salinity Control in Grand Valley" develops the methodology for determining the cost-effectiveness of individual salinity control measures and a complete "package" of salinity control measures.

Another research project conducted in Grand Valley and largely funded by the U.S. Environmental Protection Agency has provided the necessary background in soil chemistry to support the cost-effectiveness analysis in the above three reports. This second project, "Irrigation Practices, Return Flow Salinity, and Crop Yields," was supported by EPA Grant No. S-800687. Two reports resulted from this effort. The first report, "Irrigation Practices and Return Flow Salinity," focuses upon soil chemistry modeling and the prediction of irrigation subsurface return flow salinity. The second report, "Potential Effects of Irrigation Practices on Crop Yields in Grand Valley" focuses upon the impact of various irrigation practices in determining crop yields, with particular emphasis on maize and wheat.

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ABSTRACT

A summary of the results of applied research on salinity control of irrigation return flows in the Grand Valley of Colorado is presented for the period of 1969 to 1976. Salinity and economic impacts are described for the Grand Valley Salinity Control Demonstration Project which contains approximately 1,600 hectares and involves most of the local irrigation companies in the Valley. During the eight years of studies in the project area, 12.2 km of canals were lined, 26.54 km of laterals were lined, 16,400 meters of drainage tile were installed, a wide variety of on-farm improvements were constructed, and an irrigation scheduling program was implemented. On-farm improvements evaluated were solid-set sprinklers, side-roll sprinklers, drip (trickle) irrigation, furrow irrigation, and automatic cut-back furrow irrigation. The total value of the constructed improvements in the demonstration area was about $750,000. The total improvements resulted in a salt reduction of 12,300 metric tons per year reaching the Colorado River. This salt reduction results in an annual benefit to downstream water users of nearly $2,000,000. In addition, there are benefits to the local water users with increased crop yields, and to the people of Grand Valley in increased business.

This report was submitted in fulfillment of Grant No. S-802985 by the Agricultural and Chemical Engineering Department of Colorado State University under the sponsorship of the Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency. This report covers the period February 18, 1974 to February 17, 1977.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

ac	-- acre, (43,560 ft^2) one acre equals 0.405 hectare
AF	-- acre-foot, volume of water to cover one acre a depth of one foot, one acre-foot equals 0.1233 hectare-meters
BTU	-- British Thermal Unit
cal/gm	-- calories per gram
cfd	-- cubic feet per day
cfs	-- cubic feet per second, volume flow rate of water, one cfs equals 0.0283 cubic meter per second
cmd	-- cubic meter per day
CMI	-- Colorado Miner's Inch, one Colorado Miner's Inch equals 0.74 liters per second
cms	-- cubic meters per second, one cubic meter per second equals 35.31 cfs
degrees C or °C	-- centigrade temperature (also called Celsius) scale
degrees F or °F	-- Fahrenheit temperature scale
ft	-- feet, unit of length, one foot equals 0.3048 meters
gm	-- gram, 454 grams equal one pound
gpm	-- gallons per minute, volume flow rate of water, one gallon per minute equals 0.631 liters per second
ha	-- hectare, metric unit of area, one hectare equals 2.471 acres
ha-m	-- hectare-meter, volume of water to cover one hectare to a depth of one meter, one ha-m equals 8.108 AF
hr	-- hour, 60 minutes
hp	-- horsepower, one horsepower equals 7.460 x 10^{-5} erg/sec
in	-- inch, one inch equals 2.54 centimeters
km	-- kilometer, metric unit of length, one kilometer equals 0.621 miles
kPa	-- kilopascal, metric unit of pressure, 6.9 kilopascal equals one psi
lb	-- pound (mass)
lph	-- liters per hour, volume flow rate of water
l/min	-- liters per minute, volume flow rate of water

l/s	-- liters per second, volume flow rate of water
m	-- meter
m^3/s	-- cubic meters per second, volume flow rate of water
me/l	-- milliequivalents per liter
mg/l	-- milligrams per liter, equal to one ppm
mi	-- mile, one mile equals 1.609 kilometers
mm	-- millimeter
mph	-- miles per hour, velocity
N/m	-- Newton per square meter, unit of pressure, one N/m^2 equals one Pascal (6.9 kPa equals one k)
ppm	-- parts per million
psi	-- pounds force per square inch, unit of pressure
sec	-- seconds, time
UCC	-- Christiansen's Uniformity Coefficient (Christiansen, 1942)
UCH	-- Hawaiian Sugar Planters Association Uniformity Coefficient (Hart, 1961)
UCL	-- Linear Uniformity Coefficient (Karmeli, 1977)
yd	-- yard, unit of length, one yard equals 0.9144 meters
yd^3	-- cubic yard, unit of volume, one cubic yard equals 0.7646 cubic meters

ACKNOWLEDGMENTS

The authors are deeply indebted to the many individuals who carefully attended to the daily details of the field data collection and the laboratory analyses. These people include Ms. Barbara Mancuso, Mr. John Bargsten, Mr. Forrest Binder, Mr. Gregory Sharpe, Mr. David Flower, Mr. Douglas Ely, Mr. Patrick O'Connor and Mr. Larry Rumburg. In addition, Mr. Richard L. Aust and Mr. Stephen W. Smith contributed greatly towards the success of the Irrigation Field Days.

The cooperation of all the landowners and irrigators on the project who contributed labor, shared costs, and expended much effort for the construction and operation of the lateral and on-farm improvements is greatly appreciated. Their willingness to participate in this investigation is undoubtedly one of the major factors for the degree of improvement that was achieved.

The cooperation and assistance of the Grand Junction Drainage District was greatly appreciated and special thanks are due Mr. Howard K. Hiest, Mr. Capper Alexander, Mr. Wesley Land, and Mr. Bill Huber of the Board of Directors and Mr. Charles Tilton, Superintendent, and their staff. Thanks also go to Mr. Charles Bowman, Superintendent of the Mesa County Road Department and his staff for their assistance in the project. The efforts and assistance of Mr. Robert Henderson and the Directors of the Grand Valley Irrigation Company, Mr. William Klapwyk and the Directors of the Grand Valley Water Users Association, and the other irrigation companies in the area were extremely helpful. A complete list of all other agencies and Grand Valley businesses who contributed to this project would take several pages and, therefore, a collective and heartfelt thanks goes to each of them.

The irrigation scheduling computer service was provided by the Bureau of Reclamation, USDI, Grand Junction Office. We gratefully recognize Mr. Bill McCleneghan, Mr. Blaine Richards, Mr. Ray White, and Mr. Jack Ticen for their assistance.

Special acknowledgment goes to Ms. Debra Wilson and Ms. Sue Eastman for typing the many drafts of this report.

Finally, the efforts and advice given by the EPA Project Officer, Dr. James P. Law, Jr., have been extremely helpful in the successful pursuit of this project. He has generously given of his time to cooperatively achieve the goals of their project.

SECTION 1

INTRODUCTION

BACKGROUND

Approximately 10 million metric tons (11 million tons) of salts are delivered each year in the water supply serving the Lower Colorado River Basin (Figure 1). These salts reach Hoover Dam in about 1.36 million hectare-meters (11 million acre-feet) of water. Studies have indicated that roughly 37 percent of this salt load is to be contributed by irrigated agriculture in the Upper Colorado River Basin (Figure 2). Present salinity concentrations necessitate treatment of water for both municipal and industrial uses throughout the Lower Basin. In fact, concentrations at times approach the tolerance of many high-value crops such as citrus, thus requiring the use of excessive quantities of water for leaching and expensive water management programs.

This situation is expected to become even more serious, especially as many planned upstream water development projects are constructed. Thus, a program for reduction of mineral pollution is urgently needed in order to protect existing water users from quality degradation during low flow periods and to prevent the serious restriction of future basinwide economic development. Due to the relatively large salinity contribution from agriculture, it is obviously one sector in which to begin implementation of technologies which will reduce the salt loading from these areas.

The Grand Valley of Colorado is the largest contributor of salts per hectare of irrigated land in the Upper Colorado River Basin. Therefore, it was a logical place to begin investigating salinity control alternatives. Water entering the near-surface aquifers in the Grand Valley displaces highly mineralized water into the Colorado River. In any area where the water is in prolonged contact with soil, the mineral concentration of salts will tend towards chemical equilibrium with the soil. In the Grand Valley, high equilibrium salinity concentrations are known to exist in the near-surface aquifer. The key to achieving a reduction in salt loading is to reduce the groundwater inflows, which will result in less displacement of water from the aquifer into the river. In the Grand Valley, the main sources of groundwater flows are conveyance seepage and deep percolation from

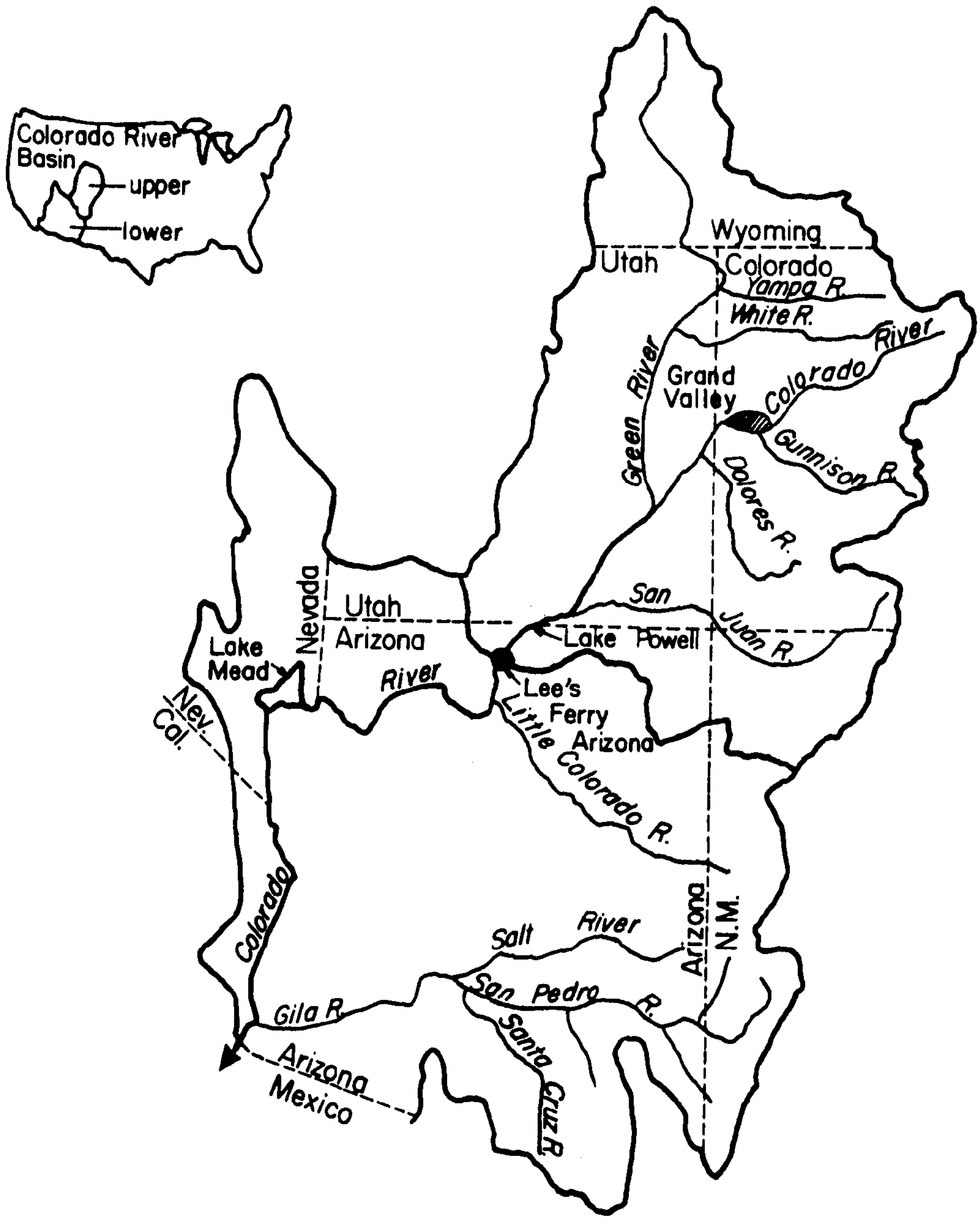


Figure 1. The Colorado River Basin.

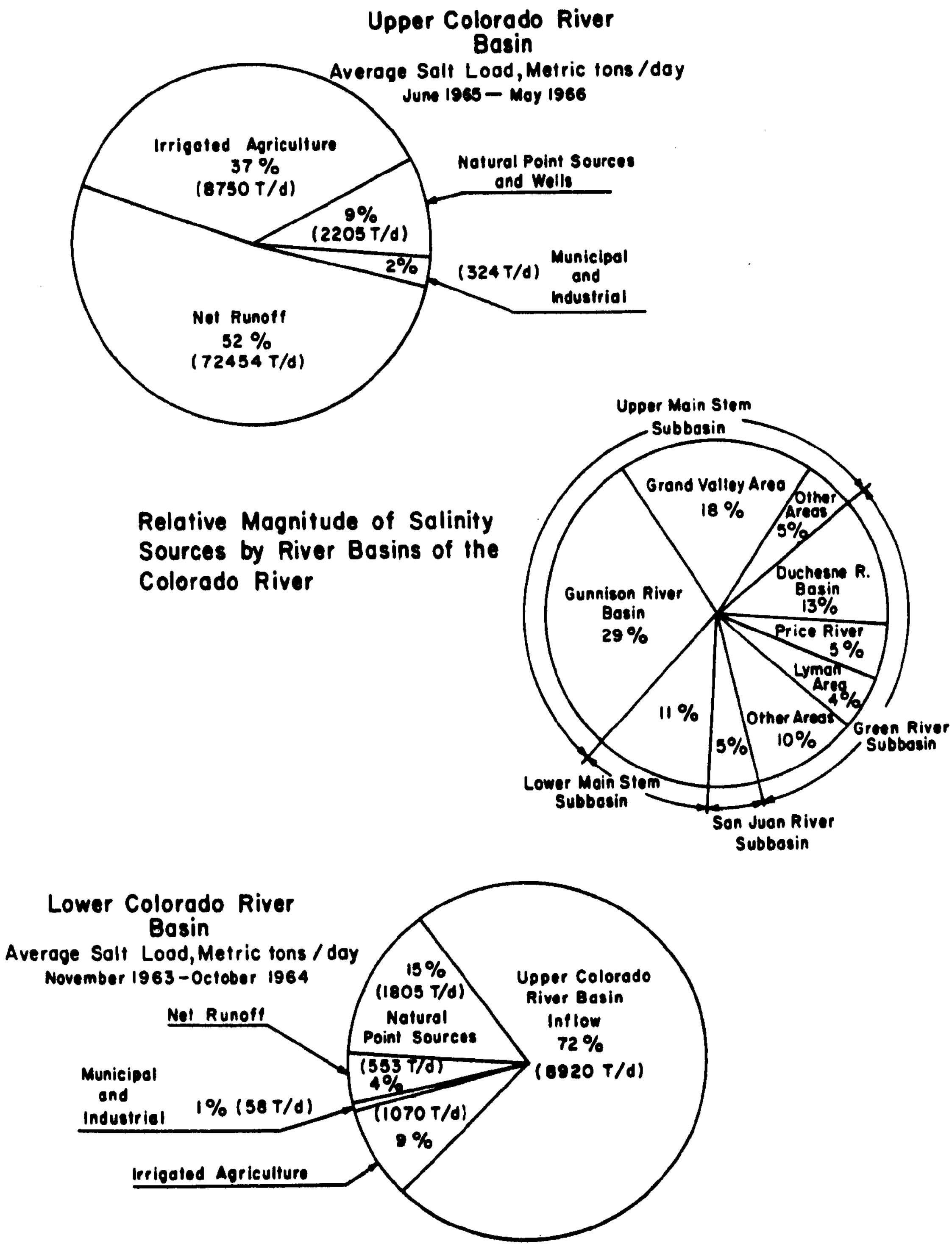


Figure 2. Relative magnitude and sources of salt in the Colorado River Basin (U.S. Environmental Protection Agency, 1971).

croplands resulting from relatively inefficient on-farm water management practices.

Canal and lateral seepage can be greatly reduced by lining the delivery system. The Grand Valley Salinity Control Demonstration Project was initiated in 1968 to study the effectiveness of linings as a salinity control measure. Since then, additional studies have been conducted on field drainage and scientific irrigation scheduling as viable salinity reduction technologies.

This demonstration project was established to show the advantage of implementing a "package" of technological improvements in reducing the quantity of highly saline subsurface return flows reaching the Colorado River. The most significant improvements in controlling irrigation return flow quality potentially comes from improved on-the-farm water management. This includes farm head ditch linings, water measurement, irrigation scheduling, conversion to sprinkler or trickle irrigation, gated pipe, cut-back furrow irrigation, field drainage, and other types of on-farm water management improvements. This concept of utilizing a package of appropriate technologies was undertaken because many of these technologies complement each other, and the net benefits would be expected to be greater than the sum of the individual improvements. Also, results from the concurrent EPA project "Irrigation Practices, Return Flow Salinity, and Crop Yields," were utilized in predicting the chemical quality changes in irrigation return flows to the Colorado River as a consequence of the demonstration project.

The results of both projects were used in the development of economically feasible guidelines for controlling the salinity from irrigation return flows. In addition, these studies should be of assistance to the national need in developing mineral pollution control methods for federal and private irrigation projects. Results can also be used as a basis for salinity control recommendations to be incorporated in water resources project evaluation reports and in programs to reduce water degradation from irrigation return flows.

PURPOSE

The costs of salinity control to compensate for future water resource developments in a region like the Colorado River Basin will be high. Savings achieved through the implementation of the most cost-effective alternatives can, therefore, be substantial. This project was designed to develop and demonstrate cost-effectiveness relationships for salinity control in the Grand Valley of western Colorado.

Economically feasible means of controlling salinity associated with irrigation return flows had been evaluated individually and independently in previous investigations. In order to extend these results to the formulation of comprehensive plans for controlling salinity on a large scale, it was necessary to describe the interrelationships which exist among the alternatives. Prior to this project, some limited evidence had indicated that the functions describing costs and effectiveness of specific salinity control measures are nonlinear. Therefore, if salinity control measures are not mutually exclusive, then an "optimal" salinity control strategy would consist of a combination of several alternatives. The respective composition of such a strategy would depend on the relative magnitude of each hydrologic segment in an irrigated area. Thus, an important step in solving salinity problems was to investigate the nature of improvements incorporating several alternatives, or in simpler terms, assessing the impact of a "package" of salinity control measures.

OBJECTIVES

The primary objective of this demonstration project was to show the advantages of implementing a "package" of technological improvements within the lateral subsystems in reducing the salt load entering the Colorado River. As defined in this project, the lateral subsystem begins at the canal turnout and includes all of the water conveyance channels below the turnout and the farmlands served by the lateral subsystem. Although major emphasis was upon on-farm improvements, considerable improvements in the water delivery conveyances and some improvements in lowering high water tables (drainage) were also required.

This project utilized each of the salinity control measures previously evaluated in Grand Valley with the additional use of various irrigation methods to demonstrate the complete package of salinity control measures. No single measure will adequately alleviate the salt load from an irrigated area. Demonstrating the complete package of salinity control measures is not only a "first," but the "packages" can also be expected to reduce the salt load beyond the sum of each individual measure because of improvements in the operation and management of each lateral.

The specific objectives of this demonstration project are summarized below:

A. Utilize salinity control technology to demonstrate the complete package of salinity control measures for nine laterals, including a preevaluation and post-evaluation of the following control measures:
   1. Utilization of existing canal lining technology developed in the Grand Valley;
   2. Utilization of irrigation scheduling technology presently in use in the Grand Valley;
   3. Evaluation of salinity control benefits resulting

from various on-farm irrigation methods as a part of this demonstration project;

4. Utilization of drainage technology previously evaluated in the Grand Valley; and
5. Utilization of the concurrent EPA research project, "Irrigation Practices, Return Flow Salinity, and Crop Yields," to predict the chemical quality changes in the Colorado River resulting from this demonstration project.

B. Determine the cost-effectiveness of each salinity control measure, various combinations of salinity control measures, and the complete package of salinity control technology for this demonstration project.

C. Conduct a two-day highly publicized field days.

D. Determine the best practicable salinity control technology for the Grand Valley, including valley-wide cost-effectiveness.

E. Analyze effectiveness of local administrative controls in implementing salinity control technology.
   1. Tailwater runoff control
   2. Permit system
      a. Individual farm
      b. Lateral
      c. Canal (Irrigation Co.)
      d. Entire valley
   3. Influent standards
      a. Farm inlet
      b. Lateral turnout
      c. Canal diversion

F. Delineate the essential elements of an educational program to transfer this information to other farmers in the Grand Valley, along with farmers in other irrigated areas of the Colorado River Basin.

This report covers all of the above objectives except A3 and D. The succeeding report "Evaluation of Irrigation Methods for Salinity Control in Grand Valley" covers objective A3. The final report of this research program, "Best Management Practices for Salinity Control in Grand Valley," is devoted to satisfying objective D.

APPROACH

The principal study area in the Grand Valley, which has been used for evaluating the effectiveness of canal and lateral lining, irrigation scheduling, and tile drainage in reducing the salt load entering the Colorado River was also used in this demonstration project (Figure 3). The advantage in continuing to utilize this study area is that the hydrology is well known. There has been considerable expenditure of funds in both equipment and personnel for instrumenting this particular demonstration area. The wealth of available information provides a

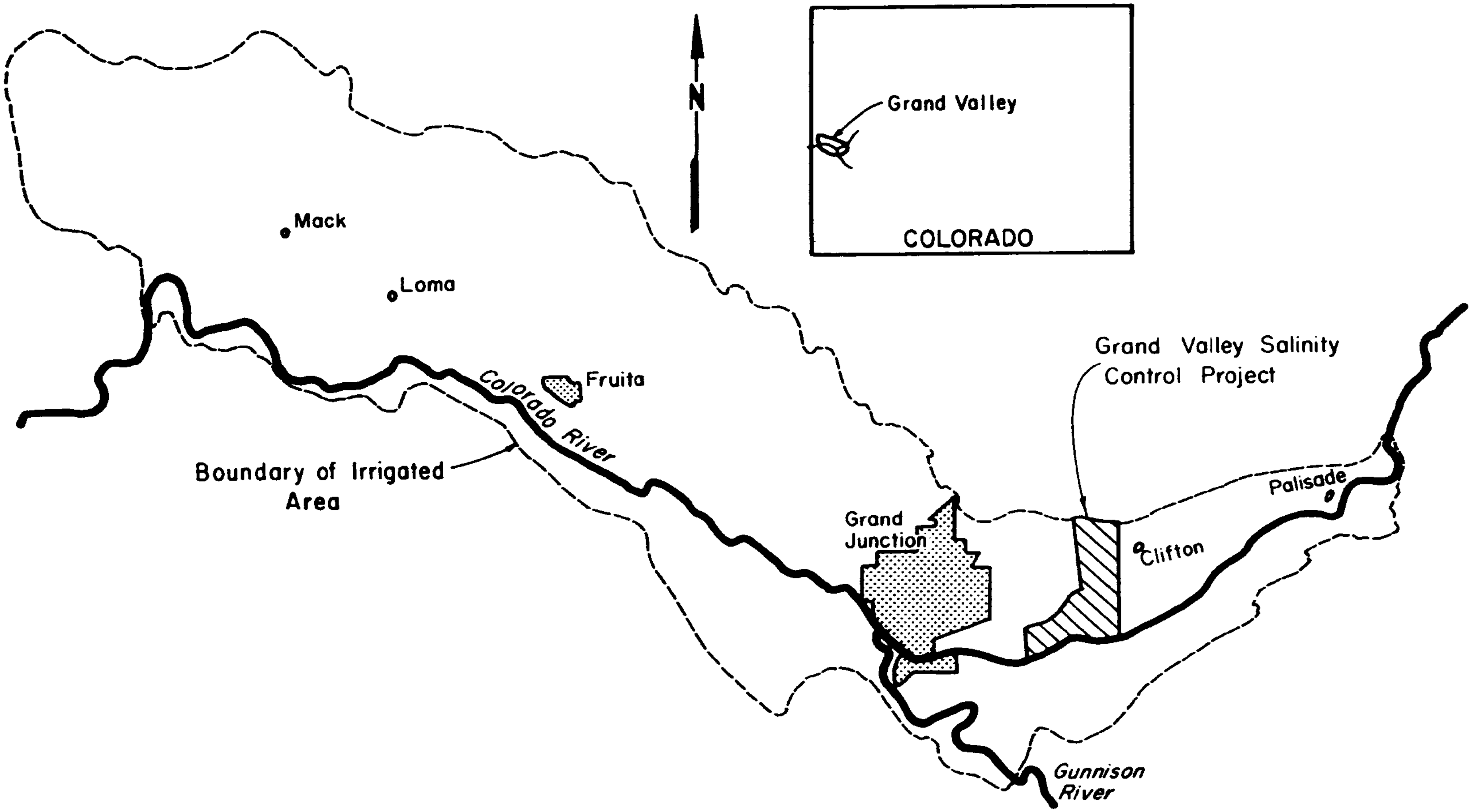


Figure 3. Location of Grand Valley Salinity Control Demonstration Project.

strong basis for evaluating the effectiveness of salinity control measures. Details of the demonstration area are shown in Figure 4.

With all the available knowledge regarding the study area, a lateral including the associated lands served by the lateral water supply was used as a subsystem for evaluating the salinity reduction in the Colorado River resulting from the implementation of a salinity control technology package. The study area was originally selected because it is fairly representative of the Grand Valley, and has five canals which traverse the area, thereby allowing greater participation by the majority of irrigation entities in the Valley.

In order to facilitate the continued participation by the irrigation interests in the Grand Valley, the laterals were selected to cover as many canals as possible. The final selection, as shown in Figure 5, had two laterals under the Highline Canal, one under the Price Ditch, three under the Grand Valley Canal, and three under the Mesa County Ditch. It should be pointed out that the lands served by the Highline Canal in the demonstration area are served under carriage contract with the Mesa County Irrigation District (Stub Ditch) and the Palisade Irrigation District (Price Ditch). Therefore, all the irrigation entities in the demonstration area are involved directly in the project.

The laterals were selected to capitalize on previous work regarding canal and lateral lining, irrigation scheduling, and drainage studies. The hydrologic knowledge already gained in this demonstration area allowed routine surface water and groundwater monitoring to evaluate the overall effectiveness of the salinity control technologies. The lands which received treatment under this demonstration project (about 20 percent of the demonstration area), along with previously constructed channel lining and drainage facilities, provided a significant impact upon salinity leaving the demonstration area.

The experimental design for the preevaluation was primarily aimed at providing specific information for the 330.7 hectares (817 acres) undergoing treatment listed in Table 1. The field data collection program allowed the design of irrigation and drainage facilities and provided sufficient data to allow predictions of salinity benefits which resulted from each specific salinity control measure. Although the postevaluation included the monitoring of water and salts entering and leaving the demonstration area, the primary emphasis was the on-site evaluation of each specific salinity control measure. The on-site evaluation was then compared with the results of the total demonstration area hydro-salinity monitoring program.

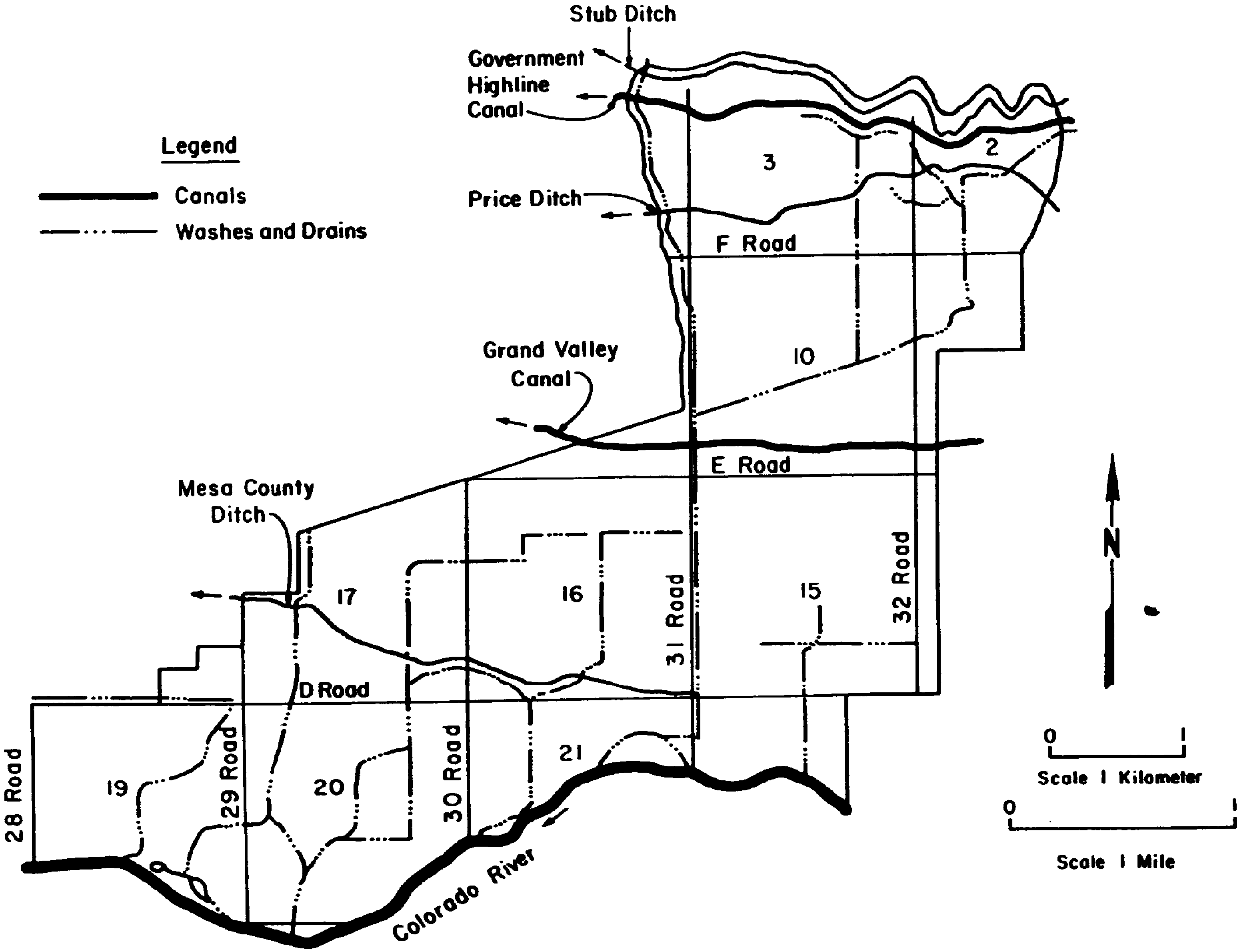


Figure 4. Grand Valley Salinity Control Demonstration Project Area.

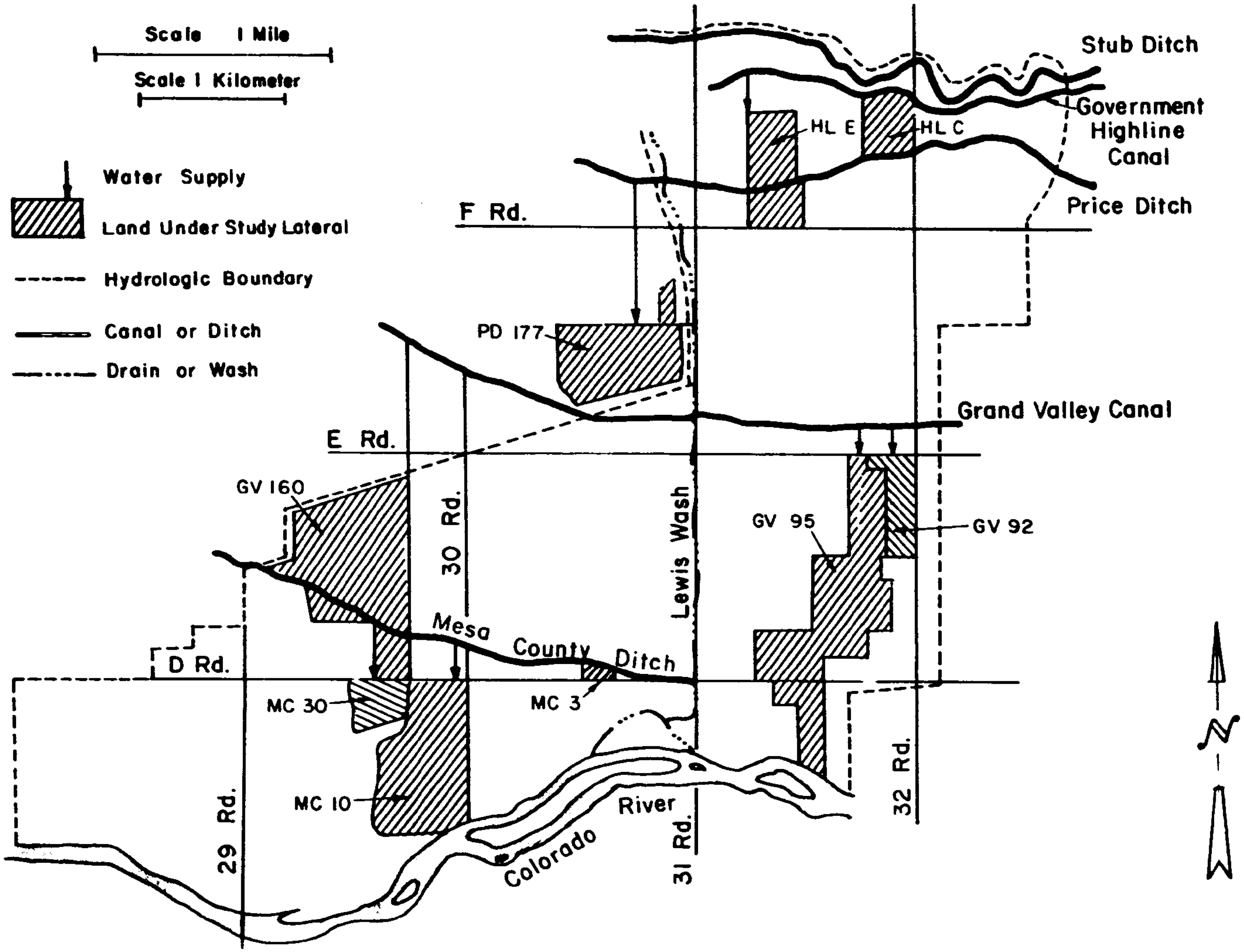


Figure 5. Location of the nine selected lateral subsystems incorporated in the project.

TABLE 1. FINAL SELECTION OF LATERALS INCLUDED IN PROJECT

Lateral Identification	Canal	Area		No.of Irrigators 5/
		Hectares	Acres	
HL C	Highline Canal	13.1	32.4	1
HL E 1/	Highline Canal	35.9	88.6	2
PD 177 1/ 4/	Price Ditch	27.8	68.8	6
GV 92	Grand Valley Canal	24.3	59.9	6
GV 95 2/ 3/	Grand Valley Canal	79.1	195.7	13
GV 160	Grand Valley Canal	78.7	194.3	8
MC 3	Mesa County Ditch	3.7	9.0	1
MC 10 1/	Mesa County Ditch	54.0	133.4	9
MC 30 2/	Mesa County Ditch	14.1	34.7	1
	TOTAL	330.7	816.8	47

1/ These laterals were part of the earlier EPA funded canal and lateral lining study.

2/ This lateral was part of the earlier EPA funded field drainage study.

3/ This lateral consolidated an additional 70 acres from two other laterals.

4/ A portion of this lateral was included in the previous EPA funded irrigation scheduling program.

5/ An irrigator is defined as a person who farms more than one acre. In actuality, 89 persons are involved in the operation of this project.

The selection of a lateral as a subsystem, rather than an individual farm, had a tremendous advantage in allowing control at the lateral turnout. In this way, both the quantity of flow and the time of water delivery could be controlled, facilitating improved water management throughout the subsystem.

A variety of irrigation methods have been demonstrated, including "tuning up" present irrigation methods being used in the study area. Considerable experience has been gained in improving the existing irrigation methods while evaluating irrigation scheduling as a salinity control measure in the Grand Valley. In addition, more advanced irrigation methods have been evaluated as to salinity benefits in the Grand Valley. The irrigation systems constructed under this project included automated farm head ditches, sprinkler irrigation, and trickle irrigation.

The most significant aspect of this particular demonstration project is the employment of a salinity control technology "package," rather than a single control measure. Experience in the Grand Valley has shown that the most significant progress is made when the gamut of questions can be answered regarding the interrelationships between water management and agricultural production. The concept of a technology package, along with an understanding of the "system" including other agricultural inputs, provides the necessary base for providing sound advice to the farmer. This, in turn, facilitates the development of credibility and, consequently, farmer acceptance.

A two-day "Field Days" was conducted during the third year of this project in the month of August. This event was primarily directed towards the growers in the Grand Valley and secondly to irrigation leaders (mostly growers) throughout the Upper Colorado River Basin. State and Federal agency personnel also attended. This was coupled with an irrigation equipment show and was cosponsored by the Colorado State University Cooperative Extension Service.

The concurrent EPA research project, "Irrigation Practices, Return Flow Salinity, and Crop Yields," which was also conducted in the Grand Valley, provided necessary input for developing the cost-effectiveness of each salinity control measure. The results from that project provided valuable information regarding increased crop yields that can be expected from improved water management practices. The combined results of these two projects are extremely important in establishing the benefits to be derived from implementing a salinity control technology package. The detailed results of this project can be found in the EPA reports entitled, "Potential Effects of Irrigation Practices on Crop Yields in Grand Valley" and "Irrigation Practices and Return Flow Salinity in Grand Valley." The combined results of the two projects are incorporated in the EPA report "Best Management Practices for Salinity Control in Grand Valley."

As a part of the demonstration project, the effects of various institutional influences upon salinity control were analyzed. These included the effects of tailwater runoff control, the requirements for implementing a permit system, and the alternative of setting "influent" standards. The information necessary for analyzing the effects of each of the above alternatives was collected as a part of the demonstration project. To allow the analysis to be projected valley-wide, some field data were collected on a random sample basis throughout the Valley.

Although not all of the institutional alternatives for implementing salinity control technology were thoroughly analyzed under this demonstration project, every attempt was made to collect the necessary "field" data for assessing the constructed alternatives. Thus, any remaining alternatives must be analyzed on a much larger scale (i.e., regional, state, or federal). Even though each irrigated area is somewhat different, the knowledge gained in the Grand Valley can be utilized in conjunction with existing and secondary sources of data for other areas (particularly irrigated areas in the Upper Colorado River Basin) to formulate plans and priorities for implementing agricultural salinity control programs in such areas.

As a final phase of the project, activity was undertaken to outline and identify the necessary elements of an educational program. This program delineates the sources of agricultural water quality problems and the effective methods for managing irrigated agriculture to improve water quality.

SECTION 2

CONCLUSIONS

The salinity control cost-effectiveness associated with each alternative improvement is the basis for determining the formulation of an implementation policy. Studies reported in the technical literature indicate that the salinity damages in the Lower Colorado River Basin range from $150 to $350 per metric ton per year when extended to the Grand Valley. Local benefits to the project such as increased crop yields, reduced irrigation system maintenance costs, increased land values and other factors were not evaluated as part of this report and are not included in the cost-effectiveness of the various alternatives. In terms of dollars per unit of annual salt load reduction achieved, the most cost-effective measures were:

1) Concrete slip form or low head PVC plastic conduit lining of laterals. The two methods are almost equal in cost-effectiveness and can reduce salinity at substantially less cost than the $150/metric ton value. Concrete slip form linings offer the advantages of easier and less frequent maintenance than pipelines, and they are more acceptable to local irrigation. Pipelines, on the other hand, are easier and more rapidly installed and can be installed by the farmer as part of his matching requirements.

2) Use of high-head PVC pipe or concrete pipe is not a cost-effective alternative to concrete linings or low-head PVC and should be discouraged. Attendant problems with the use of low-head pipe can be overcome by giving particular attention to design and installation specifications.

3) Field head ditch lining by concrete slip form or gated pipe have comparable cost-effectiveness values, and while costing more than twice as much as lateral linings to remove a unit of salinity, they still cost considerably less than the $150/metric ton value.

4) Automation of irrigation systems through automated cut-back surface irrigation, sprinkler or trickle irrigation are somewhat more costly than the

nonautomated systems, but offer a larger potential for reducing on-farm salinity contributions due to increased irrigation efficiencies. Sprinkler and trickle irrigation systems are not competitive with head ditch linings whereas automated head ditches can compete and can increase the cost-effectiveness of head ditch linings. Sprinkler and trickle irrigation systems become feasible near the $150/metric ton value.

5) Irrigation scheduling by itself is not a significant salinity control alternative, but should be part of any strategy for improved water management in order to maximize the effectiveness of physical improvements.

6) Canal linings reduce salt loading at unit costs ranging from $190 to $700 per metric ton of salt removed.

7) Desalting in conjunction with pump drainage can be expected to become feasible to reduce salt loading at approximately $320 per metric ton.

8) Field relief drainage is infeasible at any cited downstream detriment figure.

9) Cost-sharing programs are highly effective in attracting irrigators to participate in programs for improving the lateral and on-farm components of the irrigation system, provided adequate technical assistance is provided.

10) Allowing individual irrigators to use their labor to meet all or part of their matching requirements certainly contributed to the ease of accomplishing the goals of this project.

11) In Grand Valley, the jurisdiction of the irrigation companies does not include the laterals in most cases, so there are no formal arrangements for managing the irrigation water supply and settling disputes among water users.

12) The informal organizational arrangements used for the lateral improvement program, although satisfactory on most of the laterals, resulted in numerous problems on a few laterals as far as collecting required matching funds for the project, as well as some difficulties in implementing improved irrigation practices.

13) Individual on-farm improvements should be the result of individual negotiations between the irrigator and technical assistance personnel.

14) There is a clear need to involve irrigators in all phases of salinity related improvements. Where irrigators participated in design decisions, the systems were not always the most efficient, but were certainly the most workable and flexible from the standpoint of the water users. Participation in the actual construction provided operational insight, understanding of neighbor needs, a pride in workmanship, and more rapid completion of the work than by contractual methods.

15) Proper water management requires a strong emphasis toward on-farm water control structures, especially flow measurement devices. This project utilized standardized means for determining water flow rates. All flow measurement devices were designed or selected to be read directly by the farmers without the use of printed tables.

16) In investigating the advantages and disadvantages of influent control versus effluent control for a National Pollutant Discharge Elimination System type program in Grand Valley, it became readily evident that influent controls offered the greatest advantage in terms of the reduced number of control points, better monitoring capabilities, and most importantly, being able to alleviate the problem at its source rather than treating the symptoms.

17) The success of an influent approach is dependent upon: (a) use of numerous flow measuring devices; (b) adequate technical assistance for working with and advising farmers on improved irrigation practices and methods; and (c) availability of funds for making the necessary structural improvements.

18) Successful implementation requires large-scale extension type programs to provide necessary technical assistance and a strong interaction with farmers.

19) A large amount of technical assistance is required in working with farmers in designing on-farm improvements that suit their individual needs, to negotiate the financial terms, construction of the improvements, and assisting the irrigator in the proper management of his new system.

SECTION 3

RECOMMENDATIONS

As a result of this rather extensive research project, there are several recommendations which can be made concerning the implementation of a "total" salinity control program.

1) Implementation of an action salinity control program in the Grand Valley should consist of lateral improvements (i.e., concrete slip form lining or low-head PVC plastic pipe) and on-farm improvements.

2) The lateral improvement program and the on-farm program should not be two separate programs, but a single program which plans, constructs, and operates a combination of improvements moving from one lateral to the next.

3) Open hearings or public meetings must be followed up by additional contact with all the farmers on a lateral which have expressed an interest. Meetings at the irrigation company offices or in local homes will be much more effective in reaching many landowners.

4) For lateral improvement programs which require the collective action of the irrigators served by a lateral, there is a need to encourage the users to formally organize under the corporate laws of the State of Colorado that apply to irrigation, which will: (a) substantially facilitate contractual arrangements for lateral improvements; (b) provide a much simpler means of handling matching requirements; and (c) provide a better means for implementing a more comprehensive water management program for each lateral.

5) Training materials are needed to motivate farmers and help them understand the importance to themselves and their communities of improving present water management practices for increased crop production and the control of salinity.

6) An effective plan of physical improvements must be developed which will result in improved water management

for increasing agricultural productivity in the Grand Valley, while reducing the salt load in the Colorado River.

7) The plan of improvement must include sufficient flow measurement structures through the lateral subsystem to facilitate equitable distribution of the water supplies and improved irrigation practices.

8) Adequate numbers of technical assistance personnel should be available to help the irrigators develop proficiency with their system and develop a higher level of water management.

9) Given the levels of technical assistance personnel needed to work with farmers, and the current shortage of trained manpower with on-farm water management experience, special training courses will be required.

10) Once the physical facilities are complete, a program of "scientific" irrigation scheduling should be used to maximize the effectiveness of the physical improvements.

11) The success of any salinity control program rests finally with the degree of participation by the farmers themselves. Farmers who have made exceptional progress in improving their on-farm water management practices should be given special recognition.

12) The implementation program should be monitored, evaluated, and continuously refined. This process will not only maximize the effectiveness of the Grand Valley Salinity Control Program, but will provide valuable information and experience for implementing irrigation return flow quality control programs in other areas of the West.

SECTION 4

THE GRAND VALLEY

The Grand Valley is located in west central Colorado near the western edge of Mesa County. Grand Junction, the largest city in Colorado west of the Continental Divide, is the population center of the Valley (Figure 3). The Grand Valley is a crescent shaped area which encompasses about 49,800 hectares (123,000 acres) of which 57.7 percent or about 28,650 hectares (70,800 acres) are irrigated. Urban and industrial expansion, service roads and farmsteads, idle and abandoned lands account for most of the land not farmed. The Valley was carved in the Mancos Shale formation (a high salt bearing marine shale) by the Colorado River and its tributaries. The Colorado River enters the Grand Valley from the east, is joined by the Gunnison River at Grand Junction and then exits to the west.

Spectacular and colorful canyons flank the southwestern edge of the Valley (Colorado National Monument). A steep escarpment known as the Book Cliffs (which are the southern edge of the Roan Plateau) rises from the Valley floor on the north; the 3,050 meter (10,000 foot) high Grand Mesa lies to the northeast, and distantly to the southeast the San Juan Mountains can be seen; to the south and west lie the rough, steep, deeply eroded hilly lands of the high terraces or mesas of the canyon lands of the Colorado Plateau. Within the Grand Valley, the irrigated lands have developed on geologically recent alluvial plains consisting of broad coalescing alluvial fans and on older alluvial fans, terraces and mesas. Also, included in the Valley lands are stream flood plains and various rough lands occurring as terraces, escarpments, high knobs, and remnants of former mesas.

POPULATION

The majority of the population of Mesa County resides in the Grand Valley near and within the city limits of Grand Junction. In 1970 the population of the city of Grand Junction was 20,170, 37 percent of the total Mesa County population. The population has been growing steadily during the past decades, and the 1974 estimated population of Grand Junction was 27,000 while that of the Mesa County was nearly 62,000. The projected 1990 population of Mesa County is 90,000.

Grand Junction is a regional trade and service center for the considerable agricultural and mining interests in western Colorado, northwestern New Mexico, northeast Arizona, and eastern Utah because of its access to major highways, rail and airline systems. During the 1950's the area became and still is the center of the uranium exploration boom and several uranium development projects sponsored by the government. Recent program expansions related to energy have caused an economic upswing for the area. At the present time, the Grand Valley is a focal supply point for the budding oil shale and sodium bicarbonate (Nahcolite) industries which lie to the north and west. The area is also a supply and service center for a considerable oil and natural gas drilling and exploration industry.

CLIMATE

The Grand Valley area enjoys a moderate year-around climate which is influenced more by the mountain ranges in the Upper Colorado River Basin than by the latitude. The movement of air masses are affected by the mountain ranges so that the high elevations are relatively wet and cool, whereas the low plateaus and valleys are much drier and subject to wide temperature ranges. The characteristic climate in the lower altitudes is hot and dry summers and cool winters.

The Grand Valley has a climate common to all of the semiarid Colorado River Basin. Most of the precipitation to the Valley is provided from the Pacific Ocean and the Gulf of Mexico, whose respective shores are 1,200 and 1,800 kilometers (750 and 1,100 miles) away. During the period from October to April, Pacific moisture is predominant, but the late spring and summer months receive moisture from the Gulf of Mexico. The advancing air masses are forced to high altitudes and lose much of their moisture either before entering the area (Gulf of Mexico fronts) or after leaving the area (Pacific fronts).

The Grand Valley receives an average annual precipitation of only 211 mm (8.29 inches) and practically all irrigation and potable water supplies come from the nearby high mountain snowpacks. The monthly distribution of precipitation and temperature for Grand Junction is shown in Figure 6. The climate is marked by a wide seasonal range, but sudden or severe weather changes are infrequent due primarily to the high mountains around the Valley. The usual occurrence of precipitation in the winter is snow and during the growing season is in the form of light showers from thunderstorms. Severe cloudbursts occur infrequently during the late summer months and hail storms are rare.

Although temperatures have ranged to as high as 40.6 degrees C (105 degrees F), the usual summer temperatures range to the middle and low 30's degrees C (90's degrees F) in the

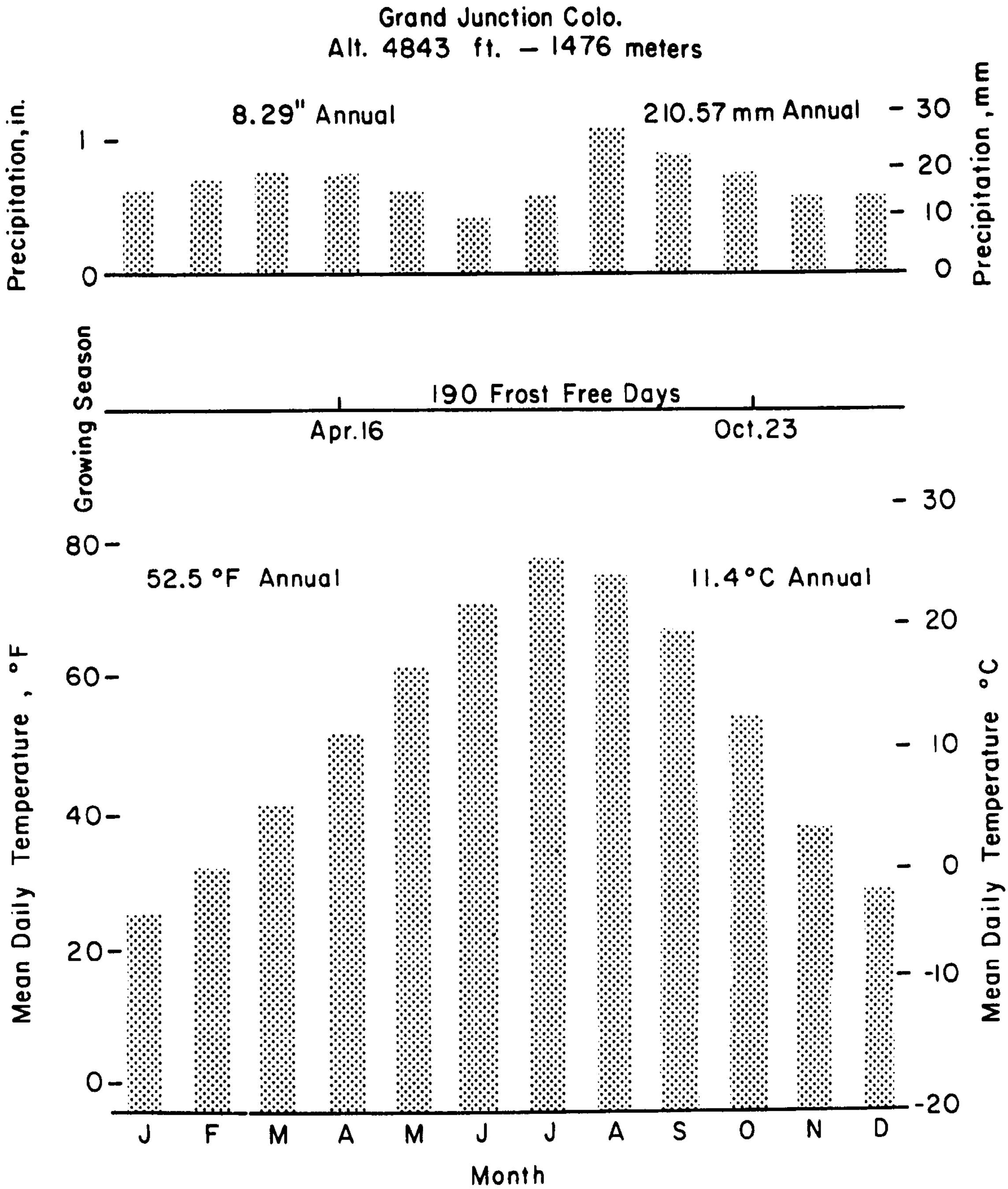


Figure 6. Normal precipitation and temperature at Grand Junction, Colorado (U.S. Department of Commerce, 1968).

daytime and around 15 degrees C (low 60's degrees F) at night. Relative humidity is usually low during the growing season, which is common in all of the semi-arid Colorado River Basin. The average annual relative humidity is 58.8 percent. The prevailing wind direction is east-southeast with an average velocity of about 13.4 kilometers per hour (8.3 mph).

GEOLOGY

The plateaus and mountains in the Colorado River Basin are the products of a series of land masses deeply eroded by wind and water. However, long before the earth movements which created the uplifted land masses, the region was the scene of alternate encroachment and retreat of great inland seas. The sediment rock formations underlying large portions of the basin are the result of material accumulated at the bottom of these seas. In the Grand Valley, the primary geologic formation is the Mancos Shale.

Mancos Shale is a very thick sequence of drab, gray, fissile, late Cretaceous marine shale that lies between the underlying Dakota sandstones and the overlying Mesa Verde formation. The thickness of the Mancos Shale usually varies from between 900 to 1,500 meters (3,000 and 5,000 feet). Due to its great thickness and its ability to be easily eroded, this shale forms most of the large valleys of western Colorado and eastern Utah. A general geologic cross-section of the Valley can be seen in Figure 7.

Because of the marine origin of the shale, it contains a very high percentage of water soluble salts which can be readily seen in the many patches of alkali (white and black) in both irrigated and nonirrigated areas. The types of salts which are present in the shale are mostly calcium sulfate with smaller amounts of sodium chloride, sodium sulfate, magnesium sulfate, and calcium and magnesium carbonates. In fact, the minerals gypsum and calcite (calcium sulfates) are commonly found in crystaline form in open joints and fractures of the Mancos Shale, as well as in the soil profile. This can be seen in Figure 8.

Due to the compactness of the clay and silt particles making up the shale, the formation is not considered water-bearing at depth. However, the weathered zone near the surface does transmit small quantities of water along joints, fractures, and open bedding planes. In this zone, the percolating water, which primarily originates from the overirrigation of cropland, dissolves the salts directly out of the shale. The soils of the Valley are also quite saline because they have been derived from the Mancos Shale.

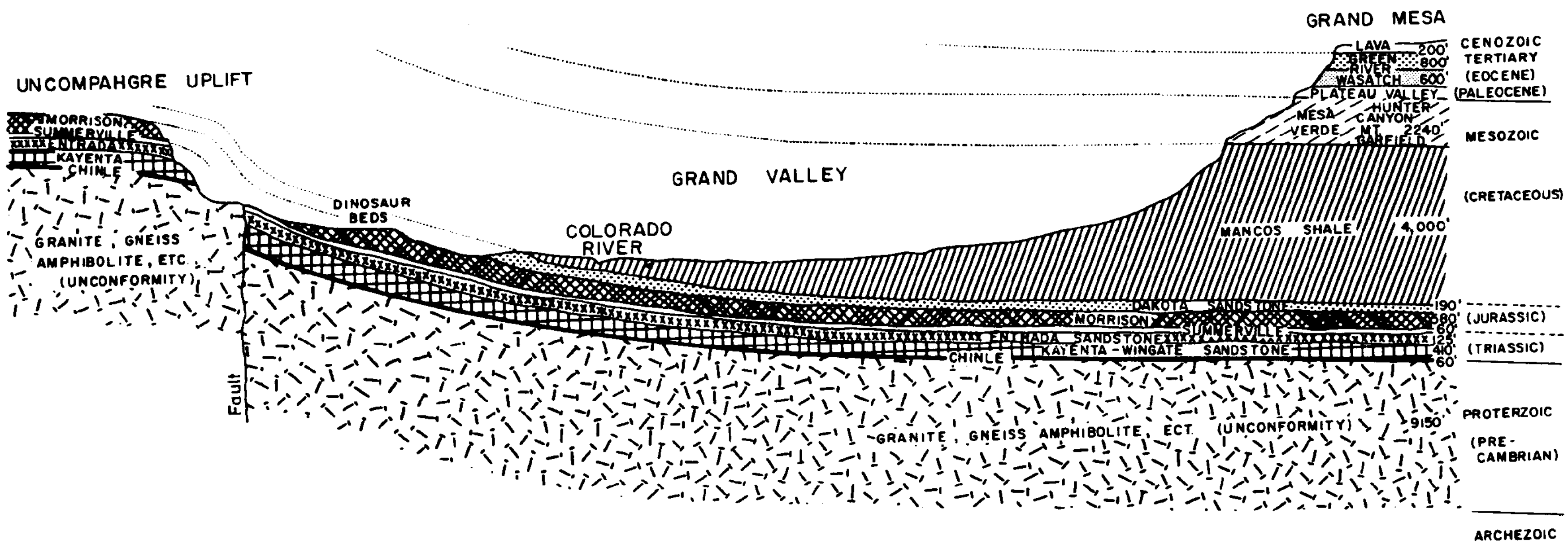


Figure 7. General geologic cross-section of the Grand Valley (U.S. Department of Agriculture, Soil Survey, Series 1940, Grand Junction Area, Colorado, 1955).

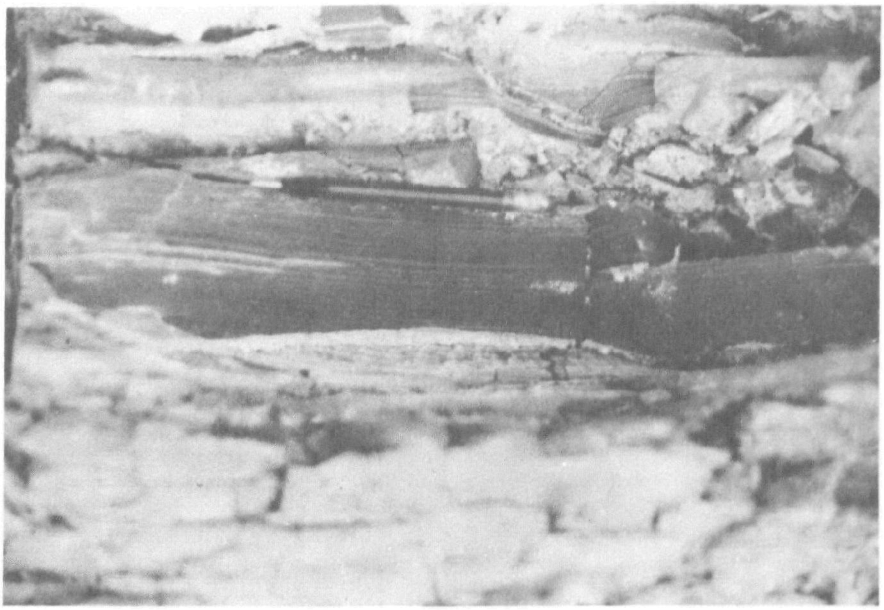


Figure 8. Photograph of crystaline salt lenses in Mancos Shale in the irrigated area of the Grand Valley.

A gravel and cobble layer has been found under some parts of the irrigated areas in the Grand Valley. It is believed to be ancient stream deposits of the Colorado River, laid down in recent geologic time, and serves as an aquifer for transmitting highly saline groundwater to the river.

SOILS

The physical features describing the project area are similar to the entire Grand Valley. The soils in the Valley were classified by the Soil Conservation Service (SCS) in cooperation with the Colorado Agricultural Experiment Station in 1955. Using these data a soil classification map of the Grand Valley's irrigated area is shown in Figure 9. The soil classification symbols, along with a general description of each symbol and the relative percent of areal extent, are tabulated in Table 2.

The dry desert climate of the area has restricted the growth of natural vegetation, and because of the lack of organic matter, the soils are very low in nitrogen content. The natural inorganic content is high in lime carbonate, gypsum, sodium, potassium, magnesium and other calcium salts. With the addition of irrigation, some locations have experienced high salt concentrations with a resulting decrease in crop productivity.

Although natural phosphate exists in the soils, it becomes available too slowly for use by cultivated crops, and fertilizer

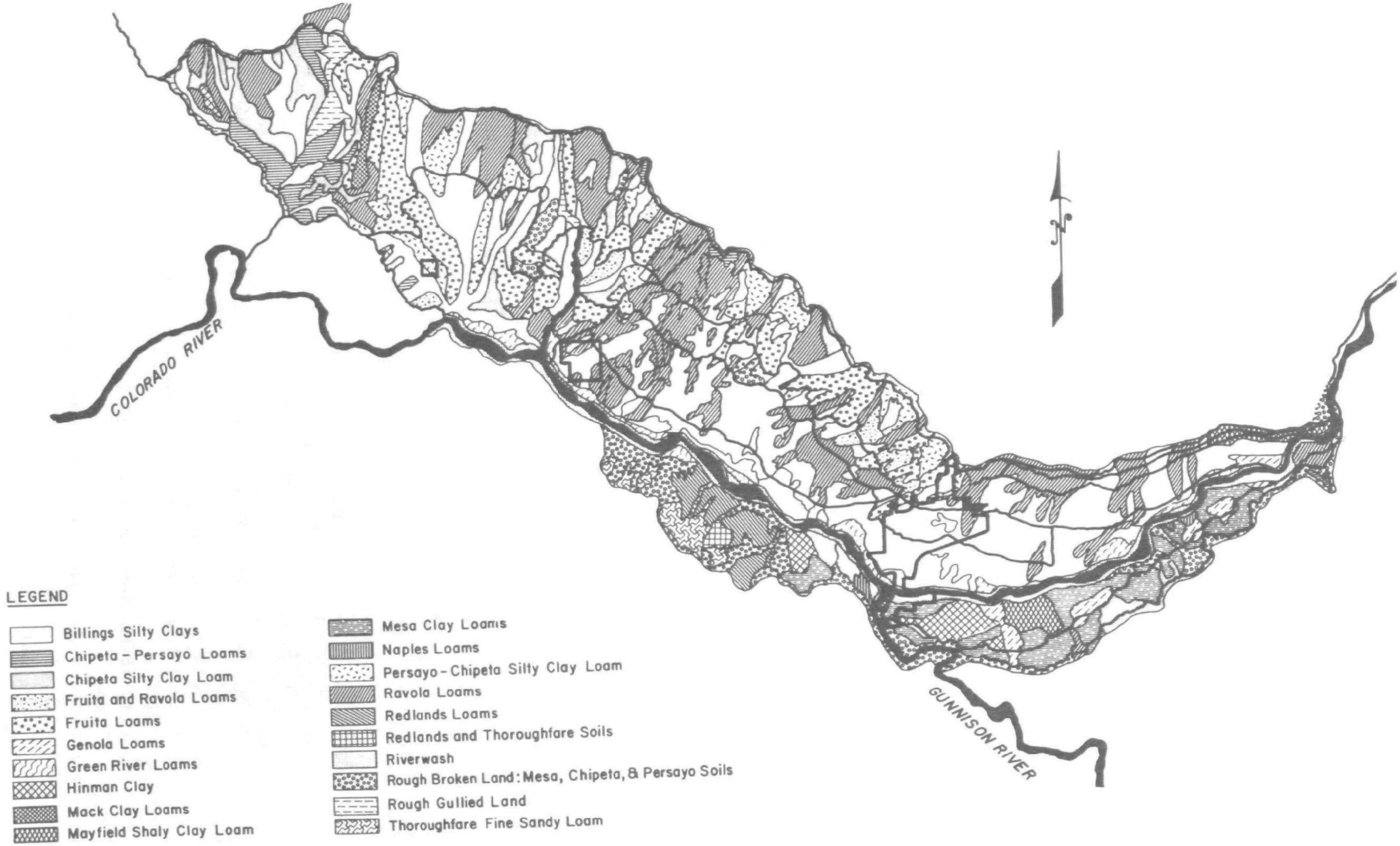


Figure 9. Soils map of irrigated lands in Grand Valley.

TABLE 2. SOIL MAPPING CLASSIFIED INDEX AND APPROXIMATE PERCENT OF AREAL EXTENT IN GRAND VALLEY, COLORADO (USDA, SOIL SURVEY, SERIES 1940, 1955).

Map Symbol	Soil Type	Approximate Percent
Bc	Billings silty clay loam, 0 to 2 percent slopes	25.4
Bd	Billings silty clay loam, 2 to 5 percent slopes	.6
Ba	Billings silty clay, 0 to 2 percent slopes	2.7
Bb	Billings silty clay, 2 to 5 percent slopes	.1
Be	Billings silty clay, moderately deep over Green River soil material, 0 to 2 percent slopes	.7
Cd	Chipeta silty clay loam, 0 to 2 percent slopes	2.4
Ce	Chipeta silty clay loam, 2 to 5 percent slopes	2.8
Ca	Chipeta-Persayo shaly loams, 2 to 5 percent slopes	.8
Cb	Chipeta-Persayo shaly loams, 5 to 10 percent slopes	1.9
Cc	Chipeta-Persayo silty clay loams, 5 to 10 percent slopes	1.5
Fe	Fruita clay loam, 0 to 2 percent slopes	2.2
Ff	Fruita clay loam, 2 to 5 percent slopes	.4
Fg	Fruita clay loam, moderately deep, 0 to 2 percent slopes	.6
Fl	Fruita clay loam, moderately deep, 2 to 5 percent slopes	1.1
Fi	Fruita gravelly clay loam, 2 to 5 percent slopes	.6
Fk	Fruita gravelly clay loam, 0 to 2 percent slopes	.1
Fm	Fruita gravelly clay loam, 5 to 10 percent slopes	.1
Fn	Fruita gravelly clay loam, moderately deep, 2 to 5 percent slopes	.5
Fo	Fruita gravelly clay loam, moderately deep, 5 to 10 percent slopes	.1
Fp	Fruita very fine sandy loam, 0 to 2 percent slopes	1.1
Fr	Fruita very fine sandv loam, 2 to 5 percent slopes	.5
Fs	Fruita very fine sandy loam, moderately deep, 0 to 2 percent slopes	.5
Ft	Fruita very fine sandy loam, moderately deep, 2 to 5 percent slopes	1.0
Fu	Fruita very fine sandy loam, moderately deep, 5 to 10 percent slopes	.1
Fc	Fruita and Ravola loams, 2 to 5 percent slopes	1.2
Fd	Fruita and Ravola loams, moderately deep, 2 to 5 percent slopes	.3
Fa	Fruita and Ravola gravelly loams, 5 to 10 percent slopes	.7
Fb	Fruita and Ravola gravelly loams, 20 to 40 percent slopes	.1
Ga	Genola clay loam, 0 to 2 percent slopes	.2
Gb	Genola clay loam, 2 to 5 percent slopes	[1]
Gc	Genola clay loam, deep over Hinman clay, 0 to 2 percent slopes	.5
Gd	Genola fine sandy loam, deep over gravel, 0 to 2 percent slopes	[1]
Gf	Genola loam, 2 to 5 percent slopes	.2
Gg	Genola very fine sandy loam, deep over gravel, 0 to 2 percent slopes	.1
Gh	Green River clay loam, deep over gravel, 0 to 2 percent slopes	.1
Gk	Green River fine sandy loam, deep over gravel, 0 to 2 percent slopes	.4

(Table 2 continued on following page)

TABLE 2 (CONTINUED).

Map Symbol	Soil Type	Approximate Percent
Gl	Green River silty clay loam, deep over gravel, 0 to 2 percent slopes	.2
Gm	Green River very fine sandy loam, deep over gravel, 0 to 2 percent slopes	1.7
Ha	Hinman clay, 0 to 1 percent slopes	.5
Hb	Hinman clay loam, 0 to 2 percent slopes	1.7
Hc	Hinman clay loam, 2 to 5 percent slopes	.3
Ma	Mack clay loam, 0 to 2 percent slopes	.5
Mb	Mayfield shaly clay loam, 2 to 5 percent slopes	.5
Mc	Mesa clay loam, 0 to 2 percent slopes	1.7
Md	Mesa clay loam, 2 to 5 percent slopes	1.8
Me	Mesa gravelly clay loam, 2 to 5 percent slopes	1.3
Mf	Mesa gravelly clay loam, 5 to 10 percent slopes	.7
Mg	Mesa gravelly clay loam, moderately deep, 2 to 5 percent slopes	.1
Mh	Mesa gravelly clay loam, moderately deep, 5 to 10 percent slopes	.4
Na	Naples clay loam, 0 to 2 percent slopes	.1
Nb	Naples fine sandy loam, 0 to 2 percent slopes	.1
Nc	Navajo silty clay, 0 to 2 percent slopes	.1
Pa	Persayo-Chipeta silty clay loams, 0 to 2 percent slopes	3.4
Pb	Persayo-Chipeta silty clay loams, 2 to 5 percent slopes	2.5
Ra	Ravola clay loam, 0 to 2 percent slopes	6.1
Rb	Ravola clay loam, 2 to 5 percent slopes	.4
Rf	Ravola very fine sandy loam, 0 to 2 percent slopes	4.7
Rg	Ravola very fine sandy loam, 2 to 5 percent slopes	.1
Rc	Ravola fine sandy loam, 0 to 2 percent slopes	2.1
Rd	Ravola fine sandy loam, 2 to 5 percent slopes	.1
Re	Ravola loam, 0 to 2 percent slopes	2.1
Rk	Redlands loam, 2 to 5 percent slopes	.8
Rh	Redlands loam, 0 to 2 percent slopes	[1]
Rl	Redlands loam, 5 to 10 percent slopes	.1
Rn	Redlands and Thoroughfare soils, shallow over bedrock, 5 to 10 percent slopes	.4
Rm	Redlands and Thoroughfare soils, shallow over bedrock, 2 to 5 percent slopes	[1]
Ro	Riverwash, 0 to 2 percent slopes	2.9
Rr	Rough broken land, Mesa, Chipeta, and Persayo soil materials	3.6
Rp	Rough broken land, Chipeta and Persayo soil materials	2.9
Rs	Rough gullied land	2.9
Tb	Thoroughfare fine sandy loam, 2 to 5 percent slopes	1.4
Ta	Thoroughfare fine sandy loam, 0 to 2 percent slopes	.1
Tc	Thoroughfare fine sandy loam, 5 to 10 percent slopes	.1

[1] Less than 0.1 percent.

applications greatly aid yields. Other minor elements such as iron are generally available for most crops except in those areas where drainage is inadequate. The soils in the area are of relatively recent origin, and consequently, they contain no definite concentration of lime or clay in the subsoil horizons as would be expected in weathered soils. Some areas in the Valley have limited farming use because of poor internal drainage, which results in waterlogging and salt accumulations.

Lying on top of the Mancos Shale and below the alluvial soils is a large cobble aquifer extending north from the river to about midway up the irrigated area for most of the length of the Valley. The approximate areal extent of this aquifer can be seen in Figure 10. The importance of this aquifer with respect to the drainage problems of the area has been demonstrated by a cooperative study in 1951 between the Colorado Agricultural Experiment Station in conjunction with the United States Department of Agriculture, Agricultural Research Service (ARS), which evaluated the feasibility of pump drainage from the aquifer. Much of this cobble aquifer is covered with a thin, tight and often discontinuous clay layer and/or a shale gravel washed from the nearby Book Cliffs.

AGRICULTURAL ECONOMIC CONDITIONS

The modification of the Colorado River's flows have yielded benefits in the form of irrigation, power generation, recreation, industrial and domestic water supply, transportation and waste disposal. In recent years, manufacturing and service industries have experienced rapid growth, surpassing mining and agriculture in economic importance in all seven basin states. Agriculture is an important source of employment and income to a local population in the Grand Valley area. In recent years, basic manufacturing and service industries have greatly contributed to the otherwise traditionally agricultural community.

In 1972, the annual per capita income for Mesa County was $3,409 compared to the Colorado per capita income of $4,006. The unemployment is generally less than the statewide level (October 1976 it was 4.3 percent compared to 5.3 percent for the state). In 1970, the median income for families was $8,065 for Mesa County. Farm population in Mesa County for 1970 was 3,898 which was a 42.7 percent decline from 1960.

The Grand Valley contains approximately 65 percent of the total irrigated croplands in Mesa County and accounts for about 75 percent of total value of farm products for the county. The 1969 census (by U.S. Department of Commerce definition, 1972) counted a total of 1,320 farms for Mesa County, which was a 21 percent decrease since 1964.

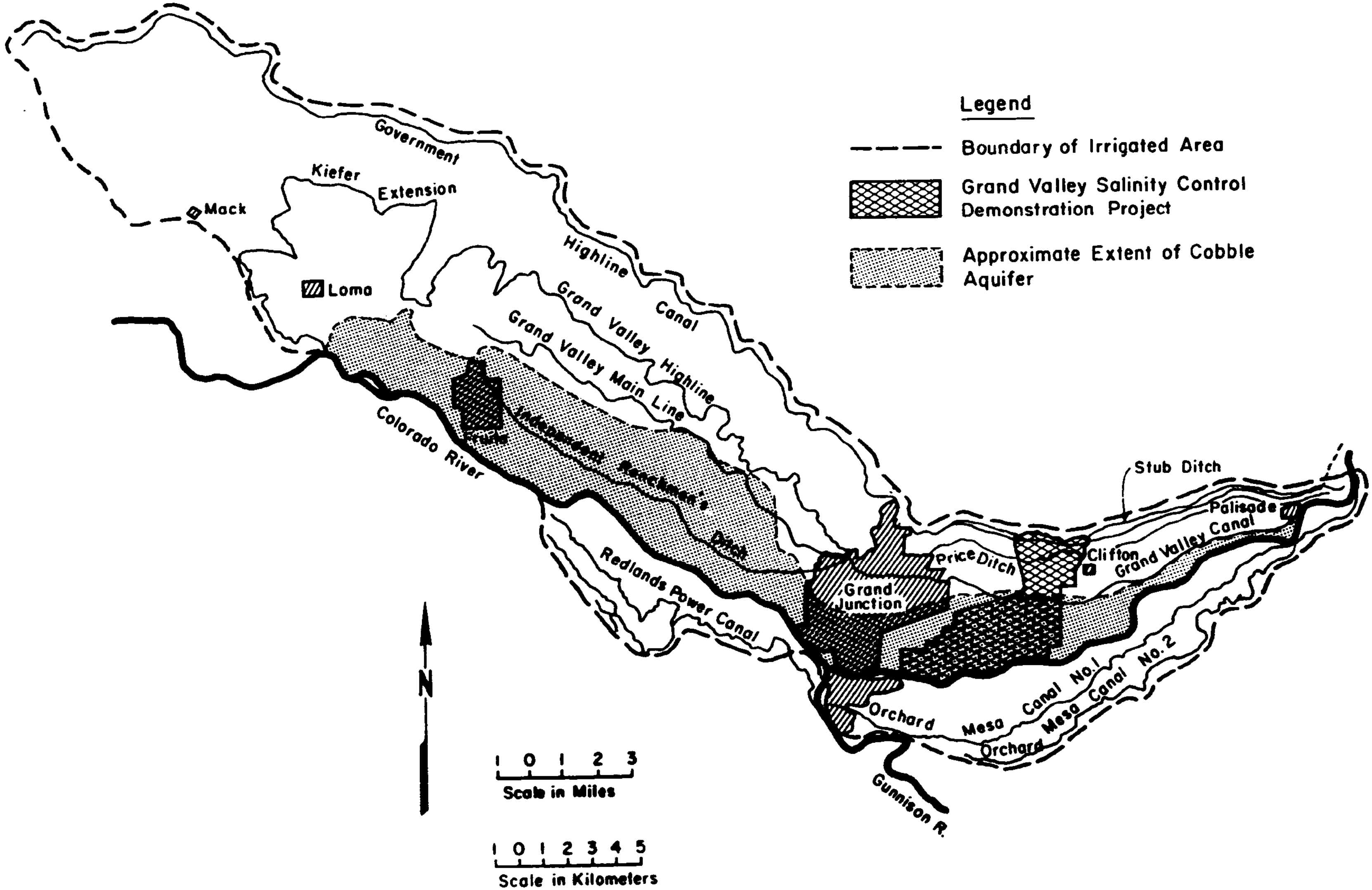


Figure 10. Approximate areal extent of cobble aquifer in the Grand Valley.

The diversified agricultural industry in the Valley is comprised of both livestock and crop production activities. Slightly less than 10 percent of the irrigated acreage is planted to pome and deciduous orchards, the produce of which is processed locally and may be shipped as far as the Atlantic seaboard. The Grand Valley has long been a favored wintering area for cattle and sheep which were grazed on high mountain summer ranges to the east and north (Young et al., 1975).

An economic survey by Leathers (1975), along with the land use inventory by Walker and Skogerboe (1971), indicates that local farming is primarily a small unit operation. The population engaged in agricultural activities is widely dispersed throughout the Valley with most living on their property. Leathers (1975) determined from sampling about 100 random selections that most farm units were less than 40 hectares (100 acres) in size (Figure 11). Using data supplied by the USDA Soil Conservation Service, a frequency distribution of field sizes is shown in Figure 12. Of the total of 7,870 fields in the Valley, 50 percent are less than 2 hectares (5 acres) in size.

AGRICULTURAL LAND USE

Although the early explorers concluded that the Grand Valley was a poor risk for agriculturally related activities, the first pioneering farmers rapidly disproved this notion with the aid of irrigation water diverted from the Grand and Blue Rivers (now the Colorado and Gunnison Rivers) entering the Valley. Through a long struggle, an irrigation system evolved to supplement the otherwise meager supply of precipitation during the hot summer months. However, the futility of irrigation without adequate drainage was quickly demonstrated in the Valley as some low lying acreages became waterlogged with highly saline groundwater. Today, the failure to completely overcome these conditions is still evident as illustrated by a summary of land use in the Valley presented in Figure 13. For example, of the more than 28,600 hectares (70,800 acres) of irrigable cropland, almost one-third is either in pasture or idle. An examination of land use in Grand Valley by Walker and Skogerboe (1971) indicated a large fraction of the 12,000 to 16,000 hectares (30,000 to 40,000 acres) of phreatophytes and barren soil were also once part of an irrigated acreage. Evidence exists that these same lands were once highly productive and subsequently ruined by overirrigation and inadequate drainage.

The various acreages of land uses in the Valley area are shown in Table 3. One of the most quoted statements in the literature concerning the Grand Valley is that approximately 30 percent of the farmable area is unproductive because of the ineffectiveness of the drainage in these areas. Examination of the results presented in Table 3 indicates that 58 percent of the Valley can be classified as usable land. However, only 43

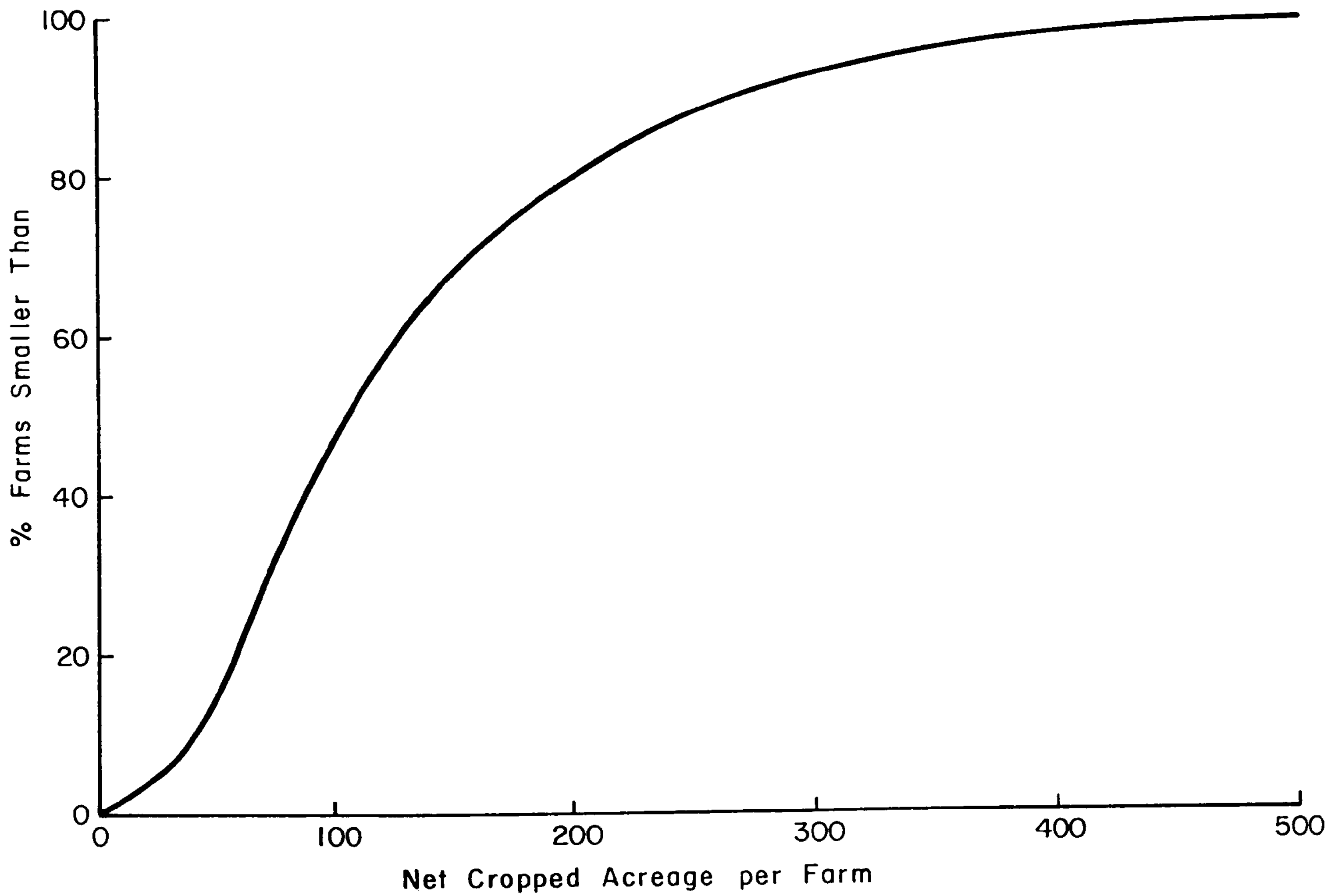


Figure 11. Frequency distribution of Grand Valley farm sizes (Leathers, 1975).

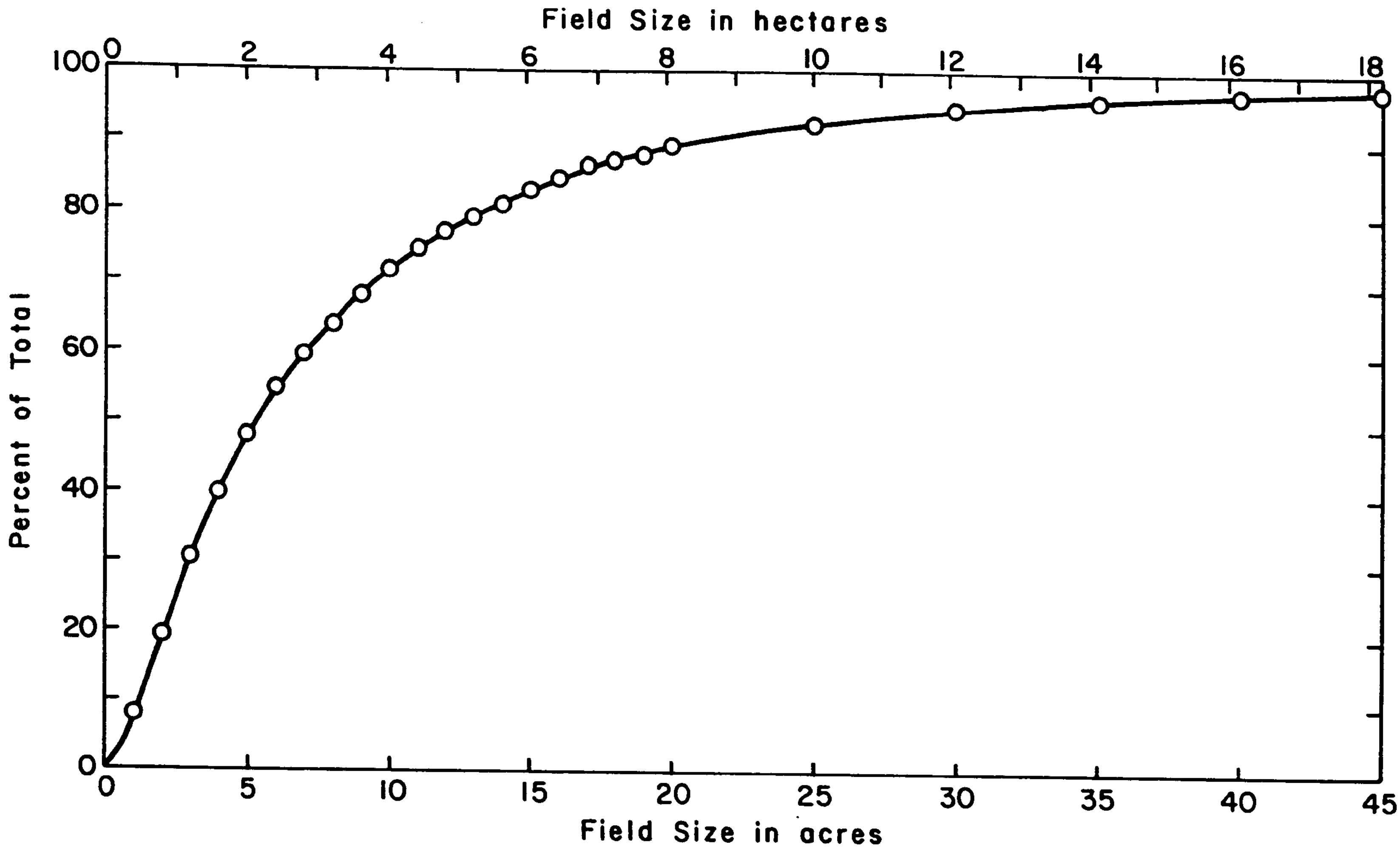


Figure 12. Frequency distribution of agricultural field sizes in the Grand Valley (USDA-SCS. Open file data, 1976).

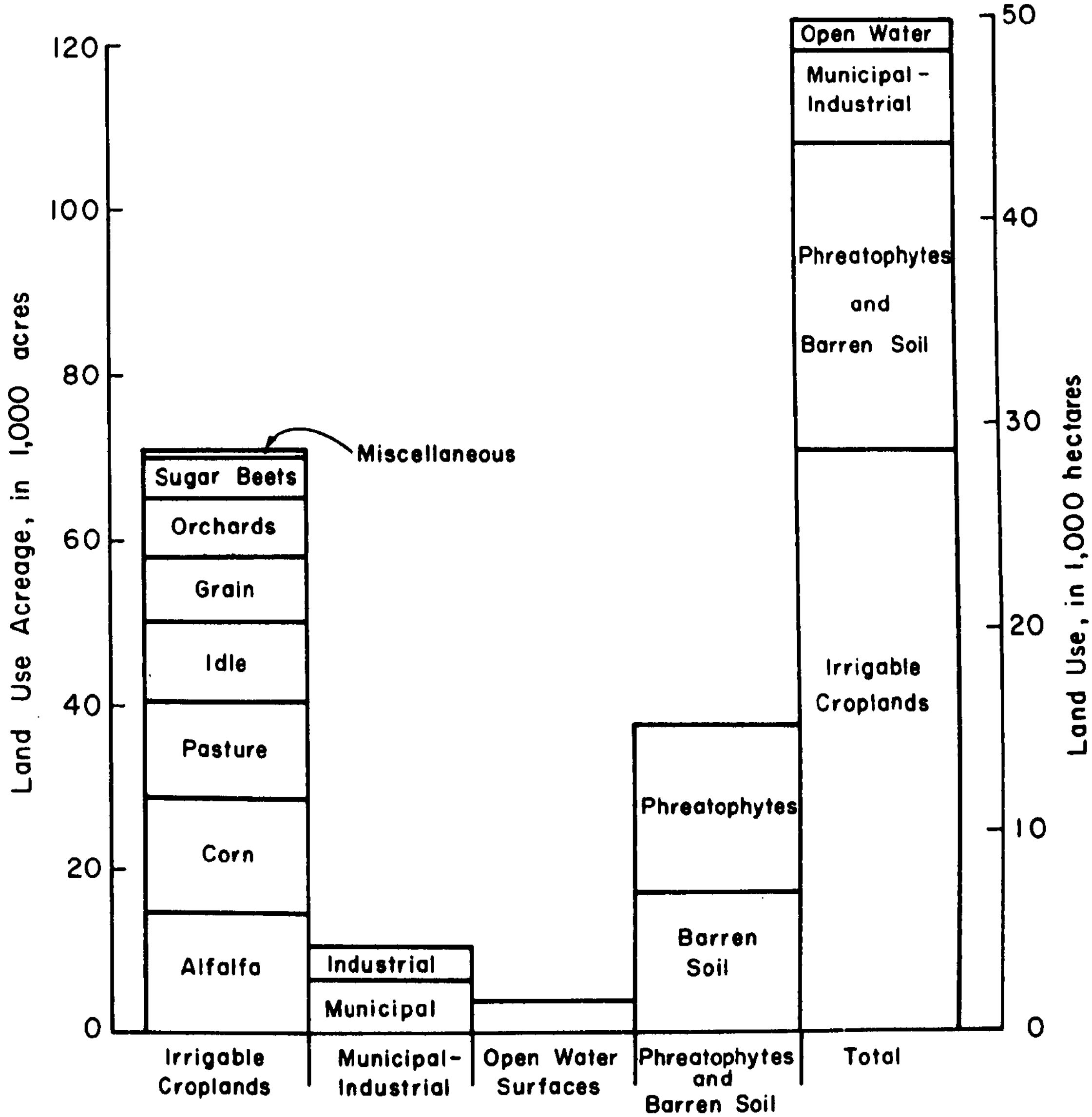


Figure 13. Agricultural land use in the Grand Valley (Walker and Skogerboe, 1971).

TABLE 3. LAND USE SUMMARY BY CANAL IN THE GRAND VALLEY, COLORADO 1969 (IN HECTARES)

Land Use Classification	Stub Ditch	Gov't Highline Canal	Price Ditch	Grand Valley Canal	Mesa County Ditch	Adjacent to River	Orchard Mesa #1 Canal	Orchard Mesa #2 Canal	Redlands Canal	Redlands Power Canal	Total
Corn	71	5979	535	6671	157	77	702	65	124		14,381
Sugar beets		3452		1726			51		32		5,261
Potatoes		95		96			78		3		272
Tomatoes		31	2	133			66		17		249
Truck Crop		161		147			53				361
Barley	33	1644	263	2311	62		204	43	18		4,578
Oats		963	70	1515	15		77	5	55		2,700
Wheat		15	22	63			26				126
Alfalfa	97	7019	551	5206	248	160	563	385	407	124	14,763
Native Grass Hay			35	84			11	9			139
Cultivated Grass Hay	6	450	109	1531	90		159	54	21	10	2,430
Pasture	43	1533	369	3642	320	6	328	269	1134	5	7,649
Wetland Pasture		11									11
Native Pasture		47	198	538	49		141	3	58	57	1,091
Orchard	247	695	1575	514	41	26	1652	1841	371		6,962
Idle	111	2948	571	4219	338	9	554	355	607	3	9,715
Other		126	6	11							143
Farmsteads	25	685	108	1221	79	5	144	90	69	25	2,451
Residential Yards	5	28	163	34	19		216	28	38		531
Urban	2	759	264	3925		44	654	49	677	36	6,410
Stock Yards		157	12	241	21		164	18	32	8	653
Refineries				40							40
Miscellaneous Industrial				621	21	83					725
Natural Ponds	31	635	37	750	48	2107	88	47	44	19	3,806
Cottonwoods (H)[1]	4	612	10	325		1190	38	22	72		2,273
Cottonwoods (M)[1]						132	4	21	4		161
Cottonwoods (L)[1]				15	3	170	7		2		197
Salt Cedar (H)	2	2262	24	1299	14	2654	31	17	836	5	7,144
Salt Cedar (M)				15	15		4	13			47
Salt Cedar (L)				59		108	51				218
Willows (H)	7	108	13	134		88	10		60		420
Willows (M)		4	16	4							24
Willows (L)		10	11								21
Cattails (H)		344	7	422	11	3	43		9		839
Cattails (M)			9				20	22			51
Greasewood (H)	16	2928	13	3481	169	760	103	217	192	5	7,884
Greasewood (M)	20	205		53	99	67	9	37			490
Greasewood (L)	2	78	62	187	34	9	132		16		520
Shrubs: Wild Rose Etc. (H)		3						9			12
Shrubs (M)							5	9			14
Shrubs (L)							[illegible]				9
Grasses and/or Sedges (H)							17			1	18
Grasses and/or Sedges (L)			12	1							13
Precipitation Only	51	10,429	337	3540	51	722	462	502	1230	5	17,329
TOTAL	773	44,416	5404	44,774	1904	8420	6876	4130	6128	303	123,128

[1]Note: H = Heavy cover, M = Medium cover, L = Light cover.

percent can actually be considered productive. In the demonstration area the percentages are 70 and 52, respectively. The use of the term productive relates to the areas producing cash crops such as corn, sugar beets, small grains, orchards, and alfalfa.

IRRIGATION PRACTICES

The prevalent method of applying water to croplands in the Valley is furrow irrigation. Small laterals carrying 0.03 to 0.14 cubic meters per second (1 to 5 cubic feet per second) divert water from the company or district operated canal systems to one or more irrigators. Water then flows into field head ditches where it is applied to the lands to supply moisture to the growing crops and maintain a low salinity root zone environment in order to sustain plant growth.

The predominantly alfalfa, corn, sugar beet, orchard, and small grain economy is served by a more than adequate water supply. The 28,665 hectares (70,830 acres) of irrigable cropland encompassed within the irrigation system enjoys a total diversion of more than 2.4 hectare-meters per hectare (8 acre-feet per acre) during normal years. Considering that the potential evapotranspiration of these croplands is usually less than 0.9 hectare-meters per hectare (3 acre-feet per acre), it is obvious that existing water use efficiencies are low. There is no groundwater used for irrigation purposes. The abandonment and withdrawal of farmlands for other uses has also contributed to the surplus of water since there has been no reduction in diversions. Most of this "excess" water is wasted into the drains. The Grand Valley water budget and the distribution of flows for 1968 is graphically presented in Figure 14.

Enough variation in climate exists in the Valley to separate the agricultural land use into three primary regions. In the eastern end of the Valley, the protective proximity to the abrupt Grand Mesa results in extended periods of frost-free days which allows apple, peach, and pear orchards to abound. In the western half of the Valley, the primary emphasis is on producing corn, alfalfa, sugar beets, and small grains. (Sugar beets are presently not grown in the Valley due to the closure of the Holly Sugar factory in the fall of 1976.) Between these two regions is a transition zone of small farms and the urban setting of Grand Junction, the population center of the area.

The farms in this transition area are particularly affected by adverse soil conditions, and high salt contributions are being returned to the Colorado River. The Grand Valley Salinity Control Demonstration Project Area, which was illustrated in Figures 3 and 4, was selected in this transition area. The primary advantage for undertaking the studies in this area was

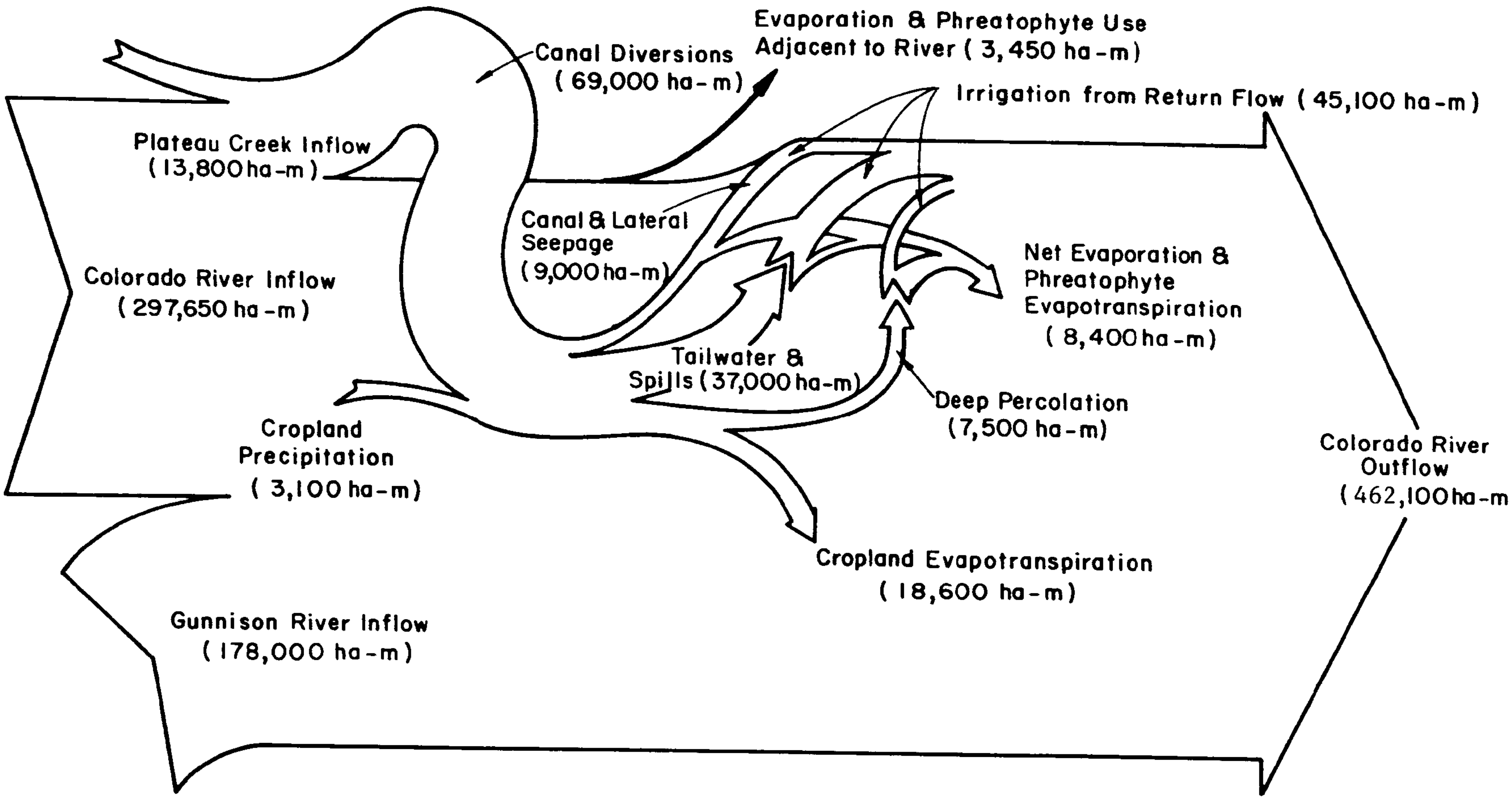


Figure 14. Graphic representation of the magnitude and distribution of water flows in the Grand Valley for 1968 (taken from Skogerboe and Walker, 1972).

that earlier phases of the Grand Valley Salinity Control Demonstration Project were conducted here and thus a great deal of data was already available to facilitate this investigation. Also, accomplishments achieved under adverse conditions can be much more meaningful than improvements on better agricultural lands.

Two main irrigation entities divert water from the Colorado River. These are the Grand Valley Water Users Association (United States Bureau of Reclamation Project) and the Grand Valley Irrigation Company. A third irrigation company, the Redlands Power and Water Company, diverts water from the Gunnison River. A number of smaller companies have carriage agreements with the two major canals for delivery of Colorado River water. These include the Palisade Irrigation District (Price Ditch) and the Mesa County Irrigation District (Stub Ditch) who have such an agreement with the Grand Valley Water Users Association (Government Highline Canal). The Grand Valley Irrigation Company is composed of several smaller canals, including the Mesa County Ditch, Kiefer Extension, the Independent Ranchman's, and others. The irrigation system of the Valley is shown in Figure 15. There are about 287 kilometers of canals in the Valley.

Canal deliveries within the system are controlled by spillage into drains and natural washes and not by regulation of the diversion at the river. This water contributes very little to the salt loading, but is often 20 percent to 25 percent of the total river diversions. If the canal systems would change to a strict demand-type delivery system and accept more responsibility for lateral water deliveries and use, the spillage would be negligible. Such a change would entail the general acceptance of more efficient irrigation methods such as trickle, sprinkler, border, cut-back furrow, dead-level irrigation, tailwater recovery systems, automation, and some change in tillage practices. In short, this would require major local institutional changes.

Historical irrigation development in the Grand Valley was reported in detail in an earlier EPA report, "Evaluation of Canal Lining for Salinity Control in Grand Valley," and only a very brief summary will be presented here. The first large-scale irrigation in the Valley began in 1882 with the construction of the Grand Valley Canal (now the Grand Valley Irrigation Company), which was privately financed. Other private systems were built during the period between 1882 and 1908 when construction started on the last major system, which was the Grand Valley Project by the United States Bureau of Reclamation (USBR). The last major construction was completed in 1926. The Grand Valley Project consists of two divisions: The Garfield Gravity Division and the Orchard Mesa Division on the north and south sides of the river, respectively.

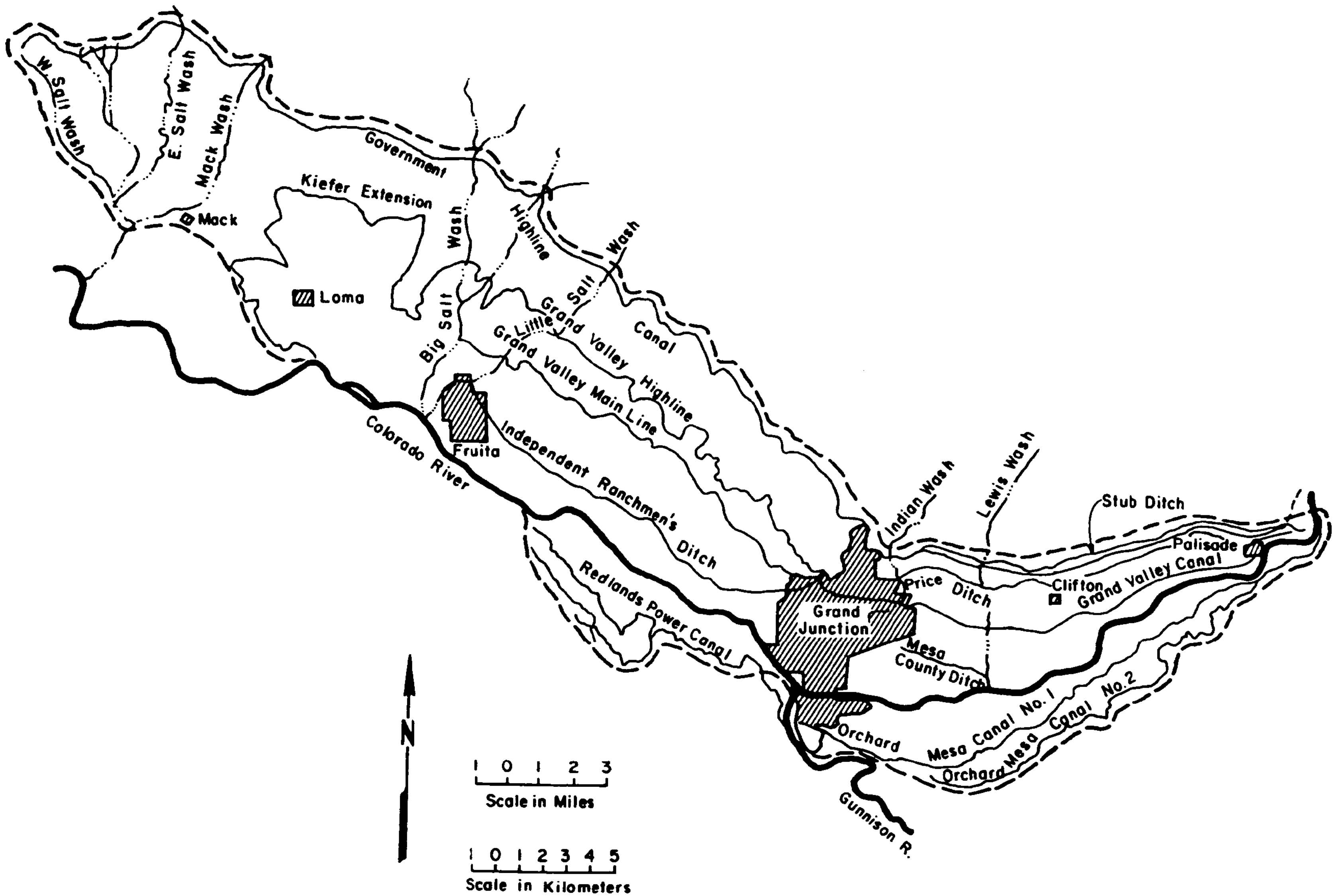


Figure 15. Grand Valley Canal Distribution System.

The canals and ditches in the Grand Valley are operated and maintained by the organizations mentioned earlier. Discharge capacities at the head of the canals range from 20 m^3/sec (700 cfs) in the Government Highline Canal to 0.8 m^3/sec (30 cfs) in the Stub Ditch and diminish along the length of each canal or ditch. The lengths of the respective canal systems are approximately 88.5 kilometers (55 miles) for the Government Highline Canal, 19.3 kilometers (12 miles) each for the Price, Stub, and Redlands Ditches, 177 kilometers (110 miles) for the Grand Valley system, and 58 kilometers (36 miles) for the Orchard Mesa Canals. The capacities, dimensions and seepage losses of the canals in the Valley are summarized in Table 4.

The term lateral is used in this text to refer to those small conveyance channels which deliver water from the company canals to the farmers' fields. These small channels usually carry flows less than 0.14 m^3/sec (5 cfs) and range in size up to 1.2 or 1.5 meters (4 or 5 feet) of wetted perimeter. There are more than 552 kilometers (343 miles) of laterals in the Grand Valley as determined by the USBR. Not counting the Redlands area of the Valley, there are 1,553 laterals in the Valley.

When water is turned into the lateral system, it becomes the responsibility of the users entitled to the diversion and not the ditch company. The only exception is the Government Highline Canal which sometimes treats their larger laterals as small canals and turnout water at headgates on these laterals. However, no effort is made beyond the headgate.

Single users served by an individual turnout are not uncommon, but most laterals serve several irrigators who decide among themselves how the lateral will be operated. Most of the multiple-user laterals, which may serve as many as 100, run continuously throughout the irrigation season with the unused water being diverted into the drainage channels. USBR figures show that the average irrigated acreage served by a lateral is between 10 and 15 hectares (25 to 37 acres).

A substantial part of the project reported herein is based on the concept of a lateral as a complete subsystem. By proper water management and rotating large flows of water around the entire lateral subsystem, irrigations can be much more efficient, and no one will suffer. This is being done in other parts of the Valley, but the cases are very few. The main reason this is not widely practiced, as it is in many other areas of the West, is that the Valley is very "water-rich" and has not had to resort to large-scale water conservation measures.

Under the Stub Ditch, Price Ditch, and Government Highline Canal (in the demonstration area), the water is allocated on a per acre basis and can never be transferred from the land.

TABLE 4. DIMENSIONS, CAPACITIES, AND SEEPAGE RATES OF CANALS IN THE GRAND VALLEY, COLORADO

Canal	Length Km	Inlet Q m^3/sec	Wetted Perimeter m	Days of Operation per Year	Effective Seepage Rate m^3/m^2/day	Seepage m^3/day	Salt Contribution m. tons/yr
Government Highline	73.7	16.99	19.19	214	0.076	77,300	54,100
Grand Valley	19.8	18.41	16.67	214	0.030	10,900	7,600
Grand Valley Mainline	21.7	7.08	13.86	214	0.046	10,800	7,600
Grand Valley Highline	37.0	8.50	12.62	214	0.046	22,100	15,400
Kiefer Extension	24.5	3.96	7.25	214	0.046	6,800	4,800
Mesa County	4.0	1.13	6.67	214	0.046	600	700
Independent Ranchman's	17.4	1.98	3.17	214	0.046	2,600	1,800
Price	9.5	2.83	7.27	214	0.046	2,200	1,600
Stub	11.3	0.85	2.94	214	0.046	1,400	1,000
Orchard Mesa Power	3.9	24.07	8.20	365	0.061	3,300	2,300
Orchard Mesa No. 1	24.1	3.02	6.46	214	0.061	7,400	5,100
Orchard Mesa No. 2	26.1	1.98	3.58	214	0.061	4,800	3,300
Redlands Power	2.9	24.07	16.88	365	0.050	1,900	1,300
Redlands No. 1 and No. 2	10.8	1.70	3.95	214	0.122	4,200	2,900
TOTAL CANALS	286.7					156,300	109,500

The allocation is 0.5 Colorado Miners Inches (38.4 Colorado Miners Inches (CMI) = 1.0 cfs) per acre (1.0 CMI/ac = 1.82 l/s/ha) and must run continuously under the by-laws of the Palisade Irrigation District (Price Ditch) and the Mesa County Irrigation District (Stub Ditch). It should be noted that west of the demonstration area, where the Government Highline Canal is not serving lands under carriage contracts, the water is provided on a limited demand basis varying from 0.75 to 1.0 cfs per 40 acres (0.021 to 0.028 m^3/s per 16.2 ha).

The Grand Valley Canal, the Mesa County Canal, and several others (which are served by waters released from the Grand Valley Canal) are entirely privately owned and have an arrangement by which the water shares can be bought, sold, rented or transferred anywhere in the entire system. One share of water is 0.4 Colorado Miners Inches (0.30 l/s).

The common irrigation philosophy concerning water duty is 1 share (4.7 to 5.8 gpm, or 0.30 to 0.37 l/s) for one acre, continuous flow; and this was a reasonable criterion when the canal systems were established. For example, if a farmer had 80 (32.4 ha) acres, he had 80 shares of water, and if the total allotment of water was rotated around the farm, the irrigations were fairly efficient. However, since that time, average farm units have become much smaller, and using the same criterion of 1 share per acre, the irrigations obviously had to become less efficient. This is because smaller streams of water have slower advance times, therefore, the opportunity time for larger amounts of deep percolation.

Practically all irrigations in the Valley utilize open ditches with siphon tubes on row crops with 30-inch row spacings. On crops such as alfalfa and small grains, the irrigations are usually a variation of flood irrigation using "corrugations" or shallow furrows and also using siphon tubes or a "cut-and-dam" system with some unlined ditches. USDA-SCS figures show that there are more than 1,640 kilometers (1,020 miles) of head ditches in the Grand Valley of which about 1,300 kilometers are unlined.

Border irrigation has not proven beneficial in the Grand Valley due to crusting, causing germination problems. However, very high irrigation efficiencies have been observed in the Grand Valley borders. The USDA-ARS is presently conducting some experiments using dead-level irrigation which is a variation of level border irrigation using furrows in an attempt to circumvent the crusting problems.

Sprinklers have met with little success in the Grand Valley, and local irrigators say that sprinklers cause crusting, compaction, and erosion problems and, therefore, will not work. This attitude is due to past experience (in the early 1950's when sprinklers were still new). The first sprinkler systems which were installed in the Valley were not designed to operate on the area soils. They generally had too high application rates and inadequate pressures. Experience and experimentation have shown, however, that application rates of around 5 mm/hr. (0.20 in/hr) and nozzle pressures of 37.9×10^4 to 41.4×10^4 Newtons per square meter (55 to 60 psi) have presented none of the aforementioned problems, but sprinklers still have not been generally accepted. Center-pivot systems are limited in the Valley primarily due to the small field sizes and also to traction problems in the heavy soils. However, side-roll sprinklers and other light, portable systems have worked quite well. Solid-set systems, especially on orchards with frost control capabilities, have been successful where installed, but have also not been widely accepted. The sprinkler systems installed by this project have been used only on established crops such as orchards or alfalfa, and their use on annual crops might require additional research on special management practices such as minimum tillage. Recent studies by the USDA-ARS in the Grand Valley with a small center-pivot on corn and reported no significant yield increases, but the high degree of water control was a definite advantage (Duke et al., 1976). Economic studies are also needed considering the costs of energy against the efficiencies obtained from other less energy-consumptive methods.

Trickle (or drip) irrigation has likewise not been accepted largely due to the high initial investment costs, and the water savings are not an economic incentive. Also, present trickle irrigation technology is essentially limited to widely spaced perennial crops such as orchards or vineyards, and these account for less than 10 percent of the total irrigated acreage in the Valley. In addition, the comparable cost of sprinklers with frost protection capabilities (which trickle irrigation systems do not have) presents some competition to trickle irrigation.

The common philosophy regarding irrigation improvements appears limited to concrete linings and land shaping rather than installing more efficient and sophisticated irrigation methods. This is due to the abundant, low-cost water. Greater irrigation efficiencies are generally not economically warranted. Also, this attitude is partly due to national ASCS regulations which do not allow cost sharing for sprinklers and gated pipe (or other types of "portable" systems).

The USDA-SCS estimates that approximately one-fifth of the head ditches and laterals in the Grand Valley have been lined, although some are undoubtedly in need of replacement. Many of the irrigation leaders in the area proudly point to this fact as a sign of local progressive irrigation practices.

A very common and generally necessary irrigation practice is to plant the crops and irrigate them up. Furrows are usually on a 30-inch (76 cm) spacing and the seeds planted halfway between two furrows. Under this practice, individual irrigation sets often run 36 to 48 hours until the field has become "blacked" out (until the water has completely soaked across all the area between furrows). This first irrigation is unquestionably the water application which has the largest contribution to deep percolation and could probably be reduced by changing tillage practices such as planting on the edge of a furrow rather than in the center. Attempts to introduce new tillage practices into the area have likewise met with limited success.

According to the SCS (1976), there are approximately 1,465 kilometers of tailwater ditches in the Grand Valley. The only tailwater reuse systems in the Valley have been installed by governmental agencies for demonstration purposes. Other than these, the only tailwater reuse is whatever return flows enter a canal or lateral and are used downstream. Most of the tailwater is diverted into the large open drains which pass through the area and is lost.

Flow measurement structures in the Valley are rare. The SCS inventory indicated that there were 840 such devices in the entire Valley. There were 92 total structures permanently installed on the CSU demonstration area during the course of the project. All but 200 of these flow measurement devices are located under the Government Highline Canal.

SALINITY CONTRIBUTION

The Grand Valley has an estimated salinity contribution averaging from 600,000 to 900,000 metric tons of salt annually to the Colorado River. The majority of these salts are a direct result of the deep percolation from irrigated farmlands and water seeping from unlined canal and lateral water delivery systems. Examination of district and canal records show that this contribution has been fairly constant over the past sixty years.

The introduction of water from these surface sources dissolves the salt contained in the saline soils and marine shales of the area. When the water reaches the shallow groundwater reservoir, the slight hydraulic gradient causes some groundwater to be displaced into the river. This displaced water has usually had sufficient time to reach chemical equilibrium with the salt concentration in the shale and/or cobble aquifer (approximately 8,700 mg/l).

The water from seepage and deep percolation tend to reach chemical saturation with the very abundant soluble gypsum and calcite that are present in the soils and geologic substrata.

The concentration of salts appears to be controlled by geologic conditions and is independent of seepage rates. The salt contributed by concentration effects and residual salts in the soils is relatively minor and the salt loading from tailwater runoff is almost negligible.

If the amount of groundwater is reduced through water management and canal and lateral linings, the concentrations of other salts such as sodium chloride will rise slightly, but not enough to compensate for the reduction in flows. Therefore, the net contribution to salt loading is essentially directly proportional to the reduction in groundwater flows.

The Grand Valley is the most significant agricultural contributor of salinity on a per acre basis in the entire Colorado River Basin. This factor makes the Grand Valley an important study area. Consequently, the results of research and implementing salinity control measures will have a greater impact on salt load reduction in the Colorado River. Also, the conditions encountered in the area are common to many locations in the basin.

SECTION 5

GRAND VALLEY SALINITY CONTROL DEMONSTRATION PROJECT

GENERAL DESCRIPTION

The study area used for demonstrating the Implementation of Agricultural Salinity Control Technology in Grand Valley was illustrated in Figures 3 and 4. This area is one of the most salt affected areas in the Grand Valley, and it was the site of the earlier projects on salinity control beginning in 1968. This area, therefore, had a great deal of historical data available to facilitate this investigation.

The demonstration area is characteristically operated by small unit farmers, and since the soils are severely affected by the high water table conditions, agricultural productivity is not presently sufficient to support most of the occupants. The majority of persons living in the area have outside jobs in local businesses and industries. In the past few years, the area has been subjected to rapid urban development. Some of the waterlogging and salinity problems, which are evident in the area, are illustrated in Figure 16.

These lands were once among the most productive in the Grand Valley (in the early 1900's), and a very significant impetus could be generated locally in support of salinity control programs if the demonstrated measures continue to be effective in returning these lands to a higher level of agricultural productivity. A soils map of the demonstration area can be seen in Figure 17. (A guide to the soil symbols was presented in Table 2.) A typical geologic cross-section of the demonstration area is presented in Figure 18.

An additional advantage of this location was that a majority of the irrigation companies in the Valley are involved in the demonstration area, thereby facilitating both the cooperation of the irrigation companies and the application of project results to other parts of the Valley.

a. An example of waterlogging problem on the tight clay soils of the Grand Valley.

b. Salinity accumulations on the surface of this field have forced it out of production (lateral GV 160).

Figure 16. Waterlogging and salinity problems in Grand Valley.

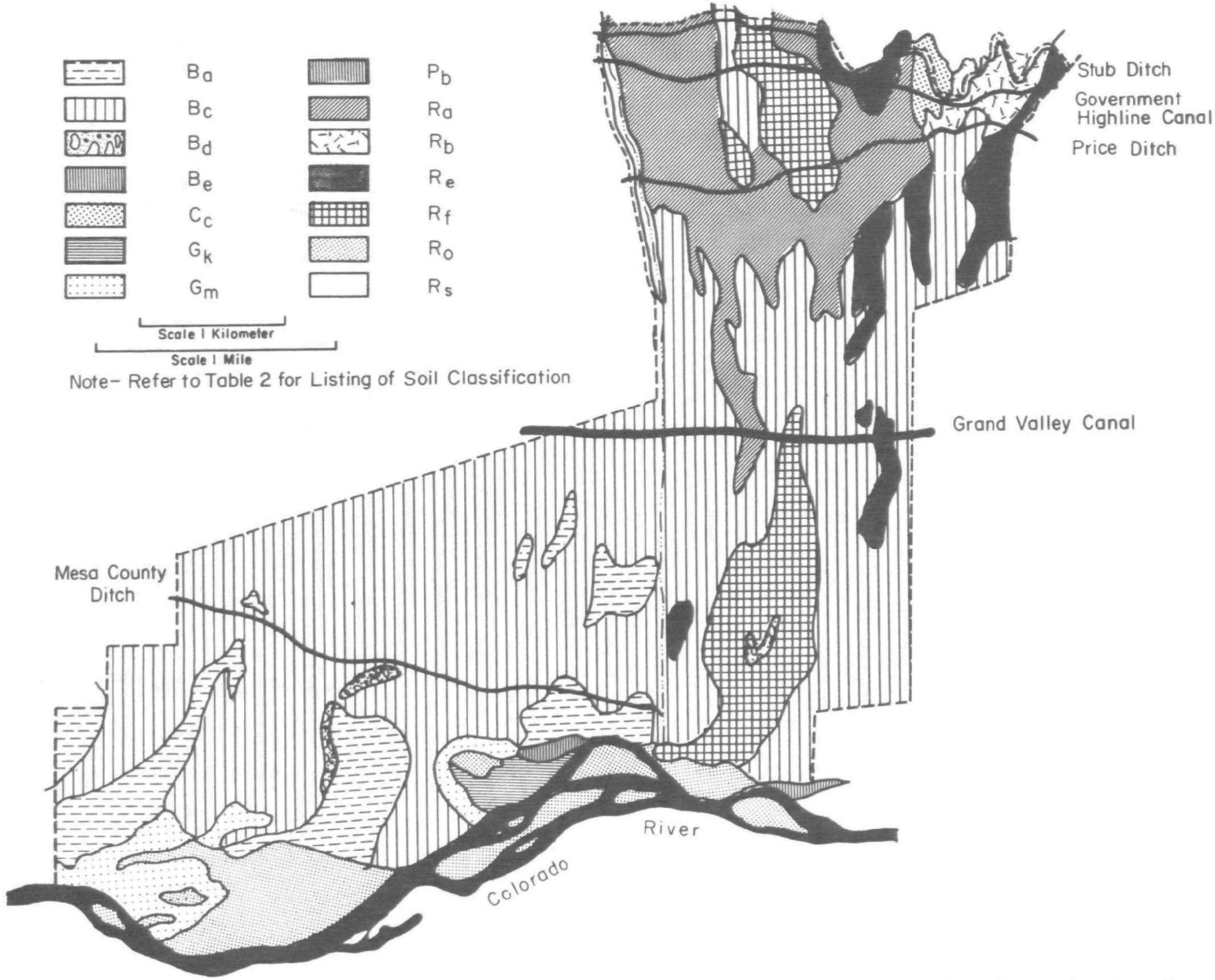


Figure 17. Soil classification map of the Grand Valley Salinity Control Demonstration Project.

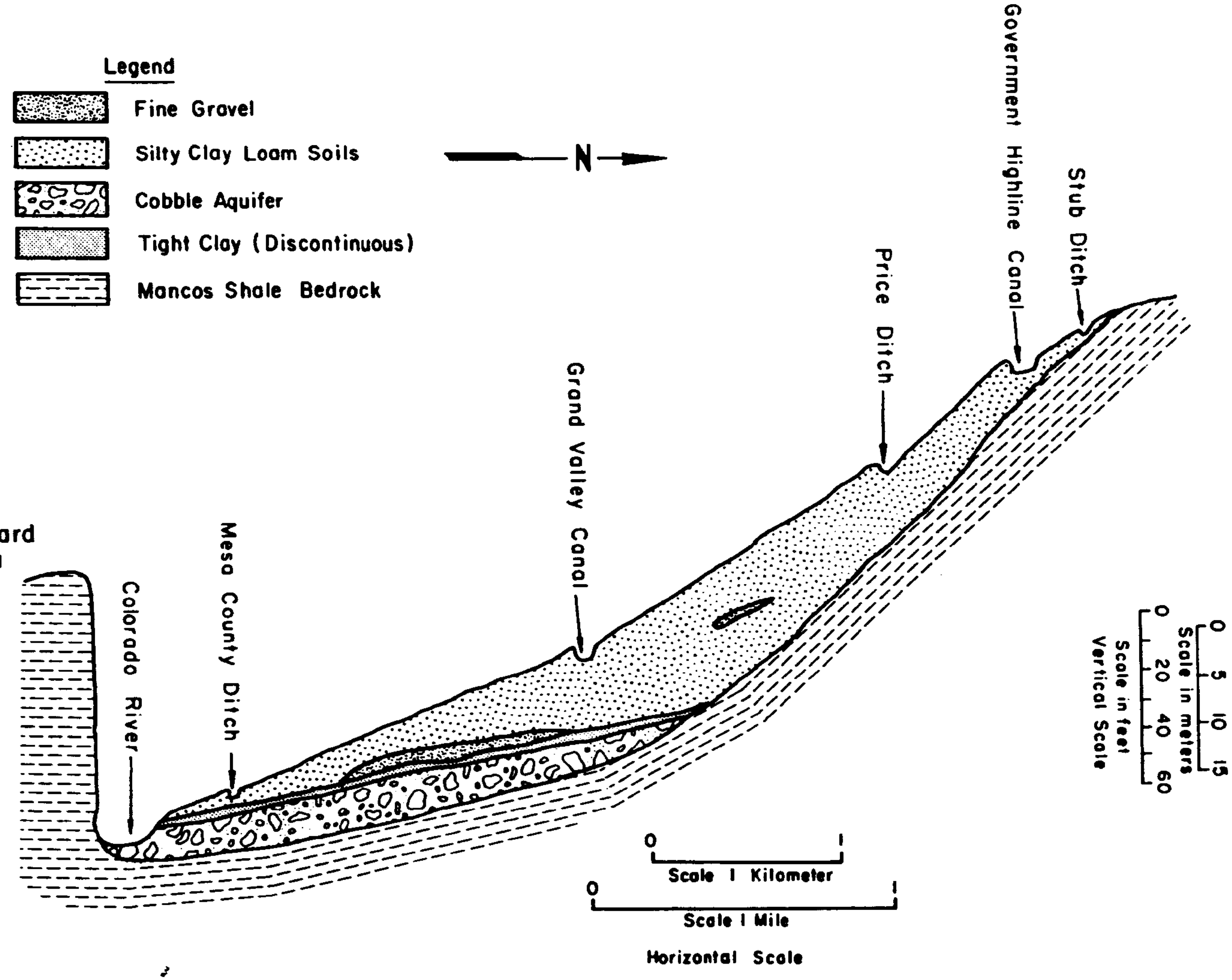


Figure 18. Typical geologic cross-section through the demonstration area.

INSTRUMENTATION

The instrumentation in the study area indicated by Figure 19 provided valuable data concerning many of the important water and salt movements. This same instrumentation has been utilized since 1968 when the first project was initiated. Figure 20 illustrates some of the procedures used to install and to collect the monitoring system data.

While some of the parameters were measured directly (i.e., drainage discharges, lateral diversions, water quality, precipitation and other climatic data), others were investigated indirectly. The parameters related to groundwater movement were monitored by using piezometers, wells, and soils analysis.

Because so many of the water and salt subsystems cannot be evaluated directly by feasible methods, peripheral investigations were made in which a portion of the area is examined in detail for reactions to changes in other parts of the flow phases. Such studies included: farm efficiency studies indicating the relative proportion of evapotranspiration, deep percolation, and soil moisture storage; cylinder infiltration tests to indicate various hydraulic properties of the soil; land use investigations which yielded the respective vegetative uses of the area; soil sampling which when analyzed in the laboratory yielded information on soil moisture, salt movements, and assisted in irrigation scheduling; and others pertaining to specific parameters of crop, water, and salt subsystems.

From 1968 through 1976, along the lower edge of the demonstration area, a network of wells and piezometers were maintained to monitor the groundwater flows out of the area to the river. Weekly water samples were taken and elevations were recorded. Several large interceptor drains carry some groundwater and tailwater out of the area to the river. These drains had flow measurement devices with recorders and measurements were taken throughout the year. While these data can only directly indicate the trends and average data for the entire area, these data can be used in conjunction with the verified hydro-salinity model of the demonstration area and the results of other concurrent research.

HYDROLOGY

Walker (1970) defined the base hydrology for the project area for 1969. The water and salt inflows to the project hydrologic area are tabulated in Tables 5 and 6, respectively. These data were formulated from individual measurements undertaken during the first phase of the salinity control studies in the demonstration area.

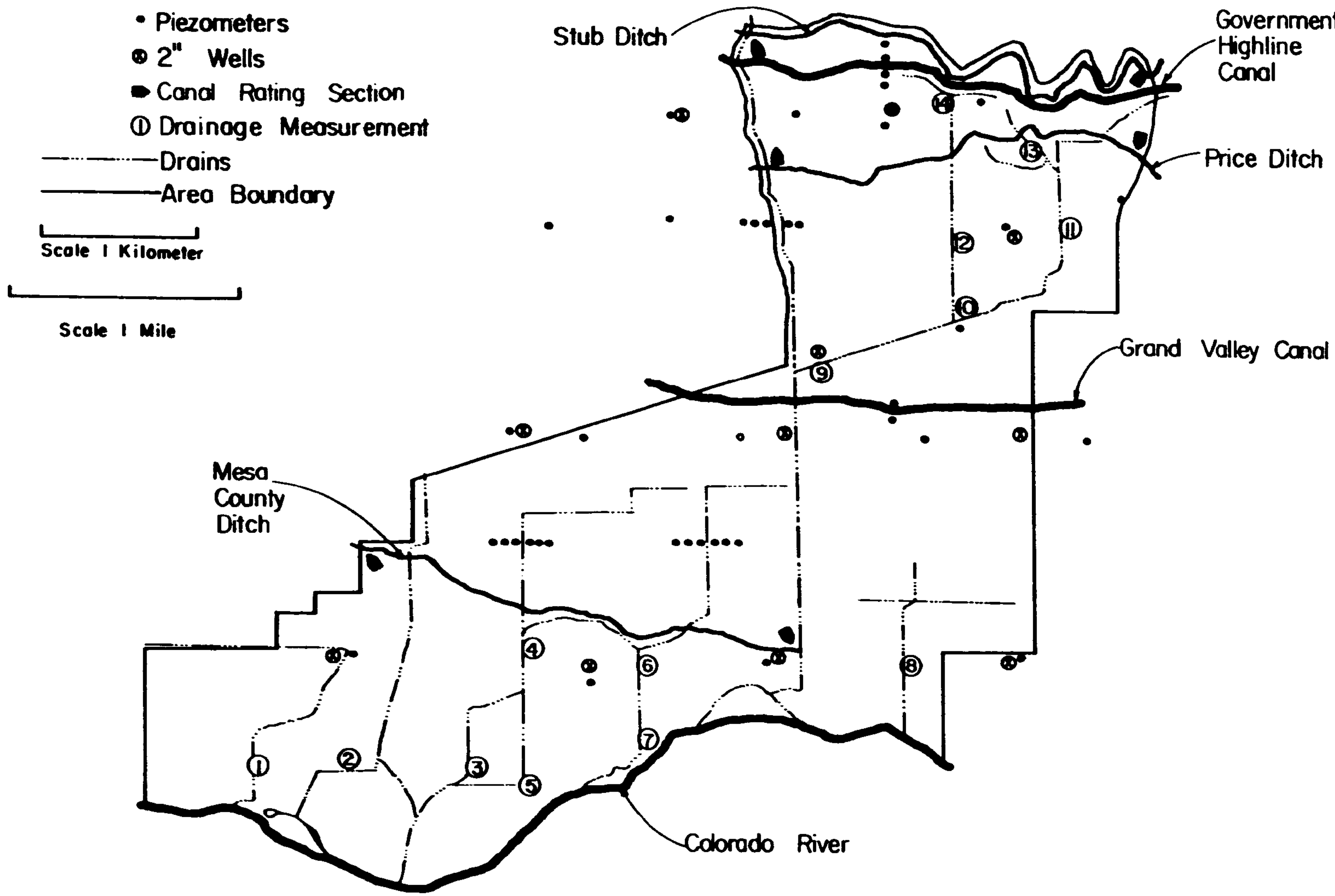
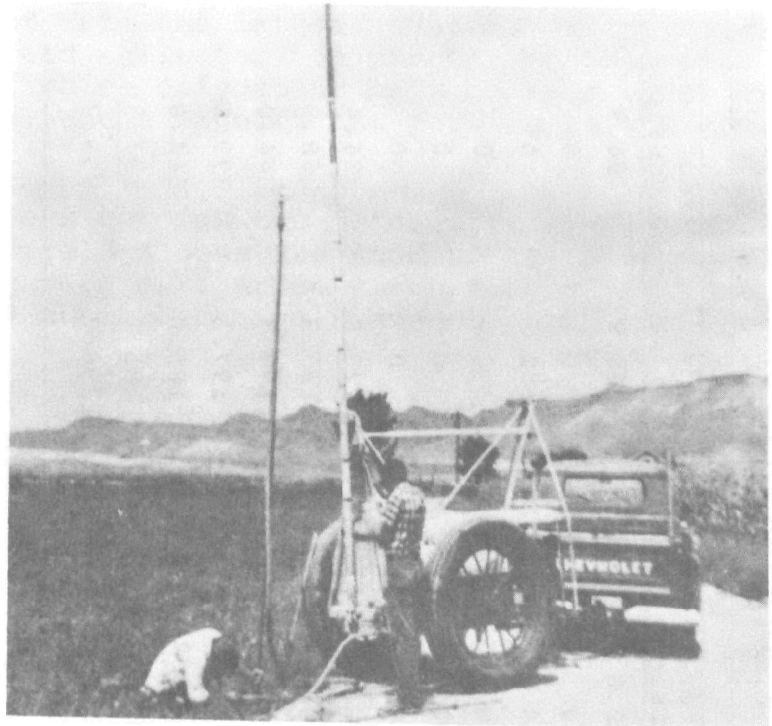
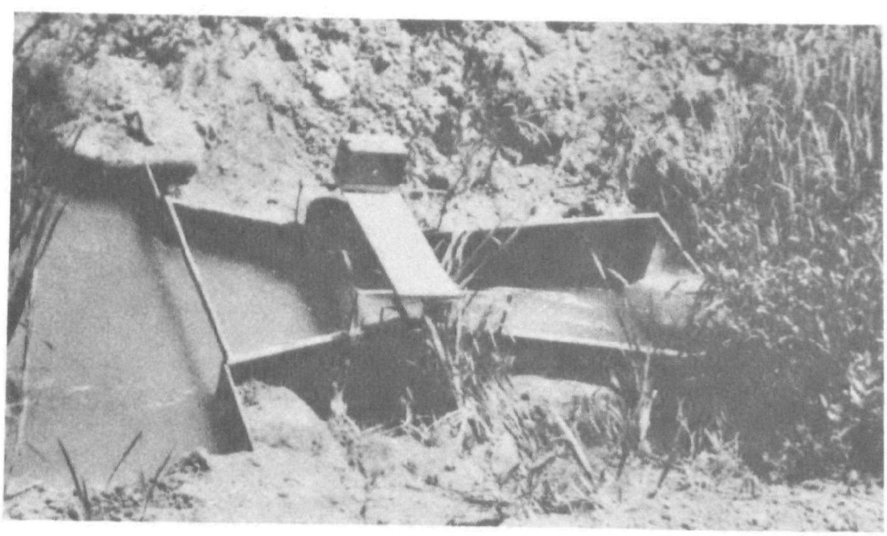


Figure 19. Location of hydrologic measurement points in the Grand Valley Salinity Control Demonstration Project Area.



a. Installation of piezometers with a jetting rig by project personnel.



b. A Cutthroat flume installed in a large open drain with a continuous water level recorder to monitor tailwater and drainage flows.

Figure 20. Installation of monitoring network.

TABLE 5. WATER BUDGET INFLOWS TO THE DEMONSTRATION AREA, IN HECTARE-METERS (WALKER, 1970)

Month	Precipitation		Canal Diversions			Lateral Diversions		
	cropland	phreat.	Seepage	spillage	lateral diversions	seepage	tailwater	root zone diversions
Oct.	24.7	4.9	14.8	148.0	252.8	9.9	148.0	94.9
Nov.	16.0	3.7	0	0	0	0	0	0
Dec.	16.0	3.7	0	0	0	0	0	0
Jan.	16.0	3.7	0	0	0	0	0	0
Feb.	22.2	4.9	0	0	0	0	0	0
March	22.2	4.9	0	0	0	0	0	0
April	22.2	4.9	14.8	246.6	360.0	14.8	120.8	224.4
May	16.0	4.9	14.8	246.6	480.9	14.8	197.3	268.8
June	16.0	4.9	14.8	246.6	556.1	14.8	197.3	344.0
July	16.0	4.9	14.8	246.6	591.8	14.8	197.3	379.8
Aug.	29.6	6.2	14.8	246.6	543.8	14.8	185.0	344.0
Sept.	24.7	4.9	14.8	246.6	397.0	14.8	185.0	197.3
ANNUAL	241.6	56.5	103.6	1627.6	3182.4	98.7	1230.7	1853.2

Of particular interest in Table 5 is that of the quantity of water diverted into the lateral system. Thirty-nine percent results in field tailwater, 58 percent of the water reaches the root zone, of which only about half of this water can be utilized by the plants, and a significant portion is thereby lost to deep percolation.

Water flows through the main delivery system from east to west and the field slopes are from north to south. The laterals run north to south on a grade which ranges from 0.2 percent to 1 percent and unlined channels are often deeply eroded.

TABLE 6. SALT BUDGET INFLOWS TO THE DEMONSTRATION AREA IN METRIC TONS OF TOTAL DISSOLVED SOLIDS (WALKER, 1970)

	Canal salt diversions			Lateral salt diversions		
Month	seepage	spillage	lat. div.	seepage	tailwater	root zone diversions
Oct.	99.8	1714.6	1769.0	63.6	1034.2	671.3
Nov.	0	0	0	0	0	0
Dec.	0	0	0	0	0	0
Jan.	0	0	0	0	0	0
Feb.	0	0	0	0	0	0
March	0	0	0	0	0	0
April	145.2	2467.6	3628.8	145.1	1215.6	2268.0
May	145.2	2467.6	4808.2	145.1	1968.6	2694.4
June	145.2	2467.6	5561.1	145.1	1977.7	3438.3
July	99.8	1723.7	4145.9	99.8	1388.0	2658.1
Aug.	99.8	1723.7	3810.2	99.8	1306.4	2404.1
Sept.	99.8	1723.7	2785.1	99.8	1306.4	1378.9
ANNUAL	834.8	14288.5	26508.3	798.3	10196.9	15513.1

Water and salt flows occurring beneath the soil surface in the project area are tabulated in Tables 7 and 8. The subsurface flows were calculated from the information obtained on the surface flows.

Comparison of the measured drainage outflows and the groundwater outflows for 1969 indicate that the drains in the study area carry approximately 27 percent of the total groundwater outflows, while only 22 percent of the total flow in the drains are groundwater flow. In addition, of the 1853.2 ha-m (15,030 acre-feet) reaching the root zone from irrigation plus 202.2 ha-m (1,640 acre-feet) from canal and lateral seepage, and 1096.1 ha-m

TABLE 7. WATER BUDGET GROUNDWATER FLOWS TO THE DEMONSTRATION AREA IN HECTARE-METERS (WALKER,1970)

	Root zone Diversions		Groundwater flows			
Month	cropland use	deep perc.	drainage flows	phreat. use	storage change	subsur. outflow
Oct.	56.7	62.9	24.7	24.7	-12.3	55.5
Nov.	16.1	0	22.2	4.9	-69.1	45.6
Dec.	8.6	7.4	18.5	3.7	-49.3	38.2
Jan.	0	16.0	14.8	3.7	-37.0	38.2
Feb.	0	22.2	8.6	4.9	-24.7	38.2
March	0	22.2	7.4	4.9	-24.7	39.5
April	83.8	162.7	37.0	37.0	74.0	49.3
May	113.4	171.4	37.0	38.2	66.6	64.1
June	205.9	154.1	37.0	40.7	37.0	74.0
July	246.6	149.2	37.0	43.1	24.7	78.9
Aug.	224.4	149.2	30.8	49.3	24.7	80.2
Sept.	140.6	81.4	61.6	34.5	-12.3	69.1
ANNUAL	1096.1	998.7	336.6	289.6	-2.4	670.8

(8,890 acre-feet) were consumed by evapotranspiration. The net result being that only 56 percent of the deep percolation and seepage losses are returned to the river.

Analysis of the results of salt budgeting indicated that for each metric tons of total dissolved solids applied to the root zone, approximately 3.2 metric tons exit through the groundwater channels.

PREVIOUS IMPROVEMENTS IN THE DEMONSTRATION AREA

In 1967, the irrigation companies of the Grand Valley began to be aware of the potential financial burden which could be placed upon the Valley's water users by salinity damages downstream, especially if they were forced to comply with salinity control measures at their own expense. Consequently, efforts were begun to initiate action based on the concept that abatement of the salinity problem would have state, regional, national, and international benefits. Furthermore, it was claimed "that development of irrigation within the Grand Valley was done without intent of damage to others, and was done within existing laws and regulations enacted after the fact." With this in mind, the

TABLE 8. SALT BUDGET GROUNDWATER SALT FLOWS IN THE DEMONSTRATION AREA IN METRIC TONS OF TOTAL DISSOLVED SOLIDS (WALKER, 1970)

	Root Zone Salt Budget				Groundwater Salt Budget			
Month	salt depository	accumulated storage	pickup	salt add. to G.W.	total salt added	drainage salt	salt storage change	salt outflow
Oct.	571.5	0	3728.6	671.3	834.6	1233.8	-743.9	3329.4
Nov.	172.4	172.4[1]	4508.8	0	0	1152.1	-5089.4	3356.6
Dec.	108.9	0	3347.6	281.2	281.2	1097.7	-3265.9	2531.1
Jan.	36.3	0	3456.4	36.3	36.3	961.6	-2449.4	2531.1
Feb.	45.4	0	3302.2	45.4	45.4	607.8	-1769.0	2739.7
March	45.4	0	3519.9	45.4	45.4	526.2	-1896.0	3039.1
April	1206.6	0	3837.5	2268.0	2558.3	2404.1	1814.4[1]	3991.7
May	1515.0	0	3728.6	2694.4	2984.7	2222.6	1814.4[1]	4490.6
June	2467.6	0	3111.7	3438.3	3728.6	2032.1	2404.1[1]	4808.2
July	2032.1	0	2821.4	2658.1	3764.9	1850.7	1478.7[1]	4735.6
Aug.	1914.2	0	3674.2	2404.1	2603.7	1542.2	1478.7[1]	4735.6
Sept.	1224.7	0	3801.2	1378.9	1578.5	1233.8	-734.8	4145.9
ANNUAL	11340.1	172.4	42838.1	15921.4	18461.6	16864.7	-6958.1	44434.6

[1] storage change from irrigation, not groundwater outflow.

irrigation companies formed a cooperative organization called the Grand Valley Water Purification Project, Inc. and petitioned the Federal Water Quality Administration for 70 percent to 30 percent matching funds on demonstrating canal lining as a salinity control measure. This money was forthcoming, and in 1968 the Agricultural Engineering Department of Colorado State University was contracted to perform the technical evaluation regarding the effectiveness of canal lining in reducing the Grand Valley's salt load to the Colorado River.

The particular demonstration area was selected because it contained lands served by the majority of irrigation companies in the Valley, and their cooperation after the project would be needed to implement the proposed changes on a valley-wide scale. After completion of this initial project, the canal companies reorganized into the Grand Valley Canal Systems, Inc. and remained active. Presently, their main purpose is to collectively represent the irrigation interests of the Valley.

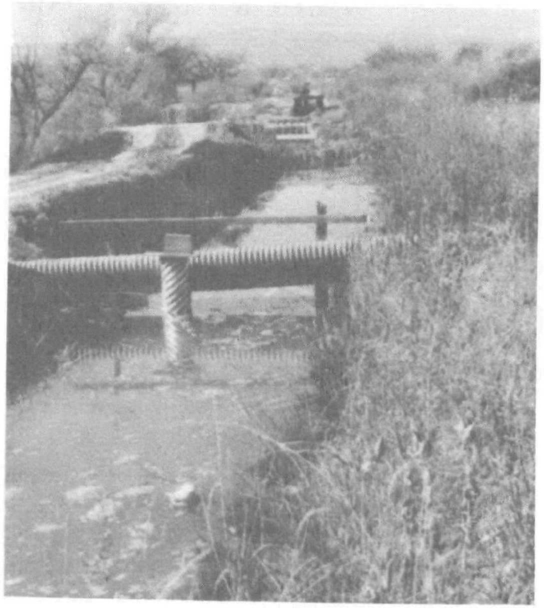
Canal and Lateral Lining

As part of this investigation, three areas were studied in the Grand Valley, one of which is the present demonstration area. The initial phase of the project involved the determination of the seepage rates from the canals and laterals in the three test areas. The ponding technique was employed to assure reliability of the results. Figure 21 shows some of the structures and data collection.

The lengths evaluated included a 4.2 kilometer (2.6 mile) section of Stub Ditch, 3.2 kilometers (2 miles) of Government Highline Canal, 3.1 kilometers (1.9 miles) of Price Ditch, and 3.5 kilometers (2.2 miles) of Mesa County Ditch. In addition, the tests were made along the 0.8 kilometer (0.5 mile) length of the Redlands First Lift Canal. A 0.24 kilometer (0.15 mile) length of Grand Valley Canal was not evaluated because of the evidently high seepage losses. A summary of the test results is shown in Table 9, indicating only moderate seepage rates in most canals and a relatively high rate in the Redlands First Lift Canal. The average seepage rates were approximately 0.05 m^3/day (cmd) (0.15 ft^3/ft^2/day (cfd)) in the Stub, Price, and Mesa County ditches; 0.08 cmd (0.25 cfd) in the Government Highline Canal; and an average rate of 0.12 cmd (0.40 cfd in the Redlands First Lift Canal.

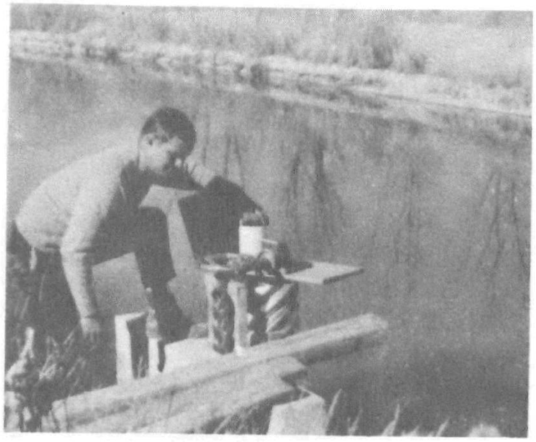
The lining of the Government Highline Canal (Grand Valley Project) was done with gunite (which is a mixture of cement, sand, and water pneumatically applied to a wire mesh, also called shotcrete) on the downhill bank of the last mile through the study area. This was done to evaluate the effectiveness of downhill linings in reaches where the canal is located directly in the shale formation. The Stub Ditch linings consisted of the standard

a. Waterlevel data collection before lining;



b. Ponding test and measurement station on an unlined section of a canal;

c. Measurement station for a ponding test after lining;



d. Project personnel collecting water level data on a lined section of a canal.

Figure 21. Canal ponding tests by project personnel.

TABLE 9. COMPARISON OF SEEPAGE RATES BEFORE AND AFTER CANAL LINING USING PONDING TESTS

Canal	Seepage rate before lining (cfd)[1]	(cmd)[2]	Seepage rate after lining (cfd)[1]	(cmd)[2]	Reduction
Stub Ditch	0.15	0.05	0.07	0.02	46.6%
Price Ditch	0.15	0.05	0.07	0.02	46.6%
Gov't Highline Canal	0.25	0.08	0.13	0.04	49.0%
Mesa County Ditch	0.15	0.05	0.03	0.01	76.0%
Redlands First Lift Canal	0.40	0.12	0.06	0.02	84.0%

[1]cfd = cubic feet per day.
[2]cmd = cubic meters per day.

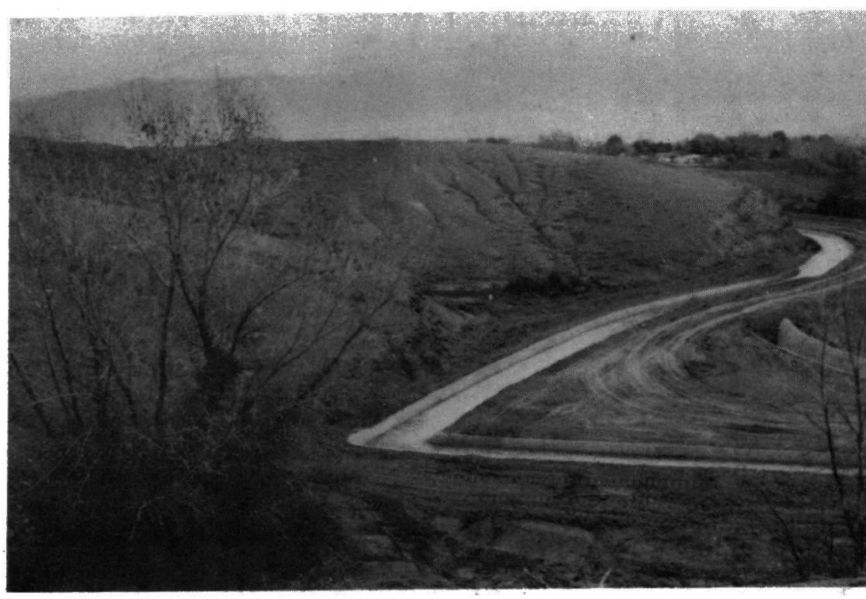
concrete trapezoidal slip form lining. The linings in the Price Ditch and the Redlands First Lift Canal were also concrete trapezoidal slip form, but larger than the Stub Ditch lining. The Mesa County Ditch in the demonstration area was lined completely with a gunite process. The Grand Valley Canal also has a short section lined by the gunite process. Figure 22 shows some of the finished linings. Figure 23 illustrates the location of the canal linings done in the demonstration area. Table 10 presents the summary of the total canal lining improvements.

The USDA-ARS, under contract to the United States Bureau of Reclamation in 1974-1975, made ponding tests on the major canals and laterals at other locations in the Valley, which resulted in close agreement with the values found in the demonstration area.

The results of the seepage rate measurements for nine lateral sections are tabulated in Table 11. The wetted perimeter of the laterals which were lined ranged between 3 and 5 feet (0.9 to 1.5 meters) and were characterized by large amounts of grass and weeds growing in the channel. The capacity of the laterals was usually between one-half and 5 cubic feet per second (0.01 to 0.14 cubic meters per second), and, in most cases, some problems with erosion have occurred as a result of the fairly steep grade. Some lengths throughout the area had already been lined, but these did not represent a significant portion of the total lateral lengths.

Numerous evaluations of seepage rates in the laterals located in the demonstration area were conducted as part of those earlier studies. The inflow-outflow method was used in these determinations. A typical loss rate of 0.003 m^3/s (0.1 cfs) per mile is representative of a usual lateral, or about 0.15 cmd (0.5 cfd). Based upon before and after ponding tests upon the small canals, the lining of most laterals would result in about an 80 to 90 percent seepage rate reduction.

a. Lining on the Price Ditch;



b. Lining on the Stub Ditch;

Figure 22. Photographs of the canal lining program.

c. A canal before lining; and

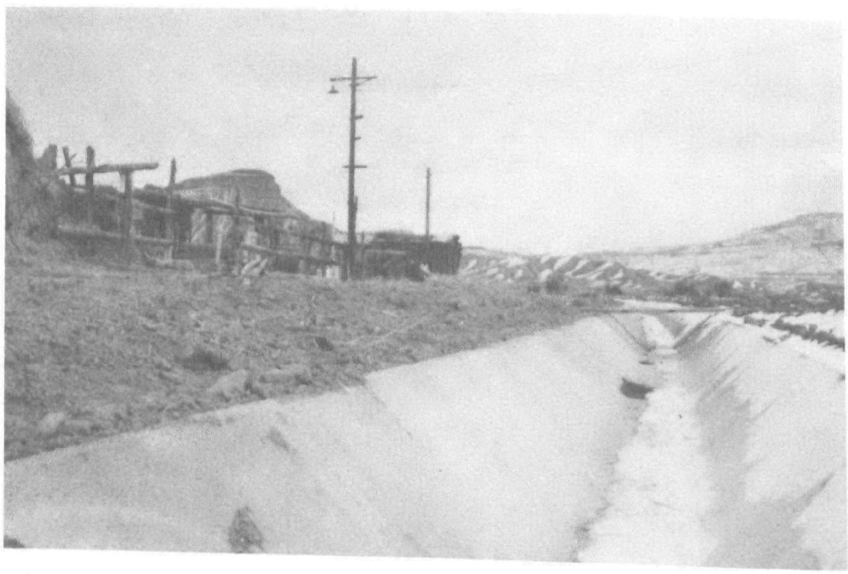


Figure 22 (continued). Photographs of the canal lining program.

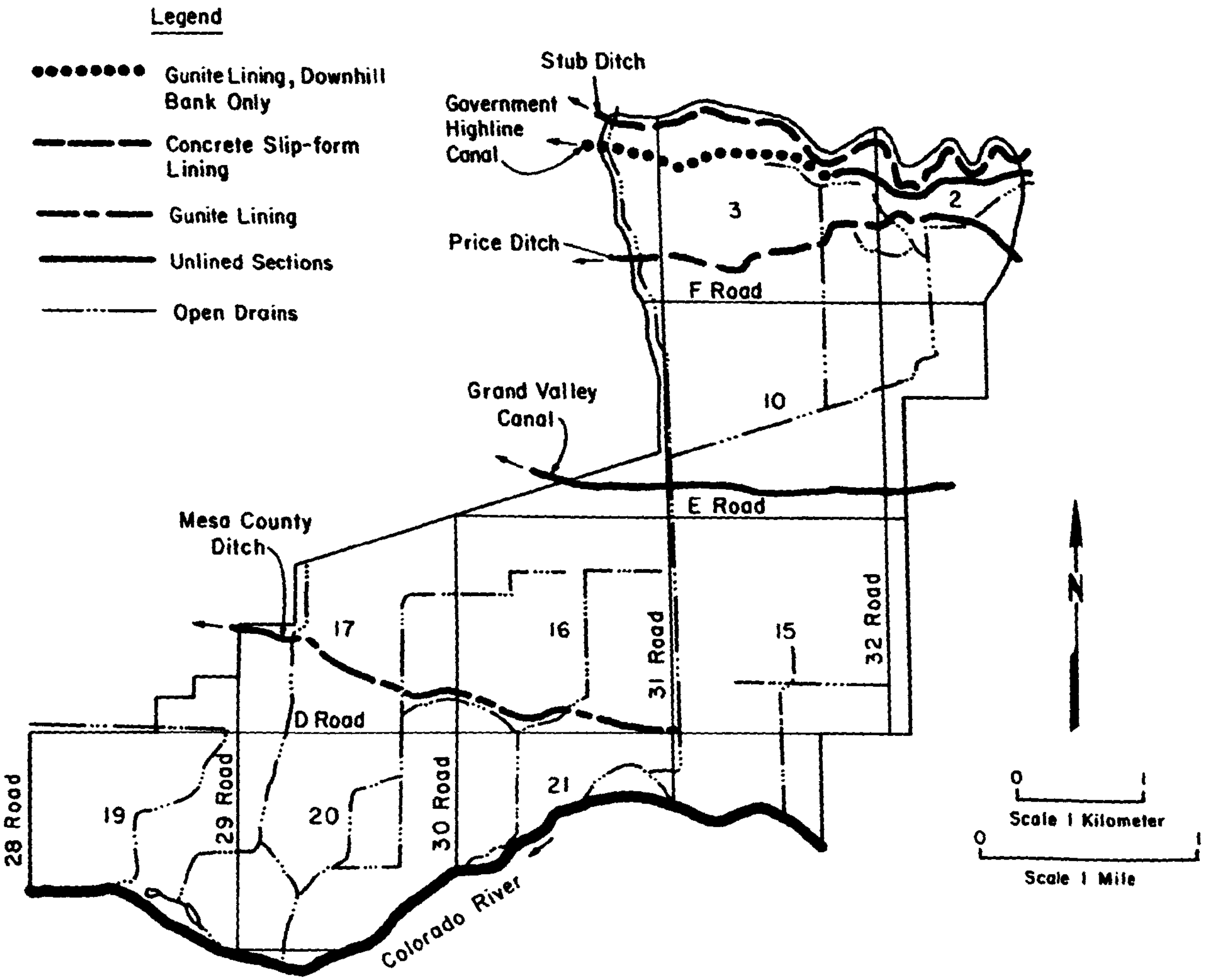


Figure 23. Location and type of canal linings constructed in the demonstration area.

TABLE 10. CANAL LINING IMPROVEMENTS SUMMARY

Map Designation	Company Name Canal Name	Type of Lining	Length (Km)
Area I (Demonstration Area)			
A	Grand Valley Irrigation Co. Mesa County Canal	Gunite	3.5
B	Palisades Irrigation Co. Price Ditch	Slip Form	3.1
C	Grand Valley Water Users Assn.[1] - Gov't Highline Canal	Gunite	1.6
D	Mesa County Irrigation Co. Stub Ditch	Slip Form	4.0
E	Grand Junction Drainage Dist.		
	Open Drains	Slip Form	
	Closed Drains	Tile	
	Laterals	Slip Form	
Area II			
F	Grand Valley Irrigation Co.[1] Grand Valley Canal	Gunite	0.24
Area III			
G	Redlands Water and Power First Lift Canal	Slip Form	0.8

[1] Downhill bank lining only.

TABLE 11. RESULTS OF EARLIER CSU (1959-1970) LATERAL LOSS INVESTIGATIONS

Canal Name	Gate No.	Study length (Ft.)	Study length (m)	Length loss (cfs)	Length loss (m^3/s)	Length loss (%)	Loss per mile (%)	Loss per mile (cfs)	Loss per mile (m^3/s)	Design Discharge[1] (cfs)	Design Discharge[1] (m^3/s)
PD	168	2175	662.9	0.030	0.00085	3.8	9.11	0.073	0.0021	1.00	0.0283
	164	3620	1103.4	0.097	0.00275	3.6	5.27	0.114	0.0032	2.50	0.0708
	151	1667	508.1	0.048	0.00136	7.4	23.46	0.152	0.0043	1.00	0.0283
GV	95	4910	1496.6	0.034	0.00096	1.5	1.61	0.037	0.0010	2.00	0.0566
	100	2970	905.3	0.020	0.00057	2.6	4.62	0.315	0.0089	1.00	0.0283
	110	5000	1524.0	0.590	0.01671	12.3	13.0	0.623	0.0176	5.00	0.1416
	120	5280	1609.0	0.030	0.00085	1.0	1.0	0.030	0.0085	3.50	0.0991
MC	46	2600	292.5	0.00	0.00000	0.0	0.0	0.00	0.0000	3.00	0.0850
	70	3540	1079.0	0.99	0.02804	18.0	26.82	1.50	0.0425	6.00	0.1699

[1] This value is inlet capacity consequently the design would need to be altered as diversions are made along a length.

A summary of the lateral linings constructed as part of this project is included in Table 12. Even though only a small fraction of the total lateral system has been improved, the linings resulted in a seepage reduction on the order of 12.3 to 24.6 hectare-meters (100 to 200 acre-feet) annually. It should be noted that the bulk of the linings were constructed above the Grand Valley Canal where water tables are relatively deep, and thus experience somewhat higher seepage rates than would be encountered in areas where water tables are higher.

TABLE 12. SUMMARY OF THE SIZES AND LENGTHS OF LATERALS LINED DURING THE EARLIER YEARS (1969 AND 1970) OF THE PROJECT

Description	Length	
	Feet	Meters
14" trapezoidal (35.56 cm)	5,941	1,810.8
12" trapezoidal (30.48 cm)	11,435	3,485.4
10" trapezoidal (25.40 cm)	624	190.2
6" x 10" rectangular (15.25cm x 25.4cm)[1]	1,478	450.5
12" x 10" rectangular(30.48cm x 25.4cm)[1]	1,987	605.6
12" diameter buried pipe (30.48 cm)	978	298.1
8" diameter buried pipe (20.32 cm)	2,111	643.4
6" diameter buried pipe (15.25 cm)	950	289.6
TOTAL	25,504	7,773.6
	or	or
	4.83 miles	7.77 km

[1]First dimension listed in description refers to the bottom width.

The benefits accrued from lining the lateral system in an area like the Grand Valley are essentially the same as described earlier concerning the canal linings. Because of the vast extent (length) of the lateral system, the effect of the laterals is much greater than the canals. As with the canal system, the appurtenances, such as the control and measurements structures, are an integral part of any lateral system improvements. The benefits derived from more efficient water management (measurement and control) cannot be ignored.

The results of this study indicated that canal and lateral lining in the test area reduced salt inflows to the Colorado River by about 4,260 metric tons (4,700 tons) annually. The bulk of this reduction is attributable to the canal linings, but clearly indicated is the greater importance of lateral linings. The length of laterals (600 kilometers), plus the head ditches (1,640 kilometers), is about eight times greater than the length of canals (286 kilometers) in the Valley. The economic benefits to the Lower Basin water users alone exceeded the costs ($350,000 construction plus $70,000 administration) of this project. It was concluded that conveyance lining in areas such as the Grand Valley, where salt loadings reach 18 metric tons or more per hectare) are a feasible salinity control measure. The local benefits accrued from reduced maintenance, improved land value, and other factors add to the feasibility of conveyance linings as a salinity management alternative.

Irrigation Scheduling

As a result of recommendations on the canal lining project, an irrigation scheduling project was initiated (1972) in the demonstration area as a salinity control measure. Since a large fraction of the water passing through the local soils returns to the river as deep percolation resulting from overirrigation, measures aimed at improving irrigation efficiencies promise a high potential for controlling salinity. Among all the methods for achieving higher water use efficiencies on the farm, "scientific" irrigation scheduling is one of the most promising and least expensive.

Irrigation scheduling consists of two primary components: crop evapotranspiration calculated by using climatic data, and soil characteristics. First of all, the field capacity and the permanent wilting point for the particular soils in any field must be determined. And, more importantly, infiltration characteristics of the soils must be measured. Only by knowing how soil intake rates change with time during a single irrigation, as well as throughout the irrigation season, can meaningful predictions be made of: (a) the proper quantity of water which should be delivered at the farm inlet for each irrigation; and (b) the effect of modifying deep percolation losses. With good climatic data and meaningful soils data, accurate predictions of the next irrigation date, and the quantity of irrigation water to be applied can be made. In order to enable the irrigator to apply the proper quantity of water, a flow measurement structure is absolutely required at the farm outlet.

The results of this demonstration project indicated that irrigation scheduling programs have a limited effectiveness for controlling salinity in the Grand Valley under existing conditions. Excessive water supplies, the necessity for rehabilitating the irrigation system (particularly the laterals), and local resistance to change, preclude higher levels of water management during successive irrigations. To overcome these limitations, irrigation scheduling must be accompanied by flow measurement at all the major lateral division points and farm inlets. In addition, it is necessary for the canal companies and irrigation districts to assume an expanded role in delivery of the water, accepting more responsibility for lateral deliveries and changing to a demand type system.

Some problems have been encountered involving poor communication between farmer and scheduler, as well as certain deficiencies in the scheduling programs dealing with evapotranspiration and soil moisture predictions. Correcting these conditions is easily rectified and will make irrigation scheduling much more effective and acceptable locally.

Water budgets were obtained from intensive investigation on two local farms. The selection of the two study farms was intended to be representative of conditions valley-wide. Analysis of the budgets reveal that approximately 50 percent of the water applied to the fields came during the April and May period when less than 20 percent of the field evapotranspiration potential had been experienced. Salt pickup estimates during this early part of the season amounted to about 60 percent of the annual total for each field (Figure 24). These results have been verified in subsequent investigations in the study areas.

Another indication of the importance of early season water management is presented in an analysis of irrigation efficiencies. As the season progressed, the soils became less permeable and the crop water use increased, causing marked improvements in irrigation efficiency. Thus, if irrigation scheduling is employed in its optimal format, salt pickup from the two fields can be reduced as much as 50 percent or more. This phenomenon is explained in detail in Section 9.

The results of this demonstration project show that irrigation scheduling is a necessary, but not sufficient, tool for achieving improved irrigation efficiencies. The real strides in reducing the salt pickup caused by overirrigation will come from the employment of scientific irrigation scheduling in conjunction with improved on-farm irrigation practices.

The project was conducted in cooperation with the existing USBR irrigation scheduling program in the Valley. During 1975-1976, the USBR worked with the Grand Valley Canal Systems, Inc. with the idea that they would eventually take over all the scheduling activities in the Valley. However, in early 1977 the Grand Valley Canal Systems, Inc. stated that they had no interest in accepting the responsibility for future irrigation scheduling programs in the Grand Valley.

Drainage

Part of the initial demonstration project on canal linings included a portion on drainage. A total of $20,000 was spent in this initial project to tile some open drains and concrete slip form some other open drains. This was done to correct two

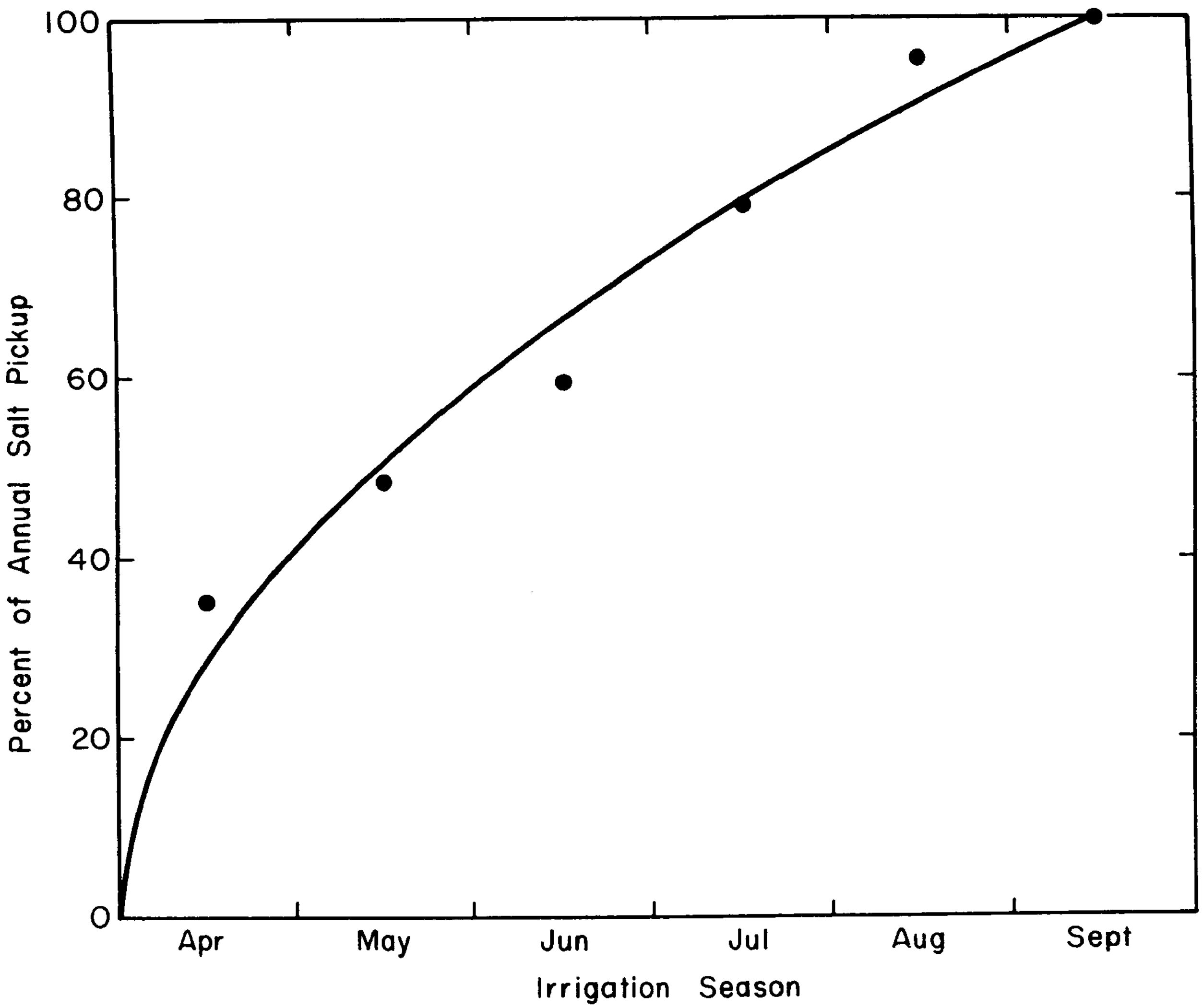


Figure 24. Seasonal distribution of salt pickup from the farms in the test area (Skogerboe et al., 1974a).

small surface problems in the area. The field data indicated that most of the open drains in the area were performing as intended and were not seeping water back into the groundwater. However, there still existed a need to evaluate the effectiveness of field drainage as a salinity control measure, and this was undertaken in 1972.

Drainage investigations in the Grand Valley began shortly after the turn of this century when local orchards began failing due to saline high water tables. Studies showed the soils to be not only saline but also to have low permeabilities.

At that time, the future development of the Bureau of Reclamation's "Grand Valley Project" loomed as a severe threat to the low lying lands between it and the Colorado River. In answer to these apparent drainage needs, the necessary solutions were clearly set forth but never fully implemented because of the large capital investment required. However, the citizens of Grand Valley did elect to form a drainage district supported by a mill tax levy in order to construct open ditch drains and some buried tile drains to correct local trouble spots. All of these efforts barely contained the rise in water tables, and today more than fifty years later, the local conditions remain essentially unchanged.

The construction of open drains has played an important role in Grand Valley. These drains serve as outlets for the tile interceptor drainage systems. They also intercept and convey tailwater runoff which would otherwise flow over surface lands, infiltrate, and contribute to additional subsurface groundwater flows, subsequently reaching the Colorado River with increased salt pickup.

This study was undertaken with the history of local drainage in mind, but for a different purpose, which was to skim water from the top of the water table before it reaches chemical equilibrium with the highly saline soils and groundwater in the cobble aquifer; and, to demonstrate to local farmers the benefits in increased crop production by improved field drainage, which results in lower soil salinity levels by permitting more effective leaching.

Three farms were selected for field drainage investigations during the 1972 irrigation season. The studies showed that the drainage problems on two of the farms could be alleviated by improved on-farm water management practices. In particular, increasing irrigation efficiency during the early part of the season would sufficiently reduce deep percolation losses, which in turn would keep the groundwater level at a satisfactory depth below the ground surface to allow good crop production.

The results from the two farms illustrate the adage--"an ounce of prevention is worth a pound of cure." Thus, the first steps in a salinity control program are to minimize: (a) seepage losses from canals and laterals; and (b) deep percolation losses from croplands (ideally, the deep percolation losses would not exceed the leaching requirement). By minimizing the amount of moisture reaching the groundwater, the requirements for field drainage will also be minimized.

The third farm had been originally selected for investigation as an example of one of the worst conditions encountered in the Grand Valley. A 4.7 hectare (11.6 acre) field on this farm was selected for construction of a relief field drainage system. Besides having a very high groundwater level, the soils had low permeability, high salt content (with a high sodium content), and the topography was irregular. In order to correct these deficiencies, the following measures were taken: (a) a drainage system consisting of 3,353 meters (11,000 linear feet) of 10.2 cm (4-inch) diameter perforated, corrugated polyethylene plastic pipe was installed on 12.2 meter (40-foot) centers at an average depth of 1.8 meters (6 feet); (b) the field was leveled to permit more uniform surface irrigation; (c) the field was plowed to a depth of 60 cm (2 feet) to increase surface permeability; and (d) the field was planted in salt tolerant Jose Tall Wheatgrass with a cover crop of oats.

Studies of the three farms, plus two additional farms investigated for irrigation scheduling, show that the field drainage effluents had a salinity averaging 3,000 mg/l less than the present subsurface irrigation return flows reaching the Colorado River.

A principal advantage of field drainage (i.e., tile or perforated pipe) is that the effluent is a point source which can then be placed into a collection system for disposal (i.e., evaporation ponds, deep well injection, or desalination). Field drainage and the collection of drainage effluents from the open drains in conjunction with salt disposal would be required to achieve a zero discharge policy for subsurface irrigation return flows. However, field drainage on a large scale would probably be one of the last salinity control measures to be implemented due to its very large initial costs.

As part of this study, an alternative use of drainage was considered. During the 1950's pump drainage offered no salinity control benefits because the salinity of the pump drainage effluent is comparable to the salinity of subsurface irrigation return flows reaching the Colorado River. A network involving pump drainage in combination with desalination would be very effective in reducing salt loads returned to the river. In determining the costs of pump drainage in combination with desalting, it becomes apparent that this alternative is quite costly (about $310 per metric tons of salt removed). However, with the recent advances in desalination technology, this alternative method of decreasing salt loads of river systems is certain to become increasingly feasible as time progresses. This control measure would likely be considered as the final step in an overall salinity control program, which would only be taken at some time in the future.

In viewing the results of this study, it is obvious that field drainage is a curative rather than preventative measure. High costs of such programs illustrate the need of first minimizing the flows passing through the root zone or seeping from canals and laterals. The small amount of water entering the groundwater could then be effectively removed by drainage systems and/or wells located at selected locations. Thus, field drainage as it pertains to objectives of salinity control is a remedy which must be considered but will probably not be implemented.

SECTION 6

PROJECT INITIATION

LATERAL SELECTION

Since this study involved the selection of several laterals in which the irrigators to be served would participate by contributing to the construction costs, total cooperation was imperative. By first publicly advertising the project, and then personally contacting one or more parties who seemed most interested, about eleven potential groups in the project area were identified. After the prople had discussed the matter among themselves, project personnel arranged meetings where the specific details of the project were outlined and questions answered. Since the average size farm in the area is about 2 to 6 hectares (5 to 15 acres), the number of people involved could possibly be as high as 100. Actually, 89 persons were involved. Interestingly, the anticipated problems of coordinating such a large group did not materialize.

The grant award for this project was received February 18, 1974. The first step in the lateral selection process began five days later when an announcement of this new project along with a location map was placed in the local newspaper (Figure 25). The article stated the funding available, its purposes and conditions for qualifying, and the availability of project representatives at an open house to be held February 27, 1974, at the local Holiday Inn to answer further questions. The response to the newspaper article was such that at least 40 individuals representing 15 laterals responded (only 10 of which were actually in the demonstration area) and further field contact was not necessary. The overwhelming response at this open house resulted in considerable time being saved and undoubtedly ranks as one of the most important events leading to the project's success.

At the open house, each inquirer was advised that the best action at the time would be to contact others on the lateral, briefly explain the project objectives, and enlist support. On March 18, 1974, contact with the individuals who came to the open house was reestablished and meetings were scheduled over the next two weeks. With the exception of two cases, the meetings were unqualified successes in gaining the acceptance of the people involved. Lateral groups accepting the project were told final

$230,000 EPA grant to fund new seepage control project

Funding has been received from the U.S. Environmental Protection Agency to construct irrigation improvements in the area between Grand Junction and Clifton, according to the Agricultural Engineering Dept. at Colorado State University.

The area is the same that received funding five years ago for concrete and gunnite lining of canals and laterals to reduce seepage.

CSU officials said the advantage in continuing work in the area is that much is already known about the underground water and the salt flowing into the Colorado River from the area. Additionally, they said, considerable money has been spent on both equipment and personnel for instrumenting the particular demonstration area.

The amount of information provides a strong basis for evaluating the effectiveness of irrigation improvements in reducing river salinity.

The study area was originally selected because it is fairly representative of the Grand Valley. Five canals traverse the area, thereby allowing greater participation by the majority of irrigation entities in the valley.

The EPA has granted $230,000 for the lining of laterals, construction of new on-farm irrigation systems, and installation of tile drainage.

The funds can be used to pay 70 per cent of the construction costs, with the farmer paying the remaining 30 per cent.

The demonstration project will use two laterals under each of the five canals in the study area. Laterals will be selected to represent a wide variety of conditions.

To participate, all of the irrigators under a lateral must be willing to share in the costs of lateral lining and on-farm irrigation improvements. A few of the laterals have already been extensively lined with concrete under the previous demonstration project.

CSU officials said the selection of a lateral and all the crop land served by a lateral, rather than an individual farm, has a tremendous advantage in allowing control at the lateral turnout. Thus both the quantity of flow and the time of water delivery can be controlled, thereby providing improved water management and higher crop yields.

The new construction program will be explained by CSU personnel at the Holiday Inn from 9 a.m. to 4:30 p.m. Feb. 27. Any irrigator having lands in the study area can inquire at that time about possibilities for participating.

The new study will use a variety of irrigation methods, including "tuning up" methods presently in use. CSU said considerable experience has been gained in improving the existing irrigation methods while evaluating irrigation scheduling as a salinity control measure in the Grand Valley. However, more advanced irrigation methods have not been evaluated in the Grand Valley for salinity benefits.

Irrigation systems to be constructed under the new project include automated farm head ditches, border irrigation, sprinkler irrigation, and trickle irrigation. Tile drainage also will be constructed on some farms.

In particular, some of the lands near the Colorado River will require drainage facilities to reclaim them for high level productivity.

CSU officials said the most significant aspect of the project is use of a salinity control "package"' rather than a single control measure.

Field days will be conducted in the third year — 1976 — of the project, probably during August.

Figure 25. Announcement of grant award in Daily Sentinel (Grand Junction, Colorado) February 23, 1974.

site selection would not be made until the fall or winter of 1974-1975 so that each lateral could be evaluated for its usefulness in satisfying the project objectives. Also, this time could be used by irrigators to finalize their own willingness to be included in the project and to reach agreement among themselves concerning such matters as cost sharing and the desirable operating characteristics of the improved irrigation systems.

The project was established on the basis that the project would pay 70 percent and the participants 30 percent of the total construction costs, not including engineering or administration costs. The 30 percent matching requirement could be paid in cash or by equal value arrangements such as direct labor, equipment rentals, land leveling costs, or through the voluntary assistance of local organizations such as the Grand Junction Drainage District.

As more was learned about the various lateral systems and the attitudes of the irrigators, it was necessary to continually reevaluate the group of laterals in terms of project objectives. In addition, throughout the first year, project personnel received numerous requests (at least two to three every week during the summer months of 1974) from other interested landowners within the project area. In fact, requests were still being received after completion of the project.

The selection of a lateral as a subsystem, rather than an individual farm, has the advantage of maintaining control at the lateral turnout. In this way, both the quantity of flow and the time of water delivery can be controlled, thereby facilitating improved water management throughout the subsystem. The lands selected demonstrated a wide variety of irrigation and drainage problems which provided a representative cross-section of the irrigated lands of the Valley. With the available knowledge regarding the study area, a lateral and the associated lands served by the lateral could be used as a logical subsystem for evaluating the salinity reduction in the Colorado River resulting from the implementation of a salinity control technology package.

The laterals selected were evaluated on the basis of four broad criteria:

1) In a lateral system, 100 percent participation must be obtained from all the water users on lands served by this lateral;

2) The degree of anticipated participation in all of the three phases of the project, which are the preevaluation, construction, and postevaluation covering the anticipated three-year period of the project;

3) The type and extent of irrigation and drainage problems represented, and the different solutions and alternatives which were agreeable and economically advantageous to the landowners; and

4) The analysis of the least cost expenditures, demonstration value to other farms, and maximum production of research results in order to realize project objectives.

One hundred percent participation was required to accomplish one of the major goals of the project, which was to demonstrate the effectiveness of a "package" of technological improvements on a broad scale for purposes of salinity control. Numerous lateral group meetings and individual discussions with irrigators were used to evaluate, as objectively as possible, the anticipated degree of voluntary participation in the project's three phases, as well as their willingness to change existing irrigation practices and methods. This was very critical since many of the proposed systems would often be designed in such a way that a return to old methods would practically be impossible, and the new proposed management methods might be mandatory for continued operation of the system. The results and implications were fully explained to all the participants before any final decisions were mutually agreed upon.

The type of physical problems and the extent of these problems were carefully examined by project personnel to insure that unnecessary duplication did not occur and that as many different problems as possible could be treated by as many methods as possible. The long-range objectives of agricultural salinity control in the Grand Valley and the Colorado River Basin were also taken into account in choosing the type of problems to be studied, and alternative control measures to be implemented.

The mix of various salinity control technologies were carefully matched to achieve a maximum research effect on each lateral subsystem. The types of planned treatments included sprinkler irrigation, drip irrigation, concrete lateral linings, concrete head ditches, gated pipe, automated cut-back furrow irrigation, land shaping and clearing, flow measurement, tailwater removal systems, buried PVC plastic irrigation pipelines, agricultural field drainage, irrigation scheduling, and various improved water management practices for each subsystem. In some cases, only increased labor spent on irrigation, in conjunction with one other type of treatment, was incorporated into the experimental design.

Once the selected laterals were identified by their special problems, the alternative solutions to alleviating these problems were presented to the landowners and a proposed course of action was planned out in complete accordance with the wishes of all parties. Project personnel then analyzed the costs of the various alternatives and prepared preliminary cost estimates. Further meetings were held with the water users under each lateral and final plans were mutually adopted. Any other information necessary for the preparation of the final bid documents to comply with the landowners' wishes was then collected.

LATERAL LAND USE

In order to determine the potential consumptive use and to provide information for irrigation scheduling and land use change comparisons, the land use of each lateral was mapped each year. It should be stated that no attempt was made by project personnel to influence the landowners as to the land use and crops grown on these fields. The land use under each lateral during the project period is summarized in Table 13.

An examination of the lateral land use data indicates that the improvements (which were essentially completed prior to the 1975 season) caused several changes in land use. For example, there was a 45 percent reduction in idle and abandoned farmlands which were put into production. In addition, some abandoned farmland was cleared of phreatophytes in preparation for returning such land to agricultural production.

The net decline in total potentially irrigable cropland was due to the withdrawal of land for the construction of a school, industrial uses, and farmstead improvements.

LATERAL HYDROLOGY

At the beginning of the 1974 irrigation season, the basis hydrologic elements under each of the selected laterals were monitored. At the canal turnout to each lateral, a flow measuring flume and a continuous water level recorder were installed to provide readings on the diversions into each subsystem. A summary of these data for the 1974 irrigation season is given in Table 14. A network of flumes were installed in selected locations to identify tailwater and wastewater flow quantities. Several series of shallow observation wells were installed to observe groundwater elevations and to delineate areas in need of special field drainage. These wells were monitored throughout the project to indicate the effectiveness of the various improvements.

Much of the flow measurement was changed for the 1975 and 1976 irrigation season as the individual laterals were constructed. Some flumes were replaced with propeller meters (in the case of pipelines), and others were switched to standardized concrete Cutthroat flumes. In fact, the only lateral measurement

TABLE 13. LAND USE DATA FOR THE LATERAL SYSTEMS FOR THE PROJECT PERIOD, IN HECTARES[1]

Land Use Classification	LATERAL IDENTIFICATION: HL C 1974	HL C 1975	HL C 1976	HL E 1974	HL E 1975	HL E 1976	PD 177 1974	PD 177 1975	PD 177 1976	GV 92 1974	GV 92 1975	GV 92 1976	GV 95 1974	GV 95 1975	GV 95 1976
Irrigated Cropland															
Corn				5.5	6.7	7.7		0.5		11.5	11.5		16.9	17.6	13.0
Truck Crop							0.2	0.2	0.2				0.5	0.5	
Barley	0.8	0.8	0.8				3.5	3.5	3.5				6.9	2.5	3.0
Oats		2.4						0.3					2.5	16.9	23.3
Wheat							1.8	1.8							
Alfalfa			2.4	1.0	1.0		1.8	2.4	2.7				11.5	11.5	10.5
Grass Hay	1.5												1.9	1.9	1.9
Pasture	0.9			4.2	3.0	3.0	1.2	1.2	1.2	8.9	8.9	8.5	14.0	9.8	9.8
Orchard	0.4	0.4	0.4	23.5	23.5	23.5	3.5	3.5	3.5				0.5	0.5	0.5
Idle	7.9	7.9	7.9				9.2	7.8	8.7				15.9	8.6	7.8
Other							1.5	1.5	1.5			1.9			
SUBTOTAL	11.5	11.5	11.5	34.2	34.2	34.2	22.7	22.7	21.3	20.4	20.4	10.4	70.6	69.8	69.8
Other Land Use															
Farmsteads	1.6	1.6	1.6	1.7	1.7	1.7	2.3	2.3	2.3	3.9	3.9	3.8	5.6	5.6	5.6
Urban							2.4	2.4	3.8						
Stock Yards													1.6	2.4	2.4
School Yards												10.1	1.3	1.3	1.3
SUBTOTAL	1.6	1.6	1.6	1.7	1.7	1.7	4.7	4.7	6.1	3.9	3.9	13.9	8.5	9.3	9.3
Industrial															
Miscellaneous							0.4	0.4	0.4						
SUBTOTAL							0.4	0.4	0.4						
Phreatophytes															
Salt Cedar															
Greasewood															
SUBTOTAL															
TOTAL	13.1	13.1	13.1	35.9	35.9	35.9	27.8	27.8	27.8	24.3	24.3	24.3	79.1	79.1	79.1

[1] 1 hectare = 2.47 acres

(Table 13 continued on following page)

TABLE 13 (CONTINUED). LAND USE DATA FOR THE LATERAL SYSTEMS FOR THE PROJECT PERIOD, IN HECTARES[1]

Land Use Classification	GV 160 1974	GV 160 1975	GV 160 1976	MC 3 1974	MC 3 1975	MC 3 1976	MC 10 1974	MC 10 1975	MC 10 1976	MC 30 1974	MC 30 1975	MC 30 1976	TOTAL 1974	TOTAL 1975	TOTAL 1976
Irrigated Cropland															
Corn		2.1	2.1				2.0	7.4	5.1				35.4	45.8	27.9
Truck Crop	0.3	0.3	0.3				0.5	0.5	0.5				1.5	1.5	1.0
Barley								3.8	10.3				11.2	10.6	17.6
Oats	1.0		1.3				1.1	11.4	9.6				4.6	31.0	34.2
Wheat													1.8	1.8	
Alfalfa	1.9	1.9	1.9				4.5	5.7	3.3	7.4	7.4	7.4	28.1	29.9	28.2
Grass Hay	13.4	14.4	14.4				3.1	0.6	0.6	6.4	6.4	6.4	26.3	23.3	23.3
Pasture	12.3	19.9	21.7	0.4	0.4	0.4	12.2	7.0	7.7				54.1	50.2	52.3
Orchard							0.4						28.3	27.4	27.9
Idle	24.6	14.9	9.7	2.6	2.6	2.6	17.8	7.8	7.1				78.0	49.6	43.8
Other													1.5	1.5	3.4
SUBTOTAL	53.5	53.5	51.4	3.0	3.0	3.0	41.6	44.2	44.2	13.8	13.8	13.8	271.3	273.1	259.6
Other Land Use															
Farmsteads	9.3	9.3	9.3	0.7	0.7	0.7	6.4	6.4	6.4	0.3	0.3	0.3	31.8	31.8	31.7
Urban	3.3	3.3	3.3										5.7	5.7	7.1
Stock Yards	0.5	0.5	0.5				1.1	1.1	1.1				3.2	4.0	4.0
School Yards													1.3	1.3	11.4
SUBTOTAL	13.1	13.1	13.1	0.7	0.7	0.7	7.5	7.5	7.5	0.3	0.3	0.3	42.0	42.8	54.2
Industrial															
Miscellaneous			2.1										0.4	0.4	2.5
SUBTOTAL			2.1										0.4	0.4	2.5
Phreatophytes															
Salt Cedar	3.6	3.6	3.6				4.9	2.3	2.3				8.5	5.9	5.9
Greasewood	8.5	8.5	8.5										8.5	8.5	8.5
SUBTOTAL	12.1	12.1	12.1				4.9	2.3	2.3				17.0	14.4	14.4
TOTAL	78.7	78.7	78.7	3.7	3.7	3.7	54.0	54.0	54.0	14.1	14.1	14.1	330.7	330.7	330.7

[1] 1 hectare = 2.47 acres

TABLE 14. ANNUAL LATERAL DIVERSIONS IN HECTARE-METERS

Lateral	Year 1974	1975	1976
HL C	6.31	[1]	20.31
HL E	58.18[2]	33.73	82.50
PD 177	96.14	41.88	60.47
GV 92	69.67	[1]	52.65
GV 95	132.96	132.65	109.43
GV 160	80.82	36.95	177.32
MC 3	[3]	[3]	[3]
MC 10	76.30	79.98	90.75
MC 30	30.70	31.57	36.15
Total	551.08	356.76	629.58

[1]Missing record
[2]Sprinkler system only
[3]Not in operation

structures which remained unchanged were some selected tailwater measurement stations.

Construction of the laterals also added a large number of flow measurement structures within the lateral subsystems. Flow measurement was available after each grower received his water. This permitted a high degree of monitoring capability, as well as a much higher level of water management on the individual farms.

During the first irrigation season (1974), a large amount of effort was made to collect the design data which would be needed for the construction of lateral improvements in 1975. This included surveying all the laterals to obtain slopes and distances, and in some cases, topographic surveys were made on selected fields. The "legal" water rights as compared to the actual water deliveries (which were measured) were determined by examining the records of the canal companies and by meeting with canal officials. Seepage losses in the laterals were measured in selected cases by measuring the inflow and outflow of a specific length of lateral. Reaches had to be over 610 meters (2,000 feet) in length to minimize the effect of flow measurement errors on the measured difference, which was the seepage loss.

In order to establish many of the parameters of on-farm distribution, a large amount of data was collected throughout the project period. For example, land use maps were updated annually and used to establish consumptive use amounts and assist in irrigation scheduling. Exhaustive ring infiltrometer tests were repeated several times each year on several crops and several soil types. Pressure plate analyses were run on representative soil types to determine the available moisture holding capacities. These data along with numerous advance-recession tests and extensive soil moisture sampling identified much of the necessary information needed to identify deep percolation quantities. In addition, some soil samples were analyzed for fertilizer requirements to assist cooperators. Field tailwater measurements were made on selected fields under different management practices and soil types to establish a basis for field runoff parameters. Examples of the data collection procedure are shown in Figure 26. The above information was utilized to calculate application and field efficiencies. A mass-balance approach was used to bring the respective flow quantities into agreement.

Concurrently with the data collection mentioned above, the regular and preestablished network of monitoring devices (observation wells, piezometers, drains, etc.) for the demonstration area was sampled and analyzed, drainage flows measured, and groundwater elevations tabulated throughout the year. A data report which presents the collective results of this network during the period 1969 through 1976, will be available from the Agricultural and Chemical Engineering Department of Colorado State University in late 1978.

a. Soil sampling by project personnel, this same instrument was also used to install observation wells on field drainage installations;

b. Preparing for infiltration tests;

c. Running advance recession tests by project personnel;

Figure 26. Data collection activities by project personnel.

d. Depicts water sampling activities in drains;

e. Depicts flow measurement in open drains; and

f. Depicts lateral flow monitoring activities.

Figure 26. (Continued).

SECTION 7

DESIGN, CONSTRUCTION AND OPERATION OF IMPROVEMENTS

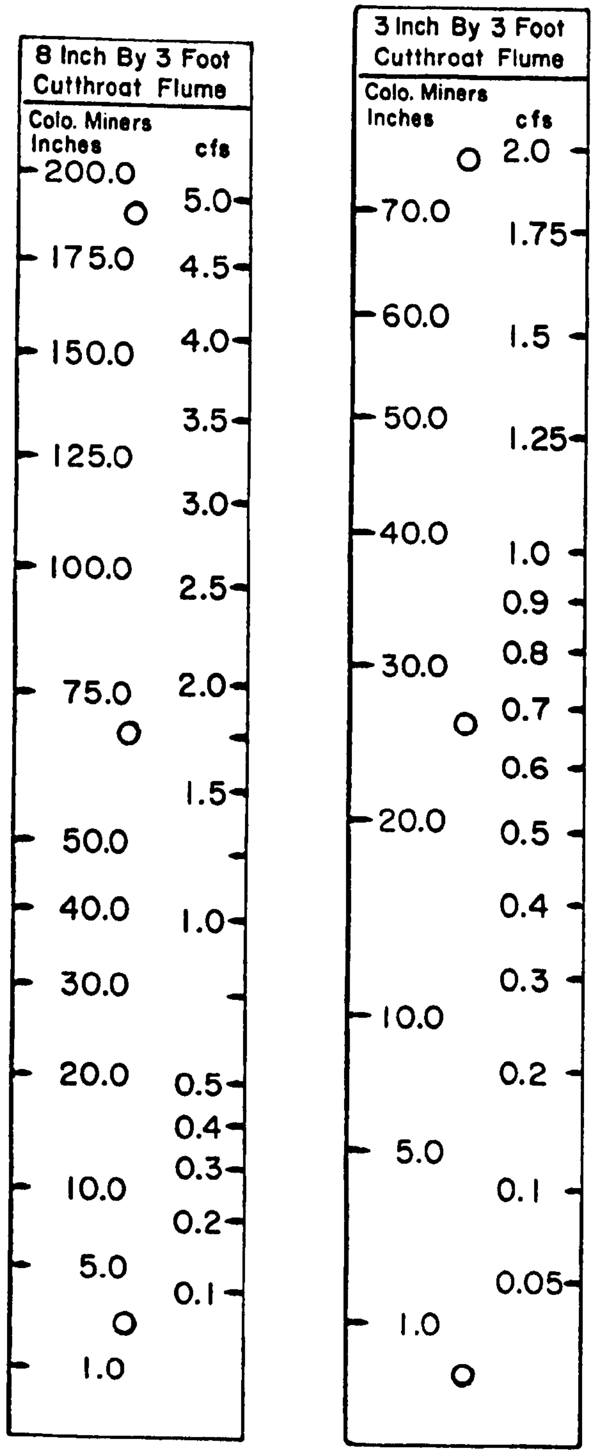
DESIGN

Design Philosophy

All of the improvements were organized into a logical experimental design in order to effectively evaluate the objectives of the project. An overall design philosophy was formulated to govern the general designs of improvements within the lateral subsystems. The first major consideration was the placement of flow measurement devices in each lateral subsystem. These measurement structures were placed immediately below the lateral headgates, at all flow divisions and after each farm delivery point on the main delivery system. The grower knew how much water he had by the difference between his and his neighbors' flow readings. All measurement devices could be read directly without the use of tables or any calculations. To accomplish this, propeller meters read in cubic feet per second (cfs), totalized in acre feet; and special enameled metal staff gauges were designed, manufactured, and placed in all the Cutthroat flumes (Figure 27) which read directly in cfs and Colorado Miner's Inches. Two sizes of Cutthroat flumes were standardized throughout the project: 1) a 20.3 cm throat width by 91 cm length (8-inch throat width by 3-foot length); and 2) a 7.6 cm throat width by 91 cm length (3-inch throat width by 3-foot length). Examples of these flumes in operation are shown in Figure 28.

Another consideration was the grade for all pipelines and concrete ditches would be governed by the general slope of the land surfaces as much as possible. This reduced costs considerably because it eliminated many costly drop structures and energy dissipation facilities. Where possible, the improvements would follow the old channels and an attempt was made to consolidate ditches and laterals to minimize the duplication of facilities. Efforts were also made to incorporate surrounding lands under one lateral in order to maximize the usefulness of the improvements.

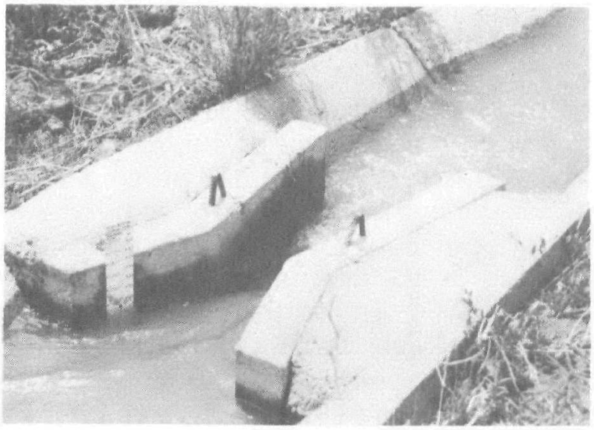
All conveyance systems were designed for approximately 200 percent of the water rights. This was done for three main reasons: (a) under the Grand Valley Canal, water rights can be sold,



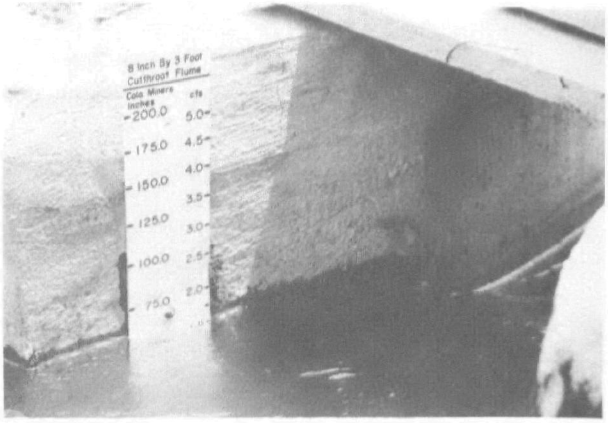
Scale
1 cm = 2.52cm

Figure 27. Staff gauges for 8-inch by 3-foot and a 3-inch by 3-foot Cutthroat flumes (can be read directly in either Colorado Miner's Inches or in cubic feet per second).

a. Precast Cutthroat flume being installed;



b. Cutthroat flume in operation in a lateral;



c. Close-up of special staff gauge in operation.

Figure 28. Cutthroat flume installation and operation.

bought, rented or transferred anywhere in the system and new water might come into the systems at any time; (b) the canal companies customarily divert what they estimate as at least 120 percent of the water rights into the lateral subsystem (often much more); and (c) the majority of the subsystems collect tailwater for reuse from other laterals. Designing for roughly 200 percent of water rights actually added very little to the costs of the systems due to standard material size availability.

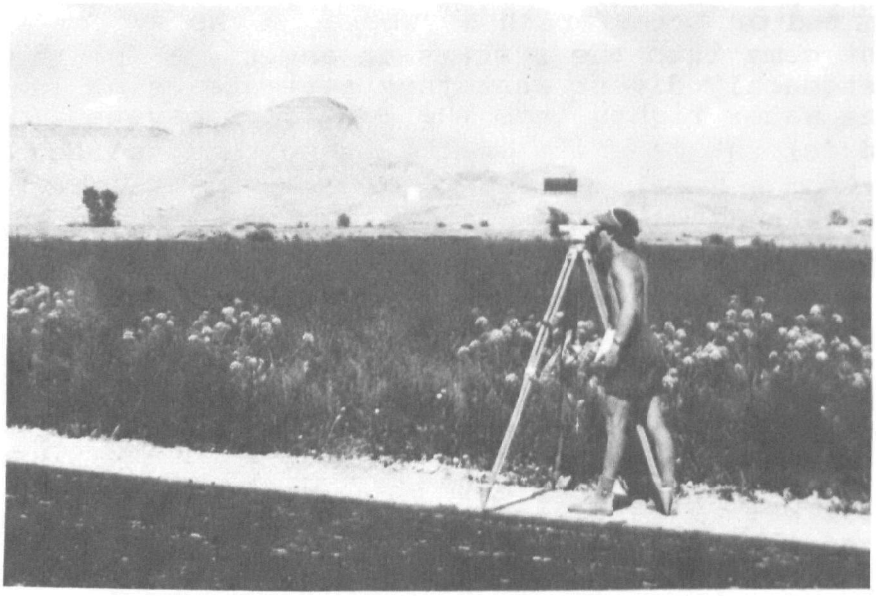
If a lateral passed through a subdivision or other urban type area, the water was conveyed in a closed conduit for health and safety reasons, for the aesthetics of eliminating an open ditch, and to minimize debris problems caused by children playing in the ditches. Under roadways and access routes, the PVC plastic irrigation pipes were encased with concrete pipe. If a corrugated metal pipe (CMP) culvert needed to be replaced or relocated, it was replaced with a high sulfate-resistant concrete pipe. The concrete pipe was about one-half the material cost of CMP, but the initial installation costs were higher. In the highly saline soil conditions of the Grand Valley, the concrete would be expected to outlast the CMP by at least 20 years. When water was taken from a lateral to irrigate ornamental lawns and shrubs in a subdivision, the subdivision water was separated from the agricultural water because the methods of operation are so different as to be incompatible with one another.

General Design Procedures

The first step in the collection of design and preevaluation information was to meet with the farmers and to walk the individual laterals with aerial photos and obtain the following information: lateral boundaries, exact locations of existing ditches, individual crop types, crop row spacing, planting dates, irrigation methods, number of sets per irrigation, all places where tailwater enters the system, all places where tailwater leaves the system, and whether it is reused or is lost. The identification of all potential problem areas such as road crossings with dimensions, division boxes and associated structures, deep erosion areas requiring fill, trees to be removed, fences, locations of buried utilities, and locations and sizes of existing special hydraulic structures such as siphons and flow measurement structures were also noted for future reference.

Project personnel then surveyed all the preselected laterals to determine pertinent information including the slopes and lengths of various reaches, cross-sections and profiles of the laterals, field sizes, run lengths, field slopes, and, in some cases, the topography of the individual fields. Some of the data collection activities are depicted in Figure 29.

After evaluating the local topography and location of existing structures, the hydraulic computations necessary to insure



a. Project personnel surveying a lateral.

b. Project personnel discussing suggested improvements.

Figure 29. Collection of lateral design information.

proper performance of the proposed individual components were made. The siting and/or relocation of structures was also considered at this time.

IMPROVING OPERATIONAL CHARACTERISTICS OF THE LATERAL SUBSYSTEMS

As various elements of the lateral subsystem were completed, project personnel operated and tested the facilities to compare the actual performance with the designed capabilities, and also to locate possible construction problems and other potential troubles. As could be expected, some problems did arise, but, for the most part, were easily corrected. These systems have worked quite well and, as planned, the greatly increased system flexibility in the selected systems permits a much higher degree of water management than was previously possible. Also, in several cases, the improved water management and irrigation scheduling have resulted in higher crop yields. Some operational characteristics, which may not have been mentioned in preceding sections of this report, are included in the following discussion.

Personal Aspects of Improving Lateral Operations

On every lateral there was one person who accepted the responsibility of organizing the lateral for the project; and as part of the original project goals, it was hoped that individuals on each lateral would take responsibility for water management operation of the lateral subsystems. However, in all cases, project personnel had to assume the responsibility because no one on the lateral would do so. Persons on the lateral realized the emotional nature of water rights and use, and justifiably did not want the headaches and problems associated with water management on a lateral scale. The lateral water users are presently content to try to work out future water distribution and use on a case-by-case, person-to-person relationship. Where project personnel managed the water distribution, it was accepted without question since they were considered "neutral," and they had a large amount of credibility with the water users.

An educational problem which seemed to exist on almost all the laterals was that even though the systems were substantially modified, there was still a considerable amount of maintenance required. However, it was a different type of maintenance and was often neglected in the beginning. A big job for project personnel was to make sure that all persons knew how to maintain the system and had a regular maintenance schedule. This was especially important in pipeline installations which had to be flushed on a regular basis due to sediment accumulations.

CONSTRUCTION AND OPERATION OF LATERAL IMPROVEMENTS

The construction was completed in three stages: in the fall of 1974, in the spring of 1975, and in the fall of 1975. There was a small amount done in the spring of 1976 for a few additions and changes which were necessary. The majority of the construction was completed by the start of the 1975 irrigation season. Based upon the designs and a complete list of materials, contractor and materials' specifications were prepared in the fall of 1974. Bids were let as necessary by Colorado State University under its format as prescribed by state law, and all low bids were accepted. Written approval from the Project Officer was requested and received. A summary of each lateral's improvements is presented in the following sections.

Lateral HL C

There are 13.1 hectares (32.4 acres) which could be served by this lateral, but at this time only 2.7 hectares (6.5 acres) are actually presently productive. The remainder was once a productive orchard but is now idle. The improvements made on this lateral included the tiling of a large open drain bisecting the 2.7 hectare field (Figure 30) and three flow measurement devices: two 6-inch Parshall flumes and one 90 degree V-notch weir.

This lateral lies directly under the Government Highline Canal, and through this section the canal is cut into a Mancos shale outcropping and, as a result, has a substantial amount of seepage. There are several large open drains in this area to intercept these saline seepage flows. One such drain traversed the 2.7 hectare field making two small, nonregular shaped fields.

The large open-interceptor drain was tiled in cooperation with the Grand Junction Drainage District who installed the tile after the project purchased all materials necessary for the job (Figure 31).

Tiling the large open-interceptor drain greatly improved the irrigation and farming efficiencies of this field. Formation of one regularly shaped field from two irregular and hard to irrigate fields has greatly reduced the labor requirements and improved the ease of irrigation. In addition, significant increases in yields have been reported.

Irrigations on the 2.7 hectare (6.5 acre) field were in strict accordance with the recommended irrigation scheduling program. The owner was very willing to follow all suggestions as to time duration of sets and the quantities of water to be applied. This was the only traditionally irrigated field where this was the case.

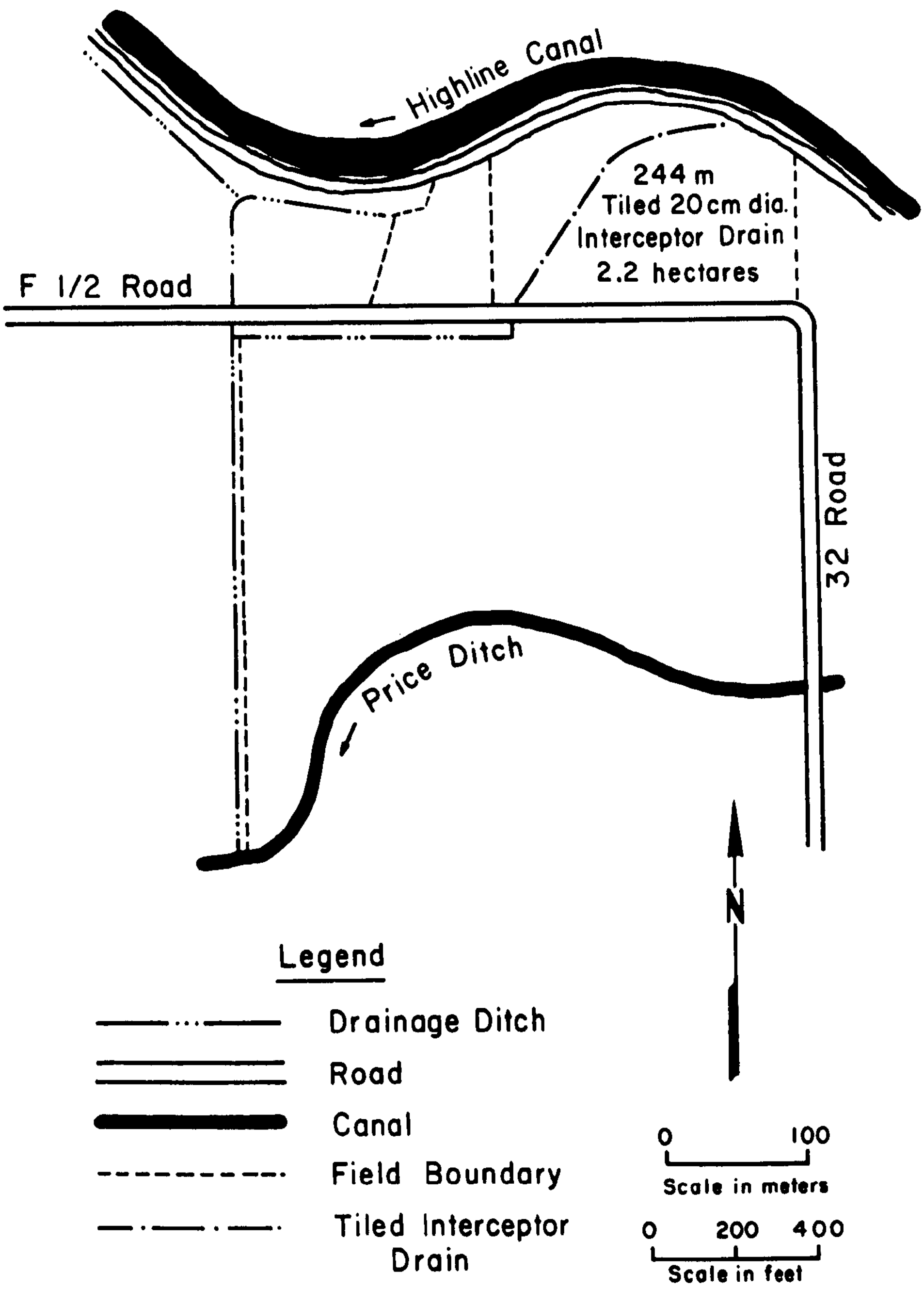
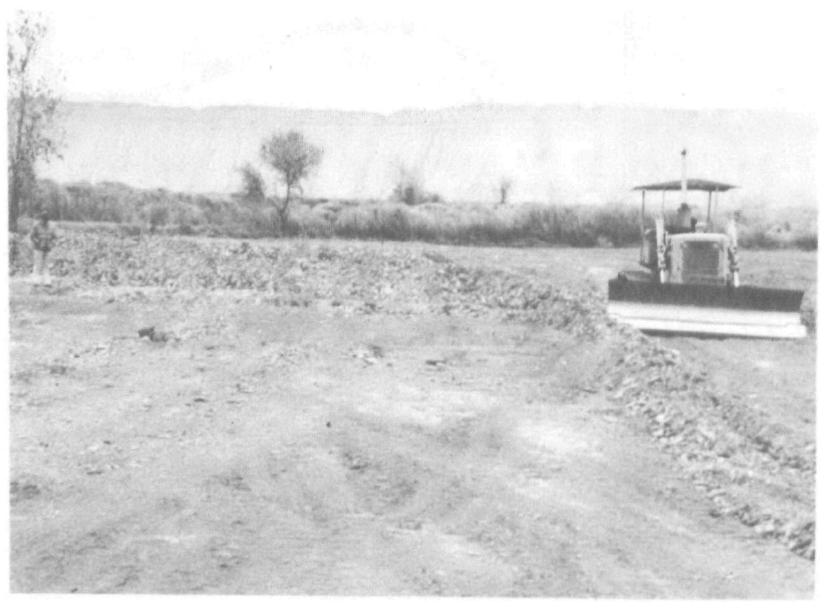


Figure 30. Map of Lateral HL C shows improvements and field locations.

a. Drain before construction; and



b. Covered drain at completion of construction.

Figure 31. Tiling of the large open drain on Lateral HL C.

The irrigations were from an earthen ditch using siphon tubes, and the proposed irrigation procedures did require more labor per set than had been used before the improvements. However, the total amount of labor for irrigating the entire field was still considerably less than before because of the more efficient field unit and elimination of 225 meters of additional head ditches.

Lateral HL E

The HL E lateral (designated HL E because it is the lateral served by turnout gate E on the Highline Canal) contains more than 23.5 hectares (58 acres) of orchards (apples, pears, and peaches). The major work on this lateral, summarized by Figure 32, consisted of the installation of overhead sprinklers on 5.2 hectares (12.8 acres) of pear orchard and installation of 329 meters (1,080 feet) of 20 cm (8-inch) diameter PVC plastic irrigation line across a corn field to replace an old collapsed pipeline. After installation of the sprinkler system, 183 meters of 20 cm diameter (600 feet of 8-inch diameter) concrete tile were installed on this lateral (in cooperation with the Grand Junction Drainage District) as a new interceptor drain. The upper portion of the orchard (under the sprinkler system) had suffered from a high-water table due to canal seepage and overirrigation on the upslope lands. The interceptor drain empties into a 25 cm (10-inch) PVC buried plastic irrigation pipeline which was installed for tailwater recovery and removal. The 402 meters (1,320 feet) of pipe were installed in an old unlined tailwater ditch carrying water from lands above the lateral. This ditch flows continuously for the entire irrigation system. The interceptor drain will be maintained by the Grand Junction Drainage District.

The sprinkler system can be used for frost protection (Figure 33) in the early spring, for cooling in the hot summer, and, of course, for normal irrigations. The sprinkler installation and materials cost $3,335 per hectare ($1,390 per acre). Operation and maintenance costs have been less than $180/hectare ($75/acre) per year. Data were collected on other parts of the orchard in order to compare the traditional irrigation methods against the overhead sprinkler irrigation system.

The average precipitation rate of the sprinkler system is 3.23 mm/hr (0.127 in/hr) and the risers are 4.6 meters (15 feet) above the ground surface on an 18.3 meter x 18.3 meter (60 x 60 foot) triangular pattern. Overall sprinkler system uniformity is described by a linear uniformity coefficient (UCL) of 86.3 percent (Karmeli, 1977), a Christiansen's uniformity coefficient (UCC) of 89.0 percent (Christiansen, 1942), and an Hawaiian Sugar Planters Association uniformity coefficient (UCH) of 88.5 percent (Hart, 1961). Water is delivered to a sump (50.5 l/s or 800 gpm) by a previously existing concrete ditch system (part of which was lined in the earlier studies) and is then pressurized by a 50-hp electric pump.

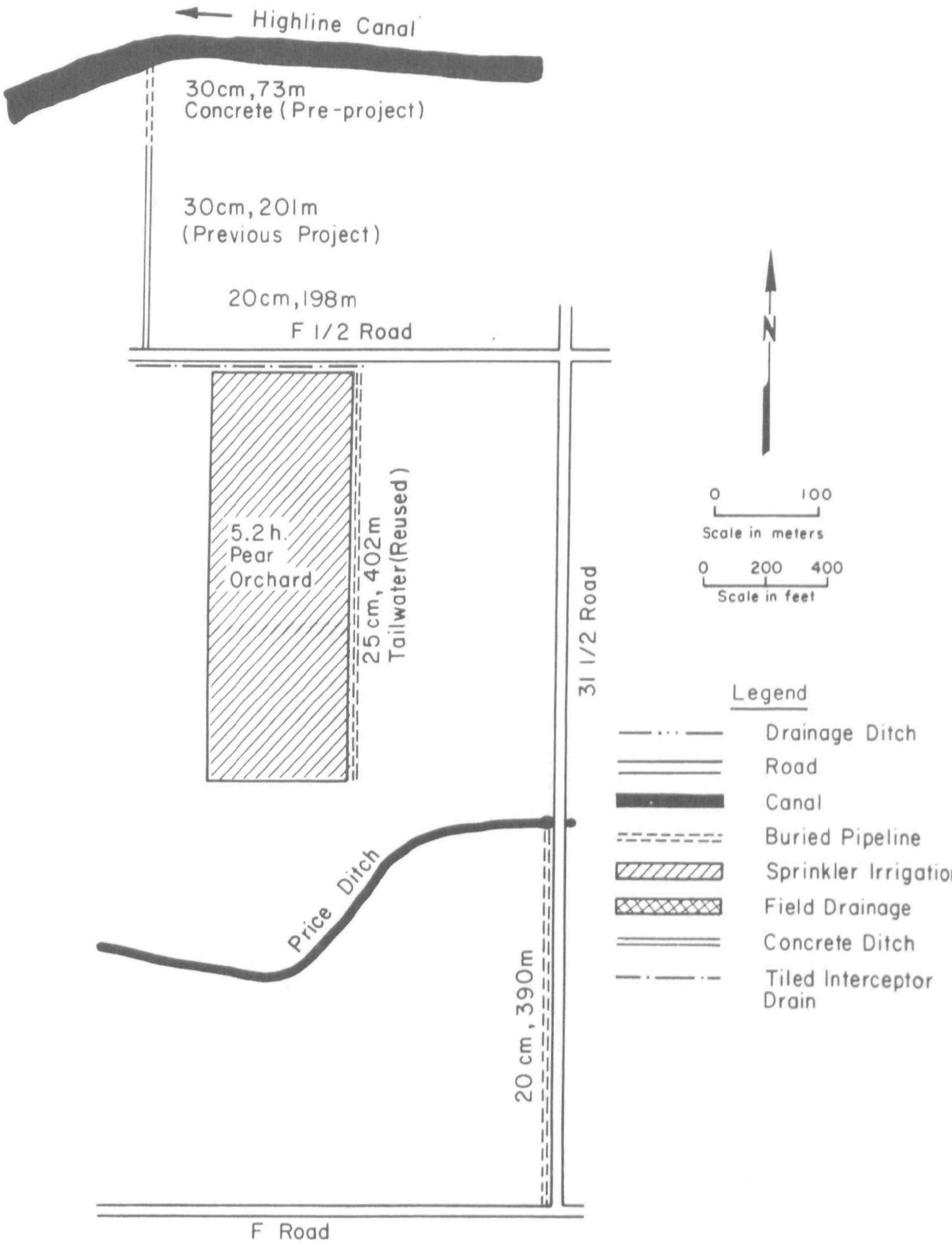
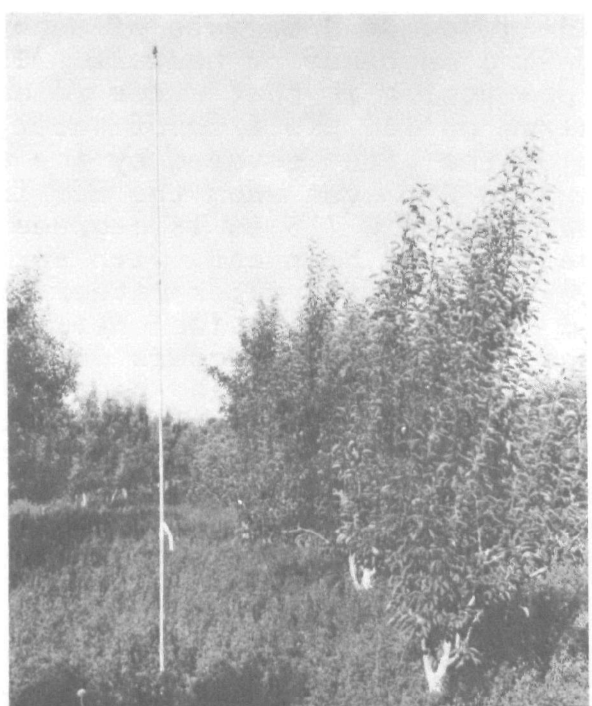


Figure 32. Map of lateral and on-farm improvements under the HL E lateral system.

a. Sprinkler in operation during a freeze period in 1976; and



b. Sprinklers in operation for irrigation.

Figure 33. Overhead sprinklers on Lateral HL E.

The sprinkler applications are measured by a 15 cm (6-inch) propeller meter in the pipeline. The 20 cm (8-inch) PVC plastic irrigation pipeline has a 20 cm (8-inch) meter to record the flow. Two 8 inch x 3 foot (20.3 cm x 91 cm) Cutthroat flumes were also installed to measure the water applied to the rest of the orchard. An electric-powered, self-cleaning trash removal screen (3.2 mm or 1/8 inch-mesh) was installed immediately upstream from the pump to remove debris from the water to prevent the sprinkler heads from becoming plugged.

The overall benefits from the overhead sprinkler irrigation system are quite numerous. The irrigations are very efficient since there is no surface runoff; deep percolation is minimized; and the entire 5.2 meters (12.8 acres) can be irrigated in one setting. Crop cooling for high fruit quality is another economic benefit of this system. The frost protection aspect of this sprinkler system is a rewarding side benefit and is the main reason that sprinkler irrigation was acceptable to this water user. In addition, the sprinklers are air pollution free and have larger energy savings when compared with oil, propane, or natural gas frost protection systems.

Research on frost control by means of sprinklers has been carried on for almost fifty years. Initial adoption of the concept has been slow due to large initial investments, but it is becoming more widely accepted because of technical or economic disadvantages of wind machines or heaters. The theory of sprinkling for frost protection is that water releases heating as it freezes (79.7 cal/gm or 144 BTU's/lb of water) and this helps to keep the part of the plant covered by ice at approximately 0 degrees C (32 degrees F), even when the air is as cold as -9.5 degrees C to -7.8 degrees C (15 to 18 degrees F). On the other hand, melting ice requires heat and, with sprinklers, this heat can be supplied by the applied water rather than by the plant. The system should remain in operation until all the ice has melted because most frost damage occurs during the thawing stages due to the extraction of moisture and heat from the plant cells resulting in cell breakdown. Sprinkling for frost protection requires that the plant be kept continually wet to maintain plants at a minimum temperature of 0 degrees C (32 degrees F). The degree of protection is directly proportional to the amount and frequency of water applied. The entire area should be irrigated in one set.

Researchers at Utah State University have recently successfully demonstrated that overhead sprinklers can delay fruit bud development and thereby greatly reduce early spring freeze damage to fruit trees. This procedure utilizes the sprinklers to provide evaporative cooling during warm periods in February and March to decrease the energy available for growth. This process will usually delay budding (bloom) from ten days to two weeks and eliminate about 80 percent of the possible freeze damage. Under present canal operating procedures in the Grand Valley, this type of frost protection cannot be practiced because the water is not turned into the canals until the first of April at the earliest.

Salinity benefits of this type of sprinkler irrigation are very evident in the great reduction of deep percolation. Under the traditional surface irrigation methods, the deep percolation was quite substantial (runs were 396 meters or 1,300 feet). This salinity control measure offers a large per acre salinity reduction, is economically advantageous to the fruit farmers, and is economically justifiable even if only for the frost control aspects. It is estimated that a grower in the Grand Valley annually has a 60 percent probability of a "total wipe out" with peaches (the major fruit crop in the area), 20 percent for apples and pears, and 80 percent for apricots due to freeze conditions without any frost protection such as heaters, smudge pots or sprinklers. With special tree training (i.e., pruning) practices, almost any variety of fruit can use overtree sprinklers for frost protection, although much caution should be used with "stone" fruits (i.e., peaches, apricots) due to their inability to support ice loadings. The orchards of the Valley have been going out of production for several years, and this type of irrigation with frost control offers great potential to assist the ailing fruit industry of the Grand Valley. For example, during the spring of 1976, this section of the orchard was saved due to the frost protection provided by the sprinkler system (Figure 33). The rest of the orchard was virtually frozen out with 22 degrees F (-5.6 degrees C) low temperature and had very little production. The 1976 frost wiped out about 30 percent of the total fruit crop in the Grand Valley. Approximately 30 percent of the Valley fruit crop was also lost in 1975 due to frost damage.

The 5.2 hectare orchard was carefully scheduled for irrigations. The soil moisture was monitored by a system of probes and tensiometers. The owner-operator of this farm is one of the most progressive farmers in the Grand Valley and was very willing to follow the scheduling and operational recommendations made by project personnel.

The 390 meter (1,280 feet) 20 cm (8-inch) diameter PVC plastic irrigation piepline which was installed to replace an old pipeline permitted farming operations directly over the pipeline, achieved essentially zero seepage, and provided a much greater degree of control over the water. The increased farming efficiency was an extra benefit and, at the same time, greatly reduced ditch maintenance.

<u>Lateral PD 177</u>

Work on the 27.8 hectare (68 acres) of lateral PD 177 consisted of the installation of 2,051 meters (6,729 feet) of buried plastic pipeline distribution system with 230 meters (760 feet) of concrete lining and installation of two drip irrigation systems on 2.2 hectares (5.4 acres) of peaches and apples. An illustrative summary of the PD 177 improvements is shown in Figure 34.

The installation of pipelines was done completely by irrigators on the lateral. The Mesa County Road Department installed the necessary new culverts under the roads after all materials and engineering were provided by the project. The delivery system above this lateral is a concrete ditch and buried pipeline arrangement constructed under the previous lining study (298 meters of 30.5 cm diameter concrete pipe and 793 meters of 30 cm x 30 cm trapezoidal concrete lining). The amount of work undertaken by the farmers themselves has been significant. Many persons donated their own time and equipment for the installation. The irrigators have a very good understanding of the system operation as a direct result of their work on the construction (Figures 35 and 36).

The drip irrigation systems (Figure 36) were initially installed on 1.5 hectares (3.4 acres) of young peaches. Later, a second system was installed on 0.7 hectares (1.6 acres) of mature apples. This will eventually cover another 3 hectares (7.2 acres) of apples. Drip irrigation is a recent development in irrigation which is gaining wide acceptance in many water short areas of the world. Water is applied directly at the plant via an "emitter" which drips water onto the soil at a very slow rate (4 to 8 liters per hour). Irrigations are on an almost daily basis to replace only the amount of water which the plants have used. The root zone is not used as a water reservoir as in other, more traditional, types of irrigation. There is virtually no deep percolation, and total water use requirements are usually one-third to one-half of the more conventional irrigation methods practiced in the area. An additional benefit of drip irrigation is that plant growth is usually much more rapid than with other irrigation methods, and in perennial crops, such as orchards, young trees will often start production much sooner (i.e., one or two years sooner) than trees grown under traditional methods. This is because the crops are never "stressed" for water; and fertilizers and pesticides can be applied directly through the system.

Water measurement on the lateral is accomplished by 14 flow measurement devices; propeller meters, Cutthroat and Parshall flumes, and a 90 degree V-notch weir. Other installations include a self-cleaning, water-powered trash screen (6.3 mm or 1/4 inch mesh) at the entrance of the pipeline to minimize trash and debris problems (Figure 35) and 207 meters (680 feet) of 15 cm (6-inch) gated pipe on approximately 2.4 hectares (10 acres).

Before the project, the eastern side of Lateral PD 177 had extreme difficulty in maintaining a dependable water supply during the irrigation season. Since implementation of the project, however, there has been no difficulty experienced. Ditch seepage has been eliminated, and the operation of the lateral

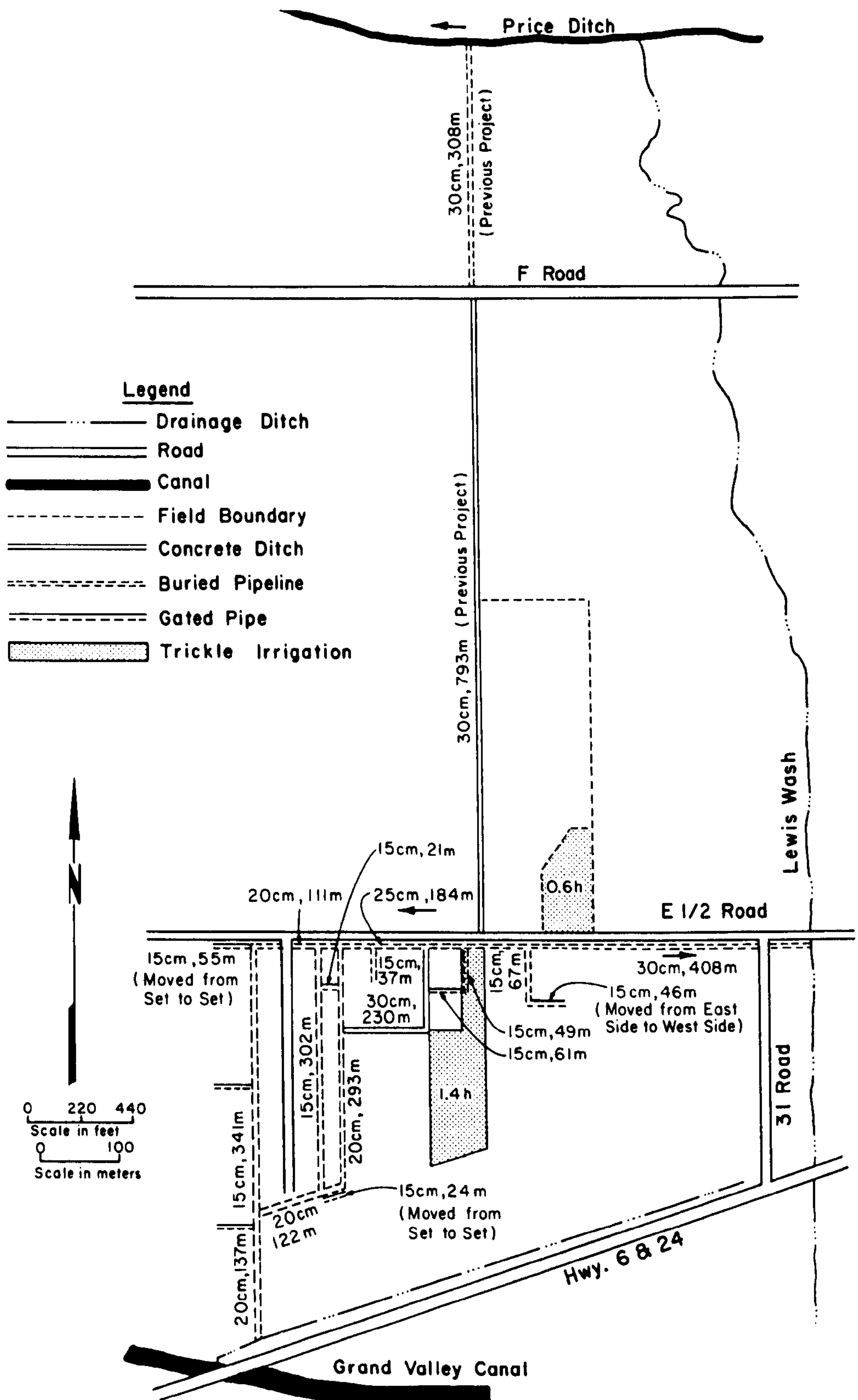
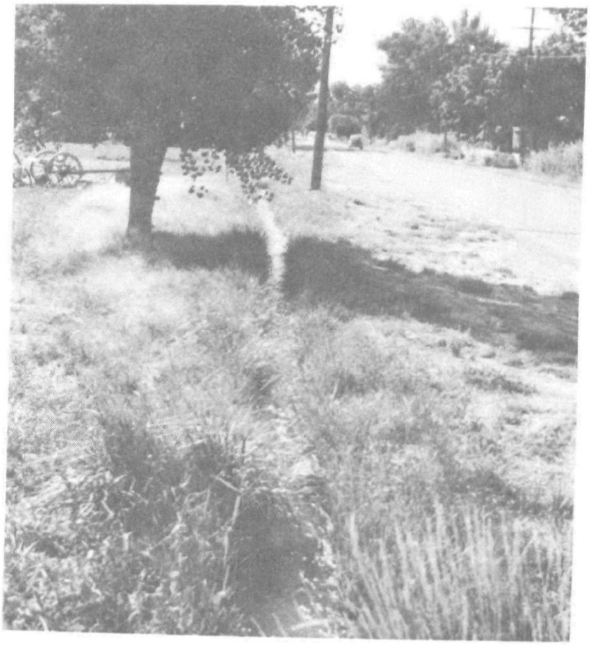
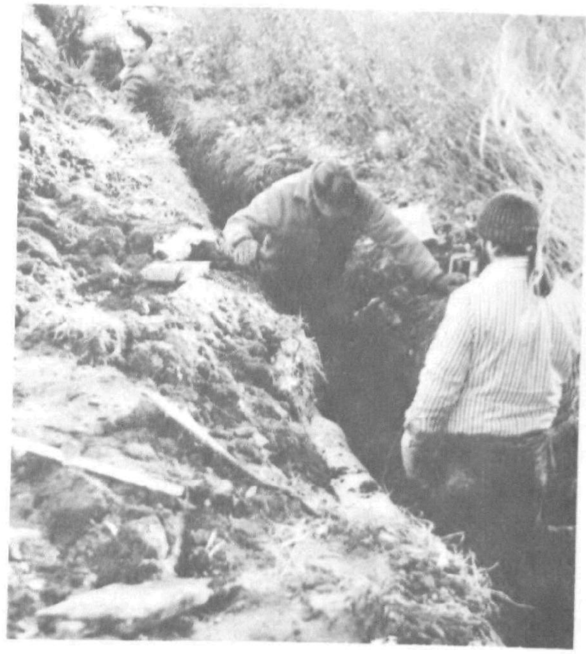


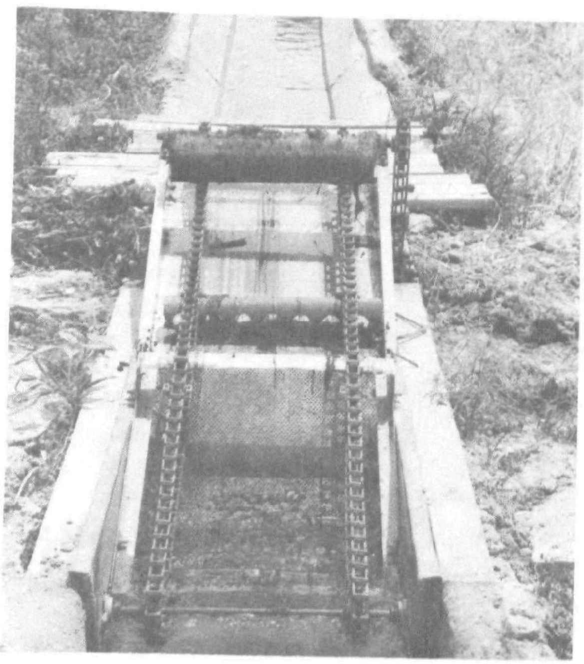
Figure 34. Map of lateral and on-farm improvements under PD 177 lateral system.



a. Section of lateral prior to improvements



b. Cooperators installing pipeline on lateral;



c. A water powered self-cleaning trash screen installed upstream of pipeline;

d. Section of lateral after installation of the pipeline with the valve box and meter box shown.

Figure 35. Construction of Lateral PD 177.

a. Cooperator installing water supply line for a drip system;

b. Drip lateral placement beside a young peach tree;

c. View of young peach orchard with laterals in place.

Figure 36. Drip irrigation on Lateral PD 177.

has changed quite substantially as the participants gained confidence in their system. For instance, irrigators who had historically diverted water continually, and had conveyed the water directly to a waste ditch if they were not using it, have now stopped this practice and are leaving the water in the system. Due to the bylaws of the Palisade Irrigation Company (Price Ditch), the system operates on a continuous flow basis. The excess water runs directly into the major canal running below the lateral and is reused. The irrigators are now confident that their water will be there when it is needed.

Another major change in the operation of this lateral is that the small subdivision at the west end of the system was, in effect, isolated from the agricultural portion of the system. The pipeline system was designed so that the agricultural users would not be disturbed by erratic urban uses. Urban use of irrigation water can be very sporadic since the urban people have outside employment and only irrigate their lawns and gardens for short periods in the evenings and on the weekends. This can be very disruptive to an agricultural user who relies on a constant nonfluctuating stream of water for the duration of his irrigation sets.

The farm-urban arrangement has greatly benefited the urban users, too, by providing a constant, dependable flow of water for their use. They are able to irrigate with very little water fluctuations and do not have to be concerned about damaging a pump due to a sudden lack of water. The urban users have had to change to a very informal scheduling arrangement since there is not enough water for everyone to irrigate their landscapes at one time, but this has worked out quite well. This type of water delivery system could have considerable water savings with the incorporation of a small reservoir at the head of a subdivision. Since landscapes are only watered for a couple of hours each day, much of the water passes through the subdivision without use and is lost to the system (although it is reused by other laterals), and a small holding pond to store this water for later use when needed could greatly increase the distribution efficiency.

Installation of drip irrigation systems on two small orchards drastically changed the operational characteristics of both orchards. Project personnel, as well as the landowner, have learned much from the operation of these systems. High frequency irrigations, wetting patterns, and nutrient balances using daily irrigations have presented many new concepts and challenges. However, the problems have been successfully dealt with, and the advantages for salinity control are tremendous.

Gated pipe was used to subdivide some very long runs with nonuniform slopes on another orchard under this lateral, resulting in much more efficient irrigations. The addition of a water-powered, self-cleaning trash screen at the head of the system was of great assistance in reducing trash and plugging problems for both siphon tubes and gated pipe, as well as the propeller meters.

Lateral GV 92

This lateral (Figure 37) was the last lateral in which construction of improvements was undertaken. The construction was completed in the spring of 1976. Approximately half of the land originally under this lateral was consolidated into another lateral (GV 95) to minimize the duplication of ditches and facilities. In fact, almost all of the tailwater from this lateral flows into the GV 95 system and is reused.

The system installed on this lateral is a concrete ditch (Figure 38) and pipeline delivery system. No on-farm construction was implemented. This was done in order to determine the salinity effectiveness of making only lateral distribution improvements. Water measurement at the headgate is accomplished by means of a metering headgate. Water division is regulated internally by means of two 8 inch x 3 feet (20.3 cm x 91 cm) Cutthroat flumes. The 24 cm (10-inch) diameter plastic pipe was installed by various irrigators on the lateral and Mesa County School District 51 (who owns land under this lateral), and they all participated on a cost sharing basis on the trapezoidal concrete ditch lining.

Lateral GV 95

Lateral GV 95 (Figure 39) was the largest lateral studied under this project and also had the largest expenditures for improvements. It is basically a buried plastic pipeline and a concrete lined distribution system. There are considerable on-farm improvements such as gated pipe, concrete lined head ditches, field drainage and a side-roll sprinkler (Figure 40). There is also a rather extensive tailwater collection and reuse system. This has assisted in stabilizing lateral flows for better water management and irrigation scheduling, as well as providing addition of water for the users. This lateral contains an additional 29 hectares (70 acres) which were consolidated from two other laterals to minimize duplication of ditches and other structures.

All of the matching monies for construction of the mainline distribution system were paid by the lateral users, and the work was done by outside contractors. The matching money was collected by the lateral users through charging each person $200 for the first share of water and $40 for each additional share with leftover funds going for future operation and maintenance (O&M) costs. Most of the on-farm improvements were paid for in cash rather than labor. As a consequence of this lack of direct involvement in the construction, many of the lateral users did not have as complete an understanding of the system operation as did water users under other laterals who directly participated in the

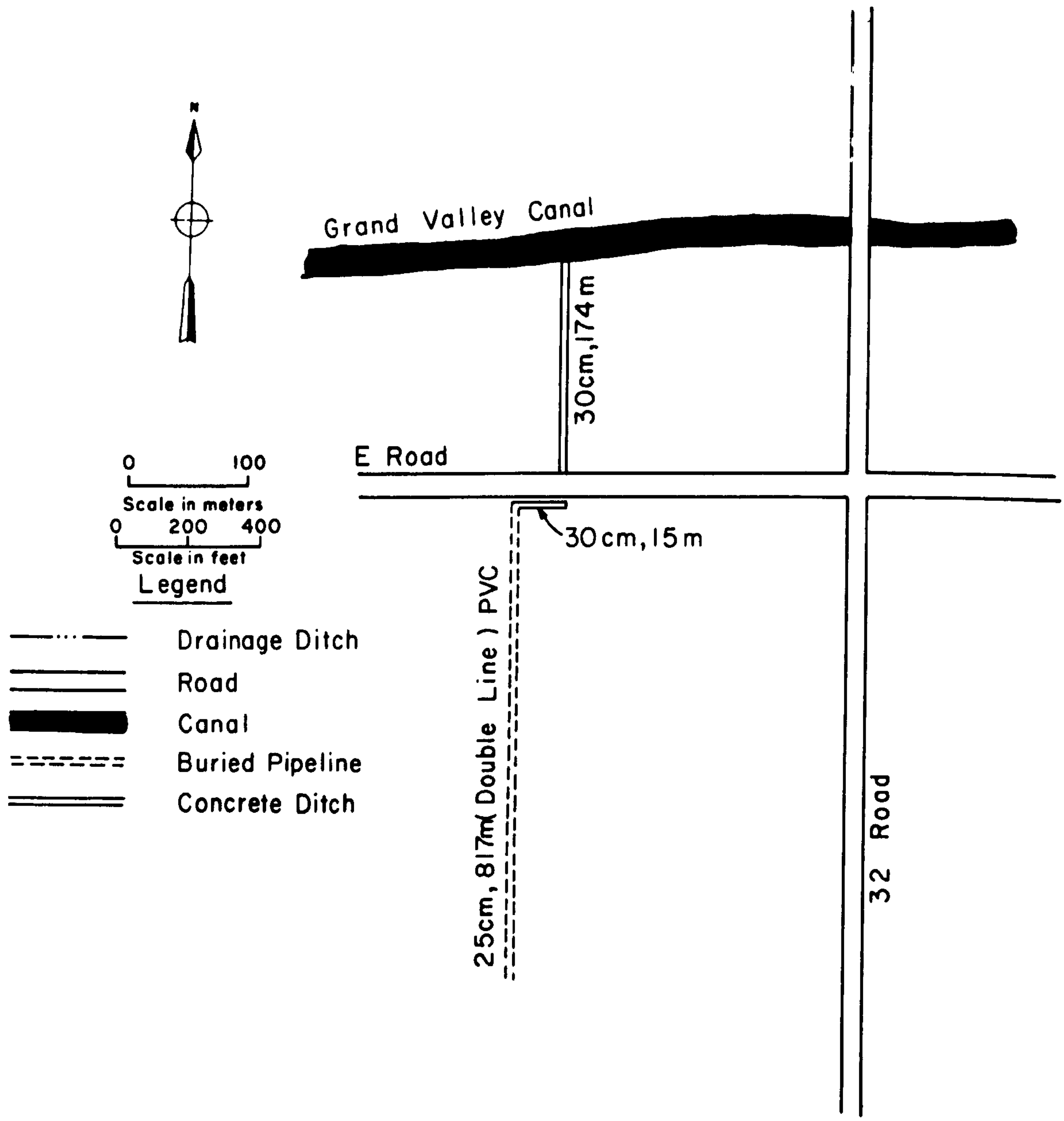


Figure 37. Map of lateral and on-farm improvements under GV 92 lateral system.

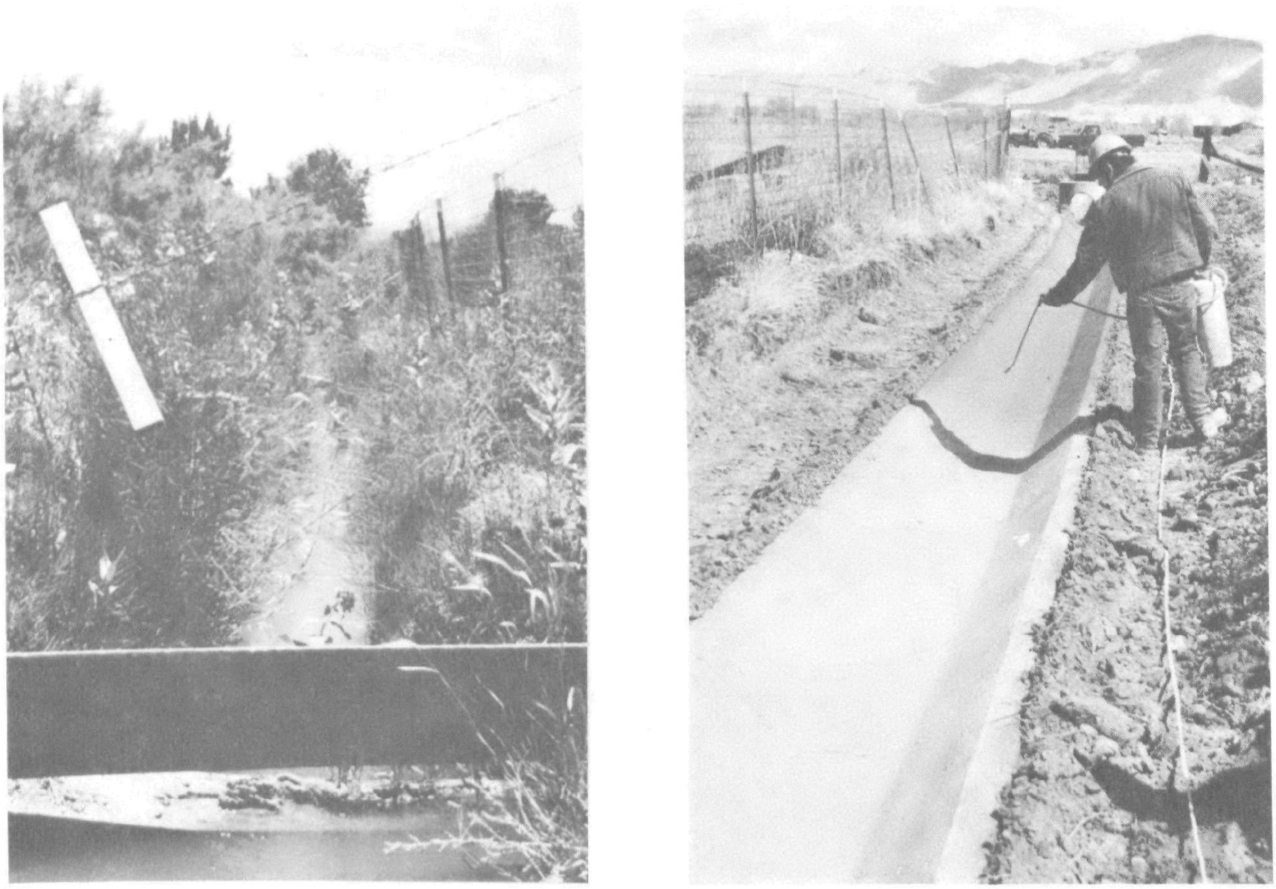


Figure 38. Lateral GV 92 before and after installation of concrete ditch.

construction. Flow measurement is taken by five propeller meters and 18 Cutthroat flumes, one Parshall flume and a 90 degree V-notch weir which make a total of 25 measurement structures.

A total of 583 meters (1910 linear feet) of 15 cm (6-inch) diameter gated pipe is in use on this lateral on 11.7 hectares (28 acres), which required some educational and management instruction on its use and limitations. Six and one-half hectares (16 acres) on the lateral received field drainage installation (2,667 meters of 10 cm polyethylene drainage tile). Another 24.3 hectares (60 acres) received land shaping and leveling treatments, which increased irrigation efficiencies on those fields. However, some soil compaction problems were observed during the first season.

On one 4.05 hectare (10-acre) field, a short (158.5 meter or 520 foot) side-roll sprinkler was installed having an average precipitation rate of 5.72 mm/hr (0.225 in/hr) and a UCL of 86.7 percent, UCC of 89.5 percent and a UCH of 88.8 percent. Water is delivered to a sump via the concrete lined distribution system.

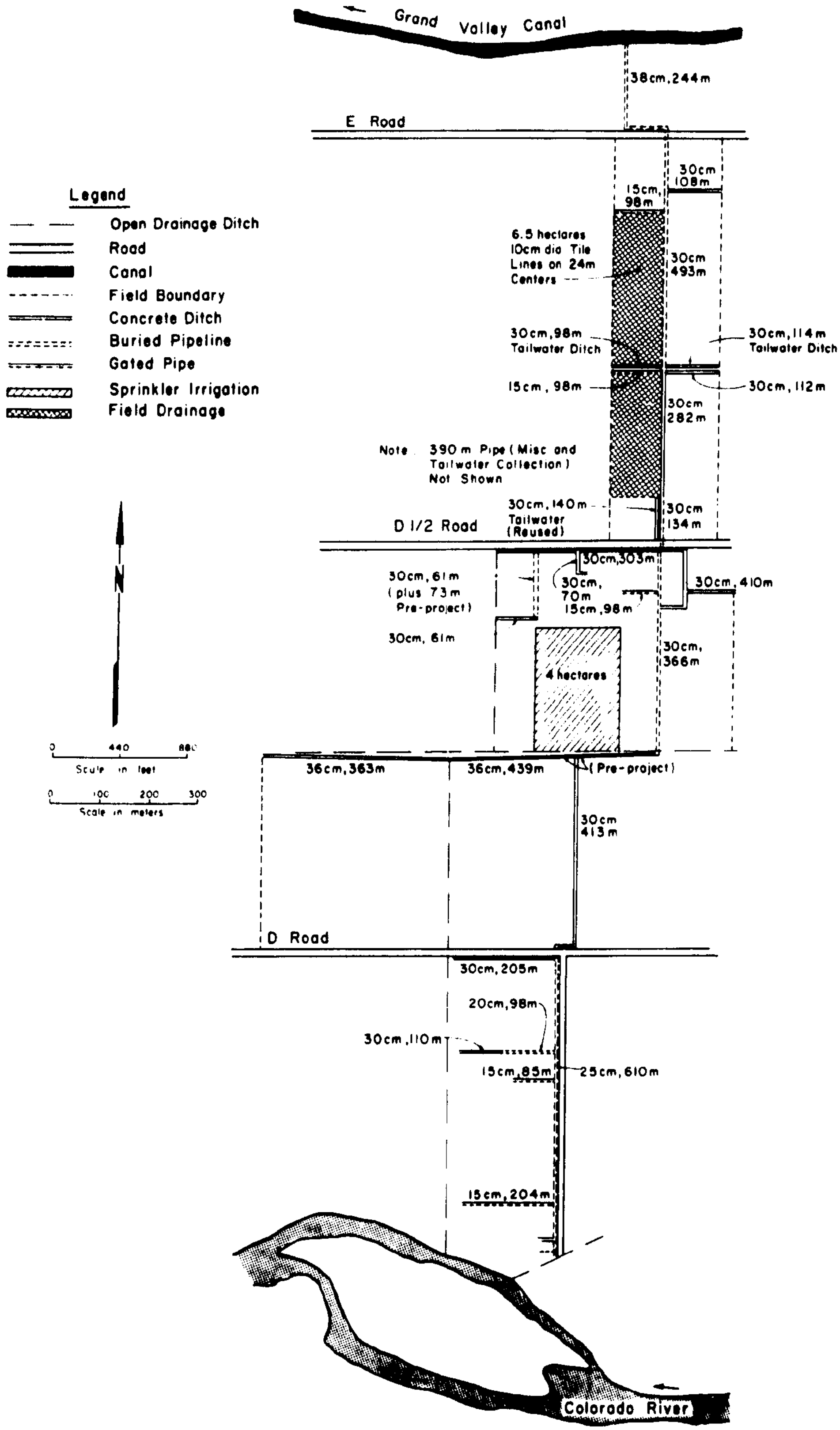
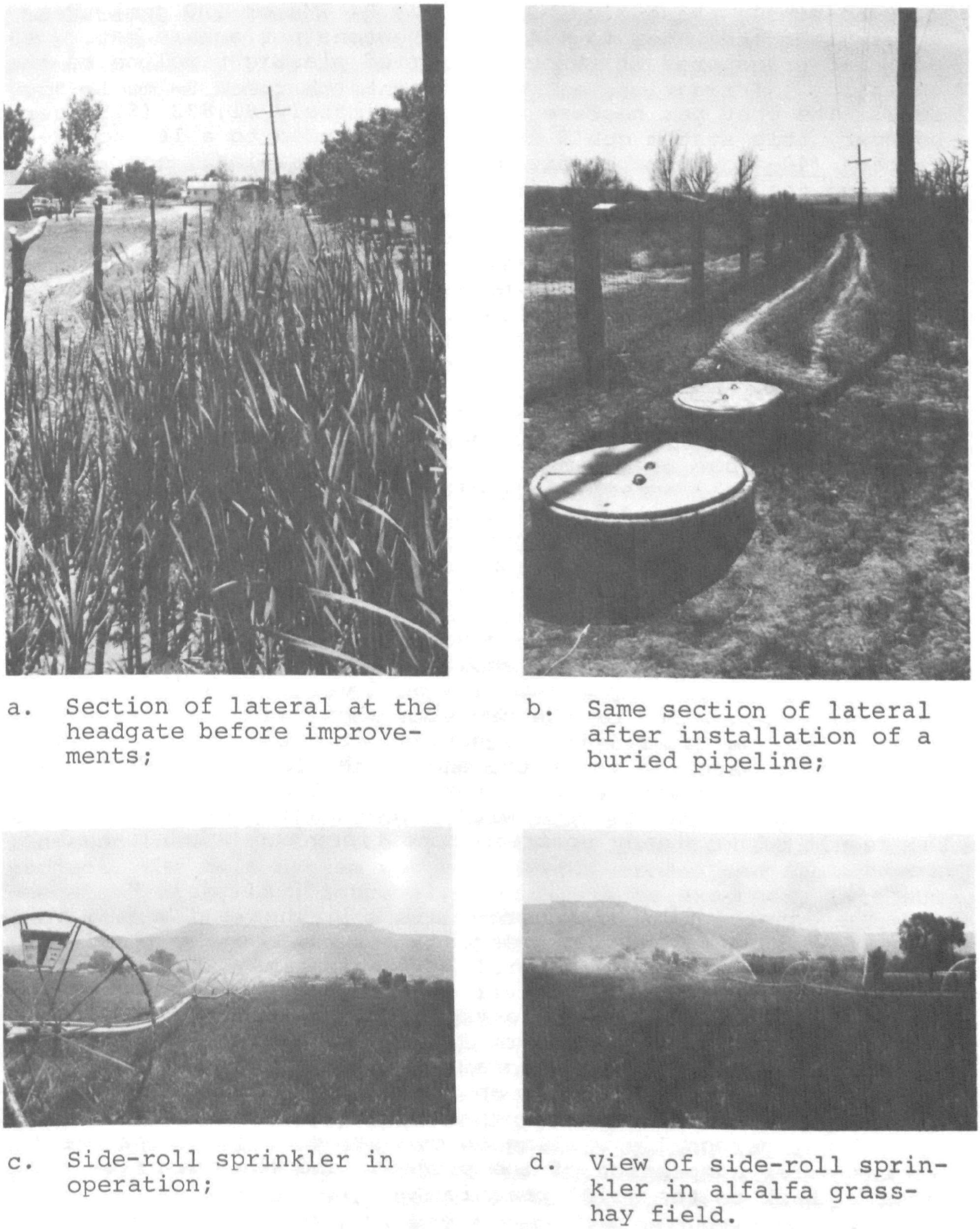


Figure 39. Map of lateral and on-farm improvements under GV 95 lateral system.



a. Section of lateral at the headgate before improvements;

b. Same section of lateral after installation of a buried pipeline;

c. Side-roll sprinkler in operation;

d. View of side-roll sprinkler in alfalfa grass-hay field.

Figure 40. Improvements on Lateral GV 95.

A 10-hp single phase electric pump (6.94 l/s or 110 gpm) then pressurizes the water to 4.4 x 10^5 Newtons per square meter (65 psi) and transports it through a buried plastic pipeline to the sprinkler. Irrigations are divided into thirteen 8- to 12-hour sets. The cost per hectare was approximately $1,872 ($780/acre); however, this system could easily be expanded to a 16- to 25-hectare (40- to 60-acre) field at little additional cost, greatly reducing the unit cost. An electric self-cleaning trash screen (3.2 mm or 1/8 inch mesh), similar to the one shown earlier, was installed at the entrance to the pump sump to minimize sprinkler plugging. This system has worked quite well, and the very pleased owners have stated that the increased yields due to the greater irrigation uniformity have more than paid for the electricity costs. Under the traditional "cut-and-dam" irrigation utilized on this field, changing each set often took at least one hour. Consequently, the sets were often left for 24 hours. Due to the greatly reduced labor requirements (one-half hour maximum/set) the sets are now 8 or 12 hours depending on water requirements rather than labor requirements. This system was installed on 4.05 hectares (10 acres) of alfalfa and grass hay, which was operated under a rigid irrigation scheduling program. There is no field tailwater and deep percolation is very minimal. Seasonal application efficiencies are on the order of 80 percent compared to a historical average of around 40 percent.

Lateral GV 95 is a long (almost 3 kilometers in length) and relatively narrow subsystem, and the speed of water deliveries is, therefore, very important to a good water management program. Prior to construction of the project, when the water was first turned into the lateral in the spring, it often took as long as two days for water to reach the end of the lateral. This slow reaction time was very evident throughout the irrigation season, and an irrigator had to cope with a continually varying flow as the result of nonsteady upstream conditions and aquatic weed growth.

The construction of concrete ditch linings and buried plastic pipelines have had a tremendous influence on the speed of water deliveries in this lateral. At this time, it takes only one hour for the water to travel from the lateral headgate to the end of the system. A fast reaction time is essential in order to provide and to maintain uniform deliveries and to establish an acceptable water rotation program. Project personnel assisted lateral landowners in setting up an agreeable lateral water management program and rotation schedules. However, no one on this lateral was personally willing to oversee the water management program after completion of the project, and the operation has reverted back to the "old" practices.

Reduced lateral seepage was quickly evidenced in several cases on this lateral. These included a lack of water in basements and the ability to cultivate lands immediately adjacent to the lateral which were no longer waterlogged during the entire irrigation season. In addition, several large deeply eroded channels were filled which resulted in more farmable land, safer farming operations, and a much more aesthetically pleasing landscape.

An operational problem encountered on this lateral was to convince the lateral irrigators that the systems were not maintenance free and that a regular program should be established. This was well explained before construction; however, it seems that some people still expected a "miracle" system that required little labor, no maintenance, and was entirely self-regulating.

Lateral GV 160

This is the second largest lateral on which work was done, and it has some of the most difficult salinity problems encountered in the Grand Valley (Figure 41). The land is very saline and agricultural production is quite low. Treatment included the installation of 2,573 meters (8,442 feet) of buried plastic pipeline, installed by persons on the lateral, and 1,898 meters (96,229 feet) of lined concrete ditch. In addition, 11.5 hectares (28.5 acres) received field drainage.

There are 27 measurement devices on this lateral to assist in the distribution of water. There were no on-farm improvements made other than the field drainage. The irrigators on the lateral did all the pipeline installation and met matching requirements on the concrete ditch linings. The landowner response was very good. In fact, one landowner with no shares of water worked very hard on the pipeline installation.

Maintenance requirements have been very low since the pipeline was installed for the main delivery system. Prior to the project, the main system was very deeply eroded and choked with weeds and cattails (Figure 42). As would be expected, late summer water delivery to the irrigated lands was less than one-half the diversion at the headgate, and maintenance was frequent and difficult.

Prior to construction of improvements under this project, Lateral GV 160 and Lateral GV 161 paralleled each other from their headgates for almost 1 kilometer without any water deliveries, and yet the two laterals were not more than 3 meters apart. As part of the project, these two laterals were consolidated into one buried plastic pipeline. Since this portion of the line is used only for delivery, and no water is diverted for irrigation (although provisions were made at two locations to accept wastewater into the system), it has a very low maintenance requirement because of being self-flushing. Historically, this section was a very high maintenance area with very high water losses. The ditches were about 2 meters deep at places and overgrown with

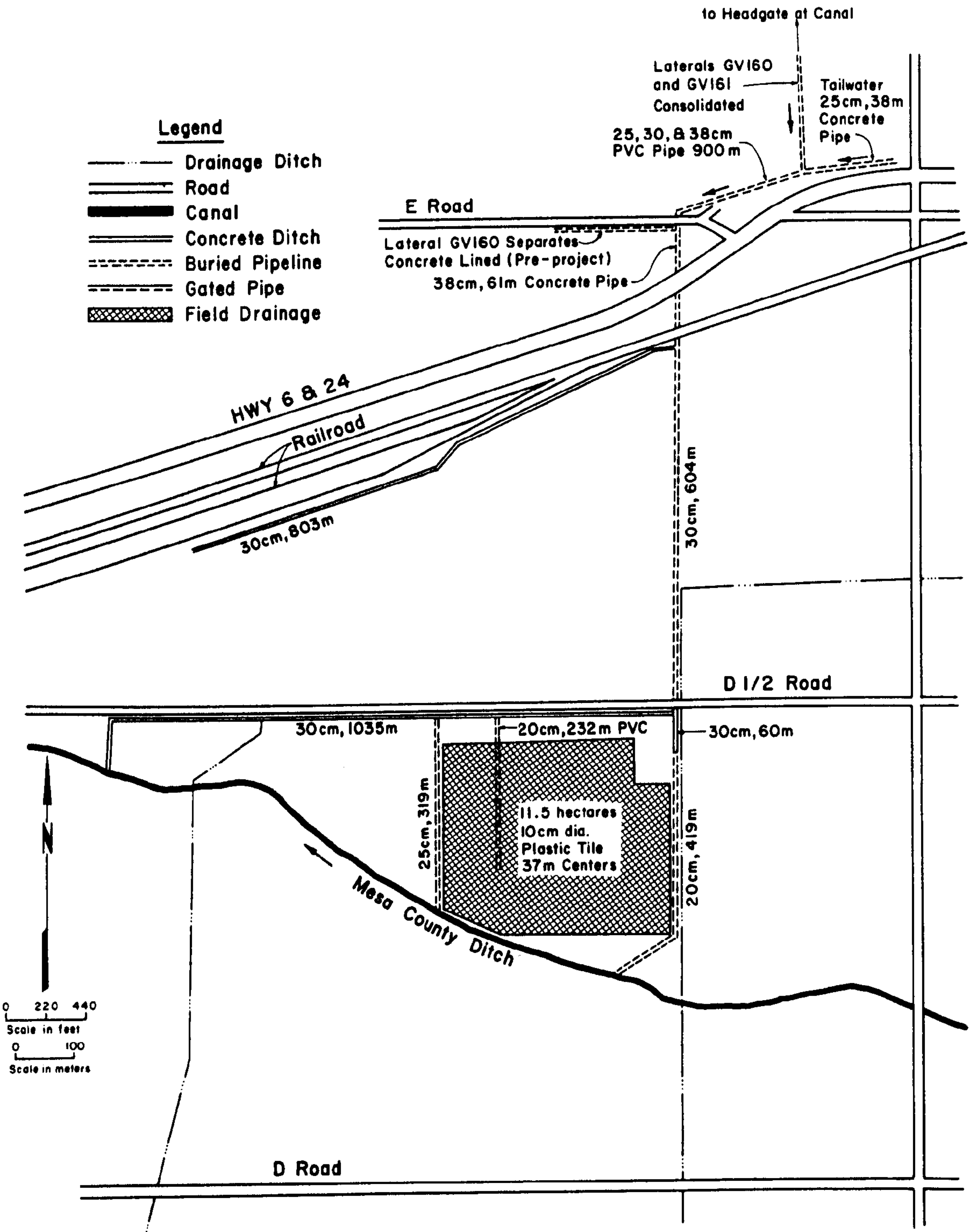
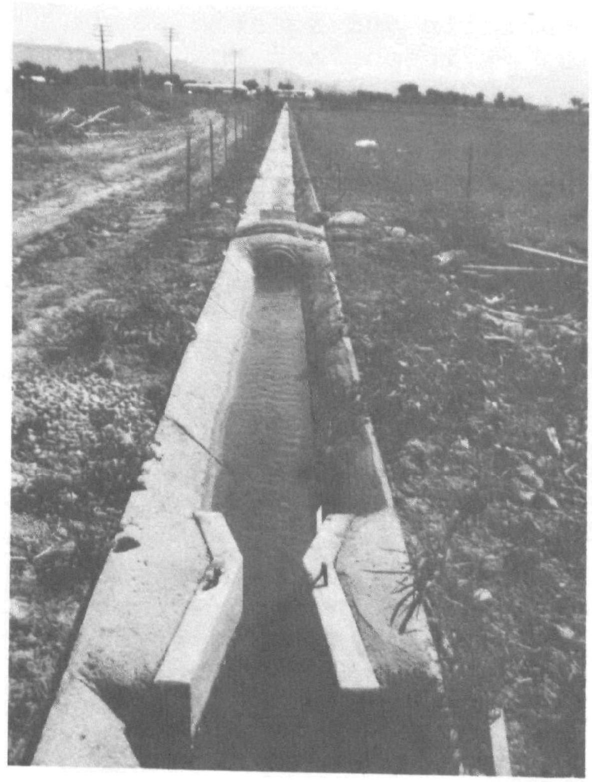
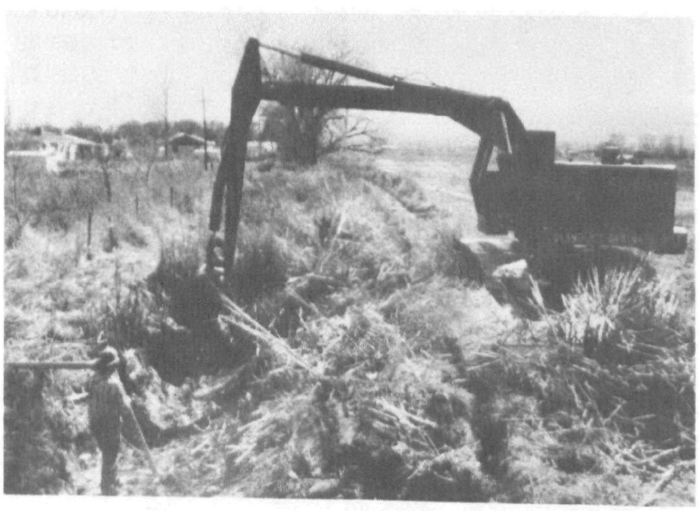


Figure 41. Map of lateral and on-farm improvements under GV 160 lateral system.

a. A farm delivery structure before improvements;



b. Farm delivery after construction with flow measurement structure;



c. Cooperators installing pipeline which consolidated two laterals into one.

Figure 42. Improvements on Lateral GV 160.

cattails and aquatic weeds. These laterals passed through a subdivision, and the buried pipeline has minimized trash problems, alleviated many health and safety hazards associated with children playing in the area, and increased land values in the area because of the more aesthetic appearance.

As part of the experimental design, it was decided that this lateral would receive only a good delivery system comprised of concrete ditch lining and buried plastic pipelines, some field drainage works, and a network of flow measurement devices. Thereafter, the water users would receive no instruction or irrigation scheduling and/or suggested water management practices. However, the resulting irrigations and practices were carefully monitored by project personnel. As expected, the vastly improved delivery system did cause a remarkable increase in irrigation activity on this lateral and did result in better water management practices. Much water was still wasted as the excesses were simply dumped into drains. The headgate was not adjusted throughout the season. Several acres of previously idle lands were replanted and irrigated, some for the first time in twenty years. The recovery of water previously lost to seepage apparently made up the difference of water needed to irrigate these "new" lands as no conflicts developed. Headgate diversions were actually slightly less than historical.

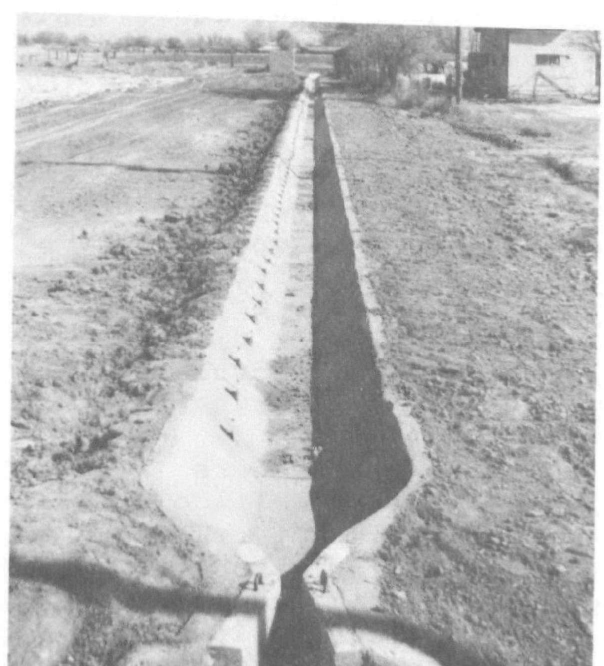
Lateral MC3

This lateral is quite small (3.7 ha) but is one example of the most saline land which could be found in the Grand Valley. In the early 1900's, this farm was a very productive pear orchard; however, since the construction of the Government Highline Canal, a high water table caused by over-irrigation on higher lands and seepage from the Mesa County Ditch has completely put this land out of production (Figure 43). The soil salinity is high and contains large amounts of sodium salts or "black alkali" (sodium adsorption ratio of the first foot of soil is in excess of 50). This lateral was selected in order to demonstrate the possible reclamation of highly saline agricultural lands.

Previously, the Mesa County Ditch, which runs across the upper boundary of this farm, was lined with gunite as part of the canal lining investigation. The first step towards reclamation of the lateral was to install field drainage to alleviate the high water table and provide a mechanism to leach the salts from the soil. The drains were constructed on a 12.2 meter (40-foot) spacing on 2.5 hectares (6.3 acres) with 1,958 meters of 10 cm diameter tile (6,425 feet). The tile was installed by the Grand Junction Drainage District.

The second step was to install a type of irrigation which could apply light, frequent irrigation which would force the salts to move down in the soil profile. One type of irrigation

a. Photograph of field in MC 3 showing the extreme salinity problem; and



b. Installation of cut-back irrigation system with measurement structure for spillage and leakage.

Figure 43. Improvements on Lateral MC 3.

which satisfies these criteria is automated cut-back furrow irrigation. This type of irrigation can apply light amounts of water frequently and facilitate very high efficiencies. An automated cut-back system was installed on this lateral (157 meters - 514 feet of concrete ditch).

Due to the extremely saline conditions, progress toward reclamation has been slow and a return to full production is expected to take several years. Water passing through the soil profile and reaching the drainage pipe has shown that the system is working as designed, and the land will eventually become productive. A summary of improvements under this lateral is illustrated in Figure 44.

Lateral MC 10

This lateral is the third largest, consisting of 54 hectares (133.4 acres) and had a good water rotation program developed prior to the project, because this lateral is one of the few in the Valley which has always been somewhat "water short." This same rotation is still in use, but has been greatly facilitated by the constructed improvements.

The users on the lateral installed all the buried plastic pipelines (1,054 meters or 3,040 feet) and have paid the matching requirement for the lateral linings (2,723 meters or 8,935 feet). Figures 45 and 46 depict the array of improvements incorporated in this lateral improvement plan. In addition, 11.3 hectares (28 acres) of productive land received land leveling treatment. Several acres of previously idle land were put back into production by the clearing of phreatophytic trees, shrubs, and land leveling. The land leveling consolidated several smaller fields into one, resulting in more efficient irrigations and more efficient farming operations. The Grand Junction Drainage District installed 4,958 meters of 10 cm diameter (16,265 feet of 4-inch diameter) polyethylene plastic drainage tile for field drainage on 6.1 hectares (15 acres) under this lateral.

Five hundred sixty-four meters (1,850 feet) of 15 cm and 20 cm (6-inch and 8-inch) gated pipe were installed on 6.7 hectares (16 acres) under this lateral, and the use of such pipe was well received by the irrigators. One farmer remarked that he did not know how he irrigated before he got his pipe. A big advantage of gated pipe is that it can be easily removed for tillage, harvesting or other farming operations, and then quickly replaced.

An automated cut-back irrigation system (Figure 47) was installed on 4.05 hectares (10 acres) of barley, which was also included as part of the field drainage construction on this lateral. It should be mentioned that even though the cut-back irrigation systems have been installed only on problem areas in

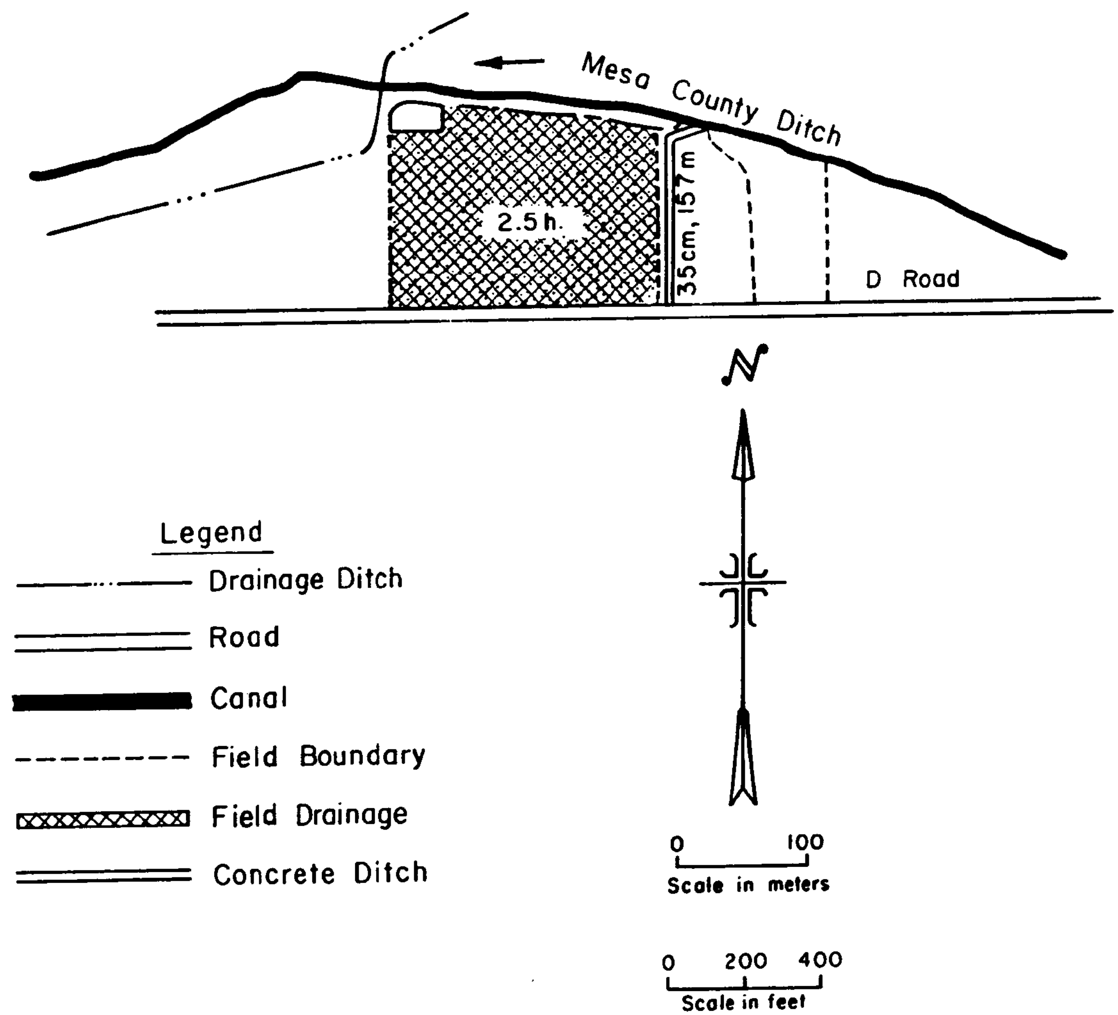


Figure 44. Map of lateral and on-farm improvements under MC 3 lateral system.

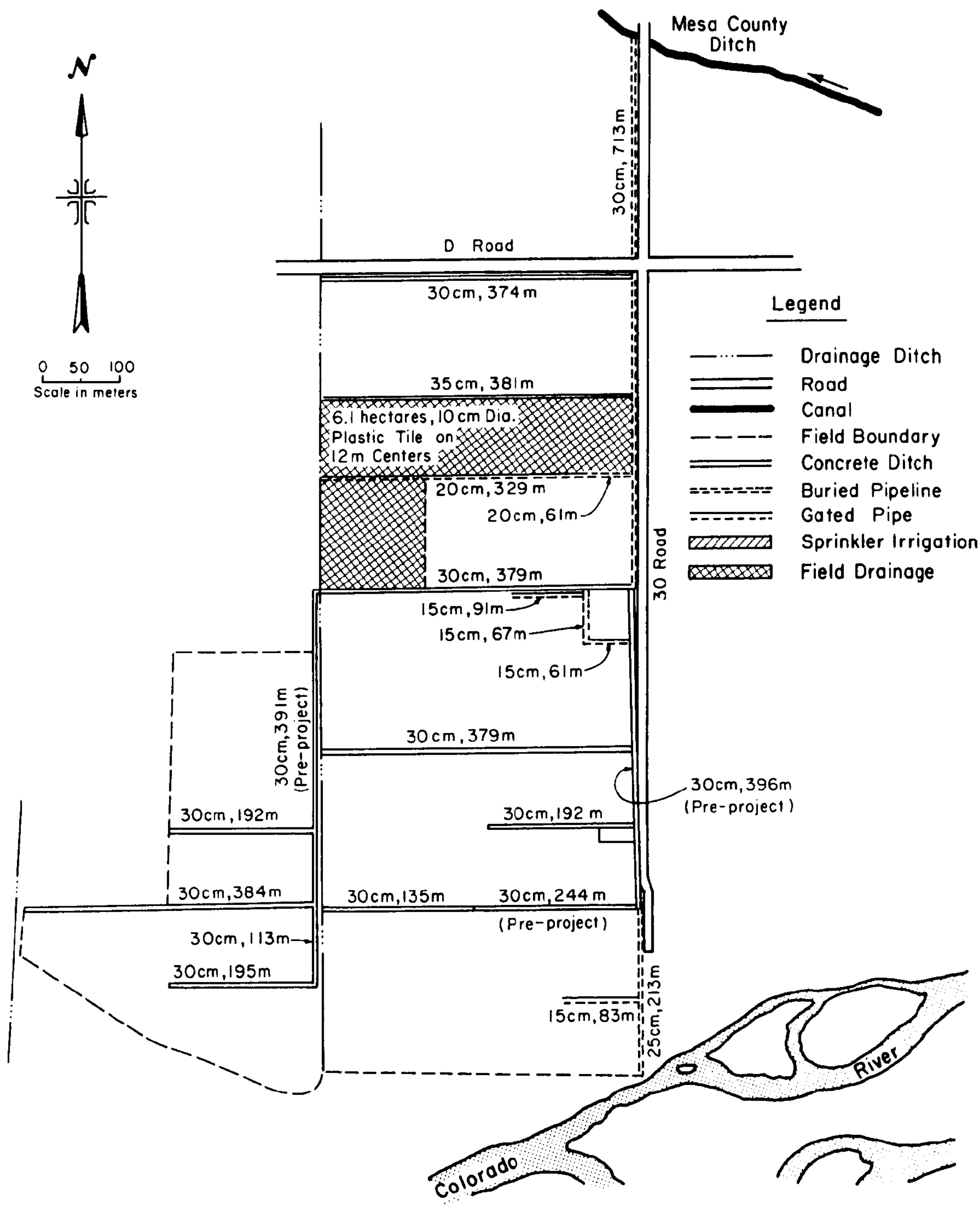
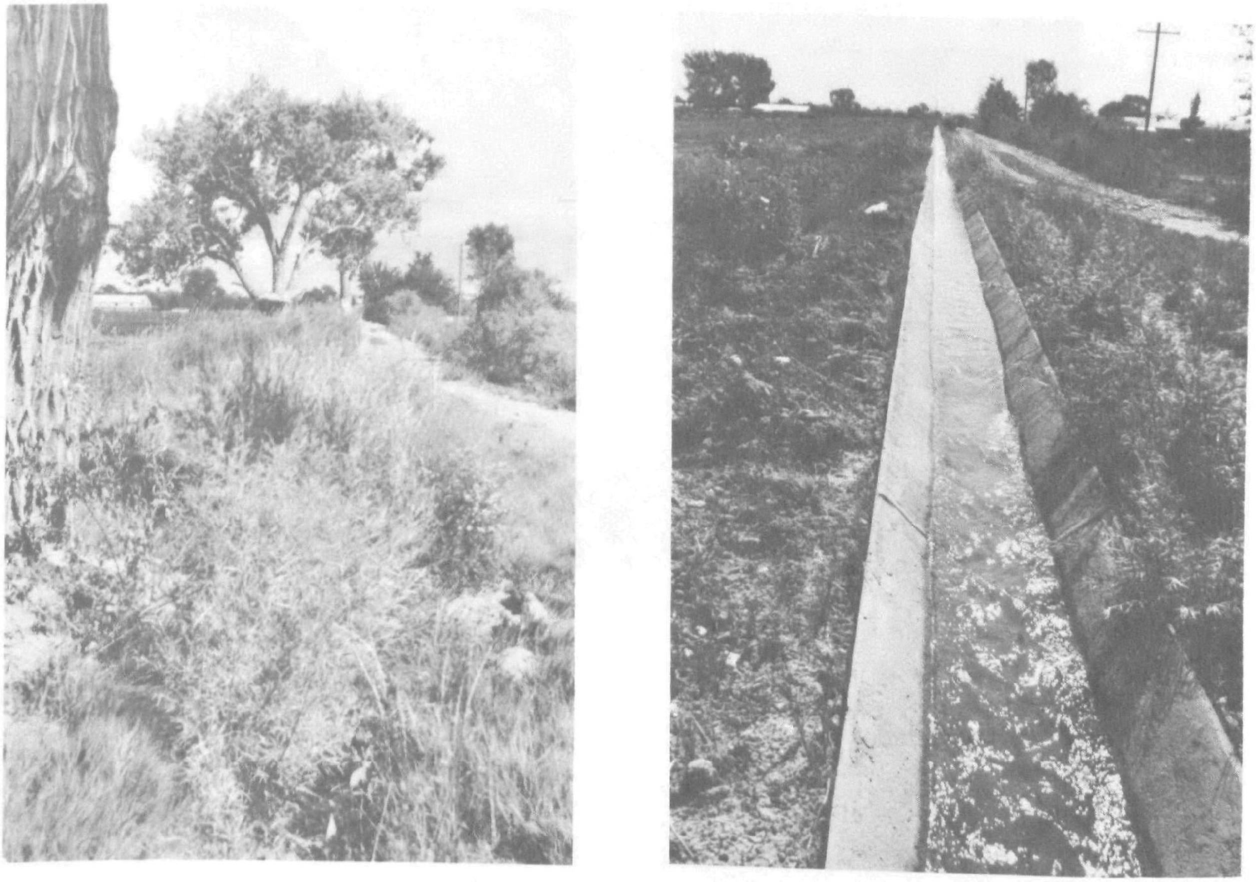


Figure 45. Map of lateral and on-farm improvements under MC 10 lateral system.



a. Section of lateral prior to lining.

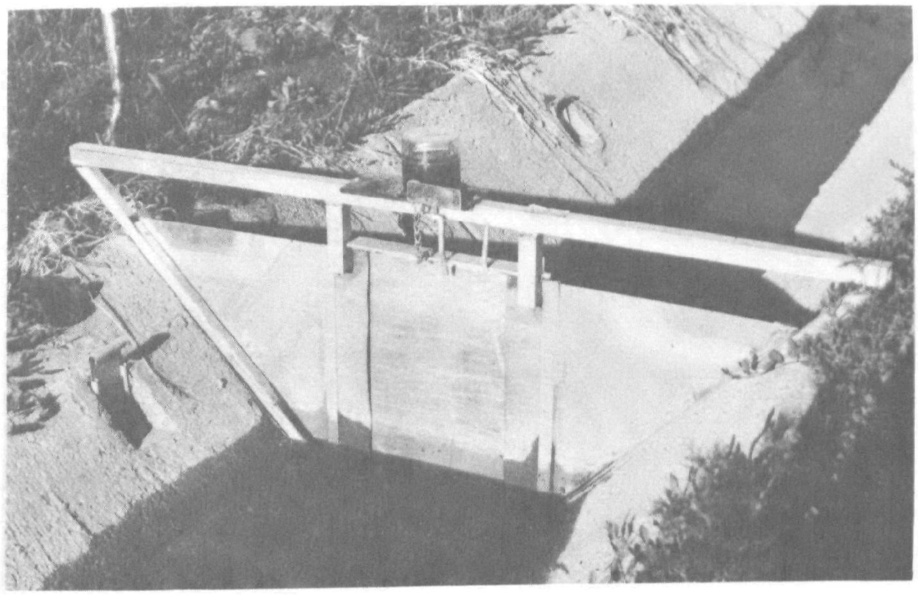
b. Same section of lateral after construction of linings (large trees were removed).

Figure 46. Improvements before and after on a section of Lateral MC 10.

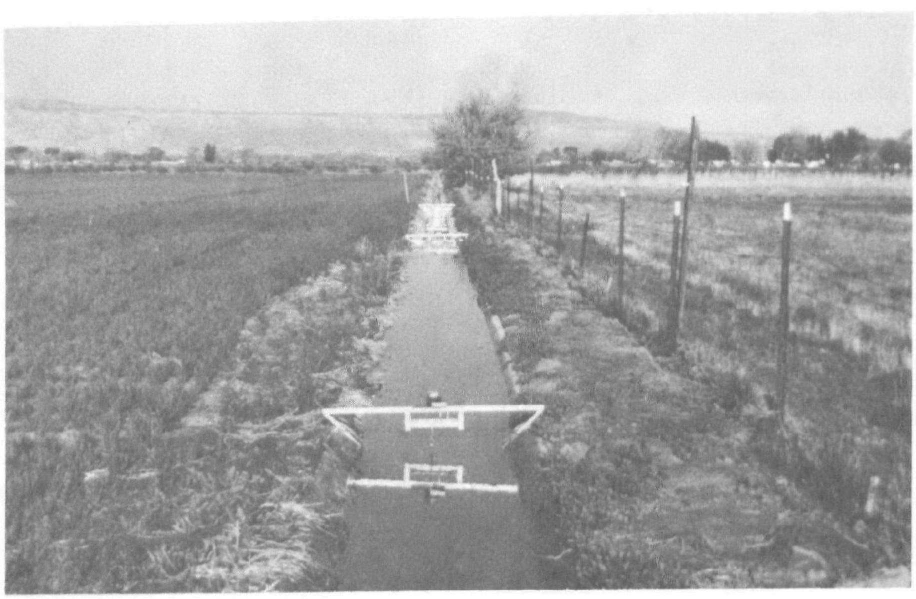
this project, it is also highly recommended for good, high production fields. This farm has experienced very remarkable improvements in crop yields in the past two years. The concept of cut-back irrigation with level bays was very novel to this farmer, and to others in the Valley, and he now supports this concept.

At this time, there are 18 flow measurement devices on this lateral. These irrigators have been quite willing to use flow measurement in their irrigation because they recognize its value as a direct result of their previously developed mutual water sharing program.

The several acres of idle land which were leveled and/or cleared of phreatophytes, planted, and irrigated increased the demand for water. This resulted in changes in the fairly rigid water rotation practices and required a larger degree of



a. Close-up view of the automatic gate developed as part of this project; and



b. The cut-back system in operation.

Figure 47. Improvements on Lateral MC 10.

cooperation between irrigators. Project personnel worked closely with the landowners to avoid any conflicts.

Water users served by this lateral were the most cooperative group and were the most willing to change existing water management practices. This was largely due to the existence of a pre-project water rotation system which worked quite well.

These farmers installed the main delivery system (buried plastic pipeline) and had a very good understanding of the system operation and required maintenance. With little urging they adopted a regular maintenance program and followed recommended irrigation schedules. The concrete ditches and flow measurement network was very beneficial in following recommended water management practices, and the easy-to-read flow measurement gauges provided a large degree of confidence in the procedures.

Lateral MC 30

This one-landowner lateral was part of the earlier study on field drainage and contains 3,353 meters (11,000 feet) of plastic drainage tile on 2.4 hectares (10 acres). Further improvements on this lateral included 1,040 meters (3,411 feet) of concrete lining, 195 meters (640 feet) of 20 cm (8-inch) diameter buried plastic piepline and 122 meters (400 feet) of 15 cm (6-inch) diameter gated pipe. There are five flow measurement structures on this lateral. This lateral and the improvements are presented in Figure 48. Figure 49 illustrates before and after construction effects on this lateral.

The large alfalfa field on the west side of the lateral previously had very long runs (almost 400 meters) and also had a slight hill in the center of the field causing the irrigation water to pond in the top half and rapidly run off on the bottom half. To minimize this uniformity problem, the field was broken into two runs using gated pipe. The gated pipe lies on top of the aforementioned hill, and the 122 meter line is moved from one side to the other side of the field during the irrigation. Use of gated pipe was called for in this case since a concrete ditch would greatly interfere with the efficiency of harvesting operations. The gated pipe could be quickly and easily moved out of the way. Besides greatly increasing the irrigation efficiency, the grower has noticed a marked increase in crop production.

The eastern field of this lateral was the recipient of 3,353 meters of 10 cm plastic tile installed during the 1973 drainage investigation. At that time, the sodic soils were very nonproductive and vegetation was sparse. At this time it is estimated that this field could be planted in 1979 to a cash value crop such as barley with very good results. Many local growers have

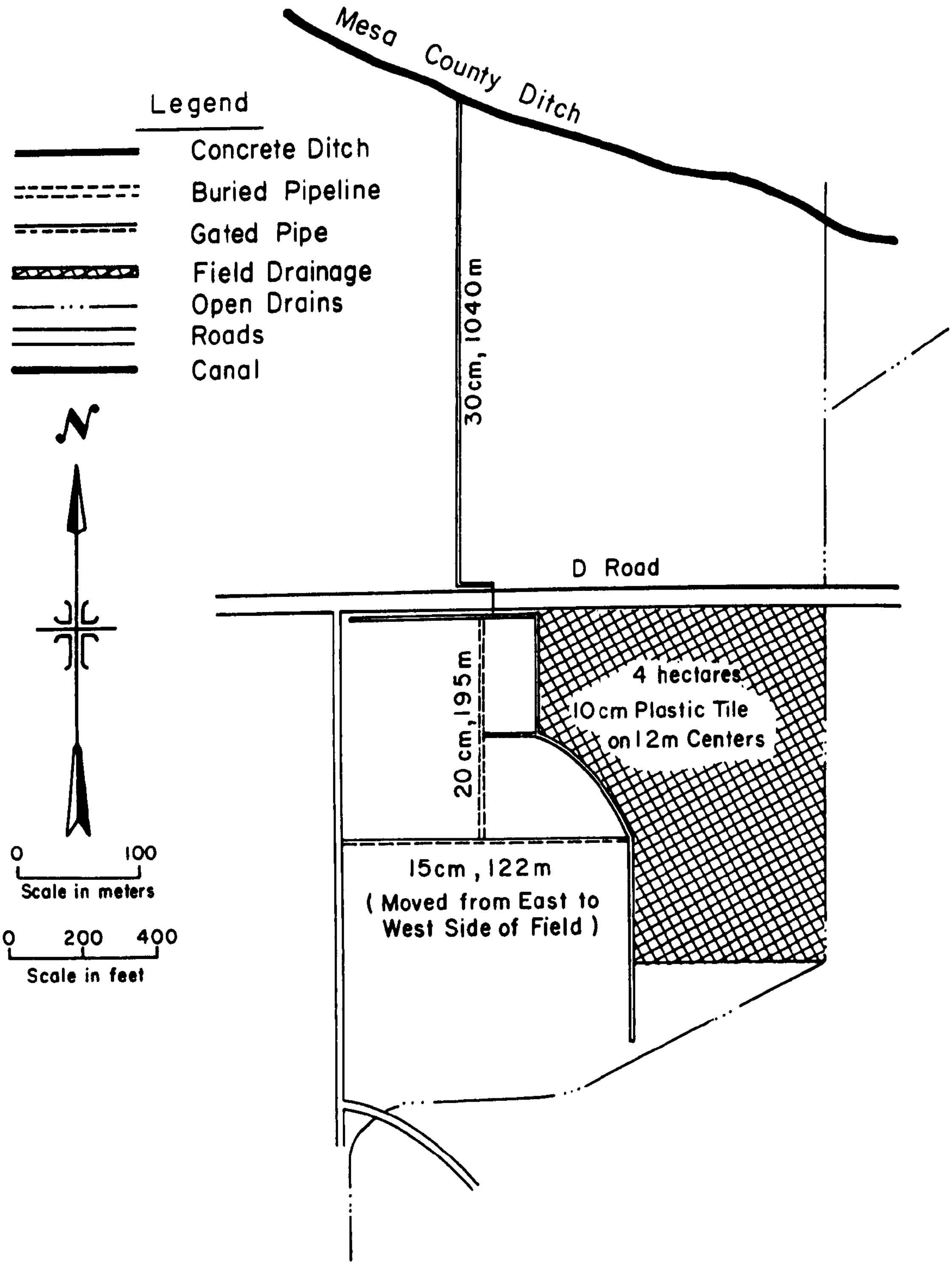
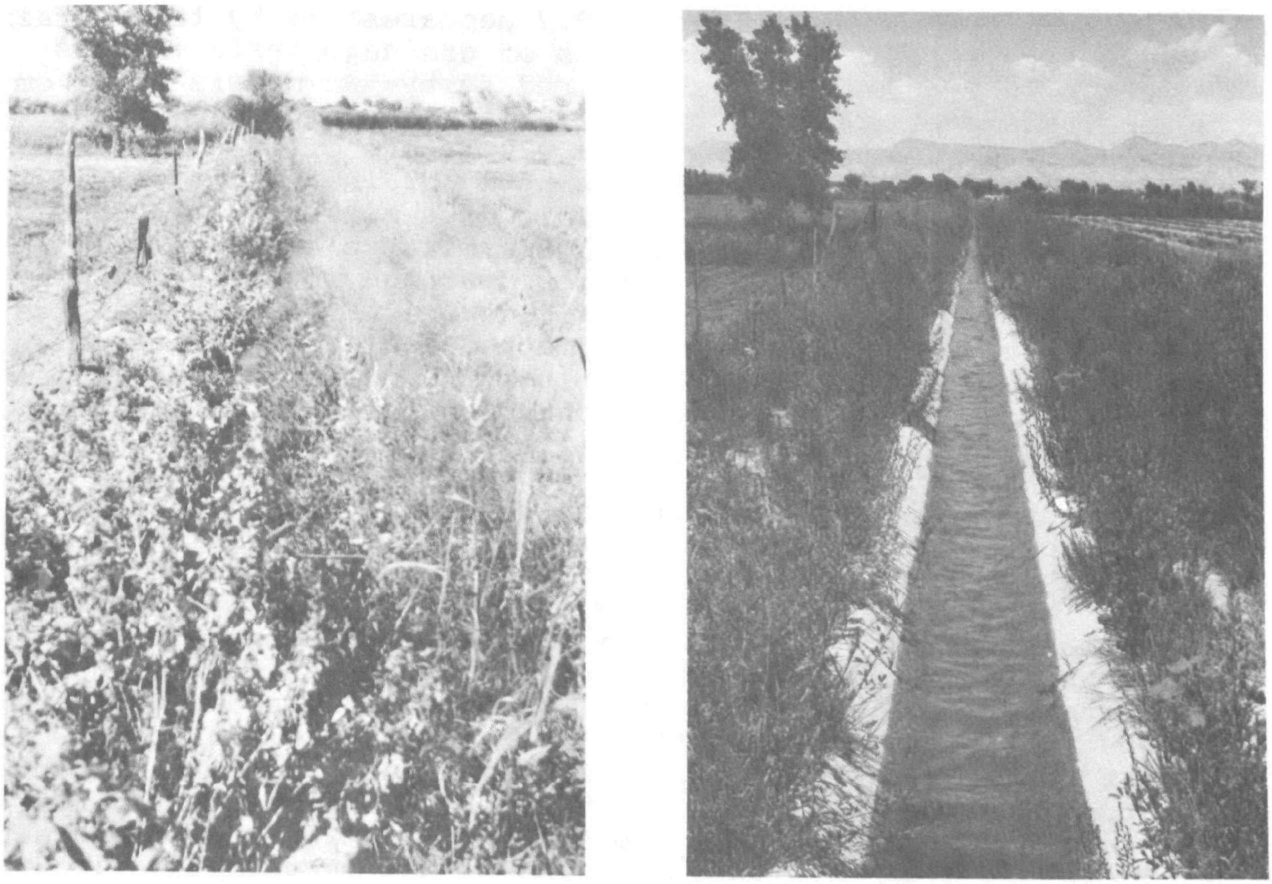


Figure 48. Map of lateral and on-farm improvements under MC 30 lateral system.



a. Section of lateral prior to construction of improvements.

b. Same section of lateral after construction.

Figure 49. Improvements on Lateral MC 30.

commented on the very noticeable change in crop quality as evidence of the successful reclamation due to the field drainage.

The installation of the concrete lining greatly reduced the maintenance requirements for the main delivery system which historically was very demanding. Prior to the project, late season flows at the field were often about one-half of the initial season deliveries due to a large population of willows and other phreatophytic growth. The concrete linings and gated pipe irrigation system greatly reduced the labor for changing individual irrigation sets.

Drainage

Field drainage for relief of localized waterlogging problems was analyzed on the basis of past drainage studies in the Grand Valley and was diagnosed by the installation of observation wells in several areas. A total of 36.8 hectares received drainage either by interceptor drainage (10.2 hectares) or by field drainage (26.6 hectares). The locations of drainage installations are shown in Figure 50. Four hundred forty-two meters of 20 cm (8-inch) diameter concrete tile were installed for use in the interceptor drains. A total of 13,079 meters of 10 cm (4-inch) diameter corrugated polyethylene plastic drainage tile was installed for the field drainage. This does not include 3,353 meters of 10 cm (4-inch) diameter of similar plastic tile installed on 4 hectares in the earlier drainage investigation in the demonstration area. All the fields which received drainage improvements were topographically mapped and had a series of observation wells installed to monitor the effectiveness. Effluent outflows and the wells were monitored for chemical quality and quantity as well as groundwater elevations.

All drainage works were installed by the Grand Junction Drainage District. The project furnished all materials for construction, and they provided all the equipment and labor necessary for the installation, consistent with their standing policy arrangement for this type of work. The work performed by the Grand Junction Drainage District more than satisfied the 30 percent matching requirements. The interceptor drains were concrete tile because they were installed in areas where plant roots would present problems, and the maintenance machinery used to correct this problem by the Grand Junction Drainage District would not work in a plastic tile. The typical installation of field drainage is illustrated in Figure 51. The actual installation is depicted in Figure 52.

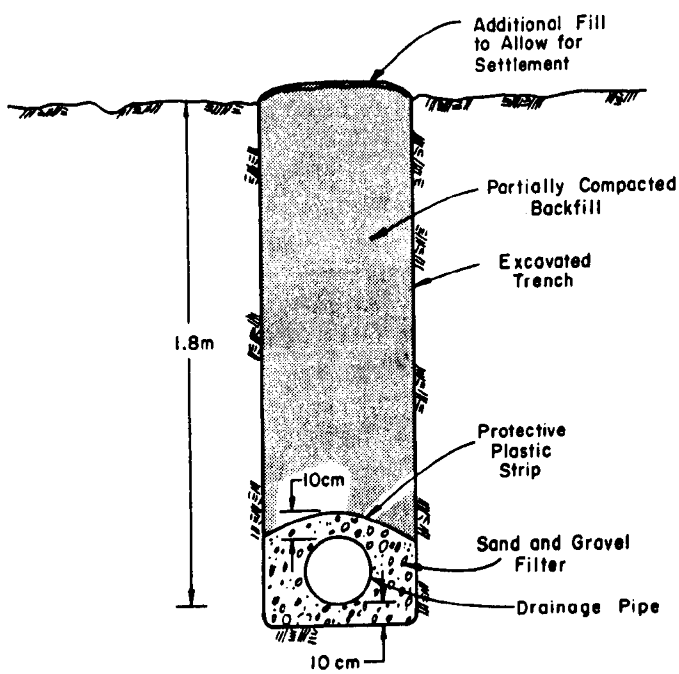


Figure 51. Typical installation of field drainage in the demonstration area.

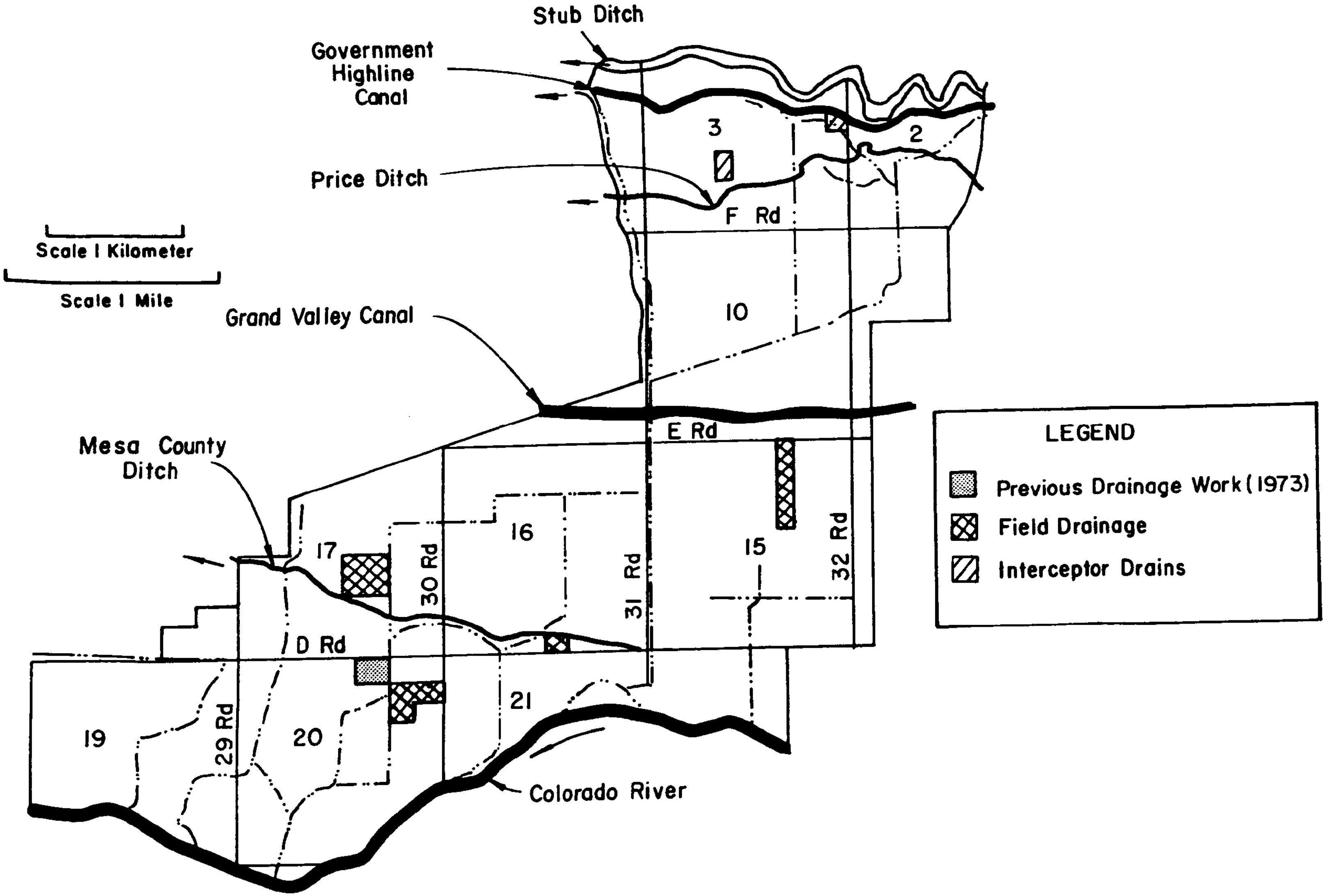
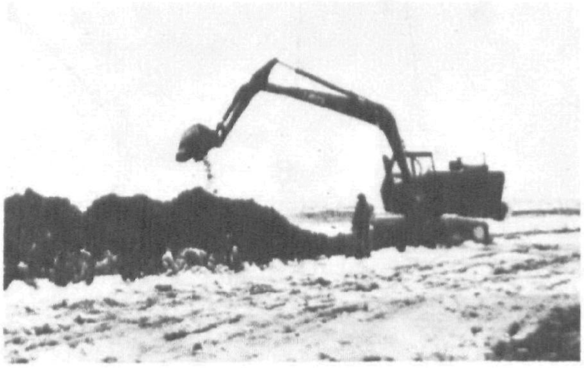


Figure 50. Location of drainage installations in the Grand Valley Salinity Control Demonstration Area.

a. Installation of field drainage on Lateral GV 95;

b. Tile placement in trench before final envelope;

c. Tile placement on Lateral MC 10;



d. Installation of drainage on Lateral MC 3.

Figure 52. Relief drainage installation in the Grand Valley.

SUMMARY OF IMPROVEMENTS AND COSTS

The total value of the lateral improvements for the project is $378,324.51, installed on 330.7 hectares for an average cost of $1,144.01 per hectare. The amount spent in project funds was $241,984.00 and the value of the participant matching was $136,340.51. A summary of the lateral improvements is presented in Table 15. The costs of the individual improvements are presented by lateral and are summarized in Table 16.

Under the terms of the project grant, as discussed in Section 6, the construction was to be cost shared on a 70 percent (project) - 30 percent (local participant) arrangement. The required matching on $241,984.00 was $103,626.17. All the project funds available for construction were stretched to the limit in order to maximize the number of improvements.

An illustrative summary of all the applied research on salinity control of irrigation return flows in the Grand Valley of Colorado is presented in Figure 53. The total improvements completed in the project area since 1969 as part of the demonstration of salinity control include: 12.2 km (7.6 miles) of large canal linings, 16,432 meters (53,913 feet) of perforated field drainage tile, construction of a wide variety of on-farm improvements, and an irrigation scheduling program. The costs of the various improvements, which totaled almost $750,000, are listed in Table 17. The total combined improvements removed almost 12,300 metric tons of salt per year. The resulting "average" cost-effectiveness is $60.48 per metric tons of salt removed. The resulting benefit-cost ratio based on downstream damages of $150 per metric ton is 2.50.

TABLE 15. SUMMARY OF PROJECT IMPROVEMENTS ON THE LATERAL SUBSYSTEMS

Types of Improvements [6]	HL C (13.1 h)	HL E (35.9 h)	PD 177 (27.8 h)	GV 92 (24.3 h)	GV 95 (79.1 h)	GV 160 (78.7 h)	MC 3 (3.7 h)	MC 10 (54.0 h)	MC 30 (14.1 h)	TOTAL (330.7 h)
Concrete Ditches (m)		[1]	230 [1]	189	2,789	1,189	157	2,723 [1]	1,040	9,026
Buried Plastic Pipelines										
Gravity systems (m)		786	2,051	817	2,312	2,573 [5]		1,054	195	9,788
Pressurized systems (m)		3,274			378					3,652
Gated Pipe (m)			207		583			564	122	1,476
Drip Irrigation (h)			2.2							2.2
Overhead Sprinklers (h)		5.2								5.2
Sideroll Sprinklers (h)					4.0					4.0
Drainage Works (h)	2.2 [4]	8.0 [4]			6.5	11.5	2.5	6.1	2	36.8
Plastic Drainage Tile (m)					2,667	3,496	1,958	4,958		13,079
Concrete Drainage Tile (m)	244	198								442
Flow Measurement (No.)	(3)	(4)	(14)	(3)	(25)	(27)	(3)	(18)	(5)	(102 TOTAL) [7]
Cutthroat Flumes (No.)		2	3	2	18	26	2	14	3	70
90° V-Notch Weirs (No.)	1		1		1					3
Parshall Flumes [3] (No.)	2		3		1			2	2	10
12" Propellor Meters (No.)			1		1			1		3
10" Propellor Meters (No.)			1		2	1				4
8" Propellor Meters (No.)		1	3		1			1		6
Other Meters (No.)		1	2		1					4
Metering Headgates (No.)				1			1			2
Debris Removal Equipment (No.)		1	1		1					3
Land Shaping, etc. (h)					24.3			11.3		35.6
Irrigated Hectares (Possible)	11.5	34.2	21.3	10.4	69.8	51.4	3.0	44.2	13.8	259.6
Total Value ($)	$ 4,857.92	$30,758.33	$43,973.43	$13,600.56	$104,788.80	$84,675.90	$18,440.73	$68,543.81	$8,685.03	$378,324.51
Value/Hectare ($)	$ 370.83	856.78	1,581.78	557.69	1,324.76	1,075.93	4,983.98	1,269.33	615.96	$ 1,144.01
Value/Irrigated Hectare ($)	$ 422.43	899.37	1,937.16	666.69	1,501.27	1,582.73	6,146.91	1,550.76	629.35	$ 1,457.34

1 These laterals were part of the earlier canal and lateral lining study and contain approximately an additional 1390 meters of concrete ditches and 390 meters of concrete pipe not included above.
2 This lateral was part of a previous drainage study and contains an additional 3353 meters of plastic drainage tile on 4 hectares not included above.
3 These flumes were removed at the end of the project since they measured field runoff.
4 Interceptor drains, concrete tile. HL C tiled a large open drain, HL E is a new drain.
5 Includes 99 meters of 25 and 38 cm diameter concrete pipe.
6 m = meters, h = hectares, No. = number.
7 This total flow measurement count does not include the flow measurement structures used in monitoring the hydrology for the whole demonstration area.

TABLE 16. COST SUMMARY OF PROJECT IMPROVEMENTS ON THE LATERAL SUBSYSTEMS

Improvements [1] (Materials + Installation)	HL C	HL E	PD 177	GV 92	GV 95	GV 160	MC 3	MC 10	MC 30	Total Costs
Concrete Ditches			$ 1,281.00	$ 2,755.00	$15,785.00	$10,892.00	$ 2,153.50	$15,844.78	$5,628.15	$54,339.43
Misc. Concrete Ditch Structure	$ 113.60	$ 40.00	335.00	279.50	2,329.24	4,215.00	327.50	4,001.87	840.00	12,481.71
Buried Plastic Pipelines		2,358.05	16,010.21	66.34	23,066.14	17,125.30		9,281.40	740.00	68,647.44
Gated Pipe and Accessories			1,408.36		4,300.95			4,432.51	875.24	11,017.06
Drip Irrigation [4]			8,513.47							8,513.47
Overhead Sprinklers [2]		15,905.87								15,905.87
Sideroll Sprinklers [2]					5,597.02					5,597.02
Plastic Drainage Tile		217.00			15,262.02	19,798.40	8,747.66	17,757.00		61,782.08
Concrete Drainage Tile	2,290.41									2,290.41
Pre-cast Cutthroat Flumes [5]		96.56	144.84	96.56	869.04	1,255.28	96.56	675.92	144.84	3,379.60
V-notch weirs	117.31		193.88		186.00					497.19
12" propeller meter			436.46		436.46			436.46		1,309.38
10" propeller meter			396.41		792.82	396.41				1,585.64
8" propeller meters		362.21	1,142.63		362.21			362.21		2,229.26
Other meters		475.64	1,442.55		267.02					2,185.21
Metering headgates				346.18			314.85			661.03
Debris Removal Equipment		399.35	409.00		385.00					1,193.35
Misc. (Cut-back gates)							598.86	787.86		1,386.72
TOTAL PROJECT COSTS [1]	$ 2,521.32	$19,854.68	$31,713.81	$ 3,543.58	$69,638.92	$53,682.39	$12,238.93	$53,580.01	$ 8,228.23	$255,001.87
MATCHING - NON-MONETARY [3]	2,336.60	10,903.65	12,259.62	10,056.98	35,149.88	30,993.51	6,201.80	14,963.80	456.80	123,332.64
TOTAL VALUE	$ 4,857.92	$30,758.33	$43,973.43	$13,600.56	$104,788.80	$84,675.90	$18,440.73	$68,543.81	$ 8,685.03	$378,324.51

1 Project costs include monetary matching received from participants
2 Costs include pressurized pipeline costs
3 Includes land shaping, pipeline installation, drainage installation, equipment rentals, etc., any costs incurred by the participants and/or any work performed by the participants
4 Installed at 2 locations - one 1.5 hectares, one 0.7 hectares (for a total of 2.2 hectares) - second to be expanded by participant to cover 3.0 more hectares - making a total 5.2 hectares under drip.
5 Does not include costs of installation which were included in concrete ditch costs ($20.00 each).

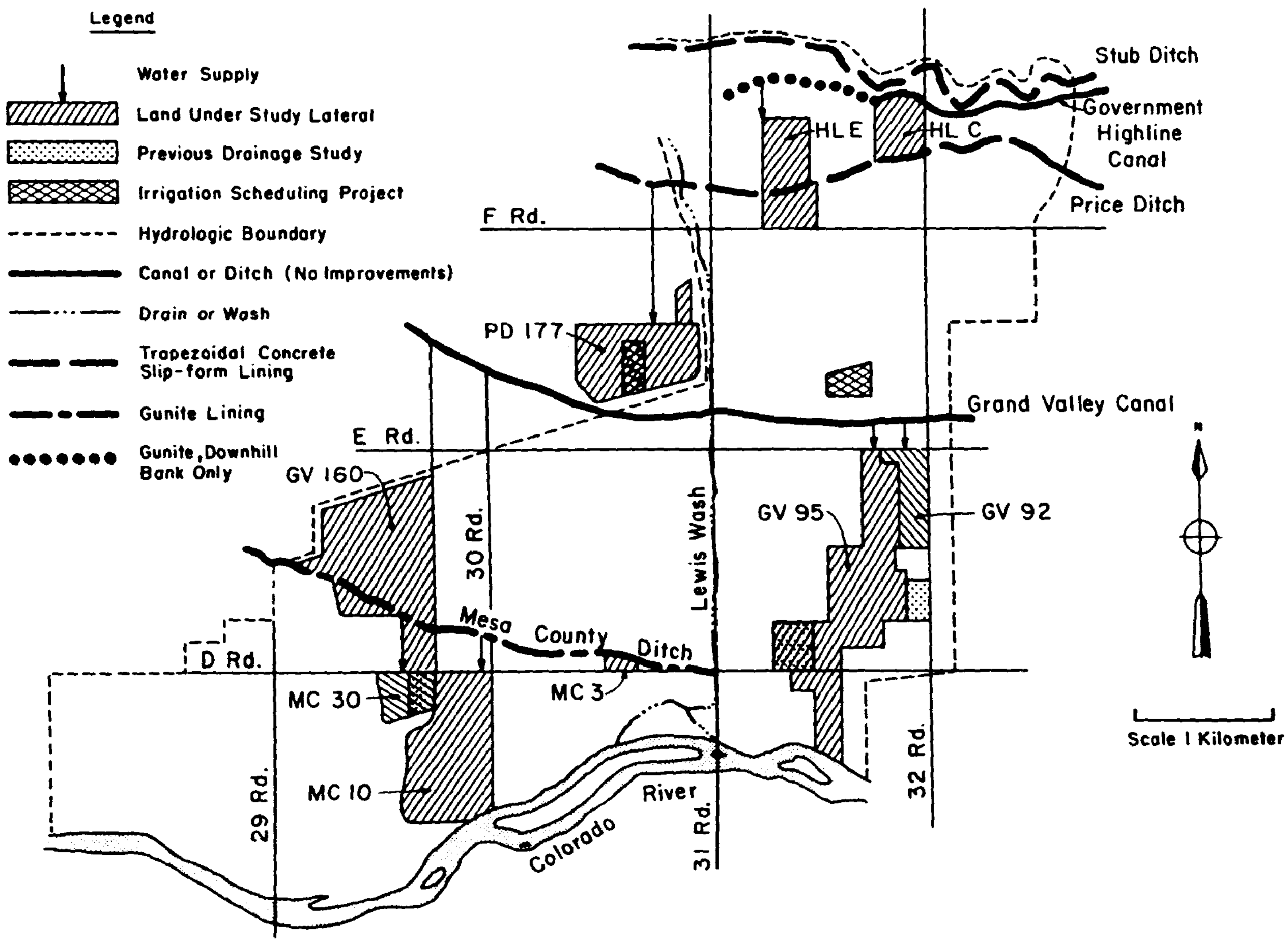


Figure 53. Total project improvements in the Grand Valley Salinity Control Demonstration Area, 1969-1976.

TABLE 17. SUMMARY OF CONSTRUCTION OF IMPROVEMENTS BY THE GRAND VALLEY SALINITY CONTROL DEMONSTRATION PROJECT

Map Designation	Company Name Canal Name	Type of Improvement	Length (mi.)	Length (km)	Perimeter (ft.)	Perimeter (m)	Area (yd²)	Area (m²)	Unit Cost ($/yd²)	Unit Cost ($/m²)	Miscellaneous Costs[1] ($)	Total Cost ($)
Area I (Demonstration Area)												
A	Grand Valley Irrigation Co. Mesa County Canal	Gunite Lining	2.2	3.5	14	4.3	17,500	14,632	3.25	3.89	2,100.00	58,975.00
B	Palisades Irrigation Dist. Price Ditch	Slip Form Lining	1.9	3.1	15	4.6	16,720	13,980	3.25	3.89	2,900.00	56,240.00
C	Grand Valley Waters Users Assn. Gov't Highline Canal	Gunite Lining	1.0	1.6	15[2]	4.6	8,800	7,358	3.50	4.19	5,800.00	36,600.00
D	Mesa County Irrigation Co. Stub Ditch	Slip Form Lining	2.5	4.0	10	3.1	14,700	12,290	3.25	3.89	3,500.00	51,275.00
E	Grand Junction Drainage Co.											
	Open Drains	Slip Form Lining										4,000.00
	Closed Drains	Tile										16,000.00
	Laterals	Slip Form Lining	4.83	7.77								110,815.00
Area II												
F	Grand Valley Irrigation Co. Grand Valley Canal	Gunite Lining	0.15	0.24	15[2]	4.6	1,320	1,104	3.50	4.19	4,000.00	8,620.00
Area III												
G	Redlands Water and Power	Slip Form Lining	0.5	0.8	12	3.7	3,500	2,926	3.25	3.89	1,600.00	11,475.00
SUBTOTAL												354,000.00
			(ft)	(m)	(in.)	(cm)	(ac)	(ha)	($/ac)	($/ha)		
Drainage Costs			11,000	3,353	4[3]	10.2[3]	10	4.1	1,694.00	4,185.82	0.00	16,940.00
SUBTOTAL												$370,940.00
Lateral Improvements												378,330.00
TOTAL VALUE of direct benefits to the Grand Valley												$749,270.00

[1] Costs of pre-construction and post-construction ponding tests above amounts in CSU contract, plus costs of installing headgates, etc.

[2] Downhill bank lining, only.

[3] Diameter of tile.

SECTION 8

PARTICIPATION AND RESPONSE BY IRRIGATORS AND LOCAL ORGANIZATIONS

LOCAL PARTICIPATION

The evaluation of a lateral in a subsystem context allows improvement of water management practices throughout the individual farms by providing more control of the quantity of flow and the time of water delivery. Efforts to maximize water management efficiency within a lateral subsystem requires substantially more interaction (unless the irrigation system is highly automated) among the irrigators themselves; thus, an important aspect of this project is the evaluation of these interactions. Also, the willingness and extent of involvement by local organizations would be very critical to the successful implementation of a valley-wide salinity control program.

Irrigator Response Prior to Construction

The project was initiated by a newspaper article inviting interested parties to an explanatory open house. More farmers responded to the open-house than could be included in the study. A strong emphasis was made at the open house discussions that the primary interest in undertaking this research and demonstration project was to reduce the salt load in the Colorado River; however, a significant by-product of this emphasis would be increased agricultural productivity under the lateral subsystems improved by this effort. Meetings were later held in the homes of the interested irrigators under the several lateral subsystems where specific details for cost-sharing and anticipated types of irrigation system improvements were discussed, including the time schedule for preconstruction field investigations, construction, and postconstruction operations.

The irrigators were generally willing to cooperate with the project, although most merely wanted to rehabilitate the existing laterals. Project personnel continuously received requests to study other laterals and to provide financial and technical assistance.

Participation by Local Organizations

There has been a large amount of participation by local organizations, which contributed substantially to the project's success. The largest degree of participation was by the Grand Junction Drainage District, closely followed by the Mesa County Road Department and the local irrigation companies.

The Grand Junction Drainage District, through their standard drainage tiling agreement (the Drainage District will install the drainage works if all materials are supplied by the owner or other parties), installed more than 13,000 meters of drainage tile for this project. Their participation and cooperation is greatly appreciated.

The Mesa County Road Department installed and replaced numerous road crossings and culverts and provided some backfill for deeply eroded areas near county roads.

The Grand Valley Irrigation Company and the Grand Valley Water Users Association provided much assistance on modifying lateral operational procedures and by replacing worn out headgates. They also agreed to let project personnel completely manage the headgates on the selected laterals, which was a very important component of the project's operation.

Meetings were held with the Grand Valley Rural Electric Association, Mesa County Tax Assessor, Mountain Bell Telephone Company, local natural gas companies, bank officials, attorneys, and water and sewer district officials in order to obtain necessary information, cooperation, and any other assistance on construction easements, utility locations and relocations, possible legal problems, and various financial aspects of the project.

Almost 610 meters (2,000 linear feet) of 30 cm (12-inch) diameter plastic irrigation pipeline was installed, free of charge, by a local construction company. They installed the pipe because Lateral GV 160 crossed about 122 meters (400 feet) of land belonging to the company. In order to make the area more usable for their construction related activities, the contractor offered to install the pipe at no charge. The project supplied all the materials.

In general, the support given by local businesses and organizations has been overwhelming and undoubtedly a very large reason for the attainment of the project's objectives. The *Grand Junction Daily Sentinel*, a local daily newspaper, was of great assistance in promoting project goals and reporting on project activities and developments.

Irrigator Participation During Construction

The scope of this study involved the selection of laterals in the demonstration area in which the irrigators served by the laterals would participate on a matching basis (70 percent project funds - 30 percent irrigator funds) in the construction phase of the study. In general, the irrigators on the larger laterals found it difficult deciding how each should contribute to the matching requirement. On the smaller laterals, the decisions were usually much simpler because there were fewer persons involved. These decisions were complicated by the fact that the 30 percent matching requirement could be partially or totally paid in labor, equipment rental, or other types of compensation (voluntary assistance by the Drainage District, etc.).

On the GV 95 Lateral, the 15 participants opted to pay their matching in cash for the main conveyance-distribution improvements. Their decision for the collection of the money involved the payment of $200 by each person on the ditch for the first share of irrigation water and a much smaller amount for each additional share. Interestingly, the individual who proposed this method of collection was a water user having only a single share, who felt that each water user gained significant benefits from the improvements that could not be equitably measured by shares alone. Any money left after completion of the project was committed for future maintenance of the lateral works.

Laterals PD 177, GV 160, MC 10, and GV 92, on the other hand, opted to do much of the work on the installation of the mainline distribution systems themselves. However, this was only applicable on buried plastic pipelines where the people could handle the installation. In almost every case, the value of the labor and equipment used in installing the pipeline averaged almost exactly 30 percent of the cost of the pipe, flow meters, and appurtenant structures. On these laterals, the irrigators still had to monetarily match on any contracted concrete-lined ditches.

On Lateral MC 30, the one farmer using this lateral had decided on a combination of concrete-lined ditch, buried pipeline, and gated pipe. He installed the pipeline and paid matching money for the concrete ditches and the gated pipe.

On Lateral HL C, the improvements consisted only of laying tile in a large open drain which bisected a field and the installation of flow measurement structures. The Grand Junction Drainage District does this type of work as a matter of policy, and their work on this lateral more than met the matching requirement.

Lateral HL E is almost all apple, pear, and peach orchards. The work undertaken on this lateral involved the installation of an overhead sprinkler system on 5.2 hectares of pears, and the installation of a buried plastic pipeline. The two owners (brother and sister) opted to have a contractor do all the installation and paid their matching requirement in cash. The overhead sprinkler system is attracting quite a lot of valley-wide attention due to the fact that it can be used for frost control and for cooling, as well as irrigation. It is the first such installation in the Grand Valley. The interceptor drain and 25 cm diameter tailwater pipeline were installed by the Grand Junction Drainage District which more than met the lateral matching requirements for this improvement.

As mentioned previously, several of the lateral groups elected to do much of the construction work themselves and were thus very involved in the day-to-day operations. On other laterals, where the construction was done by outside contractors, some of the irrigators were out every day asking questions and making suggestions on construction procedures and how to improve performance of the system. The willingness of the irrigators to become involved in the construction is desirable because they develop a much better understanding of the system design, operation, and maintenance. However, on one lateral (GV 95) the fact that the irrigators opted to pay for the construction contributed to many problems encountered later in the project. Due to the lack of daily involvement, many of these irrigators did not completely understand the system and its operation. Ultimately, this caused some personal conflicts which should not have occurred. However, with considerable time and effort, these conflicts have been resolved.

The construction work was very personally gratifying in many ways, and community effort was often required to complete the work. Many times people went out of their way to help and assist others on the laterals. For example, on the Price Ditch 177 Lateral subsystem, several people from the subdivision at the tail end of the lateral assisted in the laying of the pipeline for agricultural users. In fact, some of them even took vacation time from their jobs to work on the project. Two of the people donated their own equipment for construction of the project.

In another case, on the Grand Valley Canal 160 Lateral subsystem, people without water rights in the lateral assisted their neighbors in the pipeline construction. Also, this same lateral, a 20 cm (8-inch) plastic pipeline, replaced more than 400 meters (1/4 mile) of unlined ditches to one farm. The pipeline was completely installed by the neighbors (some of them are not even served by this lateral) of the family because the head of the household had just suffered a heart attack.

On the Mesa County 10 Lateral subsystem, people donated their own equipment for the construction of the pipeline system and received no reimbursement from their neighbors. One elderly gentleman with just a few acres had his sons come and do his share of the work on the pipe installation. In fact, this was very common on many of the laterals where community effort was required to complete the work. And generally, if a person could not come and work, he would hire someone to take his place.

Irrigator Response After Construction

The mutual cooperation between irrigators on the project has improved quite noticeably since construction began, particularly where the participants did much of the installation themselves. The new systems have reduced some antagonism which had been due to real or imagined inequalities in the requirements for ditch maintenance or inequitable allocation of water. For instance, under the new systems the maintenance requirements are generally much less because of concrete lined laterals or the use of pipelines. Also, ineffective and old division structures were replaced with new structures containing flow measuring devices, removing many areas of previous contention because of the more equitable distribution of the irrigation water supplies. However, on Lateral PD 177, there is still one irrigator who refuses to work with the other irrigators primarily due to a lack of understanding of the system operation.

As noted earlier, some of the laterals had previously developed water rotation agreements. The construction of these new systems greatly facilitated the ease and speed of water deliveries and contributed to the development of a new awareness of water rights through water measurement, all of which has promoted mutual cooperation. Consequently, rotation programs have become more widely accepted as a beneficial practice.

The actual construction process helped many irrigators to become much more aware of water delivery problems. They now have more consideration for their neighbors. There is more communication between irrigators to determine the times and amount of deliveries because of the increased emphasis upon improved water management practices.

With very few exceptions, the local participants were fully cooperative with the project and were very patient with construction delays and small problems which developed. Any complaints or suggestions were expeditiously evaluated and answered. In almost every case, complaints were a result of persons misunderstanding the operation of the new systems, which had been previously explained, but were often radically different from their old methods. When the new methods and procedures were explained and demonstrated, most all persons were satisfied with the results.

CHANGES IN IRRIGATION PRACTICES

An important part of the initial lateral selection procedure was to assess the willingness of individual irrigators to change existing irrigation methods and practices. This was critical since the proposed systems would often be designed in such a way that a return to old methods would be practically impossible, and the new proposed management methods might be mandatory for continued operation of the system. The results and implications were fully explained to all the participants before any final decisions were mutually agreed upon.

In the demonstration area, and the Grand Valley in general, irrigators are very reluctant to change past practices and methods. Water costs in the area range from about $9.90/ha-m to about $43.80/ha-m ($1.22/AF to $5.40/AF) for the season, so with the abundant low-cost water there is little economic incentive to improve efficiencies. Rehabilitation and improvement of the conveyance systems were of much more concern than on-farm changes, and, as a result, there were numerous problems in getting individual irrigators interested in improving their own farm irrigation systems and practices. Even where it had been demonstrated that improvements led to increased yields, higher irrigation efficiencies, and reduced fertilizer costs, the general attitudes were negative. Only the more progressive and innovative farmers were willing to try new methods.

The attitudes concerning field drainage were also negative for the most part. Many irrigators believed that this type of drainage was not really required since the large, widely spaced open drains in the area were functioning adequately in their opinion (in reality, these drains intercept only 27 percent of the total groundwater flows, and of the total flow carried in the drains, only 22 percent is groundwater, the remainder is surface flow which is mostly tailwater runoff). Research results to date have shown that these open drains are largely ineffective in draining nearby croplands.

Although most farmers can associate overirrigation with drainage problems, little concern is evidenced because the drainage problems generally occur in the lower parts of the Valley and, therefore, do not usually directly affect the inefficient and ineffective irrigator. The fact that the Grand Valley is the largest contributor of salinity per acre in the Upper Colorado River has no impact upon the average farmer in the area, who has no sympathy for the salinity damages being received in the Lower Colorado River Basin and the Republic of Mexico. There is some justification for their attitudes since they have been irrigating their lands for decades, and they have not contributed to the recent increases in salinity concentrations in the lower reaches of the Colorado River.

There is a large local resistance to irrigation scheduling in the Grand Valley, again probably due to the abundant, low-cost water supply. Past and on-going irrigation scheduling programs in the Valley have a history of poor communication between the farmers and the schedulers. In addition, there were definite weaknesses in the irrigation prediction methodology which became evident to the farmers very rapidly. These unfortunate results during the initial irrigation scheduling efforts are responsible for a large portion of the local resistance. To overcome these initial setbacks and regain farmer acceptance and credibility requires an even more significant demonstration of the benefits that can result from just irrigation scheduling.

Surprisingly, there was also some resistance to changing from open ditches to buried pipelines. One startling reason was that the people did not feel comfortable with the pipelines since they could not see their water. Another reason was that they did not believe that a pipe could carry as much water as their old weed-choked, large open ditch. Their primary preference was for concrete-lined ditches. However, there is a rapidly growing acceptance of pipelines as irrigators realize the rapid response of such water delivery systems, as well as the additional water control benefits and flexibility which result from pipelines.

IRRIGATOR ASSESSMENT OF IMPROVEMENTS

Almost all irrigators have been quite satisfied with the improvements and system performance. For example, the pear crop under the overhead sprinklers was saved in the spring of 1976 with the frost protection aspect of the system. In the owner's words "the system has already paid for itself" ($3,336/ha). In another case, using a side-roll sprinkler system, the owner has stated that the increased hay production due to the greater uniformity more than offset the costs of pumping (10 hp pump).

The most commonly heard assessment was that "It sure beats what we had." Irrigators have been quite favorably impressed with the small amount of maintenance required and the speed with which the system responds. On GV 95, for example, previously when water was first turned on in the spring, it often took 12 to 20 hours to travel one kilometer, and they now have to hurry to their fields in order to arrive at the same time as the water. Several farmers have commented that they have already noticed big improvements with some previously waterlogged soils, and a lack of water in their basements due to just lateral seepage reductions (although deep percolation losses are also a significant contributor to basement water problems).

The project has been for the most part beneficial to the irrigators, as well as very educational to the writers. The fact that the irrigators had to cooperate with each other in order to initially participate in the project, plus the *esprit de corps* developed during the construction process, are largely responsible for the success of this project.

IRRIGATION FIELD DAYS

On August 6 and 7, 1976, an Irrigation Field Days was held in Grand Junction that included an irrigation equipment show, tours of the demonstration project area, and tours of the EPA funded research project, "Irrigation Practices, Return Flow Salinity, and Crop Yields."

A "Field Days" to be held towards the end of the last year of the project was a part of the initial research proposal. This event was to be directed primarily toward growers in the Grand Valley and secondly to irrigation leaders (mostly growers) throughout the Upper Colorado River Basin. The primary purpose was to acquaint these target people with what had been done in the past three years, to present preliminary conclusions, and to present ideas on the direction of future salinity control programs.

Preparation

The original Field Days concept was broadened to include an irrigation equipment show in addition to special educational programs and field tours, and evolved into the "Irrigation Field Days." Hopefully, the equipment show would provide an additional incentive to attract farmers to the Irrigation Field Days and would also help fulfill a needed educational function in the Grand Valley. The scope of the presentations on the research was also broadened to include all the EPA funded research conducted by the Agricultural and Chemical Engineering Department of Colorado State University in the Grand Valley since 1969.

Due to the expansion of the program, the Irrigation Field Days was cosponsored by the Colorado State University Cooperative Extension Service. The show and tour headquarters was the Two-Rivers Plaza, a Grand Junction municipal center constructed in 1975, which contains 1,670 square meters (18,000 square feet) of exhibit space plus several meeting rooms.

Fifteen thousand brochures and seven hundred posters (Figure 54) were printed for circulation throughout the Grand Valley and the Upper Colorado River Basin. Project personnel traveled extensively throughout the basin to distribute literature and contact prominent irrigation leaders, agriculture oriented businesses, extension personnel, and local news media concerning the Irrigation Field Days. In Western Colorado, the names of farmers and landowners were obtained from local ASCS mailing lists and about 5,000 brochures were mailed directly to as much of the agricultural community as possible. In the other Upper Basin states, brochures were mailed to local Extension Service Agents for distribution through their mailing lists. Also, 200 of the posters (which were placed in public places and store windows throughout the Upper Basin) had small pockets attached for

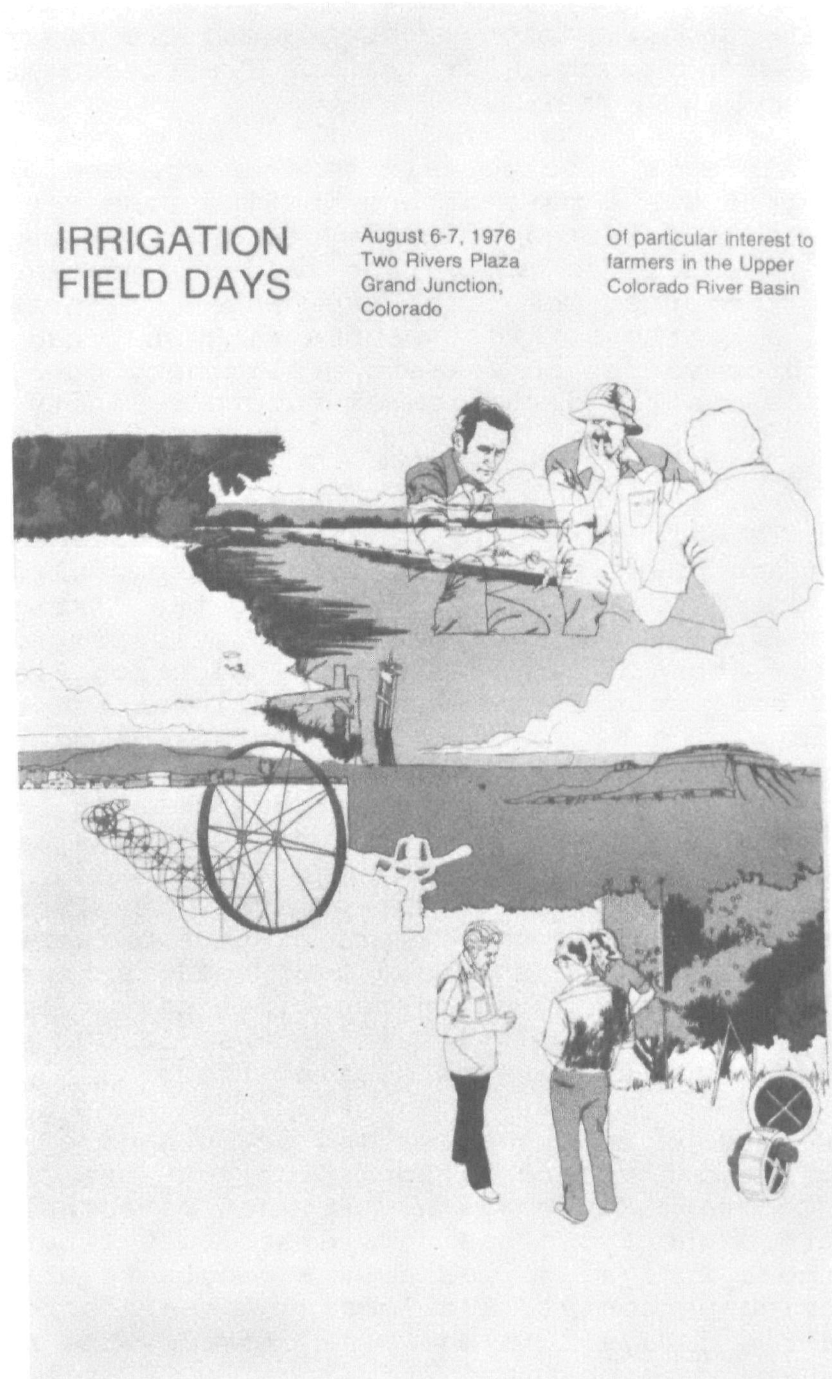


Figure 54. Advertising brochure and poster design for Irrigation Field Days.

brochures in order to distribute the information to persons who were not on the other mailing lists.

An extensive mass media advertising campaign was also undertaken in the Upper Basin States. A 5-minute interview tape was sent to Grand Junction TV and radio stations, and 30-second public service announcements (PSA's) were sent to radio stations throughout the Upper Colorado River Basin. The Cooperative Extension Service advertised on their weekly information radio shows and released several flyers to agents for general information and distribution. In addition, a local Grand Junction radio station (KEXO) ran a 15-minute live interview. Advertisements, or 30-second "spots" were purchased from the following media: *Colorado Rancher and Farmer* (a monthly statewide periodical (33,000 circulation); *Montrose Daily Press* of Montrose, Colorado; *Sun-Advocate* of Price, Utah; *The Daily Sentinel* of Grand Junction, Colorado; KREX radio of Grand Junction. Also, the *Irrigation Journal*, a monthly nationwide publication, mentioned the Irrigation Field Days in their "Dates of Interest" and "Irrigation News" columns. The Grand Junction office of the USDA, Soil Conservation Service prints a quarterly newsletter which goes to 1,300 persons in the Grand Junction area; and they also included an article on the Irrigation Field Days which was mailed about one week prior to the event.

The Grand Junction *Daily Sentinel* ran several articles preceding the Irrigation Field Days and provided very good coverage during the show. Several other publications, including the *Colorado Rancher and Farmer*, ran followup stories concerning the Irrigation Field Days.

The Equipment Show

A card file of potential exhibitors was developed from magazine ads, equipment files, and personal contacts. Initial invitations to exhibit were sent in March-May to over 200 irrigation equipment manufacturers and suppliers and other agricultural service businesses. The response was very gratifying and, ultimately, the equipment show consisted of a total of 46 exhibits, of which 41 were commercial and 3 were state and federal governmental agencies (Colorado Water Conservation Board, USDI-Bureau of Reclamation, and USDA-Soil Conservation Service), and one exhibit booth was for the project. The state and federal agencies requested booths in order to present their plans for future action programs on salinity control activities in the Grand Valley.

The Project Program

The portion of Irrigation Field Days associated with the project involved a one-day program repeated on both days. Original plans called for four tours to run each day, and each tour was to be three hours in length. Two-46 passenger buses were rented for this purpose. Project participants were available to talk to persons on the tours and also at the project's exhibit booth. There was no cost to the farmers for either the equipment show or the tours. During the day, a 16 mm 25-minute general interest irrigation movie entitled "The Magic of Water" (Alberta Agriculture) and a 20-minute 35 mm narrated slide show entitled "The Grand Valley: An Environmental Challenge" were also shown periodically in the meeting rooms adjoining the exhibition area. The Grand Valley slide show was prepared in 1974 to explain in non-technical terms the results and thrust of CSU salinity research since 1968 to the local Grand Valley residents.

On the evening of August 6, a special educational program was planned from 7 to 9 p.m. with talks on topics of special interest to local farmers and landowners. These included presentations on irrigation scheduling, frost protection by sprinkling for orchards, and drip irrigation. Figure 55 illustrates the many activities of the Irrigation Field Days.

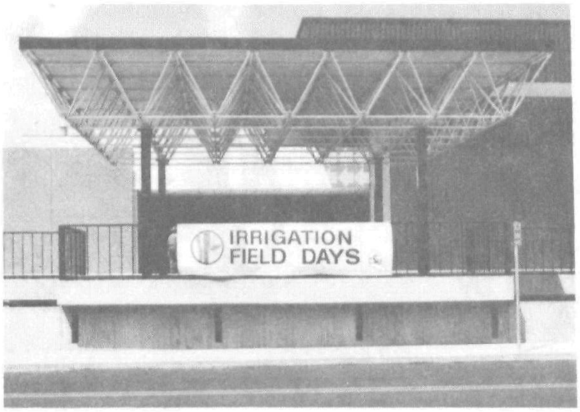
In addition, 1,000 copies of a 55 page nontechnical soft-bound report was prepared for distribution at the Irrigation Field Days. The report discussed past research activities and explained the basic reason for the salinity problem in the Grand Valley. The two concurrent research projects, their primary emphasis and preliminary conclusions were presented. Numerous photographs and maps were used to illustrate the text. Figure 56 shows the cover of the Irrigation Field Days report.

Response

Five hundred and sixty-one (561) persons registered, 380 of which were on Friday. However, many people avoided registering even though there was no registration fee, and also some persons registered for a group. The receptionists, who handled the registration and attempted to keep an accurate counting of those who did not want to register, estimated that at least 800 persons actually visited the show. Seventy-two percent (72 percent) of the registrants listed a home address outside of Grand Junction, and 18 percent were from outside of Colorado. Thirty-seven percent of the registrants were farmers/ranchers, 19 percent were with businesses, 16 percent were with various local, state, and federal government agencies, 9 percent listed other occupations, and 18 percent listed no occupation. Table 18 presents a detailed breakdown of the registrants' homes and occupations.

The Friday night (August 6) presentations had 110 persons in attendance. Farmers seemed to respond quite favorably to these talks and asked a large number of preceptive questions.

All of Friday's scheduled bus tours were full to capacity and an additional bus was rented to accommodate an extra tour.



a. Front of Two River Plaza, site of the Irrigation Field Days;

b. A cooperator discussing improvements on his farm during a tour; and

c. Special educational program offered on the evening of August 6, 1976.

Figure 55. Irrigation Field Days.

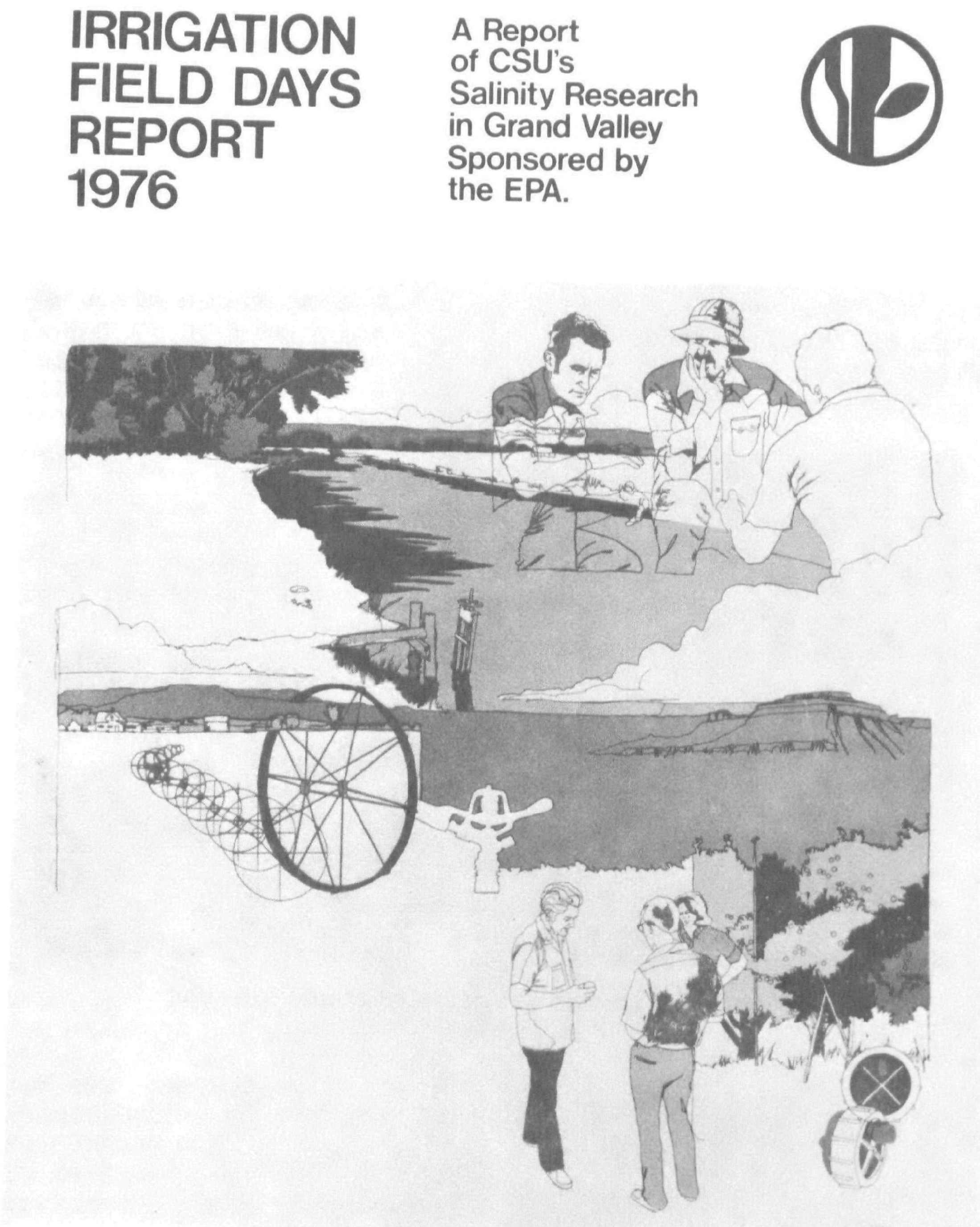


Figure 56. Cover of Irrigation Field Days report which was printed in blues, greens, and white.

TABLE 18. IRRIGATION FIELD DAYS REGISTRATION BREAKDOWN

Home Address:

In-State		Out-of-State	
Grand Valley	159	Utah	44
Outside Grand Valley	300	California	12
		New Mexico	10
TOTAL	459	Texas	6
		Wyoming	6
		Nebraska	5
		Kansas	4
		Florida	2
		Hawaii	2
		Montana	2
		Oklahoma	3
		Arizona	1
		Illinois	1
		Missouri	1
		Nevada	1
		North Dakota	1
		Washington, D.C.	1
		TOTAL	102

Occupation:

Farmer/Rancher	208
Business	108
Government	91
Other	51
No occupation given[1]	103
TOTAL	561

[1]Most of the persons in this group were probably farmers/ ranchers, but elected to leave the "Business of Occupation" line blank.

All together, 205 persons took the tour on Friday, and approximately 150 took the Saturday tours. An extra bus was also rented to provide an additional tour on Saturday.

Comments from exhibitors were very favorable. One exhibitor said that other irrigation shows generally do not have the wide range, scope, and diverse cross-section of equipment and services, except possibly in California, which was represented at this show. Letters and phone calls are still continuing to come in requesting information about the next Irrigation Field Days.

SECTION 9

EVALUATING THE EFFECTIVENESS OF LATERAL SUBSYSTEM IMPROVEMENTS

GENERAL PURPOSE

The measure of effectiveness in irrigated areas most commonly utilized is irrigation efficiency. Improving water management practices through structural and operational changes generally correct such "inefficiencies" as conveyance losses, deep percolation, and field tailwater. However, in terms of controlling the quality of irrigation return flows, some segments of the hydrology in the irrigated area are more important than others. Specifically, if salinity is the major emphasis in a study, seepage and deep percolation losses will be more important than field tailwater and conveyance wastes. If sediments are important, the reverse would be true. Consequently, the term "irrigation efficiency" is too broad. In previous work, the writers have utilized the terms "conveyance efficiency," "field efficiency," and "application efficiency." Since the definition of these terms is periodically different from source to source, care will be given in this section to clearly state the intended definition.

The effectiveness of the various lateral improvements is based on the before and after measurements of the various segments of the irrigation efficiencies noted above. The study was conducted at two levels. First, the lateral inflows and outflows occurring in measurable locations were monitored to yield a mass balance estimate of infiltration and evapotranspiration. The second level involved more detailed examination of representative fields to provide data to delineate various segments of the on-farm hydrology. Information from both sources was combined to develop lateral-by-lateral water budgets. The salinity component of the analysis is based on previous studies. Equilibrium salinity concentrations derived from field measurements were applied to the water flow in order to determine the salt loads in the respective flows.

The general procedure for evaluating the effectiveness of lateral improvements involved six steps:

1) measuring lateral inflows and surface wastes;
2) measuring lateral seepage losses;
3) monitoring water uses within the lateral as to dates and intervals of irrigations;

4) irrigation scheduling;
5) evaluation of application efficiencies; and
6) formulation of lateral water budgets.

This list with the exception of the last item has been aggregated into a single task of evaluating the lateral subsystem hydrology. The sixth step has been expanded in a separate segment of this section in order to illustrate the features of the lateral-by-lateral program.

Cropland Consumptive Use

The importance of evapotranspiration (E_t) from crop and soil surfaces in the Grand Valley was illustrated earlier in the discussion of the local hydrology. At the farm level, consumptive use amounts to approximately 39 percent of the field deliveries and 64 percent of the water infiltrating the soil profile.

Climatological and lysimeter data have been collected for the three irrigation seasons of the project in an effort to calibrate and verify various E_t estimating procedures. Although more detailed results of this work are given in a following report, it is interesting to examine some of these results. The potential evapotranspiration, E_{tp}, is defined as the evapotranspiration of a well-watered alfalfa crop with about 20 centimeters of growth. Five-day mean E_{tp} rates (Figure 57) vary substantially from period to period, but the average year-to-year variability over the three years of investigation is less than 10 percent. The E_t of individual crops, of course, is substantially different from the E_{tp} values. Table 19 shows the five-day average E_t rates for the 1976 irrigation season.

The long-term climatic records for the Grand Valley were also examined in conjunction with local evapotranspiration estimates. Based upon these data and calculations using the Modified Penman Equation with locally calibrated coefficients, the average daily E_{tp} values can be expressed as:

$$E_{tp} = 8.51 \ \exp - \left[\frac{\text{Day} - 137}{\Delta D}\right]^2 \quad . \ . \ . \ . \ . \ (1)$$

in which,

E_{tp} = average daily potential evapotranspiration rate, mm/day,
Day = modified Julian date, March 1 = 1; and
ΔD = empirical coefficient, 90 if Day > 137, 120 if Day $\leq$ 137.

Infiltration

During this study, a large number of individual infiltrometer and advance-recession tests were conducted on the commonly

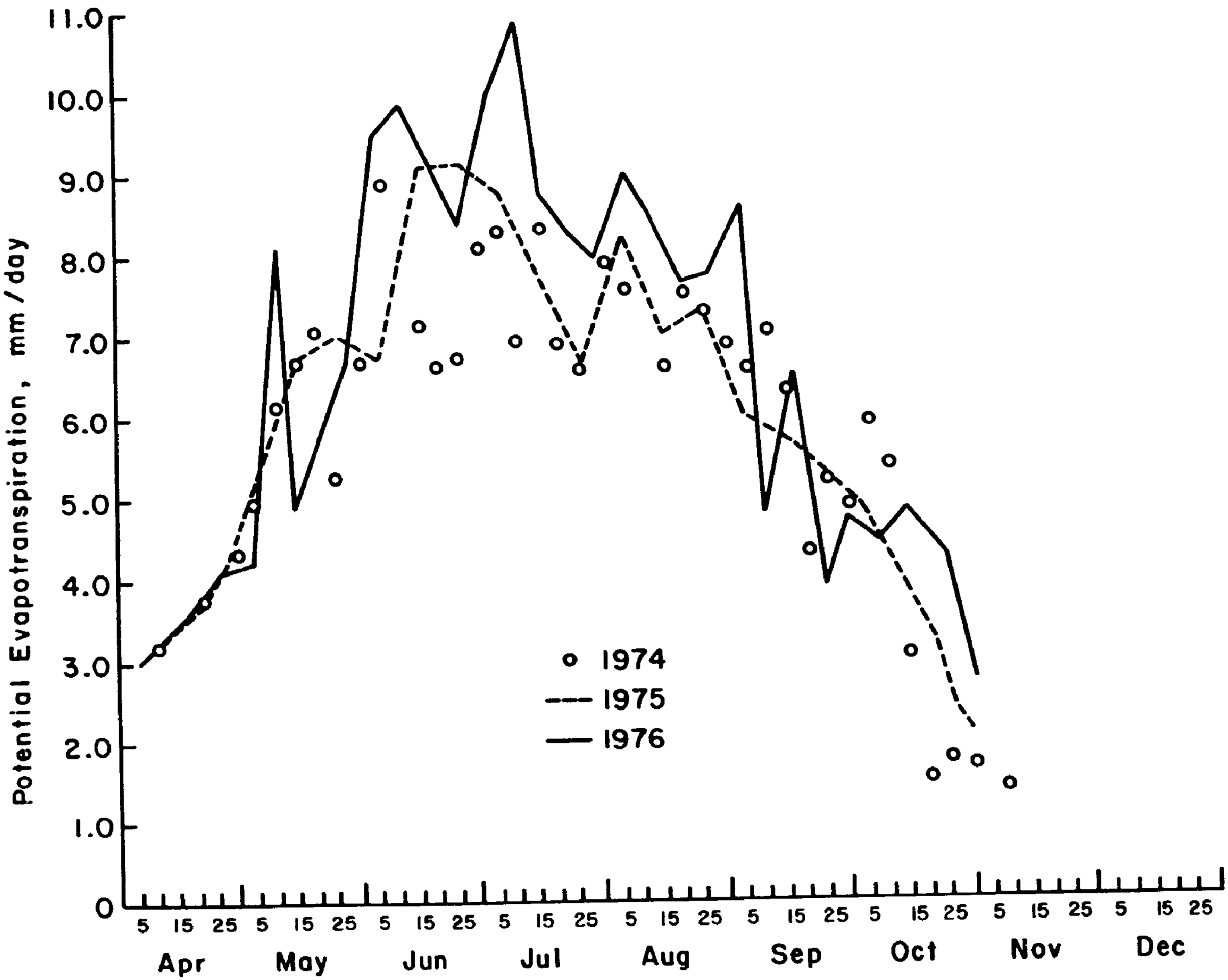


Figure 57. Potential evapotranspiration, E_{tp}, during the 1974-1976 irrigation season.

TABLE 19. EVAPOTRANSPIRATION IN THE GRAND VALLEY FOR 1976

Period	Time Interval		E_{tp} mm/Day	E_t By Crops, mm/Day Alfalfa	Corn	Pasture	Grain	Orchards
1	April	1-5	3.0	1.41	0.00	1.53	0.54	1.20
2		5-10	3.2	2.40	0.00	2.43	0.58	1.28
3		10-15	3.4	3.40	0.00	2.96	0.68	1.36
4		15-20	3.7	3.70	0.00	3.22	1.00	1.48
5		20-25	4.1	4.10	0.00	3.57	1.56	1.64
6		25-30	4.15	4.15	0.00	3.61	2.08	1.66
7	May	1-5	4.2	4.20	0.00	3.65	2.60	2.31
8		5-10	8.1	8.10	0.00	7.05	6.08	4.46
9		10-15	4.85	4.85	0.97	4.22	4.22	2.67
10		15-20	5.5	5.50	1.10	4.79	5.28	3.03
11		20-25	6.25	6.25	1.25	5.44	6.38	3.44
12		25-31	8.0	8.00	1.76	6.96	8.32	4.40
13	June	1-5	9.6	9.60	2.40	8.35	10.08	7.20
14		5-10	9.8	9.80	2.94	8.53	10.19	7.35
15		10-15	9.3	9.30	3.26	8.09	9.30	6.98
16		15-20	8.8	2.38	3.61	7.66	8.18	6.60
17		20-25	8.3	4.57	3.98	7.22	6.97	6.23
18		25-30	9.5	7.79	4.28	8.27	6.94	7.13
19	July	1-5	10.5	10.50	6.41	9.14	6.51	9.45
20		5-10	10.3	10.30	7.00	8.96	4.94	9.27
21		10-15	8.75	8.75	6.48	7.61	2.89	7.88
22		15-20	8.4	2.27	6.80	7.31	1.51	7.56
23		20-25	8.1	4.46	6.97	7.05	0.16	7.29
24		25-31	8.25	6.77	7.51	7.18	0.00	7.43
25	August	1-5	9.0	9.00	8.46	7.83	0.00	8.10
26		5-10	8.6	8.60	8.08	7.48	0.00	7.74
27		10-15	8.1	8.10	7.94	7.05	0.00	7.29
28		15-20	7.6	2.05	7.60	6.61	0.00	6.84
29		20-25	7.7	4.24	7.70	6.70	0.00	6.93
30		25-31	8.2-	6.77	8.09	7.18	0.00	7.43
31	September	1-5	7.5	7.50	7.05	6.53	0.00	5.25
32		5-10	5.0	5.00	4.50	4.35	0.00	3.50
33		10-15	6.1	6.10	5.12	5.31	0.00	4.27
34		15-20	5.25	5.25	4.10	4.57	0.00	3.68
35		20-25	4.0	4.00	2.84	3.48	0.00	2.80
36		25-30	4.7	4.70	3.15	4.09	0.00	3.29
37	October	1-5	4.5	4.50	2.57	3.92	0.00	2.93
38		5-10	4.6	4.60	2.25	4.00	0.00	2.99
39		10-15	4.8	4.80	2.02	4.18	0.00	3.12
40		15-20	4.5	4.50	1.58	3.92	0.00	2.93
41		20-25	4.0	4.00	1.16	3.48	0.00	2.60
42		25-31	2.75	2.75	0.66	2.39	0.00	1.79

encountered soil types and cropping patterns in the Valley. These data and those reported by Skogerboe et al. (1974a) and Duke et al. (1976) reveal a very large degree of variability. So much in fact, that specific limits for each major soil type are difficult to apply. The variability in soil salt content, previous cultural and farming practices, and cropping patterns contribute to the uncertainty of representing infiltration characteristics. The infiltration relationship utilized in this analysis is the Kostiakov Equation:

$$i = at^b \quad . . . . (2)$$

in which,

- i = infiltration rate in units of depth per unit time;
- t = time in minutes or hours;,
- a,b = empirical regression coefficients

The integral of Equation 2 gives the accumulated depth of infiltration as a function of time water is applied to the soil:

$$I = \frac{a}{b+1} t^{b+1} \quad . . . . (3)$$

where,

- I = applied depth after t hours in units of length.

The variability in the measured values of a and b is approximately one order of magnitude in each case. However, much of this variability can be attributed to the effects of previous irrigations on the soil structure. Examination of infiltration data for initial irrigations on lands planted to the annual crops (corn, sugar beets, and grains) resulted in an equation for infiltration rate of:

$$i = 3.13\ t^{-0.6} \quad . . . . (4)$$

in which,

- i = infiltration rate in cm/hr; and
- t = time of infiltration in hours.

The cumulative depth of infiltration would than be:

$$I = 7.82\ t^{0.40} \quad . . . . (5)$$

where,

- I = infiltrated depth in cm after t hours.

A similar examination of infiltration rates during the irrigation season and then for perennial crops (pasture, alfalfa, orchards) has led to the conclusion that these rates might be related to the expression in Equations 4 and 5. To do this, the infiltrated depth after 24 hours found in Equation 4 was compared to similar computations for initial and subsequent irrigations. Then, a regression fit of the results yielded two relationships as follows:

$$I_r = 0.999 - 0.2245\ N + 0.02089\ N^2 \quad . . . . (6)$$

and,

$$I_r = 0.3067 + 0.7032/N^2 \quad . . . . (7)$$

in which,

I_r = relative 24 hour cumulative infiltration; and
N = number of previous irrigations plus 1.

Equation 6 represents the case of perennial crops and Equation 7 the annual crops. To determine the cumulative infiltration relationship during the irrigation season, Equation 5 is multiplied by Equation 6 or 7 depending on the crop being irrigated. A graphical view of Equations 6 and 7 is given in Figure 58.

It may be interesting at this point to demonstrate the preceding analysis with its numerous assumptions and averaging. If a typical root zone depletion between irrigations for the annual crops is 11 centimeters, as data would indicate in the test fields studied, and a similar value of about 9 centimeters for the annual crop is assumed, then the application efficiency and deep percolation in the Grand Valley can be determined. In this sense, application efficiency is defined as the soil moisture requirement divided by the total infiltrated depth. These results are given in Table 20 and the time distributed application efficiencies are shown in Figure 59. In a comparison with field data, one can expect a substantial variation from these predicted values. However, in a test of the representativeness of these figures on a valley-wide basis, the acreages of each crop were multiplied by the total deep percolation to approximate total deep percolation losses in the Valley. These results are given in Table 21. As indicated, about 6,000 ha-m of deep percolation are predicted by the simplified infiltration analysis. In the previous section on the Grand Valley hydrology, the valley-wide estimate was approximately 5,000 ha-m. Thus, this analysis overestimates the earlier computation by only about 20 percent, which is quite good for such a simplistic procedure. It should be noted that the application efficiencies approach 100 percent in the late seasons because soil infiltration becomes so limiting that enough water cannot be put into the root zone. In which case, the crop is actually in a deficit situation.

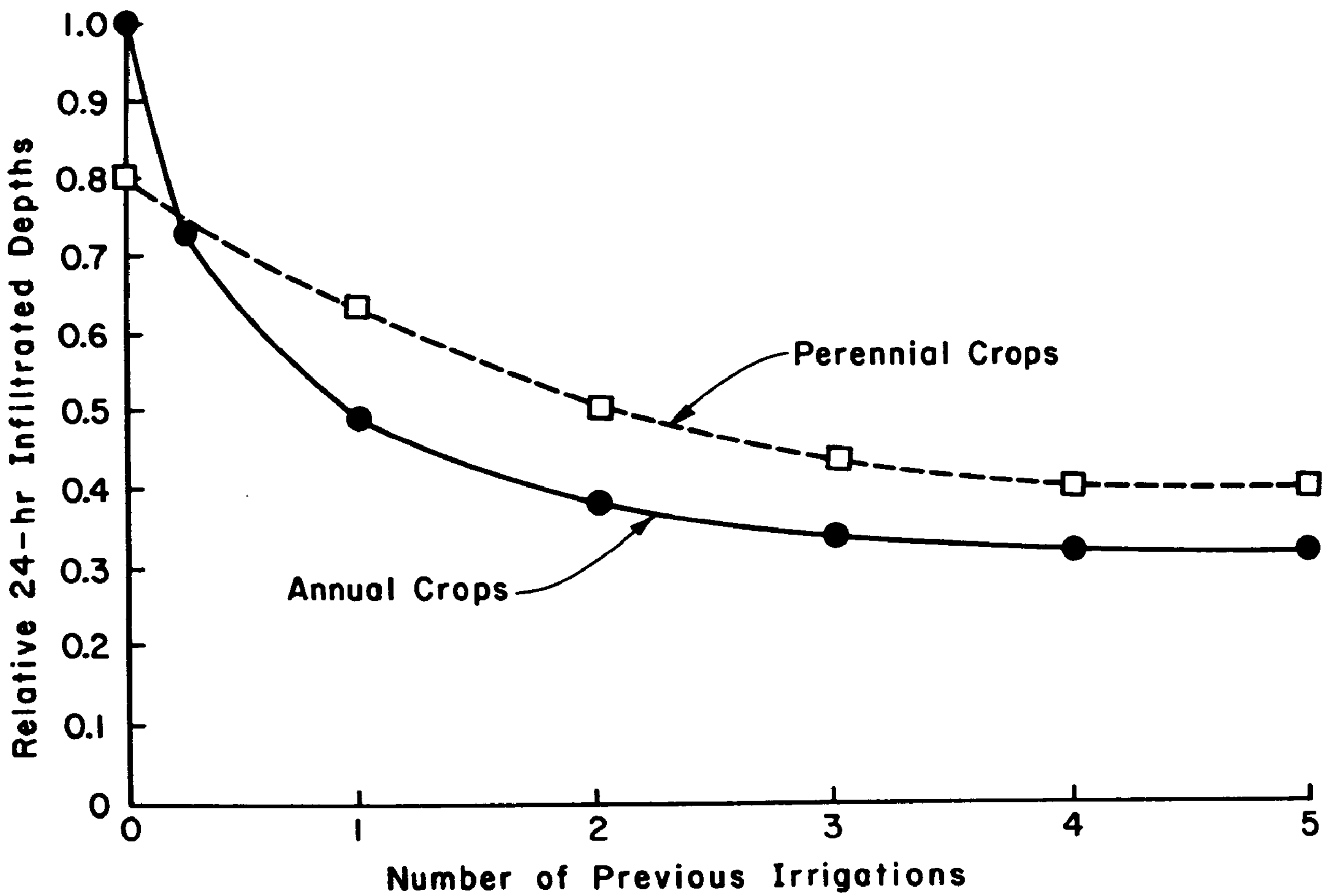


Figure 58. Relative infiltration rate function for perennial and annual crops in the Grand Valley.

TABLE 20. SUMMARY OF APPLICATION EFFICIENCIES AND DEPTHS OF DEEP PERCOLATION FOR A HYPOTHETICAL INFILTRATION MODEL OF THE GRAND VALLEY

Crop	Irrigation No.	I_r	d[1] (cm)	Deep Percolation (cm)	Application Efficiency %
Alfalfa[2]	1	0.80	22.4	11.4	49
	2	0.63	17.6	6.6	62
	3	0.50	14.0	3.0	79
	4	0.45	12.6	1.6	87
	5	0.40	11.2	0.2	98
	6	0.40	11.2	0.2	98
	7	0.40	11.2	0.2	98
				23.20	
Corn[3]	1	1.00	27.9	18.9	32
	2	0.48	13.4	4.4	67
	3	0.38	10.6	1.6	85
	4	0.35	9.8	0.8	92
	5	0.33	9.2	0.2	98
	6	0.32	8.9	-	100
	7	0.32	8.9	-	100
	8	0.32	8.9	-	100
				25.9	
Sugar Beets	1	1.00	36.9[1]	27.9	24
	2	0.48	13.4	4.4	67
	3	0.38	10.6	1.6	85
	4	0.35	9.8	0.8	92
	5	0.33	9.2	0.2	98
	6	0.32	8.9	-	100
	7	0.32	8.9	-	100
	8	0.32	8.9	-	100
				39.40	

[1]Based on 24 hours of irrigation except for first irrigation of sugar beets (48 hours)

[2]Figures would also apply to orchards and grass-hay pastures

[3]Figures would also apply to small grains even though they have about three fewer irrigations.

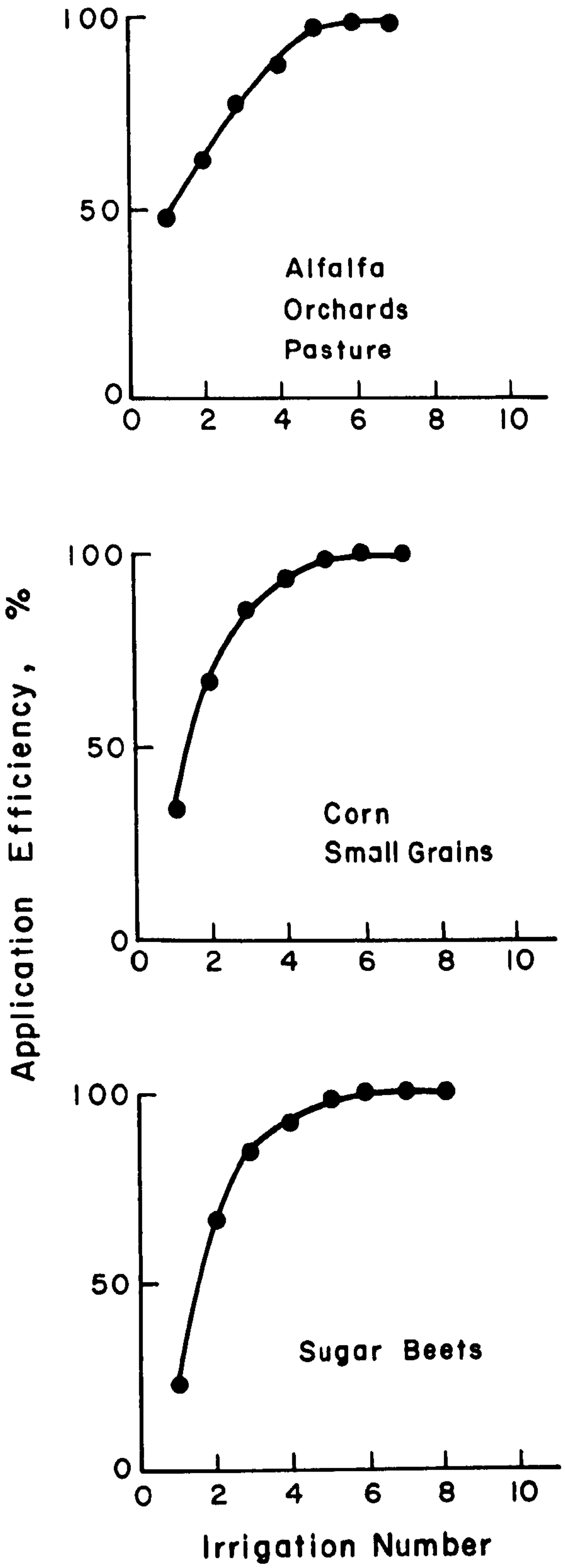


Figure 59. Seasonal distribution of computed application efficiencies for common crops grown in the Grand Valley.

TABLE 21. COMPUTED DEEP PERCOLATION IN THE GRAND VALLEY

Crop	Area[1] ha	Deep Percolation ha-m
alfalfa	5900	1370
corn	5790	1500
orchards	2800	650
pasture	4180	970
small grains	3000	780
sugar beets	2130	740
	23,800	6010

[1]1976 estimates

In the test area, 13 fields scattered under the various laterals and growing all of the crops except sugar beets and orchards were selected to compare with the predicted efficiency values. Using the above analysis, the number of predicted irrigations agreed quite well in all cases (within one or two irrigations). Deep percolation was predicted with ±50 percent accuracy in all cases except for two alfalfa fields which were substantially under-irrigated during the entire season. A number of the predictions, particularly for annual crops, were within approximately the 20 percent figure noted for the Valley. Consequently, in trying to describe the "typical condition" in the Grand Valley and thereby derive conclusions as to the effectiveness of various management alternatives, the preceding analysis should be usable.

Conveyance Seepage and Operational Wastes

Flows diverted from local canals and ditches which are not available for crop use include four parts:

1) main lateral seepage losses,
2) main lateral wastes or spills,
3) farm head ditch and tailwater ditch seepage, and
4) field tailwater.

Lateral Seepage --

The lateral system in the Grand Valley consists of approximately 600 kilometers of earthen ditch, the maintenance of which is generally ignored by both irrigators and irrigation company officials. In the spring, some efforts are expended to clean these conveyance systems, but for the most part, they are choked with weeds and debris. Because most laterals run in the north-south direction in which gradients range up to 1 to 2 percent, the poor condition of most laterals is not a serious physical impediment to the flow of water between the canal and farms. However, the condition of the laterals does cause high seepage losses in most cases. Skogerboe and Walker (1972) utilized inflow-outflow measurements in the test area to determine seepage losses and arrived at an annual loss rate of 1.3 to 20.3 ha-m/km. Duke et al. (1976) also evaluated lateral seepage rates in the Valley and found approximately the same range of seepage rates. An average annual seepage rate of 8.8 ha-m/km annually is thought to represent the typical lateral in the Valley. Thus, valley-wide lateral seepage losses amount to the estimated 5,300 ha-m per year given earlier.

Inflow-outflow tests were repeated in the laterals included in this study during the first year of the study. These data average slightly less than the 8.8 ha-m/km noted above for all but two of the laterals studied; for the laterals numbered GV 160 and GV 95, seepage rates were about double the Valley average estimate.

Lateral Operational Wastes --

Because of the abundant nature of the normal water supply in the Grand Valley, many laterals with more than two to four users will operate continuously. The flow during periods of non-use will be simply wasted into a nearby drain or wasteway. The magnitude of these wastes has not been measured and reported in the Grand Valley; therefore, comparison of this project's data with that of others cannot be made. Field tailwater is very often dumped directly back into the lateral channel (in fact, a number of water rights have been established for this situation and some irrigators use tailwater almost exclusively). Lateral wastes are essentially impossible to delineate. For most purposes, the volume of operational wastes can be determined by subtracting field tailwater from the total surface outflow.

Head and Tailwater Ditch Seepage --

For most crops grown locally, the intervals between irrigations will range from about three weeks early in the season to seven to ten days during the peak demand periods. Many fields are irrigated in three to five sets so that field head ditches carry water on the order of 50 percent of the time. Tailwater ditches would carry water about one-half as often as the head ditches, but in substantially less volumes. Seepage from tailwater ditches can be ignored without significant error. Current estimates of seepage from head and tailwater ditches are based on lateral measurements, even though the head ditch flow rates are usually much smaller than those found in the lateral. Estimates by the writers in previous work have indicated these seepage losses to be approximately 1 to 2 ha-m/km each year. Thus, the

1,300 kilometers of unlined head ditches and an almost equal number of tailwater ditches lose about 2,500 ha-m through seepage each year. This is approximately 30 to 35 percent of the total on-farm contributions to the groundwater.

Field Tailwater --

A number of studies (Duke et al., 1976 and Skogerboe et al., 1974a) have measured field tailwater to be from 34 to 43 percent of the water applied to each field. For the 13 fields isolated during the course of this study, tailwater volumes were as high as 60 percent of the applied water. The majority of fields in the test area, however, are within the 34 to 43 percent limits. If these field tailwater percentages are extended to the entire Grand Valley, field tailwater volumes would range from 11,300 ha-m (34 percent) to 16,000 ha-m (43 percent). In budgeting the water flows in the Valley, the tailwater, canal, and lateral spillage were residual calculations. Consequently, total conveyance spills would be reduced from 25,700 ha-m (34 percent field tailwater) to 21,000 ha-m (43 percent field tailwater). Total farm deliveries would therefore change from 34,300 ha-m (34 percent) to 39,000 ha-m (43 percent).

Irrigation Scheduling

Previously reported irrigation scheduling studies in the Grand Valley have indicated a comparatively small impact on irrigation efficiencies (Skogerboe et al., 1974a). Nevertheless, irrigation scheduling was initiated as part of this study on selected fields under each lateral. The fields in the study area were divided into two groups. The first group consisted of fields on which the spectrum of irrigation scheduling technology was applied, except that the irrigator was not given the scheduling recommendations. The scheduling data were then compared with the irrigation practices of individual irrigators in order to estimate the impact of the irrigation scheduling service if it had been provided to the farmer. The second group was advised of the irrigation scheduling recommendations. Data from these fields indicated the acceptability of the scheduling service to local farmers through comparison of recommended versus actual irrigation practices.

The procedures utilized in this study were similar to the irrigation scheduling methodology practiced throughout the western United States by both private and governmental services. Daily data were collected to identify the surface water balance, soil moisture deficits, and irrigation efficiencies. Evapotranspiration estimates and scheduling recommendations were supplied by the Bureau of Reclamation as part of their on-going local program. Project personnel transmitted the information directly to individual irrigators and spent substantial time explaining the basic procedures, flow measurement, and soil-water-plant relationships.

An essential tool for any irrigator is the ability to periodically determine the amount of moisture in the soil. Many farmers estimate the need for water by the plant color, while others use a shovel to observe the top 6 inches of the soil profile. For the purposes of "scientific irrigation schedule" updating, methods which yield more reliable data on the water available throughout the root zone are used. Many methods are available for this purpose varying in simplicity, cost, and performance. The typical procedure for each method is to measure the soil moisture at one foot intervals through the depth of the root zone. Three methods were compared to test their potential for use in scheduling: (a) the oven-dry or gravimetric method; (b) the carbide reaction "SPEEDY" soil tester; and (c) the "feel" tests.

The oven-dry test involves drying soil samples at 105 degrees C and comparing the dry weight against the wet weight of the original sample. The soil moisture present is then determined by multiplying by the soil bulk density.

The carbide method is based on measuring the amount of gas produced when a moist soil sample is mixed with calcium carbide. A 26-gram soil sample is mixed with calcium carbide in an enclosed container where the gas production is indicated on a pressure gauge. This reading is converted to percent moisture through a chart provided with the instrument. While the time required for each test is only 1 to 3 minutes, cleaning the canister and preparing the samples requires another 30 minutes for a 4-foot set of samples. This is a good field technique when answers are needed in a short time.

The feel test is a method of estimating soil moisture by noting certain characteristics about the soil. The ability for the soil to be "balled" on the palm of the hand, "ribboned" between the thumb and the forefinger, or by noting "free water" on the soil sample allows the tester to make estimations of the amount of moisture present. The feel test is quick and easily applied, but it is affected by different soil types and by the tester who tends to be influenced by past events such as previous irrigations and subconscious ideas of what is expected to be present.

All soil moisture testing for the purpose of updating irrigation schedules was done gravimetrically. Additionally, 341 samples were feel tested and 76 were tested with the carbide test method to determine the potential for these methods to be used in the future. All tests were taken as the percent moisture on a dry-weight basis. Using the oven-dry moisture content as the basis for comparison, each measurement was expressed as a difference between the oven-dry content and the feel test content and/or the oven-dry content and the carbide test content. A graph of the range of differences with respect to the number of tests is shown in Figure 60.

Over the period of the study, there was only slight improvements in the accuracy of the feel estimation technique. These should not be attributed to an improvement in estimating the content, but rather to experience in noting changes through the depth of the root zone. The greatest difficulty with the feel method is the ability to differentiate between soil types. The potential for improvement lies in the skill required to determine soil types and use this to reference the moisture holding capacity.

The results of the irrigation scheduling efforts substantiate earlier studies. With the exception of three cases, the irrigation scheduling service did not significantly affect irrigation efficiencies. A comparison of recommended versus actual irrigations indicated that the computer predictions were generally within two days of an actual irrigation, regardless of whether or not the irrigator was informed of the recommendations. Thus, the timing of irrigations by either farmer judgment or computer prediction was not significantly different. Further, it appears that recommendations have little effect on irrigator decisions when substantial changes are not being recommended. Studies elsewhere have indicated gradual farmer acceptance. The largely insignificant impacts of this irrigation scheduling study may be partially due to the short interval of the investigation.

Irrigation scheduling did not significantly impact the depth of water applied by the individual irrigators. The mid to late season infiltration rates are comparatively small in the Grand Valley, so the soil itself acts as the system control. Irrigators tend to maintain fixed set times rather than vary the set time to achieve a desired depth of application. The major benefits to be derived from irrigation scheduling would be in conjunction with flow measurement to specify the amount to be applied.

The three exceptions noted previously are interesting. In two cases, the method of irrigation was changed to a sprinkler system with which the irrigator had not had previous experience or preconceived concepts. In these situations, the scheduling recommendations were well received and implemented. The third exception was an irrigator with no previous furrow irrigation experience. Again, the recommendations were followed closely. These experiences lead to the conclusion that irrigation scheduling in the Grand Valley is seriously limited by reliance on past customary practices. Where new systems are constructed, irrigation scheduling can be more easily implemented.

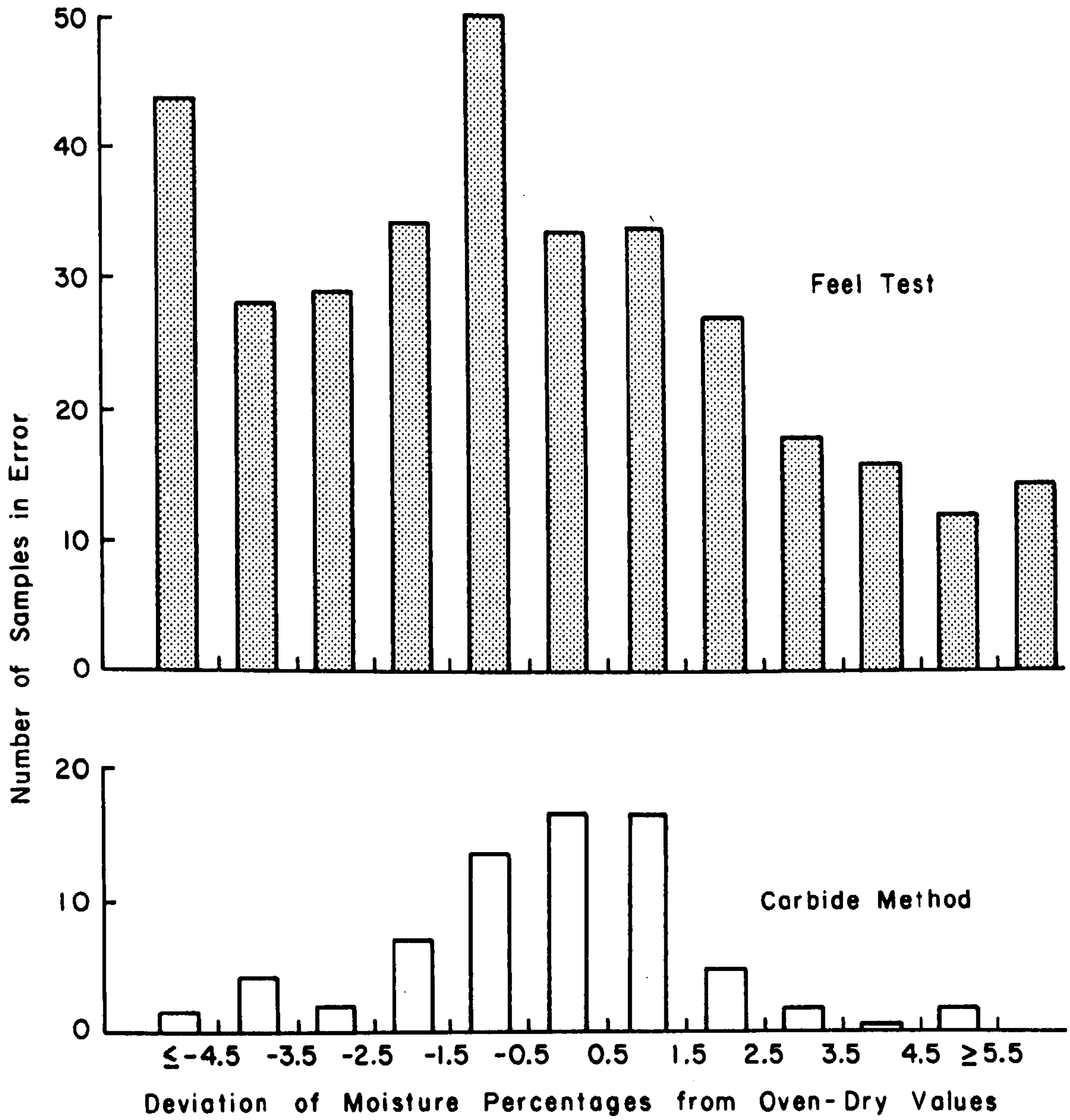


Figure 60. Differences in the estimation of the percent moisture between the feel test and the oven-dry value and the carbide test and the oven-dry value.

EVALUATING LATERAL IMPROVEMENTS

A complete listing of the field and laboratory data accumulated during this project's three years of investigation is beyond the scope of this report. Even lateral-by-lateral summaries represent a large number of pages which make it difficult to easily interpret the results. Condensed water budgets have been developed for each lateral for conditions before and after the lateral improvements. The cropping and climatological conditions were those which occurred during the 1976 irrigation season. Since this method of analysis involves substantial manipulation of the yearly data, it is probably useful to briefly describe these procedures before examining the effects under the individual laterals.

Evaluation Procedure

Prior to the lateral improvements, data were collected on inflows and outflows, field lengths, slopes, crops, soil characteristics, infiltration rates, and climatological information. Routine observations in the test area identified the dates, set intervals and frequencies of irrigations on the fields under each lateral subsystem. This same field data collection procedure was followed after the installation of lateral improvements; however, the effect was intensified because of the irrigation scheduling studies. Throughout the course of the investigation, various short-term studies, like seepage loss rates, were conducted.

The purpose of the data collection was to develop mass balance resolution of the water and salt flows under each lateral turnout. A comparison of these budgets before and after the construction yielded the measured effectiveness of the individual improvements. Local crop rotation patterns and the periodic practice of idling a field for a season create a masking variation. To overcome this difficulty, the approach taken in the analysis was to transform the results of the preconstruction studies to the postconstruction pattern and irrigation schedule. This process is largely a matter of adjusting on-farm budgets. Seepage rates in the unlined laterals, head ditches, and tailwater ditches were assumed constant from year to year.

The mass balance of water in the field area consists of inflows through the head ditch and precipitation, while the outflows consist of deep percolation, tailwater runoff, and evapotranspiration. It was also assumed (with justification) that the general irrigation practice followed by each irrigator remained the same on respective fields and crops from year to year. Then to transform the preconstruction hydrology to the postconstruction conditions, the following procedure was used. First, the irrigation schedules for the individual fields and crops were recomputed using 1976 climatological data. Then the volumes of infiltration, deep percolation, and tailwater were determined. Summing these figures yielded the estimated farm deliveries which would have occurred in 1976 if the improvements had not been made. Once the flows had been reconciled with 1976 conditions, they were condensed by summing over the irrigation season to yield an annual mass balance for each lateral subsystem. The salinity segment of the budgets was imposed on the annual water budget to determine the annual transport of salts.

The effectiveness of the lateral improvements in total was established with the aid of two main assumptions. The first of which is that the actual salinity impact was due to a reduction in the flow of water to the groundwater where the salt pickup mechanism would act. In the test area, the salt pickup rate noted previously was estimated to be 77.8 metric tons/ha-m. Of the flows entering the groundwater basin, about 44 percent are consumed by phreatophytes. Secondly, the small effect of the open ditch drainage system was assumed to be negligible.

The values of seepage losses from laterals, head ditches, and tailwater ditches were summed with deep percolation losses to give the annual subsurface return flows before and after the lateral improvements. The difference was multiplied by 43.57 (which is equal to [(1-0.44) x 77.8)] to determine the estimated salt loading reduction resulting from the improvements. To relate the benefits of this reduction to the costs expended during the project, the salt reduction was multiplied by $150 per metric ton and then divided by the lateral costs. This pseudo benefit-cost ratio is intended as a point of interest relative to the salinity control benefits of the project. The downstream damages of $150 per metric ton were derived from recent estimates of the salinity related detriments in the Lower Colorado River Basin and will be more fully developed in a subsequent report. It should be noted, however, personal communication with researchers in the Lower Colorado River Basin indicates that downstream detriments may be two to three times this figure if intermediate results are correct.

Field relief drainage was included in this study to evaluate the utility of intercepting deep percolation before reaching a higher equilibrium salinity concentration. Results of an earlier drainage study (Skogerboe et al., 1974b), indicated the intercepted drain flows would have approximately 3,000 mg/l less salinity than the groundwater, thus effecting substantial water quality improvements. This particular drainage system continued to be monitored throughout this project. The results, which were predicted by Skogerboe et al. (1974b) show a three to five year convergence on salinity values encountered at the bottom of a well-drained soil profile. In this study the impact of drainage has been included on the basis of water quality expected after accumulated salts have been removed and the system has become similar to lands not requiring relief drainage. Relief drainage would be expected to reduce salt loading to about 39 percent of that of the irrigation water. Because of low hydraulic conductivity and saline conditions of the soils, the drainage systems have been intercepting approximately 15 percent of the deep percolation at the 12 meter spacing. This rate is assumed indirectly proportional for other spacings.

Evaluation of Lateral HL C

The lands served by HL C were not improved in terms of either lateral linings or on-farm improvements. The project did participate in converting an open-ditch drain to a buried concrete line in order to consolidate two fields and make irrigation more convenient. The only emphasis of the project beyond this small improvement was irrigation scheduling. The consolidation of the two fields did, however, result in the elimination of 225 meters of unlined head ditches.

Analysis of data into the 1976 based annual summary shown in Table 22 indicated no significant impact on return flows due to irrigation scheduling alone.

TABLE 22. ANNUAL HYDROLOGIC SUMMARY FOR LATERAL HL C ADJUSTED TO 1976 CONDITIONS (ALL UNITS IN HECTARE-METERS)

Water Budget Category	Before Lateral Improvements	After Lateral Improvements
Total lateral Diversions		
Seepage	4.53	2.55[1]
Operational Wastes	0	1.98
Farm Deliveries	15.82	15.82
Total	20.35	20.35
Total Farm Deliveries		
Seepage	2.40	2.40
Tailwater	8.06	8.06
Consumptive Use	4.50	4.50
Deep Percolation	0.86	0.86
Total	15.82	15.82
Total Lateral Return Flows		
Surface Return Flows	8.06	10.04
Subsurface Return Flows	7.79	5.81
Total	15.85	15.85

Reduction in Salt Loading	11.1 m tons/year
Downstream Benefit	$16,650/year
Actual Cost	$ 4,860
Benefit-Cost Ratio	3.43

[1]Reduced by elimination of 225 m of unlined head ditches.

Evaluation of Lateral HL E

Lateral HL E represents a substantial departure from the other study laterals in the sense that these lands are already well managed with substantial improvements already in place. For example, none of the head ditches and only 33 percent of the lateral was unlined at the beginning of this project. Improvements to this system involved conversion of 5.2 hectares of orchard to overhead solid-set sprinklers and 792 meters of piped lateral.

Table 23 illustrates the before and after water budgets and economic impacts on the HL E system. The sprinkler system reduced

TABLE 23. ANNUAL HYDROLOGIC SUMMARY FOR LATERAL HL E ADJUSTED TO 1976 CONDITIONS (ALL UNITS IN HECTARE-METERS)

Water Budget Category	Before Lateral Improvements	After Lateral Improvements
Total Lateral Diversions		
Seepage	3.42	0
Operational Wastes	5.15	30.25
Farm Deliveries	73.93	52.25
Total	82.50	82.50
Total Farm Deliveries		
Seepage	0	0
Tailwater	31.79	10.99
Consumptive Use	34.00	34.00
Deep Percolation	8.14	7.26
Total	73.93	52.25
Total Lateral Return Flows		
Surface Return Flows	36.94	41.34
Subsurface Return Flows	11.56	7.26
Total	48.50	48.60

Reduction in Salt Loading	188 m tons/year
Downstream Benefit	$28,200
Actual Cost	$30,760
Benefit-Cost Ratio	0.92

deep precolation losses under the entire lateral by nearly 0.9 ha-m with another 3.4 ha-m reduction derived from the lateral linings. The benefit-cost ratio is the lowest of the project (0.92). It might, therefore, be concluded that expenditures on well-managed farming units will have less impact in terms of salinity control than investments into less well-operated systems. However, the irony of the situation is that the better farm managers are more willing to make improvements and change methods.

Evaluation of Lateral PD 177

The designation of the lands included in the project as Lateral PD 177 is somewhat misleading in the sense that only the lower lands of the lateral were actually involved. This is noted because the lateral system up to the beginning of these lands was lined as part of the earlier CSU investigations funded by EPA. These earlier improvements amounted to 1,100 meters of concrete linings. In terms of water control at the inlet to these lands, this is the only lateral considered where inflows were not controlled. The hydrology under PD 177 is shown in Table 24.

Measurements indicated that 60.5 ha-m entered this part of the system during 1976 of which only 20.56 ha-m (34 percent) were actually delivered to the fields. The installation of a buried pipeline lateral system essentially eliminates the 16.7 ha-m of seepage that occurred during the preproject period. A trickle irrigation system on 2.2 hectares of orchards was responsible for reducing deep percolation by nearly 50 percent under the lateral. This savings, along with 1.2 ha-m reduction in head ditch seepage through concrete linings and conversion to aluminum gated pipe, resulted in a total impact of 800 metric tons per year decline in salt loading attributable to this lateral. The benefit-cost analysis shows a respectable value of 2.77.

Evaluation of Lateral GV 92

The only improvements made on the GV 92 system were the concrete lining of 189 meters of lateral and the conversion of 817 meters of the same lateral to buried plastic pipeline. Seepage tests indicated that these linings would reduce seepage loss by 8.84 ha-m annually. Salt loading reductions would, therefore, be 385 metric tons per year for a benefit of $57,800. Since the project expenditure for the GV 92 improvements was $13,600, the ratio of benefits to costs is approximately 4.25.

Evaluation of Lateral GV 95

The area served by the GV 95 turnout from the Grand Valley Canal is the largest included in the project (70 ha). The funds spent for improvements were also the largest ($104,788.80). This lateral is also of interest in another respect. A great deal of the available water supply throughout the system is returned tailwater and wastes from adjacent laterals. For instance, in the 1976 season, about 36 percent of the available water came from these miscellaneous sources.

The GV 95 lateral is typical of many of the larger systems throughout the Grand Valley. Total diversions (including miscellaneous surface inflows) during the 1976 irrigation season were about 170 ha-m. Prior to the lateral linings, about 27 ha-m or 16 percent of the flows would be lost from the system by seepage.

TABLE 24. ANNUAL HYDROLOGIC SUMMARY FOR LATERAL PD 177 ADJUSTED TO 1976 CONDITIONS (ALL UNITS IN HECTARE-METERS)

Water Budget Category	Before Lateral Improvements	After Lateral Improvements
Total Lateral Diversions		
Seepage	16.66[1]	0
Operational Wastes	19.79	39.94
Farm Deliveries	24.05	20.56
Total	60.50	60.50
Total Farm Deliveries		
Seepage	4.09	2.91
Tailwater	10.34	8.84
Consumptive Use	7.00	7.00
Deep Percolation	2.62	1.81
Total	24.05	20.56
Total Lateral Return Flows		
Surface Return Flows	30.13	48.78
Subsurface Return Flows	23.37	4.72
Total	53.50	53.50

Reduction in Salt Loading	800 m tons/year
Downstream Benefit	$121,900
Actual Cost	$ 43,970
Benefit-Cost Ratio	2.77

[1]Approximately 1.1 km of concrete lining had been accomplished prior to this project under EPA funding (Skogerboe and Walker, 1972). These linings reduced seepage by about 9.7 ha-m/year resulting in a salt reduction of 421 tons annually. In 1976 this lining would have cost approximately $17,600. Recomputing the figures given above then:

Reduction in Salt Loading	1,231 m tons/year
Downstream Benefit	$184,650
Actual Cost	$ 61,570
Benefit-Cost Ratio	3.00

This project essentially eliminated these losses. However, the additional water available in the lateral through the seepage savings, the more equitable allocation due to flow measurement and the faster travel times resulted in about 26 ha-m which were simply wasted in 1976. This figure is approximately equal to previous seepage losses. Such wastes will diminish once the local irrigators become more accustomed to the operation of the lateral.

Head ditch linings, conversion to gated pipe, and a change to a side-roll sprinkler system eliminated all but 0.27 ha-m of a previous head ditch seepage loss of slightly more than 5 ha-m/year. These savings were applied to the cropped surface in 1976 in the form of larger furrow streams, or added furrows within an irrigation set. The tightness of the soils, however, prevented significant increases in deep percolation. As a result, field tailwater volumes after the improvements were increased over prior conditions. These flows could also be expected to decrease as irrigators adjust to the added water supply.

A reduction in deep percolation and head ditch seepage amounting to approximately 0.5 ha-m annually was achieved under GV 95 with the conversion of a 4 hectare hay field from the typical furrow irrigated system to a side-roll sprinkler system. Uniformity and efficiency measurements indicated that deep percolation losses were reduced from approximately 23 centimeters each year to 13 centimeters, primarily on the basis of reduced application during the early irrigation season. Replacement of head ditches resulted in another 0.1 ha-m reduction in groundwater additions. For this field, seasonal application efficiency was improved from 77 percent to 87 percent, a change of only 10 percent, but nevertheless a significant impact on the volume of deep percolation.

A summary of the GV 95 hydrology is given in Table 25. The efforts and expenditures of this project reduced salt loading from the conveyance network and croplands under the GV 95 lateral by 1,400 metric tons for a benefit of $210,100. The benefit-cost ratio for this lateral is computed to be 2.0 to 1. A 6-hectare drainage system (24 meter spacing) under this lateral intercepted approximately 0.10 ha-m of deep percolation in 1976, thereby reducing the GV 95 salt load by an additional 2.8 metric tons per year.

<u>Evaluation of Lateral GV 160</u>

Other than 11.5 hectares of field relief drainage, the major improvements under the GV 160 system were lateral and head ditch linings. This lateral represented the poorest conditions of lateral maintenance found in the test area. Seepage tests indicated loss rates almost double the values encountered elsewhere. In addition, local irrigators had constructed two closely located laterals (GV 160 and GV 161) which could be consolidated to

TABLE 25. ANNUAL HYDROLOGIC SUMMARY FOR LATERAL GV 95 ADJUSTED TO 1976 CONDITIONS (ALL UNITS IN HECTARE-METERS)

Water Budget Category	Before Lateral Improvements	After Lateral Improvements
Total Lateral Diversions[1]		
Seepage	26.81	0
Operational Wastes	0	25.64
Farm Deliveries	142.69	143.86
Total	169.50	169.50
Total Farm Deliveries		
Seepage	5.11	0.27
Tailwater	55.35	61.86
Consumptive Use	57.50	57.50
Deep Percolation	24.73	24.23[2]
Total	142.69	143.86
Total Lateral Return Flows		
Surface Return Flows	55.35	87.50
Subsurface Return Flows	56.65	24.50
Total	112.00	112.00

Reduction in Salt Loading	1,403 m tons/year
Downstream Benefit	$210,450
Actual Cost	$104,790
Benefit-Cost Ratio	2.01

[1]Includes approximately 0.10 ha-m intercepted by the relief drainage system.

[2]Includes 60 ha-m of inflows from adjacent laterals (wastes and tailwater).

further reduce seepage losses. Thus, the program for the GV 160 lateral was largely one of controlling seepage through linings and lateral consolidation.

Table 26 illustrates the before and after hydrology for lateral GV 160. More than 4,200 meters of lateral were either lined with concrete or converted to a buried plastic pipeline. Another 900 meters of previously used lateral were eliminated completely by including its lands under the GV 160 system. The total effect of these linings thereby eliminated more than 82 ha-m of seepage losses which would contribute almost 3,600 metric tons annually to the Colorado River system. Another 232 meters of field head ditches were lined with savings of about 0.5 ha-m in seepage losses. A relief drainage system installed under 11.5 hectares of GV 160 cropland would intercept about 0.13 ha-m of

TABLE 26. ANNUAL HYDROLOGIC SUMMARY FOR LATERAL GV 160 ADJUSTED TO 1976 CONDITIONS (ALL UNITS IN HECTARE-METERS)

Water Budget Category	Before Lateral Improvements	After Lateral Improvements
Total Lateral Diversions[1]		
Seepage	86.40	4.29
Operational Wastes	26.14	108.71
Farm Deliveries	121.46	121.00
Total	234.00	234.00
Total Farm Deliveries		
Seepage	10.46	10.46
Tailwater	52.23	52.23
Consumptive Use	49.00	49.00
Deep Percolation	9.77	9.77[2]
Total	121.46	121.46
Total Lateral Return Flows		
Surface Return Flows	78.37	160.94
Subsurface Return Flows	106.63	24.06
Total	185.00	185.00

Reduction in Salt Loading	3,600 m tons/year
Downstream Benefit	$539,600
Actual Cost	$ 84,680
Benefit-Cost Ratio	6.37

[1] Includes 0.13 ha-m/year intercepted by drainage system.

[2] Includes an estimated 60 ha-m inflow from adjacent lateral subsystems.

deep percolation annually, and thus reduce salt loading by 3.5 metric tons per year.

The total reduction in groundwater additions by the GV 160 lateral was 82.57 hectare-meters per year, which converts to a salinity reduction of 3,600 metric tons at a benefit of more than one-half million dollars annually. The expenditures on this system were nearly $85,000 which indicates a benefit-cost function of about 6.4 to 1. The results for this lateral clearly demonstrate the advantages of selecting the most severe salt contributors for first attention in a salinity control program.

Evaluation of Lateral MC 3

The MC 3 lateral is a single user system consisting of 3 hectares of land which had been abandoned prior to this project due to soil salinization from a high water table. A field relief drainage system under 2.5 hectares of the land coupled with installation of 157 meters of concrete head ditch linings were the improvements made under this lateral. The head ditch was designed as an automatic cut-back system, but was not utilized as such by the landowner. In fact, the land was not irrigated during this project and has since been sold. The effectiveness of these improvements cannot be determined.

Evaluation of Lateral MC 10

The annual water mass balance for Lateral MC 10 is given in Table 27. Measured inflows during the 1976 irrigation season totaled 91 ha-m of which 72 percent, or 66 ha-m were delivered to the respective fields. Seepage losses in the lateral system

TABLE 27. ANNUAL HYDROLOGIC SUMMARY FOR LATERAL MC 10 ADJUSTED TO 1976 CONDITIONS (ALL UNITS IN HECTARE-METERS)

Water Budget Category	Before Lateral Improvements	After Lateral Improvements
Total Lateral Diversions		
Seepage	15.92[1]	0
Operational Wastes	20.00	35.92
Farm Deliveries	73.08	73.08
Total	109.00	109.00
Total Farm Deliveries		
Seepage	9.05	1.74
Tailwater	25.73	33.34
Consumptive Use	29.00	29.00
Deep Percolation	9.30	9.00[2]
Total	73.08	73.08
Total Lateral Return Flows		
Surface Return Flows	45.73	69.26
Subsurface Return Flows	34.27	10.74
Total	80.00	80.00
Reduction in Salt Loading	1,027 m tons/year	
Downstream Benefit	$157,050	
Actual Cost	$ 68,540	
Benefit-Cost Ratio	2.25	

[1] 0.09 ha-m intercepted by 6.1 ha of field relief drainage results in a salinity savings of an additional 2.39 m tons/year.

[2] 396 m of this lateral were lined prior to this project.

were negligible due to 100 percent lining (with PVC pipe and slip form concrete) of the 2.6 kilometers of lateral channel. Seepage from farm head and tailwater ditches was estimated at 1.7 ha-m after the lining of all but 871 meters of head ditches (76 percent). None of the tailwater ditches were lined under the lateral. Deep percolation losses were reduced to approximately 9 ha-m. A large portion of this reduction is due to the installation of an automatic cut-back furrow irrigation system. The drainage systems installed under this lateral did not significantly impact the MC 10 hydrology, primarily because it was installed under the field irrigated by the cut-back system. The drainage system intercepted approximately 0.09 ha-m during the 1976 irrigation season, reducing salt loading by 2.39 metric tons. Total subsurface return flows thus amounted to 10.7 ha-m, which contributed 470 metric tons of salt to the river annually.

Prior to the lateral improvements, total seepage losses were determined to be about 25 ha-m per year and deep percolation losses were 9.3 ha-m/year, totaling about 34 ha-m annually. The lateral improvements thereby resulted in a decreased groundwater contribution of 23.5 ha-m per year, which translates to 1,000 metric ton per year reduction in salt loading. This salt reduction reduces downstream detriments by more than $150,000 each year and was achieved at a local cost of only 45 percent of the damage figure. This is a more than two to one benefit-cost ratio.

Irrigation efficiencies as described by field efficiency (percentage of farm deliveries utilized as consumptive use) and application efficiency (percentage of farm deliveries minus tailwater utilized as consumptive use) changed from 40 percent to 44 percent and 61 percent to 73 percent, respectively. It is evident that lateral and head ditch linings result in more available water with which to irrigate under this lateral, but the excess is primarily wasted directly back to the river. This condition results from two factors. First, the excessive water supply to the Grand Valley means that MC 10 irrigators were already receiving an adequate water supply even with the seepage losses. And secondly, the soil infiltration rates act as a control on infiltration into the root zone. Higher furrow flow rates have relatively small overall impacts on infiltrated soil moisture depths as compared to the time water runs in the furrows; and therefore, higher furrow flow rates simply result in more tailwater losses.

Evaluation of MC 30

MC 30 is a single user lateral included in a previous drainage study. Under this project, the entire lateral and head ditch length were lined with slip form concrete. One field was divided into two separately irrigated areas to achieve better uniformity of water applications. The lateral does not have significant tailwater ditches since these flows exit immediately into nearby drainage channels. A drainage system under approximately one-half of the cropped area is considered separately since it was installed prior to the initiation of this project.

During the 1976 irrigation season, 36.2 ha-m of water were delivered into the MC 30 lateral, all of which was applied to the fields. Seepage losses from the 942 meters of head ditch and 415 meters of lateral were essentially eliminated by the linings. Of the flows, 17.5 ha-m ran off the fields as tailwater (48 percent), 15.50 ha-m were used by the crops (43 percent), and 3.2 ha-m percolated below the crop root zone (9 percent). The leaching fraction for the two fields averaged 17 percent.

Prior to these improvements and under 1976 conditions, approximately 3.26 ha-m of the diversions would have been lost through lateral and head ditch seepage. These seepage losses would have resulted in a salt pickup of some 142 metric tons annually. The economics associated with this lateral's salinity control program, therefore, are 142 metric tons of salt eliminated from the Colorado River system annually at a cost of $8,685. Downstream benefits are expected to be more than $21,000 per year for a benefit-cost ratio of 2.45 to 1.

A summary of the before and after annual mass balances for irrigation diversions into the MC 30 lateral is given in Table 28.

SUMMARY

It is interesting to combine the impact of this project with improvements made previously with EPA support in the test area. Skogerboe and Walker (1972) evaluated a lateral and canal lining effort responsible for a 4,200 metric ton per year reduction to the Colorado River. Improvements constructed in this project accumulate to an 8,100 metric ton per year reduction. Together, these improvements represent 22 percent of the salt loading attributed to this area by Skogerboe and Walter (1972). Actual designated construction costs for these improvements total $350,000 (1972 base) for the earlier project and $378,000 (1976 base) for this one. Also, $17,000 was spent for the previous drainage installation under Lateral MC 30. Consequently, 12,300 metric tons have been removed from the Colorado River system at a cost of $745,000. If downstream detriments amounted to only $60 per ton of salt, these improvements in the aggregate would have been feasible. Given the $150 per ton damage figure, however, this combined local improvement yielded a benefit-cost ratio of 2.50 to 1. The numerous benefits to local agriculturalists have not been included. Walker (1975) evaluated the business multipliers in the Grand Valley associated with irrigated agriculture. A weighted average multiplier of 1.75 follows from that work, which would thereby raise the above noted benefit-cost ratio of 4.25 to 1. Other benefits (i.e., increased crop production) could be added, if known.

TABLE 28. ANNUAL HYDROLOGIC SUMMARY FOR LATERAL MC 30 ADJUSTED TO 1976 CONDITIONS (ALL UNITS IN HECTARE-METERS)

Water Budget Category	Before Lateral Improvements	After Lateral Improvements
Total Lateral Diversions		
Seepage	2.45	0
Operational Wastes	0	0
Farm Deliveries	33.75	36.20
Total	36.20	36.20
Total Farm Deliveries		
Seepage	0.81	0
Tailwater	14.24	17.50
Consumptive Use	15.50	15.50
Deep Percolation	3.20[1]	3.20
Total	33.75	36.20
Total Lateral Return Flows		
Surface Return Flows	14.24	17.50
Subsurface Return Flows	6.46	3.20
Total	20.70	20.70
Reduction in Salt Loading	142 m tons/year	
Downstream Benefit	$21,305	
Actual Cost	$ 8,686.03	
Benefit-Cost Ratio	2.45	

[1]A previous field drainage installation costing approximately $17,000 was installed on 4 ha of grass hay. Drain outflows indicate an annual flow of about 0.14 ha-m which has a salt load reduction equivalent of 3.7 m tons/year. The individual drainage benefit-cost ratio is therefore 0.03. For all of the EPA sponsored improvements on this lateral, this benefit-cost ratio is 0.57.

These cost-effectiveness figures, of course, represent an aggregate view of the salinity control feasibility in the Grand Valley. Of possibly more interest is the respective feasibility of the various alternatives for reducing salt loading. These might best be expressed in dollars per annual metric ton of salt reduction as shown in Table 29. Canal lining and desalting feasibilities are discussed by Walker (1977) and only a general consideration will be given herein. The cost-effectiveness values given in Table 29 are generally lower than figures reported by Walker (1977) primarily because various overhead costs have not been included (i.e., design, specifications, contract negotiations, etc.). It is interesting to consider these individual alternatives in a general sense and also include others that might be applied.

TABLE 29. SUMMARY OF COST-EFFECTIVENESS ASSOCIATED WITH INDIVIDUAL LATERAL SALINITY CONTROL ALTERNATIVES IN GRAND VALLEY[1]

Improvement Cost-Effectiveness $/annual ton

Lateral No.	Slip Form Concrete Linings: Lateral	Slip Form Concrete Linings: Head Ditch	PVC Pipe Lateral Linings	Gated Pipe Head Ditch Linings	Sprinkler Irrigation	Drip Irrigation	Automation Cut-back Furrow Irrigation	Field Relief Drainage	Total For Lateral
HL C	--	--	--	--	--	--	--	438	438
HL E	--	--	17	--	464	--	--	--	164
PD 177	42	72	36	59	--	308	--	--	50
GV 92	49	--	32	--	--	--	--	--	35
GV 95[2]	20	88	29	93	257	--	--	18,000	75
GV 160	10	98	12	--	--	--	--	7,017	24
MC 10	52	195	33	68	--	--	82	7,070	67
MC 30	68	68	71[3]	25[3]	--	--	--	4,600	176

[1]MC 3 was not incuded because no direct cost-effectiveness analysis could be made.

[2]Some tailwater ditches were lined with concrete ($327/ton) and pipe ($722/ton).

[3]Added to existing system to provide better irrigation uniformity.

Conveyance Channel Linings

The conveyance system in the Grand Valley consists of canals and ditches, laterals, farm head ditches, and tailwater ditches. With the possible exception of the canals and ditches, linings to reduce seepage may be implemented through either slip form concrete or PVC plastic irrigation pipe. The larger conveyance channels probably could not be feasibly lined with pipe, but would most likely be lined with slip form concrete, gunite, or a buried membrane.

Canal lining costs based on information developed locally by the Bureau of Reclamation were analyzed and reported by Walker (1977). The marginal cost-effectiveness of canal lining, assuming an optimal lining schedule among respective canals and ditches, ranged from $190 to $700 per metric ton of reduction in annual salt loading. Viewing the values presented in Table 29 as approximations to marginal cost-effectiveness shows that only field relief drainage was less feasible than canal lining. In those canals or ditches where seepage rates are comparitively high, canal lining would exhibit its most favorable cost-effectiveness posture, but probably will remain poorer than lateral and on-farm improvements.

The lateral system can be lined with either concrete slip form linings of PVC pipe with little or no economic difference. Individual circumstances would dictate such decisions. Laterals serving several irrigators will operate almost continually and would, therefore, have higher seepage losses than single user laterals (compare Laterals MC 10 and MC 30 for instance). Pipelines offer a number of advantages over concrete linings which affect the respective choice. First, it can be buried to reduce interference with surface traffic, eliminate trash and debris dumping, allow easier field weed control, and, in general, is more aesthetic. Secondly, the installation specifications for grade are much less restrictive than for concrete linings, thereby reducing the investigative and engineering requirements. Thirdly, individual irrigators can readily install pipelines themselves, which provides much greater implementation capacity than for the almost exclusive contractor requirement of concrete linings. And finally, pipelines tend to preserve hydraulic head, thus providing greater flexibility for water management at the farm turnout. A major disadvantage of pipelines in the Grand Valley situation is irrigator acceptance. Many irrigators prefer to see the water flow in order to identify maintenance needs and insure equitable division among individual turnouts. Existing maintenance standards would be inadequate for PVC pipelines, and local knowledge concerning flow measurement is relatively poor. Pipelines carry an added maintenance responsibility for the irrigators that is not required with concrete ditches. Many problems were experienced with the propeller type flow meters that were used. Debris and sediment and pipe flow conditions have to be exactly controlled, requiring a comprehensive maintenance program.

Field head ditches might be eliminated by conversion to sprinkler or drip irrigation systems, but will be most likely improved with either concrete linings or replaced by aluminum gated pipe. Figures in Table 29 do not indicate a significant difference in these two alternatives, although gated pipe is best suited to diversion from piped laterals because of less head loss in diverting the flow into the gated pipe, as well as fewer problems with debris. The costs per unit of salt reduction for head ditch linings are two to three times higher than lateral linings because of small average flows and more infrequent use. Automation is easily accomplished to improve the effectiveness of irrigations as illustrated by the cut-back system under Lateral MC 10 (Evans, 1977).

On-Farm Improvements

Nearly any field in the Grand Valley can be irrigated much more efficiently if the amount of applied water during the first two irrigations could be controlled. However, the added labor in these two irrigations would be almost double that for the existing practices (Skogerboe et al., 1974a). The soil infiltration rates for subsequent irrigations are low enough that inefficiency is difficult to achieve given the deeper rooting depths and higher E_t requirements, so little or no additional effort would be needed. Unfortunately, irrigation scheduling experience locally indicates that early season irrigations cannot be effectively controlled simply by suggestion.

The options controlling the salinity generated by deep percolation include the following:

1) automation of existing furrow irrigation systems;
2) conversion to sprinkler or drip irrigation systems; and
3) field relief drainage.

Tailwater recycling is a measure to improve the efficiency of on-farm water use, but would not significantly impact deep percolation and salinity loading to the Colorado River.

Automation of head ditches or gated pipe is an alternative with very strong qualifications in the Grand Valley. As noted previously, the low soil infiltration rates maintain irrigation efficiency at a high level except during the early growing season. Automation effectively replaces the added labor requirement during this period, making substantial improvements feasible. Automation also implies more rigid system design, which increases the ease involved in applying irrigation scheduling recommendations.

Replacing existing furrow or flood irrigation techniques with either drip or sprinkler irrigation has a direct advantage. Head and tailwater ditches can be effectively eliminated, which effects a significant salinity impact, and the soil no longer acts as a controller since application rates are generally lower than the infiltration rates. Irrigators responded well to scheduling suggestions and proved that water could be saved and production increased. Drip irrigation is ideally suited for the Grand Valley orchards (but lacks the frost protection or cooling capabilities of sprinklers), while the sprinkler systems will work well on the agronomic crops. Costs will be high to implement these conversions, but the effectiveness can also be substantial.

Field Drainage

Field drainage should primarily be installed for reclaiming saline croplands. As strictly a salinity control measure, field relief drainage is so much more expensive than other salinity control alternatives that this means of salinity control should never be implemented.

SECTION 10

LOCAL INSTITUTIONAL ASPECTS OF SALINITY CONTROL

PERMIT APPROACH

One of the objectives of this research project is to analyze the effects of various "local" institutional influences upon salinity control. The work under this objective was to include an evaluation of the effects of tailwater runoff control, the impact of a permit program, as well as evaluating the alternative of setting "influent" standards. Earlier experience with the Grand Valley Salinity Control Demonstration Project had indicated the necessary direction for a salinity control program, which dictated to a large extent the experimental design for the research and demonstration project discussed in this report. The discussion that follows is an attempt to document in a simplistic and not elaborate manner the necessary thrust for a salinity control "permit" program in Grand Valley.

EPA Permit Program

The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) created a permit system for discharges from point sources under Section 402 called the National Pollutant Discharge Elimination System (NPDES). Through the permit program, point source discharges are to be identified and their discharges monitored to ensure that the effluent discharge limitations are maintained. The permit defines the obligations of the permittee in complying with effluent limitations tailored to the specific conditions of the permittee. Also, the permit sets out a compliance schedule to be followed by the permit holder.

Because irrigated agriculture was not excluded under Section 301 of P.L. 92-500, it became subject to the permit program. Between 1973 and 1975, regulations for a permit program pertaining to irrigated agriculture were issued. There was considerable backlash from irrigators and irrigation-oriented organizations regarding the inappropriateness of such a permit program. More recently, in 1976 and 1977, EPA has proposed a new General Permit Program for irrigated agriculture.

The proposed new approach provides that water pollution from most agricultural activities is considered nonpoint in nature and thus not subject to any permit requirements. However, discharges of pollutants into navigable waters through discrete conveyences, which result from the controlled application of water, are considered agricultural activity point sources.

Agricultural activities, particularly irrigation, which result in surface discharges:

1) which contain pollutants;

2) which result from controlled application of water by any person, and which are not caused or initiated solely by natural processes of precipitation;

3) which are discharged from a discernible, confined and discrete conveyance; and

4) which are directly discharged into navigable waters;

are subject to regulation under Section 402, the NPDES permit program.

Clearly, this definition would apply primarily to irrigation return flow ditches and drains. Although these ditches are considered point sources, in most cases there are no conventional permit requirements at this time. Because of the lack of pollution control technology, discharges of agricultural wastes from agricultural activity point sources are proposed to be permitted by general permit(s).

On July 12, 1976, the EPA issued regulations which subjected agricultural activities to general rather than individual water pollution control permits. A point source is defined in the agricultural category by these regulations as any discernible, confined and discrete conveyance from which any irrigation return flow is discharged into navigable waters. Irrigation return flow is defined as "surface water, other than navigable waters, containing pollutants which result from the controlled application of water by any person to land use primarily for crops, forage growth, or nursery operations." These regulations recognized that water pollution from most agricultural activities is considered nonpoint in nature and thus not subject to any permit requirements.

The above discussion illustrates that the difficulties in implementing a permit program for irrigation return flow quality control have been more fully recognized in the last few years. The discussions that follow serve mostly as an argument for the more recent action taken by EPA. This argument will be followed by a discussion of the advantages of using influent standards, which could conceivably be included as an extension of the presently proposed EPA General Permit Program.

Nature of the Salinity Problem

Salinity problems from irrigated agriculture are the result of subsurface return flows consisting primarily of: (a) seepage losses from channels such as canals and laterals; and (b) deep percolation losses from croplands. These sources of irrigation return flow would be considered nonpoint; however, some portions of these subsurface return flows could be intercepted by open or tile drains or pumps which would then be considered point sources.

The NPDES permit program focuses upon the control of point sources of pollution. The primary point sources of irrigation return flow are canal bypass water, tailwater runoff, and collected drainage flows. These point sources are conveyed in channels and could therefore be subjected to the provisions of a permit program.

For the Grand Valley, the question becomes whether or not the implementation of a permit program to control point sources of irrigation return flow will have a significant impact upon subsurface irrigation return flows, which are the cause of increased salt loads reaching the Colorado River. In order to provide an answer to this question, as well as illustrate the magnitude of a permit program for Grand Valley, the following argument discusses tailwater runoff and drainage return flow.

Tailwater Runoff and Drainage

The combination of heavy soils having low infiltration rates and being "water rich" has resulted in a tremendous number of tailwater runoff discharge points in Grand Valley. These discharges are frequently reused by nearby farmers, dumped into adjacent laterals or canals and conveyed to other farms, or dumped into open drains or natural washes which convey return flow to the Colorado River.

Examples from the lateral improvement program will illustrate the number of tailwater runoff discharge points and the utilization of these discharges. Before construction, Lateral GV 95 and 6 points at which tailwater runoff was received from other laterals (in 1976 this was close to 40 percent of the total inflows to the lateral), 7 points at which tailwater was received from other users on this lateral for reuse, and 18 points where tailwater runoff was discharged into open drains or natural washes. After improvement, the number of discharge points was reduced from 31 to 30 (Figure 61).

Another example is Lateral GV 160, where there are 4 discharge points at which water is received from other laterals, 3 points at which water is returned to the lateral for internal reuse, 4 points where runoff is discharged to other laterals or canals and 15 points where tailwater runoff is discharged to

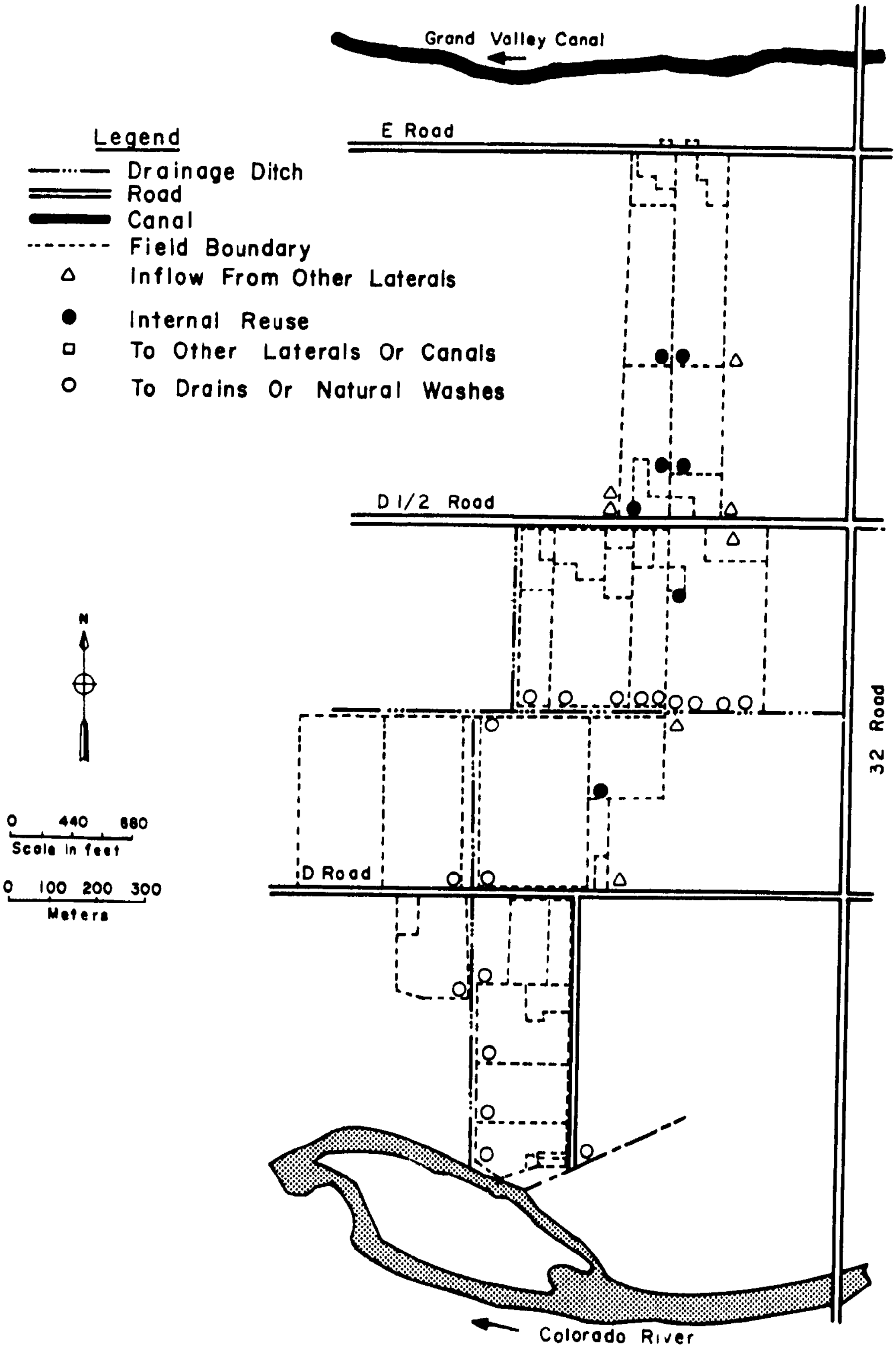


Figure 61. Identification of discharge points on Lateral GV 95.

drains or natural washes. There was no change in the number of discharge points due to the construction of lateral improvements on this lateral (Figure 62).

Before construction, for all of the nine laterals that were included in this improvement program, there were 17 points at which tailwater was received from other laterals, 21 points at which tailwater was received from other users on the lateral for internal reuse, 29 points at which tailwater runoff was discharged to other laterals or canals for reuse, and 60 points where runoff was discharged to drains or natural washes. After construction, there were still 17 points at which tailwater was received, 21 points for internal reuse, 31 points of discharge to other laterals on canals, and 58 points of discharge to drains or washes leaving the total number of discharge points unchanged at 127. These results are for an irrigated area of 275 hectares and 137 fields.

Taking into consideration the number of irrigated fields (approximately 8,500) in Grand Valley, and the size distribution of these fields, it is estimated that there are more than 15,000 individual discharge points within the irrigated area of the Grand Valley. To control tailwater runoff by permitting individual farmers would require an estimated 15,000 permits for an irrigated area of 29,000 hectares. In contrast, if each lateral and drain were permitted, less than 1,600 permits would be required. The irrigation companies could assume the responsibility for becoming the permittees, but at this time claim no responsibility below the turnout gate which discharges water from the company canal into the individual lateral.

The Grand Junction Drainage District has constructed 35 open drains (which discharge directly to the river) throughout much of the valley to convey irrigation wastewater. In addition, there are nine major natural washes on the north side of the valley which convey irrigation return flows and rainstorm runoff to the Colorado River. No individual or organizational entity will claim responsibility for these natural washes.

In the demonstration area, field measurements have shown that approximately 22 percent of the flows in the drains and washes consist of subsurface return flows intercepted by these channels, while the major portion of the saline return flows reaching the Colorado River are not conveyed by these drains and washes. If it were possible to set effluent standards for tailwater discharge, or the flows in drains and washes, such standards could only be partially successful in reducing the salt load contribution from Grand Valley.

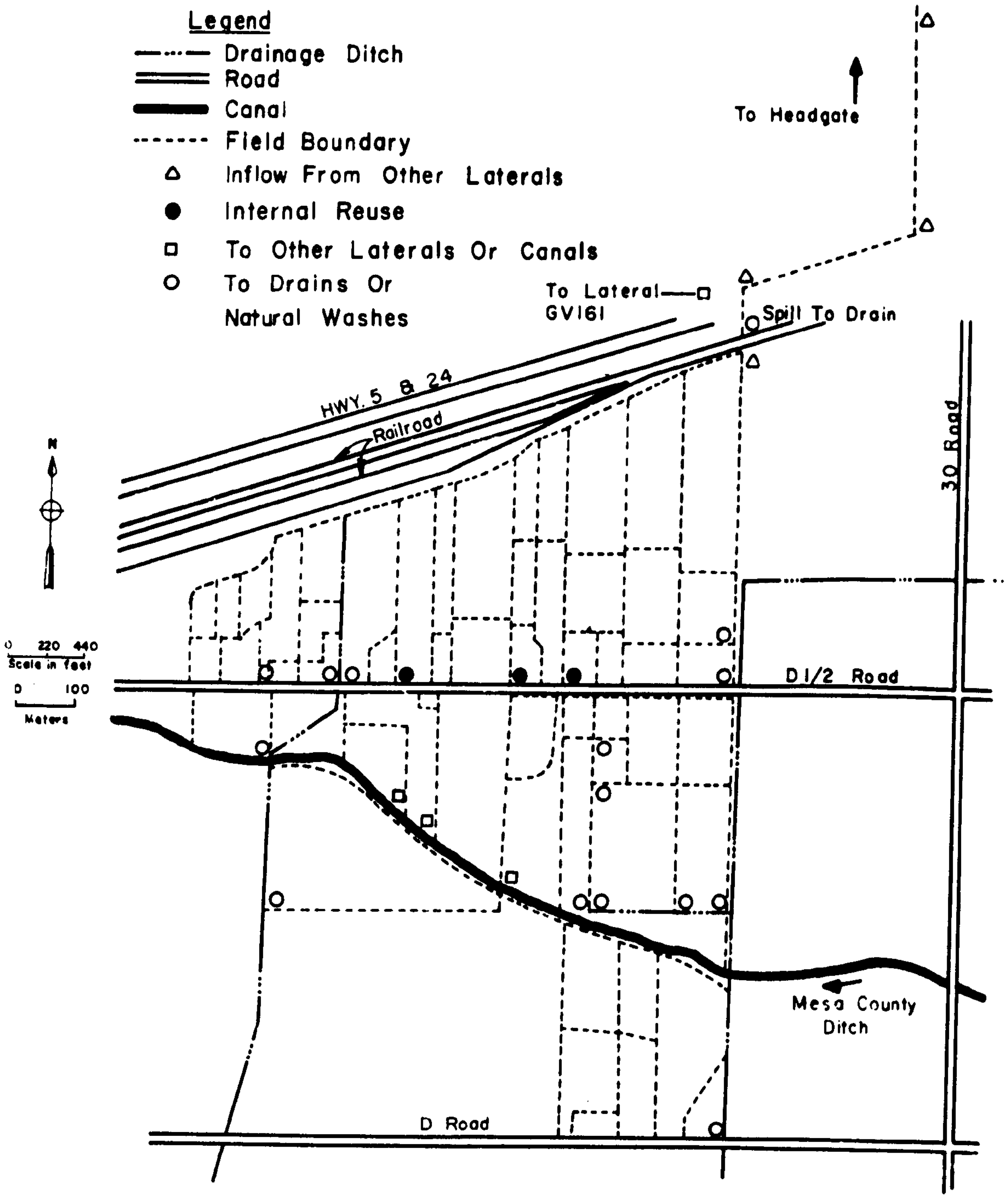


Figure 62. Identification of discharge points for Lateral GV 160.

Influent Standards

As stated earlier in this report, this research and demonstration project used each lateral as a subsystem because this provided control at the lateral turnout gate. This turnout gate is a critical control point in the irrigation system because it represents the terminal point of responsibility for most of the irrigation companies in Grand Valley (in some cases, under the Grand Valley Water Users Association, there is responsibility along the upper portions of the lateral). In turn, the control point for each irrigation company is the point of diversion from either the Colorado River or Gunnison River. The responsibility for these river diversions belongs to a water commissioner who is a state employee. The amount of water discharged at each turnout gate is the responsibility of water masters or ditch riders, who are employees of the particular irrigation company.

Generally, the water users under each lateral are not formally organized. However, in many cases, they have developed good relations among themselves in developing a water rotation, or each user gets the water on a continuous basis. There are also many cases in which there is friction regarding the distribution of the irrigation water supplies, which is aggravated by the lack of flow measuring devices along the lateral for equitable distribution of the water supply. Compounding this situation further are the numerous unmeasured tailwater runoff discharges which are returned to the irrigation water supply or picked up by neighboring farmers.

In the demonstration area, the lands under the Stub, Highline, and Price Ditches have the water rights tied to the land at 0.5 Colorado miners inch/acre continuous flow (38.4 Colorado miners inches = 1.0 cfs or 1 Colorado miners inch = 0.74 l/s). The water users served by the Grand Valley Canal and Mesa County Ditch have shares (1 share = 0.4 Colorado miners inch or 1 share = 0.30 l/s) which can be traded, sold, rented or transferred anywhere in the system.

The most common concept about water rights (or water duty) in the project area is an old rule-of-thumb that 1 share per acre (or the 0.4 to 0.5 Colorado miners inch) is adequate for proper irrigation and almost every farmer was sure his diversions were close to that amount. There are, however, only crude measurements of the water diverted from the canals into the laterals and, consequently, very little awareness as to the "actual" water quantities used.

When numerous flow measurement devices were installed in the project, most people found that they had been receiving 2 to 3 times their water allotment. After seeing their true rights, most irrigators stated that . . ."I cannot irrigate with my shares only". . . and immediately asked if they could get more water. In order to facilitate these requests, allow rotation flexibility, and meet peak water demands, the systems were over-designed based upon the water rights allocations. Proper operation of the improved lateral subsystems will result in significant diversion reduction as compared with diversions prior to this construction program.

An initial influent standard goal should be the intended water duty for the irrigated lands. This should be measured at each farm inlet, which can then be translated back to the lateral turnout gate taking into consideration lateral seepage losses (which could be essentially ignored if the laterals were lined or converted to pipelines). An important consideration should be to use either a volumetric water duty as a standard, or a variable flow rate which is dependent upon the changing water requirements of the crops during an irrigation season.

The approach of using influent standards has the advantage of alleviating the salinity problem by improved water management practices, rather than end-of-pipe treatment, or partially reducing the salt load by using effluent standards under a permit program. The success of an influent approach is dependent upon: (a) use of numerous flow measuring devices; (b) adequate technical assistance for working with and advising farmers on improved irrigation practices and methods; and (c) availability of funds for making the necessary structural improvements. The fear of loss of a water right, either by individual irrigators or the irrigation companies, will likely be the greatest constraint in implementing a valley-wide salinity control program.

TECHNOLOGY TRANSFER

Along with the research and demonstration programs, a major objective of this project has been the development of vehicles for transfer of technologies and technical packages to other irrigated areas of the Upper Colorado River Basin and regions in the western United States. Considerable experience has been gained in working directly with farmers during the life of the Grand Valley project. These experiences and farmer feedback during the Irrigation Field Days plus research findings provide a basis for the development of some broad guidelines for an extension program to facilitate the transfer of research findings to other irrigated areas in Colorado and the West.

Given this purpose, the specific objectives of an extension program are as follows:

1) encourage farmer participation;

2) train field personnel;

3) organize water users;

4) develop basic farmer training materials;

5) recognize the efforts of farmers; and

6) evaluate extension activities.

This section of the report provides a brief discussion of suggested means to attain these objectives. This includes methods to obtain farmer participation, the training of field-level personnel, the development of basic training materials, and methods for encouraging farmer organizations. The underlying philosophy and assumptions of the discussion are: (a) that the findings of the present research and improvement activities at Grand Junction are applicable for other irrigated regions; and (b) that a successful comprehensive salinity control program requires active farmer participation.

Farmer Participation

One of the unique characteristics of improving on-farm water management is that the degree of success is highly dependent upon the degree of participation of each individual farmer, as well as their ability to cooperate collectively for the common good of all water users. The construction of on-farm physical improvements only provides an increased potential for water use efficiency, whereas the degree of potential that will be achieved is dependent upon the operation and maintenance of the physical improvements. This, in turn, is dependent upon the level and ability of technical assistance provided, farmer attitudes, and the degree of credibility between those individuals providing the technical assistance and the farmers involved.

Credibility and acceptance by the farmers begins when the basic training and motivational materials are initially used to describe the problem. Efforts to organize the water users under each lateral provide an opportune time to develop early rapport with the farmers. Credibility and acceptance of the technical personnel by farmers during the planning and implementation of individual farm plans for improved water management is essential to the long-range goals of a control program. Credibility and good communication must exist during the collective negotiations in determining the physical improvements to be made on a lateral. Farmer participation is crucial during these stages in order to evolve a plan of development which is acceptable to the water users and also satisfies the goals of the salinity control program.

The final step in this process dictates the real success of the entire program. After spending vast sums of money to construct physical improvements, the test of effectiveness revolves largely around the operation, management, and maintenance of these improvements. This is the phase of the work where the rapport developed with the farmers pays huge dividends. Unfortunately, this step is very time-consuming and most frequently neglected. Considerable evaluation is required to "tune-up" these new improvements so that they are operating at their potential, and the key variable in this operation is the farmer decision maker.

Training Field Personnel

The primary agency providing technical assistance to farmers for a salinity control program will likely be the Soil Conservation Service (SCS). The SCS will likely cooperate with the U.S. Bureau of Reclamation (USBR) in the provision of required technical assistance. Given the levels of manpower needed to work with farmers, and the current shortage of trained manpower with on-farm water management experience, special short courses for training personnel will likely be required. As a complement to technical competence, personnel working directly with farmers should know how to develop good working relationships with farmer clients and have definite skills and knowledge related to organizing farmers into water user associations for action programs. Personnel also must have the capabilities required for assisting farmers in "tuning-up" furrow irrigation practices and the maintenance of improved conveyance systems. Also, technical assistance to farmers will include convincing them to use "scientific" irrigation scheduling procedures and other improved irrigation practices.

The focus on improved irrigation scheduling is essential because the existing piece-meal methods of scheduling in Grand Valley have been found to be inadequate as an individual salinity control measure.

Water User Organizations

A crucial element in implementation of an effective salinity control program is gaining the participation of the users. The unit of organization should be the lateral system because it is a natural hydrologic unit where farmers know each other and interact on a day-to-day basis. In Grand Valley, the jurisdiction of the irrigation companies does not include the laterals in most cases; so, there is an organizational vacuum for most laterals. The goal should be to gain participation by all water users on each lateral. This may not always be possibly due to human problems. While the organization could be on an ad hoc or informal basis, experience indicates that it is probably best to aim for a formal organization with rules developed by the members themselves. A formal organization with its own rules and regulations also makes it easier for the implementing agency because all parties have a knowledge of the structure and mechanisms involved. When the leadership is defined, this facilitates the work of the implementing agencies.

For example, the water users on several laterals in the Grand Valley have organized formally as nonprofit mutual irrigation companies under the state laws of Colorado. One problem the members of these associations have encountered has been lawyer fees for incorporation. This can be partially overcome by providing model sets of bylaws and other provisions to farmers considering such organization. In fact, alternative models can be provided farmers, and they should decide the set of rules and regulations which meet their special needs for the most effective means of operation and maintenance of the lateral system. These models could be provided in a well-prepared manual or booklet and made available to interested farmers. The booklet should explain the benefits of formal organization, how to organize legally, and the types of bylaws and provisions required. It is important that such a booklet be well illustrated and in easily understood language. Often such booklets are not well prepared and contain too much legal jargon which farmers cannot fully understand. The goal is to design usable materials on how-to-do-it for the farmer audience.

Basic Farmer Training Materials

Materials are needed to motivate farmers and help them understand the importance to themselves and their communities of improving present water management practices for increased crop production and the control of salinity.

Data obtained in problem identification and alternative solutions to the problem should be utilized in preparing well-illustrated materials for farmers. These materials should graphically and clearly define the problem, explain its consequences, document the contributing factors, and explain the costs and benefits. Alternative solutions should be carefully delineated and estimated costs presented.

Techniques for such communications could include slide shows, an easy-to-read booklet, and selected use of local mass media channels. The slide show developed for the Grand Valley project has been well received and has been presented many times in the community at special public meetings and for civic groups. Also, selected use of local mass media has been found to be useful. Since a comprehensive salinity control program requires changes in attitudes and behavior wherever such programs are proposed, the first major consideration should be the design of definite communication strategies. To make the program successful in reaching all water users and the community, several complementary communication methods should be used over time to reinforce the central messages. Local conditions and communication sources and channels need to be identified and used with imagination.

Essentially, salinity control is a problem of water conservation which requires much education on the part of farmers and communities.

Farmer Client Recognition

The Irrigation Field Days held at Grand Valley, and other experiences, have demonstrated the importance of farmer recognition. Farmers usually can sell a program to other farmers more successfully than public officials. Where possible, farmers should be given special recognition, because the success of any salinity control program rests finally with the degree of participation by the farmers themselves. There are a number of methods which can be effectively utilized for using farmer recognition to motivate other farmers.

The proper use of radio and television announcements and newspaper articles can be of considerable help in fostering enthusiasm for the program. The local newspaper provides excellent coverage on news related to natural resources and agriculture. Local newspapers in Grand Valley have been very helpful and always willing to include news articles pertaining to the Grand Valley Salinity Control Demonstration Project. The television station and some radio stations in Grand Junction have cooperated with the project in disseminating news related to the salinity control research activities.

The news media, in addition to news reports about current activities of the salinity program, are also very interested in covering human interest stories. If these human interest reports and farmers' testimonials are well prepared, they can create much interest in other farmers for the programs. Such publicity is free and probably can generate better image-building for state and federal agencies than they can do for themselves.

Awards should be given to those farmers who have made exceptional progress in improving their on-farm water management practices. Awards for providing leadership in the water user association under each lateral should be considered. Awards presented to each water user served by the lateral demonstrating the most efficient use of water would be highly effective in promoting the goals of an improvement program. News media coverage of such awards also provides additional incentives for improved water management on the part of other farmers. Framed photographs of farmers engaged in improvement activities with an inscription could be considered for presentation. Plaques could be presented to cooperators to show appreciation for their contributions.

An excellent method of using farmers for promoting wide interest in a project once substantial progress has been made in an improvement program is the use of field days. In the Grand Valley, a Field Day could be held annually which would involve strong participation by local farmers. Water users and irrigation company leadership from other valleys in the Upper Basin could be given special invitations to attend the Field Days in order to observe firsthand the implementation of a salinity control program. In addition, special tours could be arranged during other times of the year for a group of irrigators from any particular area to visit the Grand Valley and meet with farmers who have participated in the program. The emphasis should be farmer-to-farmer interaction with the Grand Valley farmers being highlighted rather than technical assistance personnel. These personnel, however, should play a strong backstage role in facilitating this interaction.

Evaluation of Extension Activities

It is not sufficient to randomly develop extension and promotional activities for the transfer of technologies for salinity control improvement programs. Technical personnel in such projects should be given short courses in skills needed for working effectively with farmers. Extension communication strategies should be designed into the project proposal and work plans in order that various techniques can be effectively evaluated. While technical expertise for such programs is usually adequate, there is a general weakness in designing and evaluating extension communication strategies. As stated often in this report, the key variable in achieving successful program implementation and long-term effective maintenance of improved systems is the farmer client himself. Since this is the case, professional assistance is required from extension or communication personnel to assure that sufficient attention is given to these important areas.

It is, therefore, recommended that communication techniques used for working with farmers as individuals and groups be designed into programs and evaluated to the same degree as the technical components and activities. Evaluative research techniques are available which, if properly utilized, can be used to determine the strengths and weaknesses of project implementation. Information from such evaluative studies is needed by sponsoring agencies and by project implementors to discover the most effective and efficient methods of working cooperatively with farmers.

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16. ABSTRACT

A summary of the results of applied research on salinity control of irrigation return flows in the Grand Valley of Colorado is presented for the period of 1969 to 1976. Salinity and economic impacts are described for the Grand Valley Salinity Control Demonstration Project which contains approximately 1,600 hectares and involves most of the local irrigation companies in the Valley. During the eight years of the demonstration project, 12.2 km of canals were lined, 26.54 km of laterals were lined, 16,400 meters of drainage tile were installed, a wide variety of on-farm improvements were constructed, and an irrigation scheduling program was implemented. On-farm improvements evaluated were solid-set sprinklers, side-roll sprinklers, drip (trickle) irrigation, furrow irrigation, and automatic cut-back furrow irrigation. The total value of the constructed improvements in the demonstration area was about $750,000. The total improvements resulted in a salt reduction of 12,300 metric tons per year reaching the Colorado River. This salt reduction results in an annual benefit to downstream water users of nearly $2,000,000. In addition, there are benefits to the local water users with increased crop yields, and to the people of Grand Valley in increased business.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Irrigation, Ditches, Irrigation canals, Salinity, Saline soils, Salt water, Seepage, Water distribution	*Irrigation (management, practices, effects, water, efficiency, systems), Grand Valley, Colorado River, Salinity control, *Return flow, Infiltration rates	98C

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