November 1969

WRRI Report 5

IRRIGATION

Water Requirements

for
Crop Production
Roswell Artesian Basin

FILE COPY

PLEASE RETURN

WATER RESOURCES
RESEARCH INSTITUTE

in cooperation with

AGRICULTURAL EXPERIMENT STATION

New Mexico State University
Las Cruces, New Mexico

PUBLICATIONS

A multilith series in four parts was published for the project *Irrigation Water Requirements for Crop Production, Roswell Artesian Basin, New Mexico*, as Water Resources Research Institute Report No. 4.

Parts I, II, and III contain the analysis and basic data for the subsections. Part IV is the overall project analysis and summary. These were published in limited numbers to be used as work copies and for reference and file copies, under the following titles:

**WRRI Report 4 – Irrigation Water Requirements for Crop Production,
Roswell Artesian Basin, New Mexico**

Part I–An Agronomic Analysis and Basic Data–June 1969
Part II–An Economic Analysis and Basic Data–June 1969
Part III–An Engineering Analysis and Basic Data–June 1969
Part IV–Project Analysis and Summary–June 1969

An additional publication, partially supported by funds from this project, was issued by the New Mexico Agricultural Experiment Station in cooperation with the Water Resources Research Institute:

Predictions of Crop Yields from Quantity and Salinity of Irrigation Water, by H. E. Dregne, Professor of Soil Chemistry, New Mexico State University (Agricultural Experiment Station Bulletin 543–March 1969). Information in this bulletin had an important bearing on several sections of Report No. 4, Parts I, II, and III.

IRRIGATION WATER REQUIREMENTS FOR CROP PRODUCTION,

ROSWELL ARTESIAN BASIN, NEW MEXICO

IRRIGATION WATER REQUIREMENTS FOR CROP PRODUCTION IN THE ROSWELL ARTESIAN BASIN, NEW MEXICO

This report, entitled "Irrigation Water Requirements for Crop Production in the Roswell Artesian Basin, New Mexico," was based on an interdisciplinary research project. It was conducted under WRRI No. 5700-306, through the cooperation of the New Mexico Water Resources Research Institute, the Agricultural Experiment Station, and New Mexico State University. Funds to support the work were provided in part by the Pecos Valley Artesian Conservancy District.

ACKNOWLEDGMENTS

Special appreciation is expressed to the following: U. S. Soil Conservation Service, especially work-unit personnel in Roswell, Hagerman, and Artesia, New Mexico; State Engineer Office; Agricultural Stabilization and Conservation Service personnel and the Agricultural Extension County Agents in Chaves and Eddy Counties; Robert Freeburg, Agricultural Engineer, for his work in 1966; the Pecos Valley Artesian Conservancy District Board; and finally to the farmers who participated in this study.

This report was authored by:

Robert R. Lansford, Associate Professor of Agricultural Economics
Carl E. Barnes, Assistant Professor of Agronomy
Bobby J. Creel, Agricultural Economics Research Aide
Eldon G. Hanson, Professor of Agricultural Engineering
Harold E. Dregne, Professor of Soils
Evan Carroon, Consulting Agricultural Engineer
H. R. Stucky, Director, Water Resources Research Institute

ABSTRACT

This interdisciplinary study presents information concerning crop and water management practices in the Roswell Artesian Basin, New Mexico, and their influence on water use, crop production, and returns.

Research was conducted at the Southeastern Branch Experiment Station at Artesia to evaluate the effects of six irrigation regimes on cotton production and four irrigation regimes on alfalfa production. The highest yield of cotton for the three-year study was obtained with an average of 24.77 acre-inches of irrigation water applied, while the maximum alfalfa forage yield in a two-year study was obtained with an average of 69.98 acre-inches of irrigation water applied.

Irrigation systems and practices were evaluated on 33 randomly selected units located throughout the Roswell Artesian Basin to study the water management factors associated with water diversions and application on farms and to identify sources of losses. A comparison was made to determine the relationship between the quantity of water pumped and percentages relative to land preparation, condition of crops, percentages of land fallow or planted in major crops, and varying characteristics of irrigation systems. There was a lack of correlation between water pumped and major factors which were thought to influence irrigation requirements. Other water management factors on individual farms, such as skill of operator and amount of water applied per irrigation among others, offset the influence of the above physical factors in water use throughout the basin.

The case study method was used to obtain detailed information on production requirements, costs, and returns for the principal crops produced in the Roswell Artesian Basin. Twelve study farms were selected.

Reservoirs on the case farms were surveyed and depth-storage relationships were drawn. Water seepage from two reservoirs caused losses of 9.65 and 10.8 percent of the total water pumped.

Data from test sites on two different case farms were presented to demonstrate the variations in management practices under similar soil and irrigation system conditions and the effect on crop yields. One farm diverted 45.47 acre-inches per acre in 14 irrigations and the second diverted 71.38 acre-inches per acre in seven irrigations to produce comparable per-acre yields of alfalfa.

Enterprise and whole farm budgets were constructed and compared with optimal farm organizations determined by the linear programming method for the 12 case farms. Three linear programming models were used: one model (model A) described the maximum net farm return obtainable with seven quantities of irrigation water (2.50 through 4.00 acre-feet per water-right acre); a second model (model B) described the maximum net farm return obtainable with a 5 percent increase in farm irrigation efficiency over model A with the seven quantities of irrigation water; and the third model (model C) described, for the specific quantities of irrigation water, the farm organizations and returns with an assumed crop rotation of about one-third of the water-right acres devoted to the production of alfalfa.

Three additional linear programming models were constructed based on data for the entire Roswell Artesian Basin: one model (model D) described the maximum net farm return obtainable with 10 quantities of irrigation water (2.25 to 4.50 acre-feet per water-right acre); a second model (model E) described the maximum net farm return obtainable with 52,940 acres or more of alfalfa; and the third model (model F) approached the actual cropping program with allowances for small adjustments in the cropping program.

Comparisons of the optimal farm enterprise organizations with the actual organizations indicated that: 1) net farm returns are not maximized under existing farm organizations, and 2) the diversion of 2.75 to 3.00 acre-feet of irrigation water per water-right acre would be required to maximize net farm returns in models A and B. In model C, the optimal quantity of irrigation water diversion would be between 3.75 and 4.00 acre-feet per water-right acre. In models D, E, and F the optimal quantity of irrigation water diversion would be between 2.25 to 2.50 acre-feet per water-right acre, 3.75 to 4.00 acre-feet, and 4.00 to 4.25 acre-feet per water-right acre, respectively.

CONTENTS

TABLES

Number | Page

Number Page

FIGURES

IRRIGATION WATER REQUIREMENTS FOR CROP PRODUCTION ROSWELL ARTESIAN BASIN, NEW MEXICO

Robert R. Lansford, Carl E. Barnes, Bobby J. Creel, Eldon G. Hanson,
Harold E. Dregne, Evan Carroon, H. R. Stucky

INTRODUCTION

Farmers in the Roswell Artesian Basin, as in other areas of New Mexico, are continually faced with the problems of adjusting to changing economic conditions. Some of the reasons for these problems are changes in resource and product prices, changes in technology, changes in enterprise alternatives, and changes in institutional factors. In addition, many farmers in this area are faced with the need for rapid adjustment of their farming operations to comply with a legal restriction placed on the quantity of ground water diverted for irrigation. To make this adjustment, farmers must have current information about resource requirements, production costs, and estimations of profit-maximizing enterprise combinations for various farm situations.

To supply current information on the above mentioned problems a three-year study was undertaken by the New Mexico Water Resources Research Institute in cooperation with the New Mexico Agricultural Experiment Station. This study was designed to obtain information on crops grown, yields, soil quality, water quality, types of irrigation systems, methods of irrigation, and amounts of water consumed by alfalfa and cotton, and to analyze these factors as they relate to the water requirements for crop production. A team composed of agronomists, agricultural engineers, agricultural economists, and soils specialists was selected to conduct the research. This is an overall summary report. A limited number of each of the separate reports on the agronomic, agricultural engineering, oils, and agricultural economics phases have been published for reference and data storage.

The several reports include the results obtained through carefully designed experimental procedures for the conditions found in the Roswell Artesian Basin during the period of the project, calendar years 1966, 1967, and 1968. These results may serve administrators, farmers, and other decision-makers to establish the specific water use allowable, types of farm rotations, and water management practices for the farmers in the area and for the basin as a whole.

HISTORICAL DESCRIPTION

Overexpansion in the use of ground water for irrigation has been a basic problem in the Roswell Artesian Basin since the beginning of major ground water development, about 1900.

The following is a reportorial review of the history of the three-acre-feet duty of water from the Statutes and Court Order.[1]

Section 22 of Chapter 64 of the New Mexico Session Laws of 1909, the first artesian-well law, limited the water use to three (3) acre-feet per acre per annum, in the following language:

> Sec. 22. The maximum amount of water that may be used on each acre of land under cultivation must not exceed three (3) acre-feet during the year. In order to properly determine the amount of water to be used on lands irrigated from each well, an actual measurement of the flow of each well shall be made between January 15th and February 15th, and between May 15th and June 15th of each year, taking an average of such measurement as a basis to figure the amount of time each man shall use his water.

This section was repealed in 1912.

Section 19 of Chapter 81 of the New Mexico Session Laws of 1912 limited the maximum amount of water from an artesian well that may be used on each acre of land to be irrigated to three acre-feet during any one year. This statute was subsequently repealed. After 1916, the level of artesian water began to decline rapidly. Provisions for legal restraints on the development of ground water were not enacted until 1931 (35, p. 71).

On August 21, 1931, the Roswell Artesian Basin was declared by the New Mexico State Engineer, to facilitate the orderly development of the area and to insure the protection of existing rights. After the declaration of the

[1]The Statute and Court citations have been reviewed by the attorneys for both the District and the State Engineer Office.

basin, new artesian wells could be drilled only after a permit was obtained from the state engineer. In addition, the reasonable annual diversion of ground water withdrawal was set by the state engineer at three acre-feet per acre (45, p. 5).

The rights to use of water from the Pecos River and its tributaries were adjudicated in Cause No. 712, Equity, in the United States District Court for the District of New Mexico, styled United States of America, plaintiff, *vs.* Hope Community Ditch, *et al.* The decree entered on May 8, 1933, limited the use of water to three acre-feet per acre per annum for the irrigated acreage in the Roswell area. Thereafter, the permits and licenses issued by the state engineer in the Roswell Basin contained a limitation of three acre-feet per acre per annum for the permitted or licensed acreage covered thereby.

Initially, new shallow water wells were permitted by the state engineer. Shallow water aquifers soon became a major source of irrigation water supply. On August 1, 1937, the basin was also closed to further development of the shallow water (28, p. 2).

Eight extensions in the area of the Roswell Artesian Basin have been made since 1931. Water levels have, nevertheless, continued to decline. Since the beginning of major irrigation development, water levels in the southern part of the basin have declined more than 200 feet. This has resulted in noticeable effects such as decreases in artesian and surface flows, increased pumping-lifts, and intrusion of salt water into fresh water aquifers (28).

The seriousness of these problems led to adjudication of ground water rights. In 1956 the state engineer and the Pecos Valley Artesian Conservancy District jointly filed suit to obtain a judicial determination of water rights, both artesian and shallow aquifers, in the Roswell Artesian Basin. The water rights were adjudicated in Cause No. 20294 in the District Court of Chaves County, State of New Mexico, styled *State of New Mexico, and the Pecos Valley Artesian Conservancy District* vs. *L. T. Lewis,* et al. No direct evidence was introduced in this case as to the proper duty of water required for irrigation of lands within the basin.

A companion suit was filed in the fall of 1958 to include the Hagerman Canal rights, and in 1965 this case was consolidated with the Lewis case. During the hearings on the rights in the basin it was found that about 142,000 acres of land were being irrigated, of which approximately 130,000 acres had valid rights (35, p. 72). Irrigation of the remaining 12,000 acres was declared illegal and eventually this land was removed from production. The court, on January 10, 1966, filed a partial final judgment and decree which further defined water rights in the Roswell Artesian Basin.

In the individual sub-file orders in the Consolidated Lewis and Hagerman case, the duty of water for irrigated agriculture was established at three acre-feet per acre per annum. The partial final judgment and decree therein declared that the duty decreed could

> . . . be exceeded in any one year provided that the total amount diverted during any period of five consecutive years shall not exceed five times the annual duty of water.

The court retained jurisdiction

> . . . to enter such supplementary orders for the enforcement and modification of this judgment as may be necessary.

Therefore, the court may permit the parties to introduce evidence and testimony as to what the duty of water should be in the Roswell Basin.

The court order also called for water meters to be placed on all irrigation wells by January 1, 1967. The order further provided for appointment of a watermaster to enforce provisions of the decree.

Acting on behalf of all water users in the Roswell Basin, the Board of Directors of the Pecos Valley Artesian Conservancy District entered into a contract in March, 1966, with the Water Resources Research Institute, New Mexico State University to conduct a study in the Roswell Basin. The study was to be based upon the then existing cropping pattern for the purpose of determining what duty of water was necessary for successful farming operations under such a cropping pattern. It was anticipated by the district that the results of this study would be used in reopening the partial final decree to establish what the proper duty of water should be.

Many farmers historically have diverted more irrigation water than the current annual allotment of three acre-feet per water-right acre. The rate at which use exceeds recharge into the Roswell Artesian Basin is indicated as follows: the natural annual recharge of ground water aquifers is about 265,000 acre-feet, of which about 115,000 acre-feet are naturally discharged. A balance of 150,000 acre-feet remains available for consumptive use (36, p. 80). The average total pumpage from this area for 1960-1964 was 441,600 acre-feet per year (see table 4). About 270,000 acre-feet were consumed and the remainder was returned to the underground aquifers. The consumptive use exceeded available recharge by about 120,000 acre-feet annually (36, p. 80).

Total metered water diverted, exclusive of surface water diverted under the administration of the Pecos River Watermaster, in 1967 was 387,361.5 acre-feet (17) and in 1968 it was 339,124.5 acre-feet (18). Part of the increased water diversion per water-right acre has resulted from changes in the cropping pattern. Lansford and Simkins (26) in 1966 concluded, from an analysis of 60 survey farms in the basin for the years 1948 to 1966, that the percentage of all crops except cotton and alfalfa remained fairly constant during the preceding 20 years (table 1). Cotton acreage, however, decreased as a consequence of acreage allotments under the government cotton program. The acreage of alfalfa tended to increase and replace the reduced cotton acreage. Because

Table 1. Estimated cropping pattern for the Roswell Artesian Basin for selected years, 1948-1966.

Year	Cotton	Alfalfa	Diverted and Fallow	Small Grains	Other Crops	Total
	(percent)	(percent)	(percent)	(percent)	(percent)	(percent)
1948	60.6	27.8	0.1	6.0	5.5	100.0
1950	44.8	36.0	0.6	9.5	9.1	100.0
1954	41.2	40.1	0.5	10.4	7.8	100.0
1959	38.6	44.9	1.4	5.7	9.4	100.0
1961	37.8	47.9	0.4	6.0	7.9	100.0
1963	33.5	50.2	2.0	5.1	9.2	100.0
1965	33.3	52.6	3.5	2.5	8.1	100.0
1966	25.7	50.7	12.1	2.6	8.9	100.0

Source: Lansford, Robert R., and Arthur R. Simkins, "Cropping Patterns in the Roswell Artesian Basin, 1948-1966," (Unpublished Data, Department of Agricultural Economics and Agricultural Business, New Mexico State University, 1967).

alfalfa is a major crop in the basin and has a high water requirement, many farmers are faced with the need to adjust their cropping patterns, particularly with respect to alfalfa, to comply with the reduced quantity of irrigation water for a total of no more than 15 acre-feet per acre pumped in any period of five consecutive years.

OBJECTIVES OF THE STUDY

The objectives of the overall project as stated in the agreement between the Pecos Valley Artesian Conservancy District entered into March 10, 1966, and the New Mexico Water Resources Research Institute were:

1. To assemble and analyze existing cropping patterns, water use, water quality, soil quality, and crop yields for the Roswell Underground Water Basin.
2. To determine the water requirements of crops, of farms, and of the basin under various irrigation methods, efficiencies, and cropping patterns.
3. To determine farm and basin income effects from various irrigation methods, efficiencies, and cropping patterns.

DEFINITION OF TERMS

Specialized terms used in this report are defined in the glossary.

DESCRIPTION OF THE BASIN

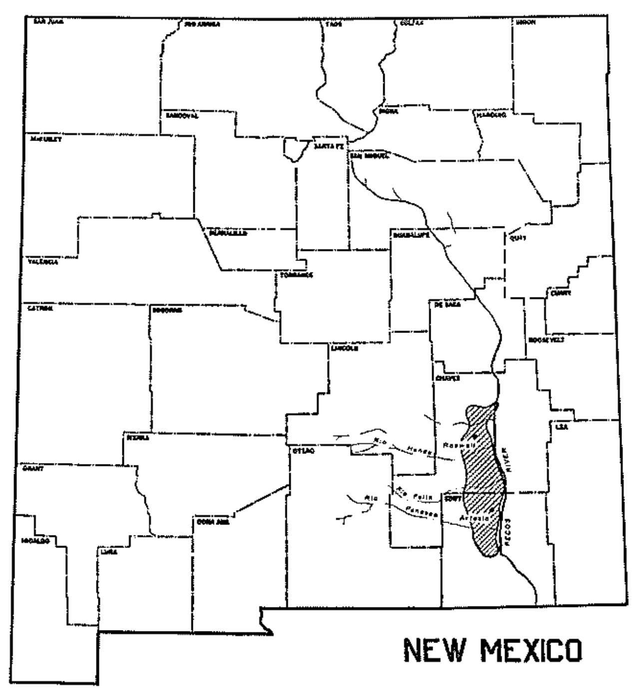
Location

The Roswell Artesian Basin is located in the Pecos River Valley in southeastern New Mexico (figure 1). The natural boundaries of the basin extend from near Vaughn on the north to Seven Rivers Hills on the south, and from the summit of the Sacramento Mountains on the west to a few miles east of the Pecos River on the east. For administrative purposes the New Mexico State Engineer has established definite boundaries for the Roswell Astesian Basin that are considerably smaller than the natural boundaries. The declared basin lies mainly along the west side of the Pecos River in Chaves and northern Eddy Counties; the remainder is in eastern Lincoln and Otero Counties. It ranges in width from approximately 4 to 66 miles, and extends about 114 miles from north to south.

At present, the declared basin encompasses an area of about 4,280 square miles. However, only a small part of this area is irrigated cropland. The principal irrigated area of the Roswell Basin is west of the Pecos River (figure 2), and extends from 24 miles north of Roswell to 24 miles south of Artesia and ranges from 6 to 8 miles in width. In the vicinity of the tributaries of the Pecos River, the irrigated area extends westward from the Pecos River as much as 20 miles.

Climate

The climate is semiarid with low average annual precipitation, low relative humidity, high temperatures, and persistent wind movement. Winters are usually mild and dry but heavy snows and extremely low temperatures have been experienced. The average annual precipitation (1931–1968) was 11.18 and 10.73 inches at



Study area–Roswell Artesian Basin

Figure 1. Location of study area.

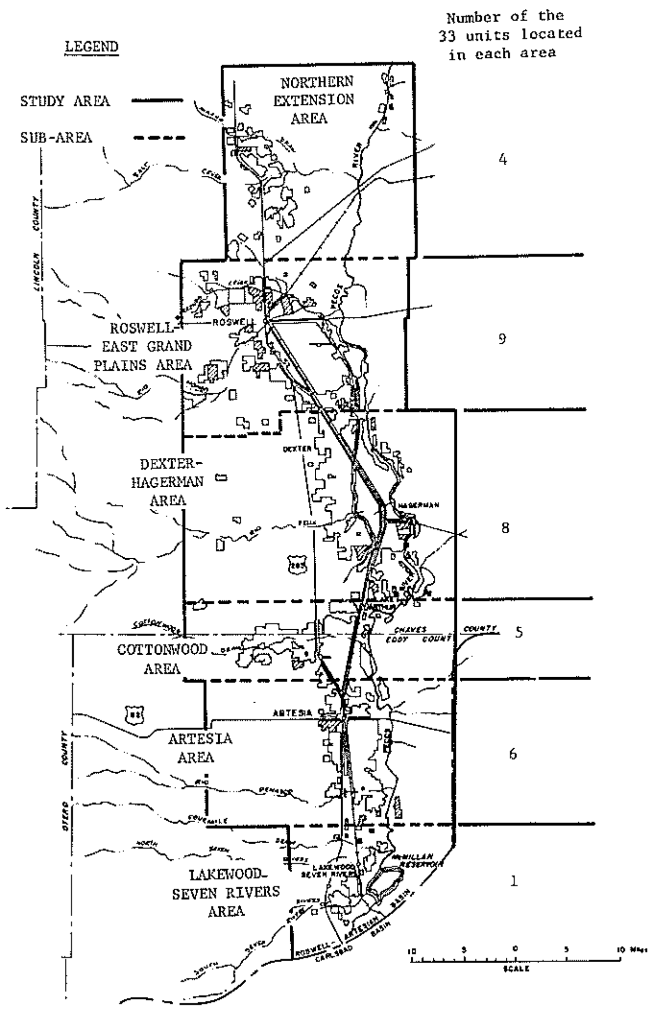


Figure 2. Location of irrigated cropland by sub-areas and respective random sample units in each, Roswell Artesian Basin, New Mexico, 1966-1968.

Roswell and Artesia respectively, and the average temperature was 57.6°F and 61°F for Roswell and Artesia (table 2) (7, 37, 46).

At Roswell, in the northern portion of the basin, the annual precipitation for 1966, 1967, and 1968 was 9.68, 11.06, and 15.84 inches respectively (table 2). In 1966 precipitation was 1.5 inches below the 1931–1968 average, 1967 was about average, and 1968 was 4.66 inches above average.

At Artesia the annual rainfall for the same years was 10.68, 4.90, and 13.96 inches respectively (table 2). In 1966, rainfall was about average, 1967 was considerably below average (4.90 inches), and 1968 was about 3 inches above average.

The average annual temperature at Roswell was 58.8, 59.8, and 57.6°F for 1966, 1967, and 1968 respectively. Two of the three years, 1966 and 1967, were above the 1931–1968 average while 1968 was average. At Artesia the average annual temperature for these years was 58.9, 59.7, and 58.8°F respectively, which was slightly below average.

The growing season or number of frost-free days for the three years was below average for both Roswell and Artesia. Roswell's frost-free period was 178, 168, and 169 days, and Artesia's was 191, 169, and 152 days for the same period. At Roswell the average date for the last spring frost is April 8, and for the first fall frost, October 28. At Artesia the last spring frost averages April 7, and the first fall frost averages November 1 (table 2). For 1966, 1967, and 1968 at both Roswell and Artesia the last spring frost occurred in late April or early May except year 1966 at Artesia. This reduced the growing season by approximately two weeks. The first fall frost typically occurs about the first of November; however, during the three-year study period, the average was about two weeks early with the first frost occurring as early as September 28. The end result was a loss of approximately one month of growing season.

Table 2. Precipitation, temperature, and growing season for 1966, 1967, and 1968, three-year average, and long-time average at Roswell and Artesia, New Mexico.

	1966	1967	1968	Average: Three Year (1966-1968)	Average: Long-Time (1931-1968)
Precipitation: (inches)					
Annual total					
Roswell	9.68	11.06	15.84	12.19	11.18
Artesia	10.68[1]	4.90[1]	13.96	9.91	10.73
Temperature: (°F)					
Average annual					
Roswell	58.8	59.8	57.6	58.7	57.6
Artesia	58.9[1]	59.7[1]	58.8	59.1	61.0
Growing Season:					
Date of last spring frost:					
Roswell	April 20	May 2	April 30	April 27	April 8
Artesia	April 6	May 2	April 29	April 22	April 7
Date of first fall frost:					
Roswell	Oct. 15	Oct. 17	Oct. 17	Oct. 16	Oct. 28
Artesia	Oct. 14	Oct. 18	Sept. 28	Oct. 10	Nov. 1
Number of frost-free days:					
Roswell	178	168	169	172	203
Artesia	191[1]	169[1]	152	171	208

[1]Weather records kept by Southeastern Branch Experiment Station, New Mexico State University, Artesia, New Mexico, 1966, 1967.

Source: *Weather Bureau, Climatological Data, New Mexico* (Annual Summaries) Vols. 34-72, 1931-1968.
Decennial Census of United States Climate—Monthly Normals of Temperature, Precipitation, and Heating Degree Days, New Mexico, Climatography of U.S. No. 81-25, U.S. Government Printing Office, Washington, D.C.

Other climatic hazards to agriculture in the area are high-velocity winds and droughts. The droughts cause drops in the recharge of water into underground aquifers and also increase the need for more frequent irrigations. Winds cause the soil to dry out more rapidly, and blowing soil may cause severe plant damage and losses in crop production. Crop damage in the area often results from severe rainstorms and hail. The hailstorms follow no predictable pattern and usually occur in localized areas.

Soils

The soils are alluvial in origin. Those on the uplands were developed from materials washed down from the Sacramento Mountains, while the soil mantle covering the flood plains has been transported by the Pecos River as sediments from the Permian formations on the upper drainage basin. Soils of this area are deep, highly calcareous loams and clay loams with a high content of fine sand, and are characterized by an almost structureless profile. They are usually low in organic matter, available phosphorus, and nitrogen. Predominant are the Reagan series on the uplands and the Reeves soils at lower benches. The major difference is in organic content, which is much higher in the Reagan soils. The Arno soils are the important series in the stream valleys (45, p. 4).

Irrigation Water Resources

There are two basic sources of diversion of irrigation water in Roswell Artesian Basin—surface and ground. Surface water was first diverted for irrigation in the basin in the early 1870's from tributaries of the Pecos River, such as North Spring, South Spring, and Berrendo Creeks, which were fed by large artesian springs in the vicinity of Roswell. In the early 1900's, drilling of artesian wells for expanded irrigation reduced the artesian flow of the springs until it was no longer economically feasible to maintain the diversion ditches used to irrigate from these tributaries (28, p. 20). At present only about 5 percent of the irrigation water supply is from surface water sources. For the most part, this is diverted from the Pecos River or it is drain flow resulting from loss during application of ground water.

The Hagerman Canal supplies a major portion of the surface water in the basin. It has been in use since 1879 and has a decreed right of 9,026 acres. The canal receives water from a combination of return flow from irrigation, water from Berrendo Creek, North Spring, Rio Hondo, and South Spring Creek, as well as supplemental water from four artesian wells, five shallow wells, and several tile drainage systems. In addition, 56 percent (5,055 acres) of the land irrigated from the Hagerman Canal receives supplemental water from other sources, principally shallow wells (28, p. 26).

An additional 3,760 acres have surface irrigation rights from the Pecos River. This water is diverted directly from the Pecos River by means of pumps.

Ground water pumped from wells supplies all municipal and industrial requirements and about 95 percent of the irrigation requirement in the basin. The principal water-yielding formations are the San Andres limestone (artesian aquifer), which is the deeper formation, and the Quaternary alluvium (shallow aquifer or valley fill). However, aquifers in the lower part of the Chalk Bluff formation in the southern part of the basin yield sufficient quantities of water for irrigation.

Geology and Hydrology

The geology of the underground water supplies as explained by Mower (29, pp. 117–118) is summarized as follows. The Yeso, Glorieta, San Andres, and Chalk Bluff formations of the Permian Age, and the alluvial deposits (valley fill) of the Quaternary Age constitute the major geologic formations in the hydrologic regime of the basin. The Glorieta sandstone overlies the Yeso and underlies the San Andres and ranges from 15 to 90 feet thick. The Yeso formation is as thick as 2,100 feet and yields only small quantities of water that is probably highly saline. The San Andres formation overlies the Glorieta sandstone and ranges in thickness from 1,000 to 1,200 feet in the farming area. The depth to the top of the San Andres ranges from less than 400 feet northeast of Roswell to more than 1,200 feet near Lakewood. The Chalk Bluff formation overlies the San Andres and forms a semipermeable layer between the San Andres and the alluvium, except in the vicinity of Roswell and northward. There the valley fill lies directly on the San Andres formation. The alluvial deposits range in thickness from 0 to more than 350 feet with the thickest deposits occurring parallel to and approximately 4 miles west of the Pecos River. The alluvium forms the storage reservoir for the shallow ground water in the basin.

Artesian

About 60 percent of the ground water used for irrigation is diverted from the artesian aquifer (17, 18). Artesian water in the northern part of the basin occurs in cracks, crevices, solution channels and cavernous zones, principally in the San Andres limestone. In the southern part of the basin the same type of openings in the San Andres and the lower part of the Chalk Bluff formation and its equivalent, the Grayburg formation, yield the artesian water.

The water is confined under pressure where the full section of the San Andres is saturated and dips beneath overlying confining beds of the Chalk Bluff formation. Water in the lower part of the artesian aquifer is saline south of Artesia because of poor circulation. A section of the artesian aquifer east and northeast of Roswell is saturated with saline water (28, p. 28).

Wells finished in the artesian aquifer range in depth from 300 to 1,200 feet. The average depth in the

Roswell-East Grand Plains Area is about 600 feet and that in the Dexter-Hagerman Area is about 1,000 feet. Wells in the Artesia Area are deeper, and have a lower supply of water and a higher seasonal drawdown than those in areas to the north. The pumping lifts range from 100 to 270 feet (10).

The specific yield from an artesian well varies with the transmissibility of the artesian aquifer. As explained by Mower (28, p. 81):

> The transmissibility of the artesian aquifer is higher and more uniform between the recharge area and the northern part of the pumped area than between the recharge area and the southern part of the pumped area. The solution cavities and channels are larger, better connected, and apparently more extensive in the vicinity of Roswell than elsewhere in the basin, and water moves from the recharge area to the wells near Roswell with relatively little loss of head.

Mower also notes that a belt of closely spaced piezometric-surface contour lines extending southwestward from the vicinity of Lake Arthur,

> . . . probably indicates an area of relatively low transmissibility as compared with areas to the north and south. This belt of low transmissibility lies between much of the recharge area and the southern part of the basin, and acts as a partial barrier to the movement of water through the artesian system to the wells in the southern part of the basin. Consequently, the rate of recharge to the artesian aquifer with relation to the rate of pumpage is less in the southern area than in the vicinity of Roswell.

Wells drilled in the artesian aquifer near Roswell have been tested at rates as high as 9,225 gallons per minute (gpm) but the average yield of such wells is usually considered to be between 2,000 and 3,000 gpm (27, p. 43).

Measurements of ground water levels have been made for a number of years in the Roswell Artesian Area. For the period 1961–1966 the artesian aquifer declined most in areas of heavy pumping near Dexter and Artesia, ranging from 26 feet to 53 feet for the 5-year period (figure 3). The 1965 water-level records indicated rises in levels in the artesian aquifer in a number of areas. These are related to reduction in pumpage and more effective precipitation during 1965 (21, p. 36).

Shallow

About 40 percent of the ground water used for irrigation in the basin is pumped from the alluvium or shallow aquifer. Hood, *et al.* (20) described the recharge into the aquifer as coming from five sources: 1) interformational leakage from the San Andres through the Chalk Bluff; 2) streamflow across the alluvium; 3) percolation losses from irrigated fields; 4) direct precipitation upon the alluvium; and 5) leakage from faulty artesian wells. The latter two are considered to be minor sources of recharge. In areas of concentrated pumping and low permeability of the aquifer, water level decline may be severe. A cone of depression forms in the water table around a discharging well. Grouping of wells causes these cones to intersect to form one large cone and continual water-level decline exists (28, p. 85). In the Dexter-Hagerman Area such a continuation of decline in the shallow aquifer has resulted in fairly large acreages of farm land going out of production due to the approaching exhaustion of economically recoverable water for irrigation (10).

Wells drilled in the shallow aquifer range from 84 to 440 feet deep, with an average depth of 217 feet. Pumping lifts average about 150 feet, and have an average yield of about 1,100 gpm (20).

This yield may be reduced as low as 100 gpm in areas of severe water table decline.

Water-level measurements for the shallow aquifer (alluvium) for 1961–1966 indicated the areas of greatest decline were near Artesia, where declines as much as 36 feet were recorded, and near Hagerman, where a decline of 26 feet was recorded (figure 4). The 1965 water-level records also indicate rises in the shallow aquifer in a number of areas, which are related to the reduction in pumpage and more effective precipitation during 1965 (21, p. 36).

Water Quality and Soil Salinity

Quality of irrigation water is as important as the amount available for irrigation to some farmers in the Roswell Artesian Basin. Among the more common crops in the basin, barley is highly salt tolerant, followed by cotton, sorghum, alfalfa, and corn, in that order. In the Pecos Valley, most of the soils are quite permeable so high water tables are not a problem. Salt damage arises largely from the use of saline water, growing salt-sensitive crops, and inadequate leaching of soil salts. Typically, well waters range from slight to moderately high in salt content. When the irrigation water is higher in salinity more water must be applied to control salt damage than if water is relatively low in salt content. When a limited quantity of water is available, yields will suffer unless the water is low in salt content or a highly salt-tolerant crop is grown (9).

Water Diversions

In 1967 the total water diverted, including that under the administration of the Pecos River Watermaster, for all uses was 397,618.3 acre-feet, of which 14,528.3 acre-feet were diverted for municipal uses, 1,582.6 acre-feet were diverted for commercial and industrial uses, and 381,507.4 acre-feet were diverted for agricultural uses (table 3).

Of the total of 381,507.4 acre-feet diverted for

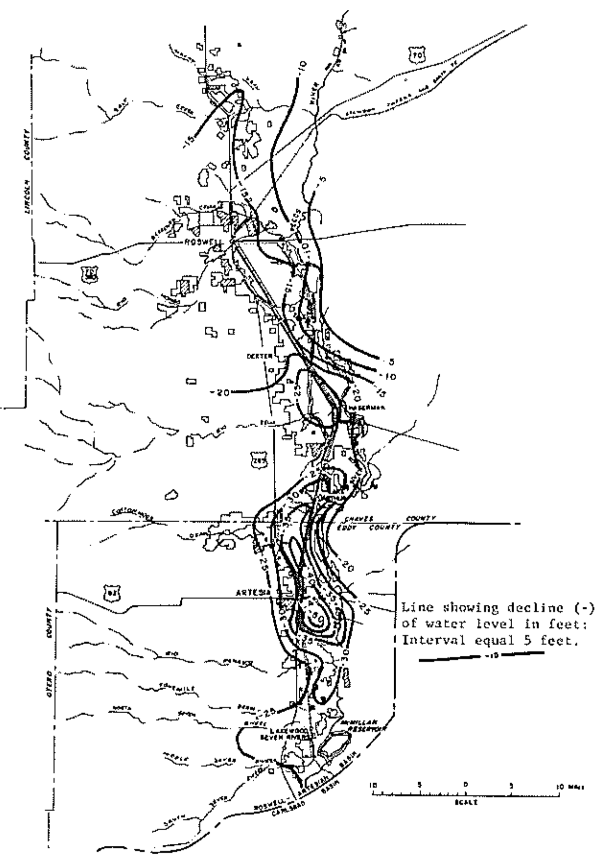


Figure 3. Change in ground water levels in artesian aquifer (1961-1966), Roswell Artesian Basin, New Mexico, 1967.

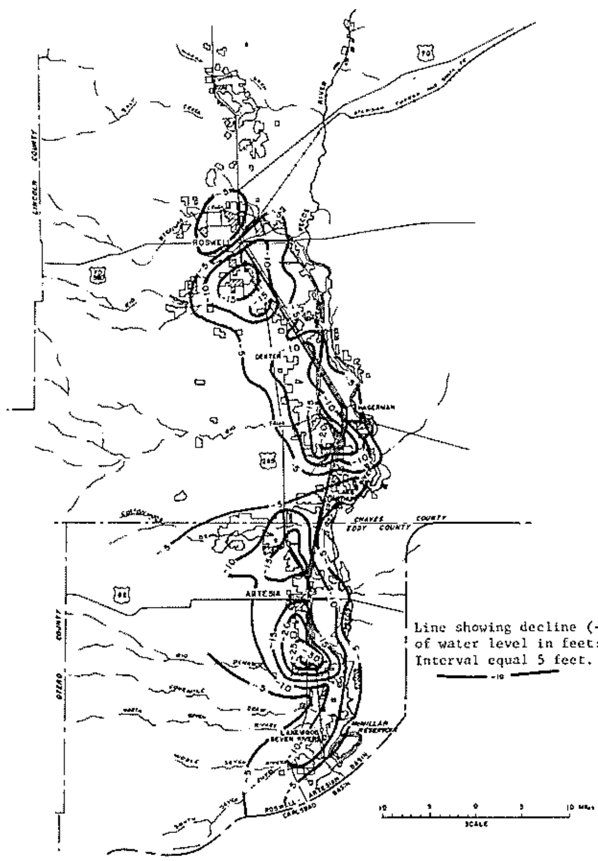


Figure 4. Change in ground water levels in alluvium (1961-1966), Roswell Artesian Basin, New Mexico, 1967.

agricultural uses 21,616.6 acre-feet were diverted from surface water sources and 359,890.8 acre-feet were diverted from wells. Of the 359,890.8 acre-feet diverted for irrigation from wells almost two-thirds, 227,586.2 acre-feet, were diverted from the artesian source and about one-third, 132,304.6 acre-feet, from the shallow or alluvium source as classified by the Roswell Basin Watermaster.

In 1968 the total water diverted, including that under the administration of the Pecos River Watermaster, for all uses was 350,109.5 acre-feet, of which 13,596.3 acre-feet were diverted for municipal uses, 1,611.1 acre-feet were diverted for commercial and industrial uses, and 334,902.1 acre-feet were diverted for agricultural uses (table 3).

Of the total of 334,902.1 acre-feet diverted for agricultural uses 22,356.5 acre-feet were diverted from surface water sources and 312,545.6 acre-feet were diverted from wells. Of the 312,545.6 acre-feet diverted for irrigation from wells almost two-thirds, 198,415.6 acre-feet, were diverted from the artesian source and about one-third, 114,130.0 acre-feet, from the shallow or alluvium source as classified by the Roswell Basin Watermaster.

In both years diversions for agricultural use accounted for over 95 percent of the total diversions. The total water diverted in 1968 for all uses was 11.95 percent less than that diverted in 1967. The 1968 amount was the lowest diverted since 1950 compared with estimates of diversions for previous years and only in 2 of the 30 years were total diversions less than in 1968 (table 4).

Prior to 1967 only estimates were available as to the amount of water diverted in the Roswell Artesian Basin. The estimated irrigation water diversions from all water sources varied from 204,000 acre-feet (1.67 acre-feet per acre) in 1941 to 529,200 acre-feet (3.78 acre-feet per acre) in 1964 with an average diversion of 423,006 acre-feet (3.01 acre-feet per acre) for 1938-1968 (table 4). Usually the lowest diversion level occurred during the year with the highest annual precipitation, and the highest diversion occurred during the year with the second lowest annual precipitation (table 4). Acreage of crops irrigated from ground water sources is also

Table 3. Tabulation of water diverted by areas, Roswell Artesian Basin, New Mexico, 1967 and 1968.

Area	1967[1] Diversion by Sources[2] Surface (ac.-ft.)	1967 Shallow (ac.-ft.)	1967 Artesian (ac.-ft.)	1967 All Source (ac.-ft.)	1967 Water-Right Acres (acres)	1967 Average Diversion per Acre (ac.-ft.)	1968 Diversion by Sources[2] Surface[3] (ac.-ft.)	1968 Shallow[4] (ac.-ft.)	1968 Artesian[4] (ac.-ft.)	1968 All Source (ac.-ft.)	1968 Water-Right Acres (acres)	1968 Average Diversion per Acre (ac.-ft.)
Northern Extension	221.8	984.6	19,839.1	21,045.5	10,610	1.98	311.5	761.3	16,996.5	18,069.3	10,810	1.67
Roswell-East Grand Plains	719.8	27,083.9	70,364.9	98,168.6	36,930	2.66	271.8	24,167.7	63,442.1	87,881.6	37,400	2.35
Dexter-Hagerman	18,212.4	51,342.2	47,758.1	117,312.7	41,560	2.83	19,323.3	44,689.9	36,924.0	100,937.2	40,080	2.52
Cottonwood	2,461.8	23,860.9	46,860.2	73,182.9	22,220	3.29	2,449.9	19,136.3	42,575.5	64,161.7	22,710	2.83
Artesia	.8	21,708.1	36,361.9	58,070.8	18,510	3.14	---	19,031.0	33,595.5	52,626.5	18,970	2.77
Lakewood-Seven Rivers	---	7,324.9	6,402.0	13,726.9	4,010	3.42	---	6,343.8	4,882.0	11,225.8	4,010	2.80
Total for basin[5]	21,616.6	132,304.6	227,586.2	381,507.4	133,840	2.85	22,356.5	114,130.0	198,415.6	334,902.1	133,980	2.50
Total pumpage		359,890.8						312,545.6				
Additional Diversion												
Municipal		15.5	14,512.8	14,528.3				203.5	13,392.8	13,596.3		
Commercial and Industrial		193.3	1,389.3	1,582.6				133.8	1,477.3	1,611.1		
Total	21,616.6	132,513.4	243,488.3	397,618.3			22,356.5	114,467.3	213,285.7	350,109.5		

[1]Garnett, Edwin T., "Economic Classification of the Irrigated Cropland in the Roswell Artesian Basin, New Mexico," (Unpublished Master's Dissertation, Department of Agricultural Economics and Agricultural Business, New Mexico State University, 1968), 171 pp.

[2]Diversion by sources classified by adjudication and analysis.

[3]Banta, E. H., *Tabulation of Water Diverted, Pecos Valley Surface Water District,* (Memorandum Report to S. E. Reynolds), New Mexico State Engineer Office, Santa Fe, New Mexico, 1968, 4 pp.

[4]Hennighausen, Fred H., and Wayne K. Lampert, *Metered Use of Water in the Roswell Basin for 1967, 1968,* (Memorandum Reports to S. E. Reynolds, State Engineer Office, Santa Fe, New Mexico, February 16, 1968, and February 4, 1969, 4 pp. each.

[5]Does not include Upper Rio Felix Area.

Table 4. Estimated acres irrigated, irrigation water diversion, and average annual precipitation, Roswell Artesian Basin, New Mexico, 1938-1968.

Year	Estimated Acres[1]	Estimated Irrigation Water Diversions: Ground Water Pumpage: Artesian (acre-feet)	Shallow (acre-feet)	Total (acre-feet)	Surface (acre-feet)	Total (acre-feet)	Total Per Acre (acre-feet)	Average Annual Precipitation (inches)
1938	111,700	188,000	90,000	278,000	52,000	330,000	2.95	10.82
1939	116,100	192,000	102,000	294,000	50,000	344,000	2.96	10.96
1940	119,800	185,000	106,000	291,000	51,000	342,000	2.85	12.49
1941	121,800	105,000	63,000	168,000	36,000	204,000	1.67	34.62
1942	125,300	196,000	118,000	314,000	52,000	366,000	2.92	13.42
1943	130,000	208,000	133,000	341,000	54,000	395,000	3.04	9.56
1944	133,400	190,000	126,000	316,000	49,000	365,000	2.74	12.55
1945	135,200	225,000	151,000	376,000	57,000	433,000	3.20	6.64
1946	135,900	207,000	139,000	346,000	52,000	398,000	2.93	11.56
1947	136,400	231,000	155,000	386,000	56,000	442,000	3.24	6.66
1948	142,500	232,000	144,000	376,000	52,000	428,000	3.00	10.20
1949	147,400	226,000	132,000	358,000	45,000	403,000	2.73	14.58
1950	157,700	237,000	125,000	362,000	41,000	403,000	2.56	13.91
1951	158,600	290,000	153,000	443,000	50,000	493,000	3.11	7.12
1952	159,000	250,000	163,000	413,000	50,000	463,000	2.91	7.69
1953	159,000	262,000	167,000	429,000	52,000	481,000	3.03	7.34
1954	158,500	261,000	176,000	437,000	49,000	486,000	3.07	9.74
1955	158,000	250,000	166,000	416,000	46,000	462,000	2.92	9.05
1956	158,000	277,000	183,000	460,000	51,000	511,000	3.23	5.68
1957	157,500	264,000	185,000	449,000	48,000	497,000	3.16	7.64
1958	146,000	258,000	127,000	385,000	33,800	418,800	2.87	16.64
1959	141,300	244,000	172,000	416,000	46,200	462,200	3.27	7.82
1960	138,000	229,000	162,000	391,000	33,600	424,600	3.08	13.04
1961	139,400	244,400	170,200	414,600	34,800	449,400	3.22	7.42
1962	136,500	252,300	177,800	430,100	31,900	462,000	3.38	11.56
1963	140,000	277,500	195,600	473,100	33,100	506,200	3.62	6.12
1964	140,000	292,800	206,400	499,200	30,000	529,200	3.78	6.06
1965	138,800	270,800	171,500	442,300	28,700	471,000	3.39	7.19
1966	137,180	NA	NA	NA	22,900	NA	NA	10.57
1967	135,200	224,900	132,300	357,200	26,600	383,800	2.84	8.24
1968	135,500	199,900	115,000	314,900	22,100	337,000	2.49	14.82
Average[2]	140,417	232,320	146,893	379,213	43,793	423,006	3.01[3]	10.70

[1]For the period 1938-1960, 10 percent was added to acreage to include fallow land.
[2]Excluding 1966. NA–Not Available.
[3]423,006 divided by 140,417 = 3.01.

Sources: 1938-1957: Acreage and diversions: Mower, R. W., Pumping in the Roswell Basin, Chaves and Eddy Counties, New Mexico, U.S. Geological Survey Open File Report, 1960, p. 47 and p. 74.

1958: Acreage and diversion: Mower, R. W., Ground-Water Levels in New Mexico, 1958, New Mexico State Engineer Technical Report 23, Santa Fe, New Mexico, 1962.

1959-1960: Acreage and diversions: Hood J. W., and J. D. Hudson, *Ground-Water Levels in New Mexico, 1960*, New Mexico State Engineer Technical Report 27, Santa Fe, New Mexico, 1962.

1961-1966: Acreage: Hennighausen, F. H., Unpublished estimates, June 26, 1969.

1961-1965: Diversions: Busch, Fred E., and J. D. Hudson, *Ground-Water Levels in New Mexico, 1965*, New Mexico State Engineer Technical Report 34, Santa Fe, New Mexico, 1967, p. 30.

1967-1968: Acreage and diversions: Hennighausen, F. H., and W. K. Lampert, *Metered Use of Water in the Roswell Basin for 1967* and *1968*; memos to S. E. Reynolds, Feb. 16, 1968; and Jan. 31, 1969, 4 pp. each.

1958-1968: Surface irrigated acreage and diversions: Banta, E. H., *Tabulation of Water Diverted, Pecos River Surface Water District*, memos to S. E. Reynolds, New Mexico State Engineer Office, Santa Fe, New Mexico, 1958-1968, 4 pp. each.

Precipitation: *Annual Precipitation: Climatological Data, New Mexico*, U.S. Weather Bureau (Annual Series) Vols. 42-72, 1938-1968. Average of Roswell and Artesia Stations.

reported in table 4 for 1938 through 1968. The total irrigation water pumped and irrigated acres serviced are graphically presented in figure 5. There is an overall relationship between acres irrigated and amount of irrigation water pumped (figure 5).

The relationship between annual precipitation and irrigation water pumped during 1938 through 1968 is presented in figure 6. There is an inverse relationship between precipitation and water pumped (r^2 = 0.49), with the abnormal year of 1941 being omitted. The data on precipitation and irrigation water pumped were omitted for 1941 because the precipitation of 34.62 inches in 1941 was more than triple the average of 10.70 inches for the 1938-1968 period and more than double the next highest year of 16.64 inches. Accurate data for goundwater pumpage was not available for 1966, therefore this year was omitted from the analysis.

The average precipitation over the 1938-1968 period excluding 1941 and 1966 was 9.88 inches and the average irrigation water pumped per irrigated acre was 3.06 acre-feet per irrigated acre. As precipitation increases, irrigation water pumpage tends to decrease with required diversions being reduced by about 0.06 acre-foot or 0.7 acre-inch for each inch of precipitation within the range of 5 to 17 inches of precipitation.

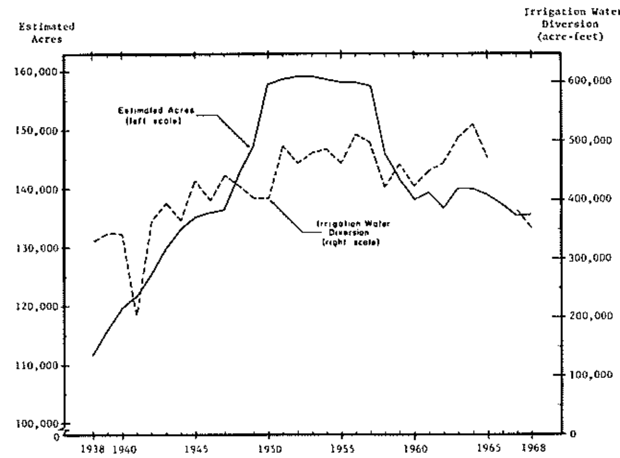


Figure 5. Estimated acres and irrigation water diversion, 1938-1968, Roswell Artesian Basin, New Mexico.

PROCEDURES

Research personnel at the Southeastern Branch Experiment Station, Artesia, and at the main station at New Mexico State University, Las Cruces, conducted this study. Agronomists, soil chemists, agricultural engineers, and agricultural economists joined in developing the procedures and in carrying out the research, using several different procedures to gather information. Intensive research was carried out on the branch experiment station plots and on two farms near the station. Detailed water use, crop yield, and economic data were derived from 12 selected case farms, and general data were assembled by a study of 33 randomly selected areas of the basin and from secondary research information. Soils survey information, water diversion, geologic and hydrologic data were obtained from available records and from agency personnel working in the field in these subject areas.

The research team, working together in close cooperation, exchanged information as it became available in order to avoid duplication of effort and to apply the findings immediately, thus permitting a more thorough consideration of the entire research problem.

The procedures for this study are presented in the following sequence: 1) research on cotton and alfalfa at the Southeastern Branch Experiment Station, 2) consumptive water use and consumptive irrigation requirement, 3) irrigation systems and practices, and 4) case study farms.

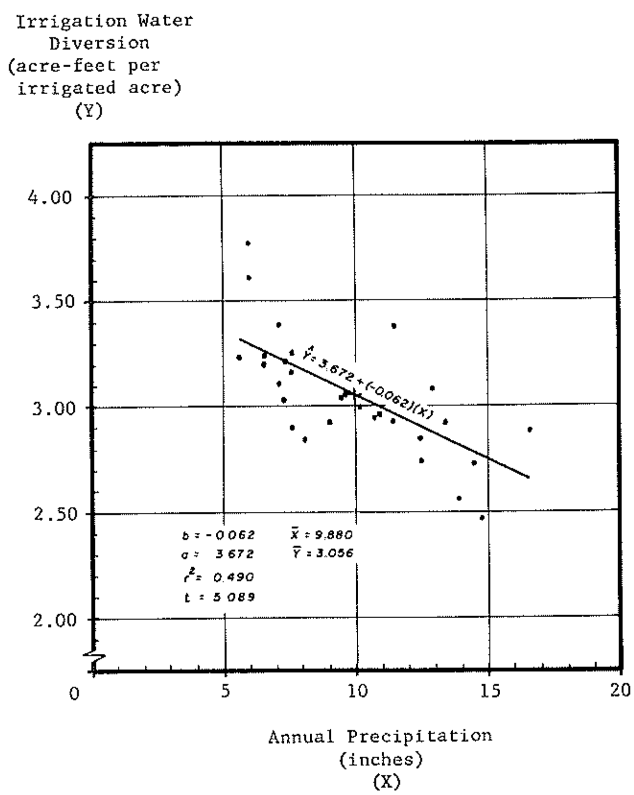


Figure 6. Relationship between annual precipitation and irrigation water diversion per acre, Roswell Artesian Basin, New Mexico, 1938-1968 (excluding 1941 and 1966).

Cotton and Alfalfa Studies

Detailed agronomic experiments were conducted at the Southeastern Branch Experiment Station at Artesia to determine the effects of different irrigation practices on cotton and alfalfa.

Acala 1517 D cotton was planted in a split-plot design with four replications. Main plots varied in irrigation regime and subplots varied in level of phosphorus fertilizer. There were six irrigation regimes and two levels of phosphorus fertilizer. The scheduled date of irrigation and acre-inches to be applied are shown in table 5. The irrigation dates are those used as a comparative illustration of the various regimes. The postbloom irrigations were applied when the uppermost open blooms were 4 to 6 inches below the tops of the plants.

The two levels of phosphorus fertilizer were 15 and 45 pounds of elemental phosphorus per acre, applied as a sidedressing during May of each year. Two sidedressed applications of nitrogen were applied, in May and June, at the rate of 40 pounds of elemental nitrogen each. Yield determinations were made by hand-picking the center two rows of each plot. Fifteen boll samples were collected from each plot prior to first harvest for use in determining lint percent, boll size, and fiber characteristics.

The effect of delaying the first postplant irrigation until July 1 as compared to June 1 irrigation was determined by comparing Regimes A with C, B with D, and E with F, and the effect of the date of the last irrigation was studied by comparing Regimes A with B, B with E, C with D, and D with F.

Zia alfalfa was planted in a split-plot design, with four replications, on April 11, 1966, using 24.4 pounds of seed per acre. Main plots varied in irrigation regime and sub-plots varied in phosphorus fertility level.

The irrigation regimes in 1966 and 1967 and acre-inches of water in each application were: Regime A, 3; Regime B, 4; Regime C, 5; and Regime D, 6. In 1968 Regime D was replaced by Regime E with an application of 8 acre-inches. Regimes A, B, and C were irrigated twice between each harvest while Regimes D and E were irrigated once each harvest.

The phosphorus fertility levels used were 35 to 70 pounds of elemental phosphorus per acre applied in February of each year as a broadcast application. Yield determinations were made by harvesting a 4-foot swath from the center of each plot and using a standard dry matter content of 22 percent to convert the green forage yields to dry forage basis.

Table 5. Scheduled irrigation dates and estimated water applications for six irrigation regimes in the cotton irrigation study, Southeastern Branch Experiment Station, New Mexico, 1966-1968.

Irrigation Regime	Preplow and Preplant	Scheduled Irrigation Date 6-1	7-1	7-20	8-5	8-20
A	9-12"	---	3-4"	3-4"	---	---
B	9-12"	---	3-4"	3-4"	3-4"	---
C	9-12"	3-4"	3-4"	3-4"	---	---
D	9-12"	3-4"	3-4"	3-4"	3-4"	---
E	9-12"	---	3-4"	3-4"	3-4"	3-4"
F	9-12"	3-4"	3-4"	3-4"	3-4"	3-4"

Computation of Consumptive Water Use and Consumptive Irrigation Requirement

To establish a basis for determining irrigation efficiencies, consumptive water use and consumptive irrigation requirement data were computed for the various crops grown on the 12 case farms in 1966-1968, using the basic procedures outlined by Blaney and Hanson (4) and Henderson and Sorenson (16). Temperature and rainfall data used were those recorded at the Roswell Weather Bureau and at the Southeastern Branch Experiment Station (Artesia).[2] Consumptive use data for Roswell and Artesia were computed by utilizing the consumptive use factor f (4, table B-3, pp. 66 and 71) and consumptive use coefficient K (4, p. 25). The value for effective precipitation used in computing consumptive irrigation requirement was obtained from total monthly precipitation at the two weather stations and applying the method of estimating monthly effective precipitation as reported by Blaney and Hanson (4, p. 21). A brief description of the periods of moisture employed in the computations for each crop appears in a report by Barnes (3, p. 8).

The consumptive irrigation requirement data were used as a basis for computing irrigation efficiencies as follows:

$$\text{Irrigation efficiency (\%)} = \frac{\text{consumption irrigation requirement}}{\text{irrigation water diversion}} \times 100$$

When irrigation water diversion was measured at the irrigation well the irrigation efficiency obtained represents farm irrigation efficiency; when measured at the point of delivery in the field it represents field irrigation efficiency.

Irrigation Systems and Practices

In June 1966, 33 sections in the basin were selected randomly to evaluate the effect of various irrigation systems, management practices, and cropping patterns on irrigation water diversions (figure 2). The 33 sample units were visited periodically during 1966-1968 and were studied on the ground with the aid of enlarged aerial photographs. Visual notes were taken in the field with respect to eight irrigation systems and practices

[2] The official weather bureau station was moved to the Southeastern Branch Experiment Station in January 1968.

previously selected as those most likely to affect the amount of water diverted.

The systems and practices noted were: 1) number of reservoirs; 2) percentage of concrete-lined conveyance ditch; 3) percentage of conveyance system consisting of underground pipe; 4) the percentage of irrigation runs greater than 0.2 mile; 5) land preparation, or percentage accomplished of needed land leveling or benching; 6) isolation percentage, or percentage of unirrigated land surrounding the irrigated land; 7) crop condition; 8) crops produced.

Each of the above systems and practices was compared with diversion of irrigation water per water-right acre for 1967 and 1968 calendar years by correlation.

Case Study Farms

Ten case-study farms were selected in the spring of 1966 and two in 1967, as representative of all farms in the basin with respect to type of farming enterprises. Farms were selected by the project research group, assisted by the county agricultural agent and Soil Conservation Service personnel in Chaves and Eddy Counties, using the following criteria: 1) the farmer's willingness to keep the necessary records; 2) irrigation water quality and quantity; 3) type of crops grown; 4) type of irrigation systems; 5) soil type; 6) geographic location.

Three farms were selected in Eddy County and nine in Chaves County, each from a different geographic location in the basin. One farm was located in the Northern Extension, four were in the Roswell-East Grand Plains Area, three in the Dexter-Hagerman Area, one in the Cottonwood Area, and three in the Artesia Area.

The case study method was used to obtain information about production requirements, costs, and returns for farms in the Roswell Artesian Basin.

Water samples were taken periodically from the irrigation wells on all case farms except Case Farm H, which had only surface water rights. Also, composite soil samples were collected from three sites in selected units of cotton and alfalfa on Case Farms J, K, and L. The sampled profiles were 0 to 10, 10 to 24, 24 to 36, and 36 to 60 inches.

Water application records for each crop grown on these farms were maintained by the cooperator. In addition, two farms were selected for more intensive measurement of water applications on selected irrigation units of alfalfa and cotton, by reading the meter on the irrigation well at the beginning and end of the irrigation on each unit. The amount of water to be applied was determined by the cooperator. Yield data for the selected units of alfalfa were obtained by weighing a random sample of 20 bales each harvest and multiplying the average weight per bale by the total number of bales produced. Yield of cotton from the selected units was determined from weights obtained at the gin.

Both enterprise and whole farm budgets were employed in the analysis of each case farm. The enterprise budgets were developed from the supervised farm records to determine the production requirements, costs, and returns for the different crop enterprises during the 1966-1968 crop years. These enterprise budgets were combined into whole farm budgets for each case farm for each year, and into typical enterprise budgets and typical whole farm budgets for each case farm for the entire three-year period. The typical enterprise budgets were used in the derivation of the coefficients for the linear programming analysis.

Linear Programming

Linear programming is a mathematical technique for determining the optimum allocation of resources to obtain a particular objective (such as minimum cost or maximum profit) when there are alternative uses for the resources. In general, these programming problems deal with the optimal allocations of limited resources to meet given objectives. In the problems considered in this study, the limited resources were the land, water, and cotton allotment. The specific objective was to maximize net farm return to land and management. The solution of a linear programming problem consists of finding the optimal feasible combination of resources from the established choices. Usually, there is an infinite number of feasible solutions, but only one solution maximizes net returns subject to the constraints imposed on land, water, and cotton allotment.

To analyze the effect of different quantities of irrigation water on net farm return a parametric linear programming model was used (24). In this type of problem, all coefficients and constraints were held fixed except for the constraint on irrigation water which was varied over a range of diversion. This allowed analysis of the effect of each of several irrigation water diversion levels.

Three linear programming models were developed for an analysis of each of the 12 case farms (models A, B, and C) and three for an analysis of the entire Roswell Artesian Basin (models D, E, and F).

The three models for the case farm analysis (models A, B, and C) were designed to maximize the net farm return to land and management for each case farm. The coefficients for the crop enterprises and the constraints on land, water, and cotton allotment were based on records of the respective farm. Other crop enterprises in addition to those actually produced were included in the programming models for all case farms studied. The coefficients for these crop enterprises were obtained either from adjusted budgets of other case farms with similar economic and agronomic characteristics, or from secondary data.

The three models for the basin analysis (models D, E, and F) were designed to maximize the net farm return to land and management for the basin as a whole. Coefficients for the crop enterprises were based on the combined records of the case farms and on secondary data. The constraints on land, water, and cotton allotment were based on records for the basin developed in 1967 by Garnett (10).

The quantities of irrigation water considered in models A, B, and C were 2.50 through 4.00 acre-feet per water-right acre, on one-quarter acre-foot intervals. The quantities considered in models D, E, and F were 2.25 through 4.50 acre-feet per water-right acre, on one-quarter acre-foot intervals.

Cotton

Three cotton diversion plans were included in the linear programming models (see table 6). These plans were designated as cotton 65, cotton 80, and cotton 95. Each acre of cotton 65 included 65 percent of the acre planted to cotton and 35 percent diverted under the government cotton program; cotton 80 included 80 percent of the acre planted to cotton and 20 percent diverted; and cotton 95 included 95 percent of each acre planted to cotton and 5 percent diverted. The water diversion and net return coefficients varied with each of the three cotton enterprises because of the different percentage of each acre planted to cotton in the three enterprises. The average irrigation water coefficients for the three cotton enterprises are presented in table 6.

Alfalfa

Four variations of alfalfa enterprises were included in the linear programming models as follows:

Alfalfa A was developed from data derived from the case farms for the production of alfalfa hay, with 4.67 acre-feet diverted, basically applied in one irrigation per cutting plus one winter irrigation, and an average yield of 5.5 tons per acre.

Alfalfa B was developed from data derived from the case farms for the production of alfalfa seed and/or pasture.

Alfalfa C had a more intensive application of water than alfalfa A, using 5.33 acre-feet of irrigation water application in two 4-inch irrigations between cuttings plus two winter irrigations, with an average yield of 7.3 tons per acre.

Alfalfa D enterprise had a more intensive application of water than either alfalfa A or C, using 6.00 acre-feet of irrigation water applied in two 5-inch irrigations between cuttings plus two winter irrigations, with an average yield of 8.5 tons per acre.

Average irrigation water coefficients for each alfalfa enterprise are shown in table 6. Alfalfa C and D were derived from expected results for irrigation regimes by Barnes (3), modified by data developed by Dregne (9).

The average irrigation water coefficients for other crop enterprises included in the linear programming models are presented in table 6.

The yields for crops used in models A, B, and C were derived from yield data on the 12 case study farms. Prices received for commodities are reported in table 7. Yield data for models D, E, and F were derived from the average yields on the 12 case farms or from secondary data (table 7). Prices were derived from data on the case study farms (table 7).

Linear Programming Models

Three parametric linear programming models (A, B, and C) were developed for each case farm using seven different irrigation water diversion levels, 2.50, 2.75, 3.00, 3.25, 3.50, 3.75, and 4.00 acre-feet per water-right acre. The detailed linear programming models for each farm are described by Lansford and Creel(24). Three

Table 6. Coefficients for crop enterprises, linear programming models, Roswell Artesian Basin, New Mexico.

Crop Enterprise	Average Irrigation Water Diversion per Acre: Models A, C, D, E, F (acre-feet)	Model B (acre-feet)
Cotton (65)[1]	1.81	1.72
Cotton (80)[2]	2.23	2.12
Cotton (95)[3]	2.65	2.52
Alfalfa (A)[4]	4.67	4.44
Alfalfa (B)[5]	3.53	3.35
Alfalfa (C)[6]	5.33	5.06
Alfalfa (D)[7]	6.00	5.70
Grain sorghum	2.25	2.14
Forage crops:		
Forage sorghum	1.47	1.40
Corn silage	1.79	1.70
Small grains:		
Oats	2.17	2.06
Barley	1.50	1.42
Rye	0.45	0.43
Pasture[8]	4.00	3.80
Pecans[8]	6.01	5.71
Fruits and vegetables[8]	3.25	0.00
Miscellaneous:		
Castor beans	2.33	2.21

[1]65 percent cotton, 35 percent diverted.
[2]80 percent cotton, 20 percent diverted.
[3]95 percent cotton, 5 percent diverted.
[4]One irrigation between cuttings.
[5]Alfalfa for seed or pasture.
[6]Two 4-inch irrigations between cuttings.
[7]Two 5-inch irrigations between cuttings.
[8]Not included in models A, B, and C.

linear programming models (D, E, and F) were developed for the Roswell Artesian Basin using 10 different irrigation water diversion levels, 2.25, 2.50, 2.75, 3.00, 3.25, 3.50, 3.75, 4.00, 4.25, and 4.50 acre-feet per water-right acre. Following is a brief statement on each of the six models.

Case Farms

Model A

Designed to provide short-term optimal solutions with present crop enterprises based on 12 case farms, using less than three acre-feet of irrigation water. This was achieved by including only the necessary constraints which were: 1) land (size of farm)–a maximum of 209.88 acres; 2) irrigation water–a maximum depending on specified diversion level; 3) cotton allotment–a maximum of 84.34 acres. The average constraints included in model A are presented in table 8.

Model B

Designed to analyze the effect of a 5 percent increase in farm irrigation efficiency, using the same case farm data and constraints as in model A.

Model C

Designed to meet the requirements of the government upland cotton program for the 12 case farms with about one-third of the water-right acres devoted to a soil conserving crop such as alfalfa. The constraints for model C were the same as for model A except for an additional constraint on a minimum alfalfa acreage of 67.64 acres. This was necessary to ensure an adequate alfalfa acreage at low diversion levels of irrigation water. The constraints for model C are presented in table 8.

Roswell Artesian Basin

Model D

Designed to provide a short-term optimal solution with present farm enterprises, using less than three acre-feet of irrigation water per acre. Similar to model A, but based on the entire Roswell Artesian Basin. The constraints were: 1) land–a maximum of 133,840 acres (water-right acres for the basin); 2) cotton allotment–a maximum of 37,800 acres; 3) irrigation water–a maximum depending on specified diversion level (table 8).

Model E

Designed to meet the requirements of the government upland cotton program for the basin with 52,940 acres or more of alfalfa, or about 40 percent of the total water-right acres in the basin. (Similar to model C but applied to the entire basin). The constraints for model E are presented in table 8.

Model F

Designed to analyze the effect of changing amounts of water diverted to a cropping pattern that closely represents the cropping pattern found in the basin in 1967. The model contained the same provisions as model E but restricted the production of grain sorghum, forage crops, pecans, and castor beans, and required the production of small grains on a minimum of 7,000 acres (table 8). Acreages of alfalfa and small grains, approximately those of the present acreage in the basin, were used as the minimum.

Optimal Quantity of Irrigation Water

By employing the so-called dual problem of linear programming, which states that the profit per unit of the last unit of irrigation water (shadow price) cannot exceed the imputed cost per unit of irrigation water, the optimal quantity of irrigation water for a farm can be determined. Although the term "shadow price" has been used as analogous to the term "value of the marginal product" which is used in marginal analysis, the term "marginal product" is not defined under the assumptions of linear programming because we have not specified what combination of enterprises is to be produced for any given irrigation water diversion level.

Table 7. Product prices and yields, linear programming models A, B, C, D, E, and F, Roswell Artesian Basin, New Mexico.

Crop	Units	Average Yield per Acre	Average Price
			(dollars)
Cotton [1]			
Lint	lb	730	0.30
Seed	ton	0.6	72.00
Price support [2]	lb	750	0.1106
Diversion [2]	lb	750	0.1070
Alfalfa hay [1]	ton	5.5	25.00
Grain sorghum [1]	cwt	55.0	1.80
Forage crops [1]	ton	19.0	7.20
Small grains [1]			
Hay	ton	3.5	20.00
Grain	bu	50.0	1.00
Pasture [3]	a.u.m.	9.0	2.70
Fruits and vegetables [3]		-- [4]	-- [5]
Miscellaneous			
Castor beans [3]	lb	2,800.0	0.06

[1] Average of 12 case farms.
[2] Projected yield.
[3] From secondary data.
[4] Lettuce, 450 cartons; onions, 500 bags.
[5] Lettuce, $1.70 per carton; onions, $1.75 per bag.

The origin of the term "dual problem" lies in the symmetry of the mathematical statements of the two linear programming problems of the firm. The primal problem is the maximization of net farm returns to land and management while the dual problem involves minimization of the factor costs of fixed and variable inputs. The former involves activity levels (combination of enterprises) which are no greater than resources permit, and the other involves an imputed price no lower than the amounts necessary to allocate all profits. The dual problem of the linear programs used was to find prices for the scarce resources which would minimize the total imputed cost of these resources to the firm and yet involve an imputed cost per unit of the next activity which is no less than the return per unit for the last unit of the activity. Thus these two properties of the dual problem of linear programming allow for imputed prices which provide criteria for decisions as to which activities (crop enterprises) are to be used by the firm and also at what level the variable input water should be used.

There are several ways of interpreting shadow prices depending on the criterion chosen for the benefit function. These can vary from the maximizing of profits from the viewpoint of an individual farmer in the Roswell Artesian Basin to the maximizing of total welfare of the society of the basin. The benefit criterion chosen for this study was one that did not reflect either extreme but one that could be applied both from the individual farmer's point of view and also reflect beneficial use of the scarce water resource in the basin. The criterion chosen was the equating of shadow prices of the net return function with the cost of pumping an additional acre-foot of irrigation water. This was an attempt to maintain a balance between the two extremes.

An individual may view any additional net return from an acre-foot of irrigation water as an indication to apply more irrigation water per acre until the additional net return is zero. However, from society's point of view it may be desirable to force the farmer to stop applying irrigation water at a much lower level than where net returns are at a maximum because there are alternative uses for the water either in the current year or in the future. Also, when the additional net return approaches zero the individual farmer may be able to receive a higher return from investments other than irrigation water. Thus the optimal net return to land and management as used in this study with respect to irrigation water is the point where the shadow price is equal to the price (cost of pumping) of an acre-foot of irrigation water.

An economically rational farmer would continue to pump irrigation water until the last acre-foot pumped generates enough additional net return to just pay for the cost of pumping that acre-foot. This is the point of maximum profit with respect to irrigation water.

Table 8. Constraints included in linear programming models A, B, C, D, E, and F, Roswell Artesian Basin, New Mexico.

Model	Item	Acres Minimum	Acres Maximum
	Case Farms		
A	Land		209.88
	Cotton allotment		84.34
B	Land		209.88
	Cotton allotment		84.34
C	Land		209.88
	Cotton allotment		84.34
	Alfalfa	67.64	
	Roswell Artesian Basin		
D	Land		133,840
	Cotton allotment		37,880
E	Land		133,840
	Cotton allotment		37,880
	Alfalfa	52,940	
F	Land		133,840
	Cotton allotment		37,880
	Alfalfa	52,940	
	Grain sorghum		5,000
	Forage crops:		
	Forage sorghum		7,000
	Corn silage		5,000
	Small grains:		
	Barley	7,000	
	Pecans		5,000
	Miscellaneous:		
	Castor beans		6,000

RESULTS

The results of this study are presented in the following sequence: consumptive use and consumptive irrigation requirement, cotton and alfalfa irrigation studies conducted at the Southeastern Branch Experiment Station, results obtained from the 33 random sample units, and results obtained from the 12 case study farms. This section includes the findings of the total research group–agronomists, agricultural engineers, and agricultural economists–and all of the investigators have contributed in various ways to the report.

Consumptive Use and Consumptive Irrigation Requirement

The computed consumptive use, effective rainfall, and consumptive irrigation requirement for the various crops are shown in tables 9 and 10. A comparison of the mean consumptive irrigation requirement for the various crops (tables 9 and 10) shows a slightly higher requirement for crops grown in the Artesia Area than in the Roswell Area. In most cases this higher consumptive irrigation requirement for the Artesia Area was the result of less effective rainfall in 1967 and thus a lower mean effective rainfall at Artesia for the time period of this study. A comparison of long-term average rainfall indicates that the expected differences between the two locations (table 2) for a longer time would be less than for the period of time involved in this study.

Table 9. Consumptive use, effective rainfall, and consumptive irrigation requirement from weather records at the Southeastern Branch Experiment Station, for crops grown in the Roswell Artesian Basin, New Mexico, 1966-1968.

Crop	Year	Consumptive Use (acre-inches)	Effective Rainfall (inches)	Consumptive Irrigation Requirement (acre-inches)
Alfalfa	1966	39.62	8.30	31.32
	1967	40.18	4.22	35.96
	1968	38.27	9.60	28.67
	Mean	39.36	7.37	31.98
Cotton	1966	27.04	7.74	19.30
	1967	28.08	4.05	24.03
	1968	26.73	7.84	18.89
	Mean	27.28	6.54	20.74
Grain sorghum	1966	25.48	5.60	19.88
	1967	26.57	4.00	22.57
	1968	24.94	7.10	17.84
	Mean	25.66	5.57	20.10
Sorghum silage	1966	19.68	5.32	14.36
	1967	19.68	3.41	16.27
	1968	19.68	6.49	13.19
	Mean	19.68	5.07	14.61
Corn silage	1966	21.00	5.32	15.68
	1967	21.00	3.41	17.59
	1968	21.00	6.49	14.51
	Mean	21.00	5.07	15.93
Small grains (spring)	1966	14.11	3.63	10.48
	1967	14.11	1.69	12.42
	1968	14.11	2.28	11.83
	Mean	14.11	2.53	11.58
Small grains (winter)	1967	18.63	1.76	16.87
	1968	18.63	5.31	13.32
	Mean	18.63	3.54	15.10

Table 10. Consumptive use, effective rainfall, and consumptive irrigation requirement from weather records at the Roswell Weather Bureau, for crops grown in the Roswell Artesian Basin, 1966-1968.

Crop	Year	Consumptive Use (acre-inches)	Effective Rainfall (inches)	Consumptive Irrigation Requirement (acre-inches)
Alfalfa	1966	38.58	8.37	30.21
	1967	39.46	8.46	31.00
	1968	38.64	11.91	26.73
	Mean	38.69	9.58	29.31
Cotton	1966	26.95	8.23	18.72
	1967	27.58	8.23	19.35
	1968	27.02	8.70	18.32
	Mean	27.18	8.39	18.80
Grain sorghum	1966	25.43	6.29	19.14
	1967	26.09	8.20	17.89
	1968	25.53	7.74	17.79
	Mean	25.68	7.41	18.27
Sorghum silage	1966	19.40	5.37	14.03
	1967	19.40	7.37	12.03
	1968	19.40	7.41	11.99
	Mean	19.40	6.72	12.68
Corn silage	1966	20.69	5.37	15.32
	1967	20.69	7.37	13.32
	1968	20.69	7.41	13.28
	Mean	20.69	6.72	13.97
Small grains (spring)	1966	13.87	3.64	10.23
	1967	13.87	1.69	12.18
	1968	13.87	2.68	11.19
	Mean	13.87	2.67	11.20
Small grains (winter)	1967	18.30	1.28	17.02
	1968	18.30	5.93	12.37
	Mean	18.30	2.40	14.70

Cotton Irrigation Study

Irrigation water applications, irrigation efficiencies, and total water applied to the cotton irrigation study during 1966-1968 are presented in table 11. The February 1966 irrigation was applied to facilitate land preparation after land-leveling operations, and the December irrigations in 1966 and 1967 were applied before plowing under the crop residue. The April 1966, March 1967, and April 1968 irrigations were applied prior to planting to provide adequate moisture for stand establishment. In 1966, Regimes B and E, and D and F received the same irrigations, because rainfall (4.20 inches) received during August 20-24 replaced a scheduled irrigation on Regimes E and F.

Irrigation efficiencies shown in table 11 are computed efficiencies based on consumptive irrigation requirements shown in table 9. Some of the efficiencies exceed 100 percent because irrigation water applied was less than was indicated by the computed consumptive irrigation requirement.

Lint yield data are shown in table 12. The combined years (mean) analysis indicates that there were significant (5 percent) differences for the interaction of irrigation regimes and fertilizer rates. The extreme example of this interaction is the decrease of 47 pounds of lint per acre for Regime B at the 45-pound level of phosphorus, compared with an increase in lint yield of 99 pounds in Regime E at the 45-pound level.

The test of significance, as presented in table 12, was employed in a manner to provide for the comparison of all treatments (an irrigation regime combined with a fertility level comprises a treatment). In this comparison, treatment E-45 with 807 pounds lint per acre was significantly higher yielding than all other treatments, while treatment F-45 with 754 pounds lint ranked second and was significantly higher yielding than the third-ranking treatment, B-15 with 713 pounds of lint. Other treatments did not differ significantly in yielding ability.

The effect on lint yield of delaying the first postplant irrigation until July 1 as compared to June 1 can be determined by comparing Regimes C, D, and F, which were irrigated on June 1, with Regimes A, B, and E respectively, which received the first postplant irrigation on July 1. The comparison of the 15-pound fertility level for each group indicated that the June 1 irrigation did not increase the lint yield. The greatest difference was in Regime B, 713 pounds per acre, with a reduction of 32 pounds per acre for the June 1 irrigation. The

Table 11. Irrigation water applications, irrigation efficiency, and total water applied for six irrigation regimes in the cotton irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1966-1968.

Date of Irrigation	Acre-Inches of Water					
	Regime A	Regime B	Regime C	Regime D	Regime E	Regime F
Feb. 21, 1966	2.80	2.80	2.80	2.80	2.80	2.80
April 1	7.97	7.97	7.97	7.97	7.97	7.97
June 1	----	----	3.06	3.06	----	3.06
July 1	4.02	4.02	3.06	3.06	4.02	3.06
July 21	4.02	4.02	4.02	4.02	4.02	4.02
August 4	----	4.02	----	4.02	4.02	4.02
Total Irrigation Water, 1966	18.81	22.83	20.91	24.93	22.83	24.93
Precipitation	11.76	11.76	11.76	11.76	11.76	11.76
Total Water, 1966	30.57	34.59	32.67	36.69	34.59	36.69
Irrigation Efficiency, percent	102.6[1]	84.5	92.3	77.4	84.5	77.4
Dec. 7, 1966	3.06	3.06	3.06	3.06	3.06	3.06
March 30, 1967	8.96	8.96	8.96	8.96	8.96	8.96
June 1	----	----	3.01	3.01	----	3.01
July 1	3.96	3.96	3.01	3.01	3.96	3.01
July 21	3.96	3.96	3.96	3.96	3.96	3.96
August 5	----	3.96	----	3.96	3.96	3.96
August 22	----	----	----	----	3.96	3.96
Total Irrigation Water, 1967	19.94	23.90	22.00	25.96	27.86	29.92
Precipitation	4.47	4.47	4.47	4.47	4.47	4.47
Total Water, 1967	24.41	28.37	26.47	30.43	32.33	34.39
Irrigation Efficiency, percent	120.5[1]	100.5[1]	109.2[1]	92.6	86.2	80.3
Dec. 6, 1967	3.01	3.01	3.01	3.01	3.01	3.01
April 5, 1968	5.97	5.97	5.97	5.97	5.97	5.97
May 31	----	----	3.17	3.17	----	3.17
July 1	4.03	4.03	2.98	2.98	4.03	2.98
July 23	4.03	4.03	4.03	4.03	4.03	4.03
August 8	----	4.03	----	4.03	4.03	4.03
August 27	----	----	----	----	2.54	2.54
Total Irrigation Water, 1968	17.04	21.07	19.16	23.19	23.61	25.73
Precipitation	12.72	12.72	12.72	12.72	12.72	12.72
Total Water, 1968	29.76	33.79	31.88	25.91	36.33	38.45
Irrigation Efficiency, percent	110.8[1]	89.6	98.6	81.4	80.0	73.4

[1]Exceeds 100 percent because irrigation water applied was less than was indicated by the computed consumptive irrigation requirement.

Table 12. Total lint yield for six irrigation regimes and two fertility levels in the cotton irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1966-1968.

Irrigation Regime	Fertility Level	Lint Yield[1]			
		1966	1967	1968	Mean
	(lbs. P per acre)	(lbs. per acre)			
A	15	744a	611a	605a	653ef
	45	731a	573a	601a	635f
	Mean	737BC	592A	603A	644A
B	15	879a	684z	577a	713c
	45	820a	650a	526a	666def
	Mean	849ABC	667A	552A	690A
C	15	716a	590a	659a	655ef
	45	741a	595a	651a	662ef
	Mean	728C	593A	655A	660A
D	15	841a	675a	525a	681cde
	45	921a	702a	491a	705cd
	Mean	881AB	689A	508A	693A
E	15	894a	752a	477a	708c
	45	915a	846a	660a	807a
	Mean	905A	799A	569A	757A
F	15	897a	730a	500a	710c
	45	967a	810a	484a	754b
	Mean	932A	770A	492A	731A
Fertility Mean	15	828A	674A	557A	687B
	45	849A	696A	569A	705A

[1]Data in the same column followed by the same letter are not statistically different at the 5 percent probability level.

average for all comparisons at the 15-pound fertility level was a reduction of 9 pounds per acre for the regimes receiving a June 1 irrigation.

A similar comparison for the 45-pound fertility level showed a trend toward increased yield for the June 1 irrigation for regimes receiving the last irrigation in late July or early August. However, Regimes E and F, last irrigated in late August, showed a decrease of 53 pounds of lint for the June 1 irrigation. The average of all comparisons for the 45-pound fertility level indicated an average increase of 4 pounds per acre for those regimes receiving a June 1 irrigation.

The combined years data for comparing the dates of the last irrigation were altered by the fact that all regimes received an effective irrigation in the form of rainfall in late August 1966. Utilizing only data for 1967 and 1968, the average yield for Regimes A and C, receiving the last irrigation on July 21-23, was 611 pounds; Regimes B and D, receiving the last irrigation on August 5-8, yielded 604 pounds; and Regimes E and F, receiving the last irrigation on August 22-27, yielded 658 pounds. These data indicate a slight increase of 7.7 percent in yield for the late August irrigation compared with the late July irrigation. This same comparison for the 1967 data amounted to a 32.4 percent increase, and, in 1968, showed a decrease in yield of 15.7 percent.

The difference in response between 1967 and 1968 may have been partially due to the difference in amount of rainfall received, as 1967 was below average and 1968 was above average in rainfall. There was also an increased incidence of verticillium wilt in 1968 (3, p. 30).

Water use efficiency data indicated that the interaction of irrigation regimes and fertility levels was significantly (5 percent) different, with the most notable differences in response being between Regimes B and E. The comparison of fertility levels in Regime B showed a decrease of 1.5 pounds of lint per acre-inch of water for 45 pounds of phosphorus, while the same comparison in Regime E showed an increase of 2.8 pounds of lint (table 13).

A summary of lint yield, water use efficiency, and irrigation efficiency is presented graphically in figure 7. These data would seem to indicate an increase in yield with increased total water available up to approximately 34.5 acre-inches per acre. Water use efficiency and irrigation efficiency tended to decrease with increased water applications. The most notable exceptions were the sharp increases in yield and water use efficiency in the comparison of Regimes D and E.

Fiber length data (table 14) indicate that Regimes A and C, last irrigated between July 21-23, produced a shorter fiber than did the other four regimes. The date of application of the first postplant irrigation had no effect on fiber length and phosphorus fertility level had little effect. The interaction of irrigation regime and fertility level was significant for micronaire data, table 15, the most notable differences being in the comparison of treatments B-15 with B-45 and E-15 with E-45.

Regimes A and C, last irrigated between July 21-23, were earlier maturing than the other regimes, as measured by percent of the total yield obtained at first picking (table 16). The percent of yield at first picking data indicate that Regime B matured earlier than Regimes D and E, while Regime F was the slowest-maturing regime. Regime F received the greatest number of irrigations and the most irrigation water of all regimes.

Table 13. Water use efficiency for six irrigation regimes and two fertility levels in the cotton irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1966-1968.

Irrigation Regime	Fertility Level	Lint per Acre-Inch of Water[1]			
		1966	1967	1968	Mean
	(lbs. P per acre)	(lbs.)	(lbs.)	(lbs.)	(lbs.)
A	15	24.3a	25.0a	20.3a	23.2ab
	45	23.9a	23.4a	20.2a	22.5abc
	Mean	24.1A	42.2A	20.2A	22.9A
B	15	25.4a	24.1a	17.1a	22.2bc
	45	23.7a	22.9a	15.6a	20.7def
	Mean	24.6A	23.5A	16.3AB	21.4A
C	15	21.9a	22.3a	20.7a	21.6cde
	45	22.7a	22.5a	20.4a	21.9cd
	Mean	22.3A	22.4A	20.5A	21.7A
D	15	22.9a	22.2a	14.6a	19.9f
	45	25.1a	23.1a	13.7a	20.6ef
	Mean	24.0A	22.6A	14.1B	20.2A
E	15	25.8a	23.3a	13.1a	20.8ef
	45	26.5a	26.2a	18.2a	23.6a
	Mean	26.2A	24.7A	15.6AB	22.2A
F	15	24.4a	21.2a	13.0a	19.6ef
	45	26.3a	23.6a	12.6a	20.8ef
	Mean	25.4A	22.4A	12.8B	20.2A
Fertility Mean	15	24.7A	23.0A	16.5A	21.4B
	45	25.3A	23.6A	16.8A	21.9A

[1]Data in the same column followed by the same letter are not statistically different at the 5 percent probability level.

The percent total soluble salts present in soil samples taken from the plots were collected (3, pp. 45-46) primarily to determine whether salt content increased in those regimes receiving the lesser amounts of water. A comparison of the data taken at the beginning and toward the end of the study indicated no accumulation of salts. However, the time period involved was relatively short for this condition to have become established, and the total precipitation received during the last year of the study may have considerably affected the amount of salt leached below the sampled profile.

A supplementary test was conducted (3, p. 15) in 1968 to evaluate the response of the various treatments with respect to verticillium wilt. The test area was a site that had produced barley the previous two years. The verticillium wilt index data for the added test area indicated an absence of symptoms, whereas the data from the original test site indicated a higher incidence of verticillium wilt. The comparison of lint yield data for 1968 showed that yields were measurably higher for the added test area, emphasizing the value of maintaining a crop rotation program in the farming operation.

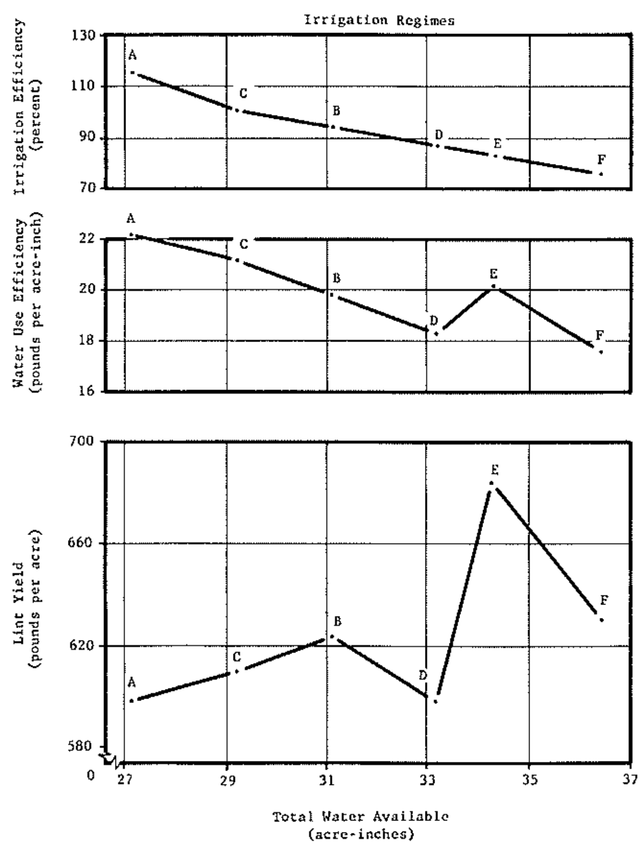


Figure 7. Mean total water available including rainfall, lint yield, water use efficiency, and irrigation efficiency for six regimes in the cotton irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1967-1968.

The relative soil moisture depletion index was determined for the six regimes in the 1967 cotton irrigation study. The data indicated that approximately two-thirds of the total measured depletion was from the upper 24 inches of the soil profile. The period of high moisture use occurred from July 1 to September 6 and there was increased depletion from the lower soil profiles as the season progressed, an indication of root growth into the lower profiles during the season.

Alfalfa Irrigation Study

Acre-inches of water applied and irrigation efficiencies for the alfalfa irrigation study are shown in table 17. Forage yield and water use efficiency data are presented in table 18.

The effect of one irrigation per harvest compared with two irrigations per harvest, using the same total amount of water, may be determined by comparing Regime A and Regime D in 1967 and Regime B and E in 1968. In 1967 Regime A received two 3-inch irrigations per harvest and yielded 4.49 tons per acre and 192.9 pounds of forage per inch of water. Regime D received one 6-inch irrigation per harvest and yielded 3.58 tons per acre and 136.8 pounds of forage per inch of water. Both the forage yield and water use efficiency were significantly higher for Regime A with two irrigations per harvest.

Similarly, in 1968, Regime B (two 4-inch irrigations) produced a significantly higher forage yield (8.30 tons) and water use efficiency than did Regime E (one 8-inch irrigation) with 7.31 tons. In 1967 Regime C (two 5-inch irrigations) produced the highest forage yield of 7.93 tons per acre followed in order by Regime B (two 4-inch irrigations) with 6.60 tons, Regime A with 4.49 tons, and Regime D with 3.58 tons per acre. In each case the differences in yield were statistically significant (5 percent).

Regime B had the highest water use efficiency in 1967 with 216.3 pounds of forage per inch of water but was not significantly higher than Regimes A and C; however, Regime D with 136.8 pounds of forage was significantly lower in efficiency than the other three regimes. In 1968 Regime C produced the highest yield of 9.29 tons per acre, followed in order by Regimes B, E, and A. Again each of the differences was significant.

Table 14. Fiber length data for six irrigation regimes and two fertility levels in the cotton irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1966-1968.

Irrigation Regime	Fertility Level (lbs. P per acre)	Fiber Length[1, 2] 1966 (in.)	1967 (in.)	1968 (in.)	Mean (in.)
A	15	1.19a	1.16e	1.19a	1.18a
	45	1.20a	1.20bcde	1.18a	1.19a
	Mean	1.20A	1.18B	1.19B	1.19B
B	15	1.22a	1.24ab	1.23a	1.23a
	45	1.22a	1.20bcde	1.26a	1.23a
	Mean	1.22A	1.22AB	1.24A	1.23A
C	15	1.17a	1.18de	1.20a	1.18a
	45	1.17a	1.17e	1.19a	1.18a
	Mean	1.17A	1.18B	1.19B	1.18B
D	15	1.24a	1.23abc	1.26a	1.24a
	45	1.21a	1.25a	1.24a	1.23a
	Mean	1.23A	1.24A	1.25A	1.24A
E	15	1.22a	1.22abcd	1.25a	1.23a
	45	1.21a	1.19cde	1.24a	1.21a
	Mean	1.21A	1.20AB	1.24A	1.22A
F	15	1.22a	1.22abcd	1.23a	1.22a
	45	1.22a	1.22abcd	1.23a	1.22a
	Mean	1.22A	1.22AB	1.23AB	1.22A
Fertility Mean	15	1.21A	1.21A	1.22A	1.22A
	45	1.20A	1.20A	1.22A	1.21A

[1]Data in the same column followed by the same letter are not statistically different at the 5 percent probability level.

[2]1966 data are "upper half mean length' and 1967 and 1968 data are "2.5 percent span length."

Table 15. Micronaire data for six irrigation regimes and two fertility levels in the cotton irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1966-1968.

Irrigation Regime	Fertility Level (lbs. P per acre)	Micronaire[1] 1966	1967	1968	Mean
A	15	4.4a	4.0a	4.0a	4.2ab
	45	4.4a	3.9a	4.2a	4.2ab
	Mean	4.4A	4.0A	4.1AB	4.2A
B	15	4.4a	3.7a	4.0a	4.0bc
	45	4.4a	3.3a	3.4a	3.7d
	Mean	4.4A	3.5A	3.7C	3.9B
C	15	4.6a	4.0a	4.2a	4.3a
	45	4.6a	3.8a	4.1a	4.2ab
	Mean	4.6A	3.9A	4.2A	4.2A
D	15	4.1a	3.6a	3.6a	3.8cd
	45	4.4a	3.8a	3.4a	3.9cd
	Mean	4.3A	3.7A	3.5C	3.8B
E	15	4.4a	3.7a	3.5a	3.9cd
	45	4.6a	4.1a	4.0a	4.2ab
	Mean	4.5A	3.9A	3.8BC	4.0AB
F	15	4.4a	3.8a	3.7a	4.0bc
	45	4.6a	3.9a	3.4a	4.0bc
	Mean	4.5A	3.9A	3.6C	4.0AB
Fertility Mean	15	4.4A	3.8A	3.8A	4.0A
	45	4.5A	3.8A	3.8A	4.0A

[1]Data in the same column followed by the same letter are not statistically different at the 5 percent probability level.

Regime B had the highest water use efficiency with 240.4 pounds of forage per inch of water but was not significantly higher than Regime C with 227.4 pounds.

The combined years data (table 18) for Regimes A, B, and C show that Regime C with 8.61 tons of forage per acre was significantly higher-yielding than Regime B with 7.45 tons, and Regime B was significantly higher-yielding than Regime A with 5.20 tons. Water use efficiency for Regimes B and C was not significantly different but both were significantly higher than Regime A.

The data from the alfalfa irrigation study indicate that higher yields can be obtained by irrigating twice per harvest compared with once per harvest when the same total amount of water per harvest is used. The combined years data, presented graphically in figure 8, indicate 1) the yield of forage increases in a near linear response as the total water available increases, when the same number of irrigations per harvest are employed, 2) water use efficiency increases with increased water applications up to two 4-inch applications per harvest, and 3) irrigation efficiency, computed on the basis of consumptive irrigation requirement (table 17), decreases in a near linear response as yield increases, within the limits of total water applications used in this study.

Comparative total soil moisture depletion data for four irrigation regimes in the alfalfa study for 1967 and 1968 were determined (3). There was an increase in total

Table 16. Percent of total yield obtained at first picking for six irrigation regimes and two fertility levels in the cotton irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1966-1968.

Irrigation Regime	Fertility Level	Percent of Total Yield at First Picking[1] 1966	1967	1968	Mean
	(lbs. P per acre)				
A	15	69.4b	68.6a	42.6a	60.2a
	45	64.2c	56.4a	44.2a	54.9a
	Mean	66.8A	62.5A	43.4A	57.6A
B	15	50.9d	44.5a	26.6a	40.7a
	45	49.6e	43.5a	29.7a	41.0a
	Mean	50.3B	44.0B	28.2B	40.8B
C	15	73.8a	63.3a	47.2a	61.4a
	45	73.8a	64.3a	47.5a	61.8a
	Mean	73.8A	63.8A	47.4A	61.6A
D	15	46.6f	37.1a	18.6a	34.1a
	45	43.7g	38.1a	23.2a	35.0a
	Mean	45.1B	37.6BC	20.9B	34.5C
E	15	44.4g	30.7a	25.7a	33.6a
	45	47.3f	34.0a	24.8a	35.4a
	Mean	45.8B	32.3C	25.3B	34.5C
F	15	42.4h	28.2a	19.1a	29.9a
	45	39.9i	26.8a	17.0a	27.9a
	Mean	41.2B	27.5C	18.0B	28.9D
Fertility Mean	15	54.6A	45.4A	30.0A	43.3A
	45	53.1B	43.8A	31.1A	42.7A

[1]Data in the same column followed by the same letter are not statistically different at the 5 percent probability level.

Table 17. Irrigation water applied, precipitation, total water applied, and irrigation efficiency for the alfalfa irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1967-1968.

Crop Year	Irrigation Regime A	B	C	D[1]	E[1]
1967					
Total hay yield (tons)	4.49	6.60	7.93	3.58	
Water applied, acre-inches					
Total irrigation water	42.23	56.60	69.97	47.86	
Precipitation	4.47	4.47	4.47	4.47	
Total water	46.70	61.07	73.44	52.33	
Irrigation efficiency, percent	85.2	63.5	51.4	75.1	
1968					
Total hay yield (tons)	5.91	8.30	9.29		7.31
Water applied, acre-inches					
Total irrigation water	42.28	56.42	70.00		62.05
Precipitation	12.72	12.72	12.72		12.72
Total water	55.00	69.14	82.72		74.77
Irrigation efficiency, percent	67.8	50.8	41.0		46.2

[1]Regime E replaced Regime D in 1968.

Table 18. Total dry forage yield and water use efficiency for the alfalfa irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1967-1968.

Irrigation Regime	Yield of Dry Forage (tons per acre)[1] Harvest Number First	Second	Third	Fourth	Fifth	Sixth	Total Yield	Water Use Efficiency
								(lbs per ac.-in.)
1967								
A	0.70b	0.59a	0.78c	0.68c	0.90c	0.83c	4.49c	192.9a
B	0.98ab	0.86a	1.18b	1.12b	1.35b	1.11b	6.60b	216.3a
C	1.22a	1.11a	1.50a	1.40a	1.47a	1.25a	7.93a	213.6a
D	0.80b	0.49a	0.55c	0.56c	0.60d	0.58d	3.59d	136.8b
1968								
A	1.28d	0.93c	1.25b	0.69d	1.02b	0.75b	5.91d	211.4bc
B	1.77b	1.68b	1.47a	1.21b	1.18a	0.99a	8.30b	240.4a
C	2.18a	1.98a	1.50a	1.43a	1.15a	1.05a	9.29a	227.4ab
E	1.49c	1.50b	1.21b	0.93c	1.16a	1.02a	7.31c	195.5c
Mean								
A	0.98c	0.76c	1.01c	0.69c	0.96b	0.79c	5.20c	202.2b
B	1.38b	1.27b	1.32b	1.17b	1.26a	1.05b	7.45b	228.2a
C	1.70a	1.54a	1.50a	1.41a	1.30a	1.15a	8.61a	220.5a

[1]Data in the same column and within the same time period, followed by the same letter, are not significantly different at the 5 percent probability level.

depletion in those regimes (D and E) receiving a single irrigation per harvest, compared with the regimes (A and B) receiving the same amount of water per harvest but applied in two applications. Coupled with the higher yields obtained with two irrigations per harvest, these data emphasize the importance of maintaining adequate moisture in the upper 24-inch soil profile to promote forage production of alfalfa. A relatively low amount of moisture depletion occurred below the 36-inch depth.

Irrigation Water Quality and Soil Salinity

Indications of water quality in the Roswell Artesian Basin were obtained from the results of the analysis of

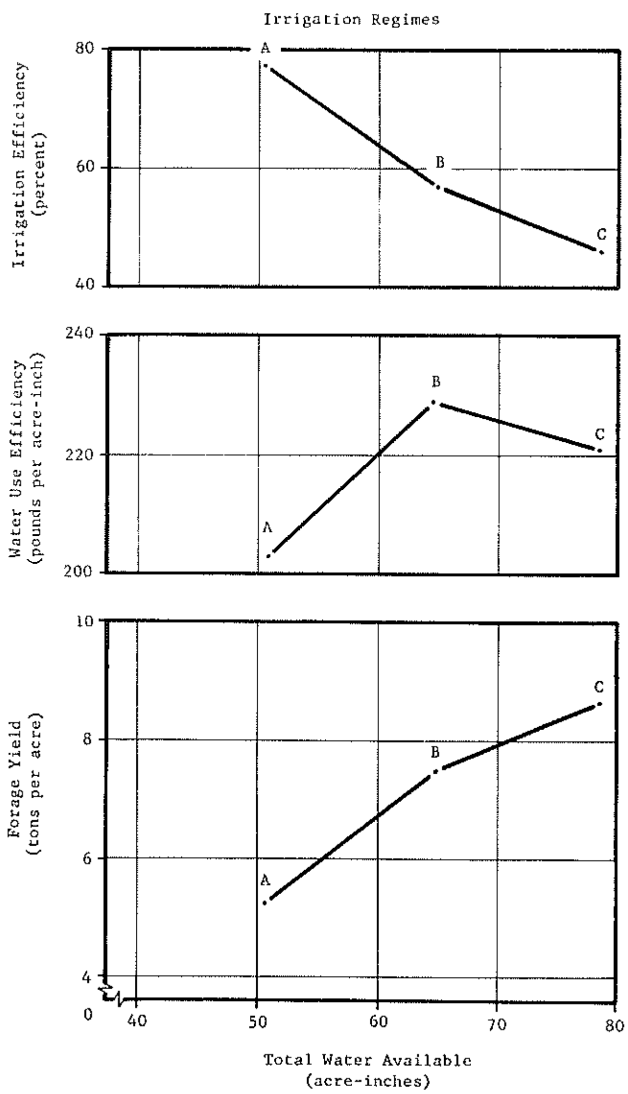


Figure 8. Mean total water available including rainfall, forage yield, water use efficiency, and irrigation efficiency for three regimes in the alfalfa irrigation study, Southeastern Branch Experiment Station, Artesia, New Mexico, 1967-1968.

water samples taken from the irrigation well(s) at the Southeastern Branch Experiment Station, Artesia, and on the cooperating farms (table 19). The data are useful in the prediction of potential yield and water requirements as reported by Dregne (9).

Following is an example of the application of these data, using data from the irrigation well at the Southeastern Branch Experiment Station. The mean electrical conductivity was 1780 micromhos (EC X 10^6) or 1.780 millimhos (EC X 10^3). For alfalfa, the relative yield with 42 acre-inches of water would be approximately 40 percent, and with 66 acre-inches, approximately 90 percent. For spring barley, the relative yield would be 60 percent with 9 acre-inches of water and 100 percent with 18 acre-inches of water. For corn, approximately 28 acre-inches of water would be required to produce 100 percent of the yield potential. It should be noted that the water quality data for Case Farm C (3, pp. 78-79) appeared to be the only instance where there was a theoretical potential of sodium accumulation in the soil; however, the extremely high salt content of this water, coupled with the gypsiferous character of most of the soils in the basin, precludes the potential development of a sodium hazard.

The percent total soluble salts present in soil samples taken from five case farms were determined (3, table D-2) and from alfalfa and cotton fields on three case farms (3, table D-3). With two exceptions, these data indicated that leaching had been sufficient to prevent an accumulation of salts in the soil. The exceptions were Case Farm A, where additional leaching will be required

Table 19. Mean electrical conductivity and total soluble salts of water samples taken from irrigation well(s) at the Southeastern Branch Experiment Station and on cooperating farms, Roswell Artesian Basin, New Mexico, 1966-1968.

Source of Sample	Electrical Conductivity EC x 10^6	Total Soluble Salts (ppm)
Southeastern Branch Experiment Station	1780	1140
Case Farm		
A	3580	2290
B	4208	2690
C	7172	4590
D	911	580
E	877	560
F	925	590
G	1727	1100
I	2150	1380
J	1206	770
K	1026	660
L	1518	970
Average	2300	1471

to maintain a satisfactory salt level, and the October 2, 1967, sampling on Case Farm C, which indicated a substantial increase in salt content as compared to the May 4, 1967, sampling. The lower salt content for 1968 samplings on Case Farm C may have been caused by leaching resulting from above-average rainfall during 1968.

Water Use and Cropping Practices

The 33 random sample units of approximately 350 acres in size were compared with the remainder of the basin with respect to kind and amount of crops grown, total amount of water diverted for irrigation, and water diversion for specific crops.

Data on the percentage of crops grown on all 33 random sample units were quite comparable with the crops data for the basin, table 21, and the same was true when the random units in any one area were compared with the total for that area.

Cropping patterns in the Northern Extension Area differed from the basin average more markedly than did those of the other areas. In this area the percentage of land not cropped and the percentage of land in forage crops was considerably higher than for the other areas of the basin. The percentage not cropped was 47.6 compared with 20.0 for the basin; forage crops, 9.9 compared with 4.9 for the basin; and alfalfa 14.9 compared with 39.6 percent for the basin. This cropping pattern reflects a relatively low rate of water diversion per water-right acre, discussed in other sections of this report.

The sample units differed little in water diversion from other farms in their respective areas (table 20). The average amount of water pumped for the random sample units in a given section of the basin was comparable to that of the whole section in which the sample was located. The same was true when the combined 33 samples were compared with the basin as a whole. In every instance water diversion was appreciably less in 1968 than in 1967.

Table 20. Average irrigation water diversion by sub-area for the Roswell Artesian Basin and 33 random sample units, 1967-1968.

Sub-Area	1967		1968	
	Basin (acre-feet)	Sample (acre-feet)	Basin (acre-feet)	Sample (acre-feet)
Northern Extension	1.96	1.67	2.12	1.47
Roswell-East Grand Plains	2.53	3.08	2.37	2.44
Dexter-Hagerman	2.92	2.79	2.51	2.31
Cottonwood	3.42	3.06	2.99	2.85
Artesia	3.14	3.12	2.81	2.75
Lakewood-Seven Rivers	3.43	3.54	2.80	3.27
Total	2.85	2.96	2.53	2.48

The primary reason for the below-average per-acre irrigation water diversion for the Northern Extension in 1967 was the large number of uncropped acres. Only 52.4 percent of the water-right acres were being cropped in the Northern Extension in 1967 (10, p. 43). Above-average precipitation and more than 20 percent of the water-right acres out of production were the main reasons for the slightly below average water diversion in the Roswell-East Grand Plains Area.

In the Dexter-Hagerman Area, diversions were slightly above average because of the relatively higher percentage of cropland devoted to alfalfa. In the Cottonwood, Artesia, and Lakewood-Seven Rivers Areas, reduced precipitation probably accounted for much of the above-average irrigation water diversion per water-right acre in 1967. In addition, the Cottonwood and Artesia Areas had above-average percentages of the water-right acres devoted to production of alfalfa (10, p. 88). In the Lakewood-Seven Rivers Area the percentage of water-right acres devoted to the production of pecans was almost three times that for the average of the basin (10, p. 116).

Data were recorded for percentage of the various crops and fallow land on the 33 sample units, and the data were analyzed by correlation to determine their

Table 21. Comparison of land use and irrigation water diversion among study units of the Roswell Artesian Basin, New Mexico, 1967.

Item	Roswell Artesian Basin[1]	12 Case-Study Farms[2]	33 Random Sample Areas
Land Use Percent in 1967			
Cotton	23.1	26.4	24.7
Alfalfa	39.6	37.2	42.7
Grain sorghum	3.5	3.8	1.1
Small grains	6.4	8.6	5.7
Other forage crops	4.9	9.5	7.6
Fallow and diverted	11.1	11.5	16.6
Other[3]	2.5	0.0	1.6
Out of production	8.9	3.0	0.0
Total	100.0	100.0	100.0
Irrigation Water Diversion, 1967 Acre-Feet			
Per water-right acre	2.85	3.05	2.96
Per cultivated acre	3.13	3.08	2.96
Per cropped acre	3.58	3.69	3.55

[1]Source: Garnett, Edwin T., "Economic Classification of the Irrigated Cropland in the Roswell Artesian Basin, New Mexico" (Unpublished Master's Thesis, Department of Agricultural Economics and Agricultural Business, New Mexico State University, 1968), 171 pp.

[2]Source: Simkins, Arthur R., "An Economic Analysis of Irrigation Water Requirements for Crop Production in the Roswell Artesian Basin, New Mexico" (Unpublished Master's Thesis, Department of Agricultural Economics and Agricultural Business, New Mexico State University, 1968), 205 pp.

[3]Includes pasture, pecans, fruits and vegetables, castor beans, and soybeans.

relationship to irrigation water diversion for 1967 and 1968. The percentage of land in alfalfa had a statistically significant correlation (22.2 percent in 1967 and 47.9 percent in 1968) with increased water diversion. The percentage of fallow land had a negative coefficient of determination, 13.4 percent in 1967 and 40.4 percent in 1968. As fallow land is increased irrigation water is reduced about 0.02 acre-feet per water-right acre per acre of fallow land for the basin.

Eight irrigation systems and practices used in 1968 on the 33 sample units were evaluated to determine their influence on irrigation water diversion. Three of the eight were found to influence the amount of irrigation water diverted, with coefficients of determination of 14.1, 14.4, and 15.9 percent for the length of run, isolation percentage, and crop condition respectively. It is considered that the low correlations in these and the other variables were caused by differences in other water management practices, which would obscure the relationships that normally might be expected.

Comparison of the cropping pattern on the 33 sample units for 1967 and 1968 revealed that cotton acreage increased approximately 6.4 percent, alfalfa acreage decreased 1.5 percent, small grains increased 1.7 percent, grain sorghum decreased 1.0 percent, and fallow land decreased 5.5 percent. Statistically only cotton and fallow acreages showed any significant change in the cropping program for the two years. A more detailed description of the above analysis appears in a report by Carroon and Hanson (6).

Case Study Farms

The 12 case farms used in this study were arbitrarily selected rather than being a random sample of farms in the Roswell Artesian Basin. Therefore statistical inferences concerning relationships of these farms to the whole basin cannot be made without qualification.

However, in comparing the 12 case study farms with the basin in 1967 they appeared to be quite typical of the basin (table 21). The average cropping program and irrigation water use for the 12 farms was reasonably representative of the average for all farms in the Roswell Artesian Basin. The major difference in 1967 was the production of alfalfa on a slightly larger percentage of the water-right acres for all farms in the basin compared with the 12 case farms (table 21). However, production of other forage crops was greater on the case study farms than on all farms in the basin.

In 1967 the average irrigation water diversion for the Roswell Artesian Basin was about the same as that on the 12 case study farms (table 21). The average irrigation water use for the basin was 2.85 acre-feet per water-right acre, 3.13 acre-feet per cultivated acre, and 3.58 acre-feet per cropped acre. The average irrigation water use for the 12 case study farms was 3.05 acre-feet per water-right acre, 3.08 acre-feet per cultivated acre, and 3.69 acre-feet per cropped acre (table 21). The lower per-water-right-acre diversion in the basin resulted primarily from a greater percentage of uncropped acreage compared with the 12 case study farms.

A physical summary of the 12 case study farms, based on detailed descriptions of each farm in a report by Lansford and Creel (24), appears in table 22. The physical irrigation systems are discussed, followed by results of an intensive irrigation study on two case farms, an economic analysis based on data from the 12 case study farms, and finally, an economic analysis based on data for the entire Roswell Artesian Basin.

The average size of the 12 case farms was 209.88 water-right acres (table 22). However, 10 of the 12 case farms double-cropped part of the water-right acreage, making an average of 235.21 acres in cultivation, which is 12.1 percent above the average water-right acreage. The average net farm return for the typical case study farm was $91.35 per water-right acre. The average utilization of cropland in percent was as follows: cotton, 29.4; diverted land, 6.8; alfalfa, 42.3; forage crops, 4.9; grain sorghum, 3.4; small grains, 10.4; and fallow or out of production, 2.8. On a water-right acre basis, cotton accounted for 32.5 percent, diverted 7.5 percent, and alfalfa 42.9 percent of total cropped acreage.

The three-year average irrigation water diversion (per water-right acre) on the 12 case study farms ranged from 1.41 to 4.46 acre-feet with an average of 3.27 acre-feet for all 12 farms. Diversions for alfalfa ranged from 1.30 to 5.37 acre-feet with an average of 4.23 acre-feet for all 12 farms. The primary reason for the low diversion level on Case Farm F was the production of alfalfa for seed during all three years of the study. The irrigation water diversions for the remaining crops on each of the case farms are presented in table 22.

Yields per acre by crops and case farms are reported in table 22. Cotton yields ranged from 504.2 to 975.3 pounds with an average of 728.7 pounds on the 12 case farms. Alfalfa yields ranged from 1.41 to 6.85 tons with an average yield of 5.46 tons per acre. The extremely low yield of alfalfa hay was on Case Farm F where alfalfa was produced primarily for seed during all three years of the study.

Farm irrigation efficiency, calculated from data developed by Barnes (3), averaged 61.21 percent for the 12 case study farms (table 22) and ranged from 42.72 to 84.35 percent. The average irrigation efficiency on cotton was 59.41 percent with a range from 42.09 to 81.17 percent. The irrigation efficiency on alfalfa ranged from 43.47 to 65.54 percent with an average of 54.41 percent on 11 of the 12 case farms. Irrigation efficiency was based on cotton, corn silage, and oats for Case Farm F because of the alfalfa seed production. Case Farms G and H also produced alfalfa seed and Case Farms A and G grazed alfalfa during part of the growing season (table 22). Irrigation efficiencies for the remaining crops produced on the case farms are presented in table 22.

Table 22. Physical summary of twelve case study farms, Roswell Artesian Basin, New Mexico, average 1966-1968.

Item	Unit of Measurement	Case Farm A	B	C	D	E	F	G	H	I	J	K	L	Average
Typical Cropping Program (cropped acres)														
Cotton planted	acres	102.60	74.62	57.00	67.40	75.90	160.77	53.70	70.62	33.50	39.54	23.37	58.83	68.15
Cotton diverted	acres	32.50	17.00	13.30	24.30	16.70	26.93	11.70	7.77	9.45	12.96	4.13	13.07	15.82
Alfalfa	acres	79.10	156.10	64.00	121.80	122.20	80.00	91.10	93.43	74.70	79.27	40.66	78.43	90.07
Forage sorghum	acres		7.20	11.70	28.40				3.25					4.21
Corn silage	acres				46.60		100.00						6.30	12.74
Grain sorghum	acres			17.30	15.60	58.30						10.03		8.44
Small grains	acres	24.00	31.60	42.00	46.90	84.50	40.00	56.00		3.25	16.90			28.76
Fallow	acres	25.40	2.18	7.00	4.80	7.00	18.97	9.20	2.18	1.30	2.73	3.43		7.02
Total cropped acres	acres	263.60	288.70	212.30	355.80	364.60	426.67	221.70	177.25	122.20	151.40	81.62	156.63	235.21
Total water-right acres	acres	232.00	278.90	158.50	303.70	280.00	400.00	187.20	174.00	122.20	151.40	79.00	151.70	209.88
Cotton planted	percent	38.92	25.85	26.85	18.94	20.82	37.68	24.22	39.84	27.42	26.12	28.63	37.56	29.40
Cotton diverted	percent	12.33	5.89	6.26	6.83	4.58	6.31	5.28	4.38	7.73	8.56	5.06	8.35	6.80
Alfalfa	percent	30.01	54.07	30.15	34.23	33.51	18.75	41.09	52.72	61.13	52.36	49.82	50.07	42.33
Forage sorghum	percent		2.49	5.51	7.98				1.83					1.48
Corn silage	percent				13.10		23.44						4.02	3.38
Grain sorghum	percent			8.15	4.39	15.99						12.29		3.40
Small grains	percent	9.10	10.95	19.78	13.18	23.18	9.37	25.26		2.66	11.16			10.39
Fallow	percent	9.64	0.75	3.30	1.35	1.92	4.45	4.15	1.23	1.06	1.80	4.20		2.82
Total cropped acres	percent	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total water-right acres	percent[1]	88.01	96.61	74.66	85.36	76.80	93.75	84.44	98.17	100.00	100.00	96.79	96.85	90.95
Net farm return per water-right acre	dollars	115.93	92.60	52.06	84.57	100.74	90.40	71.36	140.06	75.91	77.03	102.83	92.68	91.35
Typical Irrigation Water Diversion (per acre)														
Cotton planted	ac-ft	2.55	2.51	2.80	2.38	2.03	1.83	2.70	3.74	3.29	2.60	3.63	3.39	2.79
Cotton diverted	ac-ft													
Alfalfa	ac-ft	4.79	4.44	4.01	4.54	3.70	1.30	3.81	5.37	4.36	4.57	5.12	4.69	4.23
Forage sorghum	ac-ft		1.10	2.05	1.84				2.86					1.96
Corn silage	ac-ft				1.97		1.32						2.07	1.79
Grain sorghum	ac-ft			1.32	1.08	1.91						3.03		1.84
Small grains	ac-ft	1.04	2.68	1.40	1.99	1.99	0.80	1.19		0.43	2.79			1.59
Fallow	ac-ft													
Average	ac-ft	2.89	3.42	3.29	3.19	3.09	1.41	2.68	4.46	3.58	3.38	4.09	3.75	3.27

Table 22. Physical summary of twelve case study farms, Roswell Artesian Basin, New Mexico, average 1966-1968, continued.

Item	Unit of Measurement	Case Farm A	B	C	D	E	F	G	H	I	J	K	L	Average
Typical Yield (per acre)														
Cotton														
Lint	lb.	706.9	854.4	504.2	632.2	903.5	550.8	617.7	970.4	773.9	587.9	975.3	666.7	728.66
Seed	ton	0.54	0.65	0.38	0.48	0.70	0.38	0.53	0.74	0.63	0.47	0.77	0.52	0.57
Alfalfa														
Hay	ton	4.33	6.00	4.90	6.80	6.60	1.41[2]	4.05	6.85	5.87	6.26	5.80	6.60	5.46
Pasture	a.u.m.	11.22						10.25						10.74
Seed	lb.						22.73	113.80	21.60					52.71
Forage sorghum														
Silage	ton		15.00		22.95									18.98
Pasture	a.u.m.			5.00					7.20					5.82
Corn silage	ton				17.70		16.90						15.00	16.53
Grain sorghum	cwt.			34.00		67.50						65.00		55.50
Small grains														
Seed and grain	bu.		57.50	40.60	61.80	75.00		29.40			37.12			50.24
Hay	ton				3.90		3.35	3.30						3.52
Pasture	a.u.m.	9.33	9.60		5.70			9.00		5.00	3.55			6.74
Typical Farm Irrigation Efficiency														
Cotton planted	percent	59.12	63.21	56.02	63.34	77.53	81.17	59.12	42.09	54.31	58.72	47.31	50.98	59.41
Cotton diverted	percent													
Alfalfa	percent	47.03	57.39	56.89	48.59	54.06		65.54	43.47	62.86	57.48	50.63	54.61	54.41
Forage sorghum	percent		53.39	48.74	51.88				34.94					47.24
Corn silage	percent				64.32		90.75						63.12	72.73
Grain sorghum	percent			112.94	78.56	77.84						55.13		81.12
Small grains	percent	118.97	68.53	91.22	63.01	63.94	81.10	97.51		78.77	48.14			79.02
Weighted average	percent	61.45	60.63	68.06	57.66	65.80	84.35	72.74	42.72	60.75	56.68	50.18	53.50	61.21

[1]Percent of total cropped acres.
[2]Alfalfa for seed.

A typical whole farm budget for the 12 case farms was developed to compare with results of linear programming solutions to determine the economic effect of restricting the diversion of irrigation water at seven different levels. The composition of the average net farm return of $91.35 per water-right acre is presented in table 23.

Peak Water Requirements

Demand for water by various crops is greatest during parts of June, July, and August. For alfalfa, pasture, sorghum, and cotton the average peak consumptive use should be near 0.30 inch per day during part of this period in the major irrigated areas of southern New Mexico. Measurements by Hanson (12) in Mesilla Valley record alfalfa as using 0.33 inch per day in June as an average peak rate, and a peak of 0.35 inch per day for cotton in August. Israelsen and Hansen (23) record peak consumptive use for intermountain, desert, and western high plains regions for various crops as follows:

Crop	*Consumptive Use, inches per day*
Alfalfa	0.29 to 0.32
Pasture	0.28 to 0.30
Small grains	0.20 to 0.22
Cotton	0.28
Grain sorghum	0.20

Computations from Blaney and Hanson data (4) give somewhat lower figures for Roswell and Artesia, with alfalfa and sorghum using 0.25 inch per day, and cotton 0.23 inch per day. Recent work indicates these computations may be lower than actual measurements would show.

Considering these data, it is estimated that an adequate water supply for the major crops should provide at least 0.30 inch per day for consumptive use for good crop production throughout the basin during the months of peak water use. According to rainfall records for the basin, precipitation averages about 0.05 inch per day from June through August. By subtracting the average daily precipitation R from the peak daily consumptive use U, the daily average peak requirement $U - R$ (.30 − .05) is computed to be about 0.25 inch per day.

This value has been used in constructing figure 9 which may be used to evaluate the adequacy of pump discharges and reservoirs for meeting peak irrigation requirements on farms throughout the basin.

It is considered that rates of flow and irrigation efficiencies which provide 0.25 inch per day represent a near minimum for irrigation systems in the Roswell Area in view of the probability of periods of deficient precipitation. The probability of no effective rainfall in the Roswell Area during June through August, by one-week periods, ranges from 19 to 48 percent, and by two-week periods, from 3 to 18 percent (11).

Table 23. Average typical net farm returns for 12 case study farms, Roswell Artesian Basin, New Mexico, 1966-1968.

Crop	Acres	Net Farm Return to Land and Management: Per Acre	Net Farm Return to Land and Management: Farm
		(dollars)	(dollars)
Cotton planted	68.15	177.68	12,108.89
Cotton diverted	15.82	60.00	949.20
Alfalfa	90.07	50.29	4,529.62
Forage sorghum	4.21	60.00	252.60
Corn silage	12.74	54.05	688.63
Grain sorghum	8.44	60.07	506.99
Small grains	28.76	4.75	136.61
Fallow	7.02	0.00	0.00
Total	235.21[1]	91.35[2]	19,172.54

[1]Cropped acres; net return per cropped acre was $81.51.

[2]Per water-right acre which was 209.88 acres. The difference between 235.21 and 209.88 was 25.33 acres which was double cropped.

Water needed daily by plants may be obtained in part from moisture stored previously in the soil and the remainder from water applied during the current irrigation cycle. On farms having soil with good water holding capacity, crops may do well with irrigation systems which provide somewhat less than 0.25 inch per day if peak demand periods are relatively short. Under cropping conditions where demands remain relatively high for two or three months, as with alfalfa, the soil moisture reserve may be largely depleted on farms having minimal rates of flow available from pumps and canals. Under this condition the daily water used by plants will be limited by pump and ditch deliveries. This appears to be the situation with Case Farms A, F, and G where moisture deficiencies have resulted in relatively lower yields or limitations on cropping systems (table 24).

Production is highest if crops are adequately irrigated during vegetative and flowering stages. Since consumptive use is near a maximum during the flowering stage it is important that irrigation systems have adequate capacity to satisfy near peak water requirements.

When rate of discharge from wells is less than approximately 13 to 15 gpm per cropped acre, reservoirs are required for overnight storage if irrigation is to be done during 12 to 14 of the daylight hours with efficiencies ranging from 55 to 70 percent (figure 9). Figure 9 shows that a pumping rate of 10 gpm per cropped acre is required for about 18.8 hours of pumping each day to provide water with 60 percent irrigation efficiency for daily requirements of 0.25 inch per day. Figure 10 may be used to determine the reservoir storage required for different pumping rates.

The use of figures 9 and 10 is illustrated with the following example:

Given: A farm with 100 cropped acres
Well capacity of 1,000 gpm
Daytime irrigation to be 12 hours per day
Farm irrigation efficiency of 60 percent

Problem: (a) Hours required for overnight storage pumping
(b) Required storage, acre-feet

Solution: (a) Well discharge =

$$\frac{1{,}000\ \text{gpm}}{100\ \text{cropped acres}} = \frac{10\ \text{gpm per}}{\text{cropped acre}}$$

Daily pumping time required = 18.8 hours (see figure 9, broken lines)

(b) Nighttime pumping required = 18.8 - 12 = 6.8 hours

Reservoir storage = .01250 acre-feet per cropped acre for 6.8 hours of pumping with 10 gpm per cropped acre (see figure 10, broken lines)

Total storage =

$$\frac{.0125\ \text{acre-feet}}{\text{cropped acre}} \times 100\ \text{cropped acres} = 1.25\ \text{acre-feet}$$

Figure 9 also may be used to determine the minimum size of stream for daily irrigation under selected farm irrigation efficiencies.

For a farm irrigation efficiency of 55 percent and 24 hours per day operation, a stream of 8.5 gpm per cropped acre is required to provide 0.25 inch of water per day in the root zone. No reservoir storage would be required. With pump irrigation using internal combustion engines, daily operation should allow about 4 hours per day for servicing pumps and motors; thus for 20 hours of irrigation per day, a stream of 10.2 gpm per cropped acre is required with 55 percent irrigation efficiency.

Irrigation Supply and Systems

The adequacy of rates of diversion of irrigation water on the case farms may be evaluated by using figure 10 and table 24. The diversion rates on most of the case farms are subject to seasonal variation similar to variations measured on the pump at the Southeastern Branch Experiment Station as presented in table 25. Variations in well discharges were quite critical for Case Farms F and G.

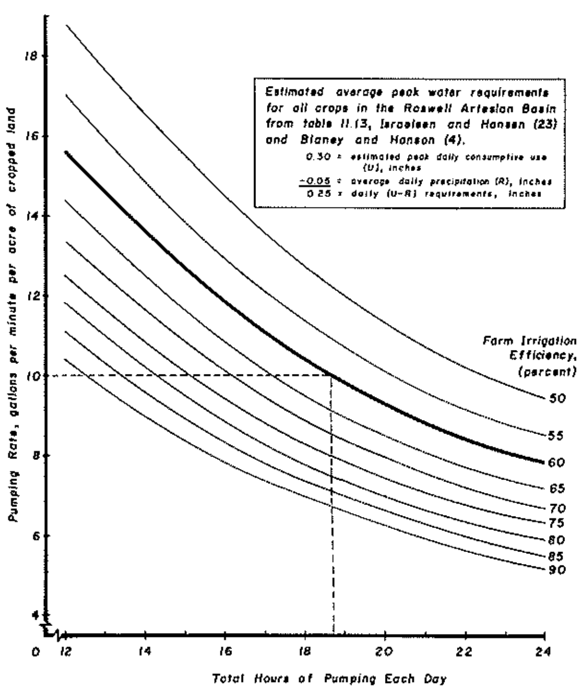


Figure 9. Pumping rates per acre of cropped land and daily hours of pumping required for irrigation to provide 0.25 inch per day with different farm irrigation efficiencies.

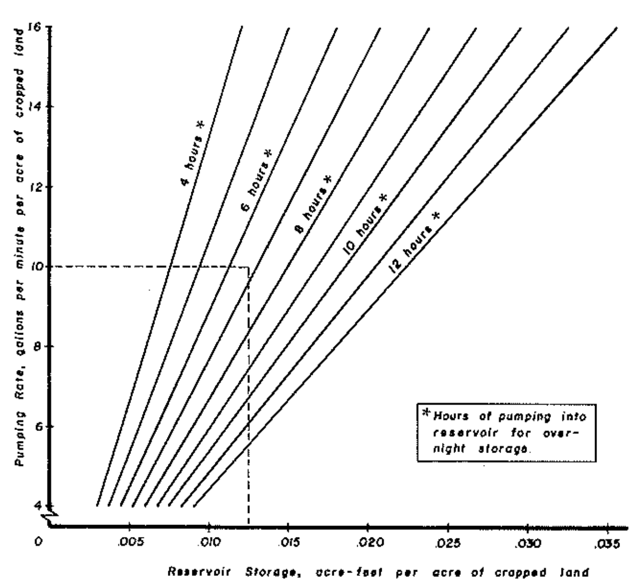


Figure 10. Acre-feet of water stored in reservoir per acre of cropped land for different pumping rates and hours of pumping.

In discussing the adequacy of diversion rates of irrigation water, some of the case-study farmers indicated that they lacked a sufficient stream of water for adequate irrigation of their farms, either with or without reservoirs, while others indicated that they had sufficient streams to split the head of water coming out of the reservoir or direct from wells. The operator of Case Farm A indicated that the available stream of water was insufficient to follow the desired cropping program. When he could not adequately irrigate alfalfa to obtain a satisfactory yield of hay, he grazed it with sheep to salvage the limited production.

The operator of Case Farm B indicated that the amount of irrigation water available was adequate after re-leveling the farm and shortening the irrigation runs on alfalfa. Case Farm C had a sufficient stream of water, allowing heads to be split so as to irrigate two fields at the same time. One large reservoir was removed from Case Farm D at the end of 1967 and an ample flow of water appeared to be available for irrigation directly from the well. Case Farm E had a sufficient diversion from wells so the heads could be split and two fields irrigated at the same time.

Case Farm F had a limited quantity of irrigation water available (5.2 gpm per cultivated acre), which partially dictated the cropping program on this farm, especially the production of seed alfalfa. Case Farm G, with an average of only 4.0 gpm available per cultivated acre, had difficulty in maintaining an adequate irrigation program. During periods of peak water use by cotton, alfalfa was inadequately irrigated, thereby lowering the yield. Much of the alfalfa was either cut for seed or used for pasture.

The amount of irrigation available to Case Farm H depended on the flow of the Pecos River from which the operator pumped directly. Case Farm I re-leveled and put in an underground irrigation pipeline to allow adequate irrigation of the farm with the small stream of water (6.5 gpm per cultivated acre). Case Farms J, K, and L had ample supplies of water for adequate irrigation.

Case Farm J used a reservoir sparingly, Case Farm K used a reservoir to obtain a larger head, and Case Farm L did not have a reservoir.

Where the rate of discharge from wells is small, the reservoirs have potential value in saving water by making larger streams available with diversions from water stored by overnight pumpings. The alternative is to irrigate at night without using a reservoir.

The reservoir storage on the case farms ranged from 1.0 to 5.2 acre-feet and the average was 3.27. The capacity of well(s) supplying these reservoirs ranged from 372 to 3,200 gallons per minute.

Reservoirs also enable greater acreage to be irrigated during daytime operation, and the increase depends on the amount of water applied per irrigation. Case Farm J, which irrigated with light 3- to 4-inch applications per irrigation, thus might use the farm reservoir storage of 1.0 acre-foot to increase the area irrigated during daytime by 3 to 4 acres daily. Likewise, with the storage capacity of 3.0 acre-feet, a farm using the light irrigation practice could increase daytime irrigation by approximately 10 to 13 acres daily. With 9- to 10-inch applications similar to those of Case Farm L, the increase would

Table 24. Estimated available irrigation water, land in cultivation, and size of stream by case farms, Roswell Artesian Basin, New Mexico.

Case Farm	Total Available Water (gpm)	Land in Cultivation (acres)	Size of Stream per Cultivated Acre (gpm)
A	1,110	206.6	5.4
B	2,700	278.9	9.7
C	3,200	158.5	20.2
D	3,000	303.7	9.9
E	3,700	280.0	13.2
F	2,080	400.0	5.2
G	750	187.2	4.0
H	---	---	---
I	800	122.2	6.5
J	2,750	151.4	18.2
K	850	79.0	10.8
L	2,100	151.7	13.8
Average	2,147	210.8	10.2*

* Weighted average.

Table 25. Variation of pump discharges during 1966 at the Southeastern Branch Experiment Station, Artesia, New Mexico.

Date Recorded	Running Time (minutes)	Pump Discharge Daily Average (gpm)	Pump Discharge Monthly Average (gpm)
January 17	450	1,021	
January 18	420	1,033	1,027
February 8	350	1,063	
February 16	189	1,072	1,068
March 1	187	1,016	
March 29	301	845	930
April 4	616	720	
April 6	554	729	724
May 16	259	924	
May 23	280	810	
May 30	367	754	829
June 28	268	564	564
July 5	120	510	
July 20	491	494	502
August 2	504	313	
August 8	519	372	
August 9	304	382	
August 11	604	369	
August 17	131	440	375
September 19	378	683	683
October 26	246	939	939
December 5	237	943	
December 20	412	930	936

Source: 1966 Annual Report, Southeastern Branch Experimental Station, Artesia, New Mexico.

be almost 4 acres daily for the average storage of 3.00 acre-feet.

Losses from Irrigation Systems

Seepage from reservoirs, and gate leakage may greatly nullify water savings. The Southeastern Branch Experiment Station research personnel made two reservoir seepage tests in March 1967 with water stage recorders. An analysis of the chart records revealed that a small (0.35 acre) reservoir near Artesia (Case Farm J) was losing 0.24 acre-inch per hour when about half full. As the well was pumping 1,012 gpm, this loss was 10.8 percent of the total pumped.

A larger (0.95 acre) reservoir (Case Farm A) showed a loss of 0.25 acre-inch per hour. As this reservoir was 2.7 times larger than the one described above, this was not considered an excessive loss per unit area for the size of the structure. However, the well produced only 1,110 gpm, and the loss represented 9.65 percent of the amount pumped. The quantity of water supplied by this well was only 5.3 gpm per cultivated acre. The use of the reservoir was considered necessary for efficient irrigation due to the number of acres to be irrigated.

A seepage test was conducted on an underground mortar-joint concrete-pipe installation near Artesia (Case Farm J) in October 1967 to determine the extent of water losses from this source. The installation had a loss of 244.5 cubic feet per day in 4,520 feet of 12-inch pipe, which was well within the allowable loss although there was one visible leak.[3] All hydrant valves were in good condition.

Mortar-joint concrete pipe has caused excessive water losses in many systems. In sandy subsoils, faulty joints may cause serious leaks that are not apparent on the ground surface and may thus go unnoticed.

It was noted that many of the older concrete ditches had cracks and deterioration extensive enough to cause leakage. In the Roswell Artesian Basin, siphons are generally used to convey water from concrete ditches to the fields, and thus there is no appreciable loss problem with turnout gate leakage. Leaking box gates were observed which allowed water to flow to places where it was not used beneficially. The significance and control of such losses have been further discussed by Hanson (15).

A profile survey of 1,000 feet of an unlined ditch on Case Farm F indicated that 300 feet at the lower end were sufficiently level for conducting a static ponding test, using a water stage recorder. The test was conducted immediately following a regular irrigation, so that it would measure the seepage from a wetted ditch, not the water necessary for wetting the ditch. Dams of earth-filled sacks covered with plastic sheeting were placed at each end of the 300-foot section. A water stage recorder with stilling well was installed at the midsection to compensate for any wind disturbance of the water level. The ditch was filled and left overnight.

The water stage recorder chart was analyzed in two-inch depth increments, using an assumed parabolic cross-section of observed depth and average top width. The seepage loss per hour varied approximately directly with the wetted area and the depth of water. The well on this ditch system produced about 2,000 gpm and the length of the longest ditch was about 3,425 feet. For the Silty Clay Loam soil at this test site the rate averaged 0.0368 cubic foot per hour per square foot of wetted ditch per foot of depth. The loss was about 4.5 percent of the water pumped.

Number and Frequency of Water Applications

Water management on individual farms has been a controlling influence on efficient use of water in view of the variability of results shown in correlations from the 33 random sample units.

Irrigation water applications, irrigation efficiency, and yield for selected irrigation units of alfalfa and cotton on Case Farms J and L are presented in table 26. The effect of irrigation frequency is discussed below.

Alfalfa—One difference in the management of water on these two farms was the application of two irrigations per cutting for alfalfa on Case Farm J, and one irrigation per cutting on Case Farm L.

In 1967, application of 45.47 acre-inches per acre in 14 irrigations produced 8.53 tons of forage per acre with an irrigation efficiency of 79.1 percent on Case Farm J, while 71.38 acre-inches per acre applied in seven irrigations produced 8.48 tons of forage per acre with an irrigation efficiency of 50.4 percent on Case Farm L (table 26).

In 1968, 40.21 acre-inches per acre of water in 13 irrigations produced 5.18 tons of forage per acre with an irrigation efficiency of 71.3 percent on Case Farm J, and on Case Farm L, 68.54 acre-inches per acre of water in six irrigations produced 8.69 tons of forage with an irrigation efficiency of 41.8 percent. The lower yield on Case Farm J in 1968 was partially attributed to cutworm and hail damage to the second cutting. There was a difference of 25.9 inches of water applied in 1967 and 28.3 inches in 1968 with practically the same yield on each farm.

These data would seem to substantiate findings of the irrigation study at the Southeastern Branch Experiment Station, where increased yield resulted with less water, when irrigation water was applied twice as compared to one irrigation per cutting.

Cotton—In 1967 a total of 34.06 acre-inches per acre applied in six irrigations produced 486 pounds of lint cotton per acre with an irrigation efficiency of 70.5 percent on Case Farm J, while 45.94 acre-inches per acre applied in seven irrigations on Case Farm L produced 857 pounds of lint with an irrigation efficiency of 52.3 percent (table 26). During 1968, 29.80 acre-inches per acre applied in five irrigations produced 619 pounds

[3] As specified in Standard No. A 261.3, ***American Society of Agricultural Engineers' 1968 Yearbook.***

Table 26. Number and frequency of irrigations, irrigation water applied, irrigation efficiency, and yield for alfalfa and cotton for selected units on Case Farms J and L, Roswell Artesian Basin, New Mexico, 1967-1968.

Crop	Item	Unit of Measure	Case Farm J 1967	Case Farm J 1968	Case Farm L 1967	Case Farm L 1968
Alfalfa						
	Yield of hay	tons/acre	8.53	5.18[1]	8.48	8.69
	Number of irrigations	----	14	13	7	6
	Average days between growing season irrigations	----	16	14	28	30
	Irrigation water applied	acre-inches per acre	45.47	40.21	71.38	68.54
	Irrigation efficiency	percent	79.1	71.3	50.4	41.8
Cotton						
	Yield (lint)	pounds/acre	486	619	857	418
	Number of irrigations	----	6	5	7	5
	Average days between growing season irrigations	----	28	28	29	37
	Irrigation water applied	acre-inches per acre	34.06	29.80	45.94	27.07
	Irrigation efficiency	percent	70.5	63.3	52.3	69.8

[1]Some worm and hail damage.

of lint with an irrigation efficiency of 63.3 percent on Case Farm J, and on Case Farm L, 27.07 acre-inches per acre applied in five irrigations produced 418 pounds of lint with an irrigation efficiency of 69.8 percent.

Linear Programming Solutions–Case Farms

Following are results of linear programming solutions for models A, B, and C. The results for each model will be compared with the respective typical whole farm budget.

Linear Programming–Model A

The typical cropping program under actual use in the study period for the average of the 12 case farms diverted an average of 3.27 acre-feet of irrigation water per water-right acre with a per-acre net return to land and management of $91.35 (table 23). The solutions for linear programming model A with 2.50 acre-feet of irrigation water available indicated that an average net return of $106.43 per water-right acre would be obtained if crop enterprises were combined optimally (table 27). The average net return per acre would have been increased from 16.5 percent or $15.08 per water-right acre above the typical return with the crop enterprises indicated in model A at the 2.50 acre-feet diversion level to 27.6 percent or $25.25 per water-right acre above the typical return at 4.00 acre-feet. Net returns at the 2.50 acre-feet level increased primarily from a larger acreage of planted cotton, grain sorghum, and castor beans, and a reduction in the acreage of small grains and alfalfa (table 27).

With increased levels of irrigation water diversion per water-right acre, returns increased at a decreasing rate. The increased levels of returns were achieved primarily by increases in the acreage of alfalfa D and decreases in the acreage of grain sorghum, castor beans, forage sorghum, and fallow land. In model A, cotton acreage would remain unchanged over the seven levels of irrigation water diversions with 95 percent of the cotton allotment planted and 5 percent of the cotton allotment diverted (table 27).

The acreage of each crop that would be produced at each of the seven diversion levels (2.50, 2.75, 3.00, 3.25, 3.50, 3.75, and 4.00 acre-feet per water-right acre) and the net return per water-right acre at the different diversion levels are presented in table 27.

Linear Programming–Model B

Linear programming model B did not contain provisions for a crop rotation program but did represent a 5 percent increase in irrigation efficiency above model A on each crop. Solutions for linear programming model B with 2.50 acre-feet of irrigation water per water-right acre indicated the average net return of $109.27 per water-right acre would be obtained if crop enterprises were combined optimally (table 27). The average net return per acre would have been increased 19.6 percent or $17.92 per water-right acre above the typical return with the crop enterprises indicated in model B at the 2.50 acre-feet level and 28.5 percent or $26.08 per water-right acre above the typical return at 4.00 acre-feet diversion level.

Net returns increased in model B primarily from a larger acreage of planted cotton, and increases in grain sorghum, and castor beans, and a reduction in small grains and alfalfa at the 2.50 acre-feet diversion level (table 27).

With increased levels of irrigation water diversions per water-right acre, returns increased at decreasing rates primarily by the substitution of alfalfa D for grain sorghum, castor beans, forage sorghums, and fallow land. The cotton acreage would remain unchanged (table 27).

The acreages of each crop that would be produced at each of seven diversion levels and the respective net returns per water-right acre are presented in table 27.

The economic effect of a 5 percent increase in irrigation efficiency can be estimated by comparing solutions from model A with solutions from model B (figure 11). A 5 percent increase in irrigation efficiency increased the optimal net returns by an average of 1.1 percent ($1.25) per water-right acre.

The solutions for linear programming model B represented the maximum net farm return that would be expected with different levels of irrigation water with a 5 percent increase in irrigation efficiency. Models A and B contained no provisions for a crop rotation program. Although the solutions for these models may be valid for one or more years, crop yields and thus net farm return may be reduced if the optimal cropping programs were followed for extended time periods.

Linear Programming—Model C

Linear programming model C provided for a crop rotation program, with a minimum of about one-third of each farm producing alfalfa. The solutions for linear programming model C with 2.50 acre-feet of irrigation water per water-right acre indicated that the average net return of $85.49 per water-right acre would be obtained if crop enterprises were combined optimally (table 27). The average net return per acre at the 2.50 acre-feet level would have been decreased 6.4 percent or $5.86 per water-right acre below the typical net farm return but increased by 27.6 percent per water-right acre above the typical return at the 4.00 acre-feet level. Net returns at the 2.50 acre-feet level decreased primarily because a larger percent of the average typical farm was left fallow (21.7 percent) due to the provision that approximately one-third of the water-right acres be in alfalfa.

With increased levels of irrigation water diversions per water-right acre, returns initially increased at almost a constant rate from 2.50 acre-feet to 3.25 acre-feet per water-right acre primarily because fallow acreages were being brought into the production of larger acreages of cotton, grain sorghum, or castor beans (table 27). As irrigation water diversion per water-right acre increased

Table 27. Average whole farm budget and linear programming solutions for 7 quantities of irrigation water for 12 case study farms, Models A, B, and C, Roswell Artesian Basin, New Mexico, 1966-1968.

	Average Whole Farm Budget		Linear Programming Solutions													
			2.50 Acre-Feet per Acre		2.75 Acre-Feet per Acre		3.00 Acre-Feet per Acre		3.25 Acre-Feet per Acre		3.50 Acre-Feet per Acre		3.75 Acre-Feet per Acre		4.00 Acre-Feet per Acre	
Crop	Acres	Net Return per Water-Right Acre (dollars)	Acres	Net Return per Water-Right Acre (dollars)	Acres	Net Return per Water-Right Acre (dollars)	Acres	Net Return per Water-Right Acre (dollars)	Acres	Net Return per Water-Right Acre (dollars)	Acres	Net Return per Water-Right Acre (dollars)	Acres	Net Return per Water-Right Acre (dollars)	Acres	Net Return per Water-Right Acre (dollars)
Model A																
Cotton (65)																
Cotton (80)	83.97															
Cotton (95)			84.37		84.37		84.37		84.37		84.37		84.37		84.37	
Alfalfa (A)	90.07															
Alfalfa (B)																
Alfalfa (C)																
Alfalfa (D)			17.86		29.20		41.40		54.15		65.86		77.58		89.30	
Grain Sorghum[1]	8.44		64.17		57.45		50.46		41.63		33.83		26.03		18.23	
Small Grains	28.76															
Castor Beans[1]			22.56		22.69		20.71		18.36		16.01		13.66		11.31	
Forage Sorghum[1]	4.21		13.96		12.39		10.82		9.25		7.69		6.12		4.55	
Corn Silage	12.74															
Fallow	7.02		6.96		3.78		2.12		2.12		2.12		2.12		2.12	
Total	209.88[2]	91.35	209.88	106.43	209.88	109.74	209.88	112.13	209.88	113.49	209.88	114.53	209.88	115.56	209.88	116.60
Model B																
Cotton (65)																
Cotton (80)	83.97															
Cotton (95)			84.37		84.37		84.37		84.37		84.37		84.37		84.37	
Alfalfa (A)	90.07															
Alfalfa (B)																
Alfalfa (C)																
Alfalfa (D)			23.72		36.17		49.66		60.71		74.48		86.82		97.40	
Grain Sorghum[1]	8.44		60.61		53.55		44.65		37.73		28.08		19.87		13.41	
Small Grains	28.76															
Castor Beans[1]			22.88		21.71		19.24		16.76		14.29		11.81		9.34	
Forage Sorghum[1]	4.21		13.15		11.49		9.84		8.19		6.54		4.89		3.24	
Corn Silage	12.74															
Fallow	7.02		5.15		2.59		2.12		2.12		2.12		2.12		2.12	
Total	209.88[2]	91.35	209.88	109.27	209.88	111.68	209.88	113.09	209.88	114.19	209.88	115.29	209.88	116.38	209.88	117.43
Model C																
Cotton (65)			40.05		5.86											
Cotton (80)	83.97		3.58		34.19											
Cotton (95)			40.74		44.32		84.37		84.37		84.37		84.37		84.37	
Alfalfa (A)	90.07		36.96		28.14		19.02									
Alfalfa (B)			10.50		10.34		8.69		1.01							
Alfalfa (C)			17.98		24.64		29.41		25.65		11.72		6.39			
Alfalfa (D)			2.20		4.51		10.52		41.48		60.60		74.63		91.30	
Grain Sorghum[1]	8.44		7.74		11.08		19.63		23.02		29.00		24.70		18.23	
Small Grains	28.76															
Castor Beans[1]			1.01		2.78		4.53		6.72		9.69		10.77		9.31	
Forage Sorghum[1]	4.21		3.54		11.53		17.27		14.91		8.29		6.12		4.55	
Corn Silage	12.74				4.41											
Fallow	7.02		45.58		28.08		16.44		12.72		6.21		2.90		2.12	
Total	209.88[2]	91.35	209.88	85.49	209.88	94.31	209.88	102.30	209.88	107.69	209.86	111.58	209.88	114.59	209.88	116.59

[1]With respect to income generation, grain and forage sorghums and castor beans, as used in this study, are almost equal and therefore interchangable.

[2]Average water-right acres for 12 case study farms, cropped acres equal 235.21 acres.

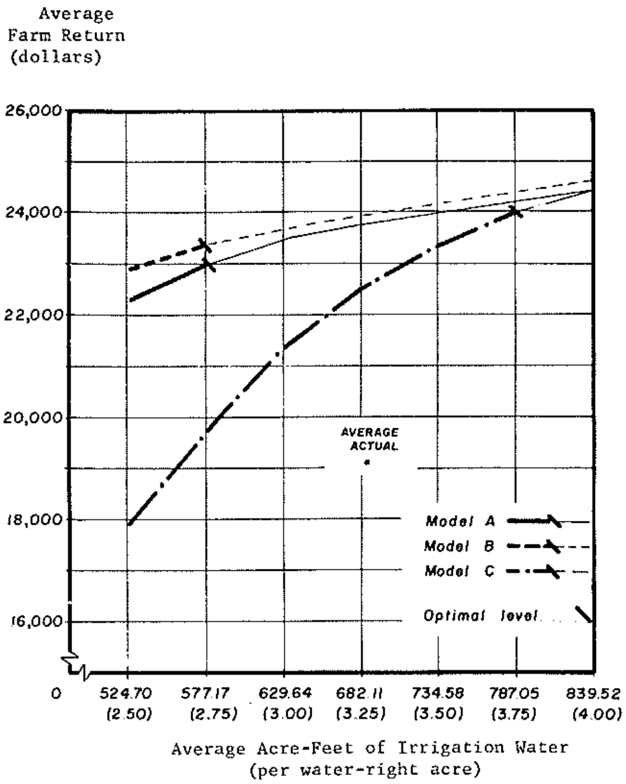


Figure 11. Average farm return and optimal point for operation for seven quantities of irrigation water of 12 case farms, models A, B, and C, Roswell Artesian Basin, New Mexico, 1967.

from 3.25 to 4.00 acre-feet, net returns increased at a decreasing rate primarily from a substitution of alfalfa D for grain sorghum, castor beans, or forage sorghum (table 27).

The acres of each crop that would be produced at each of the diversion levels and the respective net returns per water-right acre are presented in table 27.

The economic effect of forcing in a crop rotation of about one-third of the average-sized farm into alfalfa can be estimated by comparing solutions from model A with solutions from model C (figure 11). Net returns would be reduced by 24.5 percent ($20.94) per water-right acre at the 2.50 acre-feet diversion level to virtually no economic effect at the 4.00 acre-feet level.

The results obtained from linear programming models A, B, and C are graphically summarized in figure 11, which shows the effect of seven quantities of irrigation water on net farm returns. In models A and B, as irrigation water is increased from 524.70 to 629.64 acre-feet (2.50 to 3.00 acre-feet per water-right acre), net farm return increases at almost a constant rate. From 629.64 to 839.52 acre-feet (3.00 to 4.00 acre-feet per water-right acre) the rate of increase is at a lower constant rate for models A and B.

In model C, as irrigation water is increased from 524.70 to 629.64 acre-feet (2.50 to 3.00 acre-feet per water-right acre), the net farm return increases at almost a constant rate. From 629.64 to 734.58 acre-feet (3.00 to 3.50 acre-feet per water-right acre) the net farm return increases at a lower rate, and from 734.58 to 839.52 acre-feet (3.50 to 4.00 acre-feet per water-right acre) the net farm return increases at a still lower rate.

Since the 12 case study farms are reasonably typical of the farms in the Roswell Artesian Basin, the net returns in the basin would appear not to be maximized under existing cropping programs and irrigation water diversion (figure 11). In general, net farm returns would be increased with the implementation of different cropping programs. A comparison of the typcial whole farm budget (3.27 acre-feet per water-right acre) to the optimal cropping programs at the 3.25 acre-feet level in each of models A, B, and C reflects increased net returns per water-right acre under the optimal cropping programs as follows: Model A, 24.2 percent ($22.14); model B, 25.0 percent ($22.84); and model C, 17.9 percent ($16.34) (table 28 and figure 11). These increased net returns were generated with larger percentages of the water-right acres planted to cotton, increased acreages of such crops as grain sorghum, castor beans, or forage sorghum, and decreased acreages of alfalfa, small grains, and fallow (table 28). However, the smaller acreage of alfalfa would be produced on a more intensive basis.

A comparison of the whole farm budget (3.27 acre-feet per water-right acre) with the optimal cropping programs at the 3.00 acre-feet level in each of models A, B, and C reflects increased net returns per water-right acre under the optimal cropping programs as follows: Model A, 22.7 percent ($20.78); model B, 23.8 percent ($21.74); and model C, 12.0 percent ($10.95). These increased net returns were generated with larger percentages of the water-right acres planted to cotton, increased acreage of such crops as grain sorghum, castor beans, or forage sorghum and decreased acreages of alfalfa, corn silage, and small grains (table 29).

Optimal Quantity of Irrigation Water

The shadow prices (marginal value products) for an additional acre-foot of irrigation water are presented in table 30. The optimal level of irrigation water diversion for each model can be determined by equating the shadow price with the cost of pumping an acre-foot of irrigation water, which was $7.68. These optimal levels are shown for models A, B, and C in figure 11.

The average shadow prices for model A at the 577.17 and 629.64 acre-feet diversion levels (2.75 acre-feet and 3.00 acre-feet per water-right acre) were $8.58 and $4.80, respectively (table 30). Somewhere between these two diversion levels the shadow price for an additional

Table 28. Comparison of average typical cropping program with models A, B, and C at 3.25 acre-feet of irrigation water diversion per water-right acre, Roswell Artesian Basin, New Mexico, 1966-1968.

	Cropping Program			
Item	Average of 12 Case Study Farms	Model A	Model B	Model C
	(percent)	(percent)	(percent)	(percent)
Crops				
Cotton planted	32.5	38.2	38.2	38.2
Cotton diverted	7.5	2.0	2.0	2.0
Alfalfa (A and B)	42.9	0.0	0.0	0.5
Alfalfa (C)	0.0	0.0	0.0	12.2
Alfalfa (D)	0.0	25.8	28.9	19.8
Forage sorghum	2.0	4.4	3.9	7.1
Corn silage	6.1	0.0	0.0	0.0
Grain sorghum	4.0	19.8	18.0	11.0
Small grains	13.7	0.0	0.0	0.0
Castor beans	0.0	8.8	8.0	3.2
Fallow	3.3	1.0	1.0	6.0
Total	112.0[1]	100.0	100.0	100.0
Net return per water-right acre, dollars	91.35	113.49	114.19	107.69

[1]Does not add up to 100.00 percent because of double cropping.

Table 29. Comparison of average typical cropping program with models A, B, and C at 3.00 acre-feet of irrigation water diversion per water-right acre, Roswell Artesian Basin, New Mexico, 1966-1968.

	Cropping Program			
Item	Average of 12 Case Study Farms	Model A	Model B	Model C
	(percent)	(percent)	(percent)	(percent)
Crops				
Cotton planted	32.5	38.2	38.2	38.2
Cotton diverted	7.5	2.0	2.0	2.0
Alfalfa (A and B)	42.9	0.0	0.0	13.2
Alfalfa (C)	0.0	0.0	0.0	14.0
Alfalfa (D)	0.0	19.7	23.7	5.0
Forage sorghum	2.0	5.2	4.7	8.2
Corn silage	6.1	0.0	0.0	0.0
Grain sorghum	4.0	24.0	21.2	9.4
Small grains	13.7	0.0	0.0	0.0
Castor beans	0.0	9.9	9.2	2.2
Fallow	3.3	1.0	1.0	7.8
Total	112.0[1]	100.0	100.0	100.0
Net return per water-right acre, dollars	91.35	112.13	113.09	102.30

[1]Does not add up to 100.00 percent because of double cropping.

acre-foot of irrigation water for the whole farm is equal to $7.68, which is the profit-maximizing point with respect to irrigation water, and likewise for model B, at the 577.17 and 629.64 acre-feet diversion levels the average shadow prices were $9.03 and $5.06, respectively (table 30). Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole farm is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

In model C the average optimal quantity of irrigation water was between 787.05 and 839.52 acre-feet (3.75 and 4.00 acre-feet per water-right acre) (table 30). The average shadow prices for model C at the 787.05 and 839.52 acre-feet diversion level were $11.54 and $4.13, respectively. Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole farm is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

The primary reason for the higher optimal irrigation water diversion level for model C was the requirement that about one-third of the water-right acres be in alfalfa. This forced cropland to be left fallow at the lower levels of diversion. Fallow acreage accounted for about 22 percent of the water-right acres at the 2.50 acre-feet diversion level, 13 percent at the 2.75 acre-feet level, 8 percent at the 3.00 acre-feet level, 6 percent at the 3.25 acre-feet level, and 3 percent at the 3.50 acre-feet level.

At the diversion level of 3.00 acre-feet per water-right acre, net farm return per water-right acre is not affected in models A and B because the optimal quantity was between 2.75 and 3.00 acre-feet per water-right acre. In model C at the diversion level of 3.00 acre-feet per water-right acre, which is below the average optimal quantity of 3.75 and 4.00 acre-feet per water-right acre,

Table 30. Shadow prices (marginal value products) for an additional acre-foot of irrigation water for the seven quantities of irrigation water diversion for models A, B, and C, Roswell Artesian Basin, New Mexico, 1966-1968.

Acre-Feet of Irrigation Water		Shadow Price (MVP)[1]		
		Model A	Model B	Model C
total	per acre	(dollars)	(dollars)	(dollars)
524.70	(2.50)	12.63	10.83	36.54
577.17	(2.75)	8.58*	9.03*	35.05
629.64	(3.00)	4.80	5.06	24.20
682.11	(3.25)	4.13	4.35	15.96
734.58	(3.50)	4.13	4.35	13.38
787.05	(3.75)	4.13	4.35	11.54*
839.52	(4.00)	4.13	4.12	4.13

* Optimal quantity of irrigation water.

[1]When values are greater than $7.68 (cost of pumping one acre-foot of irrigation water) it is profitable to increase irrigation diversion; when values are less than $7.68 it is profitable to decrease irrigation water diversion until shadow price is equal to $7.68.

the net farm return is reduced from 12 to 14 percent ($12.29 to $14.29) per water-right acre. For the average-sized farm in this study (209.88 acres) net farm returns are reduced by $2,600 to $3,000.

The difference between the average net farm return per acre for the 12 case farms and the optimal net farm return generated by the linear programming solutions was primarily the result of differences in the cropping programs (figure 11). The average typical cropping program for the 12 case farms was approximately 29.4 percent cotton planted, 6.8 percent cotton diverted, 42.3 percent alfalfa, 1.5 percent forage sorghum, 3.4 percent corn silage, 3.4 percent grain sorghum, 10.4 percent small grains, and 2.8 percent fallow on a cropped acreage basis. The 12 case farms diverted an average of 3.27 acre-feet of irrigation water per water-right acre and produced an average net return of $91.35 per water-right acre.

The solutions for model A at the optimal quantity of irrigation water diversion indicated that the net farm return could be increased about $111.00 per acre with between 2.75 and 3.00 acre-feet of irrigation water. The cropping program for the optimal quantity of irrigation water was about 38 percent cotton planted, 2 percent cotton diverted, 23 percent alfalfa, 22 percent grain sorghum, 9 percent castor beans, 5 percent forage sorghum, and 1 percent fallow.

In model B the solutions indicated that the net farm return could be increased to about $112.00 per acre at the optimal quantity of irrigation water. This was achieved with a cropping program of about 38 percent cotton planted, 2 percent cotton diverted, 21 percent alfalfa, 23 percent grain sorghum, 10 percent castor beans, 5 percent forage sorghum, and 1 percent fallow.

In model C the solutions indicated that the net farm return could be increased to about $116.00 per acre at the optimal quantity of irrigation water. This was achieved with about 38 percent cotton planted, 2 percent cotton diverted, 41 percent alfalfa, 10 percent grain sorghum, 5 percent castor beans, 3 percent forage sorghum, and 1 percent fallow.

Linear Programming Solutions–Roswell Artesian Basin

Following are results of linear programming solutions for models D, E, and F. A typical basin budget was developed to compare with results of linear programming solutions to determine the economic effect of restricting the diversion of irrigation water at 10 different levels. The composition of the average net basin return of $73.90 per water-right acre is presented in table 31. The 1967 estimated net farm return to land and management for Roswell Artesian Basin was approximately $9.9 million.

Linear Programming–Model D

The estimated typical cropping program for the basin in 1967 diverted an average of 2.85 acre-feet of irrigation water per water-right acre with a per-acre net return to land and management of $73.90 (table 31). However, the solutions for linear programming model D with 2.25 acre-feet of irrigation water available indicated that an average net return of $97.17 per water-right acre would be obtained if crop enterprises were combined optimally (table 32). The average net return per acre would have been increased from 31.5 percent or $23.27 per water-right acre above the estimated basin return with the crop enterprises indicated in model D at the 2.25 acre-feet diversion level to 42.5 percent or $31.42 per water-right acre above the estimated basin return at 4.50 acre-feet. Net returns at the 2.25 acre-feet level increased primarily from a larger acreage of planted cotton, forage crops other than alfalfa, and miscellaneous crops, and a reduction in the acreage of alfalfa, small grains, grain sorghum, pasture, pecans, fruits and vegetables, and fallow (table 32).

With increased levels of irrigation water diversion per water-right acre, returns increased at almost a constant rate from 2.50 to 4.50 acre-feet per water-right acre. The increased returns were achieved primarily by increases in the acreage of alfalfa D and decreases in the acreage of castor beans (miscellaneous). In model D cotton acreage would remain unchanged over the 10 levels of irrigation water diversions with 95 percent of the cotton allotment planted and 5 percent of the cotton allotment diverted (table 32).

The acreage of each crop that would be produced at each of the 10 diversion levels and the respective net returns are presented in table 32.

Table 31. Crop acreage, irrigation water diversion, and estimated net basin return for the Roswell Artesian Basin, 1967.

Crop	Acres[1]	Irrigation Water Diversion		Net Basin Return	
		Per Acre	Basin	Per Acre	Basin
		(acre-feet)	(acre-feet)	(dollars)	(dollars)
Cotton planted	30,922	2.79	86,272	190.74	5,898,063
Cotton diverted	6,958	0.00	0	77.54	539,523
Alfalfa	52,942	4.50	238,240	50.29	2,622,453
Grain sorghum	4,645	2.25	10,451	60.07	279,025
Other forage crops	6,519	1.63	10,626	50.00	325,950
Small grains	8,520	1.37	11,672	4.75	40,470
Pasture	1,414	4.00	5,656	14.04	19,853
Pecans	1,549	6.01	9,309	65.00	100,685
Fruits and vegetables	249	3.25	809	50.00	12,450
Miscellaneous[2]	197	2.33	459	65.70	12,943
Fallow[3]	7,869	1.02	8,013	0.00	0
Out of production	12,056	0.00	0	0.00	0
Total	133,840	2.85[4]	381,507	73.90[4]	9,891,415

[1]Source: Garnett, Edwin T., "Economic Classification of the Irrigated Cropland in the Roswell Artesian Basin, New Mexico," (Unpublished Master's Thesis, Department of Agricultural Economics and Agricultural Business, New Mexico State University, 1968), 171 pp.

[2]Includes castor beans and soybeans.

[3]Part of the fallow acreage was planted in alfalfa in the fall of 1967.

[4]Weighted average.

Linear Programming–Model E

Linear programming model E did contain provisions for a crop rotation program with a minimum of about 40 percent of the water-right acres devoted to the production of alfalfa. Solutions for linear programming model E with 2.25 acre-feet of irrigation water per water-right acre indicated the average net return of $69.54 per water-right acre would be obtained if crop enterprises were combined optimally (table 32). The average net return per acre at the 2.25 acre-feet level would have been decreased 5.9 percent or $4.36 per water-right acre below the estimated basin return but increased by 42.5 percent or $31.42 per water-right acre above the estimated basin return at the 4.50 acre-feet level.

Net returns at the 2.25 acre-feet level decreased primarily because a larger percentage of the acreage was left fallow (25.1 percent) due to the provision that approximately 40 percent of the water-right acres be in alfalfa.

With increased levels of irrigation water diversion per water-right acre, return increased at decreasing rates. the increased levels of returns as irrigation water diversions were increased from 2.25 acre-feet per water-right acre to 4.60 acre-feet were achieved primarily by increases in the acreage of alfalfa and the decreases in the acreages of other forage crops and fallow land. The cotton acreage would remain unchanged at the 5 percent diversion level (table 32).

The acreage of each crop that would be produced at each of 10 diversion levels and net return for the basin associated with each diversion are presented in table 32.

The economic effect of forcing in a crop rotation of about 40 percent of water-right acres into alfalfa can be estimated by comparing solutions from model D with solutions from model E (figure 12). Net returns would be reduced from between 28.4 percent ($27.63) per water-right acre at the 2.25 acre-feet diversion level to virtually no economic effect at the 4.00, 4.25, and 4.50 acre-feet levels.

Linear Programming–Model F

Linear programming model F did contain provisions for a crop rotation program similar to the estimated cropping program in the basin during 1967. Only small adjustments in the cropping program for the basin were provided because of the constraints imposed in the linear programming model (see table 8). The solutions for linear programming model F with 2.25 acre-feet of irrigation water per water-right acre indicated the average net return of $66.89 per water-right acre would be obtained if crop enterprises were combined optimally (table 32). The average net return per water-right acre at the 2.25 acre-feet level would have been decreased 9.5 percent or $7.01 per water-right acre below the estimated basin return but increased by 38.0 percent or $28.11 per water-right acre above the estimated basin return at 4.50 acre-feet. Net returns at the 2.25 acre-feet level decreased primarily because a larger percent of the water-right acres were left fallow (25.2 percent) due to the provision that approximately 40 percent of the water-right acres be in alfalfa at 2.50 acre-feet level.

With increased levels of irrigation water diversions per water-right acre, returns initially increased at almost a constant rate from 2.25 acre-feet to 3.50 acre-feet per water-right acre primarily because fallow acreages were being brought into the production of larger acreages of other forage crops, grain sorghum, or castor beans. From 3.25 to 4.00 acre-feet of irrigation water diversion per water-right acre, net return increased at a decreasing rate primarily from a substitution of alfalfa D for grain sorghum, castor beans, or other forage crops (table 32).

The acres of each crop that would be produced at each of the 10 diversion levels and net return to the basin associated with each diversion level are presented in table 32.

The economic effect of forcing in a crop rotation of this nature can be estimated by comparing solutions from model D with solutions from model F (figure 12). Net returns would be reduced from 31.2 percent ($30.28) per water-right acre at the 2.25 acre-feet diversion level to 3.1 percent ($3.31) at the 4.50 acre-feet diversion level.

The results obtained from linear programming models D, E, and F are graphically summarized in figure 12, which indicates the effect of 10 quantities of irrigation water on the per-acre net farm returns to the Roswell Artesian Basin.

In model D as irrigation water is increased from 2.25 acre-feet to 2.50 acre-feet per water-right acre, net farm return per acre increases at a constant rate. From 2.50 acre-feet to 4.50 acre-feet per water-right acre net farm return per acre increases at a lower constant rate.

In model E as irrigation water is increased from 2.25 to 2.75 acre-feet per water-right acre, net farm return per acre increases at a decreasing rate, between 2.75 and 3.75 acre-feet it increases at a constant rate, and from 3.75 to 4.50 acre-feet per water-right acre it increases at a decreasing rate.

In model F as irrigation water is increased from 2.25 to 2.50 acre-feet per water-right acre the net return per acre increases at a constant rate, from 2.50 to 3.50 acre-feet it increases at a lower constant rate, and from 3.50 to 4.50 acre-feet it increases at a decreasing rate.

Solutions for linear programming models D, E, and F were also computed at 2.85 acre-feet per water-right acre in order to have a direct comparison with the estimated cropping patterns and net returns for the basin in 1967. The solutions for model D indicated that the net returns would have been increased 36.3 percent or $26.79 per water-right acre with 2.85 acre-feet of irrigation water (figure 12). The increased return above the estimated basin return was achieved primarily by an increase in planted cotton acreage and a decrease in land fallow and out of production (table 33).

The solutions for model E indicated that the net returns would have been increased 17.8 percent or $13.14 per water-right acre with 2.85 acre-feet of

Table 32. Estimated basin budget and linear programming solutions for 10 quantities of irrigation water for models D, E, and F, Roswell Artesian Basin, New Mexico, 1966-1968.

		Estimated Basin Budget 1967			Linear Programming Solutions: 2.25 Acre-Feet per Acre			2.50 Acre-Feet per Acre			2.75 Acre-Feet per Acre			3.00 Acre-Feet per Acre		
Variable	Crop	Acres	Irrigation Water (ac.-ft.)	Net Returns (dollars)	Acres	Irrigation Water (ac.-ft.)	Net Returns (dollars)	Acres	Irrigation Water (ac.-ft.)	Net Returns (dollars)	Acres	Irrigation Water (ac.-ft.)	Net Returns (dollars)	Acres	Irrigation Water (ac.-ft.)	Net Returns (dollars)
	MODEL D															
X_1	Cotton (65)															
X_2	Cotton (80)	37,880[1]	86,272	6,437,586												
X_3	Cotton (95)				37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830
X_4	Alfalfa (A)	52,942	238,240	2,622,453												
X_5	Alfalfa (B)															
X_6	Alfalfa (C)															
X_7	Alfalfa (D)							2,897	17,382	220,143	12,014	72,084	912,944	21,131	126,786	1,605,745
X_8	Grain Sorghum	4,645	10,451	279,025												
X_9	Other Forage Crops	6,519	10,626	325,950	26,545	39,021	1,433,430									
X_{10}	Small Grains	8,520	11,672	40,470												
X_{11}	Pasture	1,414	5,656	19,853												
X_{12}	Pecans	1,549	9,309	100,685												
X_{13}	Fruits and Vegetables	249	809	12,450												
X_{14}	Miscellaneous	197	459	12,943	69,415	161,737	4,560,566	93,063	216,836	6,114,239	83,946	195,594	5,515,252	74,829	174,352	4,916,265
	Fallow	19,925	8,013	0											f	
	Total	133,840	381,507	9,891,415	113,840	301,140	13,004,826	133,840	334,600	13,345,212	133,840	368,060	13,439,026	133,840	401,520	13,532,840
	MODEL E															
X_1	Cotton (65)															
X_2	Cotton (80)	37,880[1]	86,272	6,437,586												
X_3	Cotton (95)				37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830
X_4	Alfalfa (A)	52,942	238,240	2,622,453												
X_5	Alfalfa (B)				52,940	186,878	1,786,725	52,940	186,878	1,786,725	45,830	161,780	1,546,763	32,284	113,963	1,089,585
X_6	Alfalfa (C)															
X_7	Alfalfa (D)										7,110	42,660	540,289	20,656	123,936	1,569,649
X_8	Grain Sorghum	4,645	10,451	279,025												
X_9	Other Forage Crops	6,519	10,626	325,950	9,442	13,880	509,868	32,204	47,340	1,739,016	43,020	63,238	2,323,080	43,020	63,239	2,323,080
X_{10}	Small Grains	8,520	11,672	40,470												
X_{11}	Pasture	1,414	5,656	19,853												
X_{12}	Pecans	1,549	9,309	100,685												
X_{13}	Fruits and Vegetables	249	809	12,450												
X_{14}	Miscellaneous	197	459	12,943												
	Fallow	19,925	8,013	0	33,578	0	0	10,816	0	0						
	Total	133,840	381,507	9,891,415	133,840	301,140	9,307,423	133,840	334,600	10,536,571	133,840	366,060	11,420,962	133,840	401,520	11,993,144
	MODEL F															
X_1	Cotton (65)															
X_2	Cotton (80)	37,880[1]	86,272	6,437,586												
X_3	Cotton (95)				37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830
X_4	Alfalfa (A)	52,942	238,240	2,662,453												
X_5	Alfalfa (B)				52,940	186,878	1,786,725	52,940	186,878	1,786,725	42,483	149,965	1,433,801	28,936	102,144	976,590
X_6	Alfalfa (C)															
X_7	Alfalfa (D)										10,457	62,743	794,627	24,004	144,024	1,824,064
X_8	Grain Sorghum	4,645	10,451	279,025				5,000	11,250	300,350	5,000	11,250	300,350	5,000	11,250	300,350
X_9	Other Forage Crops	6,519	10,626	325,950	2,299	3,380	124,146	7,737	11,610	411,873	12,000	19,240	607,800	12,000	19,240	607,800
X_{10}	Small Grains	8,520	11,672	40,470	7,000	10,500	31,150	7,000	10,500	31,150	7,000	10,500	31,150	7,000	10,500	31,150
X_{11}	Pasture	1,414	5,656	19,853												
X_{12}	Pecans	1,549	9,309	100,685												
X_{13}	Fruits and Vegetables	249	809	12,450												
X_{14}	Miscellaneous	197	459	12,943				6,000	13,980	394,200	6,000	13,980	394,200	6,000	13,980	394,200
	Fallow	19,925	8,013	0	33,721	0	0	17,283	0	0	13,020	0	0	13,020	0	0
	Total	133,840	381,507	9,891,415	133,840	301,140	8,952,851	133,840	334,600	9,935,128	133,840	368,060	10,572,758	133,840	401,520	11,144,984

[1]Cotton planted estimated at 81.6 percent of allotment.

Table 32. Estimated basin budget and linear programming solutions for 10 quantities of irrigation water for models D, E, and F, Roswell Artesian Basin, New Mexico, 1966-1968, continued.

	Linear Programming Solutions, Continued																	
	3.25 Acre-Feet per Acre			3.50 Acre-Feet per Acre			3.75 Acre-Feet per Acre			4.00 Acre-Feet per Acre			4.25 Acre-Feet per Acre			4.50 Acre-Feet per Acre		
Variable	Acres	Irrigation Water	Net Returns	Acres	Irrigation Water	Net Returns	Acres	Irrigation Water	Net Returns	Acres	Irrigation Water	Net Returns	Acres	Irrigation Water	Net Returns	Acres	Irrigation Water	Net Returns
		(ac.-ft.)	(dollars)		(ac.-ft.)	(dollars)		(ac.-ft.)	(dollars)		(ac.-ft.)	(dollars)		(ac.-ft.)	(dollars)		(ac.-ft.)	(dollars)
MODEL D																		
x_1																		
x_2																		
x_3	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830
x_4																		
x_5																		
x_6																		
x_7	30,248	181,488	2,298,546	39,365	236,191	2,991,346	48,483	290,898	3,684,223	57,600	345,600	4,377,024	66,717	400,302	5,069,825	75,835	455,004	5,762,626
x_8																		
x_9																		
x_{10}																		
x_{11}																		
x_{12}																		
x_{13}																		
x_{14}	65,712	153,110	4,317,278	56,595	131,867	3,718,292	47,477	110,620	3,119,239	38,360	89,378	2,520,252	29,243	68,136	1,921,265	20,126	46,894	1,322,278
	133,840	434,980	13,626,654	133,840	468,440	13,720,468	133,840	501,900	13,814,292	133,840	535,360	13,908,106	133,840	568,820	14,001,920	133,840	602,280	14,095,734
MODEL E																		
x_1																		
x_2																		
x_3	37,880	100,382	7,010830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830
x_4																		
x_5	18,737	66,142	632,374	5,191	18,324	175,196												
x_6																		
x_7	34,203	205,217	2,599,086	47,749	286,495	3,628,447	52,940	317,640	4,022,911	57,600	345,600	4,377,024	66,717	400,302	5,069,825	75,834	455,004	5,762,626
x_8																		
x_9	43,020	63,239	2,323,080	43,020	63,239	2,323,080	19,021	27,961	1,027,134									
x_{10}																		
x_{11}																		
x_{12}																		
x_{13}																		
x_{14}							23,999	55,917	1,576,734	38,360	89,378	2,520,252	29,243	68,136	1,921,265	20,126	46,894	1,322,278
	133,840	434,980	12,565,370	133,840	468,440	13,137,553	133,840	501,900	13,637,609	133,840	535,360	13,908,106	133,840	568,820	14,001,920	133,840	602,280	14,095,734
MODEL F																		
x_1																		
x_2																		
x_3	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830	37,880	100,382	7,010,830
x_4																		
x_5	15,389	54,322	519,379	1,843	6,506	62,201												
x_6																		
x_7	37,551	225,306	2,853,500	51,097	306,582	3,882,861	57,758	346,548	4,389,030	63,335	380,008	4,812,827	70,166	420,997	5,331,914	77,608	465,649	5,897,432
x_8	5,000	11,250	300,350	5,000	11,250	300,350	5,000	11,250	300,350	5,000	11,250	300,350	5,000	11,250	300,350	5,000	11,250	300,350
x_9	12,000	19,240	607,800	12,000	19,240	607,800	12,000	19,240	607,800	12,000	19,240	607,800	7,794	11,711	414,492	352	519	19,008
x_{10}	7,000	10,500	31,150	7,000	10,500	31,150	7,000	10,500	31,150	7,000	10,500	31,150	7,000	10,500	31,150	7,000	10,500	31,150
x_{11}																		
x_{12}																		
x_{13}																		
x_{14}	6,000	13,980	394,200	6,000	13,980	394,200	6,000	13,980	394,200	6,000	13,980	394,200	6,000	13,980	394,200	6,000	13,980	394,200
	13,020	0	0	13,020	0	0	8,202	0	0	2,625	0	0						
	133,840	434,980	11,717,209	133,840	468,440	12,289,392	133,840	501,900	12,733,360	133,840	535,360	13,157,157	133,840	568,820	13,482,936	133,480	602,280	13,652,970

irrigation water (figure 12). The increased return was achieved primarily by an increase in planted cotton acreage and decrease in land fallow and out of production.

The solutions for model F indicated that the net returns would have been increased 15.4 percent or $6.81 per water-right acre with 2.85 acre-feet of irrigation water (figure 12). The increased return was achieved primarily by an increase in planted cotton acreage and a decrease in land fallow and out of production (table 33).

Optimal Quantity of Irrigation Water

The shadow prices (marginal value products) for an additional acre-foot of irrigation water are presented in table 34. The optimal level of irrigation water diversion for each model can be determined by equating the shadow price with the cost of pumping an acre-foot of irrigation water, which was $7.68. These optimal levels are shown for models D, E, and F in figure 12.

Average shadow prices for model D at diversion levels of 301,140 and 334,600 acre-feet (2.25 acre-feet and 2.50 acre-feet per water-right acre) were $13.60 and $2.80, respectively (table 34). Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole basin is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

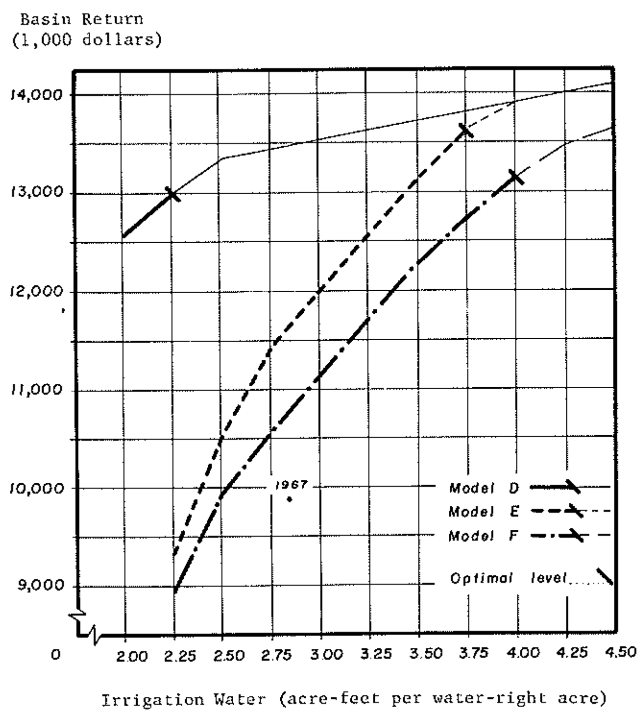


Figure 12. Basin return and optimal point for operation for eleven quantities of irrigation water, models D, E, and F, Roswell Artesian Basin, New Mexico, 1967.

The average shadow prices for model E at the 501,900 and 535,360 acre-feet diversion levels (3.75 acre-feet and 4.00 acre-feet per water-right acre) were $13.60 and $2.80, respectively (table 34). Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole basin is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

In model F the average optimal quantity of irrigation water was between 535,360 and 568,820 acre-feet (4.00 and 4.25 acre-feet per water-right acre) (table 34). The average shadow prices for model F at the 535,360 and 568,820 acre-feet diversion levels were $12.66 and $7.13, respectively. Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole basin is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

The primary reason for the higher optimal irrigation water diversion level for model E was the constraint that about 40 percent of the water-right acres be in alfalfa. This forced cropland to be left fallow at the lower levels of diversion. Fallow acreage accounted for about 25 percent of the water-right acres at the 2.25 acre-feet diversion level and about 8 percent at the 2.50 acre-feet level.

In model F the optimal irrigation water diversion level was higher mainly because of the constraint that about 40 percent of the water-right acres be in alfalfa, about 5 percent in small grains, and only about 4 percent in grain sorghum, 9 percent in forage crops, and about 4 percent in miscellaneous (castor beans) crops. This forced cropland to be left fallow at all except the 4.25 and 4.50 acre-feet diversion levels. Fallow acreage accounted for about 25 percent of the water-right acres at the 2.25 acre-feet diversion level, 13 percent at the 2.50 acre-feet level, 10 percent at the 2.75, 3.00, 3.25, and 3.50 acre-feet levels, 6 percent at the 3.75 acre-feet level, and 2 percent at the 4.00 acre-feet level.

At the irrigation water diversion level of 3.00 acre-feet per water-right acre for the basin, net farm return per water-right acre would not be affected in model D because the optimal quantity was below 3.00 acre-feet (between 2.25 and 2.50 acre-feet per water-right acre). Comparing the optimal quantity with 3.00 acre-feet in model E, net farm return would be reduced between 12 and 14 percent ($12.28 and $14.31) per water-right acre. For the basin, net farm returns would be reduced between approximately $1.6 and $1.9 million. Comparing the optimal quantity with 3.00 acre-feet in model F, net farm return would be reduced between 15 and 17 percent ($15.04 and $17.47) per water-right acre. For the basin, net farm returns would be reduced between $2.0 and $2.3 million.

The difference between the estimated net farm return per acre for the basin in 1967 and the optimal net farm return generated by the linear programming solutions was primarily the result of differences in the cropping programs (figure 12).

Table 33. Crop acreage, irrigation water diversion, and estimated net farm return for Roswell Artesian Basin in 1967, and linear programming solutions at 2.85 acre-feet per water-right acre diversion level for models D, E, and F, Roswell Artesian Basin, New Mexico, 1967.

Crop	Acres	Irrigation Water Diversion Per Acre (acre-feet)	Irrigation Water Diversion Basin (acre-feet)	Net Farm Return Per Acre (dollars)	Net Farm Return Basin (dollars)
			ESTIMATED 1967		
Cotton planted	30,922	2.79	86,272	190.74	5,898.063
Cotton diverted	6,958	0.00	0	77.54	539,523
Alfalfa	52,942	4.50	238,240	50.29	2,622,453
Grain sorghum	4,645	2.25	10,451	60.07	279,025
Other forage crops	6,519	1.63	10,626	50.00	325,950
Small grains	8,520	1.37	11,672	4.75	40,470
Pasture	1,414	4.00	5,656	14.04	19,853
Pecans	1,549	6.01	9,309	65.00	100,685
Fruits and vegetables	249	3.25	809	50.00	12,450
Miscellaneous[1]	197	2.33	459	65.70	12,943
Fallow[2]	7,869	1.02	8,013	0.00	0
Out of production	12,056	0.00	0	0.00	0
Total	133,840	2.85	381,507	73.90	9,891,415
			MODEL D		
Cotton planted	35,986	2.79	100,382	190.74	6,863,970
Cotton diverted	1,894	0.00	0	77.54	146,861
Alfalfa	15,661	6.00	93,966	75.99	1,190,079
Grain sorghum					
Other forage crops					
Small grains					
Pasture					
Pecans					
Fruits and vegetables					
Miscellaneous[1]	80,229	2.33	187,096	65.70	5,275,644
Fallow					
Out of production					
Total	133,840	2.85	381,444	100.69	13,476.554
			MODEL E		
Cotton planted	35,986	2.79	100,382	190.74	6,863,970
Cotton diverted	1,894	0.00	0	77.54	146,861
Alfalfa	52,940	4.11	217,822	43.75	2,315,908
Grain sorghum					
Other forage crops	43,020	1.47	63,240	54.00	2,323,080
Small grains					
Pasture					
Pecans					
Fruits and vegetables					
Miscellaneous[1]					
Fallow[2]					
Out of production					
Total	133,840	2.85	381,444	87.04	11,649,819
			MODEL F		
Cotton planted	35,986	2.79	100,382	190.74	6,863,970
Cotton diverted	1,894	0.00	0	77.54	146,861
Alfalfa	52,940	4.27	226,092	46.42	2,457,327
Grain sorghum	5,000	2.25	11,250	60.07	300,350
Other forage crops	12,000	1.60	19,240	50.65	607,800
Small grains	7,000	1.50	10,500	4.45	31,150
Pasture					
Pecans					
Fruits and vegetables					
Miscellaneous[1]	6,000	2.33	13,980	65.70	394,200
Fallow	13,020	0.00	0	0.00	0
Out of production					
Total	133,840	2.85	381,444	80.71	10,801,658

[1]Castor beans and soybeans.
[2]Part of this was planted in alfalfa in the fall of 1967.

Table 34. Shadow prices (marginal value products) for an additional acre-foot of irrigation water for the 10 quantities of irrigation water diversion for models D, E, and F. Roswell Artesian Basin, New Mexico, 1966-1968.

Acre-Feet of Irrigation Water total	per acre	Shadow Price (MVP)[1] Model D (dollars)	Model E (dollars)	Model F (dollars)
301,140	(2.25)	13.60*	36.73	36.73
334,600	(2.50)	2.80	36.73	25.68
368,060	(2.75)	2.80	17.10	17.10
401,520	(3.00)	2.80	17.10	17.10
434,980	(3.25)	2.80	17.10	17.10
468,440	(3.50)	2.80	17.10	17.10
501,900	(3.75)	2.80	13.60*	12.66
535,820	(4.00)	2.80	2.80	12.66*
568,820	(4.25)	2.80	2.80	7.13
602,280	(4.50)	2.80	2.80	4.85

* Optimal quantity of irrigation water.

[1] When values are greater than $7.68 (cost of pumping one acre-foot of irrigation water) it is profitable to increase irrigation diversion; when values are less than $7.68 it is profitable to decrease irrigation water diversion until shadow price is equal to $7.68.

The estimated cropping program for the basin in 1967 was approximately 23 percent cotton planted, 5 percent cotton diverted, 40 percent alfalfa, 4 percent grain sorghum, 5 percent other forage crops, 6 percent small grains, 1 percent pasture, 1 percent pecans, less than 1 percent fruits and vegetables and miscellaneous, and 14 percent fallow and out of production (10). The basin in 1967 diverted an average of 2.85 acre-feet of irrigation water per water-right acre and produced an estimated net farm return of $73.90 per water-right acre.

The solutions for model D at the optimal quantity of irrigation water diversion indicated that the net farm return could be increased to about $98.44 per acre with between 2.25 and 2.50 acre-feet of irrigation water. The cropping program for the optimal quantity of irrigation water was about 27 percent cotton planted, 1 percent cotton diverted, 1 percent alfalfa, 10 percent other forage crops, and 61 percent miscellaneous (castor beans) crops.

In model E the solutions indicated that the net farm return could be increased to about $102.91 per acre at the optimal quantity of irrigation water. This was achieved with a cropping program of about 27 percent cotton planted, 1 percent cotton diverted, 42 percent alfalfa, 7 percent other forage crops, and 23 percent miscellaneous (castor beans) crops.

In model F the solutions indicated that the net farm return could be increased to about $101.37 per acre at the optimal quantity of irrigation water. This was achieved with about 27 percent cotton planted, 1 percent cotton diverted, 50 percent alfalfa, 4 percent grain sorghum, 8 percent other forage crops, 5 percent small grains, 4 percent miscellaneous (castor beans) crops, and 1 percent fallow.

DISCUSSION

The answer to the question of how much irrigation water is required on any farm in the Roswell Artesian Basin is determined by 1) the crops to be grown, 2) the management decisions of the operator as to when and how the irrigation water will be applied, and 3) the salinity of the water used for irrigation. Also the basin water balance must be considered as a factor in the operations of the farms and the basin as a whole. In addition, the amount of irrigation water required will vary from one year to another depending on the amount and timing of rainfall during the crop year. These factors are discussed briefly in this section to point up the part that each may play in the final decision to be made by the farmers, the regulatory officials, and courts in the management of the total water supply in the Roswell Artesian Basin.

Crop Selection

The crops grown in the Roswell Artesian Basin have a great influence on the average acre-feet of water required per water-right acre in the basin. A farmer often has a preference for growing a particular crop, based on his past experience, the farm equipment he has on hand, and the available market outlet. However, most farmers are considering possible shifts in their crop mix that would permit a more beneficial use of their allocated water, both in terms of the required amount of water diversions and method af application for each crop, and in the yield they might expect under a given situation.

Each of the linear programming models used in this study chooses a combination of enterprises from all possible combinations that will yield the highest net farm return, subject to the acreage, water, cotton allotment and other constraints. Thus the optimal cropping program at each irrigation water diversion level tends to become the maximum cropping program and in all likelihood would probably not be attained by all farmers in the basin because of personal likes and dislikes for certain crop enterprises, insufficient volume of irrigation water available for the optimal program, salinity of irrigation water, and other related factors.

Crop Rotation

It is definitely known, and research is available for substantiating, that crop rotations in a total cropping system over a period of time are beneficial. Some of the main benefits are 1) disease control, 2) insect control, 3) weed control, and 4) improvement of soil tilth. These conclusions have been derived mainly from research findings and from the experiences of farmers in a given area. However, advantages and disadvantages of comparing a specific rotation with another rotation are not known for the Roswell Artesian Basin. For this reason, the cropping patterns used in this study were primarily those presently being used by the farmers in the Roswell Artesian Basin.

In the irrigated areas of the Southwest, rotation of cotton and alfalfa with sorghum, small grains, corn, and grasses tends to reduce plant disease losses (34). Summer fallow has generally been associated with a decrease in soil organic matter. It has not been as effective as crop rotation in disease control. The continued production of a given crop over a period of years has been associated with increased populations of insect pests, and crop rotation has also been effective in breaking this host-pest cycle and thus reducing insect damage.

Crop rotation is also used in weed control. Some weeds are more prevalent in row-cultivated crops, such as cotton, while others are more predominant in broadcast-seeded crops, such as small grains and alfalfa. The rotation of these crops can thus be used as one method of controlling weeds.

A rotation, including both shallow, fibrous-rooted crops such as small grains and sorghum and deep-rooted crops such as alfalfa, has been associated with improved soil tilth. The shallow, fibrous-rooted crops tend to increase organic matter content in the upper soil profile while the deep-rooted crops apparently improve the lower profiles through root penetration, which makes for improved water penetration and aeration as these roots decompose.

Fallow and Out of Production

In the optimal linear programming solutions there is virtually no fallow cropland, yet in the basin approximately 20 percent of the water-right acres were fallow and diverted in 1967. Garnett (10) estimated, on the per-cropped-acre basis, that irrigation water diversions averaged 3.58 acre-feet in 1967, which was 26 percent above 2.85 diverted per water-right acre. In only six years out of the 1938-1968 period has irrigation water pumpage exceeded 3.50 acre-feet per acre for the basin, and in four of the ten years preceding 1969, the diversions were below 3.25 acre-feet per acre (table 4). The diversions per acre during 1966, 1967, and 1968 may have been influenced by the federal Upland Cotton Program which encouraged farmers to leave part of their farms fallow to lower the planted acreage of cotton.

In some areas of the basin the production of irrigation wells is low and all of the water-right acres cannot be irrigated adequately. Other areas have a combination of water rights that requires that a certain percentage of the total diversion be from the artesian, shallow, or surface sources. On one of the case farms almost half of the water rights were shallow but only one of the three wells was developed in the shallow aquifer and produced only about 80 to 100 gallons per minute (gpm). This partially dictated the cropping program which included cotton, alfalfa for seed, and above the average amount of fallow land. Because of the cropping program the net return figures were below the net return generated by the linear programming models, which did not consider the problem of an inadequate stream of irrigation water. Another case farm had a similar water supply problem with three small shallow wells producing a total of less than 1,000 gpm. Few alternative cropping programs were available to this farmer because of the water supply problem, resulting in a much lower net return than those generated from the linear programming models.

Several of the case farms apparently had an adequate stream of irrigation water and net returns from the linear programming models generally showed less increase per acre compared with those for farms with inadequate streams. On these farms the increased net returns were due to combining enterprises in a different manner. Usually the planted cotton acreage should have been increased, diverted acreage decreased, alfalfa acreage decreased but farmed more intensively, and sorghums or castor beans acreage increased.

Effect of Crop Mix on Water Diversion and Return

The combination of crops grown also affects the total water diversions required to produce those crops, the average amounts of water diverted per crop acre and per farm, and the income derived from the specific crop mix.

In tables 35, 36, and 37, three alternative crop combinations based on a 100-acre unit are shown for alfalfa, cotton, and grain sorghum, as compared with the 1967 actual cropping program for the basin.

Cotton

In table 35, Example 1, cotton is increased from the 1967 acreage by 6.9 acres to 30 acres, with a corresponding decrease of 6.9 acres in fallow and out of production. This increased cotton acreage resulted in an increased diversion of 0.13 acre-foot of water per acre and an increase in net return of $13.16 per acre over the 1967 crop mix. In Example 2, cotton was increased another 8 acres to 38 acres with fallow and out of production correspondingly reduced. This resulted in an increased water diversion of 0.35 acre-foot per acre, and an increase in net return of $28.42 per acre over the 1967 base.

Alfalfa

In table 36, Example 1, with approximate 1967 basin average yield and price, alfalfa is increased from the 1967 acreage by 7.5 acres to 47 acres with fallow and out of production being decreased by 7.5 acres. This increased alfalfa acreage resulted in an increased diversion of 0.28 acre-foot of water per acre and an average increased net return of $3.77 per acre over the 1967 crop mix (table 38). In Example 2, alfalfa was increased an additional 7 acres to 54 acres with fallow and out of production correspondingly reduced. This resulted in increased water diversion of 0.59 acre-foot per acre and increased net return of $7.29 per acre over the 1967 base.

In all three of the examples in table 36, the acreage of cotton diverted was unchanged. These examples indicate the important effect of increased cotton acreage on net return, and that this net return requires relatively smaller

Table 35. Cotton: Irrigation diversion for each crop and per-acre and total net return based on a 100-acre farm at three levels of cotton acreage, Roswell Artesian Basin, New Mexico.

Crop	Acres	Irrigation Water Diversion		Net Farm Return	
		Per Acre (acre-feet)	Total (acre-feet)	Per Acre (dollars	Total (dollars)
		BASIN - 1967 Actual Cropping Program (Cotton 23.1%)			
Cotton planted	23.1	2.79	64.45	190.74	4,406.09
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Alfalfa	39.5	4.50	177.75	50.29	1,986.45
Grain sorghum	3.5	2.25	7.87	60.07	210.24
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow[2]	5.9	1.02	6.02	0.00	0.00
Out of production	9.0	0.00	0.00	0.00	0.00
Total	100.0	2.85	284.85	73.90	7,390.00
		BASIN - 1967 (Cotton Increased to 30%)[3] Example #1			
Cotton planted	30.0	2.79	83.70	190.74	5,722.20
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Alfalfa	39.5	4.50	177.75	50.29	1,986.45
Grain sorghum	3.5	2.25	7.87	60.07	210.24
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow	0.0	1.02	0.00	0.00	0.00
Out of production	8.0	0.00	0.00	0.00	0.00
Total	100.0	2.98	298.08	87.06	8,706.11
		BASIN - 1967 (Cotton Increased to 38%)[3] Example #2			
Cotton planted	38.0	2.79	106.02	190.74	7,248.12
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Alfalfa	39.5	4.50	177.75	50.29	1,986.45
Grain sorghum	3.5	2.25	7.87	60.07	210.24
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow	0.0	1.02	0.00	0.00	0.00
Out of production	0.0	0.00	0.00	0.00	0.00
Total	100.0	3.20	320.40	102.32	10,232.03

[1]Castor beans and soybeans.

[2]Part of this was planted in alfalfa in the fall of 1967.

[3]The increased acreage came from the fallow and out of production acres as shown for 1967.

Table 36. Alfalfa: Irrigation diversion for each crop and per-acre and total net return based on a 100-acre farm at three levels of alfalfa acreage, Roswell Artesian Basin, New Mexico.

Crop	Acres	Irrigation Water Diversion Per Acre (acre-feet)	Irrigation Water Diversion Total (acre-feet)	Net Farm Return Per Acre (dollars)	Net Farm Return Total (dollars)
BASIN - 1967 Actual Cropping Program (Alfalfa 39.5%)					
Alfalfa	39.5	4.50	177.75	50.29	1,986.45
Cotton planted	23.1	2.79	64.45	190.74	4,406.09
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Grain sorghum	3.5	2.25	7.87	60.07	210.24
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow[2]	5.9	1.02	6.02	0.00	0.00
Out of production	9.0	0.00	0.00	0.00	0.00
Total	100.0	2.85	284.85	73.90	7,390.00
BASIN - 1967 (Alfalfa Increased to 47.0%)[3] Example #1					
Alfalfa	47.0	4.50	211.50	50.29	2,363.63
Cotton planted	23.1	2.79	64.45	190.74	4,406.09
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Grain sorghum	3.5	2.25	7.87	60.07	210.24
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow	0.0	1.02	0.00	0.00	0.00
Out of production	7.4	0.00	0.00	0.00	0.00
Total	100.0	3.13	312.58	77.67	7,767.18
BASIN - 1967 (Alfalfa Increased to 54.0%)[3] Example #2					
Alfalfa	54.0	4.50	243.00	50.29	2,715.66
Cotton planted	23.1	2.79	64.45	190.74	4,406.09
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Grain sorghum	3.5	2.25	7.87	60.07	210.24
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow	0.0	1.02	0.00	0.00	0.00
Out of production	0.4	0.00	0.00	0.00	0.00
Total	100.0	3.44	344.08	81.19	8,119.21

[1]Castor beans and soybeans.
[2]Part of this was planted in alfalfa in the fall of 1967.
[3]The increased acreage came from the fallow and out of production acres as shown for 1967.

Table 37. Grain Sorghum: Irrigation diversion for each crop and per-acre and total net return based on a 100-acre farm at three levels of grain sorghum acreage, Roswell Artesian Basin, New Mexico

Crops	Acres	Irrigation Water Diversion Per Acre (acre-feet)	Irrigation Water Diversion Total (acre-feet)	Net Farm Return Per Acre (dollars)	Net Farm Return Total (dollars)
BASIN - 1967 Actual Cropping Program (Grain Sorghum 3.5%)					
Grain sorghum	3.5	2.25	7.87	60.07	210.24
Cotton planted	23.1	2.79	64.45	190.74	4,406.09
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Alfalfa	39.5	4.50	177.75	50.29	1,986.45
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow[2]	5.9	1.02	6.02	0.00	0.00
Out of production	9.0	0.00	0.00	0.00	0.00
Total	100.0	2.85	284.85	73.90	7,390.00
BASIN - 1967 (Grain Sorghum Increased to 11%)[3] Example #1					
Grain sorghum	11.0	2.25	24.75	60.07	660.77
Cotton planted	23.1	2.79	64.45	190.74	4,406.09
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Alfalfa	39.5	4.50	177.75	50.29	1,986.45
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow	0.0	1.02	0.00	0.00	0.00
Out of production	7.4	0.00	0.00	0.00	0.00
Total	100.0	2.96	295.71	78.40	7,840.53
BASIN - 1967 (Grain Sorghum Increased to 18%)[3] Example #2					
Grain sorghum	18.0	2.25	40.50	60.07	1,081.26
Cotton planted	23.1	2.79	64.45	190.74	4,406.09
Cotton diverted	5.2	0.00	0.00	77.54	403.21
Alfalfa	39.5	4.50	177.75	50.29	1,986.45
Other forage crops	4.9	1.63	7.99	50.00	245.00
Small grains	6.4	1.37	8.77	4.75	30.40
Pasture	1.0	4.00	4.00	14.04	14.04
Pecans	1.2	6.01	7.12	65.00	78.00
Fruits and vegetables	0.2	3.25	0.65	50.00	10.00
Miscellaneous[1]	0.1	2.33	0.23	65.70	6.57
Fallow	0.0	1.02	0.00	0.00	0.00
Out of production	0.4	0.00	0.00	0.00	0.00
Total	100.0	3.11	311.46	82.61	8,261.02

[1] Castor beans and soybeans.
[2] Part of this was planted in alfalfa in the fall of 1967.
[3] The increased acreage came from the fallow and out of production acres as shown for 1967.

increases in water diversion. Also, they show that increased alfalfa acreages resulted in much smaller increase in net return, but required a much larger diversion of water.

Grain Sorghum

In table 37, Example 1, 7.5 acres of grain sorghum were substituted for fallow and out of production. This increase in grain sorghum resulted in increased irrigation water diversion of 0.11 acre-foot per acre and increased net return of $4.50 per acre over the 1967 crop mix. In Example 2, grain sorghum was increased an additional 7 acres to 18 acres with fallow and out of production correspondingly reduced. This resulted in increased irrigation water diversion of 0.26 acre-foot per acre, and increased net return of $8.71 per acre over the 1967 base.

Forage and Grain Crops

Using grain sorghum as an example, agronomic results indicate that grain sorghum, forage sorghum, corn for grain and for silage, with the relatively high yields potentially possible on the average quality of soils and water in the basin, can produce net returns as high as those of alfalfa and with considerably lower water diversion.

Tables 35, 36, and 37 are summarized in table 38 and figure 13, which permits the following direct comparison: A slight increase in the acreage of planted cotton will increase returns substantially with only a small increase in irrigation water diversions. Grain sorghum appears to have an advantage over alfalfa in income generation with lower increases in irrigation water diversions.

Cropping Program Choices

In determining whether the cropping programs generated by the linear programming models can be adopted by the farmers in the Roswell Artesian Basin, the government programs for cotton and other crops, and the long-run effect of alternative cropping programs on soil productivity must be taken into account.

For instance, in considering the effect of government programs on the choice of alternative crops, model D with 60,000 acres of castor beans is unrealistic for the basin in 1969-1970 because this crop itself is now under a government production control program. The one processing plant in New Mexico has an allotment of 6,000 acres, which obviously limits the acreage of castor beans to 6,000 or less.

The government program in recent years required that a portion of each participating farm devote a certain percentage of the farm to soil-conserving crops such as alfalfa and barley. Alfalfa acreage, however, probably will decrease under the current water allowance of 3.0 acre-feet per year per water-right acre because of its high requirement for water. Grain or forage corn and sorghums offer an alternative to alfalfa in view of increasing demands for grain and roughages by the expanding feedlot industry in the area. Assuming a 4 to 1 ratio in nutritive value, 30 tons of forage sorghum or corn silage per acre would replace an acre of alfalfa.

Table 38. Comparison of net return and water use in substituting cotton, alfalfa, or grain sorghum for fallow and land out of production, based on 1967 crop mix, Roswell Artesian Basin, New Mexico.

		Average of Crop Increase	Increased Water Diversion	Increase Over 1967 Base: Total Water Diversion	Increase Over 1967 Base: Net Return
		(acres)	(acre-feet per acre)[1]	(acre-feet per acre)	(dollars)
Cotton	Example 1	6.9	.13	2.98	13.16
	Example 2	14.9	.35	3.20	28.42
Alfalfa	Example 1	7.5	.28	3.13	3.77
	Example 2	14.5	.59	3.44	7.29
Grain Sorghum	Example 1	7.5	.11	2.96	4.50
	Example 2	14.5	.26	3.11	8.71
Average				2.85	

[1] 1967 base for crop mix.

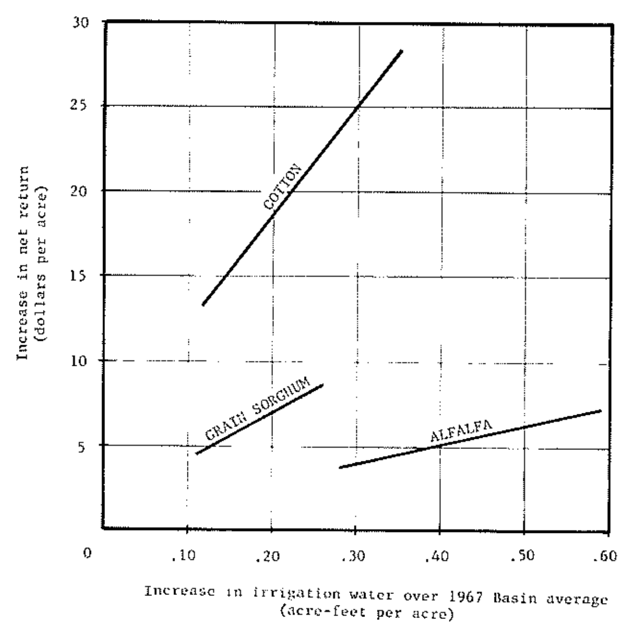


Figure 13. Comparison of net return and water use in substituting cotton, alfalfa, or grain sorghum for fallow and land out of production, based on 1967 crop mix, Roswell Artesian Basin, New Mexico.

Forage prices would have to be favorable, however, to make these crops competitive with alfalfa.

A possible fertilizer deficiency problem associated with the growing of corn and sorghums also must be considered. There is some evidence in the basin of reduced cotton yields, which are most likely a result of late winter or spring plowdown of corn or sorghum stubble. If sufficient nitrogen is added to offset that required for rapid decomposition of corn and sorghum residues, cotton yields should not be reduced. If early fall plowdown is practiced, only minimal nitrogen should be needed to avoid reduced cotton yields.

Barley acreage probably will be unchanged with the present cultural practices, but with improved seed and cultural practices barley might become competitive with sorghums and corn silage. If irrigation water quality deteriorates further, barley could even become a major crop in the basin because of its salt tolerance and its value to the developing livestock feeding operations in the area. Barley has a rotational value because it helps to counteract verticillium wilt when grown before cotton.

Factors in Crop Selection

The question, thus, is which combination of crops in the total cropping program on each farm will most favorably influence the total irrigation requirement of the basin, the overall immediate agricultural income, and the long-term water quantity and quality conditions in the basin. To assist in answering this question, a brief statement has been developed for several of the crops that are adapted to the basin to indicate the advantages and disadvantages to be considered in shifting from one crop to another, to hold water diversions to a practical minimum and to produce the highest practical income.

Factors in Crop Selection

	Advantages	*Disadvantages*
Cotton	1. Irrigation requirement less than three acre-feet of water, or 28 to 34 inches per acre. 2. Quite tolerant to saline water after seedling stage. 3. Highest per-acre income of all crops in basin. 4. Market currently well established in the area.	1. Regulated by government program; increases above the allotted acreage are currently not permitted. 2. Yields may be affected by wilt.
Alfalfa	1. Market well established for alfalfa hay. 2. Medium income per acre. 3. Serves as feed base for range livestock and cattle feeding industries. 4. Important in present crop rotation. 5. Multiple harvests lessen chance of complete crop failure. 6. Provides cash income during growing season.	1. Highest irrigation requirement of major crops in basin (48 to 60 inches per acre). 2. Much of the market is to dairies at distant points, reducing cash value compared with a nearer market. 3. Relatively intolerant to salinity.
Grain sorghum	1. Irrigation requirement less than cotton or alfalfa (21 to 27 inches per acre). 2. Medium income per acre. 3. Currently enjoys a ready market both from local and distant purchasers. 4. With comparative potential yields, sorghum is a good competitor with alfalfa, given suitable soils and water for both.	1. Immediate ready market is uncertain for grain from 30 to 35 percent of the land. 2. Additional fall nitrogen required if grown before cotton. 3. Bird damage heavy in some varieties. 4. Relatively intolerant to salinity.
Spring barley	1. Lowest irrigation requirement among feed grains commonly grown in the basin (18 to 24 inches per acre). 2. Appears to assist in control of cotton diseases in the crop rotation. 3. Most tolerant of all crops to salinity.	1. Lowest cash income of all major crops grown in the basin, excepting its value in rotation in increasing cotton yields.

	Advantages	Disadvantages
Pecans	1. High-income specialty once established (10 to 15 years required). 2. Not affected by government programs.	1. High irrigation requirement (48 to 72 inches per acre). 2. Greater competition likely from increased plantings of improved varieties in New Mexico and other states.
Corn	1. Low irrigation requirement compared with alfalfa (21 to 24 inches per acre). 2. Has an expanding market. 3. Is high in feeding value. 4. Is compatible with present cropping patterns.	1. Yields generally lower in the basin than in major corn-producing areas. 2. Relatively intolerant to salinity.
Castor beans	1. Relatively low irrigation requirement (27 to 30 inches per acre). 2. Relatively good returns to land and management. 3. Extensive, shallow root zone, beneficial to soil structure. 4. Low disease and insect problem.	1. Possible source of poison from volunteer plants growing in forage corn and sorghum fields. 2. Limited market because of production allotments to processors under farm program. 3. Not currently rated under farm program as a soil-conserving crop. 4. Relatively intolerant to salinity.
Improved permanent irrigation pasture	1. Fits into expanding livestock industry in the basin. 2. Needs no reestablishment. 3. Beneficial to soil structure and tilth. 4. Quite tolerant to salinity after germination.	1. Highest irrigation requirement of any crop in the basin (60 to 72 inches per acre). 2. Requires intensive management for high yields. 3. Income is quite low under present practices in basin.
Lettuce	1. Relatively low irrigation required (24 to 30 inches per acre). 2. Occupies land only 90-120 days. 3. Yields two crops per year. 4. Harvest does not conflict with cotton. 5. Possible high-income crop. 6. Fits with onion or grain rotation.	1. Highly fluctuating market. 2. Highly susceptible to tipburn and insect damage. 3. Highly perishable crop. 4. High labor requirement for harvest. 5. Sensitive to salinity.
Onions	1. Relatively low irrigation requirement (30 to 36 inches per acre). 2. Somewhat more stable market than lettuce. 3. Maximum 90 days of storage life. 4. Wide range of adaptability in crop rotation program.	1. Highly fluctuating market. 2. High labor requirement for harvest. 3. Weeds may be a problem on summer onions. 4. Sensitive to salinity.

Water and Soil Salinity

Salinity of the water is sometimes a limiting factor in crop selection, even as government programs, especially in cotton, castor beans, and certain other crops limit the acreage and therefore the amount of the crop which can be marketed. Saline water is a real problem in some parts and on some farms of the basin, particularly northeast of Roswell. The total soluble salts on 11 of the 12 case farms ranged from a high of 7172 micromhos ($EC \times 10^6$) or 4590 parts per million (ppm) on one farm to a low of 877 micromhos or 560 ppm on another (table 19). The average for the 11 farms was 2294 micromhos or 1468 ppm.

Figure 14 shows the increase in amount of water applied that would be necessary to maintain maximum yields in the Pecos Valley at various salinity levels of the irrigation water. It is evident that high-salt water must be applied in larger amounts than low-salt water to maintain good yields. The difference is only moderate for barley but becomes excessive for alfalfa when water salinity exceeds three or four millimhos (9).

A good crop yield is dependent upon a good initial stand. Most crops are more sensitive to soil salinity when they are germinating than when they are established and growing, but corn and sorghum are more tolerant in the germination stage. Of the five crops in this study, barley has the greatest tolerance during germination, followed by sorghum, corn, cotton, and—the least tolerant—alfalfa. The crop sequence with respect to salt tolerance during germination, when related to soil salinity after growing one of the five crops, indicates that the crop sequence most likely to achieve maximum water use on an initially low-salt soil would be alfalfa-cotton-corn-sorghum-barley (figure 15). Following barley, when the soil salinity presumably would be high, a thorough leaching of the topsoil would be necessary to reduce salinity levels low enough to permit alfalfa seed to germinate. Any crop could follow any other crop if adequate leaching were done before seeding (9).

In the reclamation of a saline soil, salt tolerance data indicate that barley should be the first crop grown, followed by sorghum, corn, cotton, and finally, alfalfa, where the irrigation water is relatively saline.

Management and Frequency and Method of Irrigation

It would appear that water management on individual farms has been the controlling influence on efficient use of water in view of the findings of Carroon and Hanson (6).

The effect of management is further evident in irrigation schedules for test sites on Case Farms J and L. The test sites on each farm contained approximately the same acreage, water quality, and soil and topography conditions. Alfalfa yield on Farm J was 8.53 tons compared with a yield on Farm L of 8.48 tons per acre. The Farm L test site received 71.38 inches per acre or 25.91 inches more water than the 45.47 acre-inches applied to the Farm J test site for the season (3).

Farm J had 14 irrigations averaging 3.25 acre-inches per irrigation in comparison to seven irrigations on Farm L averaging 10.20 acre-inches per irrigation (3). Usually two to three weeks elapsed between irrigations on Farm J, and four to five weeks between irrigations on Farm L.

Other research shows that the above results presented for alfalfa have also been observed by other workers in alfalfa and in cotton and other crops (12, 14, 39).

The increase in yield with increased frequency of irrigation on productive soils is associated with maintenance of adequate aeration and a continuous supply of soil moisture in the root zone, especially in the upper half where the uptake of water and nutrients by the roots is the greatest (39).

The extreme up-and-down variation of moisture percentage in the soil with less frequent surface irrigation helps explain the retarded yield with infrequent irrigations. As the moisture level lowers between irrigations, the soil moisture tension increases and more energy must be expended to remove the moisture from the soil. This condition is usually more pronounced in the upper part of the root zone where there are more roots and aeration is better. Increased frequency of irrigation with less water at each application provides moisture more readily available to the plants in the upper part of the root zone.

Plants may wilt severely before an irrigation even though there is an ample supply of available moisture in

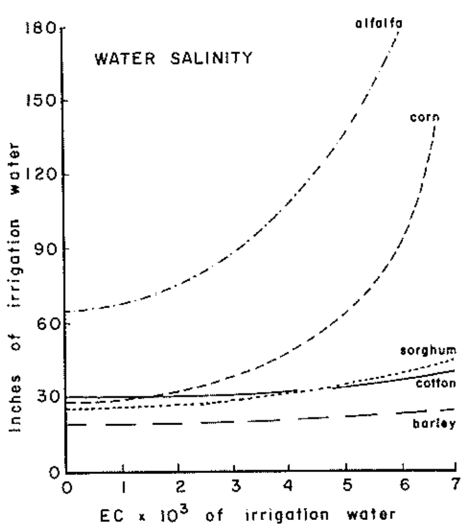


Figure 14. Amount of irrigation water required to maintain maximum yields with waters of different salinities.

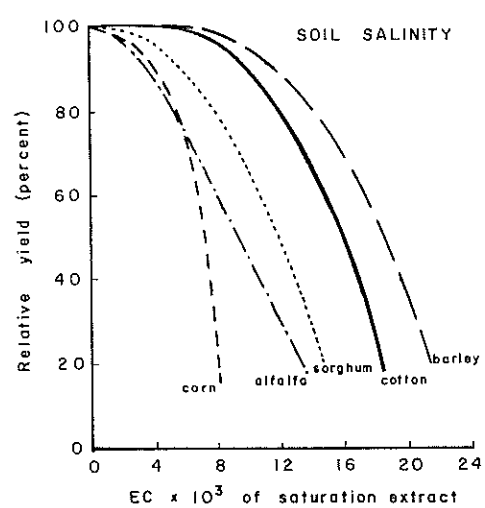


Figure 15. Relation of corn, alfalfa, sorghum, cotton, and barley yields to soil salinity.

the lower half of the root zone. Because the root growth in the lower zone is relatively sparse, there are not enough roots to move water sufficiently fast from the soil to the plant to prevent wilting. Moisture in the lower root zone is beneficial to crop yield and it can keep the plant from dying, but it is not as effective in promoting high crop production as is ample available moisture in the upper root zone. This accounts for the beneficial effect on alfalfa yields of the light and more frequent irrigations.

Management and Water Measurement

Inasmuch as irrigation concepts differ greatly among irrigators, and the specific irrigation problems vary greatly among farms, it follows that efficient water management requires the measurement of irrigation water diverted on farms. This principle was demonstrated during a test in the irrigation of plots by visual judgment conducted at the New Mexico Agricultural Experiment Station in Mesilla Valley.

An experienced irrigator was asked to irrigate a four-acre field containing 16 border strips, each 25 feet wide and 265 feet long. The irrigator was to apply a sufficient amount of water for an adequate irrigation. This amount was to be determined "by eyeball" similar to the manner in which irrigation is usually accomplished on farms throughout the state. At the same time when the irrigator was irrigating by visual judgment, the amount of water applied was being determined accurately with water-measuring equipment. The results are presented in table 39, which shows that the amount of water applied varied from 2.5 to 7.3 acre-inches per acre among the border plots in the same field. This test was made during the daytime. If the test had been made during night irrigation as must frequently be done on farms, one would expect that there would have been greater variation in the amount of water applied because of reduced visibility.

Table 39. Variation in amount of water applied by visual judgment to 16 borders in the same field, New Mexico Agricultural Experiment Station, Mesilla Valley, 1968.[1]

Border Plot Number[2]		Irrigation Water Applied
		(acre-inches per acre)
1		2.8
2		2.5
3		3.6
4		2.6
5		5.1
6		5.7
7		4.4
8		4.6
9		3.5
10		4.5
11		4.7
12		2.9
13		4.7
14		7.3
15		5.2
16		4.4
	Average	4.3
	Minimum	2.5
	Maximum	7.3

[1]Unpublished data from a daytime test conducted by the Agricultural Engineering Department, New Mexico State University.

[2]Border plots were 25 feet wide and 265 feet long.

Water management might be improved in the basin if farmers checked the meters on the wells during irrigations to determine the amount of water applied to borders and fields. This information would be useful in determining desirable adjustments in the width of borders and in length of irrigation time periods, to increase the water use efficiency.

To improve water management practices appreciably on a given farm it is necessary to know how much water is being applied to border strips, furrows, and specific fields. Since all pumps on farms throughout the basin are equipped with meters, farmers have an opportunity to use water measurements in improving irrigation practices. It is also essential that they have an understanding of certain fundamental irrigation concepts such as the head size, length of run, infiltration rate, and water-holding capacity of the soil, to enable them to use water measurements to the greatest advantage.

Some demonstration programs on farms could be helpful to farmers in solving problems that appear to be the cause of unduly high water applications.

Water Meters

Project research personnel observed some meters that were inoperative. They were also questioned concerning the percentage of inoperative meters and the amount of water that may have been pumped but not metered. Although these items were not considered as part of the project, proper metering is a necessity since farmers are now required to meter wells—first to measure compliance with the court order, and, second and most important, to secure as uniform treatment as possible between the owners and operators of the irrigated farms in the basin.

When the court required the wells to be metered the order provided that each farm owner would be responsible for the purchase, installation, and maintenance of the meters. Meters became available through three outlets in the area, with the result that three types of maintenance equipment and supplies are required to service the meters. Some of the meters gave more trouble to farmers than others and repairs were often unavailable, causing inadequate servicing of some meters at times, and even periods when no meters were in operation on certain wells.

The California-Arizona litigation which involves the Gila River in western New Mexico resulted in meters being required. However, those meters are maintained by the state.

An arrangement whereby all meters are supervised and maintained by the conservancy district, by the state, or by some cooperative arrangement, appears to have the following advantages:

1. The meters may be checked systematically and any found to be out of order or recording improperly may be immediately replaced, thus providing more consistent metering of all wells in the area.

2. A supply of repair parts and service equipment is maintained, thus avoiding possible delays in meter repairs.

3. A few meters may be held in reserve and replacements can be made with a minimum down-time in the metering of all wells in the jurisdiction of the court.

4. A program of systematic maintenance, including oiling of meters, is made possible and will prevent failure of many originally quite satisfactory meters due to lack of minor maintenance work.

5. The cost to farmers may be made more uniform by eliminating differences in type of meters, and by relieving certain owners of costs resulting from random acts of vandalism.

The usual practice among municipal or privately owned utility companies is for the cost of the original meters to be borne by property owners, but the meters are supplied, installed, operated, and maintained by the company with no further direct charges to the property owner for the meter or for servicing. This procedure may have application in the metering of all ground water diversions in the basin.

Basin Water Balance

The general objective in establishing a duty of water for the basin has been basically to protect and extend the water resource, and thereby protect the individual water rights in the basin. Limiting ground water withdrawals to encourage the most practical beneficial use of water in the basin for a longer period of time, should assist in extending the productive life of the basin while maintaining reasonable incomes to the farmers and the community.

Historically, from the early 1930's water development and use in the Roswell Artesian Basin has been a subject of discussion, legislation, and court action. Studies have been conducted by federal, state, and local agencies to determine the amount of recharge and withdrawals and the effect these had or might have on the quantity and quality of water available for future use.

In 1964, Sorenson and Borton (36) reported that an estimated average of about 400,000 to 430,000 acre-feet of water was being diverted in recent years, and that an estimated 270,000 acre-feet was being consumed, with 150,000 acre-feet of net recharge and thus an estimated annual net depletion in the basin of 120,000 acre-feet. From available records the 1960-1964 diversions for the basin were 441,600 acre-feet of ground water. By dividing the 270,000 acre-feet consumed by the 1960-1964 diversion, an estimated 61 percent of the total diverted was consumed annually during the five-year period.

The pumpage in the Roswell Artesian Basin, as recorded by meters, resulted in a net withdrawal of 66,000 acre-feet in 1967 with a withdrawal of 38,000 acre-feet in 1968 above recharge as compared with the five-year average (1960-1964) of 120,000 acre-feet, when about 441,600 acre-feet or 3.48 acre-feet per acre per annum was diverted for irrigation.

Estimates of consumption were made for the basin, based on per-acre diversions of 2.50 to 4.00 acre-feet by quarter acre-feet intervals, and on the 1968 total water-right acreage of 128,245 acres, and considering average precipitation for the area. For practical purposes the 61 percent consumption figure derived for 1960-1964 was applied to the estimated diversion at the several per-acre rates. From these calculations, the estimated consumption above recharge was calculated under each withdrawal situation. The estimates ranged from an excess withdrawal above recharge in 1968 of 38,000 acre-feet at a diversion rate of 2.44 acre-feet per acre to an estimated excess withdrawal of 163,000 acre-feet at a diversion rate of 4.00 acre-feet per acre (table 40).

To put these figures into a form suitable for comparison, it was calculated that, on the 1968 basis, 26,000 acres of land using 2.44 acre-feet per acre would have to be retired in order for the recharge to equal net withdrawal, or, in other words, to "bring the basin in balance." With the 4.00 acre-feet withdrawn per acre for the 128,245 water-right acreage, the calculated consumption above net recharge would be 163,000 acre-feet—or, at a diversion rate of 4.00 acre-feet per acre, 67,000 acres would have to be withdrawn from the production of crops in order to "bring the basin in balance."

Table 40 may serve as a guide to the farmers and those administering the use of water in the basin in estimating how much water may be withdrawn at various levels of pumping in comparison to the reported average for 1960-1964 and the recorded diversion for 1967 and 1968.

Administration of Water Rights

It is evident that there are numerous factors to be considered in the administration of the water rights of the Roswell Artesian Basin. For example, withdrawal in excess of recharge is one item to be considered. A second is the amount of water diverted for each acre on each farm in the basin and the effect of varying

Table 40. Irrigation water pumpage per acre and for the basin, estimated consumption, estimated consumption above net recharge, and approximate acreage retirement required to balance the basin for three periods of record and for seven calculated rates of diversion, Roswell Artesian Basin, New Mexico.

	Irrigation Water Pumpage: Per Irrigated Acre (acre-feet)	Irrigation Water Pumpage: Whole Basin (acre-feet)	Estimated Consumption (acre-feet)	Estimated Consumption as Percent of Diversion (percent)	Net Recharge (Basin Recharge Less Natural Discharge) (acre-feet)	Estimated Consumption Above Net Recharge (acre-feet)	Approximate Acreage Retirement Required to Balance Basin (acres)
1960-64	3.48[1]	441,600[1]	270,000[2]	61	150,000[2]	120,000[2]	57,000
1967	2.81	359,900[3]	216,000	61	150,000	66,000	39,000
1968	2.44	312,500[4]	188,000	61	150,000	38,000	26,000
Calculated Rates of Diversion[5]							
	2.50	320,600	196,000	61	150,000	46,000	30,000
	2.75	352,700	215,000	61	150,000	65,000	39,000
	3.00	384,700	235,000	61	150,000	85,000	46,000
	3.25	416,800	254,000	61	150,000	104,000	53,000
	3.50	448,900	274,000	61	150,000	124,000	58,000
	3.75	480,900	293,000	61	150,000	143,000	62,000
	4.00	513,000	313,000	61	150,000	163,000	67,000

[1]Average of ground water pumpage except for 1960 which includes surface diversions.

[2]Sorenson, Earl F., and Robert L. Borton, *Water Resources of New Mexico: Occurrence, Development and Use*; p. 80.

[3]Hennighausen, F. H., and W. K. Lampert, *Metered Use of Water in the Roswell Basin for 1967*: memo. to S. E. Reynolds, February 16, 1968, 4 pp.

[4]Hennighausen, F. H., and W. K. Lampert, *Metered Use of Water in the Roswell Basin for 1968*: memo. to S. E. Reynolds, January 31, 1969, 4 pp.

[5]Estimates based on average precipitation for the area and on a total of 128,245 acres.

diversions on the income per acre for each type of crop. A third consideration is the income per acre-foot of water used, and a fourth is the income per farm with various types of crops being grown.

There is no one easy policy decision that can be made to relieve the pressure of continued use above recharge in the basin. To solve this problem all of its various aspects must be given full consideration by all concerned. It is to be hoped that these deliberations will yield a solution that will be adopted for the most feasible use of the Roswell Artesian Basin's most important natural resource—water.

LITERATURE CITED

1. Banta, E. H., *Tabulation of Water Diverted, Pecos Valley Surface Water District*, Memo to S. E. Reynolds, New Mexico State Engineer Office, Santa Fe, New Mexico, 1967, 4 pp.

2. Banta, E. H., *Tabulation of Water Diverted, Pecos Valley Surface Water District*, Memo to S. E. Reynolds, New Mexico State Engineer Office, Santa Fe, New Mexico, 1968, 4 pp.

3. Barnes, Carl E., *Irrigation Water Requirements for Crop Production in the Roswell Artesian Basin, New Mexico, An Agronomic Analysis and Basic Data.* Water Resources Research Institute, New Mexico State University, Report 4, Part I, 1969.

4. Blaney, H. F., and E. G. Hanson, *Consumptive Use and Water Requirements in New Mexico*, New Mexico State Engineer Technical Report 32, Santa Fe, New Mexico, 1965.

5. Busch, Fred E., and J. D. Hudson, *Ground Water Levels in New Mexico, 1965*, New Mexico State Engineer Technical Report 34, Santa Fe, New Mexico, 1967, 124 pp.

6. Carroon, Evan, and Eldon G. Hanson, *Irrigation Water Requirements for Crop Production in the Roswell Artesian Basin, New Mexico, an Engineering Analysis*, Water Resources Research Institute, New Mexico State University, Report 4, Part III, 1969.

7. *Decennial Census of U. S. Climate–Monthly Normals of Temperature, Precipitation, and Heating Degree Days, New Mexico*, Climatography of United States No. 81-25, United States Government Printing Office, Washington, D. C.

8. Dregne, Harold E., "Irrigation Water Quality," *Proceedings of the Tenth Annual New Mexico Water Conference*, New Mexico State University, 1965, pp. 94-100.

9. Dregne, Harold E., *Prediction of Crop Yields from Quantity and Salinity of Irrigation Water*, Agricultural Experiment Station, New Mexico State University, Bulletin 543, 16 pp.

10. Garnett, Edwin T., "Economic Classification of the Irrigated Cropland in the Roswell Artesian Basin, New Mexico," (Unpublished Master's Dissertation, Department of Agricultural Economics and Agricultural Business, New Mexico State University, 1968), 171 pp.

11. Gifford, R. O., G. L. Ashcraft, and M. D. Magnuson, *Probability of Selected Precipitation Amounts,* Bulletin T-8, Agricultural Experiment Station, University of Nevada, October 1967.

12. Hanson, E. G., *Influence of Irrigation Practices on Alfalfa Yield and Consumptive Use*, New Mexico Agricultural Experiment Station Bulletin 514, New Mexico State University, 1967.

13. Hanson, E. G., "The Future of Subsurface Irrigation: A Method of Saving Water," *Proceedings of the Fourteenth Annual New Mexico Water Conference*, New Mexico State University, March 1969.

14. Hanson, E. G., and Walter G. Knisel, *Influence of Irrigation Practices on Cotton Production and Fiber Properties*, New Mexico Agricultural Experiment Station Bulletin 483, New Mexico State University, 1964.

15. Hanson, E. G., *The Seepage Problem Defined*, American Society of Agricultural Engineers, Paper No. 66-728 (mimeo).

16. Henderson, D. C., and E. F. Sorenson, *Consumptive Irrigation Requirements of Selected Irrigated Areas in New Mexico*, New Mexico Agricultural Experiment Station Bulletin 531, New Mexico State University, 1968.

17. Hennighausen, F. H., and W. K. Lampert, *Metered Use of Water in the Roswell Basin for 1967*, memo to S. E. Reynolds, February 16, 1968, 4. pp.

18. Hennighausen, F. H., and W. K. Lampert, *Metered Use of Water in the Roswell Basin for 1968*, memo to S. E. Reynolds, January 31, 1969, 4 pp.

19. Hood, J. W., and J. D. Hudson, *Ground-Water Levels in New Mexico 1960*, New Mexico State Engineer Technical Report 27, Santa Fe, New Mexico, 1962.

20. Hood, J. W., R. W. Mower, and M. J. Grogin, *The Occurrence of Saline Ground Water Near Roswell, Chaves County, New Mexico*, New Mexico State Engineer Technical Report 17, Santa Fe, New Mexico, 1960, 93 pp.

21. Hudson, J. D., *Ground-Water Levels in New Mexico, 1965*, New Mexico State Engineer Technical Report 34, Santa Fe, New Mexico, 124 pp.

22. IBM, *1130 Linear Programming-Mathematical Optimization Subroutine System (1130 LP-MOSS) (1130-CO-16X) Program Reference Manual*, Application Program No. H20-0345-0, Technical Publications Department, 1967, 64 pp.

23. Israelsen, Orson W., and Vaughn E. Hansen, *Irrigation Principles and Practices*, John Wiley and Sons, Inc., New York, 1962.

24. Lansford, Robert R., and Bobby J. Creel, *Irrigation Water Requirements for Crop Production in the Roswell Artesian Basin, New Mexico: An Economic Analysis*, Water Resources Research Institute, New Mexico State University, Report 4, Part II, 1969.

25. Lansford, Robert R., and Gene Ott, *Castor Beans Costs and Returns in the Roswell Artesian Basin*, Plant Science Guide, Cooperative Extension Service, New Mexico State University, Circular 400 A-504, 2 pp.

26. Lansford, Robert R., and Arthur R. Simkins, "Cropping Patterns in the Roswell Artesian Basin, 1948-1966," (Unpublished Data, Department of Agricultural Economics and Agricultural Business, New Mexico State University, 1967).

27. Maddox, George E., "Availability and Quality of Ground Water in the Pecos River Basin," *Proceedings of the Tenth Annual New Mexico Water Conference*, New Mexico State University, 1965, pp. 36-46.

28. Mower, R. W., *Pumping in the Roswell Basin, Chaves and Eddy Counties, New Mexico*, U. S. Geological Survey Open File Report, 1960, 88 pp.

29. Mower, R. W., *Water-Level Measurements in Observation Wells, 1951-1955, and Atlas of Maps Showing Changes in Water Level for Various Periods from Beginning of Record through 1954, New Mexico*, New Mexico State Engineer Technical Report 13, Santa Fe, New Mexico, 1959, 219 pp.

30. Mower, R. W., *Changes in Water Levels in 1955 and Annual Water-Level Measurements in January and February 1956*, New Mexico State Engineer Technical Report 16, Santa Fe, New Mexico, 1960.

31. Mower, R. W., *Ground-Water Levels in New Mexico, 1956*, New Mexico State Engineer Technical Report 19, Santa Fe, New Mexico, 1960.

32. Mower, R. W., *Ground-Water Levels in New Mexico, 1957*, New Mexico State Engineer Technical Report 22, Santa Fe, New Mexico, 1961.

33. Mower, R. W., *Ground-Water Levels in New Mexico, 1958*, New Mexico State Engineer Technical Report 23, Santa Fe, New Mexico, 1962.

34. Presley, John T., and Luther S. Bird, "Diseases and Their Control," *Advances in Production and Utilization of Quality Cotton: Principles and Practices*, Iowa State University Press, Ames, Iowa, 1968, pp. 349-366.

35. Sorenson, Earl F., "Use of Water in the Pecos River Basin, New Mexico," *Proceedings of the Tenth Annual New Mexico Water Conference*, New Mexico State University, 1965, pp. 68-75.

36. Sorenson, Earl F., and Robert L. Borton, "Settlement, Development, and Water Use," *Water Resources of New Mexico: Occurrence, Development and Use,* State Planning Office, Santa Fe, New Mexico, 1967, pp. 74-96.

37. Southeastern Branch Experiment Station, New Mexico State University (Unpublished Weather Records, Artesia, New Mexico, 1966 and 1967).

38. State of New Mexico, *et al.* vs. L. T. Lewis, Hagerman Canal Company, *et al.* (Consolidated Number 14945, District Court of Chaves County, State of New Mexico), Partial Final Judgment and Decree (mimeo, 6 99), 1966.

39. Taylor, S. A., *A Continuous Supply of Soil Moisture to a Growing Crop Gives Highest Yield*, Utah Agricultural Experiment Station, Reprint 618.

40. The American Farm Economic Association, *Journal of Farm Economics, Proceedings Number*, Volume XXIII, February 1941, 398 pp.

41. United States Department of Agriculture, Agricultural Stabilization and Conservation Service, *The 1966 Upland Cotton Program*, (mimeo), January 1966, 10 pp.

42. United States Department of Agriculture, Agricultural Stabilization and Conservation Service, *The 1967 Upland Cotton Program*, (mimeo), January 1967, 10 pp.

43. United States Department of Agriculture, Agricultural Stabilization and Conservation Service, *The 1968 Upland Cotton Program*, (mimeo), January 1968, 10 pp.

44. United States Department of Agriculture, Consumer and Marketing Service—Cotton Division, *Summary of Cotton Fiber and Processing Test Results*, Agricultural Information Bulletin 335, April 1969, 119 pp.

45. Water Utilization Planning Service, *Special Report on Water Utilization in Chaves and Eddy Counties, New Mexico*, United States Department of Agriculture, Bureau of Agricultural Economics, June 1942, 219 pp.

46. Weather Bureau, *Climatological Data, New Mexico*, (Annual Summaries) Volumes 34-72, 1931-1968.

GLOSSARY

Certain specialized terms used throughout the reports are presented in alphabetical order below, to facilitate the reading of the report for those who may be unfamiliar with some of the more technical terms.

Average typical farm: As used in this study, refers to the simple average of the twelve typical farms, which in turn refer to the modal average of each for the three years of this study.

Coefficient: The constant elements in a linear programming equation; for example, "amount of water required by one acre of alfalfa."

Coefficient of determination (r^2): The proportion of a total sum of squares that is attributable to another source of variation, the independent variable.

Concrete-lined ditch: An open concrete-lined irrigation ditch used to convey irrigation water from the well or storage reservoir to another irrigation water conveyance device or to the site of application.

Constraint: The upper or lower bound or limit of the equation or inequality relating the variables in an optimization problem.

Consumptive irrigation requirement: The quantity of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required for crop production.

Consumptive use: The unit amount of water utilized per unit of time on a given area in the process of transpiration, in the building of plant tissue, in evaporation from adjacent soil, water surface, or snow, or in intercepted precipitation, in any specified time. Consumptive use is expressed in volume per unit area by time, such as acre-inches or acre-feet per acre, per day, month, or season.

Correlation: A measure of the degree to which variables vary together or a measure of the intensity of association.

Cropped acreage: Land on which crops were growing at time of study.

Cultivated land: Land to which cultural practices were actively applied during the preceding two years including the years in which this study was conducted (includes cropped, fallow, and diverted land).

Daily average precipitation: The average daily precipitation during the periods of peak consumptive use.

Daily peak consumptive use (U): The average daily consumptive use in the major part of the growing season during which the rate of evapo-transpiration is the greatest.

Diverted: Land devoted to conservation uses for a period of time as specified in the provisions of the 1966, 1967, and 1968 Upland Cotton Programs.

Earthen primary and secondary laterals: Earthen ditches commonly used to convey irrigation water from some intermediate point in the irrigation conveyance system to the site of application. Secondary earthen laterals commonly subdivide an irrigation site or field.

Effective precipitation: Precipitation during the growing period of the crop that becomes available to help meet the consumptive water requirements of crops. It does not include deep percolation below the root zone nor surface runoff.

Enterprise budget: The various resource requirements and their quantity, costs which are required in the production of one acre of a specific crop, and the return associated with the production of this unit.

Frost-free period: The period from the date of the last recorded temperature of 32° F or less in the spring until the date of the first recorded temperature of 32° F or less in the fall.

Irrigated cropland: Land on which water is artificially supplied for the production of agricultural products and/or on which the owner has the physical facilities and legal right to do so.

Irrigation efficiency: The percentage of irrigation water pumped or diverted, that is stored in the soil and that is available for consumptive use. When the water is measured at the farm headgate or at the irrigation well it is called farm irrigation efficiency; when measured at the field it is designated as field irrigation efficiency.

Irrigation regime: A sequence of irrigation water applications on a given field or farm.

Irrigation requirement: The quantity of water diverted, exclusive of precipitation, that is required for crop production, or the consumptive irrigation requirement divided by irrigation efficiency. It includes surface evaporation and other economically unavoidable wastes. It is expressed in acre-inches or acre-feet per acre, or in depth in inches or in feet. Additional water which may well be necessary for leaching is not included in the definition.

Irrigation system: The ditches, pipes, furrows, and border strips through which irrigation water is applied to land, and the reservoirs, gates, checks, turnouts, valves, and other devices or structures by which water flow is regulated and controlled.

Isolation percentage: The percentage of fallow or desert land that surrounds an area of irrigated land. Used as a measure to estimate the relative exposure of irrigated crops to hot, dry winds from surrounding unirrigated areas which may increase the consumptive use of irrigated crops.

Land preparation: The grading of land to remove high areas and fill low areas so that water will flow evenly over the land surface with a continuous smooth slope or on a constant grade. (Sometimes referred to as leveling, land leveling, or land grading.)

Length of run: The distance that water must run in border strips to furrows or over the surface of a field from one head ditch to another, or to the end of a field.

Linear programming: A technique for finding the best solution from among all solutions of a system of linear inequalities. Also includes the formation of the problem in linear programming terms, algorithms for finding the best solution, and the analysis of the effect of changes in the values of problem parameters.

Linear programming problem: A mathematical problem of minimizing or maximizing a linear function of n variables, subject to n independent restrictions, such as requirements that each variable be non-negative, and also subject to a definite number of other linear constraints.

Management: Same as water management.

Marginal value product: The amount by which the total revenue changes when an additional unit of input is added.

Maximize: Finding the values of the variables which give the largest possible value to the objective function.

Maximum: A set of values of the variables which give the largest possible value to the objective function.

Micronaire: A measure of fiber fineness and an indication of fiber maturity. This is an instrument test which measures the resistance of a plug of cotton to air flow. Because the instrument measures may differ from the actual weight per inch, depending upon the fiber characteristics of the sample, the results are reported in terms of "micronaire" or "mike reading" instead of micrograms per inch.

Model: A synthetic system which is patterned after an actual system but which is easier to manipulate. The synthetic system is designed to resemble the actual system in ways considered important, so that its manipulation can provide information.

Net basin return: The compensation for farm capital in land and for management of the operators employed in the production of all crop enterprises in the Roswell Artesian Basin.

Net returns to land and management: The compensation for farm capital in land and for management of the operator employed in the production of a given crop enterprise.

Objective function: That function of the independent variables whose maximum or minimum is sought in an optimization problem.

Optimal: A set of values of the variables which optimizes the objective function.

Optimal cropping program: The optimal combination of crops in a linear programming problem that result in an optimal solution.

Optimal net returns: A set of values of the variables which optimizes (maximum or minimum) the objective function when it refers to net returns.

Optimize: To maximize or minimize an objective function.

Optimum: Same as optimal.

Out of production: Land on which cultural practices were not applied during the two years preceding the study.

Parameters: A secondary variable in a linear programming problem which may change any or all of the constraints, thus forming a new problem. The parameter changes referred to in this study involve changing the quantity of the irrigation water resource.

Parametric programming: A method for investigating the effect on an optimal linear programming solution of a sequence of proportionate changes in the elements of a single row or column of the matrix.

Regression coefficient (b): The measure of the slope of the regression line. When this value is positive, both variables increase or decrease together; when it is negative, one variable increases as the other decreases.

Reservoir: An artificial pond for storage, regulation, and control of water.

Shadow price: The dual solution to a linear programming problem. The change in the objective function per unit increase in the corresponding constant.

Solution: A set of values for the variables which satisfy the given constraints.

Typical: The model average during the three years of this study, 1966, 1967, and 1968.

Underground pipeline: A covered pipeline used to convey irrigation water from a well or storage reservoir to another water conveyance device or to the site of application.

Value of the Marginal Product: Same as marginal value product.

Water diversion: Gross quantity of water diverted into an irrigation system from a pump, river, or canal. It is expressed in volume measure–for example, acre-inches. Or it may be expressed in volume per unit area–for example, acre-inches per water-right acre.

Water management: The use of structures and practices to regulate and control water diverted from any source for crop production.

Water-right acres: Land on which the owner has the legal right to apply irrigation water as defined by adjudication or permit.

Water stage recorder: An instrument that continually records the water level in a stream or reservoir.

Water use efficiency: The pounds of matter or crop yield produced per acre-inch of water available.

Whole farm budget: The total cost, total returns, and net returns associated with production of all crop enterprises on a given farm (summation of enterprise budgets).