AN ANALYTICAL INTERDISCIPLINARY EVALUATION OF THE UTILIZATION OF THE WATER RESOURCES OF THE RIO GRANDE IN NEW MEXICO

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This study was part of an interdisciplinary-interuniversity research project entitled "An Analytical Interdisciplinary Evaluation of the Utilization of the Water Resources of the Rio Grande in New Mexico."

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These consultants were included in the research effort and made contributions both in advice to the study group and in data development. The architectural consultant provided information on landscape architecture and aesthetic functions of the environment as related to alternative settlement patterns. Sociological and population problems in the Rio Grande region were considered by the Development Sociologist and included in the interregional models. The law consultant served on

legal phases which developed as the major investigators proceeded in the research, and his advice was considered in the final analysis of the study. The Industrial Engineer helped in the development of industrial water-use coefficients. Robert R. Lansford served as the coordinator for all phases of the project.

Although the research team is solely and totally responsible for statements and conclusions in this report, many people helped in the work: Fred Roach, Graduate Assistant at the University of New Mexico, helped with the development of the socio-economic model. One of the key elements of this study was the use of a technical advisory committee composed of representatives from state and federal agencies. The willingness of this advisory committee to work with the study group was outstanding. Many of the changes in the study reflected the advice offered by members of the technical advisory committee. Membership of the Advisory Committee was:

Mr. Robert F. Stephens	U.S. Bureau of Sport Fisheries and Wildlife
Mr. T. A. Garrity	U.S. Bureau of Indian Affairs
Mr. William E. Hale	U.S. Geological Survey
Mr. W. J. Anderson	U.S. Bureau of Land Management
Mr. James Kirby	U.S. Bureau of Reclamation
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Mr. Phil Mutz	New Mexico Interstate Stream Commission
Mr. Pete Metzner	Middle Rio Grande Council of Governments
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ABSTRACT

An interdisciplinary approach to the solution of the water resource problems of the Rio Grande region in New Mexico was made possible by the integration of hydrology, geology, and engineering with economics. Research procedures developed to carry out this study were closely coordinated by the investigators to achieve the primary objective of evaluation of the social and economic impacts of alternative water-use policies.

A socio-economic model was developed to represent the New Mexico economy, with special emphasis placed upon the Rio Grande region. Inputs into the socio-economic model were obtained from separate studies covering the hydrological, agricultural, municipal, and industrial areas.

Three sets of alternatives were considered: 1) growth without a water constraint; 2) growth, holding surface water constraint; 3) growth, holding both surface and ground water constraint.

Without a water constraint, both production and depletions are expected to exhibit the largest increase (59.2 percent and 49.6 percent, respectively). When a surface water constraint is imposed, the value of production is reduced by only $5.6 million in the year 2000, and by $14.2 million in 2020; water depletions are expected to decrease about 27 percent by 2020. When a total water constraint is imposed, the value of production is decreased $2.7 million below that expected when using only a surface water constraint, and water depletions are reduced only slightly.

*KEYWORDS: *New Mexico, *Rio Grande Basin, *Water resources, *Socio-economic model, Interdisciplinary, Ground water appropriation, Water law, Compacts, Treaties, Litigation, Adjudication of water rights, Water quality, Water utilization, Population, Employment, Industrial, Recreation, Water management, Input-output coefficients, Linear programming model, Surface-groundwater conjunctive use model, Economic land classification, Irrigation diversions and depletions.*

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CHAPTER I

INTRODUCTION

The complexity of today's resource systems makes it almost mandatory that their management be achieved through the application of the talents and technology of a variety of disciplines, while the legal and institutional structures of water use make their understanding and application a requisite to good management. Although economic justification should be the foundation of decisions on alternative uses of water, the social and cultural implications must be fully considered since the optimal use of water implies a maximization of the benefits returned to society through a broad range of beneficial uses. In order to formulate plans and policies for future water resources development in the Rio Grande Basin of New Mexico, the assessment of future water supplies and requirements necessitates a major consideration of future rates and patterns of economic development.

A U. S. Senate Select Committee (1961) report estimated that the Upper Rio Grande and Pecos Basins were the shortest of water in relation to projected demand to 1980 of any basin in the continental United States. This projection was documented by the U. S. Water Resources Council study (1968) which studied the complete Rio Grande drainage area in Colorado, New Mexico, and Texas (Figure 1). The Water Resources Council study identified the major problems to be water deficiencies and groundwater storage depletion, poor quality because of mineral pollution, heavy sediment loads in many tributaries, excessive nonbeneficial consumptive use, and frequent floods causing extensive damage.

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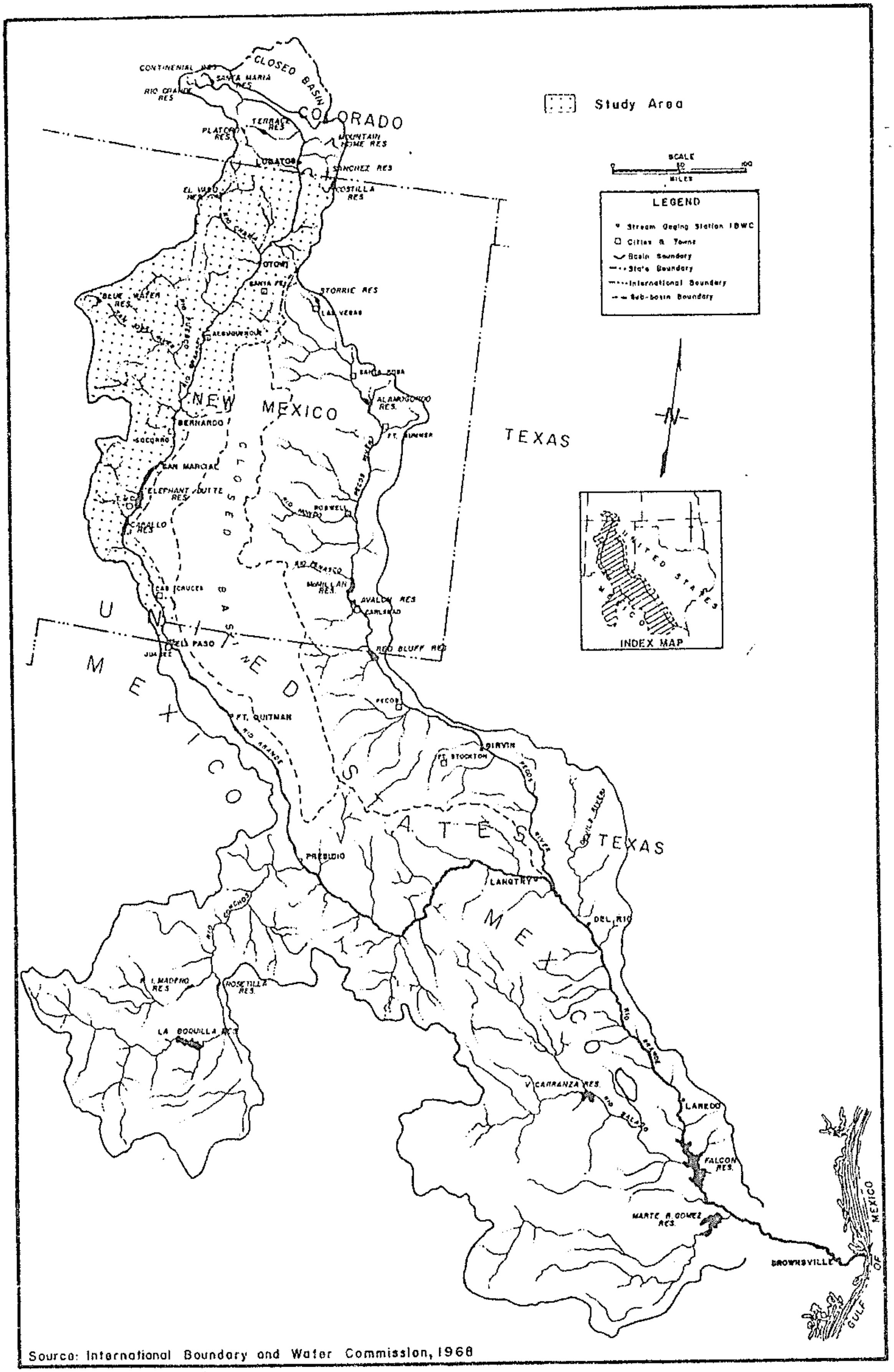

Source: International Boundary and Water Commission, 1968

Figure 1. Rio Grande drainage basin.

The Council further stated that these water problems must be solved since projected water withdrawals for the year 2020 are estimated to be about two and one-half times greater than the present average runoff in the region.

The Problem

Making the best use of the fully appropriated water supply in most areas of the Rio Grande remains the major problem facing the State of New Mexico. A continuing and succeeding effort in this direction is being made by a number of state and federal agencies, particularly the New Mexico State Engineer, the New Mexico Interstate Stream Commission, the Bureau of Reclamation, the U. S. Army Corps of Engineers, United States Geological Survey, and the Soil Conservation Service.

Although certain aspects of the problems of the river system have been subject to detailed investigation, the rapid rate at which the technological potential has increased makes it highly desirable for persons whose primary concern is not with the institutional structure of existing water resources agencies to study, evaluate, and develop proposals to enchance the use of the resources of the Rio Grande.

This project was proposed as a research program whose basic purpose was the application of some of the newer, and as yet unperfected, analytical techniques to the water resources problems of the river to continue to develop and test other methods in the solution of typical system problems.

Objectives

The primary objective of this study is to evaluate the social and economic impacts of alternative water-use policies which were designed to solve the water scarcity problems of the Rio Grande region of New Mexico. To pursue this objective it was necessary to develop a socio-economic model for the evaluation of alternative water-use patterns in the Rio Grande region. The model required the following:

1. Construction of a model of the interchange between ground water and surface water on various reaches of the Rio Grande;

2. evaluation of the social and economic costs of changes in irrigated agriculture with respect to water supplies, to population, and to alternative uses of water; and
3. evaluation of the social and economic needs of the population for water-based recreation in the Rio Grande region of New Mexico.

The socio-economic model utilizes mathematical programming input-output analysis with regional income as the basis for economic comparison. Constraints on the model are water availability, recreational resources, pollution capacity of streams, labor force availability, and population.

Previous Investigations

Studies of the water-related problems of the Rio Grande began in the 1880's along with the controversies over the division of the surface waters of the Basin among the three states of Colorado, New Mexico, and Texas, and between the United States and Mexico.

The Follett report (1896) covered comprehensively and in detail the streamflow, irrigated areas, canal systems, ditches, and diversions for every section of the Basin from San Luis Valley in Colorado to El Paso, Texas. A report was made by H. W. Yeo (1910), an engineer with the Bureau of Reclamation, of a detailed investigation of the extent of irrigation in the Rio Grande Valley of New Mexico. Engineers Harold Conkling and E. B. Debler (1919) reported to the Bureau of Reclamation on an extensive investigation made to determine the water supply, irrigation development, and possibilities of future development in the San Luis Valley, in the Middle Rio Grande Valley, and under the Rio Grande Project.

Debler (1924) made an investigation and report to the Bureau of Reclamation on the water supply and requirements of the Rio Grande Project. Debler and Elder (1927) carried on an extensive investigation in the Middle Valley for the Middle Rio Grande Conservancy District, and J. L. Burkholder (1928), chief engineer of the Middle Rio Grande Conservancy District, made a report covering the district's investigations and the final plan for flood control, drainage, and irrigation.

Beginning in 1923, when provisions were made by Colorado and New Mexico for the appointment of their representatives on the Rio Grande

Compact Commission, investigations have been carried on under the direction of the State Engineers. Much of the data and results of the earlier studies are included in reports, unpublished, of C. R. Hedke (1924, 1925), E. P. Osgood (1928), R. G. Hosea (1928), and H. W. Yeo (1928).

The Natural Resources Committee (N.R.C.) conducted an investigation during 1936 and 1937 which represents the most comprehensive collection of data on the Rio Grande Basin to date. The primary purpose of this investigation, known as the Rio Grande Joint Investigation (1938), was to determine the basic facts needed in arriving at an accord among the states of Colorado, New Mexico, and Texas on an equitable allocation and use of Rio Grande waters. In general, this investigation sought facts relating to the available water supply, the water uses and requirements, and the possibilities of additional water supplies by storage, importations, and salvage of present losses and wastes.

Many other studies and investigations have been carried out on the Rio Grande Basin, both from a basin-wide view or for specific purposes such as ground water hydrology. The New Mexico State Engineer, U. S. Geological Survey, and International Boundary and Water Commission, as well as many other agencies, have been instrumental in conducting investigations of the Rio Grande.

General Description of the Rio Grande Region

The Rio Grande is one of the longest river systems in the United States, with its headwaters in the San Juan and Sangre de Cristo mountains of southern Colorado and northern New Mexico (Figure 1). It flows 700 miles from north to south through southern Colorado and central New Mexico to the Texas state line, and then forms the boundary between Mexico and the United States until it discharges into the Gulf of Mexico.

The Rio Grande Basin is relatively isolated from other major urban and industrial centers. The regional economy was based chiefly on agriculture, with livestock production predominating, and the population distribution patterns of the Rio Grande have closely followed those of the irrigated land. In recent years urban areas have grown rapidly as a result of nuclear research and governmental and military activities.

Manufacturing is increasing in importance in the Basin. In the past, it has been largely associated with production for local markets and industries, including food processing, lumber products, printing and publishing, and concrete and stone products. Trends in manufacturing indicate a broadening of the industrial base with less dependence on resource-based industries; an example of this is the recent expansion in electronic manufacturing in Albuquerque.

The principal application of the waters of the Rio Grande system is for irrigated agriculture, with municipal, industrial, and recreational demands taking on greater importance as the population of the area grows. The pattern of water use is expected to change with the anticipated growth in the Basin population and economy. While irrigation will still represent the largest portion of the demand for water, the projected increase in urban and industrial uses will probably restrict the growth of irrigation.

The Rio Grande Basin is geographically divided by a narrow gorge a few miles below Fort Quitman, Texas (Figure 1). Above Fort Quitman, about 32,000 square miles of drainage area are contributory to the river. Of these 32,000 square miles, 25,680 are in New Mexico, 4,655 are in Colorado, and the remainder are about equally divided between Texas and Mexico (N.R.C. 1938, p. 143). It is generally accepted that all of the water originating in the Upper Basin is consumptively used above Fort Quitman.

The Rio Grande Basin in New Mexico may be divided into three sections (N.R.C. 1938, p. 143); these are the Upper, Middle, and Lower Basins. The Upper Basin extends from the Colorado-New Mexico state line to Otowi Bridge at the head of White Rock Canyon in northern Santa Fe County, and is some 100 miles in length. The Middle Basin is some 190 miles in length and extends from Otowi Bridge to Elephant Butte Reservoir. The Lower Basin extends from the reservoir to the New Mexico-Texas state line and is some 140 miles in length. The total length of the river basin within the state is about 430 miles. A map of the Rio Grande drainage basin in New Mexico is presented in Figure 2.

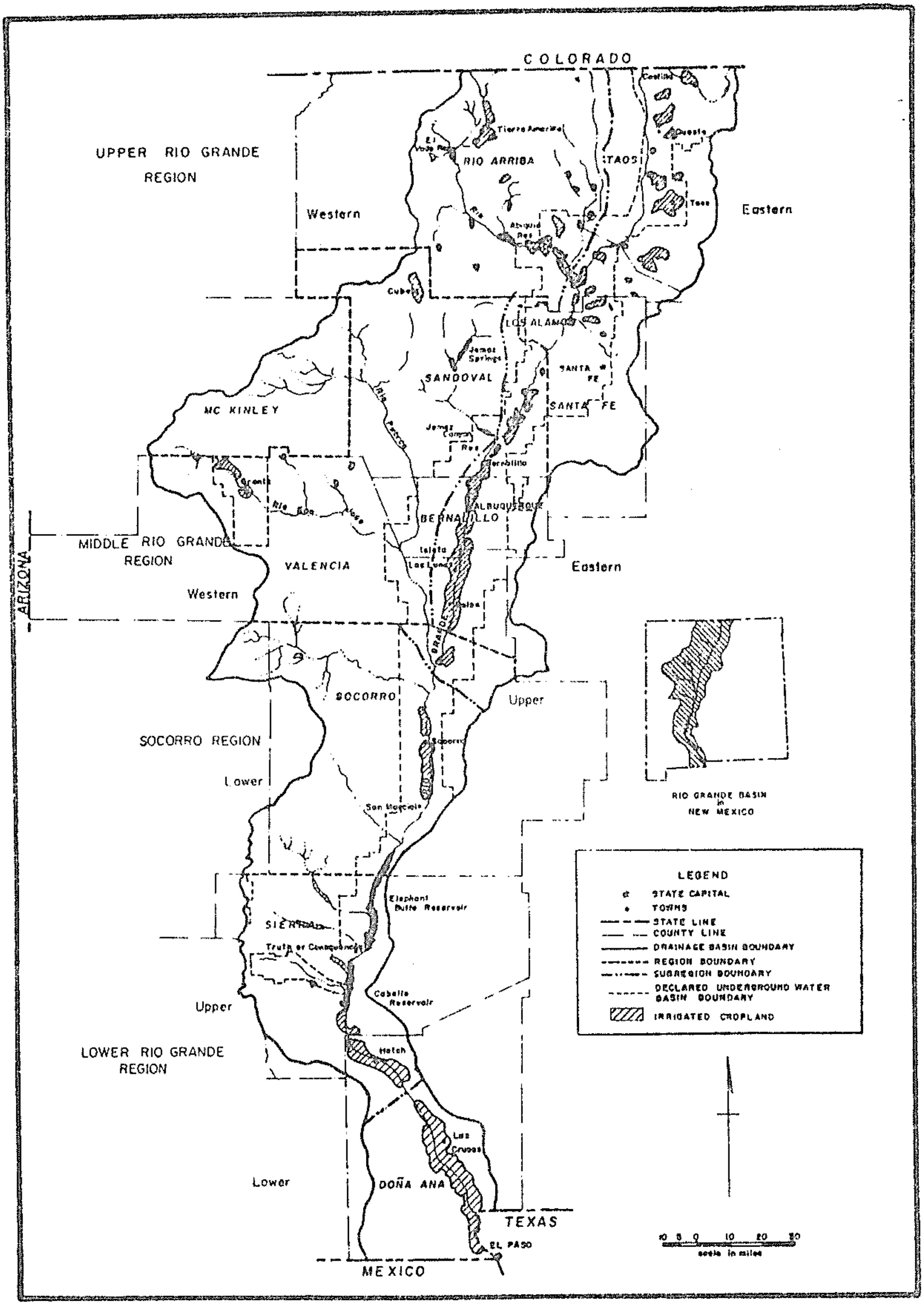

Figure 2. Rio Grande drainage basin in New Mexico, for this study, as of January 1970.

The Rio Grande is a complex stream that flows through a succession of basins connected by narrow canyons or other restrictions. Bryan (N.R.C. 1938, p. 198) described this as follows:

> It may be roughly likened to a stream flowing from one sand-filled tub to another through narrow troughs. Each tub differs to size and shape from the others and contains sand of a different quality. In these tubs water is lost by evaporation and is also gained by local rainfall on the sand. The troughs also differ in shape and length, and in some of them there is a gain of water.

These various basins consist of broad plains flanked by mountain ranges. The river has incised itself, together with its inner valley, many hundreds of feet below the original upland surface. The inner valley, or flood plain, has a nearly flat floor in basin areas and varies in width from one to six miles. Away from the flood plain of the river, the basin grades into a plain or plateau area bounded by a series of north-south trending mountain ranges.

Historical Development of Surface Water

Early development. History shows that inhabitants of the Rio Grande Valley have always made beneficial use of the surface waters of the Rio Grande. When the area was discovered by Spanish explorers under Coronado in 1540, Indians were cultivating land and bringing water to it by irrigation ditches as their ancestors had long done (N.R.C. 1938, p. 66). Remnants of old ditch systems date back to at least 900 A. D. In 1896, Follett noted that there were 17 or 18 Pueblo Indian settlements still existing in what is now known as the Middle Valley of New Mexico, each holding a land grant two leagues square and with its own pueblo containing from 200 to 600 people. He estimated that prior to the middle of the sixteenth century there were some 15,000 to 20,000 people living from products raised by irrigation in the Rio Grande drainage above the Jornada del Muerto, and the area of irrigated land probably exceeded 30,000 acres (1896). Thus, Indian irrigation development in the Rio Grande Basin reached its peak prior to the Spanish occupation.

The first Spaniards to visit the area were treasure seekers under Coronado. They accomplished little in the way of developing the country, and returned to Mexico in 1542. It was not until 1598 that a real colonizing expedition under Don Juan de Oñate came into the Valley and founded the settlement of San Gabriel near the mouth of the Rio Chama. Here, with the assistance of 1,500 Indians, Oñate built a canal or "acequia" which was probably the first Spanish ditch in the country (Follett, 1896).

This settlement was abandoned in 1605, and the inhabitants and capital transferred to Santa Fe where they and their descendants remained until 1680. Exploration and colonization were carried on from Santa Fe for a period of about 75 years, but in 1680 the Indians rose in revolt and drove the Spaniards out of the country. They remained in El Paso for 12 years and, in 1692, under Don Diego de Vargas, they returned to Santa Fe and the Rio Grande Valley (Follett, 1896).

The Spanish land grants were made at this time in recognition of services rendered during the Pueblo Rebellion, and the real development of the country began. In almost regular progression down the river to the south, settlement and development followed. Bernalillo was founded about 1700, and Albuquerque was settled in 1706. In 1739 certain residents of Albuquerque, dissatisfied with conditions there, moved a few miles south to Tome. One of the reasons for the dissatisfaction of the original settlers with Albuquerque was the shortage of water for their fields (Follett, 1896).

The original Indian inhabitants of the lower portion of the Rio Grande Valley were not agricultural people. They had no permanent town and did not cultivate (or irrigate) their lands. The first white settlement in the lower Rio Grande Valley was founded in 1659 on the south side of the river about where the Mexican city of Juarez now stands, and was called El Paso. Irrigation development expanded from this settlement both north and south, and by 1821, at the time of Mexican Independence, the development included some portions of the Mesilla Valley as far north as the community of Dona Ana. Settlement of the Las Cruces and Mesilla areas occurred in the 1840's and 1850's, respectively. Spanish development of the Rincon and Socorro Valleys was delayed because of the presence of Apaches (Follett, 1896).

Recent development. In the early 1890's water shortages began to occur along the Rio Grande in the Middle and El Paso Valleys, and people near Juarez, across the river from El Paso, complained to the Mexican government. The matter was taken up through diplomatic channels, and a claim for damages of $35,000,000 was filed by Mexico against the United States, alleging that the shortages were due to increased diversions from the river by water users in Colorado and New Mexico. As a result, the International Boundary Commission was directed to make an investigation and report covering the whole Upper Rio Grande situation. This was done by W. W. Follett (1896) under appointment from the commission. The purpose of Follett's investigation is quoted as follows:

> This study was made for the purpose of investigating the claim of the Mexican Government that the people of the United States have taken from the inhabitants of Mexico water which was theirs by ancient right of prior appropriation. It also extends to a consideration of the probability of there being a water supply sufficient to successfully serve a reservoir at El Paso, the construction of which by the United States is suggested as a recompense to the Mexicans for their alleged loss of water.

Follett found that there was in fact a decrease in the flow of the river at El Paso, as claimed, and was due to very large increases in acreages of irrigated cropland in the San Luis Valley of Colorado. The use of water in New Mexico for irrigation had not materially increased and hence was not the cause of the decreased flow, but like the Mexican citizens, the people of New Mexico also suffered from the decreased flow of the river. The outcome of this study was the "embargo" of 1896. The "embargo" was an order by the Secretary of the Interior which prevented further irrigation development of any magnitude in the Rio Grande Basin in Colorado and New Mexico through suspension of all applications in those states for right-of-way across public lands for the use of Rio Grande water.

Following the "embargo," the Department of Interior undertook an investigation of the river. This investigation revealed the feasibility of construction of Elephant Butte Reservoir for the storage and regulation of Rio Grande water, which could furnish reasonable demands for water by Mexico as well as supply water to an estimated 155,000 acres in New Mexico and Texas. Congress authorized construction of the storage dam in 1905 and appropriated $1,000,000 toward its construction. On May 21, 1906, a treaty was signed between the United States and Mexico wherein the United States guaranteed to Mexico, in return for relinquishment of all damages, the annual delivery in perpetuity of 60,000 acre-feet of water in the Rio Grande at the head of the Mexican canal near El Paso (Witmer 1968, p. 443).

The construction of Elephant Butte Dam and other initial works was completed in 1916; Caballo Reservoir was constructed some 20 miles downstream in 1938. Construction of these works did not solve all of the water supply problems in the Basin, and the three Basin states, Colorado, New Mexico, and Texas, continued to dispute the division of the water supply. The federal government also continued, until 1925, to place restrictions on further development in the upper two states (N.R.C. 1938).

These interstate disputes over the division and use of the waters of the Rio Grande resulted in the forming of the Rio Grande Compact Commission in 1923. Colorado, New Mexico, Texas, and the United States were represented on the Commission. A temporary compact which did not set up definite allocation, but which did establish a situation of "status quo," of waters of the Upper Basin was ratified in 1929. In March 1938 a final and permanent compact was concluded and was ratified by the three states and approved by the United States in 1939 (Witmer 1968, p. 280). The primary purpose of the compact was to remove all causes of the controversy and provide for an equitable apportionment of the waters of the Rio Grande among the three states.

The San Juan-Chama project was authorized in 1962 by Public Law 87-483 as a participating project of the Upper Colorado River Storage Project. The project authorizes an annual average diversion of 110,000 acre-feet of water from the upper tributaries of the San Juan River in the Upper Colorado River Basin. The waters are collected from three tributary stream systems in Colorado and carried through a series of tunnels and canals penetrating the Continental Divide into Heron Reservoir on Willow Creek, a tributary of the Rio Chama in New Mexico. The imported waters will be used to serve the city of Albuquerque with municipal water; to provide supplemental water for irrigation of lands in the Middle Rio Grande Conservancy District; to replace depletions in the Rio Grande Basin caused by new projects for irrigation on several tributaries of the Upper Rio Grande in New Mexico; and to maintain a permanent recreation pool in Cochiti Reservoir.

The San Juan-Chama Project is the first major inter-basin transfer of water in New Mexico. In a physical sense, it also constitutes an interstate transfer of water, although the water imported is within New Mexico's allocation under the Upper Colorado River Basin Compact.

Historical Development of Ground Water

There had been little utilization of ground water as a basic source of supply for irrigation in the Rio Grande Basin up to the late 1930's because of technological limitations. The reasons for ground-water development since the early 1940's were increased irrigated acreage, declining surface water quantity, and greater domestic and industrial demands of urban areas. In general, agricultural development of ground water to supplement surface water irrigation in New Mexico has had a minor effect on the vast quantities of ground water in storage. In some areas, about one-to-two feet per year of ground water is being pumped to supplement about two feet per year of surface water; in addition, development of ground water for domestic and industrial purposes has caused local stresses of a more noticeable nature such as, for example, in the Albuquerque area.

Ground water appropriation. All of New Mexico's ground water and surface water belong to the public and are subject to appropriation in accordance with law. It is within the State Engineer's authority to supervise the appropriation and the use of ground water. When the State Engineer finds that the waters of an underground water supply have reasonably ascertainable boundaries and when he so proclaims, he assumes jurisdiction over the appropriation of such waters.

Long before the establishment of the Rio Grande Underground Water Basin by the State Engineer in 1956, geologic and hydrologic studies showed the Rio Grande and the underlying ground water reservoir to be hydraulically connected. As a consequence, water pumpage would affect river flow, and the prospect of additional ground water development in the vicinity of the river prompted the State Engineer to declare the Rio Grande Underground Water Basin (Figure 2). In this way he initiated a method of administration of conjunctive ground and surface waters which was probably unique in the United States; i.e., new appropriations of ground water in the Rio Grande Basin are permitted under the conditions that the appropriator (1) acquire and retire from usage surface water rights in amounts sufficient at each point in time to compensate for the increasing effects of his pumping on the stream, or (2) provide for replacement water such as under the San Juan-Chama project.

Legal Institutions Affecting Water Use*

Reflecting its paramount importance in a semi-arid state, water in New Mexico is a commodity owned by the people, and its use is closely governed by law. The institutions affecting water use range from the ancient community ditch associations to federal water importation projects involving interstate compacts, reclamation conservancy districts, etc. New Mexico has been a leader among the western states in terms of ground water management, extensive use of interstate stream compacts, and the facility of water rights transfers.

Water laws. The state's water laws are based on the doctrine of prior appropriation as found in Article XVI of the Constitution, with administration vested in the State Engineer. Rights perfected in surface waters before 1907 and in underground waters before the declaration of a basin by the State Engineer are not fully administrable until their priority, location, extent, etc., are adjudicated by court decree. The strict administration of surface flows according to priorities has not

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* *The following section on Water and Legal Institutions was contributed by Philip B. Mutz, Staff Engineer, New Mexico Interstate Stream Commission.*

seen widespread application up to the present time, although certain stream systems have been administered for many years. Ground water is subject to regulation within the same general scheme of law applying to surface waters when included within an underground water basin declared by the State Engineer. About one-third of the state's area is within such declared basins.

Compacts. Utilization of water in the state is subject to provisions of eight interstate compacts entered into between New Mexico and other states. The waters of the Rio Grande system in New Mexico are subject to the Rio Grande Compact and to the Amended Costilla Creek Compact.

The Rio Grande Compact between the states of Colorado, New Mexico, and Texas was adopted in 1939, and it apportioned the flows of the Rio Grande to the three states. Under provisions of the compact, Colorado is obligated to deliver at the Colorado-New Mexico state line a quantity of water determined from a schedule based on the annual runoff above major uses in Colorado. Likewise, New Mexico is obligated to deliver a quantity of water at Elephant Butte Dam determined from a schedule based on the annual runoff at the Otowi gaging station, located on the Rio Grande near San Ildefonso. A system of debits and credits is provided in the compact so that neither Colorado nor New Mexico is required to deliver each year the exact quantity set forth in the schedules of deliveries. For purposes of administering the compact and for delivery by New Mexico, "Texas" begins at Elephant Butte Dam. This anomaly was probably created because the major irrigation system below the dam serves the interstate Rio Grande Project of the Bureau of Reclamation and the principal water supply reservoir is Elephant Butte. The compact covers only that portion of the Rio Grande drainage in Texas above Fort Quitman.

The compact of 1939 was preceded by the 1929 Rio Grande Compact, an interim agreement among the same three states, which basically provided that the three states maintain a "status quo" on the river until a permanent compact could be negotiated and consummated.

The Amended Costilla Creek Compact was adopted in 1963 between the states of Colorado and New Mexico. The amendments of 1963 provide minor changes in the allocations and points of delivery of water made by the Costilla Creek Compact of 1944 between the same two states. The compact allocates to the two states the natural flows of Costilla Creek and storage in Costilla Reservoir and provides a schedule for delivery of the natural flow of the stream on a daily basis during the "Irrigation Season." The area covered by the compact is the Costilla Creek drainage in Colorado and New Mexico.

Treaties. Two international treaties between the United States of America and the United States of Mexico affect water use from the Rio Grande in New Mexico. The first treaty, executed in 1906, obligates the United States to deliver annually 60,000 acre-feet of water in the bed of the Rio Grande at the headworks of the Acequia Madre Diversion Dam located above the City of Juarez, Mexico; a provision is included that in the case of extraordinary drought or serious accident to the irrigation system (Rio Grande Project) in the United States, the amount delivered to the Mexican Canal shall be diminished in the same proportion as the water delivered to lands under the irrigation system in the United States. The second treaty, consummated in 1933, launched a cooperative effort between the two nations to relieve the towns and agricultural lands in the El Paso-Juarez Valley from flood dangers. Also, stabilization of the International Boundary was to be obtained by rectifying the channel of the Rio Grande, and flood control was to be improved by construction of Caballo Dam and a rectified channel from Caballo to El Paso.

Litigation. New Mexico Supreme Court decisions have helped shape New Mexico water law in many important areas, principally those involving the nature of ground-water rights initiated before the management of mined ground-water basins, the transferability of rights, and the necessity for interrelated administration of surface and related ground waters.

Adjudication of water rights. New Mexico statutes direct the State Engineer to make hydrographic surveys and investigations of each stream system and source of water in the state, beginning with those used most for irrigation, in order to obtain records required for development of the water supply and for determination and adjudication of water rights.

Currently, extensive work is being carried on in the Upper Rio Grande. A survey of the Red River stream system is underway. Surveys have been completed on the Rio Hondo, Rio Taos, Rio Truchas, Rio Santa Cruz, Rio Pojoaque stream systems (which are tributaries to the Rio Grande), the El Rito and Rio Ojo Caliente stream systems (which are tributies of Rio Chama), and adjudication suits are pending in the Federal District Court. Adjudications have been completed and court decrees entered for all water rights, except for Indian rights, on the Rio Puerco de Chama and the main stream of Rio Chama below El Vado Dam. The State Engineer established the Rio Chama Watermaster District and appointed a watermaster who began administration on the Rio Chama below El Vado in 1972. Another recent survey, adjudication, and decree covered the Las Animas Creek stream system near Truth or Consequences.

Declared underground basins. When the State Engineer finds that the waters of an underground stream channel, artesian basin, reservoir, or lake have reasonably ascertainable boundaries, and when he so proclaims, he assumes jurisdiction over the appropriation and use of such waters.

In 1956 the State Engineer declared the Rio Grande Underground Water Basin which covers a large portion of the Rio Grande stream system above Elephant Butte Dam. Subsequently, several extensions to the original basin were declared and the total declared area is about 11,566 square miles. Also, the State Engineer has declared the Bluewater Underground Water Basin, comprising about 269 square miles; the Hot Springs Underground Water Basin, about 38 square miles; the Las Animas Creek Underground Water Basin, about 75 square miles; and the Sandia Underground Water Basin, about 73 square miles.

Also, in closed drainage basins separate from, but adjacent to, the Rio Grande drainage system, the State Engineer has declared the Estancia Underground Water Basin, comprising about 1,498 square miles in Torrance, Bernalillo, and Santa Fe counties, and the Nutt-Hockett Underground Water Basin, comprising about 133 square miles, in Luna, Dona Ana, and Sierra counties.

CHAPTER II

PHYSICAL DESCRIPTION OF THE RIO GRANDE REGION

From a river basin viewpoint, the Pecos River drainage is a part of the Rio Grande system; however, for purposes of this study the Pecos River is not considered a part of the Rio Grande region. For this study, the Rio Grande region (Figure 2, p. 7) was divided into four subregions as follows: The Upper Rio Grande region which extends from the New Mexico-Colorado state line to Otowi Bridge, including the counties of Rio Arriba, Taos, and Santa Fe; the Middle Rio Grande region from Otowi Bridge to the Socorro-Valencia county line, including the counties of Sandoval, Bernalillo, and Valencia; the Socorro region, which includes Socorro County; and the Lower Rio Grande region from the Socorro-Sierra county line to the New Mexico-Texas state line. This differs from other previous divisions in that the Middle Rio Grande Basin generally includes the designated Socorro region. A distinction was made primarily because the Socorro region, even though served by the Middle Rio Grande Conservancy District, is essentially a separate area in relation to the type of agriculture, hydrology, geology, and the influence of the Albuquerque metropolitan area.

Topography

The Rio Grande Basin varies from precipitous mountains to broad, relatively featureless plains. The river flows through a series of structural basins that were formed chiefly by faulting and other deformation of the older rocks and their subsequent filling with sedimentary and volcanic deposits. The valleys or flood plains along the Rio Grande are relatively narrow, ranging in width from a few hundred feet to about five miles. These valleys are generally bordered by steep bluffs from less than 50 to several hundred feet high. From the bluffs, generally inclined plains extend back to the mountains.

The several parts of the Rio Grande depression differ in their altitude above the river and in the degree of dissection. Some parts are smooth plains, others are a maze of steep-walled gulches, and still others are basalt-covered plateaus. All these areas, except the flood plain of the Rio Grande within the inner valleys and the flat floors of some of the principal tributary streams, have a deep water table and low runoff (N.R.C. 1938).

Land

Within the Rio Grande region there are approximately 16.9 million acres but only 1.7 percent, or 280,785 acres, are irrigated. The land ownership of the Rio Grande region is reported in Table 1. Federal and state ownership account for about 43 percent of the total land area in the Rio Grande region.

Within the region the acreage of forest land controlled by the Forest Service accounts for about 22 percent of the total land area; land administered by the Bureau of Land Management (BLM) accounts for about 15 percent; defense less than 1 percent; and other federal ownership about 3 percent. State ownership accounts for about 8 percent. Private ownership accounts for about 37 percent. Indian ownership accounts for about 12 percent of the total land area.

Irrigated cropland. The irrigated cropland is located in a somewhat narrow strip along the rivers in the Rio Grande region (Figure 2). There are approximately 281,000 acres of irrigated cropland, of which about 73 percent is cropped acreage and about 81 percent is cultivated acreage (Table 2). The acreages of the various crops produced are also reported by subregion in Table 2. In terms of acres, alfalfa was the most important, accounting for about 22 percent of the total irrigated cropland. The next most important crop was cotton with about 20 percent. Out-of-production and idle acreage also accounted for about 20 percent of the total irrigated cropland.

Climate

The Rio Grande Basin in New Mexico encompasses a wide range of climate. The average annual precipitation varies from about 8 inches per year in the Las Cruces area to over 30 inches per year in the upper elevations of the Sangre de Cristo Mountains in the north. The average

Table 1. Land ownership, in acres, in the Rio Grande Drainage Basin, New Mexico, 1971

Region and County[1]	Federal Forest	BLM	Defense	Other	Total	State[2]	Private	Indian[3]	Total Land Area	Inland Water	Total Area
Upper Rio Grande											
Taos	461,200	199,800	--	24,300	685,300	102,700	545,200	110,300[4]	1,443,500	400	1,443,900
Rio Arriba	1,154,200	215,000	--	45,600	1,414,800	181,400	816,500	185,000	2,597,700	10,000	2,607,700
Mora	9,900	--	--	--	9,900	--	--	--	9,900	--	9,900
San Miguel	6,900	300	--	--	7,200	600	1,900	--	9,700	--	9,700
Santa Fe	158,600	61,000	--	35,200	254,800	38,400	409,800	75,700	778,700	300[5]	779,000
Los Alamos	--	--	--	68,300	68,300	--	3,700	--	72,000	--	72,000
Subtotal	1,790,800	476,100	--	173,400	2,440,300	323,100	1,777,100	371,000	4,911,500	10,700	4,922,200
Middle Rio Grande											
Sandoval	418,400	192,580	2,600	177,400	790,980	93,060	903,730	516,740	2,304,510	1,200[6]	2,305,710
Bernalillo	53,100	17,520	45,800	140	116,560	28,500	271,020	268,230	684,310	--	684,310
Torrance	49,140	2,400	--	--	51,540	19,800	53,600	16,400	141,340	--	141,340
Valencia	262,620	211,100	--	--	473,720	102,260	1,008,540	626,380	2,210,900	1,300	2,212,200
McKinley	15,370	149,520	--	35,500	200,390	65,300	398,580	173,800	838,070	480	838,550
Subtotal	798,630	573,120	48,400	213,040	1,633,190	308,920	2,635,470	1,601,550	6,179,130	2,980	6,182,110
Socorro region											
Socorro	598,050	556,000	3,800	80,300	1,238,150	277,780	1,129,570	65,700	2,711,200	13,900[7]	2,725,100
Catron	75,400	15,500	--	--	90,900	14,900	51,000	--	156,800	--	156,800
Subtotal	673,450	571,500	3,800	80,300	1,329,050	292,680	1,180,570	65,700	2,868,000	13,900	2,881,900
Lower Rio Grande											
Sierra	403,500	450,500	--	1,900	855,900	218,700	434,700	--	1,509,300	36,100	1,545,400
Dona Ana	--	915,670	21,640	7,800	945,110	230,120	232,700	--	1,407,930	--	1,407,930
Subtotal	403,500	1,366,170	21,640	9,700	1,801,010	448,820	667,400	--	2,917,230	36,100	2,953,330
Basin Total	3,666,380	2,986,890	73,840	476,440	7,203,550	1,373,520	6,260,540	2,038,250	16,875,860	63,680	16,939,540

[1] Includes only county area lying within the Rio Grande Drainage Region (Figure 2).
[2] Includes state trust and deeded land and lands administered by other state agencies.
[3] Includes both trust and deeded Indian lands.
[4] Includes transfer of 48,000 acres from Forest Service to Taos Indian Pueblo.
[5] Includes 56 acres for proposed Nambe Falls Reservoir.
[6] Includes 1,200 acres for Cochiti Lake under construction.
[7] Includes 1,801 acres for La Joya and Bosque del Apache Lakes.

Source: Estimated from Bureau of Land Management Quadrangle Maps; acreage of lakes and reservoirs from New Mexico State Engineer Office Preliminary Report, "Reservoirs and Lakes in New Mexico with 40 or more surface acres," February 8, 1971.

Table 2. Acres of irrigated cropland, by use, in the Rio Grande Basin, New Mexico, 1970

Cropland Use	Upper Rio Grande Region	Middle Rio Grande Region	Socorro Region	Lower Rio Grande Region	Total Rio Grande Basin	
	. . . .	. acres. . .	. . . .	. . . . .	acres	percent
Cotton	--	--	1,402	54,437	55,839	19.9
Alfalfa	15,954	26,712	6,362	13,717	62,745	22.3
Sorghum	4	467	685	4,626	5,782	2.1
Corn	1,100	2,353	979	2,000	6,432	2.3
Small grains	3,498	5,960	1,749	980	12,187	4.3
Improved pasture	8,144	6,148	2,347	2,010	18,649	6.6
Other hay and native pasture	21,210	649	12	--	21,871	7.8
Chile	120	172	100	3,126	3,518	1.3
Orchards	2,956	1,117	36	6,273	10,382	3.7
Spring lettuce	--	(260)*	(25)*	(4,100)*	(4,385)*	(1.6)*
Fall lettuce	--	218	27	4,306	4,551	1.6
Spring onions	--	--	--	(2,240)*	(2,240)*	(0.8)*
Fall onions	--	27	69	466	562	0.2
Miscellaneous vegetable and family gardens	633	1,084	106	890	2,713	1.0
Subtotal cropped acreage[1]	53,619	44,907	13,874	92,831	205,231	73.1
Diverted and fallow[2]	3,820	6,954	1,627	8,462	20,863	7.4
Prepared land	--	519	389	--	908	0.4
Subtotal cultivated acreage[3]	57,439	52,380	15,890	101,293	227,002	80.9
Idle[4]	9,789	7,667	610	2,489	20,555	7.3
Out of production[5]	19,802	11,548	--	1,878	33,228	11.8
Total irrigated cropland[6]	87,030	71,595	16,500	105,660	280,785	100.0

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* Double cropped acreage, not included in total.

[1] Irrigated cropland on which crops were growing at the time the field survey was conducted, and on which crops had been produced during the current crop year.

[2] Acreage of irrigated cropland which was not cropped under provisions of the Agricultural Adjustment Programs or had been tilled in past two years.

[3] Irrigated cropland to which cultural practices were actively applied during the preceding two years, including the year in which this study was conducted. (Includes cropped, fallow, and diverted acreage).

[4] Irrigated cropland not actively farmed for the two past consecutive years but farmed within the past five years. (Includes suspended land which was not serviced by ground water).

[5] Irrigated cropland not actively farmed within the past five years.

[6] Irrigated cropland: Land on which water is artificially applied for the production of agricultural products, on which the owner has the physical facilities or right to engage in such practices.

Source: Adjusted from: Lansford, R. R., and Sorensen, E. F., "Planted Cropland Acreage in New Mexico in 1969, 1970," New Mexico Agriculture--1970, Agricultural Experiment Station Research Report 195, New Mexico State University, Las Cruces, New Mexico, pp. 6-12, tables 6 and 8; and Lansford, R. R., "Planted Cropland Acreage in New Mexico in 1970 and 1971," New Mexico Agriculture--1971, Agricultural Experiment Station Research Report 235, New Mexico State University, Las Cruces, New Mexico, pp. 31-37, tables 17 and 18.

annual precipitation in the trough of the Rio Grande Basin varies from 12 inches per year in the northern part (elevation over 7,000 feet) to 8 inches per year in the southern part (elevation less than 4,000 feet). The precipitation varies throughout the year. Most of the precipitation occurs as rainfall during the months of July, August, and September and is caused by the lifting effects of summer thermals and the mountains.

The relative dryness causes the daily temperature to fluctuate more than in humid areas. Daily temperatures may have up to a 40° F difference between the maximum and minimum. The yearly average temperature varies from 45° F at Taos to 60° F at Las Cruces. Summertime maximum temperatures exceed 100° F in Las Cruces and 80° F in Taos.

The combination of high temperatures and low precipitation creates high evaporations. Evaporation occurs from three kinds of surfaces: (1) open water surfaces such as reservoirs, rivers, and open ditches; (2) moist soil; and (3) vegetation through transpiration. Evaporation is the combined total of surface evaporation and transpiration. Potential evapotranspiration is the maximum evapotranspiration possible when the water supply in the ground is unlimited. The moisture deficit is the potential evaporation minus rainfall and stored water. The moisture deficit is high throughout New Mexico, especially within the Rio Grande Valley. The following estimates for annual moisture deficits are from The Climate of New Mexico and are:

STATION	ELEVATION	ANNUAL MOISTURE DEFICITS
Santa Fe	7,200	11.2
Albuquerque	4,965	22.2
Socorro	4,617	23.4
Las Cruces	3,881	25.3

The moisture deficiency inhibits the growth of vegetation; consequently, farmlands require irrigation of crops. The evaporation from bodies of water cannot be measured directly but is estimated by using a nearby Class A Evaporation Pan. Lake evaporation is assumed to be a constant percentage of the evaporation from a Class A Pan. The average Class A land pan evaporation is presented in Table 3.

Table 3. Average Class A land pan evaporation in inches, Rio Grande region in New Mexico

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Bosque del Apache (1947-1962)	3.21	4.42	8.18	10.49	12.80	13.79	12.08	11.02	8.68	6.40	3.80	2.74	97.61
Caballo Dam (1942-1962)	3.65	5.42	9.34	12.34	15.28	16.80	13.96	12.29	10.36	7.56	4.83	3.22	115.05
El Vado (1936-1962)	1.84*	1.85*	3.69*	5.74	7.78	9.73	8.97	7.55	6.39	4.57	2.20	1.23*	61.54*
Elephant Butte Dam (1934-1962)	3.49	5.30	8.95	12.58	15.80	17.41	14.75	12.94	10.66	8.17	5.13	3.42	118.60
Jemez Dam (1954-1962)	2.96*	2.97*	5.93*	9.76	12.70	14.98	13.97	12.10	10.34	7.12	4.03	1.98*	98.84*
Narrows (1947-1962)	2.99	4.68	7.72	11.09	13.67	15.26	13.59	11.81	10.18	7.52	4.36	2.84	105.71
Santa Fe (1948-1962)	2.25*	2.26*	4.51*	8.17	9.62	10.94	10.29	8.79	7.90	5.47	3.48	1.50*	75.18*
State University (1918-1962)	2.94	4.39	7.61	10.01	12.20	13.20	11.96	10.33	8.37	6.10	3.78	2.64	93.53

* Calculated by percentage distribution.
Source: Dinwiddie, 1967 (p. 136).

Surface Water

Stream flow in the Rio Grande is generated chiefly by the melting snow in Colorado and in the Upper Rio Grande Basin of New Mexico. Rainfall from summer thunder showers supplements the supply during July, August, and September. Below Otowi Bridge, intermittent tributaries flow primarily during thunderstorms. The perennial streams are located in the northern part of the Basin above Albuquerque, and they include Red River, Rio Hondo, Rio Taos, Embudo Creek, Rio Chama, and Jemez River. Flow from the Rio Puerco and Rio Salado is infrequent and heavily laden with silt. The average discharges of the Rio Grande and its tributaries are presented in Table 4. In the Rio Grande Basin in New Mexico, most of the water is generated above Bernalillo and then consumed below Bernalillo.

The Rio Grande is not a regulated stream in the usual sense. Only two reservoirs, Elephant Butte and Caballo, exist on the main stem in New Mexico, and they are operated in tandem. Elephant Butte Dam is also the measuring point for the flows received by "Texas" under the provisions of the Rio Grande Compact. A third reservoir, Cochiti Lake, is presently under construction above Bernalillo on the main stem.

From the Colorado-New Mexico state line south through the Rio Grande Gorge, the stream is declared a Wild and Scenic river. Below Cochiti, most of the water is diverted into the canals of the Middle Rio Grande Conservancy District and the Elephant Butte Irrigation District. Diversion dams, canals, drains, and levees are used to regulate and control the water within the districts. Control of tributary inflow to the Rio Grande is by reservoirs on the Rio Chama, Jemez River, Rio Santa Cruz, Costilla Creek, and Galisteo.

Ground Water

The Rio Grande aquifer consists of a series of structural basins formed chiefly by faulting and other deformation of the older rocks and their subsequent filling with sedimentary and volcanic deposits. This series of basins forms a structural depression generally referred to

Table 4. Average surface water discharges in the Rio Grande Basin

	Period of Average	Average Discharge	Drainage Area
		(Acre-feet/yr)	(Square Miles)
Rio Grande near Lobatos, Colo.	1899-1960	462,400	7,700*
Rio Grande near Cerro, N. Mex.	1948-1960	257,700	8,440*
Red River at mouth, near Questa, N. Mex.	1950-1960	59,220	190
Rio Grande below Taos Junction Bridge, near Taos, N. Mex.	1925-1960	556,730	9,730*
Embudo Creek at Dixon, N. Mex.	1923-1925 & 1926-1955	60,090	305
Rio Chama near Chamita, N. Mex.	1912-1960	409,300	3,200
Santa Cruz, Riverside, New Mexico	1942-1950	7,020	138
Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex.	1895-1905 & 1909-1960	1,155,000	14,300*
Rio Grande at Cochiti, N. Mex.	1924-1960	990,400	14,600*
Santa Fe River near Santa Fe, N. Mex.	1913-1960	6,130	18.2
Galisteo Creek at Domingo, N. Mex.	1941-1960	7,310	640
Rio Grande at San Felipe, N. Mex.	1925-1960	1,057,000	16,100*
Jemez River below Jemez Canyon Dam, N. Mex.	1936-1937 & 1943-1960	36,920	1,038
Rio Grande near Bernalillo, N. Mex.	1941-1960	834,000	17,300*
Rio Grande at Albuquerque, N. Mex.	1941-1960	815,900	17,440*
Rio Grande, Belen, N. Mex.	1941-1956	705,900	18,230*
Rio Grande floodway near Bernardo, N. Mex.	1936-1938 & 1941-1960	791,300	19,230*
Rio Puerco near Bernardo, N. Mex.	1940-1960	40,900	7,350
Rio Salado near San Acacia, N. Mex.	1947-1960	9,050	1,330
Rio Grande at San Acacia, N. Mex.	1936-1960	828,900	26,770*
Rio Grande at San Marcial, N. Mex.	1895-1960	970,800	27,700*
Rio Grande below Elephant Butte Dam, N. Mex.	1915-1960	771,030	29,450*
Rio Grande below Caballo Dam, N.Mex.	1938-1960	689,200	30,700*
Rio Grande at El Paso, Tex.	1897-1913 & 1916-1960	608,400	32,207*

* Includes 2,940 miles in closed basin of San Luis Valley, Colo.

as the Rio Grande depression, graben, or trough (Figure 3). It is mostly filled with the Santa Fe group sediments, alluvial fans, and valley alluvium. This valley fill of unconsolidated to loosely consolidated sediments is saturated with water and is mostly stream-connected. It generally has high permeability and is extremely thick: in some areas it is over 10,000 feet. High permeability and extreme thickness combine into large values for transmissivities: in some places it is greater than 250,000 gallons per day per foot. Well yields are rather high; for example, an average of 860 gpm is reported for the Albuquerque area.

Of secondary importance are the bedrock aquifers in the Rio Grande Basin. They are primarily composed of sandstone, conglomerate, or limestone, and yield small to moderate amounts of water to wells which are used mainly for small supplies of water for domestic and stock purposes. Some limestone aquifers may yield large amounts of water locally. The San Andres limestone, for example, really extensive within the Rio Grande Basin, could yield large amounts of water (yields of 3,000 gpm near Grants have been reported); however, with the dissolved solids content increasing with distance from the recharge areas, extensive development may be prohibitive. Lava flows covering the mesas are not reliable aquifers but may yield moderate amounts of water to wells when saturated and where fractures are tapped (up to 200 gpm in some instances).

Because of the lack of data, an estimate of the amount of ground water within the Rio Grande trough is not very reliable. The unknown saturated thickness of the aquifer, and water at greater depths which may not be directly usable because of possibly poorer chemical quality, makes any estimate of the water supply tentative. Data compiled by Z. Spiegel (1955) indicate that storage coefficients for some areas lie around 0.2, and that the thickness of the saturated valley fill is between 2,000 and 20,000 feet with an areal extent of about 8,000 square miles. Using a conservative average saturated thickness of fill of 4,000 feet and an average storage coefficient of 0.2, 4 billion acre-feet of water might be stored in the valley fill of the Rio Grande Basin.

The U.S.G.S. in cooperation with the New Mexico State Engineer Office observes and records changes of water levels on a continuing

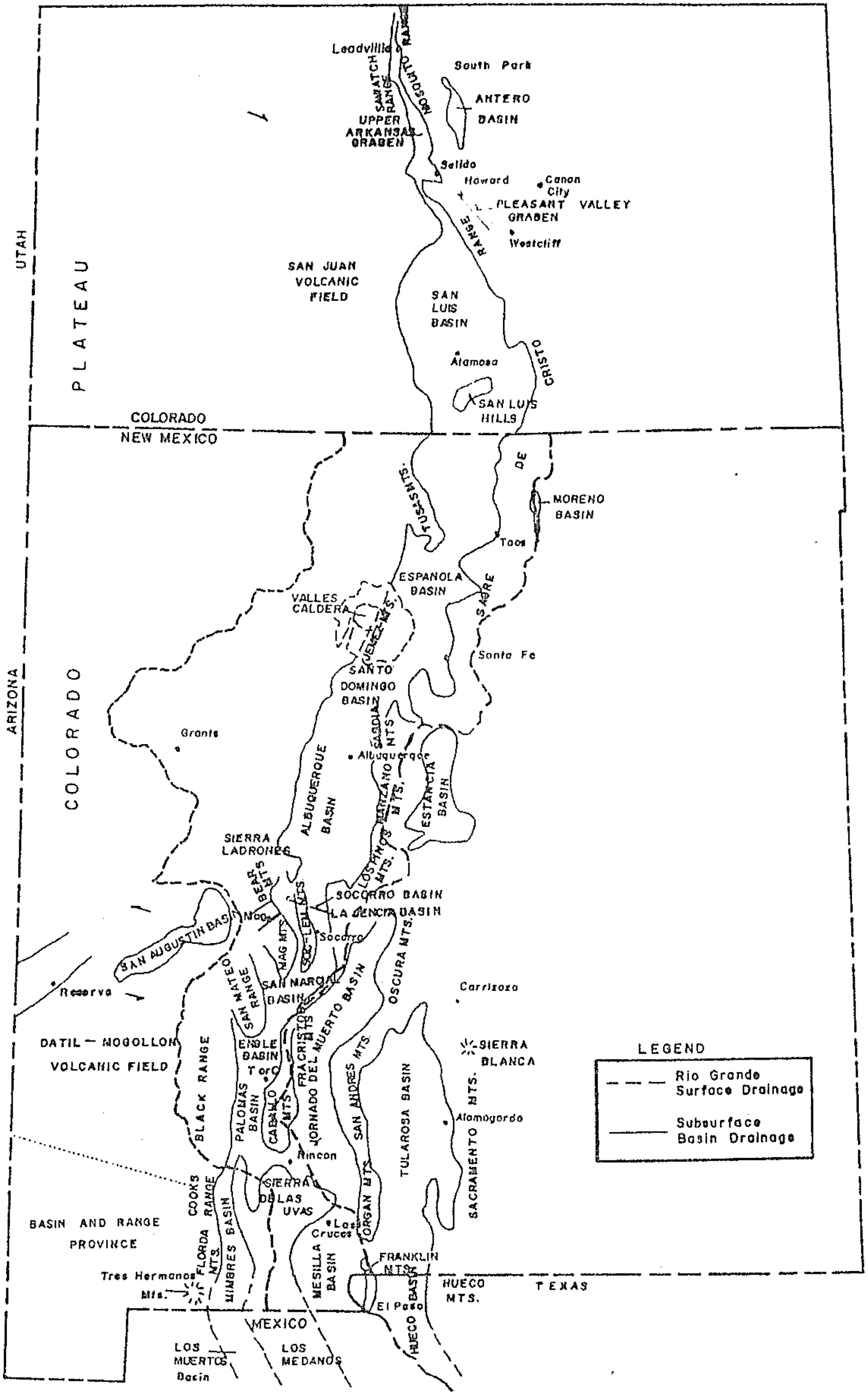

Figure 3. Generalized map of the Rio Grande Rift (After Chapin, 1971).

basis in parts of the Rio Grande Basin. The areas of observation constitute only a small part of the total Basin and are usually located where ground water is used extensively for irrigation. They are, with beginning date of program: Sunshine Valley (1955), Santa Fe area (1951), Albuquerque-Belen area (1956), Hot Springs area (1939), and Rincon and Mesilla Valleys (1957). Observed water levels and changes are published yearly in the State Engineer Basic Data Reports. A recent report of the State Bureau of Mines (N. Clark and W. Summers, 1971) gives water level records for the Socorro and Magdalena area.

Water Quality

The quality of the surface water of the Rio Grande reflects the use of the water upstream. Table 5 illustrates the general decline of the water quality along the Rio Grande during a recent year. Below Otowi Bridge all ionic constituents increase while flow decreases. The consumption of water by irrigated agriculture tends to concentrate constituents. In addition, exchange of ions between the water and soil can increase certain ionic concentrations. Little documentation is available on the quantitative effects of ion exchange on the quality of the Rio Grande's water. Electrical Conductivity and the Sodium Absorption Ratio (SAR) are used to define the salinity, and sodium hazards and are also used in determining the economic classification of land.

Large concentrations of sediment in the Rio Grande constitute another major water quality problem. Table 6 presents total loads of suspended sediment as measured at selected gaging stations during 1967. Substantial loads are carried by the Rio Grande to be deposited in Elephant Butte Reservoir. Sediment management and control is a major problem throughout the Middle Rio Grande Conservancy District. Heavy silt loads carried by the Rio Grande below its confluence with the Rio Puerco at Bernardo have settled and caused the river bed to become aggraded. Most of the sediment is produced by the collapse of channel walls where tributaries flow through deep gorges in silty soil and by the surface erosion of lands with sparse vegetation.

Table 5. Surface water quality of the Rio Grande at selected gaging stations, 1967

Station	Average Discharge CFS	Ca mg/e	Ma mg/e	Na mg/e	Cl mg/e	SO_4 mg/e	HCO_3 mg/e	Dissolved Solids mg/e	Electrical Conductivity Ec x 10^6 at $25^{o}C$
Rio Grande at Otowi Bridge 1967 Water Year.	802	49	8.0	29	8.6	81	150	276	429
Rio Grande Conveyance Channel at San Marcial 1967 Water Year.	454	90	16	99	--	--	218	632	972
Rio Grande at El Paso, Texas 1967 Calendar Year.	321	87	19	151	130	262	--	809	1,220

Note: Discharge and quality parameters are time averaged. Parameters not measured or reported are identified by --.

Table 6. Total suspended sediment loads at selected gaging stations, 1967 water year

Station	Suspended Sediment Tons/year
Rio Chama near Chamita 3 miles upstream from mouth	3,016,743
Rio Grande at Otowi Bridge	2,650,962
Galisteo Creek at Domingo 4 miles upstream from mouth	1,251,818
Rio Grande near Bernalillo	4,379,253
Rio Puerco near Bernardo 3 miles upstream from mouth	12,257,979
Rio Grande Conveyance Channel at San Marcial	10,502,515
Rio Grande Floodway at San Marcial	2,633,789
Rio Grande at El Paso, Texas	208,112*

*Reported for Calendar Year 1967.

There is a possibility that ground water below a certain depth (perhaps 2,000 feet) in the Rio Grande trough may be of lower quality and may not be directly usable. Lack of adequate subsurface data precludes an extensive survey of ground water quality. The data available come from local (e.g. municipal) studies, mostly of electrical conductivity analyses. Table 7 presents a summary of the quality data of ground water from selected wells in the Rio Grande Basin as presented by Dinwiddie (1967). The data presented in Table 7 were derived from samples taken at shallow depths (less than 200 feet).

Locally increased dissolved solid contents are due to urbanization and agricultural development, as is seen from Table 7: i.e., salinity tends to increase from north to south along the valley. In general, as demand for water increases and as desalinization becomes more economical,

Table 7. Summary of water quality data from selected wells in the Rio Grande Basin, New Mexico

	Sulfate (ppm)	Chloride (ppm)	Conductance (micromhos at 25° C)	Total Hardness as CO_3(ppm)
Alluvium in Sunshine Valley north of Questa	43	18	190	98
Santa Fe Group near Santa Fe	30	8	354	150
Santa Fe Group near Albuquerque	111	17	556	108
Santa Fe Group near Las Cruces	227	153	1,210	441
San Andres Limestone near Grants	380	70	1,460	613
Ojo Alamo Sandstone west of Cuba	202	25	715	276

the total ground water resources of the Rio Grande Valley will have to be evaluated in terms of the fresh water as well as the more saline water at lower depth. An excellent compilation of the saline ground water resources of the Rio Grande Basin was done by T. E. Kelly et al., (May 1970).

Water Utilization

Water in the Rio Grande Basin is supplied from surface sources, underground sources, and combinations of the two. Ground water meets most of the municipal, industrial, commercial, mineral, power production, rural domestic, and stock-watering requirements. Surface sources furnish the primary supply of water for irrigation. In 1970, about 45 percent of all the acreage in the Basin was supplied entirely from surface sources; about 7 percent was dependent entirely on ground water; and the remaining 48 percent received a combination of both surface and ground (Lansford and Sorensen, 1972).

During the period 1969-1970, about 576,000 acre-feet were depleted annually from the sources listed in Table 8. Irrigation depletions accounted for almost 90 percent of the depletions (excluding reservoir and stock pond evaporation) and about 40 percent of total depletions.

Population

In the middle of the sixteenth century about 20,000 Pueblo Indians lived in villages in the Middle Valley and Taos area. By 1680, approximately 3,000 Spanish people had settled in the Santa Fe area and nearby communities. The Indian population began to decline during the Pueblo Revolt of 1680 and continued to do so for a long time thereafter. By 1750, approximately 4,000 people were reported living in 20 Spanish villages in New Mexico, all in the Rio Grande Basin. By 1830, the Basin population (including Pueblo Indians) was estimated to have been 40,000. In 1960, the census data indicated that the population of the Basin was 484,700, 352,300 of whom were urban dwellers and 132,400 were rural residents (Table 9). Of the state's total 1960 population (some 951,000), 51 percent were residents of the Rio Grande Basin. In 1970, the population of the Basin was 572,170: 74.7 percent were urban and 25.3 percent were rural residents. During the 20-year period between 1950-1970, urban inhabitants of the Basin increased almost 245 percent while rural population decreased by 5 percent (Table 9).

Employment

Employment data for the Rio Grande Basin and for the rest of the State of New Mexico for the years 1960 and 1970 are reported in Table 10. The total civilian work force in the Basin increased 26.0% during the decade compared with 2.4% in the rest of the state. The unemployment rate increased from 5.7% to 6.0% in the Basin compared with a change from 5.5% to 6.7% in the rest of the state. In all reported categories, except agriculture, the Basin has increased its portion of the total employment in the state. The largest gains for the Basin as a whole were made in contract construction and wholesale and retail trade.

Table 8. Summary of estimated water depletions and diversions by major sectors in the Rio Grande region, 1969-70

	Estimated Total Depletions[1]					Estimated Total Diversions[1]				
	Subregion				Rio Grande Region[2]	Subregion				Rio Grande Region[2]
Major Sector	Upper	Middle	Socorro	Lower		Upper	Middle	Socorro	Lower	
					acre-feet					
1. Agriculture[3]	80,000	105,000	43,000	278,000	506,000	197,000	253,000	100,000	647,000	1,197,000
a. Surface	(75,000)	(95,000)	(32,000)	(225,000)	(427,000)	(188,000)	(238,000)	(81,000)	(560,000)	(1,067,000)
b. Ground	(5,000)	(10,000)	(11,000)	(53,000)	(79,000)	(9,000)	(15,000)	(19,000)	(87,000)	(130,000)
2. Mining, Oil and Gas	3,030	1,500	150	150	4,730	7,100	3,750	300	300	11,450
3. Industrial	250	1,500	25	100	1,875	2,250	14,850	300	875	18,275
4. Commercial Trade and Services	4,200	13,700	200	1,900	20,000	10,500	34,250	500	4,775	50,025
5. Municipal[4]	3,550	28,600	400	5,250	37,800	7,100	51,150	825	8,725	67,800
6. Rural	2,050	2,550	200	1,050	5,650	3,400	4,200	350	1,750	9,700
Total	93,080	152,850	43,975	286,450	576,155	227,350	361,200	102,275	663,425	1,354,250
	Percentage of the Regional Total					Percentage of the Regional Total				
1. Agriculture[3]	85.94	68.69	97.78	97.05	87.82	86.65	70.04	97.77	97.52	88.38
2. Mining, Oil and Gas	3.25	0.97	0.34	0.05	0.83	3.11	1.03	0.29	0.04	0.84
3. Industrial	0.26	0.98	0.05	0.03	0.32	1.00	4.11	0.29	0.13	1.34
4. Commercial Trade and Services	4.51	8.96	0.45	0.66	3.47	4.61	9.48	0.48	0.71	3.69
5. Municipal[4]	3.81	18.71	0.90	1.83	6.56	3.10	14.16	0.80	1.31	5.00
6. Rural	2.20	1.66	0.45	0.36	0.98	1.49	1.16	0.34	0.26	0.71
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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[1] Depletions estimated by utilizing depletion to diversion ratios and by using information from the State Engineer's Office, as well as from several other states in the Southwest. The depletions are in acre-feet.

[2] Total of the four regions.

[3] Includes stock pond evaporation and irrigated pasture - first number is total of ground and surface.

[4] Includes the public and governmental sectors.

Table 9. Population for New Mexico and the Rio Grande region

	Urban	Percent of* Total	Rural	Percent of Total	Total	Percent Change from 1960 Census
1950						
New Mexico	341,889	50.2	339,298	49.8	681,187	28.1
Rio Grande Region	175,230	53.5(51.3)	152,557	47.2(45.0)	327,787	(A)
Rest of State	166,659	47.2(48.7)	186,741	52.8(55.0)	353,400	(A)
1960						
New Mexico	626,479	65.9	324,544	34.1	951,023	39.6
Rio Grande Region	318,553	57.2(50.8)	237,948	42.8(73.3)	556,501	70.0
Rest of State	307,926	78.0(49.2)	86,544	22.0(26.7)	394,522	11.6
1970						
New Mexico	708,775	69.8	307,225	30.02	1,016,000	6.8
Rio Grande Region	426,960	74.7(60.3)	144,730	25.3(47.1)	571,690	2.8
Rest of State	281,335	63.4(39.7)	162,495	36.6(52.9)	443,830	12.5

*The percents in parentheses represent the two regions' portion of urban and rural population respectively, on a state-wide basis.

(A) Los Alamos county did not exist in 1940; percentage change therefore not calculable.

Table 10. Employment[1] for New Mexico and the Rio Grande region [2]

	1960					1970				
Classification	Rio Grande River Basin	% of Total	Rest of State	% of Total	Total	Rio Grande River Basin	% of Total	Rest of State	% of Total	Total
Total Civilian Work Force	170,391	52.26	155,609	47.73	326,000	214,608	57.39	159,292	42.60	373,900
Unemployment	9,650	53.02	8,550	45.16	18,200	12,907	54.45	10,793	45.54	23,700
Rate	5.7		5.5			6.0		6.7		
Non-Ag. Wage & Salary	131,691	55.73	104,609	44.26	236,300	175,053	60.36	114,947	39.63	290,000
Manufacturing	10,146	60.75	6,554	39.24	16,700	12,727	60.03	8,473	39.96	21,200
Mining	1,761	8.63	18,639	91.36	20,400	1,620	9.58	15,280	90.41	16,900
Contract Construction	10,521	55.96	8,279	44.03	18,800	10,870	68.36	5,030	31.63	15,900
Public Utilities, Transportation, & Communications	10,091	48.98	10,509	51.01	20,600	10,254	51.01	9,846	48.98	20,100
Wholesale & Retail Trade	26,750	54.14	22,650	45.85	49.400	37,829	62.01	23,171	37.98	61,000
Real Estate, Finance, & Insurance	6,391	66.57	3.209	33.42	9,600	8,639	69.66	3,761	30.33	12,400
Services & Misc.	25,437	68.19	11,863	31.80	37,300	37,236	69.60	16,264	30.40	53,500
Government	40,272	63.45	23,205	36.55	63,477	56,640	63.56	32,460	36.43	89,100
All Other Non-Ag.	21,121	46.62	24,179	53.37	45,300	19,952	50.13	19,848	49.86	39,800
Agriculture	7,897	43.19	10,384	56.80	18,281	6,126	30.32	14,074	69.67	20,200

[1] Based on ESC data.

[2] County definition.

Recreation

Estimated water-based recreational availability of streams and lakes for the Rio Grande Basin by region and for the rest of the state is presented in Table 11. The Rio Grande Basin comprises 54% of the total miles of trout streams in New Mexico but only 29% of the miles of warm water streams. Lakes and reservoirs in the Rio Grande Basin account for 52% of the total acreage availability in the state of New Mexico. Within the Basin, 87% of the lakes and reservoirs are located in the Lower Rio Grande region.

Table 11. Estimated recreational availability of stream and lakes, by region, Rio Grande region, New Mexico

Region	Miles of Stream: Trout Stream	Warm Water	Total Miles	Acres of Water in Lakes and Reservoirs [1]: Fishing Only	Combined Use	Total
	- - - - miles	- - - - -		- - - - - acres	- - - - -	
1. Upper	685	-	685	1,443	3,600	5,043
2. Middle	325	105	430	199	2,350	2,549
3. Socorro	5	100	105	2	-	2
4. Lower	34	182	216	28,095	23,734	51,829
5. Rest of State	892	952	1,844	20,345	35,356	55,701
Total	1,941	1,339	3,280	50,084	65,040	115,124

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[1] Maximum supply available at spillway.

Water Management

Management of water and related lands involves several federal and state agencies, municipal and county governments, irrigation districts, conservancy districts, and innumerable private entities. The New Mexico statutes provide for the formation of irrigation and conservancy districts which are in cooperation with the United States. Once a district is formed it is a legally stable institution with broad powers to perform the purposes for which it was organized. Irrigation and conservancy districts are able to borrow money, tax lands for the indebtedness, and charge for the water they deliver.

Since the early 1900's, surface water irrigation in the Rio Grande Basin in New Mexico has been under the jurisdiction of irrigation districts, conservancy districts, and community ditch systems. The principal organized districts in New Mexico are as follows:

District	Year Formed	Acres Served
Llano Irrigation Company	1915	
Santa Cruz Irrigation District	1925	2,110
Middle Rio Grande Conservancy District	1925	81,610
Bluewater-Toltec Irrigation District	1923	5,500
Elephant Butte Irrigation District	1917	90,640

In addition to the above, there are more than 400 community and private ditch systems on the main stem and tributaries of the Rio Grande. The acreages served by these individual ditch systems vary in size from a few acres to over 200 acres.

Most of the surface-water irrigated cropland in the reach above Otowi Bridge (see Figure 2) is served by community irrigation ditches, one small irrigation district (Santa Cruz), and one small irrigation company (Llano). The area of Otowi Bridge to San Marcial, excluding tributaries, comprises the Middle Rio Grande Conservancy District. This district is divided into four divisions: Cochiti, Albuquerque, Belen, and Socorro. In addition, the district furnishes surface water to the Indian Pueblos of Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta.

The Middle Rio Grande Conservancy District has contracted with the Bureau of Reclamation to maintain and operate the system which consists of 180 miles of main canals, 587 miles of laterals, and 399 miles of open and concrete pipe drains.

The Bluewater-Toltec Irrigation District in western Valencia County is the only irrigation district in the tributary units in the middle reach of the Rio Grande. Most of the irrigation water of the district has been leased to uranium companies. The remaining surface-water-supplied land receives water from community ditches.

Nearly all of the surface-water-irrigated cropland below San Marcial is served by the Elephant Butte Irrigation District. However, there are several small community irrigation ditches serving small scattered acreages. The Elephant Butte Irrigation District is divided into two divisions, Rincon and Mesilla, for operational purposes. The District has contracted with the Bureau of Reclamation for maintenance and operation of the district. The project includes some 348 miles of distribution system and about 235 miles of land drains.

The management of the ground water resource in the Rio Grande drainage basin is primarily a private entity function. However, the New Mexico State Engineer can control the use of ground water in an area by defining and declaring an underground water basin. Nearly all of the irrigated cropland in the Rio Grande Basin above Elephant Butte Dam is in a declared ground water basin with only isolated tributary units outside of these basins (Figure 2). Therefore, the development of ground water is under the jurisdiction of the New Mexico State Engineer. The region below Elephant Butte Dam has only two small declared underground water basins, Animas and Hot Springs.

CHAPTER III

METHOD AND PROCEDURES

An interdisciplinary approach to the solution of the water resource problems of the Rio Grande region in New Mexico was made possible by the integration of hydrology, geology, and engineering with economics. Research procedures developed to carry out this study were closely coordinated by the investigators to achieve the stated objectives. Inputs into the socio-economic model were obtained from separate studies covering the hydrological, agricultural, municipal, and industrial areas.

Socio-economic Model

The socio-economic model is essentially a linear programming model designed to represent the New Mexico economy with special emphasis placed upon the Rio Grande region. It consists primarily of an input-output table of technical coefficients for five regions (four of which are within the Rio Grande region and one encompasses the rest of the state) and a set of constraints placed upon each region's set of predominantly water-connected resources.[1] These constraints include:

(1) Recreational resources available
  a) Water skiing
  b) Boating
  c) Fishing
(2) Water resources available
  a) Surface supplies
  b) Ground supplies
  c) A combination of both
(3) Pollution carrying capacities
  a) Biological oxygen demand (BOD)
  b) Total dissolved solids (TDS)
(4) Human resources available
  a) Labor force
  b) Population types

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[1] *A detailed formulation of the model is presented in Appendix A.*

The year 1967 was chosen as the base year for the coefficients in the model because it was the latest year for which output figures on a statewide and county basis could be derived.

Model description. A mathematical programming model incorporating interregional input-output coefficients for the production sectors of the economy and social and environmental impacts of the production sectors was developed. The model incorporates the outputs of the individual subinvestigations in the Rio Grande study and is utilized to project future water use patterns and economic development under alternative legal, institutional, social, and environmental assumptions.

An optimal solution of the model for a given set of economic and demographic conditions can be obtained by maximizing the model's objective function. Each production sector in each region contributes to the total value added according to its level of production, while negative impacts on the environment, such as water pollution, or on the labor force, such as unemployment, impose a cost to the system. The optimal solution will provide the optimal mix of production sectors and their geographical distribution which satisfies the state's final demands and resource availabilities while internalizing the environmental and social effects.

A major component of the model is the interregional input-output model developed for this study utilizing the 1960 New Mexico State Input-Output Table developed by the New Mexico Bureau of Business Research and the 1967 state outputs. Regional I-O tables were derived from the state table for the four Rio Grande regions and for the rest of the state. Transactions among the five regions were calculated in order to derive the interregional input-output table.

The classification of major sectors within New Mexico's economic description used the 1960 I-O study's breakdown which included 50 sectors. The original 50-sector model was then aggregated into a 24-sector matrix for each region (Table 12). The aggregation became necessary for two main reasons: 1) There was a lack of reliable secondary sources from which a good analysis could proceed with all 42 private sectors per each region; and 2) the logistics problem and the time required

Table 12. Definition and classification of production sectors

Production Sector	1960 I-O Study	Major SIC Codes	Production Sector Description
Agriculture			
1	1,2		Meat animals, farm dairy products and poultry
2	3		Food grains and feed crops
3	4		Cotton and cottonseed
4	5		Vegetables, fruits and nut trees, miscellaneous food products
5	6	7	Agricultural services
Mining			
6	7,8,11,12	10,12,14	Metals and non-metals
7	9,10	13	Crude petroleum and natural gas, oil and gas field services
Manufacturing			
8	13	201	Meat packing and other meat products
9	14	202	Dairy products
10	15	204,205	Grain mill and bakery products
11	16	remainder of 20	Miscellaneous food products
12	17,21	24,25,32	Lumber and wood products, concrete and stone products
13	19,20	28,29	Chemicals and petroleum refining
14	22,23	19,34,35,36,38, 371-373	Electrical machinery and equipment, scientific instruments, fabricated metal products
15	18,24	22,23,27,31,39	Printing and publishing, miscellaneous manufacturing
Transportation Communications Utilities			
16	25,26	40,41,42,45,47	Railroads and all other transportation
17	27	46,4924	Gas and oil pipelines
18	28,29,30	48,49	Communications, electric and gas utilities
Trade			
19	31,34	50,52,53,54,56,57,59	Wholesale trade and most retail trade
20	32,33	55,58	Retail auto dealers and gas stations, eating and drinking places
Finance, Insurance, and Real Estate			
21	35,36	60,61,62,63,64,65,67	Finance, insurance, and real estate
Services			
22	37,38,39,40	70,72,73,75,76,78,79	Hotels, motels, personal services, business services
23	41,42	80,81,82,88,89,37(p)	Medical and professional services, research and development
Construction			
24	47	15,16,17	Contract construction

to assimilate all the necessary data would be exorbitant and would make any economic analysis and policy implications take a secondary priority.

Aggregation of the sectors into a 24-sector matrix was based primarily on three criteria. First, the procedure accounted for labor skill patterns among the original sectors and attempted to insure whole and comparable SIC codes. Second, water use patterns and similarity in water coefficients (national studies) were relied upon to aggregate. Third, a similar set of input structures was strived for in the aggregation process.

The objective function (see Appendix A) is constructed to maximize value added within the state subject to several separate cost components. Typically, value added per unit measures the payment to households as wages, payments to governments as taxes, and payments to business as profits. The goal, therefore, is to maximize this "net addition" to the state. The cost components serve as mechanisms to encourage the system to use as little as possible of the "resources" that these cost components reflect.

One cost component puts a high price in the initial model on generating recreation capacity in a region. This serves to minimize any building of recreational facilities to satisfy demands until all present resources are utilized and maximum transfers have taken place. Another cost component serves to place a price on the system upon "transferring" recreational capacity. This cost is less than the cost associated with generating new capacity; however, a cost still exists because there is a certain decrease in use if one has to travel to other regions to use facilities.

An additional cost component assigns a price to the system of cleaning up the streams once the standards have been violated. Therefore, there is a cost assigned to the system for exceeding the pollution-carrying capacity of streams. Another cost component is assigned to transferring pollution-carrying capacity among the regions. This cost, as in recreation, is less than the cost of cleaning up a region's stream.

The cost varies depending on several stream flow characteristics and the actual point of pollution within one region in relation to another region.

A further cost component places a price upon the transfer of surface water from one region to another. There is a definite loss or gain of water when its use is transferred between regions; there is a loss of pollution-carrying capacity and recreational use to the region doing the transferring. In addition, legal constraints and costs exist within any transfer mechanism. Therefore, a cost is assigned to the system for transferring this important resource from region to region.

The cost assigned to the system for "allowing" unemployment within a region becomes another component. Unemployment insurance, welfare payments, etc. are just a few of the elements considered in the cost to the state as a whole.

There is a definite price charged to the system for any additional water made available for use within a region. This availability could be water salvage, intrabasin purchases and transfers, purchases of ground water supplies, or the acquisition of water rights. These will all have a price which is an additional cost component. If labor is needed from outside the system, an extraordinarily high price is charged for acquiring such labor. The price is assigned so that no labor should be purchased unless mistakes have been made in calculating labor use and coefficients initially.

The objective function is thus concerned with maximizing value added, subject to the following costs:

(1) Under-utilization of the labor force (unemployment)
(2) Transfer cost
  a) Pollution-carrying capacity of a stream
  b) Excess recreation capacity
  c) Excess water
(3) Maintaining stream standards
(4) Creating additional recreational use capacity
(5) Adding additional water to each region
(6) Transferring additional labor to the system

The actual value of the objective function is not really important: only the relative differences when various transfers, movements, and additions of resources are used in solving the model. In addition, differential pricing in the cost components can be considered and weighted by using the mechanism of the objective function to assign relative weights to all activities.

Model components. Results and interpretations from the socioeconomic model are only as good as the assumptions within the model and the reliability of the basic input data. Consequently, a major proportion of the time and effort of this study went into the preparation of the basic hydrologic, agricultural, and economic data.

Hydrologic Data

Before an economic evaluation of water use can be made, the availability of surface water and trough water must be determined. Within the trough of the Rio Grande Valley there is a continual exchange between the surface water of the river and the ground water of the surrounding alluvium. Therefore, a model of the exchange of ground water and surface water is necessary if a good description of the pumping effects is desired. In addition, the diversions and depletions must be known in order to have a reliable model.

Surface water availability. Surface water availability could be determined from water use records. However, detailed water use records are not available and they are expensive to gather. Consumptive use data are scarce, but it is recognized that nearly all of the beneficial consumption of surface water in the Rio Grande region can be charged to agriculture. Therefore, if a reliable estimate of the surface water consumption by irrigated agriculture can be made, then surface water availability can be estimated.

The surface water availability, excluding nonbeneficial uses, river channel losses, and reservoir evaporation, within a region was determined by adding the flow out of the region to the estimates of the quantity of water depleted by irrigated agriculture. The quantity of water depleted by agriculture was estimated using the quantity of irrigated acreage, the type of crops, and the consumptive irrigation requirement of each crop. In addition, estimates of incidental depletion for agricultural uses were made. The flow out of the region was the average flow at a gaging station for the calendar years of 1958 through 1968. This period of record was chosen because it avoids major droughts and floods and because it reflects the present water management practices on the Rio Grande.

It cannot be assumed that available water within one region can be passed intact to another region. Natural conveyance and evaporation losses will deplete a transfer of water between regions. Thus, water transfers between regions must be adjusted in varying proportion to the quantities transferred.

Ground water availability. In the Rio Grande region there exists an intimate relationship between surface water and ground water, and, therefore, ground water availabilities are not simply related to pumpage but are also controlled by precipitation, amount and frequency of runoff in streams, return of irrigation water, and evapotranspiration. The management of such a system should be based on a conjunctive operation of surface and ground water.

For a comprehensive alternative water use analysis it is necessary to know both the ground water availability and the behavior of the aquifer under projected stresses. Since historical records of the hydrologic system, in most instances, are inadequate to permit direct analysis of Basin behavior under projected stresses, it was decided that a ground water system simulator be developed. The most efficient and practical simulator for this study appeared to be a mathematical analogue of the hydrologic basin, solved by digital computer. Such a hydrologic system can be schematically represented as in Figure 4:

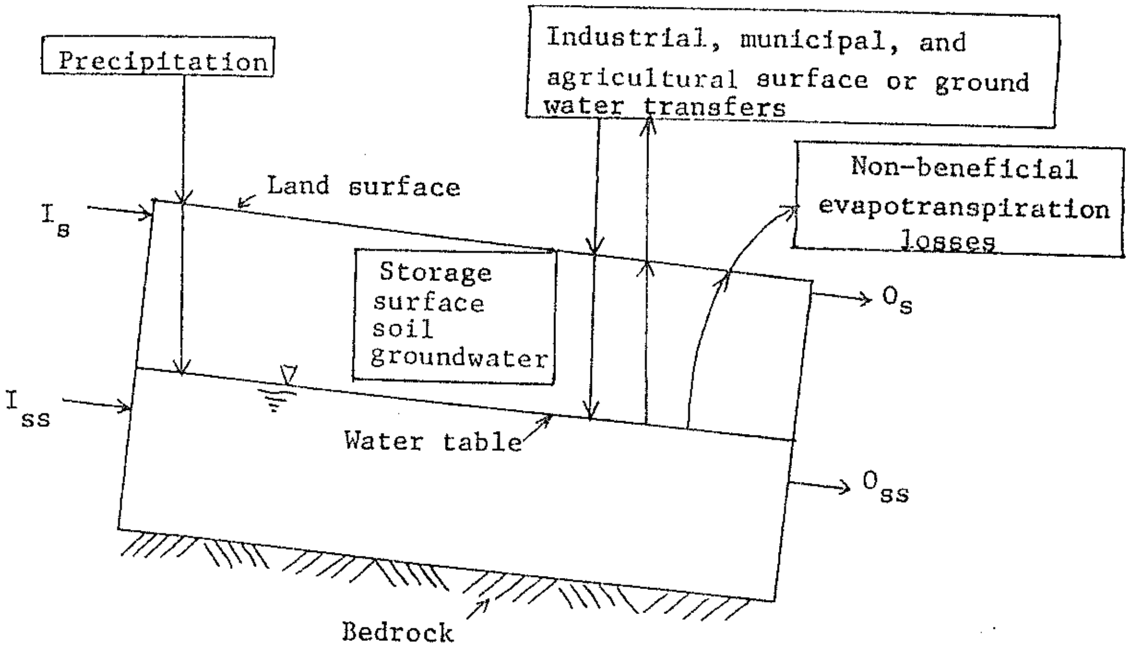

Figure 4. Schematic of hydrologic basin.

In this Figure, I = inflow, O = outflow, and the subscripts s and ss, respectively, stand for surface and subsurface. Figure 4 is simply a representation of the statement of continuity: i.e., the conservation of mass which is the basis for developing the fundamental flow equation or mathematical analogue which is written as:

$$\frac{\partial}{\partial x}\left(Kh\frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(Kh\frac{\partial H}{\partial y}\right) = S\frac{\partial H}{\partial t} + \frac{Q}{\delta x \delta y} \qquad (1)$$

where K = hydraulic conductivity; h= saturated thickness: H = water table elevation (total head) above datum; S = effective porosity (storage coefficient); Q = net withdrawal rate from aquifer; x, y = space dimensions; t = time dimensions; δx, δy = surface area of element.

The above equation is a nonlinear partial differential equation obtained by combining Darcy's law with the continuity principle and is applicable to transient, two-dimensional flow in heterogeneous, anisotropic, incompressible, unconfined, saturated, porous media.

Implicit finite differences are utilized to solve equation 1 on a digital computer. The resulting system of simultaneous equations is either solved directly by Gauss-Elimination or by Line Successive Over Relaxation, depending upon the size of the problem: i.e., number of equations.

The first step when applying the model to a particular study area is to verify or calibrate its behavior. This verification consists of simulating a historical period, for which both ground water levels and stream records are available, until model and prototype match. Checking and updating should be continued as more data become available.

The next step is the simulation (or extrapolation) of future possible conditions. Conditions can be altered to give different responses. For this study a series of cases for each subbasin was run which simulated conditions from extreme dry to extreme wet combined with a set of water demands ranging from large to small.

A vast amount of data is thus obtained in the form of aquifer responses for given conditions. Realizing that these data are the result of the solution of a continuity equation of the form

$$I - O = \Delta S / \Delta t \qquad (2)$$

it is possible to estimate an analogous relationship from the data obtained. In equation (2) I = inflow, O = outflow, and ΔS = change in storage during a time period Δt. The relationship postulated was of the following form

$$\Delta d = f(d_n, L) \qquad (3)$$

where Δd = change in water-table elevation for the time period (year) considered, d_n = water elevation at the end of previous time period (year), and L = a lump factor combining surface water inflow and outflow, precipitation, and beneficial and nonbeneficial water uses.

Results of the simulation runs were tabulated with averaged spatial responses: i.e., results do not reflect a variation in water-table elevation along lines perpendicular to the river bed. It was felt that average conditions per subbasin would suffice for the purpose of this study and, hence, that lateral aquifer response could be averaged out.

A stepwise multiple regression analysis, combining linear and nonlinear (exponential and logarithmic) terms of the different factors involved, was performed. The equations obtained, with their graphical representation for each subbasin, are presented in the hydrology section of Chapter V.

Ground water availability in the socio-economic model for the four subregions within the RGRB was assumed to be unlimited in the period of analysis. It was felt that with the tremendous storage in the aquifer, the relatively short time span of analysis (50 years), and the intricate relationship of the ground and surface waters, especially in Regions 1 (Upper), 2 (Middle), and 3 (Socorro), that this assumption would not significantly affect the results or inferences of the model. Built into the model was the effect of time and increased pumpage on surface water flow or availability. Each year the pumpage from ground water will decrease surface flow due to either or both of the two following reasons: 1) decreased flow from ground to surface from the reduction in the ground water-table gradient; 2) increased flow from the surface supplies to the ground water aquifer or table.

In Region 4 (Lower) ground water availability was also assumed to be unlimited during the 50-year period of analysis. The relationship between ground and surface waters is not the same as those in Regions 1, 2, and 3, but this was allowed for in the ground-surface model described above. This relationship was used to develop pumpage effects on river flow for the socio-economic model. The agricultural irrigation system in Region 4 is well controlled, and thus pumpage through time has a fairly small effect on river flow in comparison to the other three Regions. Municipal and industrial pumpage at this time represent only about 13 percent of total gross pumpage in the region. As pumpage from these sectors in time increases, this particular portion of gross pumpage will have an increasing effect on river flow.

Water Diversions and Depletions

Knowing the quantity of water used in the Rio Grande region for the many various purposes was important before evaluating alternative uses. The diversions and depletions of water by the four major water-using sectors, agricultural, municipal, industrial, and recreational, were determined for each of the Rio Grande subregions.

Agricultural. Irrigation water in the Rio Grande region comes from both surface and ground sources. Ground water is used primarily to supplement the surface source, but is the only source for about 17,380 acres of irrigated cropland in the region.

The Rio Grande region was divided into four subregions. These subregions were further divided in each case to facilitate the reporting of the information on irrigation water diversions and depletions.

Since records of ground water pumpage were not available, a theoretical approach was used for their determination. A technique developed by Blaney and Criddle (1962), known as the Blaney-Criddle formula, was used to determine the consumptive irrigation requirements for the region. This formula has been used extensively in New Mexico and is considered to provide reasonable estimates of water use.

Briefly, this procedure was developed by correlating measured consumptive use data with monthly temperature, monthly percentages of yearly daytime hours, precipitation, and growing or irrigation season. The coefficients thus developed allowed for the computation of consumptive use of each crop if the monthly temperature, the latitude, and the growing period of the crop were known, and if the computed monthly percent of annual daytime hours was available. After total consumptive use was computed, the net amount of irrigation water necessary to satisfy consumptive use was found by subtracting the amount of effective precipitation from the total consumptive water requirement. This net requirement or consumptive irrigation requirement for any period divided by the irrigation efficiency results in the irrigation requirement of the crop for that period.

To provide the climatological data necessary, 19 weather stations were selected as representative of the climatic conditions in specific irrigated agricultural areas in the Rio Grande region. Monthly temperature, precipitation, percent of annual daytime hours, and the latitude for each station were used with the acreages of each crop, consumptive use coefficients, and crop growing season in a computer model developed to arrive at the per-unit consumptive use, consumptive irrigation requirement (CIR), and irrigation requirement (IR). The total consumptive irrigation requirements and irrigation requirements for each region were computed by multiplying acreages by CIR and IR.

This method thus provided the theoretical total water consumption by irrigated agriculture. Surface water delivery data were obtained from the Bureau of Reclamation for the two large surface water districts and were estimated for the remaining smaller community and private systems. The surface water deliveries were then subtracted from the total irrigation requirements to arrive at an estimate of the ground water pumpage.

In some areas of the Upper Rio Grande region the total irrigation requirement was modified to reflect a less-than-full water supply situation. These values were developed for comparison purposes only and should not indicate that these areas actually required less water for comparable crop production, since in most cases the crop condition reflected the shortage.

Municipal and rural domestic. Water use estimates for both diversions (new water intake) and depletions (consumptive use) were made, utilizing data from the State Engineer Office and the Bureau of the Census. Their estimates are on a per capita basis and adjustments were made to reflect only the actual withdrawal by the urban population.

Industrial. Estimates of production diversion and depletion per unit for industrial water originated from several sources. The manufacturing sector estimates were calculated using national data and averages based upon SIC code classifications (Census of Manufacturers). For each sector within each region a weighted national average was used in estimating the coefficients. For the mining sectors, the coefficients were derived by using Stotelmeyer's (1962) total water use estimate in 1962, and weighting them based upon each region's portion of the total mineral production within the state. Oil and gas production estimates were made also, using the same report and method. The remainder of the sectors' coefficients (consisting of primarily trade and related services) were derived from several studies made by other states (California, Utah, and Arizona). It was assumed in the construction of the model that there was no difference among each region's water use coefficients per unit of output in the mining, manufacturing, trade, and services sectors.

Recreational. Consumptive use by reservoirs for recreational activities within each region were estimated by using evaporation rates and surface acres for various months of the year. In New Mexico very few reservoirs maintained primarily for recreational use exist. Almost all dams and reservoirs were constructed for irrigation, power, or flood control and sediment abatement purposes. However, where reservoirs do have great recreational use and activity, evaporation estimates were made and entered under the recreation consumptive use heading.

Recently, several permanent pools have been established (still on paper), and the evaporation loss directly attributable to recreation will play an increasing role in water resource use and development.

Agricultural Data

The evaluation of the land resources of the Rio Grande region was concerned primarily with the irrigated cropland because of the importance of the irrigated agriculture sector to the region's economy and because irrigation water use accounted for approximately 90 percent of the water used within the region. There were over 280,000 acres of irrigated cropland in the drainage basin in 1970, utilizing over 750,000 acre-feet of irrigation water. To evaluate the potential for any change in the irrigated agriculture sector it was necessary to evaluate irrigable land potentials within each region and to specify potential areas of growth and/or decline. The land resource evaluation was made from two approaches. The first was an economic classification of the irrigated cropland, and the second was an inventory of the crop acreages and cropping patterns.

The economic classification of the irrigated cropland in the Rio Grande drainage basin within New Mexico was based on the Cornell system of economic land classification and previous studies conducted in the state, specifically the Pecos River Basin (Lansford et al., 1970). Through the use of soil quality, water quality and quantity variables, and other economic indicators, maps were constructed to show geographically localized differences in income expectancies within the Rio Grande Basin. The Cornell system of economic land classification and the procedures developed in the Pecos River Basin studies provided an effective base for an attempt at forecasting farm income expectancies. Due to the nature of the variables chosen and incorporated into the study to indicate future income expectancies, it was necessary to supplement the knowledge of the economist in areas such as agronomy, geology, hydrology, and water-use law.

Soil Data

A base map was drawn showing the location of the irrigated cropland acreage. Soils with the same characteristics were designated on the map by means of SCS soil survey symbols. A further designation was made according to the SCS capability classification for each of the different soils. It was considered desirable for purposes of this study to group the soils in such a way as to reflect differences in productivity, managerial requirements, and responsiveness to intensive cultural practices. After consulting with SCS personnel and county agents, and interviewing farmers, the soils were assigned to one of three groups depending on the degree of limitation of the above characteristics. A productivity index was used to reflect 100-percent expected yields of eight major crops produced on these different soils. Group I soils were considered to be those with only slight, if any, limitations; Group II, those with moderate limitations; and Group III, those with severe limitations. Such a grouping was considered to reflect the long-run economic potential of different soils in the basin. A detailed description of the soils is given in Appendix B.

Water Data

Technical reports from the State Engineer Office, U. S. Geological Survey, Bureau of Reclamation, and irrigation districts provided basic data concerning irrigation water source, quality, quantity, legal requirements, and irrigated acreage. State Engineer and U. S. Geological Survey reports and data were used primarily to determine the source. The source of irrigation water was considered to be important to the economic classification from the standpoints of cost of diversion, quality of the water, and dependability of the supply.

Water quality. Quality of water is important in irrigated agriculture. The more dissolved solids a water contains, the less suitable it becomes for use as irrigation water. In general, the higher the concentration of salts, the greater the excess of water that must be applied to the crops in order to keep the concentration of dissolved salts in the soil moisture within satisfactory limits. Generally, when water of inferior quality is used for irrigation, crop selection is restricted either to salt-tolerant crops such as cotton and barley or moderately salt-sensitive crops such as alfalfa and most vegetables with frequent heavy irrigation (Dregne, 1969).

Results of a study by Dregne and Maker (1954, p. 6) indicated that the chloride ion is the most common anion in well waters in New Mexico. The chloride ion has a directly toxic effect on some plants, aside from its effect on the salinity of the soil solution.

Ground-water quality data used in this study were obtained from various U. S. Geological Survey reports and from reports and chemical analysis of the U. S. Bureau of Reclamation observation wells.

The quantity of soluble salts and the proportion of sodium were considered the most important factors that affect the quality of the ground water in the basin. Basler and Alary (1968) noted that environmental factors (distance to drains, canals, laterals, etc.) influence the quality of the shallow ground water in the area. The complexity and variation from area to area are such that the quality of the shallow ground water cannot be attributed to a single source.

The quality of the ground water was indicated primarily by the chemical analysis of a few select wells located throughout the basin, which allowed only a generalized analysis of the ground-water quality. Data available on the ground-water quality in the basin were expressed as electrical conductivity in terms of specific conductance (micromhos at 25° C) and allowed the calculation of, or reported, the sodium adsorption ratio (SAR). Since the salinity hazard was important throughout the basin and the sodium hazard in certain areas, the combination (salinity-sodium hazard) was considered as a reliable and satisfactory indicator of the ground-water quality.

Surface-water quality was considered an important factor in the economic classification, since surface water constitutes a large portion of the total water used for irrigation in the basin. Until recently, most of the irrigated lands were served from surface-water sources. Conover (1954) noted that only 11 wells were pumping in the Lower region below Elephant Butte Reservoir in 1946. The number of wells increased rapidly after 1946. Presently, it is estimated that over 90 percent of the cropland in the Socorro and Lower regions receive supplemental water from wells owned and operated by the landowners themselves.

These generalities about the quality of the Rio Grande and the various drains and canals in the valleys were used as guidelines in the development of the water quality classification.

On the basis of the salinity-sodium hazard, the ground and surface water was grouped into one of three classes, (Table 13). The combination of the ground and surface water classifications resulted in the following categorization. Class I water was considered suitable for use for most crops under most conditions. Class II water was considered satisfactory for most crops if proper management practices were used. Class III water was considered unsuitable as a primary source, but suitable as a supplemental source of water if the primary source was of better quality.

Water quantity. Quantity of water was used primarily to refer to the general availability of surface water and to changes in the ground-water level in the basin. Changes in the ground-water level were

Table 13. Criteria for determining preliminary economic land classification designation, Rio Grande Basin, New Mexico

Soil Productivity		Water Quality			Water Quantity		
					Amount		
Group	Soil Survey Classification (Capability Class)	Electrical Conductivity (EC x 10^6 at 25°C)	Sodium Adsorption Ratio (SAR)[1]	Class	Surface	Ground	Class
I	I	0 - 750	0 - 18	1	2.5 or more acre-feet per acre	less than 5 feet decline	1
II	II	750 - 2250	18 - 26	2	1.5 to 2.5 acre-feet per acre	5-10 feet decline	2
III	III and IV	more than 2250	greater than 26	3	less than 1.5 acre-foot per acre	greater than 10 feet decline	3

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[1] $SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$

determined from U. S. Geological Survey reports. The information was primarily in the form of periodic measurements of observation wells located throughout the region.

The quantity of water pumped from the ground-water source was considered important to the economic classification, since in most cases the ground water is lower quality than the surface water. Information on the amount of ground water pumped for irrigation was not available. Consumptive irrigation requirements based on the 1969 cropping pattern in the basin were used to determine the total quantity of irrigation water required.

The quantity of surface water delivered to the irrigation districts has varied from years of "shortages" to years of "full-supply." These shortages, in general, were distributed evenly among the farms in the districts and were primarily not localized problems or limitations. This limited the use of surface-water quantity aspects of the basin to a more generalized nature. The amount of surface water available to the lands in the irrigation districts was obtained from the Bureau of Reclamation.

The water quantity classification was developed from the information available on the changes in the ground-water level and the surface-water availability. The classification criteria are reported in Table 13.

Class I indicated only minor limitations regarding income expectancies as they are reflected by receiving less than maximum economic yields from surface water and by increased pumping cost due to increased depth of lift with pumped water. Class II indicated the possibility of reduced cropped acreage on farms or reduced yields with surface water; and the possible need to lower pumps; and in some areas, increased likelihood of decreasing water quality in the ground water. Class III reflected the probability of both leaving parts of farms fallow and experiencing reduced yields with surface water; and the necessity of lowering pumps or greatly increasing the potential of reduced water quality.

Other Data

Information was compiled on various factors considered to affect the income-producing potential of the land in the basin which was considered necessary to make the judgment decisions. For purposes of this study these factors were referred to as "Economic Indicators." These economic indicators were divided into the following four categories according to their characteristics.

Historical data. Cropping patterns, crop acreages, yields, farm size, and values of production were obtained from various sources within the Rio Grande region.

Enterprise budgets. Budgets were constructed for the more important crops in the basin. These budgets were developed in different areas, and farms selected for interview were chosen on the basis of their soil, water quality, and water quantity conditions. Thus the enterprise budgets were designed to show the extent and effect of differences in the major variables: soil productivity, water quality, and water quantity.

The measure of profits used in constructing the enterprise budgets was net return to land. Net return to land does not include interest charges on the land investment and operating capital, but a charge is made for all purchased inputs such as seed, fertilizers, insecticides, herbicides, etc.; labor; fuel and repairs for machinery and equipment; and fixed machinery equipment costs consisting of depreciation, interest on investment, taxes, insurance, and shelter.

Farmstead and equipment. Characteristics of the farmstead and equipment were considered in the field survey. Differences in such factors as appearance of the farmstead, type and condition of equipment and irrigation system, and condition of the growing crops were noted.

Urban encroachment. Urban encroachment was considered an important factor in the area. Most of the farmland of the basin is located in a relatively narrow strip adjacent to the Rio Grande. The potential for expanding irrigation outside of this area within the basin is limited by a lack of water and by economic restrictions rather than by a shortage of suitable soils (Maker et al., 1971a, 1971b, 1972a, 1972b).

Much of the growth of cities and towns has been at the expense of the irrigated cropland. Inspections of aerial photographs for the late 1930's and early 1940's and the mid-1960's were made concerning the patterns of urban encroachment. These patterns were projected for the future in estimating areas which may go out of agricultural production.

In order to relate this factor to the economic classification, the irrigated cropland in the basin was grouped into two primary categories. Group I cropland was not considered to be affected by urban encroachment in the foreseeable future; Group II was cropland on the fringes of the communities and along the main transportation routes which was expected to be affected by urban encroachment in the immediate future. Cropland which did not fall into either of the two categories was considered stable with respect to urban encroachment. The Group I and Group II areas were assigned a plus or minus, respectively, which was used to modify the preliminary classification map with respect to urban encroachment.

Relationship of the Variables

The information available for the water quality and water quantity variables in the basin was limited to information of a general nature, as pointed out previously. This limited its use in the classification to a more generalized sense in which the water quality and water quantity information developed was used to modify the soil productivity map. The combination of the soil productivity, water quality, and water quantity variables resulted in a preliminary classification which delineated those areas in the basin with slight, if any, moderate, or severe limitations of the primary variables. The criteria used for designating the land areas as Economic Class I, II, or III for this preliminary classification are presented in Table 13. This preliminary classification resulted in an "ideal" classification, but in cases where the particular combinations did not result in an ideal classification, a plus or minus was assigned to the resulting designation. It was not uncommon for certain land areas in the basin to appear as marginal to one category or another. In such cases the colored slides made during the field survey were used to verify decisions regarding the category into which such lands should be placed. In other cases it was necessary to make field rechecks of certain areas. This preliminary classification map was then modified according to the economic indicators collected for the area. To modify the preliminary classification map, the historical data on cropping patterns, crop acreages, yields, farm size and values of production, the enterprise budgets for the more important crops in the basin, the farmstead and equipment characteristics, and the urban encroachment groups were used.

Population and Employment Data

Population figures and coefficients were obtained from the U. S. Bureau of Census for the years 1950, 1960, and 1970. Population figures for the Rio Grande region were derived by utilizing enumeration districts that corresponded most closely to the drainage area boundaries. The distribution percentage and changes in both the basin (partial counties only) and the region (whole counties where the majority of each county is within drainage area) were calculated from the reported population.

Employment data were derived from the data published by the Employment Security Commission (NMESC). Although on a statewide basis the information is fairly detailed, figures for counties are limited due to disclosure laws and regulations. The NMESC data was supplemented by unpublished data. A coefficient was derived for all 24 major sectors within each region, including estimates for the governmental, non-agricultural, and miscellaneous service sector. Both NMESC and Bureau of Census data were used to develop the past and present labor force make-up in the description of each region.

Recreation Data

Three primarily water-related recreation activities were incorporated into the socio-economic model. These activities are: 1) boating,

2) water skiing, and 3)fishing--both warm and cold water (no differences between the two were assumed for the demand or supply analysis).

Each person in New Mexico will demand a certain number of activity occasions in any or all of the above three activities during a year. Demand can be used in two different contexts: one is the concept of actual participation and the other is the concept of desired participation. Both concepts have been utilized in recreation demand studies in various parts of the country. Due to the detailed breakdown required for the mathematical programming model, the ORRRC study report #19 entitled "National Recreation Survey" was used to develop the coefficients. That study used demand in the "desired" sense, which implies that not all of this demand would be realized in actual use for every time period for every area of the country. It does, however, assign a "welfare" criteria to each person involved.

The concept of desired demand was used in the ORRRC study for two reasons. One, by assigning a "welfare" concept to recreation demand, it puts a premium on one part in the quality of life make-up. Two, it serves as a realistic maximum that could be assumed when trying to estimate present and future water-based recreation demand. The national study took 1960-61 as its base year for interviews, sampling populations, and then correlation to the whole population. The country was divided into appropriate quadrants and a separate analysis was performed for each portion. Also, for further differentiation and detail the population was broken down according to job classification (U. S. Census breakdown). Further, the analysis broke the demand into seasonal components.

For this Rio Grande study, each particular production sector within the socio-economic model has certain types of job skills associated with the employed labor force within the sector. By using SIC classifications and their descriptions of job skills involved (correlating them closely to the national study's classification), estimates were made for each sector's employment of the demand of activity occasions within each season for the three recreation activities involved in the model. By using interpolating techniques and percentage distributions where necessary, a "demand" coefficient per person employed was developed by each sector for each of the five regions used in the model.

The national study was based on the implicit assumption that only persons 12 years of age and older were used in the sampling and whole populations. Thus for each region in the model, a population of 12 years of age and over was extracted out of the 1970 census. This figure was assumed to closely approximate the actual 12 years of age and over population for the year 1967 (the base year for the analysis). An average family size of persons 12 years of age and over was then calculated for each region by dividing the pertinent population figure by the employment for each region (ESC definition of employment). The "demand" coefficient for employed persons in each of the production sectors within each region was then multiplied by the average family size of persons 12 years of age and over to incorporate all the appropriate population into the model. One further step was taken to put the coefficients in terms of activity occasions demanded per million dollar unit of output in each particular sector by season (summer vs. winter).

Within the model the recreation seasons were defined to correspond with the agricultural seasons in the various regions:

Region 1 (Upper) - Summer: April - October (212 days)
Winter: November - March (153 days)
Region 2 (Middle)- Summer: March - October (243 days)
Winter: November - February (122 days)
Region 3 (Socorro) Summer: March - October (243 days)
Winter: November - February (122 days)
Region 4 (Lower) - Summer: March - November (273 days)
Winter: December - February (92 days)
Region 5 (rest of state) - Summer: March - October (243 days)
Winter: November - February (122 days)

All employed persons and their families were accounted for in the above procedures, but a slightly different method was needed to estimate the demand for recreation of the unemployed and their respective families in the model. An average of the 24 production sectors in each region was used to calculate the coefficient for each unemployed person. The three service sectors were correlated as closely as possible with the national study's breakdown for these categories.

Thus far the initial demand coefficients for every person 12 years of age and over for each region have been taken care of by tying these to employment, family size, and units of output (based on number of employed in each production sector) to the production sectors. The national survey was made for the years 1961-62. For the purpose of the present study it was assumed that the derived coefficients represent an upper limit of the present available water resources, make-up of the population, and previous use figures in the activities for the state as a whole. Therefore, these particular "demand" coefficients for all categories were assumed to remain the measure of future demand for the period of analysis under consideration in the model. The model is so developed as to allow discreet changes in the "demand" coefficients for analysis in certain periods of the future if the information and data become available.

The supply side of the recreation sector is much more difficult to evaluate. Surveys and studies have been conducted in the past, ranging anywhere from accounting procedures of actual use to an estimated use based upon demographic and population figures for the surrounding area. For the purpose of this study it was decided to develop maximum and probable use criteria, and then apply them to the inventory of water-based resources for each region.

When undertaking the initial development of the use criteria, New Mexico did not have any published or official use standards for its water resources. Therefore, many studies and publications by other states were reviewed in order to develop appropriate measures for New Mexico, and considerable weight was given to the standards of adjoining and similar states.

In the development of final use criteria, the inventory of water resources (suited for the three water-based recreational activities used in the model) came from several state sources: primarily the State Game and Fish Department, the Department of Parks and Recreation, and the State Planning Office. The estimated regional inventory is presented in Chapter II, Table 11. The combined acreage is assumed to be available to all three activities, with water skiing and boating dominating the use.

The use criteria or standards used for this study were as follows:

1) Boating - 1.67 acres of water per activity occasion per day (three people per boat).
2) Water skiing - 2 acres of water per activity occasion per day.

The total surface acres in the combined category were assumed to be used primarily by boating and water skiing, with fishing being the least intensive user of the same combined surface acres. The surface acres were evenly divided between boating and water skiing. The standards were adjusted downwards somewhat to account for the fishing activity that would normally take place upon the combined acreage. The use criteria presented above reflect the adjustments.

3) Fishing - Each activity occasion per day requires 3.5 surface acres (taking into account the combined acreage) or 1/2 to 1 mile of trout stream, or 1/4 to 1/2 mile of river.

The stream and river standards were not the same for each region because of the varying conditions on each stretch of stream or river. Certain regions or areas of the state are better situated in terms of quality of their waterways for fishing. These use criteria are intended to be used as maximal rates given the quantity and quality of waterways, the past quantity and quality of fish (both native and stocked), and future analysis of carrying capacities of the various rivers and streams. Using inventory and use criteria standards, the upper limit for future use was developed by assuming that the actual use will manifest itself every day of the year and that the lakes, reservoirs, streams, and rivers maintain their 1967 levels and water carrying capacities. These upper limits are presented in Table 14. Multiplying each activity by 365 (number of days in a year), one can obtain the maximum possible supply on a yearly basis for each activity and each region.

Of course, the quality and type of waterways within each region, the present use patterns, the increasing crowding effect, the actual carrying capacity of fishing waters, and the actual supply of water resources available from year to year (wet vs. dry year) all act to reduce the realistic upper limit that should be placed on the available supply of each of the recreational activities in the respective regions. Thus, a utilization percentage was applied to the derived upper bound to arrive at the realistic estimated maximum supply.

Table 14. Estimated water based activity-occasion per day capacity by type and region, Rio Grande region, New Mexico

	Activity occasion per day capacity		
Region	Fishing	Boating	Water Skiing
1. Upper	5,500	1,078	900
2. Middle	3,000	704	588
3. Socorro	350	0	0
4. Lower	12,000	7,106	5,934
5. Rest of State	22,000	10,586	8,889
Total	42,850	19,454	16,311

Summary of Methods and Procedures

A graphic schematic presentation of the project schedule is presented in Figure 5. This represents individual sections of the research effort, and indicates major emphases and interrelationships. The first year's work primarily involved basic data collection, compilation, and exchange, and the adaption of the socio-economic model. The second year was spent primarily in analyses of interrelationships, aggregations, verifications, and incorporation of data, and inputs from all sections in this phase were coordinated for use in the model. In the third year, final computer analyses were completed. Analyses and interpretations of the socio-economic model were made by the research group.

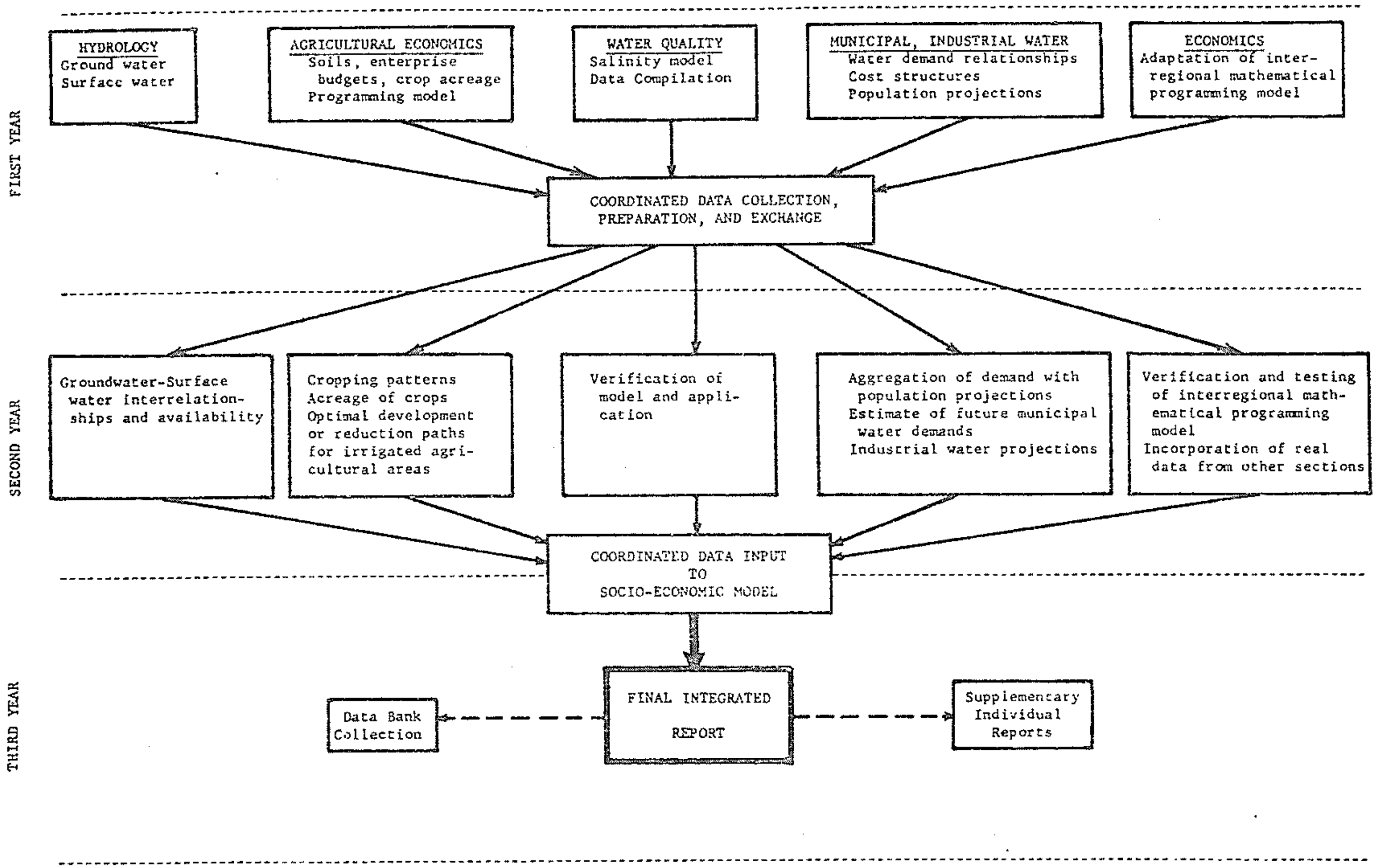

Figure 5. Project schedule for analytical interdisciplinary evaluation of the utilization of the water resources of the Rio Grande in New Mexico.

CHAPTER IV

RESULTS AND IMPLICATIONS

The comprehensiveness of the study was made possible through the inclusion of a wide range of disciplines and area studies. These disciplinary activities were designed primarily to provide necessary information for the socio-economic model. These activities included data collection, analysis, and interpretation. Secondary data was compiled in each study area whenever possible. In a number of study areas more detailed investigations were necessary for incorporation into the socio-economic model. Some of these activities resulted in additional information beyond the needs of the socio-economic model but are of sufficient importance to be reported here.

Some of the findings are presented in Chapter II under the physical description, while others are reported in the separate regional data bank publications. In this Chapter specific findings of the agricultural and hydrological studies are reported because of their importance in the interpretation of the socio-economic model results.

Agricultural Resources

The agricultural sector is the major user of water in the Rio Grande region. Irrigated agriculture accounts for about 2 percent of the land area, and historically has consumed approximately 90 percent of the water resources.

An economic land classification of the 280,785 acres of the irrigated cropland in the Rio Grande Basin was based on an adaptation of the Cornell system using soil and irrigation water quality and quantity as the primary variables. Among the factors in determining the four subregions were similarities of farming practices, farm size, and source of irrigation water.

Soil productivity information was obtained primarily from the Soil Conservation Service and the Bureau of Indian Affairs. Data on irrigation water diversions, source, and water quality were obtained from the State Engineer Office, U. S. Geological Survey, and Bureau of Reclamation.

Soils and irrigation water quality and quantity were categorized into three groups (Table 15). Approximately 11 percent of irrigated cropland was categorized as highly productive (Group I). Approximately 42 percent of the irrigated cropland has moderate limitations of slope, high water table, and moderate alkalinity which restrict maximum crop production and income (Group II). The Group III soils account for about 47 percent of the acreage in the Basin. These soils present management difficulties and have a low income potential. The primary difficulties in the northern portion of the Rio Grande region are excessive slope, coarse textures, shallow depth, a high degree of salinity, and low permeability; these may severely restrict the productive capacity of these soils in the southern half of the region.

Where the irrigation water is of inferior quality, crop selection is restricted either to salt-tolerant crops such as cotton and barley or moderately salt-sensitive crops such as alfalfa and most vegetables. Frequent heavy irrigations must be used to compensate for inferior quality water. Class I water was considered suitable for all crops; Class 2 water was satisfactory with improved management practices; and Class 3 was considered satisfactory as a supplement source if the primary source was of Class 1 or 2 quality (Table 12). Irrigation water quality in the Lower Rio Grande region was considered to be of sufficient importance to lower the classification on some of the cropland in the extreme southern portion of the region.

Irrigation water quantity refers to the adequacy of the source (Table 13). Quantity Class 1 water is a suitable amount for adequate economic yields (more than two acre-feet per acre), Class 2 indicates the probability of lowering maximum economic yields (1-2 acre-feet per acre), and Class 3 indicates the probability of uneconomic yields (less than one acre-foot per acre). Surface irrigation water quantity was considered to be a moderate to severe limitation in the Upper region. The primary source of irrigation water varies among the subregions. In the Upper region about 90 percent of the cropland is supplied by surface water only, while the majority of irrigated cropland in the Socorro and Lower regions is supplied by combined surface and ground

Table 15. Acreage of irrigated cropland by soil productivity groups, Rio Grande Basin, New Mexico

Soil Productivity Group[1]	REGIONS				Total	
	Lower Rio Grande	Socorro	Middle Rio Grande	Upper Rio Grande		
	(acres)	(acres)	(acres)	(acres)	(acres)	(percent)
Group I	21,546	1,501	7,170	600	30,817	11.0
Group II	49,366	9,158	37,046	23,440	119,010	42.4
Group III	34,748	5,841	27,379	62,990	130,958	46.6
TOTAL	105,660	16,500	71,595	87,030	280,785	100.0

1. Soils included in each group are described in Appendix B.

sources (Table 16). Because of frequent inadequacies of surface water, cropland irrigated with a combination of ground and surface water sources was considered to have an advantage.

Table 16. Acres of irrigated cropland by sources of water, Rio Grande region, New Mexico, 1970

	Source of Water			
Region	Surface Only	Ground Only	Combined Surface and Ground	Total
	acres			
Upper	79,800	6,170	1,060	87,030
Middle	53,865	800	16,930	71,595
Socorro	2,200	850	13,450	16,500
Lower	920	9,560	95,180	105,660
Total	136,785	17,380	126,620	280,785

Irrigation Diversions and Depletions

The total consumptive irrigation requirements and total irrigation requirements by season for the Rio Grande region are reported in Table 17. These are the theoretical water requirements for the region. The irrigation requirements ranged from 1.94 acre-feet per acre in the Upper region to 3.70 acre-feet in the Socorro region. The Middle and Lower regions were inbetween with 3.02 and 2.91 acre-feet per acre, respectively. The differences are due primarily to cropping patterns and climatic conditions. The total irrigation requirements, surface water deliveries, and ground water pumpage are reported in Table 18 for the Rio Grande region. The distribution by source was about two-thirds surface and one-third ground.

It is necessary to evaluate not only soil and water but the way it is handled and the way it appears to respond to a given level of management. The organization of the farm unit with respect to size and combination of enterprises were considered important indicators of future

Table 17. Seasonal and total consumptive irrigation requirements and irrigation requirements for irrigated lands in the Rio Grande region

	Cropped Acreage	Consumptive Irrigation Requirements[1]			Irrigation Requirements[2]			Total Per Cropped Acre[4]
		Summer[3]	Winter[3]	Total	Summer[3]	Winter[3]	Total	
		. . . .acre-feet.			. . . .acre-feet.			acre-feet
Upper Rio Grande region	53,619	67,462	192	67,654	168,659	480	169,139	1.94
Middle Rio Grande region	44,907	94,770	1,149	95,919	213,977	2,590	216,567	3.02
Socorro region	13,874	29,200	1,286	30,486	58,400	2,572	60,972	3.70
Lower Rio Grande region	92,831	182,194	1,997	184,191	303,659	3,328	306,987	2.91
Total Rio Grande Basin	205,231	373,626	4,624	378,250	744,695	8,970	753,665	2.68

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1. The quantity of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required consumptively for crop production (Blaney and Hanson, 1965, p. 5).
2. The quantity of water, exclusive of precipitation, that is required for crop production or the consumptive irrigation requirement divided by the irrigation efficiency.
3. For months in season see p. 60.
4. Total irrigation water requirements divided by crop acreage from Table 2.

Table 18. Total irrigation requirement by source of water, Rio Grande region, New Mexico, 1970

Region	Total Irrigation Requirements[1]	Surface Water Deliveries[2]	Ground Water Pumpage[3]
	(acre-feet)	(acre-feet)	(acre-feet)
Upper Rio Grande region	169,139	157,148	11,991
Middle Rio Grande region	216,567	139,901	76,666
Socorro region	60,972	35,740	25,232
Lower Rio Grande region	306,987	176,693	130,294
Total	753,665	509,482	244,183
Per acre	2.68	1.81	0.87

1. The quantity of water, exclusive of precipitation, that is required for crop production or the consumptive irrigation requirement divided by the irrigation efficiency. It includes surface evaporation and other economically unavoidable wastes, (Blaney and Hanson, 1965)

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

   Irrigation efficiency: The percentage of irrigation water that is available for consumptive use. When the water is measured at the farm headgate is is called farm-irrigation efficiency; when measured at the field, it is designated as field-irrigation efficiency; and when measured at the point of diversion, it is designated as project efficiency.

2. The amount of water delivered to the farm headgate.

3. Ground water pumpage is the amount of water required to supplement the surface water deliveries.

Note: Assumes a full-water-supply for calculation of consumptive use.

success since returns from farming stem from both capital and labor. A detailed field survey was conducted, making notes of observations on crops, buildings, irrigation systems, and practices being used.

Cropping patterns varied from one subregion to another, but alfalfa was the most frequently grown crop in all subregions (Table 2). Cotton was the second most frequently grown crop, but was the most important in income generation. Cotton and alfalfa accounted for almost 60 percent of the cropped acres, with the remainder composed primarily of low income-generating crops such as small grains, grain sorghum, forage crops, and irrigated pasture.

About three percent of the irrigated cropland in the Rio Grande region was considered to have only minor income expectancy limitations and was classified as Economic Land Class I (Table 19). All of this land was located in the Lower Rio Grande region. Economic Land Class II includes about 24 percent of the irrigated cropland in the Rio Grande region, most of which is in the Lower region. Irrigation water quality, dependability of surface water, soil productivity, and farm size are common problems associated with these lands. Slightly more than 72 percent of the irrigated cropland in the Rio Grande region had severe limitations and was classified as Economic Land Class III. The land in this class is located primarily in the Upper and Middle regions, with small amounts in the other subregions. Many of the farms in the Upper region in this class are small part-time farms. As a rule, the state of repair of irrigation systems, machinery, and buildings is not as good as that in Classes I and II.

Income expectancies measured in terms of net returns to land and management for the Rio Grande region were estimated to be greater than $100 per cultivated acre for Economic Class I land and less than $35 per cultivated acre for Economic Class III land.

Water Resources

Hydrologically the four regions along the Rio Grande River in New Mexico are typified by their water use patterns. Under original equilibrium conditions, the Rio Grande aquifer system discharged into the

Table 19. Acreage of irrigated cropland by economic land classes, Rio Grande Basin, New Mexico

Economic Land Class	REGIONS				Total	
	Lower Rio Grande (acres)	Socorro (acres)	Middle Rio Grande (acres)	Upper Rio Grande (acres)	(acres)	(percent)
Class I	8,655	0	0	0	8,655	3.1
Class II	55,060	9,360	3,720	0	68,140	24.3
Class III	41,945	7,140	67,875	87,030	203,990	72.6
TOTAL	105,660	16,500	71,595	87,030	280,785	100.0

river (river accretion) over most of its New Mexico reach. Agricultural, municipal, and industrial development, however, have now tremendously modified this original equilibrium. Water levels have dropped in most areas, decreasing river accretion or, in some cases, changing the river reach from accretion to depletion, as for example in the Albuquerque area where ground water levels along the river have dropped below river level. Depending upon the pumping rate, new equilibria can eventually be established again although with different river flow characteristics.

Ground water availabilities in each of the four regions were determined from the conjunctive surface-ground use model as explained in Chapter III. Ground water responses related to surface water availabilities and total ground water demand were obtained for each of the regions; a discussion of each follows.

Upper Rio Grande Region. The Santa Fe formation is the major aquifer in the region. Beneath the lava plateau to the west of the Rio Grande both the andesite-basalt and the alluvial sediments furnish an adequate supply of moderately hard water for domestic and stock use. The water table varies from about 250 to 750 feet beneath the surface, although some perched ground water bodies, yielding an intermittent water supply, are found at shallow depths along arroyos.

Irrigation with ground water has only recently been developed in the Upper region, and for this purpose wells yielding 600 to 3000 gallons of water per minute are common. Water-table depths range from about 20 to about 280 feet below the surface, with specific capacities of the wells generally being less than 20 gpm per foot of drawdown. The quality of the water is satisfactory for irrigation. In the western half of the valley, the alluvial sediments cover and are interbedded with lava. Several of the deep irrigation wells have penetrated the lava. In general, the lava has not been tapped for irrigation water because of the availability of water at shallow depths within the alluvial sediments and because of the great depth of water in the lava where it is not overlain by alluvial sediments. The interbedding of the alluvial sediments with the lava flows causes perching of ground water in the sediments due to the contrasting permeabilities of the lavas and the sediments. Lava flows transmit water much faster through the fractures under lower gradients than do the sediments which generally have a much lower permeability.

Surface water and ground water in the Upper region are closely related and have to be managed conjunctively. For example, since the Rio Grande flow is gaining through accretion in the entire region (Figure 6), development of ground water for irrigation will decrease the availability of surface waters almost proportionally to the consumptive use of the pumped amount. Although water levels are dropping in the area, the situation is far from dramatic because the natural recharge in the area far exceeds withdrawals. The equilibrium that existed between recharge and discharge has been disturbed but will eventually reestablish itself, although very slowly, as long as the water table is above river level. Ground water levels are considerably above river level (Figure 6) with rather steep gradients almost perpendicular to the river, indicating natural recharge from the mountain sides and through the lava caps.

For analysis of the surface-ground water interrelationship of the Upper region, the mathematical simulator of this study uses 130 grid cells (10 x 13) and covers an area, as shown in Figure 6, 52 miles long and 12 miles wide. Transmissivities for the area range from 6,000 to 370,000 gallons per day per foot with an average specific yield of 0.18. Historical conditions from 1955 to 1965 were simulated to calibrate model parameters. The most difficult component for the area appeared to be the estimate of natural recharge and boundary flow. The results of fifteen simulation cases from extreme dry to extreme wet, each over a 40-year period, were analyzed, as discussed before, by stepwise multiple regression analysis. The following surface water-ground water relationship was obtained

$$\Delta d = -0.5 \ d_n + 29.1 \log_{10}(L + 0.2 \times 10^7) - 166.5 \qquad [4]$$

in which Δd = decline (-) or rise (+) of the water table in any year (feet), d_n = depth (feet) to the water table in antecedent years with respect to river level considered as zero, L = a lump factor in acre-feet per year. The lump factor consists of the following: river inflow (+), river outflow (-), 5% of annual average precipitation (+), non-beneficial evapotranspiration losses (-), and the agricultural, municipal, and industrial water needs supplied by the ground water system (-).

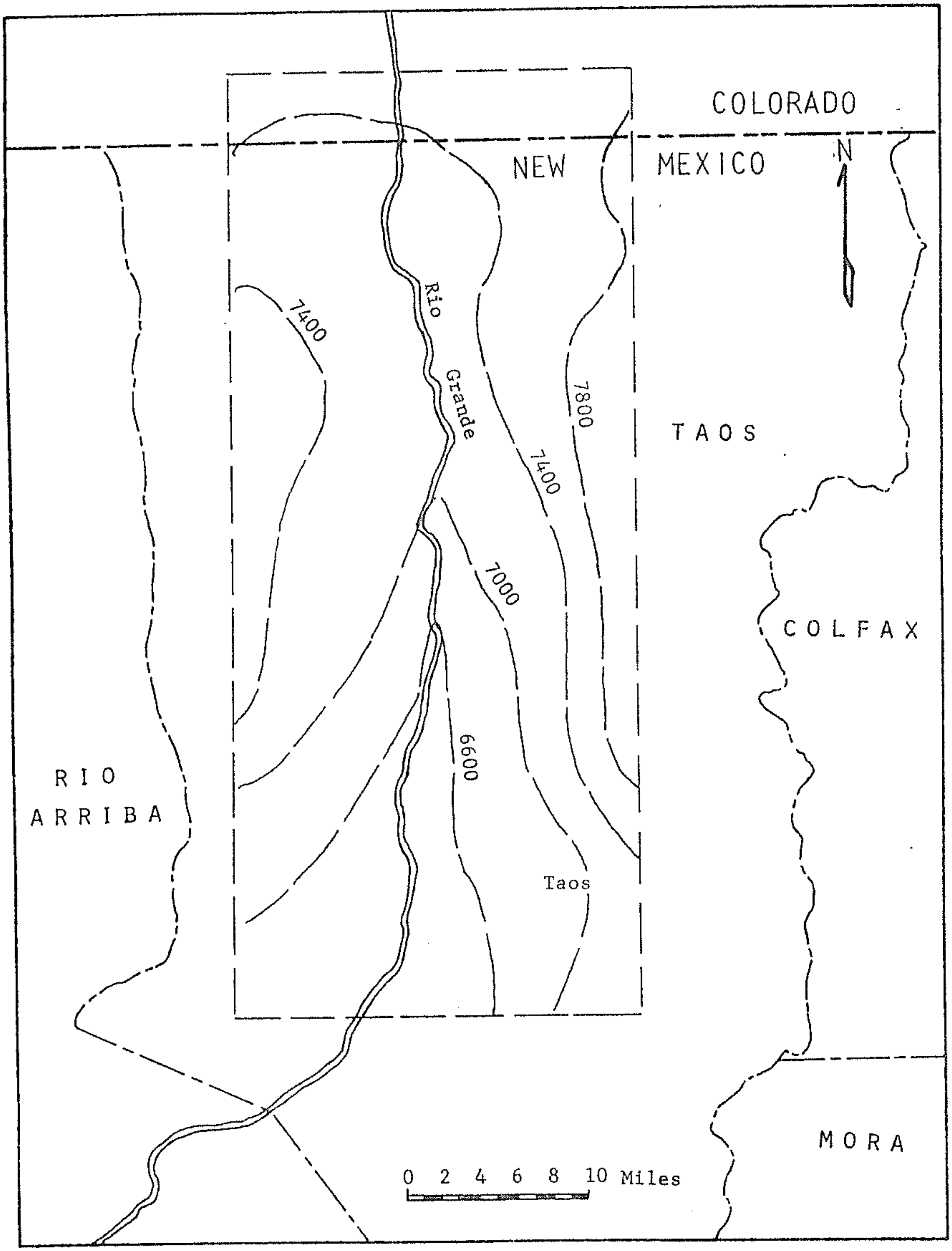

Figure 6. The Upper Rio Grande Region study area with 1965 water-table contours.

The applicability of this relationship is demonstrated in Figure 7. It shows the very slow response in time of the aquifer system with respect to establishing new hydrologic equilibria as well as the aquifer response in case of a sudden doubling of the pumping after 20 years of present-rate pumping.

Middle Rio Grande Region. The Albuquerque ground water system is to a large extent affected by the urban development of the city of Albuquerque. Ground water use is expected to increase rapidly (Reeder, et al., 1967) with declining ground water levels. The importance of this study is to analyze the interrelationship of surface water and ground water of the Albuquerque area as affected by water use under a variety of assumptions and hydrologic conditions.

Due to differences in permeability, saturated thickness, and recharge or discharge of ground water, the water table is irregularly sloping, at a low gradient, diagonally down valley (Reeder, et al.) from the base of the Sandia and Manzano Mountains on the east and from the Rio Puerco on the west toward a generally southward trending zone about eight miles west of the Rio Grande.

Precipitation and seepage from the river as well as from drains and irrigation canals are the main sources of recharge. Discharge is mainly due to pumpage; evapotranspiration is of little significance except to the north and to the south of the city of Albuquerque.

The Rio Grande river channel in most of its reach throughout the Albuquerque area is not entrenched into the valley floor (Reeder, et al.). There has been some aggradation, raising the river bed slightly above the valley floor. Moreover, pumping of ground water and low irrigation drains keep the ground water table substantially below the average river level. As a consequence, the river loses water to the groundwater system in most of the Albuquerque area. This trend of increasing induced recharge from the river is expected to continue.

The conjunctive use surface-ground water model of the Albuquerque area uses a 16 x 10 grid system (a total of 160 rodes). This covers an area of 20 miles (transversal) by 64 miles (longitudinal) as shown in Figure 8.

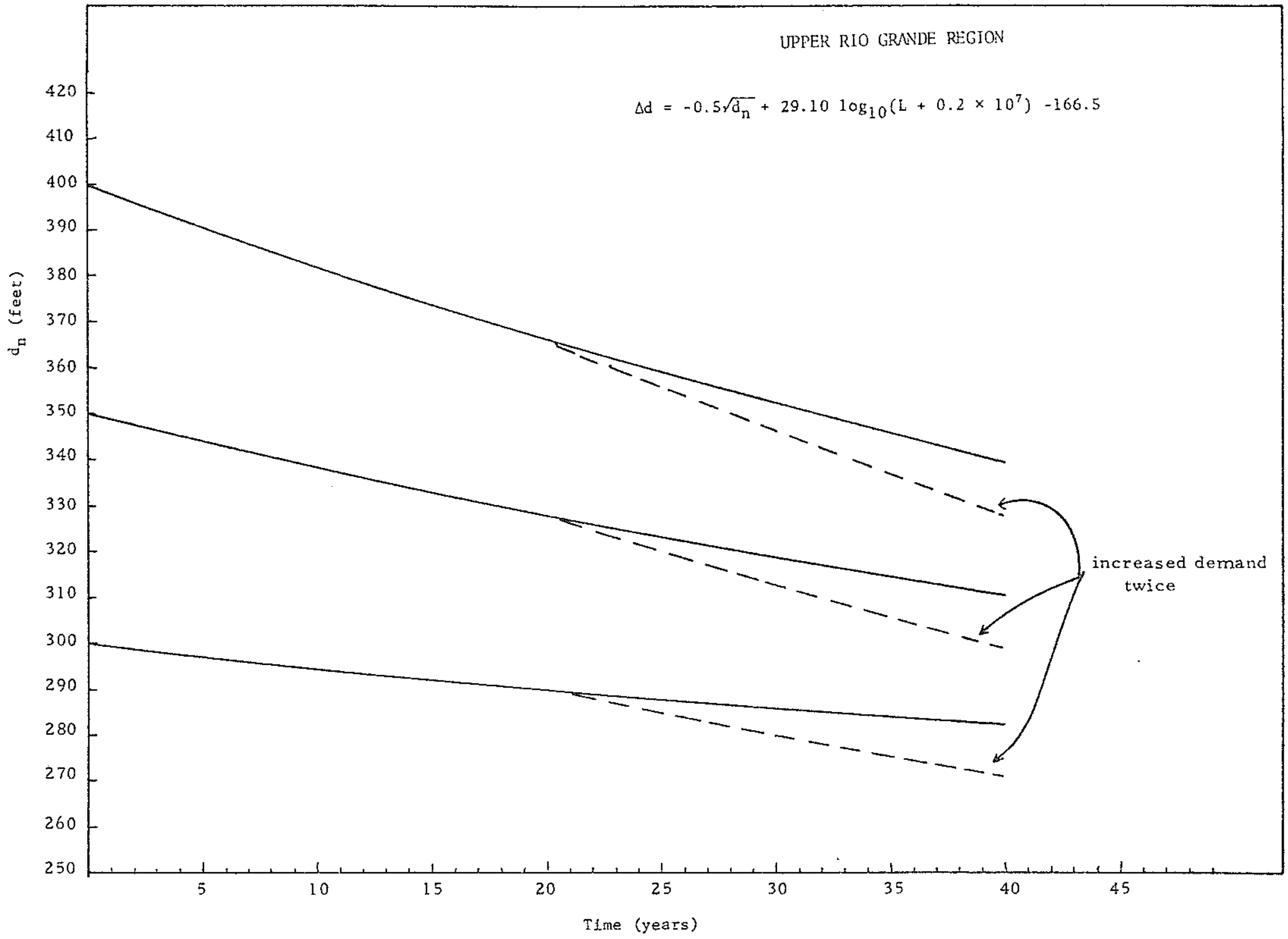

Figure 7. Depth (feet) to the water table [d_n] with respect to time for the Upper Rio Grande Region, New Mexico

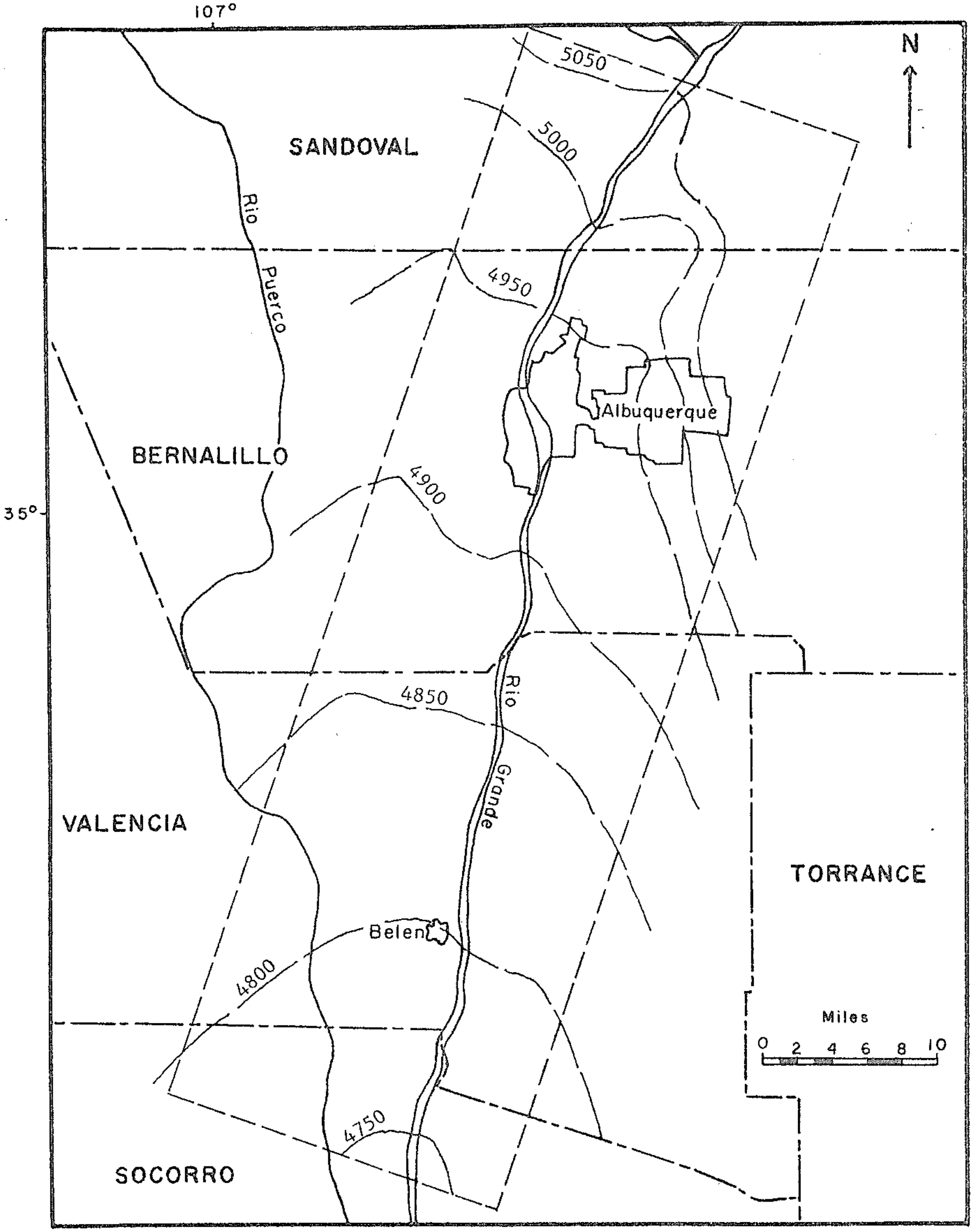

Figure 8. The Middle Rio Grande Region study area with 1968 water-table contours.

Transmissivities range from 6,000 in the alluvial fans along the mountains to 600,000 gallons per day per foot near the Rio Grande (Reeder, et al.). From estimated saturated thicknesses (Joesting, et al. 1961) hydraulic conductivities were calculated and ranged from 11.7 to 112 feet per day. The estimated specific yield (storage coefficient) is 0.2 for both sides of the river (Bjorkland and Maxwell, 1961).

Historical conditions from 1962 to 1968 were simulated to verify and adjust model parameters. Major outputs (or inputs) are industrial and municipal water demands for the Albuquerque area. Agricultural ground water usage, mainly to the north and to the south of the city, was estimated from consumptive use data and irrigated acreage patterns (Table 17).

Ground water velocities are characteristically slow in the Albuquerque area, ranging from 0.2 to 0.3 feet/day. Aquifer response due to pumpage should therefore be quite pronounced on a short-term basis. Continual ground water withdrawal in the Albuquerque area will have a pronounced effect upon the recharge from the river. In addition, the gradient will increase to the north, thus increasing flow into the area from the north (Figure 8).

Simulation of the Albuquerque ground water basin resulted into the following relationship:

$$\Delta d = -113.1 - 28.4 \ \mathrm{EXP}(d_n/200) + 21.4 \log_{10}(L + 3 \times 10^6) \quad [5]$$

(symbols defined earlier).

The application of the above relationship can be demonstrated in different ways. Figure 9 assumes, for example, a present water-table elevation at river level and assumes also a normal projected growth for the Albuquerque area. Water levels are expected to drop about 50 feet during the next 30 to 40 years, at which time virtual equilibrium conditions are reached. Equation [5] combines lateral and longitudinal water-table variations into an average value for the area. However, it is easily understood that the largest water-table drop is expected in the vicinity of the city of Albuquerque which could be on the order of 80 feet, tapering off to the north, south, east, and west to about 30 feet.

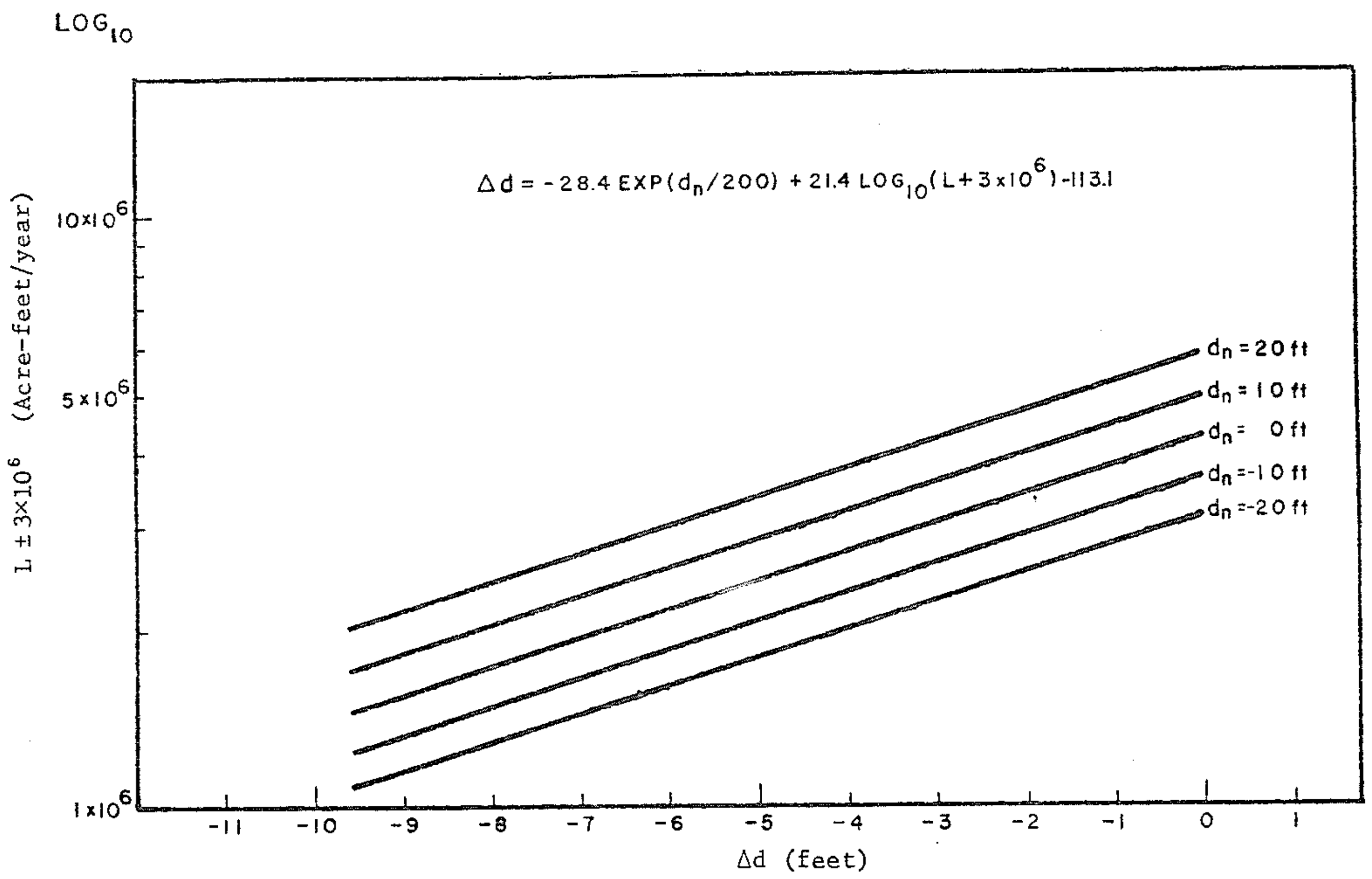

Figure 9. Expected declines in the water-table level in the Albuquerque area utilizing varying depths to water, Middle Rio Grande Region, New Mexico.

Figure 9 also demonstrates the applicability of Equation [5] in case of changing conditions: for example, the effects of a sudden doubling of the water demand. The interrelationship is further demonstrated by Figure 10. Entering this graph with a particular value, different values for Δd (+ or -) are obtained, depending upon the water-table elevation of a previous year (d_n).

The results of this study were also compared with the predictive calculations for the year 2000 by Reeder, et al., (1967) shown in Figure 11.

Socorro Region. Agriculture, in supplementing its surface water irrigation, is by far the largest user of ground water. Therefore, Socorro's ground water is characterized by seasonal fluctuations. Under present conditions a near hydrologic equilibrium seems to be appearing. The 1962 to 1966 water level data show little variation. A 1962 water-table map for the Socorro region, including the Snake Ranch Flats area, is presented in Figure 12.

For the conjunctive surface-ground water use modeling of the Socorro Valley, the area was subdivided into a 12 x 21 grid system. The total area covered is shown by the rectangle on Figure 12. Transmissivities in the area varied from 6,000 to 360,000 gallons per day per foot (Hantush, 1961). The lower values apply in the alluvial fans along the mountain ranges, the higher values in the central portion of the Valley. Areas of lower hydraulic conductivity along the mountain ranges can be identified from the water-table map where much steeper gradients can be noticed.

Specific yields for the Socorro Valley as computed by Hantush (1961) were within very close range, i.e., 0.23 to 0.24. Since the test well (less than 100 feet in depth) only partially penetrated the aquifer, it may be that these values are slightly overestimated and that a value around 0.20 may be considered more reasonable because of compaction with depth.

The verification procedure for the Socorro Valley consisted of simulating the historical conditions from 1962 to 1964. Seasonal

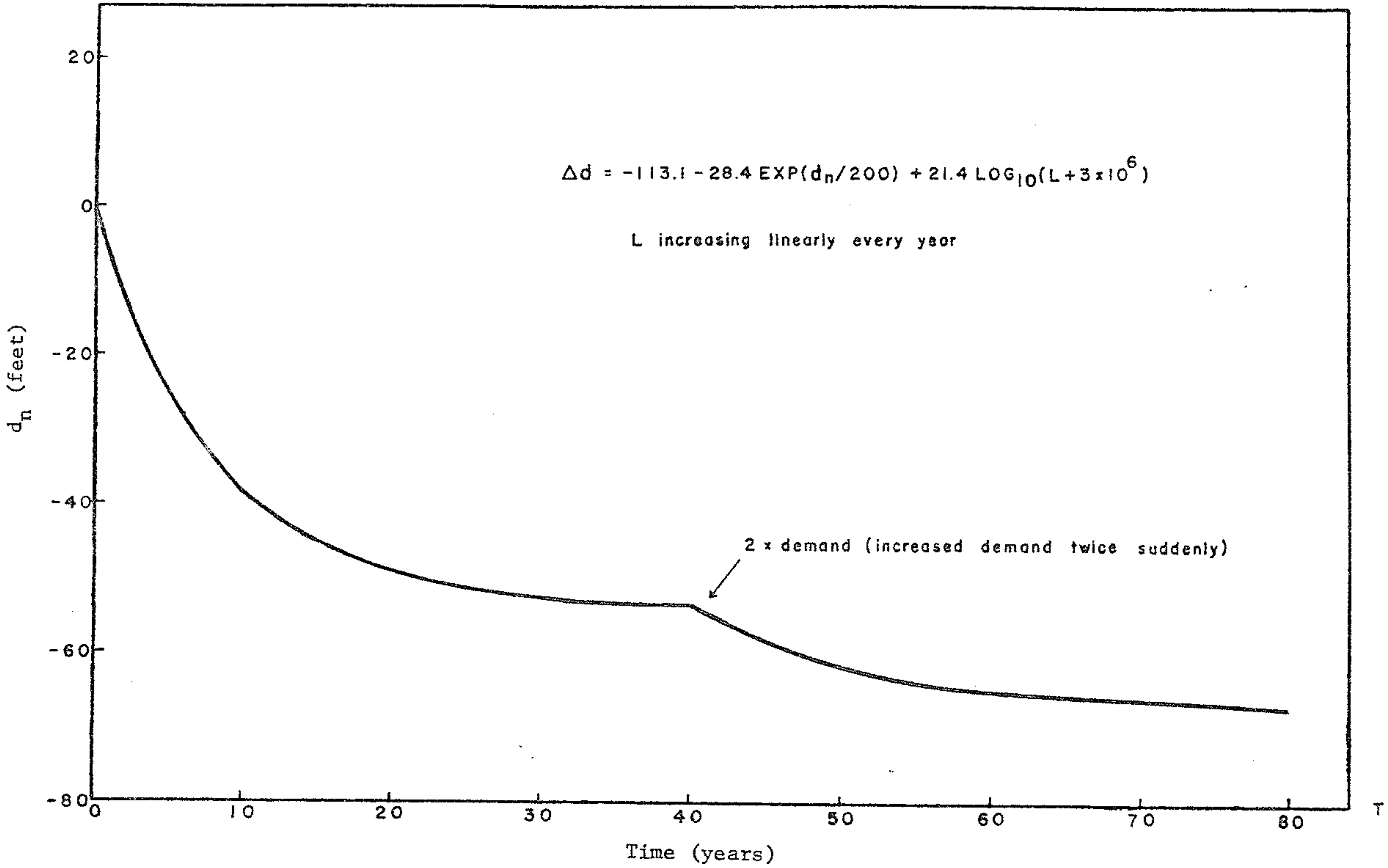

Figure 10. Depth (feet) to the water table [d_n] with respect to time for the Albuquerque section, Middle Rio Grande Region, New Mexico.

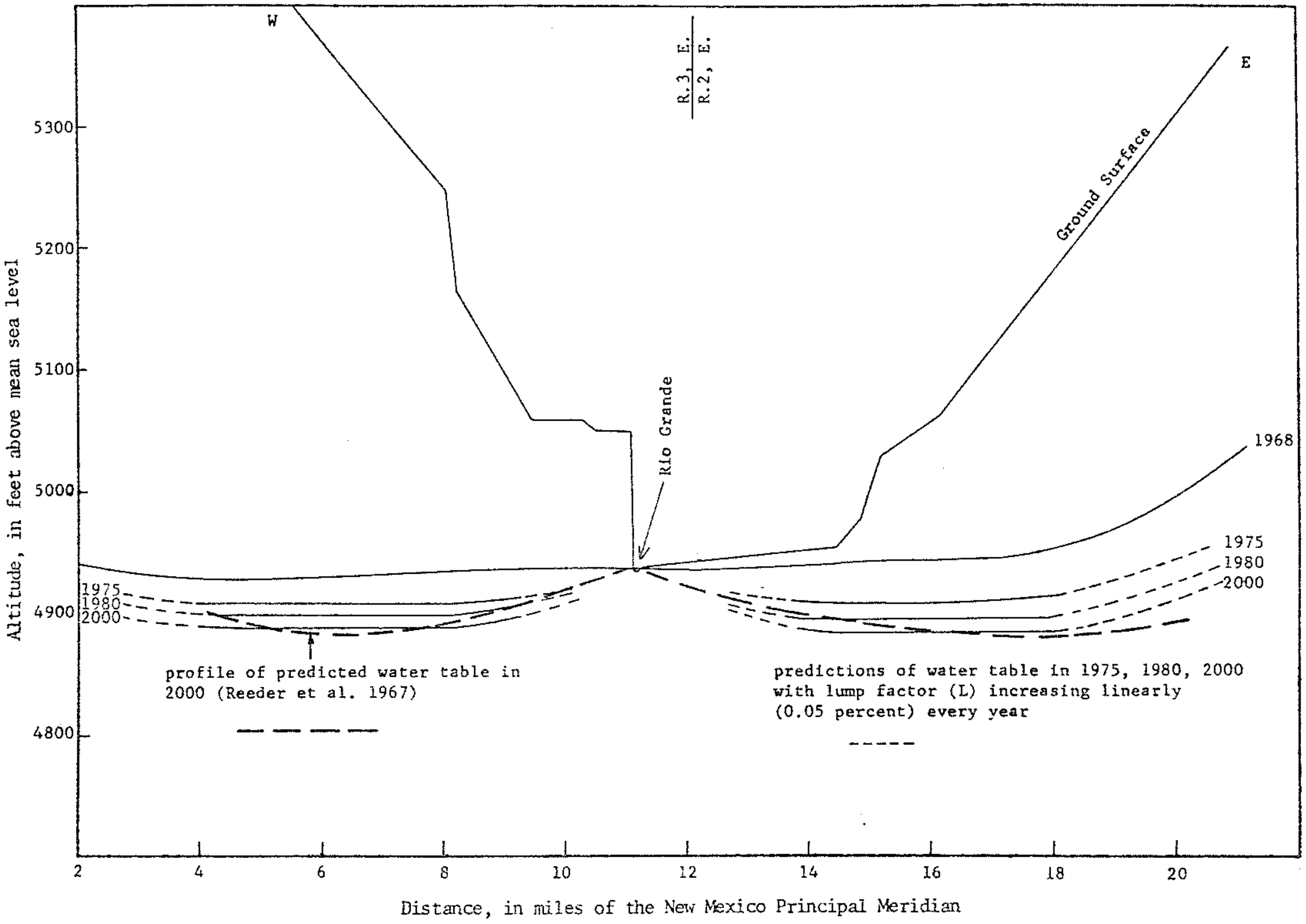

Figure 11. Comparison of predicted water-table levels for 1975, 1980, and 2000 with Reeder et al., 1967, for 2000, Albuquerque section, Middle Rio Grande Region, New Mexico

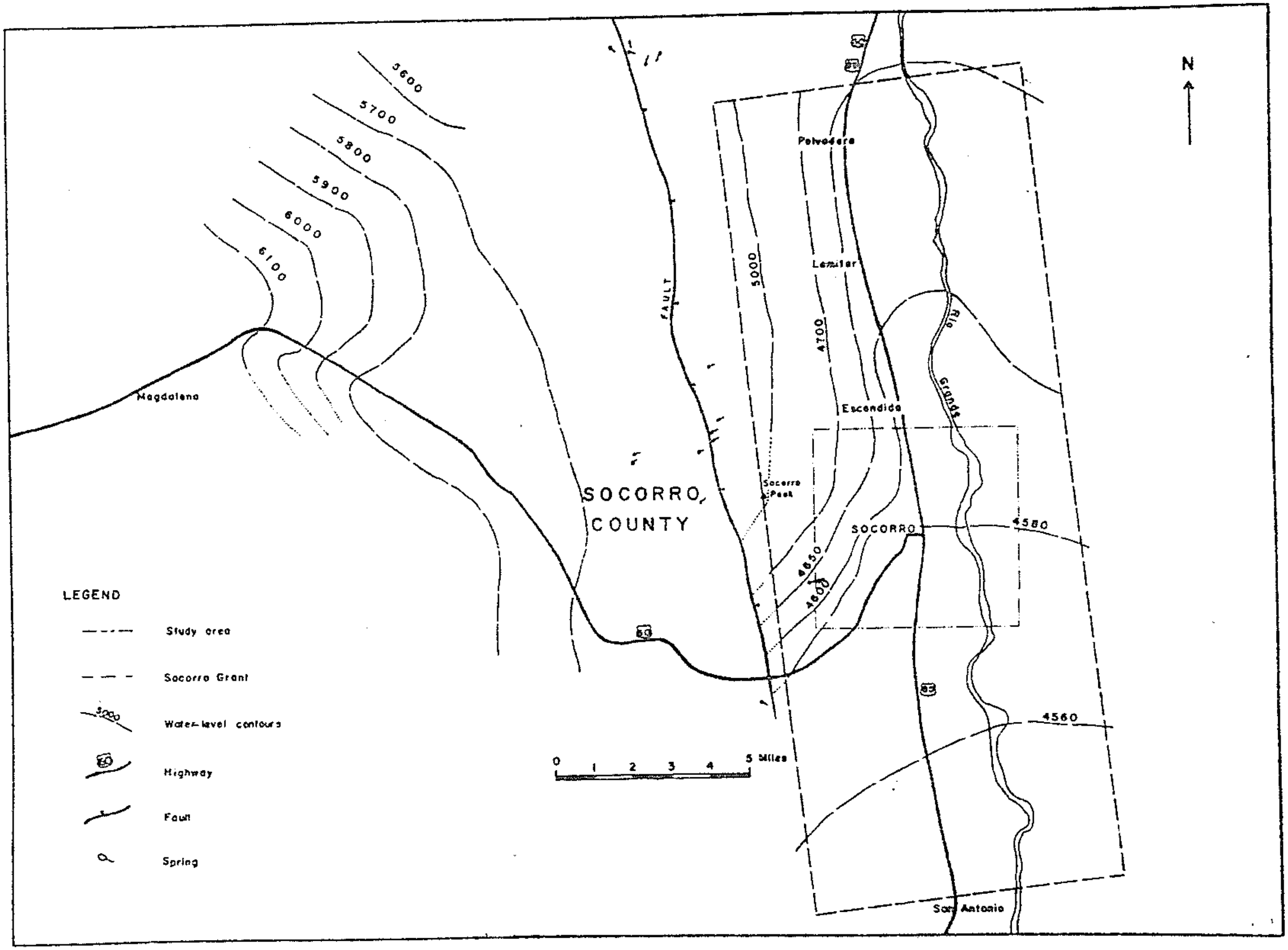

Figure 12. The Socorro Region study area with 1962 water-table contours.

fluctuation of hydrologic variables as well as agricultural withdrawal schedules were programmed for each of the 12 x 21 grids of the study area.

In general, flow velocities in the Socorro ground water basin are rather small, roughly 0.10 feet per day, and, therefore, the system should be quite sensitive to pumping and recharge on a short term basis. This behavior was pronounced in the calibration runs of the Socorro region. The river has a significant effect upon the ground water system of the Socorro Valley. Also, pumping rate is the dominant factor affecting changes of ground water-table.

The stepwise multiple regression analysis of the data obtained from the simulation runs gave the following surface water-ground water interrelationship:

$$\Delta d = -384.3 - 0.00336\, d_n - 0.00028\, d_n^2 + 60.7 \log_{10}(L + 0.2 \times 10^7) \quad [6]$$

(symbols explained previously).

At present, the average elevation of the water-table above river level is almost 20 feet. Using this value as a starting point for d_n, for 1970, and projecting water demands for the Socorro area, including expected growth, water levels are calculated to drop about seven feet by the year 2010 (Figure 13). If pumping were discontinued after 20 years, a slow recovery of the average water-table elevation would be observed (Figure 13). These results demonstrate that the Socorro ground water system is in near hydrologic equilibrium under present conditions. Figure 13 presents water-table behavior over time for three different initial water-table elevations of 20, 10, and 0 feet, respectively.

Lower Rio Grande Region. The ground water resources of the Lower Rio Grande region are used (1) to supplement the surface waters for agricultural use, (2) as the municipal supply for Las Cruces, Hatch, Berino, and other towns, (3) as an industrial water supply, and (4) for rural domestic use. Most of the water use is within the Mesilla and Rincon Valleys, and, therefore, this ground water study concentrates on only these two sections. The lower part of the Rincon Valley and the Mesilla Valley have different subsurface geological formations. The lower Rincon Valley from Hatch to Selden Canyon has a recent valley fill

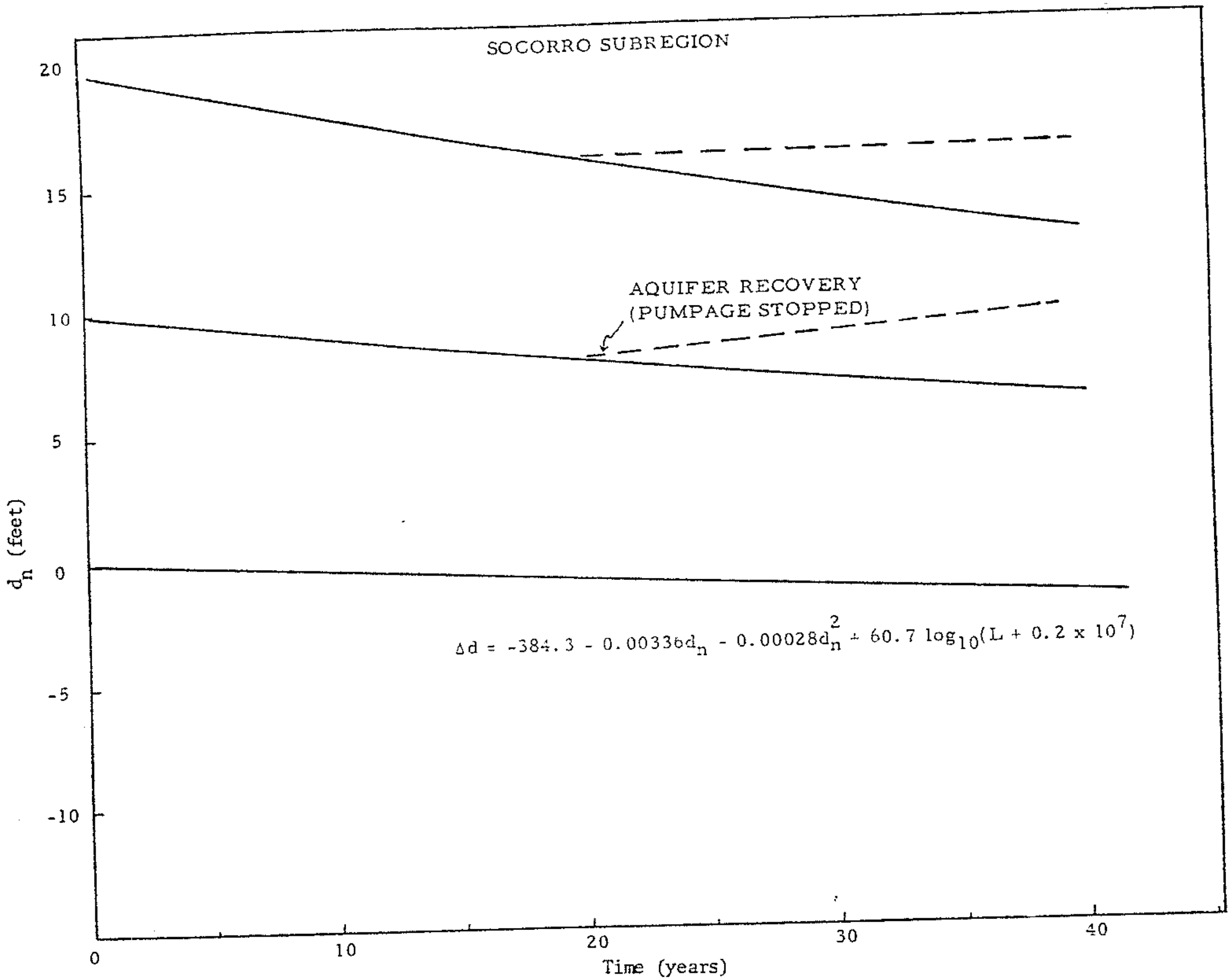

Figure 13. Depth (feet) to the water table [d_n] with respect to time for the Socorro Region, New Mexico

less than 200 feet thick which is underlain by clay (King, et al., 1969). The Mesilla Valley has the recent valley fill also less than 200 feet thick, and it is underlain by the Santa Fe formation, a mixture of sand and gravel interbedded with numerous clay lenses. The valley fill in both Valleys is a relatively fast backfill of an earlier river cut. The backfill and valley floors were completed about 10,000 years ago. The upper fill is fine-grained sands and silts, while the lower part of the fill is mainly gravel (King, et al., 1969). All ground water development within the Valleys is within this valley fill, and it is assumed that the basic aquifer constants within the two Valleys are identical. Therefore, most information will be used interchangeably between the Rincon and Mesilla Valleys.

Most known aquifer data for the Mesilla Valley was evaluated in a subproject study by Richardson (1971) and later published as a report by Richardson, Gebhard, and Brutsaert (1971). The study included all of the irrigated cropland within the Mesilla Valley (Figure 14).

The water budget for the Mesilla Valley is difficult to generalize over the entire region because of the interaction of the surface water flow and the elevation of the ground water table. The ground water system is recharged by deep percolation from excess irrigation waters, seepage from canals, some leakage from the Rio Grande, and recharge from precipitation. The flow in the Rio Grande at the lower end of the Mesilla Valley depends upon the flow in the drains which is controlled by the elevation of the water table.

Average transmissivity of the valley fill in the Mesilla Valley was 75,000 gpd per foot (Conover, 1954). Richardson (1971) used a 75,000 gpd per foot transmissivity in the direction perpendicular to the river and then doubled the transmissivity in the down-valley direction. Estimates of storativity range from 25 percent by Conover (1954) to 15 percent by others. A storativity of 20 percent created the best simulation of historic data.

The relationship developed for the Lower Rio Grande region is

$$\Delta d = -237.15 - 2.8\ \mathrm{EXP}(d_n/100) + 37.77\ \log_{10}(L + 2 \times 10^6) \qquad [7]$$

in which the symbols are as explained before. The significance of this

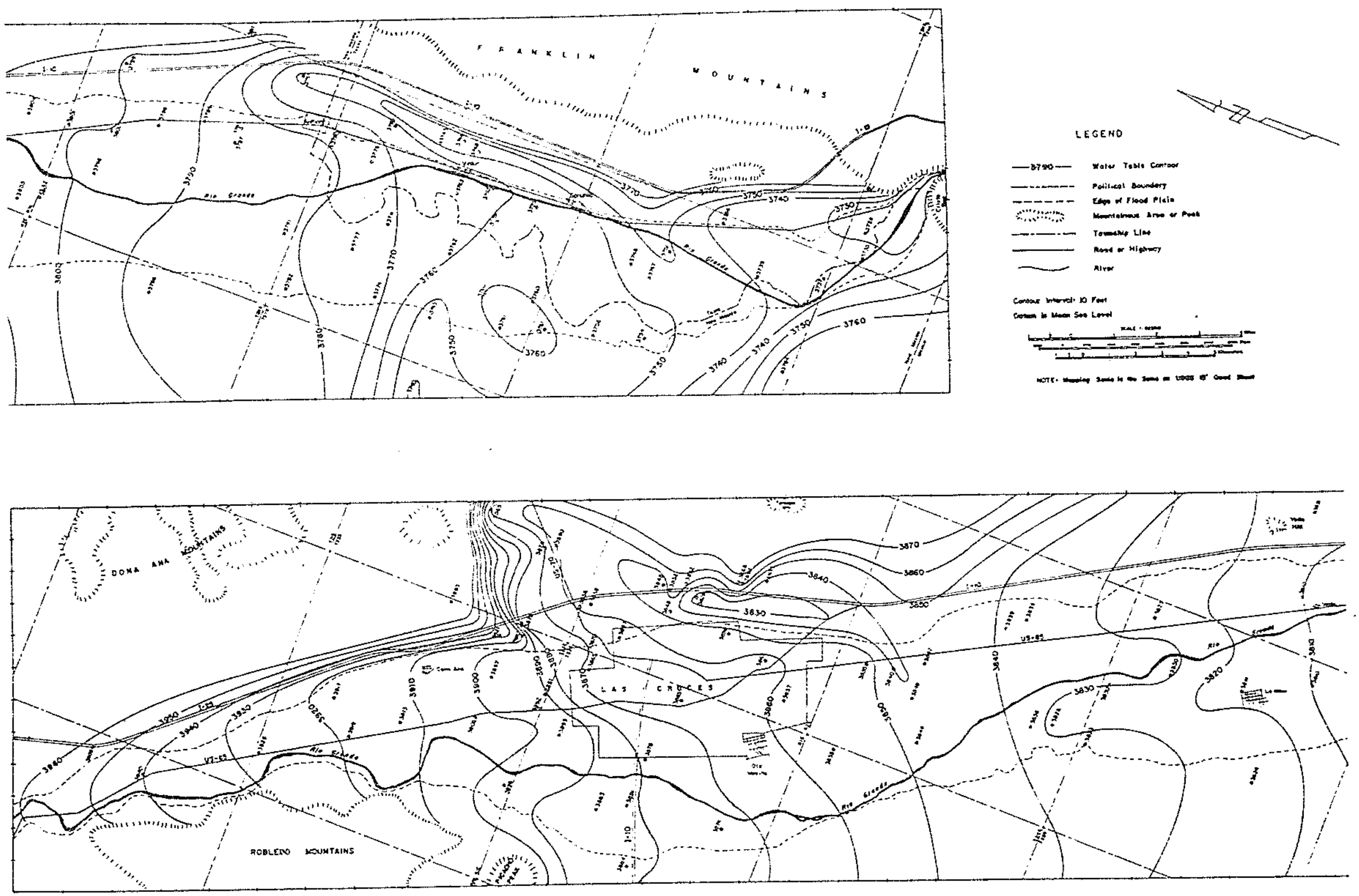

Figure 14. The Lower Rio Grande Region study area (Mesilla Valley) with 1967 water-table contours.

relationship is demonstrated by Figures 15 and 16. In Figure 15, depth to the water table, d_n, is plotted as a function of time. Starting at present with an average d_n, such as -3 feet, and using present projection rates for the area, water levels are expected to drop approximately another seven feet during the next 40 years with a tendency to level off thereafter. Figure 16 allows calculation of the drop (-) or rise (+) of the water table, Δd, given the depth of the water table at any time and the L-value.

Summary. The relationships discussed in the previous sections are summarized in Table 20, which also includes the study period and average L-values for each area.

The surface-groundwater interrelationship of a certain region is most clearly demonstrated by calculations of river accretion and depletion as affected by pumping. Figure 17 is an attempt to summarize the results in this manner. The Rio Grande in the Upper Rio Grande region is gaining water, whereas in the Middle Rio Grande region it is losing water. In the Socorro region the river is gaining at present but could change from a gaining to a losing river reach if ground water demands were suddenly doubled. The Lower Rio Grande reach is slightly losing.

More specifically for the Albuquerque area, the accretion or depletion per mile can be estimated for any future time: for example, 10 years from the present about 4.4 cfs/mile or 3,185.6 acre-feet/year/mile will be diverted from the Rio Grande.

The Socio-economic Model

The socio-economic model was utilized to simulate long-run production and water utilization patterns in the Rio Grande Basin under alternative assumptions. Each simulation process starts with the same basic solution to the model, and continues with annual changes to satisfy the alternative conditions for a period of 20 years. The basic solution used 1970 conditions and closely approximates the actual production levels and resources used in the base year 1970. Differences between the basic solution of the model and the actual production levels in 1970 result from the optimization

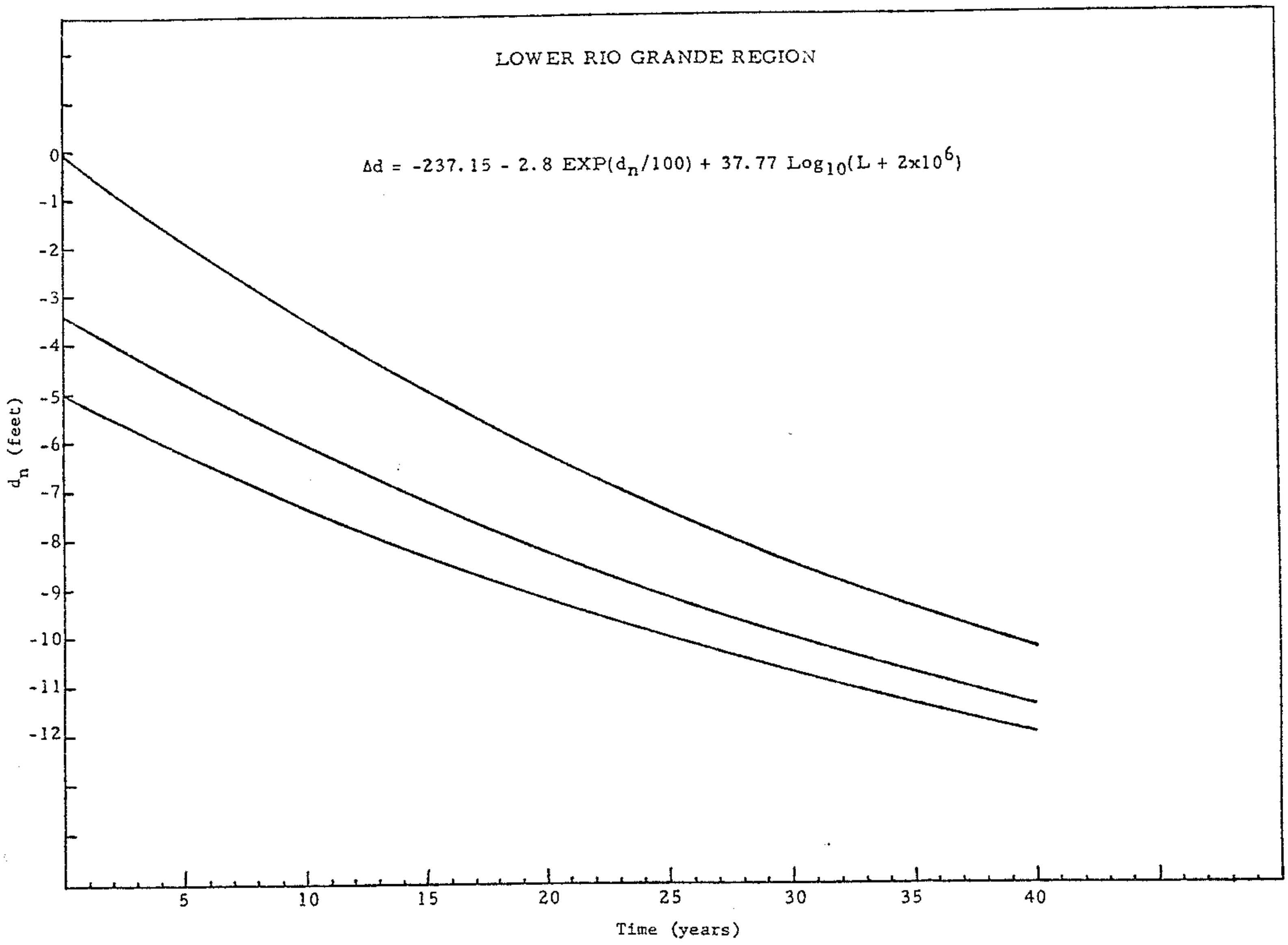

Figure 15. Depth (feet) to the water table [d_n] with respect to time for the Mesilla Valley section, Lower Rio Grande Region, New Mexico

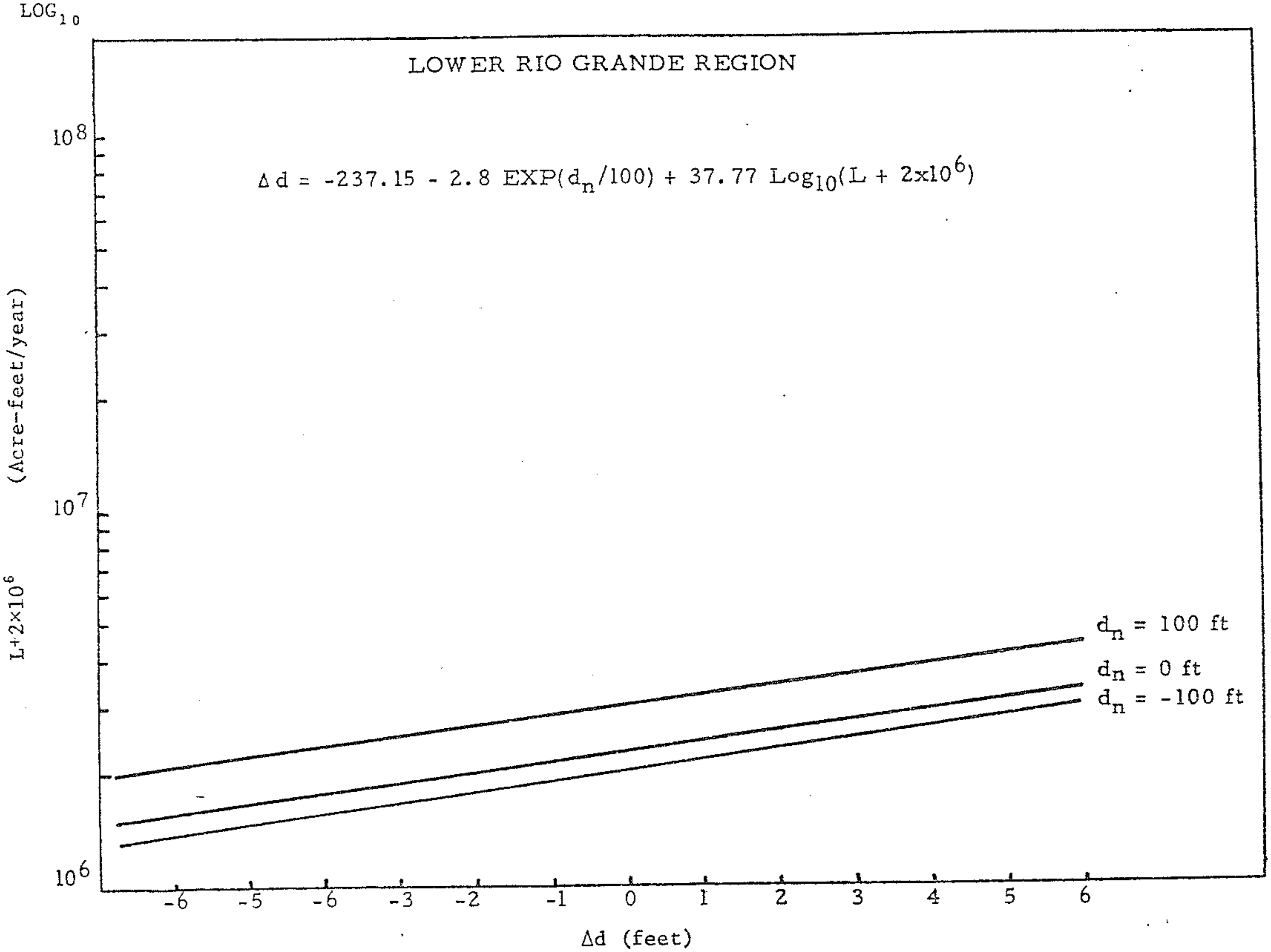

Figure 16. Expected declines in the water-table level in the Mesilla Valley section utilizing varying depths to water, Lower Rio Grande Region, New Mexico.

Table 20. Conjunctive surface-ground water use equations by region, Rio Grande region, New Mexico

Region	Equation[1]	Study Period	Average $L \left(\frac{\text{ac-ft}}{\text{yr.}}\right)$
UPPER	$\Delta d = -0.5 \sqrt{d_n} + 29.10 \text{ LOG}_{10} (L + 0.2\text{x}10^7) -166.5$	30 years	-695,010
MIDDLE	$\Delta d = -113.1 - 28.4 \text{ Exp } (dn/200) + 21.4 \text{ LOG}_{10} (L + 3\text{x}10^6)$	20 years	-148,450
SOCORRO	$\Delta d = -384.3 - 0.00336\ d_n - 0.00028\ d^2_n + 60.7 \text{ LOG}_{10} (L + 0.2\text{x}10^7)$	25 years	-133,090
LOWER	$\Delta d = -237.15 - 2.8 \text{ EXP}(d_n/100) + 37.8 \text{ LOG}_{10} (L + 2\text{x}10^6)$	40 years	54,670

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1. See Equation 4, page 74.

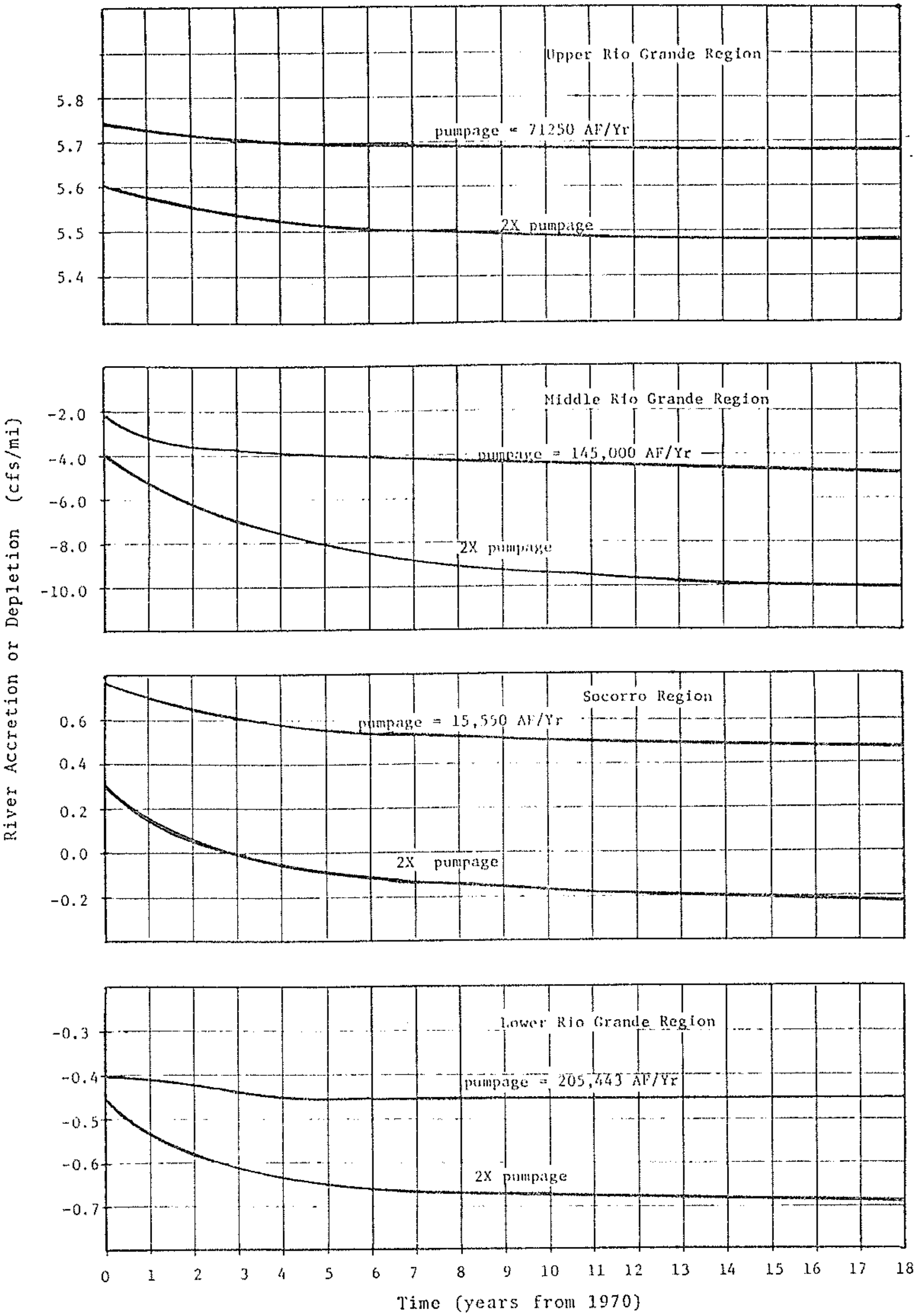

Figure 17. Average pumpage effects by region as a function of time, Rio Grande region, New Mexico

procedures used. The optimal use of resources in the model allows for social considerations such as recreation demands and unemployment levels. This basic optimal solution of the model was used as a point of departure for the alternative solutions; hence, a description of the basic solution will be presented first.

The Basic Solution of the Model

The economy of New Mexico was represented in the model by twenty-four production sectors (Table 12). All sectors were defined in the model in units of one million dollars of production. Each sector had its own demands for resources such as water, labor, etc., and its contribution to the total benefits to the state's economy, measured by the value added of each one million dollar unit. Tables 21 and 22 present some of the major results of the basic model and relate them to water utilization. Table 21 presents measures of outputs, inputs, and efficiencies of water use by sector. Detailed levels of production for all twenty-four sectors measured in value of total output are presented in Table 21. The value added generated by each sector ranges from 17.7 percent of the total value of output in the Meat Packing Industry (Sector 8) to 74.1 percent in Retail Auto and Eating Places (Sector 20). The weighted average value added in the Rio Grande region was 58 percent of total output. The large coefficients of output per unit of water in the nonagricultural sectors are a result of the low water consumption in these sectors.

Table 22 magnifies the differences between the agricultural sectors and all other producing sectors. While the agricultural sectors produced only 4.1 percent of the total output, 3.9 percent of the total value added, and provided only 6.7 percent of the total employment, they consumed 94.9 percent of all the water used in production in the Rio Grande region. The trade and services sectors played the opposite role using only 3.9 percent of all water depleted by the production sectors, but were responsible for 78 percent of the total value of output and 81.5 percent of the total value added.

Table 21. Production, water use, and employment in the Rio Grande region, New Mexico--basic solution

Sector[1]		Total Output ($1 million)	Total Value Added ($1 million)	Employment	Total Water Depletions (acre-feet)	Output per Acre-foot (dollars)	Value Added per Acre-foot (dollars)	Water Depletions per Employee (acre-feet)
Agriculture	1	39.453	13.536	2,055	66,046	597	205	32.14
	2	9.272	5.958	1,223	205,740	45	29	168.23
	3	10.781	6.615	291	168,736	64	39	579.85
	4	23.968	18.911	3,366	55,677	431	340	16.54
	5	5.369	3.280	503	68	78,956	48,235	.14
Mining, Oil and Gas	6	81.785	52.342	1,731	2,977	27,472	17,582	1.72
	7	26.276	19.050	190	1,593	16,495	11,959	8.38
Manufacturing	8	20.651	3.655	273	62	333,081	58,952	.23
	9	25.948	6.798	505	111	233,756	61,243	.22
	10	14.197	4.160	535	20	709,850	208,000	.04
	11	30.069	11.276	539	189	159,095	59,661	.35
	12	56.158	26.731	2,337	854	65,759	31,301	.37
	13	7.924	1.751	109	296	26,770	5,916	2.72
	14	70.346	29.616	4,070	156	450,936	189,846	.04
	15	50.658	26.692	2,139	137	368,307	194,832	.06
Commercial Trade and Services	16	109.914	72.983	5,006	273	402,615	267,337	.05
	17	13.499	9.314	266	34	426,441	273,941	.13
	18	104.965	68.227	4,519	4,487	23,393	15,205	.99
	19	325.238	214.332	22,070	1,597	203,656	134,209	.07
	20	98.320	70.004	11,302	579	169,810	120,905	.05
	21	177.374	131.434	7,232	1,741	101,881	75,493	.24
	22	151.552	88.355	13,170	1,940	78,120	45,544	.15
	23	517.916	286.408	17,474	6,369	81,318	44,969	.36
	24	172.462	71.744	9,559	3,038	56,768	23,616	.32
	Total	2,143.895	1,243.172	110,464	522,720	4,101[2]	2,378[2]	4.73[2]

1. For sector definition see Table 12, page 40.
2. Weighted average.

Table 22. Production, water use, and employment for major sectors in the Rio Grande region, New Mexico--basic solution

Major Sector	Total Output ($1 million)	Total Value Added ($1 million)	Employment	Total Water Depletions (acre-feet)	Output per Acre-foot (dollars)	Value Added per Acre-foot (dollars)	Water Depletions per Employee (acre-feet)
1. Agriculture	88.843	48.300	7,438	496,267	179	97	66.78
2. Mining, Oil & Gas	108.061	71.392	1,921	4,570	23,645	15,622	2.38
3. Manufacturing	275.751	110.679	10,507	1,825	151,096	60,646	.17
4. Trade & Services	1,671.240	1,012.801	90,598	20,058	83,320	50,494	.22
Total	2,143.895	1,243.172	110,464	522,720	4,102[1]	2,378[1]	4.73[1]
	(percent)	(percent)	(percent)	(percent)			
1. Agriculture	4.1	3.9	6.7	94.9			
2. Mining, Oil & Gas	5.0	5.7	1.7	0.9			
3. Manufacturing	12.9	8.9	9.5	0.3			
4. Trade & Services	78.0	81.5	82.1	3.9			
Total	100.0	100.0	100.0	100.0			

[1] Weighted average.

The regional distribution of water depletions by major production sectors and municipal and rural uses is presented in Table 23. The significance of the agricultural sectors as major water users was maintained in all regions, although their share is reduced in the Middle Rio Grande region to 70.39 percent where 18.56 percent of the total water use was for domestic purposes.

The socio-economic model was used to estimate the effects of population growth on the distribution of production and water requirements for the period 1970-1990 in the Rio Grande region. Regional population projections used in the model were based on the New Mexico Bureau of Business Research county projections (Table 24). An increase in population affects the final demand for consumer products, the labor force, as well as the direct demand for water for municipal and rural use.

An increase in the final demand will affect all twenty-four sectors according to the interrelationships of the Input-Output Table. Because of these predetermined relationships, any change in the final product mix produced within the region will require a change in the model constraints.

Water recreation demands in the Rio Grande region in the base year (1970) and the distribution of supply by origin are presented in Tables 25-27. The major supply area for water skiing and boating is the Lower Rio Grande. Recreationers from the Middle, Socorro, and Lower regions, as well as out-of-state visitors, utilize the availability in the Lower region.

In the concentrated population centers of the Middle Rio Grande region, demands exceed supply of water-based recreation by 453,235 (551,654 - 98,419) activity-occasion days (AOD) in water skiing, 146,210 activity-occasion days in boating, and 807,318 activity-occasion days in fishing. The Lower region supplies 589,672 activity-occasion days of water skiing but demands only 67,719, resulting in a difference of 521,953 AOD (Table 25); in boating there is a net supply of 293,943 AOD (Table 26); and in fishing there is a net supply of 382,904 AOD (Table 27). The Lower Rio Grande region satisfies about 43 percent of

Table 23. Summary of depletions by major sector in the Rio Grande region (acre-feet)--basic solution

	Region				Total Rio Grande Region
Major Sector	Upper	Middle	Socorro	Lower	
	acre-feet				
1. Agriculture	78,614	106,465	44,044	278,947	508,070
a. Surface	(72,150)	(95,166)	(31,529)	(224,105)	(422,950)
b. Ground	(6,464)	(11,299)	(12,515)	(54,842)	(80,035)
2. Mining, Oil & Gas	2,852	1,500	108	111	4,571
3. Manufacturing	224	1,485	29	87	1,825
4. Commercial Trade & Services	4,195	13,705	203	1,957	20,060
5. Municipal	3,862	25,568	407	4,362	34,199
6. Rural	2,042	2,527	203	1,051	5,823
Total	91,789	151,250	44,994	286,515	574,548
	percent				
1. Agriculture	85.64	70.39	97.89	97.36	88.43
2. Mining, Oil & Gas	3.11	0.99	0.24	0.04	0.80
3. Manufacturing	0.25	0.98	0.06	0.03	0.32
4. Commercial Trade & Services	4.57	9.06	0.45	0.68	3.49
5. Municipal	4.21	16.90	0.91	1.52	5.95
6. Rural	2.22	1.66	0.45	0.37	1.01
	100.00	100.00	100.00	100.00	100.00

Table 24. Population projections by region, Rio Grande region, New Mexico, 1970-2020

	Region				Total Rio
Year	Upper	Middle	Socorro	Lower	Grande Region
1970	111,610	373,355	9,763	76,962	571,690
1980	123,372	419,897	10,870	85,630	639,769
1990	135,133	466,440	11,978	94,297	707,848
2000	146,895	512,982	13,085	102,965	775,927
2010	158,656	559,525	14,193	111,632	844,006
2020	170,418	606,067	15,300	120,300	912,085
Average Annual Percent Growth	1.054	1.247	1.134	1.126	1.191

Source: Based on county projections by the New Mexico Bureau of Business Research

Table 25. Water-based recreation (water skiing) in the Rio Grande Basin by region--basic solution

Supplying Region	Demanding Region Upper	 Middle	 Socorro	 Lower	 Out of State	Total Supply
	. . . .	.(activity-occasion	days).	. . . . . .		
Upper	121,402				8,281	129,683
Middle		98,419				98,419
Socorro						
Lower		255,459	13,897	67,719	252,597	589,672
Total Rio Grande region	121,402	353,878	13,897	67,719	260,878	817,714
Rest of State	18,643	154,768				173,411
Out of State		43,008	1,544			44,552
Total Demand	140,045	551,654	15,441	67,719	260,878	1,035,737

Table 26. Water-based recreation (boating) in the Rio Grande Basin by region--basic solution

Supplying Region	Demanding Region Upper	Middle	Socorro	Lower	Out of State	Total Supply
	. . . .	(activity-occasion days)	. . . . . .	. . . . . .	. . . . . .	. . . . . .
Upper	64,012				15,673	79,685
Middle		78,616				78,616
Socorro						
Lower		74,923	5,639	28,145	213,381	322,088
Total Rio Grande region	64,012	153,539	5,639	28,145	229,054	480,389
Rest of State		74,923				74,923
Out of State		16,364	1,023			17,387
Total Demand	64,012	244,826	6,662	28,145	229,054	572,699

Table 27. Water-based recreation (fishing) in the Rio Grande Basin by region--basic solution

Supplying Region	Demanding Region					Total Supply
	Upper	Middle	Socorro	Lower	Out of State	
	. . . .(activity-occasion days).					
Upper	380,437	250,258			162,706	793,401
Middle		365,600				365,600
Socorro			30,760		9,371	40,131
Lower				264,910	408,909	673,819
Total Rio Grande region	380,437	615,858	30,760	264,910	580,986	1,872,951
Rest of State		549,268	3,230	26,005		578,503
Out of State		7,792				7,792
Total Demand	380,437	1,117,918	33,990	290,915	580,986	2,459,246

the Middle Rio Grande region's demand for water skiing, about 23 percent for boating, but none of the Middle Rio Grande region's demand for fishing. The out-of-state demands far exceed out-of-state supplies for all three water-based recreation activities.

Alternative Solutions of the Model

Three alternative solutions of long-run production and water-use patterns, utilizing a population growth at an average rate of 1.19 percent annually or 59.5 percent for the period 1970-2020, are presented below. The three alternatives differ only in water constraints. In the first alternative, water availability was not constrained. The production sectors were permitted to grow as required in order to supply the products demanded. Thus additional surface water for agricultural use would become available as needed: for example, by water importation or water-saving technological developments. Ground water sources were assumed to be sufficient to permit the required increases in pumpage but not to substitute for surface sources.

The assumption that surface water can be imported to satisfy any future demands is not a realistic assumption. There are only limited opportunities for water importation, such as the San Juan-Chama diversion. It is more likely that no additional surface water will be available in the future. The second alternative reflects this assumption and places a constraint on surface water availability: i.e., the 1970 surface water supplies plus the San Juan-Chama diversion water. Any increase in water demands is required to be satisfied within the region. Under the assumptions of the model, surface and ground water are used in agriculture in a fixed proportion. The effect of limiting surface water availability to 1970 levels implies that growth in agricultural production can be expected only in areas where the availability of surface water exceeds depletions. No effect should be expected in the nonagricultural sectors because ground water depletions have not been restricted.

Under the legal constraints imposed by the water laws of New Mexico, the mining of ground water is restricted by ability of the State Engineer to declare a ground water basin closed to future development. Most of the Rio Grande region in New Mexico lies within declared basins. The third alternative reflects constraints placed on both surface and ground water resources. Total surface water availability for use in the Rio Grande region was restricted to the average surface flow in the Rio Grande, including the supplementary flow from the San Juan-Chama project. Ground water pumpage was initially restricted in this set to the total pumpage in 1970. It was assumed that any future growth will require the transfer of surface water rights from agriculture to other production sectors, rural, domestic, and municipal uses. A transfer mechanism was added to the model to allow the transfer of surface rights to ground water rights. Additional pumpage was permitted only to the extent that surface water depletions were reduced.

In the following tables, additional diversions refer to the effect of pumpage upon the river. Within the alluvial deposits of the Rio Grande the surface water and ground water are connected, and pumpage either diverts water from the river or intercepts water destined for the river. Calculations of the additional diversions were obtained from interpretations of Figure 17. In order to maintain interregional deliveries, the total surface water availability in each region was reduced annually to compensate for the additional diversions. These additional diversions will be presented for each alternative.

Alternative 1: No water constraint. The long-run effects of population growth under the above assumptions are presented in Tables 28 and 29. Table 28 presents the production levels required to satisfy the increases in local demand and expected increases in nonagricultural out-of-state sales. Total value of output in the Rio Grande region is expected to increase at approximately the same rate as the population increase. This amounts to an increase of more than $1,258 million in the total value of output for the period 1970-2020.

Agricultural production is expected to increase only 37.5 percent ($33.3 million). This smaller increase results from the assumption that additional surface water will not be made available for agricultural exports and will be used only for local increases in demand for agricultural products. The major increases in agricultural products are

Table 28. Production ($1 million) and percentage change in production by region and sector--no water constraint

		Region									
		Upper Rio Grande		Middle Rio Grande		Socorro		Lower Rio Grande		Total Rio Grande region	
Year	Sector	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)
1970	Agriculture	12.2		21.7		8.6		46.3		88.8	
	Mining	55.8		45.1		2.4		4.7		108.1	
	Manufacturing	22.2		213.9		2.5		20.2		258.8	
	Services	322.7		1,181.1		23.2		144.3		1,671.3	
	Total	412.9		1,461.7		36.8		215.5		2,126.9	
1980	Agriculture	13.3	8.4	24.4	12.5	8.8	2.4	49.0	5.9	95.5	7.5
	Mining	61.9	11.0	50.7	12.5	2.7	11.3	5.3	11.3	120.6	11.6
	Manufacturing	24.6	11.0	240.4	12.4	2.8	11.0	22.4	11.2	290.2	12.1
	Services	358.2	11.0	1,327.9	12.4	25.8	11.1	160.4	11.2	1,872.3	12.0
	Total	458.0	11.0	1,643.4	12.4	40.1	9.1	237.1	10.0	2,378.7	11.8
2000	Agriculture	15.3	25.1	29.8	37.5	9.3	7.3	54.5	17.7	108.9	22.5
	Mining	74.2	33.0	62.0	37.4	3.3	34.0	6.3	33.8	145.8	34.9
	Manufacturing	29.5	33.0	293.3	37.1	3.3	33.4	26.9	33.6	353.0	36.4
	Services	429.2	33.0	1,621.6	37.3	31.0	33.4	192.6	33.5	2,274.5	36.1
	Total	548.2	32.8	2,006.6	37.3	46.9	27.3	280.4	30.1	2,882.1	35.5
2020	Agriculture	17.3	41.3	35.2	62.5	9.7	12.2	60.0	29.4	122.1	37.5
	Mining	86.5	55.1	73.2	62.3	3.8	56.7	7.4	56.3	170.9	58.2
	Manufacturing	34.4	55.0	346.1	61.8	3.9	55.6	31.5	56.1	415.8	60.7
	Services	500.3	55.0	1,915.3	62.2	36.2	55.7	224.8	55.8	2,676.6	60.2
	Total	638.4	54.6	2,369.9	62.1	53.6	45.5	323.7	50.2	3,385.5	59.2

Table 29. Water depletions (acre-feet) and percentage change in water depletions by region and sector--no water constraint

			Region									
			Upper Rio Grande		Middle Rio Grande		Socorro		Lower Rio Grande		Total Rio Grande region	
Year	Water	Sector	Water depletions	Change from 1970	Water depletions	Change from 1970	Water depletions	Change from 1970	Water depletions	Change from 1970	Water depletions	Change from 1970
			(ac.-ft.)	(percent)	(ac.-ft.)	(percent)	(ac.-ft.)	(percent)	(ac.-ft.)	(percent)	(ac.-ft.)	(percent)
1970	Surface	Agriculture	72,150		95,166		31,529		224,106		422,951	
	Ground	Agriculture	6,460		11,299		12,516		54,842		85,116	
	Ground	Mining	2,852		1,500		108		111		4,570	
	Ground	Manufacturing	224		1,485		29		87		1,825	
	Ground	Services	4,195		13,705		203		1,957		20,060	
	Ground	Mun. & rural	5,565		27,780		578		5,222		39,144	
		Total	91,446		150,935		44,963		286,325		573,666	
1980	Surface	Agriculture	81,541	13.0	108,976	14.5	32,946	4.5	241,015	7.6	464,478	9.8
	Ground	Agriculture	7,659	18.6	12,966	14.8	13,186	5.4	59,014	7.6	92,824	9.1
	Ground	Mining	3,166	11.0	1,687	12.5	120	11.1	123	10.8	5,906	11.5
	Ground	Manufacturing	249	11.2	1,668	12.3	32	10.3	97	11.5	2,046	12.1
	Ground	Services	4,657	11.0	15,410	12.4	226	11.3	2,176	11.2	22,468	12.0
	Ground	Mun. & rural	6,151	10.5	31,243	12.5	643	11.3	5,810	11.3	43,848	12.0
		Total	103,423	13.1	171,950	13.9	47,153	4.9	308,235	7.7	630,760	10.0
	Additional diversions		1,920		11,050		2,680		1,010		16,600	
2000	Surface	Agriculture	100,364	39.1	136,628	43.6	35,808	13.6	257,937	22.7	547,657	29.5
	Ground	Agriculture	10,062	55.8	16,304	44.3	14,541	16.2	67,363	22.8	108,271	27.2
	Ground	Mining	3,793	33.0	2,061	37.4	144	33.3	148	33.3	6,147	34.5
	Ground	Manufacturing	298	33.0	2,034	37.0	38	31.0	116	33.3	2,486	36.2
	Ground	Services	5,581	33.0	18,819	37.3	271	33.5	2,613	33.5	27,283	36.0
	Ground	Mun. & rural	7,324	31.6	38,169	37.4	774	33.9	6,987	33.8	53,254	36.1
		Total	127,422	39.3	214,015	41.8	51,576	14.7	352,084	23.0	745,098	29.9
	Additional diversions		5,760		33,150		8,040		3,030		49,800	
2020	Surface	Agriculture	118,067	63.6	164,279	72.6	38,647	22.6	308,687	37.7	629,680	48.9
	Ground	Agriculture	12,286	90.2	19,643	73.9	15,885	26.9	75,710	38.1	123,523	45.1
	Ground	Mining	4,421	55.0	2,435	62.3	169	56.5	173	55.9	7,199	57.5
	Ground	Manufacturing	348	55.4	2,399	61.6	44	51.7	136	56.3	2,927	60.4
	Ground	Services	6,504	55.0	22,229	62.2	315	55.1	3,050	55.9	32,098	60.0
	Ground	Mun. & rural	8,497	52.7	45,095	62.3	906	56.8	8,163	56.3	62,660	60.1
		Total	150,123	64.2	256,080	69.7	55,966	24.5	395,919	38.3	858,087	49.6
	Additional diversions		9,600		55,250		13,400		5,050		83,000	

expected in the Middle Rio Grande region which also expects the largest population increase. This results from the interregional Input-Output matrix structure which does not allow for changes in the interregional transfer coefficients.

The total nonagricultural production is expected to increase by \$1,225 million. The expected increase in agricultural production represents only 2.7 percent of the total increase in the value of production, while it represents 86.2 percent of the additional water depletions required. Table 29 presents surface and ground water depletions accompanying the changes in production in Table 28.

Water depletions in the year 2020 are expected to reach almost 860,000 acre-feet. This increase of 284,421 acre-feet over the depletions in 1970 will be required to meet the projected population needs in 2020. Of this amount the agricultural sectors will require 245,136 acre-feet, the remaining production sectors 15,769 acre-feet, and domestic increases will require 23,516 acre-feet. The increase in agricultural depletions will be met by utilizing 206,729 acre-feet of surface water and 38,407 acre-feet of ground water. All increases in surface water will be used by agriculture.

<u>Alternative 2: Surface water constraint</u>. Table 30 presents production levels under the surface water constraints, and Table 31 presents expected water depletions for this alternative. The cost of imposing a surface water constraint can be measured in the decline in the value of production (\$14.2 million). The Rio Grande regional value of production without a constraint would be \$3,385.5 million, and \$3,371.3 million with a surface water constraint. Direct agricultural production would decrease \$12.3 million, and the indirect effects of reduced agricultural production would account for the other \$1.9 million in manufacturing and services associated with agriculture. Surface water depletions in the Socorro and Lower regions in the base year 1970 approached the average annual availability for these regions. The Upper and Middle regions are expected to benefit from the additional surface water to be supplied by the San Juan-Chama diversion project. Thus the long-run average annual availability

Table 30. Production ($1 million) and percentage change in production by region and sector--surface water constraint

		Region									
		Upper Rio Grande		Middle Rio Grande		Socorro		Lower Rio Grande		Total Rio Grande region	
Year	Sector	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)
1970	Agriculture	12.2		21.7		8.6		46.3		88.8	
	Mining	55.8		45.1		2.4		4.7		108.1	
	Manufacturing	22.2		213.9		2.5		20.2		258.8	
	Services	322.7		1,181.1		23.2		144.3		1,671.3	
	Total	412.9		1,461.7		36.8		215.5		2,126.9	
1980	Agriculture	13.3	8.4	24.3	12.3	8.5	-0.9	47.9	3.4	94.0	5.8
	Mining	61.9	11.0	50.7	12.5	2.7	11.3	5.3	11.3	120.6	11.6
	Manufacturing	24.6	11.0	240.4	12.4	2.8	11.0	22.4	11.2	290.1	12.1
	Services	358.2	11.0	1,327.8	12.4	25.8	11.0	160.3	11.1	1,872.2	12.0
	Total	458.0	10.9	1,643.2	12.4	39.8	8.3	235.9	9.5	2,377.0	11.8
2000	Agriculture	15.0	22.6	29.6	36.7	8.4	-2.9	50.9	9.8	103.9	16.9
	Mining	74.2	33.0	62.0	37.4	3.3	34.0	6.3	33.8	145.8	34.9
	Manufacturing	29.5	33.0	293.2	37.1	3.3	33.1	26.9	33.6	352.9	36.4
	Services	429.2	33.0	1,621.5	37.3	30.9	33.1	192.3	33.3	2,274.0	36.1
	Total	547.9	32.7	2,006.2	37.3	45.9	24.7	276.5	28.3	2,876.5	35.2
2020	Agriculture	16.0	30.4	32.3	49.0	8.2	-5.0	53.4	15.2	109.8	23.6
	Mining	86.5	55.1	73.2	62.3	3.8	56.7	7.4	56.3	170.9	58.2
	Manufacturing	34.3	54.9	345.9	61.7	3.9	55.0	31.4	56.0	415.5	60.6
	Services	500.2	55.0	1,914.5	62.1	36.0	55.2	224.3	55.4	2,675.0	60.1
	Total	637.0	54.3	2,365.9	61.9	51.9	41.2	316.5	46.9	3,371.3	58.5

Table 31. Water depletions (acre-feet) and percentage change in water depletions by region and sector--surface water constraint

			Region									
			Upper Rio Grande		Middle Rio Grande		Socorro		Lower Rio Grande		Total Rio Grande region	
Year	Water	Sector	Water depletions (ac.-ft.)	Change from 1970 (percent)	Water depletions (ac.-ft.)	Change from 1970 (percent)	Water depletions (ac.-ft.)	Change from 1970 (percent)	Water depletions (ac.-ft.)	Change from 1970 (percent)	Water depletions (ac.-ft.)	Change from 1970 (percent)
1970	Surface	Agriculture	72,150		95,166		31,529		224,106		422,951	
	Ground	Agriculture	6,460		11,299		12,516		54,842		85,116	
	Ground	Mining	2,852		1,500		108		111		4,570	
	Ground	Manufacturing	224		1,485		29		87		1,825	
	Ground	Services	4,195		13,705		203		1,957		20,060	
	Ground	Mun. & rural	5,565		27,780		578		5,222		39,144	
		Total	91,446		150,935		44,963		286,325		573,666	
1980	Surface	Agriculture	81,541	13.0	108,976	14.5	29,010	-8.0	224,383	0.1	443,911	5.0
	Ground	Agriculture	7,659	18.6	12,965	14.7	11,183	-10.7	54,872	0.1	86,678	1.8
	Ground	Mining	3,166	11.0	1,687	12.5	120	11.1	123	10.8	5,096	11.5
	Ground	Manufacturing	249	11.2	1,668	12.3	32	10.3	97	11.5	2,045	12.1
	Ground	Services	4,657	11.0	15,409	12.4	225	10.8	2,175	11.1	22,466	12.0
	Ground	Mun. & rural	6,151	10.5	31,243	12.5	643	11.3	5,810	11.3	43,848	12.0
		Total	103,423	13.1	171,948	13.9	41,213	-8.3	287,460	0.4	604,044	5.3
	Additional diversions		1,920		11,050		2,680		1,010		16,600	
2000	Surface	Agriculture	94,243	30.6	136,628	43.6	23,659	-25.0	222,374	-0.8	476,904	12.8
	Ground	Agriculture	9,079	40.5	16,302	44.3	8,357	-33.2	54,292	-1.0	88,031	3.4
	Ground	Mining	3,793	33.0	2,061	37.4	144	33.3	148	33.3	6,147	34.5
	Ground	Manufacturing	298	33.0	2,033	36.9	38	31.0	116	33.3	2,485	36.2
	Ground	Services	5,580	33.0	18,818	37.3	270	33.0	2,609	33.3	27,277	36.0
	Ground	Mun. & rural	7,324	31.6	38,169	37.4	774	33.9	6,987	33.8	53,254	36.1
		Total	120,317	31.6	214,011	41.8	33,242	-26.1	286,526	0.1	654,098	14.0
	Additional diversions		5,760		33,150		8,040		3,030		49,800	
2020	Surface	Agriculture	90,393	25.3	114,745	20.6	18,298	-42.0	220,345	-1.7	443,781	4.9
	Ground	Agriculture	7,842	21.4	13,031	15.3	5,527	-55.8	53,707	-2.1	80,106	-5.9
	Ground	Mining	4,421	55.0	2,435	62.3	169	56.5	173	55.9	7,198	57.5
	Ground	Manufacturing	347	54.9	2,395	61.3	44	51.7	136	56.3	2,922	60.1
	Ground	Services	6,503	55.0	22,220	62.1	314	54.7	3,043	55.5	32,080	59.9
	Ground	Mun. & rural	8,497	52.7	45,095	62.3	906	56.8	8,163	56.3	62,660	60.1
		Total	118,003	29.0	199,921	32.5	25,258	-43.8	285,567	-0.3	628,747	9.6
	Additional diversions		9,600		55,250		13,400		5,050		83,000	

in these two regions exceeds their 1970 depletions. Total surface water availability is reduced over time because of the increased effect of ground water pumping over time and the increases in pumpage necessary to satisfy growth requirements. This explains the reduction in surface water depletions in the Socorro region in 1980, in the Lower region in 2000, and in the three lower regions in 2020. The decrease in ground water depletions for agricultural use in the same years results from the fixed ground-surface relationship assumed for agricultural production. This assumption was necessary in order to avoid further surface flow depletions which would take place if ground water were substituted for surface water in agricultural production. The total surface water usage decreases in the fifty-year period due to the effect on the river of continued pumpage at an increasing rate, even though the total average flow in the Rio Grande is increasing by 110,000 acre-feet (from the San Juan-Chama).

Ground water depletions for nonagricultural use are expected to increase by 65,599 acre-feet (60 percent). Total water depletions are expected to increase only 9.6 percent and reach 628,747 acre-feet in 2020. This is almost 30,000 acre-feet less than the amount required where no water constraint was imposed.

The demand for agricultural products which could not be satisfied in this case is allowed to be supplemented by agricultural imports or by reduction of exports.

Alternative 3: Surface and ground water constraint. Production and water depletions in this alternative are presented in Tables 32 and 33. The additional constraint on ground water availability shows its impact mainly in the Socorro region where agricultural production must be reduced in order to release enough water rights to allow the other sectors to reach their required level. The cost of imposing the additional constraint on ground water is $2.7 million in 2020 when considering only a surface water constraint, and $16.9 million compared to the alternative without any constraint on water.

Table 32. Production ($1 million) and percentage change in production by region and sector--total water constraint

Year	Sector	Region									
		Upper Rio Grande		Middle Rio Grande		Socorro		Lower Rio Grande		Total Rio Grande region	
		Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)	Production ($1 million)	Change from 1970 (percent)
1970	Agriculture	12.2		21.7		8.6		46.3		88.8	
	Mining	55.8		45.1		2.4		4.7		108.1	
	Manufacturing	22.2		213.9		2.5		20.2		258.8	
	Services	322.7		1,181.1		23.2		144.3		1,671.3	
	Total	412.9		1,461.7		36.8		215.5		2,126.9	
1980	Agriculture	13.3	8.4	24.3	12.2	8.5	-0.9	47.8	3.3	94.0	5.8
	Mining	61.9	11.0	50.7	12.5	2.7	11.3	5.3	11.3	120.6	11.6
	Manufacturing	24.6	11.0	240.4	12.4	2.8	11.0	22.4	11.2	290.1	12.1
	Services	358.2	11.0	1,327.8	12.4	25.8	11.0	160.3	11.1	1,872.2	12.0
	Total	458.0	10.9	1,643.2	12.4	39.8	8.3	235.8	9.4	2,376.9	11.8
2000	Agriculture	14.7	19.9	28.5	31.5	8.4	-3.0	50.6	9.3	102.1	15.0
	Mining	74.2	33.0	62.0	37.4	3.3	34.0	6.3	33.8	145.8	34.9
	Manufacturing	29.5	33.0	293.2	37.1	3.3	33.2	26.9	33.6	352.9	36.4
	Services	429.2	33.0	1,621.2	37.3	30.9	33.1	192.2	33.3	2,273.7	36.0
	Total	547.6	32.6	2,004.9	37.2	45.9	24.7	276.2	28.2	2,874.5	35.2
2020	Agriculture	15.5	27.0	30.6	41.2	8.2	-5.0	53.0	14.4	107.3	20.8
	Mining	86.5	55.1	73.2	62.3	3.8	56.7	7.4	56.3	170.9	58.2
	Manufacturing	34.4	55.0	346.0	61.8	3.9	55.3	31.4	56.0	415.7	60.7
	Services	500.2	55.0	1,914.2	62.1	36.0	55.2	224.3	55.4	2,674.7	60.0
	Total	636.5	54.2	2,364.0	61.7	52.0	41.2	316.0	46.7	3,368.6	58.4

Table 33. Water depletions (acre-feet) and percentage change in water depletions by region and sector--total water constraint

Year	Water	Sector	Region Upper Rio Grande Water depletions (ac.-ft.)	Upper Rio Grande Change from 1970 (percent)	Middle Rio Grande Water depletions (ac.-ft.)	Middle Rio Grande Change from 1970 (percent)	Socorro Water depletions (ac.-ft.)	Socorro Change from 1970 (percent)	Lower Rio Grande Water depletions (ac.-ft.)	Lower Rio Grande Change from 1970 (percent)	Total Rio Grande region Water depletions (ac.-ft.)	Total Rio Grande region Change from 1970 (percent)
1970	Surface	Agriculture	72,150		95,166		31,529		224,106		422,951	
	Ground	Agriculture	6,460		11,299		12,516		54,842		85,116	
	Ground	Mining	2,852		1,500		108		111		4,570	
	Ground	Manufacturing	224		1,485		29		87		1,825	
	Ground	Services	4,195		13,705		203		1,957		20,060	
	Ground	Mun. & rural	5,565		27,780		578		5,222		39,144	
		Total	91,446		150,935		44,963		286,325		573,666	
1980	Surface	Agriculture	81,541	13.0	108,976	14.5	29,010	-8.0	223,443	-0.3	442,970	4.7
	Ground	Agriculture	7,659	18.6	12,965	14.7	11,183	-10.7	54,637	-0.4	86,444	1.6
	Ground	Mining	3,166	11.0	1,687	12.5	120	11.1	123	10.8	5,096	11.5
	Ground	Manufacturing	249	11.2	1,668	12.3	32	10.3	97	11.5	2,045	12.1
	Ground	Services	4,657	11.0	15,409	12.4	225	10.8	2,174	11.1	22,466	12.0
	Ground	Mun. & rural	6,151	10.5	31,243	12.5	643	11.3	5,810	11.3	43,848	12.0
		Total	103,423	13.1	171,948	13.9	41,213	-8.3	286,284	-0.0*	602,869	5.1
	Additional diversions		1,920		11,050		2,680		1,010		16,600	
2000	Surface	Agriculture	87,204	20.9	114,337	20.1	23,658	-25.0	219,402	-2.1	444,601	5.1
	Ground	Agriculture	7,949	23.1	13,329	18.0	8,357	-33.2	53,552	-2.4	83,187	-2.3
	Ground	Mining	3,793	33.0	2,061	37.4	144	33.3	148	33.3	6,147	34.5
	Ground	Manufacturing	298	33.0	2,033	36.9	38	31.0	116	33.3	2,485	36.2
	Ground	Services	5,580	33.0	18,815	37.3	270	33.0	2,609	33.3	27,273	36.0
	Ground	Mun. & rural	7,324	31.6	38,169	37.4	774	33.9	6,987	33.8	53,254	36.1
		Total	112,148	22.6	188,744	25.1	33,241	-26.1	282,814	-1.2	616,947	7.5
	Additional diversions		5,760		33,150		8,040		3,030		49,800	
2020	Surface	Agriculture	81,934	13.6	80,986	-14.9	18,298	-42.0	215,417	-3.9	395,634	-6.2
	Ground	Agriculture	6,484	0.4	8,528	-24.5	5,527	-55.8	52,479	-4.3	73,018	-14.2
	Ground	Mining	4,421	55.0	2,435	62.3	169	56.5	173	55.9	7,198	57.5
	Ground	Manufacturing	348	55.4	2,397	61.4	44	51.7	136	56.3	2,924	60.2
	Ground	Services	6,503	55.0	22,217	62.1	314	54.7	3,043	55.5	32,076	59.9
	Ground	Mun. & rural	8,497	52.7	45,095	62.3	906	56.8	8,163	56.3	62,660	60.1
		Total	108,187	18.3	161,658	7.1	25,258	-43.8	279,411	-2.4	574,510	0.2
	Additional diversions		9,600		55,250		13,400		5,050		83,000	

* Less than 0.05 percent.

Total value of annual output in the Rio Grande region is expected to increase by $1,241.7 million between the years 1970-2020. This increase of 58.3 percent is close to the projected population increase in the region.

Average annual surface water availability in the Rio Grande region in the base year 1970 was 527,100 acre-feet, 422,951 acre-feet of which were depleted. The total pumpage in the base year reached 300,000 acre-feet, 150,715 of which were depleted.

Total surface availability is reduced to 443,800 acre-feet by the year 2020 as a result of the increased effect of continued pumpage at an increasing rate. The increased demand for water by the nonagricultural sectors required a transfer of 47,166 acre-feet from surface rights to ground water pumpage. Annual agricultural production in 2020 is $18.5 million more than in 1970. The increase in agricultural production occurred primarily in the Middle Rio Grande region where water depletions in the base year reached only 55 percent of average annual availability which was 170,000 acre-feet. By the year 2020, total surface availability in that region had declined to 67.5 percent of the 1970 availability. In addition, increased demand for nonagricultural water use required the retirement of additional surface rights.

Summary. In the previous discussion three sets of alternatives were presented for the Rio Grande region. The first was an analysis of the region's growth without a water constraint. The second was an analysis of growth, holding surface water constraint. The third was an analysis of growth, holding both surface and ground water constraint. A summary of the solutions for these alternatives is presented in Table 34.

Without a water constraint, both production and depletions are expected to exhibit the largest increase (59.2 percent and 49.6 percent, respectively). When a surface water constraint is imposed, the value of production is reduced by only $5.6 million in 2000 and by $14.2 million in 2020 (Table 34). Water depletions are expected to decrease about 27 percent (229,340 acre-feet) in 2020 when imposing a surface water constraint (Table 34 and Figure 18).

Table 34. Summary of alternative solutions for the Rio Grande region, New Mexico

Alternative	Sector	1970		1980		2000		2020	
		Production ($1 million)	Depletion (acre-feet)	Production ($1 million)	Depletion (acre-feet)	Production ($1 million)	Depletion (acre-feet)	Production ($1 million)	Depletion (acre-feet)
NO WATER CONSTRAINT									
	Agriculture	88.8	508,067	95.5	557,302	108.9	655,928	122.1	753,203
	Mining	108.1	4,570	120.6	5,096	145.8	6,147	170.9	7,199
	Manufacturing	258.8	1,825	290.2	2,046	353.0	2,486	415.8	2,927
	Services	1,671.3	20,060	1,872.3	22,468	2,274.5	27,283	2,676.6	32,098
	Mun. & rural	-	39,144	-	43,848	-	53,254	-	62,660
	Total	2,126.9[1]	573,666	2,378.7[1]	630,760	2,882.1[1]	745,098	3,385.5[1]	858,087
	Additional diversions				16,600		49,800		83,000
SURFACE WATER CONSTRAINT									
	Agriculture	88.8	508,067	94.0	530,589	103.9	564,935	109.8	523,887
	Mining	108.1	4,570	120.6	5,096	145.8	6,147	170.9	7,198
	Manufacturing	258.8	1,825	290.1	2,045	352.9	2,485	415.5	2,922
	Services	1,671.3	20,060	1,872.2	22,466	2,274.0	27,277	2,675.0	32,080
	Mun. & rural	-	39,144	-	43,848	-	53,254	-	62,660
	Total	2,126.9[1]	573,666	2,377.0[1]	604,044	2,876.5[1]	654,098	3,371.3[1]	628,747
	Additional diversions				16,600		49,800		83,000
TOTAL WATER CONSTRAINT									
	Agriculture	88.8	508,067	94.0	529,414	102.1	527,788	107.3	469,652
	Mining	108.1	4,570	120.6	5,096	145.8	6,147	170.9	7,198
	Manufacturing	258.8	1,825	290.1	2,045	352.9	2,485	415.7	2,924
	Services	1,671.3	20,060	1,872.2	22,466	2,273.7	27,273	2,674.7	32,076
	Mun. & rural	-	39,144	-	43,848	-	53,254	-	62,660
	Total	2,126.9[1]	573,666	2,376.9	602,869	2,874.5	616,947	3,368.6	574,510
	Additional diversions				16,600		49,800		83,000

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[1] Does not add due to rounding.

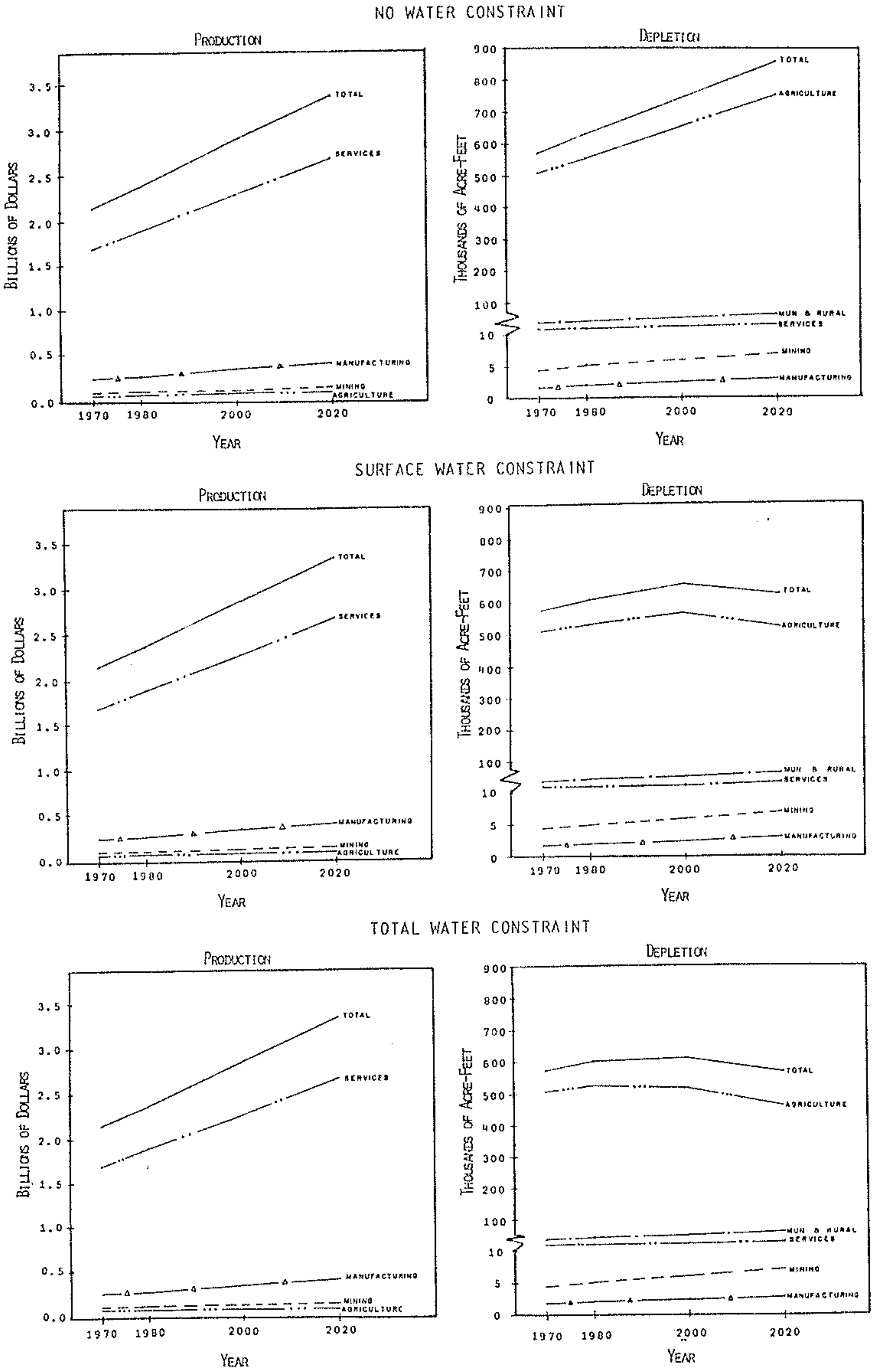

Figure 18. Summary of alternative solutions for the Rio Grande region, New Mexico

In 2000, when a total water constraint is imposed, value of production is decreased by $2.0 million below that expected when using only a surface water constraint and water depletions are reduced only by about 37,000 acre-feet (Table 34). In 2020 the value of production is expected to be reduced to $3,368.6 million, decreased $2.7 million before the value obtained when only a surface water constraint is imposed and decreased by $16.9 million below the no-water-constraint alternative (Table 34).

Water depletions are expected to decrease from 858,087 acre-feet without any water constraints to 574,510 acre-feet with a total water constraint, a 33 percent reduction. The impact of this reduction is expected to be felt mainly in the Middle Rio Grande and Socorro regions where agricultural water depletions must be reduced in 2020 to release enough water rights for the other sectors' growth. The Middle Rio Grande region is expected to deplete for nonagricultural uses all of the surface water rights by the year 2075. Without water imports, increased pumpage restrictions will have to be placed on manufacturing, services, and municipal water usage at this time. Any allocation of surface water rights to agriculture will require these changes at an earlier date. Another alternative might be interregional transfer of water rights. The other regions are expected to have enough surface water rights to last for many years. The Albuquerque metropolitan area has about 90 percent of the expected population increase in the total Rio Grande region, and the pumpage necessary to sustain its growth increases its effect on the Rio Grande flow by more than 1,000 acre-feet annually.

The supply of water for water-based recreation is expected to be the highest under the alternative of no water constraint (Table 35), and reduced about 5 percent when a constraint is placed on the importation of surface water or mining of ground water. The major effect is felt in the surface water where all of the water-based recreation occurs.

Table 35. Estimated water-based recreation by type in the Rio Grande region

	Water Skiing	Boating	Fishing
	. . . . (activity-occasion days)	. . . .	
No Water Constraints			
1970	817,773	480,389	1,872,950
1980	858,247	504,584	1,904,992
2000	939,195	552,975	2,591,525
2020	1,132,085	596,668	2,643,000
Surface Water Constraints			
1970	817,773	480,389	1,872,950
1980	858,347	504,625	2,015,576
2000	939,285	553,210	2,595,245
2020	1,160,546	596,894	2,643,000
Surface & Ground Water Constraints			
1970	817,773	480,389	1,872,950
1980	858,273	504,624	1,904,542
2000	939,332	553,356	2,592,460
2020	1,134,160	596,919	2,643,000

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APPENDIX A: SOCIO-ECONOMIC MODEL

The socio-economic model is essentially an interregional linear programming model for the State of New Mexico. The objective function for the model can be represented by the following equation:

$$\text{Maximize} \sum_{i=1}^{5} \sum_{j=1}^{24} X_{ij} V_j - \sum_{i=1}^{5} \sum_{k=1}^{3} \sum_{s=1}^{2} PR_{iks} CPR_{iks}$$

$$- \sum_{i=1}^{5} \sum_{\substack{i'=1 \\ i \neq i'}}^{5} \sum_{k=1}^{3} \sum_{s=1}^{2} TR_{ii'ks} CTR_{ii'ks}$$

$$- \sum_{i=1}^{5} \sum_{l=1}^{2} PPOL_{il} CPPOL_{il} - \sum_{i=1}^{4} \sum_{\substack{i'=1 \\ i' \neq i}}^{4} \sum_{l=1}^{2} \sum_{s=1}^{2} TPOL_{ii'ls} CTPOL_{ii'ls}$$

$$- \sum_{i=1}^{4} \sum_{\substack{i'=1 \\ i \neq i'}}^{4} \sum_{s=1}^{2} TW_{ii's} CTW_{ii's} - \sum_{i=1}^{5} UE_i CUE_i$$

$$- \sum_{i=1}^{5} PL_i CPL_i - \sum_{i=1}^{5} \sum_{s=1}^{2} PW_{is} CPW_{is}$$

Definition and description of symbols:

- i is the number of the region.
- i' is the number of the region into which the particular "resource" is being transferred.
- j is the number of the sector.
- k is the type of recreation.
- l is the type of pollution.
- s is the season (as defined for the model).

$i = 1$ Region 1 Upper Rio Grande River Basin
2 Region 2 Middle Rio Grande River Basin
3 Region 3 Socorro Basin
4 Region 4 Lower Rio Grande River Basin
5 Region 5 Rest of the State

$j = 1\text{-}24$ See Table 12 for classification and description of production sectors

$k = 1$ Boating (primarily pleasure)
2 Waterskiing
3 Fishing (both warm and cold water)

$s = 1$ Summer
2 Winter

$l = 1$ BOD
2 TDS

X_{ij} = The level of activity in million dollar units of a particular sector j within region i.

V_j = The value added per unit (million dollar units) of a particular sector j (assumed to be equal in all regions--explained in greater detail later).

PR_{iks} = The amount of additional recreational "use" in activity occasions in region i of type k in season s to satisfy demands.

CPR_{iks} = The cost of a unit (activity occasion) of additional recreational "use" in region i of type k in season s.

$TR_{ii'ks}$ = The amount in activity occasions of recreational "use" transferred from region i to region i' of type k in season s.

$CTR_{ii'ks}$ = The cost per unit (activity occasion) of transferred recreational "use" from region i to region i' of type k in season s.

$PPOL_{il}$ = The amount of pollution in pounds in region i of type l charged to the system to meet standards.

$CPPOL'_{il}$ = The cost per unit (pounds) of "purchased" pollution in region i of type l.

$TPOL_{ii'ls}$ = The amount of pollution in pounds transferred from region i to region i' of type l in season s.

$CTPOL_{ii'ls}$ = The cost per unit (pounds) of transferred pollution from region i to region i' of type l in season s.

$TW_{ii's}$ = The amount of water in acre-feet transferred from region i to region i' in season s (surface water only).

$CTW_{ii's}$ = The cost per unit (acre-feet) of transferred water from region i to region i' in season s.

UE_i = The amount of labor in employees in region i that remains unemployed within the system.

$CUE_{i'}$ = The cost per unit (employee) of unemployed labor in region i.

PL_i = The amount of labor in employees needed from the outside in region i.

$CPL_{i'}$ = The cost per unit (employee) of "additional" labor.

PW_{is} = The amount of water in acre-feet purchased in region i in season s (surface water only).

$CPW_{i's}$ = The cost per unit (acre-feet) of purchased water in region i in season s.

The objective function is set up to maximize value added within the state subject to several separate cost components. Typically, value added per unit (V_j) measures the payment to households as wages, payments to governments as taxes, and payments to business as profits. The goal, therefore, is to maximize this "net addition" to the state. The cost components serve as mechanisms to encourage the system to use as little as possible of the "resources" that these cost components reflect.

The first cost component (CPR_{iks}) puts a fairly high price in the initial model on generating recreation capacity in a region. This serves to minimize any building of recreational facilities to satisfy demands until all present resources are utilized and maximum transfers have taken place. The second cost component ($CTR_{ii'ks}$) serves to place a price on the system upon "transferring" recreational capacity. This cost is less than the cost associated with generating capacity to insure all recreational capacity within the state is utilized to satisfy demands before construction starts on further capacity. However, a cost still exists because there is a certain decrease in use if one has to travel to other regions to use facilities.

The third cost component ($CPOL_{ils}$) assigns a price to the system of cleaning up the streams once the standards have been violated. Therefore, there is a cost assigned to the system for exceeding the pollution-carrying capacity of streams. The fourth cost component ($CTPOL_{ii'ls}$) is assigned to transferring pollution-carrying capacity among the regions. This cost, as in recreation, is less than the cost of cleaning up a region's stream. The cost varies depending on several stream flow characteristics and the actual point of pollution within one region in relation to another region.

The fifth cost component ($CTW_{ii's}$) places a price upon the transfer of surface water from one region to another. There is a definite loss or gain of water when its use is transferred down or up-stream. There is a loss of pollution-carrying capacity and recreational use to the region initiating the transfer. In addition, legal constraints and costs exist within any transfer mechanism. Therefore, a cost is assigned to the system of transferring this important resource from region to region.

The cost (CUE_i) assigned to the system for "allowing" unemployment within a region becomes the sixth component. Unemployment insurance, welfare payments, etc. are just a few of the elements considered in the cost to the state as a whole.

There is a definite price (CPW_{is}) charged to the system from any additional water made available for use within a region. This availability could be water salvage, intrabasin purchases and transfers, purchases of ground water supplies, or the acquisition of water rights. These will all have a price which is the seventh cost component. If labor is needed from outside the system, a very high price (CPL_i) is charged for acquiring such labor. The price is assigned so that no labor should be purchased unless mistakes have been made in calculating labor use and coefficients initially.

The objective function is thus concerned with maximizing value added subject to these costs.

- (1) Under-utilization of the labor force (unemployment).
- (2) Transferring.
  - a) Pollution-carrying capacity of a stream.
  - b) Excess recreation capacity.
  - c) Excess water.
- (3) Maintaining stream standards.
- (4) Creating additional recreational use capacity.
- (5) Adding additional water to each region.
- (6) Transferring additional labor to the system.

The actual value of the objective function is not really important: only the relative differences when various transfers, movements, and additions of resources are used in solving the model. In addition, differential pricing in the cost components can be considered and weighed by using the mechanism of the objective function to assign relative weights to all activities.

Model Constraints

Production Constraints

$$\sum_{i=1}^{5} \sum_{j=1}^{24} a_{ij} X_{ij} \geqq FD_{j*} \text{ for all } i*, j* \quad i* = 1,\ldots,5 \quad j* = 1,\ldots,24$$

a_{ij} = Coefficient in the I-A matrix for each region i and each sector j.

X_{ij} = Amount of production (activity) in region i of sector j.

FD_{j*} = Represents the actual calculated final demand figure for all sectors within the state, where j* represents the sector number associated with the actual constraint. (Asterisks denote constraint side of the equation.)

Each sector must produce a specified amount of product for final consumption. This constraint equation insures that the specific final demand is met for each production sector by each region's associated production sector. The a_{ij}'s serve to fix a technical relationship between and among all the sectors. The a_{ij}'s were derived from a regional input-output table (which will be discussed shortly). This constraint simply states that each and every production activity will have to be at least as great as a predetermined final demand for that activity. Final demand includes not only goods and services purchased within the state, but exports as well.

Labor Constraint

$$\sum_{j=1}^{24} l_{ij}X_{ij} + UE_i + \sum_{m=1}^{3} S_{mi} = LA_{i*} \qquad \text{for all } i^* \quad i^* = 1,\ldots,5$$

l_{ij} = Labor coefficients per unit of output for each region and each sector.

X_{ij} = Amount of production (activity) in region i of sector j.

UE_i = Unemployment (number within the total available labor force) in region i.

S_{mi} = Type of service employment within each region i--consists of three categories: 1) governmental, 2) nonagricultural, and 3) miscellaneous.

LA_{i*} = Labor availability within each region i^*. (Asterisks denote constraint side of the equation.)

Each production activity per unit requires a certain amount of labor to produce it. The l_{ij}'s were derived for each sector within each individual region from ESC data by using primary (2 digit) SIC codes. These l_{ij}'s are computed on covered and reported wage and salary works. The ESC also makes estimates of the number of people in certain employment groupings for each county. The three types of service employment were developed from these estimates to insure all employment would be accounted for within the model. Unemployment was added as a separate item with a cost in the objective function to account for all the labor availability. Thus, the sum of all labor used by the 24 production sectors, plus a given amount of "service" type of employment, plus any unemployment that exists must be equal to the labor available for each region. Presently, the labor constraint allows no labor movement among the unemployed in each region.

Recreation Constraint

$$\sum_{j=1}^{24} r_{ijks}X_{ij} - PR_{iks} - \sum_{\substack{i'=1\\ i\neq i'}}^{5} TR_{ii'ks} + r_{iks}UE_{i} + \sum_{m=1}^{3} r_{imks}S_{mi} \leq RCP_{i*k*s*}$$

for all $i*$, $k*$, $s*$, $i* = 1,\ldots,5$ $k* = 1,.,3$ $s* = 1,2$

r_{ijks} = Recreation coefficient related to employment--represents the recreation "demanded" by each employee and his family employed in sector j within region i of type k in season s.

X_{ij} = Amount of production (activity) in region i of sector j.

PR_{iks} = The amount of recreation "use" required in region i of type k in season s to meet the "demand" created within the system (represents the amount not presently available within the region or "transferrable" to the region).

$TR_{ii'ks}$ = The amount of recreation available in region i that was utilized by region i' of type k in season s (a cost is imposed to the system in the objective function).

r_{iks} = Represents the recreation "demanded" by each unemployed person and his family in region i of type k in season s.

UE_{i} = Amount of unemployment within region i.

r_{imks} = Represents the recreation "demanded" by each person and his family within all three service groups in region i of type k in season s.

S_{mi} = Amount of service type (three possible) of employment in region i.

RCP_{i*k*s*} = Recreational capacity (utilization ratios of full capacity rates) within region i* of type k* in season s*. (Asterisks denote constraint side of equation.)

Given a certain assumed capacity for each type of recreational activity, a constraint is placed upon the system. "Transfers" or movements from one region to another are allowed once the capacity within a certain region is reached. In addition, a mechanism is provided whereby the system is allowed to generate new recreational capacity at a cost (PR_{iks}). The recreational coefficients were derived from data developed by the OBRRC in the early 1960's. These coefficients were developed for each employment type which was classified into several different groupings and for each season as defined for the model. Because the report used only a survey for people 12 years old and over, the coefficients also assume only the population 12 years and older within each region. Family size per employee is also based upon the 12 years and older population when aggregating coefficients to arrive at a coefficient that will represent employees in a particular sector j within a region i and his "family."

The transfers are allowed to take place among all regions to insure that all recreational capacity is utilized before new recreational capacity is allowed to be generated. A transfer here implies that someone in region 3 will travel to region 4 to enjoy boating where unused capacity exists instead of building a reservoir within region 3.

Although the unemployed have fewer resources and money, they still "demand" a certain amount of recreation. Therefore, coefficients were developed for this segment of the labor force and their families. The service employment coefficients were derived also to insure all the labor force and associated families were represented in this constraint.

Capacity for each recreational activity within the model was developed by using certain standards for each activity, compiling a maximum use estimate, and deriving probable maximum utilization rates for each given the region and activity.

Regional recreational counter:

$$\sum_{j=1}^{24} r_{ijks} X_{ij} - PR_{iks} + r_{iks} UE_i + \sum_{m=1}^{3} r_{imks} S_m - C'R_{i*k*s*} = 0$$

for all i*, k*, s*   i* = 1,...,5 k* = 1,1,3   s* = 1,2
where all the coefficients and activities except $C'R_{i*k*s*}$ have the same definition and value as in the recreation constraint.

$C'R_{i*k*s*}$ = The amount of recreation activity consumed of type k* in season s* in region i* by all users within region i* (where the asterisks denote the constraint side of the equation).

This counter was added to record the amount of a recreational activity actually consumed by the "demanders" that reside within a particular region itself. Because of the allowance of a transfer mechanism, many users in other regions could be using recreational activities in this particular region. Thus, this counter mechanism was established to keep track of recreational "demand" generated within, and consumed by, the region.

Water Constraint

$$\sum_{j=1}^{24} w_{ijns} X_{ij} + \sum_{k=1}^{3} W_{iks} PR_{iks} + \sum_{p=1}^{2} w_{ip} P_{ip} - \sum_{\substack{i'=1 \\ i \neq i'}}^{4} TW_{ii'ns} \leq WA_{i*n*s*}$$

for all i*, n*, s*   i* = 1,...,5   n* = 1,2   s* = 1,2

w_{ijns} = Water coefficient per unit of output in region i of sector j of either surface (n = 1) and/or ground (n = 2) in season s.

X_{ij} = Amount of production (activity) of sector j in region i.

w_{iks} = Water coefficient for each region i of recreational activity k in season s.

PR_{iks} = The amount of recreational activity of type k in region i in season s generated (created) to satisfy "demands."

w_{ip} = Water coefficient per unit of population, either urban ($p = 1$) or rural ($p = 2$) in region i.

P_{ip} = The population, urban and rural, in region i.

$TW_{ii'ns}$ = The amount of water transferred from region i to region i' (only within the four regions contained in the RGRB) of type n (surface only initially - $n = 1$) in season s.

WA_{i*n*s*} = Water availability in region $i*$ in season $s*$ of type $n*$. (Asterisks denote constraint side of equation.)

The agricultural and recreation uses constitute the only surface water use in the model as it is presently set up. The surface coefficients for agriculture were derived from consumptive use data supplied from NMSU Agricultural Economics Department (Table A-1).

Ground-water users in the model constitute all production sectors, including a portion of agriculture, and the urban and rural population (Table A-1). These coefficients were derived from various sources; the basic ones were national use studies, studies on water use from other states, and the New Mexico Engineer Office.

At present a transfer mechanism is incorporated within this water constraint for surface water flows only. In addition, these transfers are allowed only within the RGRB among the four regions.

Regional water counter:

$$\sum_{j=1}^{24} w_{ijns} X_{ij} + \sum_{k=1}^{3} w_{iks} PR_{iks} + \sum_{p=1}^{2} w_{ip} P_{ip} - C'W_{i*n*s*} = 0$$

for all $i*$, $n*$, $s*$ $\quad i* = 1,\ldots,5 \quad n* = 1 \quad s* = 1,2$

where all the coefficients and activities, except $C'W_{i*n*s*}$, have the same definition and value as in the water constraint.

Appendix A

Table A-1. Water depletion coefficients by region and production sector for surface and ground water in acre-feet per million dollars output and for municipal and rural use in acre-feet per 1000 persons

Sector		Upper Rio Grande Region	Middle Rio Grande Region	Socorro Region	Lower Rio Grande Region
		- - - - - - - - Acre-feet per million dollars output - - - - - - - - - - - - - - - -			
Surface Water Coefficients					
Agriculture	1	3,686.19	1,142.02	1,137.47	564.20
	2	21,859.31	21,434.19	13,758.88	14,928.35
	3	0.00	0.00	10,064.73	12,539.99
	4	8,287.56	8,211.33	6,725.62	1,950.84
Ground Water Coefficients					
Agriculture	1	57.60	49.70	49.88	33.89
	2	3,509.38	2,857.89	7,003.54	3,717.65
	3	0.00	0.00	5,123.15	3,122.87
	4	1,330.52	1,094.84	3,423.47	485.83
	5	12.00	12.00	12.00	12.00
Mining, Oil, and Gas	6	45.80	28.71	44.06	23.42
	7	60.85	60.02	0.00	0.00
Manufacturing	8	3.01	3.01	3.01	3.01
	9	4.27	4.27	4.27	4.27
	10	0.00	1.36	0.00	5.61
	11	20.48	14.27	21.77	11.10
	12	16.63	15.61	24.43	6.31
	13	0.00	37.42	0.00	0.00
	14	1.61	2.28	1.61	1.78
	15	4.29	2.33	1.50	2.75
Commercial trade and services	16	2.50	2.49	2.49	2.49
	17	2.50	2.49	2.49	2.49
	18	47.75	38.63	50.78	58.88
	19	4.91	4.91	4.91	4.91
	20	5.30	5.44	5.88	9.04
	21	9.82	9.82	9.82	9.86
	22	14.20	12.58	13.52	12.07
	23	12.30	12.30	12.30	12.30
	24	17.62	17.62	17.62	17.62
		- - - - - Acre-feet per 1000 persons -			
Municipal		65.00	85.00	85.00	85.00
Rural		42.00	42.00	42.00	42.00

$C'W_{i*n*s*}$ = The amount of water actually consumed by the users within a particular region $i*$ in season $s*$, where $n* = 1$--surface water only as the model is now set up.

This counter was added to record the amount of surface water actually used by sectors within a particular region i, including the residents within the same region. Because of the allowance of a transfer mechanism, users in the other regions within the RGB may be using region i's water. Thus, the counter mechanism was established to keep track of water use within the region.

The population withdrawal coefficient is negligible at present, based upon the assumption that uses are supplied from ground water only.

Pollution Constraint

$$\sum_{j=1}^{24} P_{ijls}X_{ij} + \sum_{p=1}^{2} P_{ips}P_{ip} - \sum_{s=1}^{2} POL_{ils} - \sum_{\substack{i'=1\\ i'\neq 1}}^{4} TPOL_{ii'ls} \leq POLCP_{i*l*s*}$$

for all $i*$, $l*$, $s*$ $\quad i* = 1,\ldots,5 \quad l* = 1,2 \quad s* = 1,2$

P_{ijls} = Pollution coefficient for sector j in region i of either BOD ($l = 1$) or TDS ($l = 2$) in season s.

X_{ij} = Amount of production (activity) of sector j in region i.

P_{ips} = Pollution coefficient of either urban ($p = 1$) or rural ($p = 2$) population in region i in season s.

P_{ip} = Urban or rural population in region i.

POL_{ils} = Amount of pollution needing to be cleaned up by the system (at a cost) to maintain stream standards in region i of either BOD or TDS in season s.

$TPOL_{ii'ls}$ = Amount of pollution capacity in type l (BOD or TDS) that is "transferred" from region i to region i' in season s.

$POLCP_{i*l*s*}$ = Pollution capacity in region $i*$ of type $l*$ in season $s*$.(Asterisks represent constraint side of the equation.)

Assuming the stream serves as a carrier of wastes, the amount of total use by all users in region i cannot exceed a certain standard. The coefficients were derived from many and varied sources, and therefore represent many different opinions of the magnitude of the prevalent pollution. Although the vast majority of the 24 production sectors in each region are served by municipal sewer systems, a net contribution was still estimated for each. Agricultural, mining, and municipal components of the model are the chief polluters in New Mexico.

When excess pollution capacity exists within a region it is allowed to be "transferred" to another region in the RGB. The transfer mechanism does have a cost when used by other regions. If stream standards are above the present quality, one region may be able to pollute the stream further given that the standards are again met when measured in the first region.

A mechanism was incorporated within this constraint to allow the system, through each individual region, more pollution from the users of the stream as long as each region is allowed to "clean up" the excess over the standards. The cost figure assigned to such a process was fairly high due to scales of economies and present technology levels within the treatment industry.

Pollution carrying capacity of each segment of the stream (regional boundaries) can be estimated by using stream standards as the maximum limit. Of course, within each region the actual extent of the pollution will depend on the actual place where BOD and TDS enters the waterway as well as certain characteristics of the stream flow at the time. In the present model, due to the lack of appropriate secondary sources of data, only very general averages were used.

Regional pollution counter:

$$\sum_{j=1}^{24} P_{ijls} X_{ij} + \sum_{p=1}^{2} p_{ip} P_{ip} - \sum_{s=1}^{2} POL_{il} - C'POL_{i^*l^*s^*} = 0$$

for all i^*, l^*, s^* $i^* = 1,\ldots,5$ $l^* = 1,2$ $s^* = 1,2$

where all the coefficients and activities, except $C'POL_{i^*l^*s^*}$, have the same definition and value as in the pollution constraint.

$C'POL_{i*l*s*}$ = The amount of pollution-carrying capacity actually required by the users within a region i* that reside in region i*. (Asterisks denote constraint side of equation.)

This counter was added to record the amount of pollution-carrying capacity, by type and season, actually needed and used by users within a particular region i*. Because of the allowance of a transfer mechanism, users in other regions may make use of unused capacity within region i*. Only the regions that encompass the RGB are allowed to transfer the unused capacity to one another. Thus, the counter mechanism was established to keep track of pollution requirements within the region where all the users reside within the same region.

Population Constraint

$P_{ip} = POP_{i*p*}$

for all i*, p* $i* = 1,\ldots,5$ $p* = 1,2$

P_{ip} = A counter mechanism (coefficient of variable in the model = 1) to force each region to incorporate the reported urban and rural population within the system (p = 1, urban; p = 2, rural).

POP_{i*p*} = The number of urban (p = 1) and rural (p = 2) population within region i. (Asterisks denote the constraint side of the equation).

This constraint was designed so that the model would be forced to use the reported population figures. The urban and rural populations both have several requirements that must be met, thus the constraint. Water use and needed pollution-carrying capacity by region are the two requirements that must be satisfied within the mechanism of the model. The procedure used above in the population constraint was the most efficient to insure that requirements and needs of the population were incorporated into the model.

Service Employment (Labor) Constraint

$S_{im} = SER_{i*m*}$

for all $i*$, $m*$ $\quad i* = 1,\ldots,5 \quad m* = 1,2,3$

S_{im} = A counter mechanism to force each region i to employ a given amount of labor of type m.

SER_{i*m*} = The actual calculated figure for each type $m*$ of service employment in region $i*$. (Asterisks denote constraint side of the equation.)

Since the labor coefficients were derived using ESC data, only covered and reported employment within each region were used for the production sector derivation purposes. A large amount of estimated labor still existed which was taken care of by this constraint. Each region is forced to employ a given number of people in three types of subsidiary services: government; nonagricultural, which includes many varied skill types; and miscellaneous.

Outside Labor Constraint

$PL_i \leq PLCP_{i*}$

for all $i*$ $\quad i* = 1,\ldots,5$

PL_i = Amount of labor actually needed over and above what is available within a region i (available at a substantial cost).

$PLCP_{i*}$ = The maximum amount of labor outside that could be available. (Asterisk denotes the constraint side of the equation.)

The main purpose of this constraint was to allow the system to "purchase" labor from outside the region if mistakes had been made in the calculation and estimation of the labor coefficients. A very high price is placed upon the activity of "purchasing" outside labor to insure that the system is only allowed to use what is available within each region.

Outside Water Constraint

$$PW_{ins} \leq PWCP_{i^*n^*s^*}$$

for all i^*, n^*, s^* $i^* = 1,\ldots,5$ $n^* = 1$ $s^* = 1,2$

PW_{ins} = The amount of water needed from outside region i (after transfer within the basin has been exhausted) to satisfy demands in surface water only ($n = 1$) in season s.

$PWCP_{i^*n^*s^*}$ = The amount of outside transfer availability to a particular region i^* in season s^* of surface water only in the present model. (Asterisks denote the constraint side of the equation.)

This constraint allows for purchase and inter-basin transfers of surface water from areas outside of the state. It also allows for net additions from water salvage of any type within a particular region. This constraint allows the model to test for the effects of additional water into a particular region. Any number of additional acre-feet with varying costs may be added with the mechanism and procedure set up by this constraint.

APPENDIX B

SOIL PRODUCTIVITY GROUPS IN THE RIO GRANDE REGION, NEW MEXICO

Group I

Soils in productivity Group I have few limitations that restrict their uses for irrigated crop production and are suited to a wide range of crops, especially those common to the Rio Grande region. Some soils in Group I have certain slight limitations which require more careful management practices. As a group, however, they have few limitations, and in most cases corrective management practices are easy to apply. The following limitations may occur either singly or in combination: (1) gentle slopes;(2) moderate susceptibility to shallow water tables and accumulation of alkali;(3) moderate effects of past erosion; (4) somewhat unfavorable soil structure and workability. These soils may require special soil-conserving cropping systems, soil conservation practices, and tillage methods (such as terracing, bordering, strip cropping, fertilization, green manure crops, deep plowing, or specialized land planning), depending on the occurrence and severity of the above limitations. The exact combination of practices varies from area to area, depending on the soil characteristics and farming systems. Group I soils account for about 11 percent of the irrigated acreage in the Rio Grande region.

In the Upper, Middle, and Socorro regions, the soils are deep and of desirable texture which, combined with a favorable structure, makes them relatively easy to till; and under cultivation a good tilth can be obtained if properly handled. They are sufficiently drained and free from toxic concentrations of soluble salts. The soils in this group are naturally productive and practically free of gravel and stones. The water-holding capacity is good, and consequently the amount of water required to produce crops is not excessive. The surface of the land in this group is level or very gently sloping, which makes it susceptible to easy irrigation. There is no accelerated erosion of any type on these lands, and they are not subject to overflow from arroyos which would tend to deposit detrimental material. The productive capacity is high since they either have a high fertility level or they respond well to fertilizer inputs. Moisture penetration is generally moderate.

In the Lower region, the soils are generally deep, medium textured, moderately stratified, and almost level. The productive capacity is high since they either have a high fertility level or they respond well to fertilizer inputs. Moisture penetration is moderate and the textures are conducive to easy handling.

Group I soils account for less than one percent of the irrigated acreage in the Upper region, about ten percent in the Middle region, about nine percent in the Socorro region, and about twenty percent in the Lower region.

(The above described soil productivity groups and those described in Table B-1 were defined for purposes of this study and are not necessarily consistent with Soil Conservation Service classifications.)

Group II

Group II soils account for about 42 percent of the irrigated acreage in the Rio Grande region. Soils in this group have certain moderate restrictions that reduce the choice of crops, reduce their productive capabilities, or require special management practices. The conservation and management practices required are usually more difficult to apply and maintain on these soils than on the Group I soils. These soils are fairly well adapted to irrigated agriculture, but were classified in this group because their productive capabilities were somewhat limited for general farming.

The limitations may restrict the amount of clean tillage, timing of planting, tillage, and harvesting, or some combination of these. The limitations may result from the effects of one or more of the following: (1) moderate slopes; (2) moderately high water tables and accumulations of alkali; (3) high moisture penetration; (4) low moisture-holding capacity; (5) low fertility; and (6) moderate salinity or sodium content.

Soils in Group II commonly require grade leveling and deep plowing to expose and break up the highly stratified subsoil textures. In some areas of the region, part of the soils in Group II have limited use because of high water table, slow permeability, and the hazard of alkali accumulation. Each distinctive kind of soil in Group II has one or more special managerial requirements for successul use, generally due to either moderate amounts of alkali, unfavorable soil characteristics, topography, erosion, or impeded drainage.

The amount of irrigation water required to produce crops is comparatively high as these soils have a low water-holding capacity. They require frequent and light irrigations, and if water is not always available for these needed frequent irrigations, crop failures are apt to result.

This group accounts for about 27 percent of the irrigated acreage in the Upper region, about 52 percent in the Middle region, about 56 percent in the Socorro region, and about 47 percent in the Lower region.

(The above described soil productivity groups and those described in Table B-2 were defined for purposes of this study and are not necessarily consistent with Soil Conservation Service classifications.)

Group III

Soils in Group III have severe limitations that restrict the choice of crops, require careful management, or both. They account for 47 percent of the irrigated acreage in the Rio Grande region. This group included lands mapped as nonagricultural but which were being farmed. These soils include shallow unproductive soils in areas subject to overflow from arroyos, and very heavy, compact, and moderately impervious clay soils which have a high content of salts and a rather high alkaline reaction. Alkali was an important factor in the classification of lands in this group. Where alkali is the only limiting factor, these lands can be improved to Group II by the leaching out of excess salts under favorable water-table and drainage conditions. In general, however, alkali was usually associated with other limiting factors, such as unfavorable soil characteristics and impeded drainage.

Crop selections are more limited for these soils than for soils in Group II. Conservation practices are more difficult to apply and maintain. Soils in Group III may be well suited for only one or two of the common crops, or the yield may be low in relation to inputs over a long period of time. Use for cultivated crops is limited as a result of one or more permanent features such as: (1) steep slopes; (2) severe susceptibility to water and wind erosion; (3) severe effects of past erosion; (4) shallow soils; (5) low moisture-holding capacity; (6) excessively high water tables; and (7) severe salinity or sodium accumulations.

In the Upper region, the soils are primarily mountain soils of relatively recent origin and in most cases are shallow, gravelly, and contain little organic matter. Group III soils occur in relatively large areas and are widespread throughout the Upper region, accounting for over 72 percent of the irrigated acreage.

In the Middle Rio Grande region, Group III includes about 38 percent of the irrigated croplands. They are located primarily along the river and near the sides of the valley. They are widespread in the western part of the region in the tributary areas, and account for a larger percentage of the irrigated cropland in the western area than in the eastern area in this region.

In the Socorro region, Group III includes about 35 percent of the irrigated croplands. They are located primarily along the river and near the sides of the valley. In many cases these soils occur in small, isolated areas within farming units; their influence is exerted on the surrounding farmland since they are subject to wind and water erosion and require more special management than either of the other groups.

In the Lower region, Group III soils account for about 33 percent of the total acreage of irrigated croplands. The Group III soils are located primarily along the river, near the sides of the valley, and in the tributary areas. They occur in this region also in small, isolated areas within farming units.

(The above described soil productivity groups and those described in Table B-3 were defined for purposes of this study and are not necessarily consistent with Soil Conservation Service classifications.)

APPENDIX B

Table B-1. Principal soils in productivity Group I, Rio Grande region, New Mexico

Map Symbol	General Location*	Soil Name	Soil Description
120	I	Jocity loam, 0 to 1 percent	These soils are deep (40" or more), with loamy surface soils and subsoils. They have moderate water-holding capacity, and minor slopes.
41	I	El Rancho clay loam, 0-1 percent	These soils are deep, moderately permeable, occur on nearly level slopes. The erosion hazard is slight.
Sa	II	San Jose loam, 0-1 percent slopes	These soils are well-drained, reddish-brown, calcareous, alluvial soils that developed on flood plains and low terraces. The parent material is stratified, but predominantly medium-textured, calcareous alluvium. These soils have moderate to rapid permeability, low salinity hazard, and good workability.
Sb	II	San Jose loam, sandy substratum, 0-1 percent slopes	
+/A-(2)1	II, III	Anthony clay, 0-1%	These soils are level to gently sloping. They have no apparent erosion or drainage problems, and the subsoils are predominantly of poorly stratified, light-textured materials. Strata of porous gravelly materials are also quite common in the subsoil. Typically, a slight lime accumulation zone is found at depths of 2 to 3 feet. Excellent drainage conditions exist over the major part of these soils.
+/AA-(2)1	II, III	Anthony clay, 1-3%	
+/A-(1)4	II, III	Gila clay loam, 0-1%	The surface of these soils is relatively level or very gently sloping. The surface soils are distinctly calcareous, and because of their age, little profile development has taken place. The subsoil consists of alternate layers of stratified materials which are also variable in texture. The distribution of this soil is very irregular, but in general it parallels either the present or former stream channels. These soils contain a fair amount of organic matter and are, in general, reasonably productive.
+/A-(2)2	II, III	Anthony sandy clay, 0-1%	These soils are similar to Anthony clay soils described above, with the exception of the sandy surface texture.
+/A-(1)1	II, III	Gila clay, 0-1%	This soil is similar to the Gila clay loam described above, with the exception of the heavier surface texture.
+/A-(1)5	II, III	Gila sandy clay loam, 0-1%	This soil is similar to the other soils of the Gila series. It is a medium-textured soil which is, in general, highly productive.
(1)4	IV	Gila clay loam	These soils are deep, medium-textured alluvial soils that are almost level. Moisture penetration is moderate and the textures are conducive to easier handling. These soils are susceptible to the same detrimental effects of shallow water table or excessive alkali accumulation as the heavier textured Gila soils in Groups II and III, but generally occur on the higher levels in the valley where these conditions do not exist. The fertility of these soils is generally high.
(1)5	IV	Gila sandy clay loam	
(1)6	IV	Gila silty clay loam	
(1)7	IV	Gila loam	These soils are similar to those described above except for texture, which is lighter. Moisture penetration is moderate, and textures are such that cultivation practices are very simple. Fertility is generally high, and shallow water table or accumulation of alkali cause only slight problems. These soils occur primarily in the lower lying areas of the valley floor, but also occur on the higher levels of the adjacent slopes.
(1)8	IV	Gila silt loam	
(1)9	IV	Gila very fine sandy loam	
(1)10	IV	Gila fine sandy loam	

* I--Upper Rio Grande Region
II--Middle Rio Grande Region
III--Socorro Region
IV--Lower Rio Grande Region

APPENDIX B

Table B-2. Principal soils in productivity Group II, Rio Grande region, New Mexico

Map Symbol	General Location*	Soil Name	Soil Description
111	I	Fruitland sandy loam, 0-3 percent	This soil occurs on moderate slopes. It is rapidly permeable; runoff and erosion are moderate. The depth is moderate to deep (36 - 60"). Water-holding capacity is low and fertility is low.
117	I	Fruitland sandy loam, silty substratum, 0-3 percent	
114/AB	I		
122	I	Jocity loam, 1-3 percent	These soils are similar to the Jocity loam of Group I, but exhibit steeper slopes and higher erosion hazard.
20	I	Ancho clay loam	This soil occurs on nearly level to gently sloping slopes. It has moderate permeability. Runoff is medium and erosion hazard is slight. The depth is moderate to deep (36-60"), and water-holding capacity is moderate. Fertility is moderate.
41/B	I	El Rancho sandy clay loam, 1-3 percent	This soil occurs on gently sloping slopes. The permeability is moderate. Depth, water-holding capacity, and fertility are moderate.
43S	I		
362	I	Doak loam, 1-3 percent	These soils are generally deep, 40 inches or more, with loamy surfaces and loamy subsoils. They are moderately permeable. Water-holding capacity is moderate. They are moderately susceptible to water erosion.
Pd	II	Prewitt clay loam, 0-1 percent slopes	Soils of this group are well-drained, reddish-brown, calcareous, alluvial soils developing on flood plains and low terraces. The parent material is stratified, but predominantly moderately fine-textured, calcareous alluvium. The soils resemble those of the San Jose series but differ from them in having moderately fine-textured materials. They are coarser textured than the Ladrillo soils. These soils generally have slow permeability, moderate to slight salinity hazard, and fair workability.
Pe	II	Prewitt clay loam, sandy substratum, 0-1 percent slopes	
$\frac{2221}{A}$	II	(unnamed)	These soils are moderately heavy-textured, deep (over 36 inches), with slow permeability. Slopes are less than 1 percent.
$\frac{3221}{A}$	II	(unnamed)	These soils are medium-textured, deep (over 36 inches), with slow permeability. Slopes are less than 1 percent.
$^{+}$/A-(1)1-S	II, III	Gila clay, 0-1%, saline	These soils are similar to the Gila clay soils described in Group I, but exhibit saline conditions, slight erosion, or have a light-textured subsoil phase or a heavy-textured subsoil phase.
$^{\circ}$/A-(1)1	II, III	Gila clay, 0-1%	
$^{+}$/A-L(1)1	II, III	Gila clay, 0-1%, light-textured subsoil phase	
$^{+}$/A-H(1)1	II, III	Gila clay, 0-1%, heavy-textured subsoil phase	
$^{+}$/A-(1)3-S	II, III	Gila silty clay, 0-1%, saline	These soils are similar to other soils of the Gila series, but are typically saline.
$^{+}$/A-(1)4-S	II, III	Gila clay loam, 0-1% saline	These soils are similar to other Gila soils, but are saline, or experience steeper slopes.
$^{+}$/AA-(1)4	II, III	Gila clay loam, 1-3%	
$^{+}$/A-(1)5-S	II, III	Gila sandy clay loam, 0-1%, saline	These soils are similar to other Gila soils, with the exception of being saline, having steeper slopes, experiencing slight erosion, and having gravelly subsoil phases.
$^{+}$/AA-(1)5	II, III	Gila sandy clay loam, 1-3%	
⊕/AA-0(1)5	II, III	Gila sandy clay loam, 1-3%, gravelly subsoil phase	

Table B-2. Continued.

Map Symbol	General Location*	Soil Name	Soil Description
$^{+}$/A-(1)10-S	II, III	Gila fine sandy loam, 0-1%, saline	These soils are lighter-textured, experience saline conditions, steeper slopes, and slight erosion.
$^{+}$/AA-(1)10	II, III	Gila fine sandy loam, 1-3%	
$^{\oplus}$/A-(1)10	II, III	Gila fine sandy loam, 0-1%	
$^{+}$/A(1)11-S	II, III	Gila sandy loam, 0-1%, saline	These soils are similar to those of the Gila series, with the exception of being saline and having a light subsoil phase.
$^{+}$/A-L(1)11	II, III	Gila sandy loam, 0-1%, light-textured subsoil phase	
^{3}/AA-(2)1	II, III	Anthony clay, 1-3%	These soils are similar to the soils described in Group I, but experience moderate erosion hazards.
$^{+}$/AA-(2)2-S	II, III	Anthony sandy clay, 1-3%	These soils are similar to those described in Group I, but have steeper slopes and experience slight saline conditions.
^{o}/A-(2)4	II, III	Anthony clay loam, 0-1%	These soils are similar to those described in Group I, but have experienced from slight to moderate wind and water erosion.
^{2PK}/AA-(2)4	II, III	Anthony clay loam, 1-3%	
$^{\oplus}$/AA-(5)5	II, III	Algodones sandy clay loam, 1-3%	These soils range in color from a reddish-brown to red in both the surface soil and subsoil. They occupy sloping to nearly level alluvial fans and intermittent stream bottoms just above the first bottom lands. They are low in organic matter but highly calcareous. The lime is disseminated throughout with no apparent accumulations. Visible specks and streaks of gypsum are quite common in the subsoil. They are well-drained and free from harmful concentrations of alkali. In general, they have high fertility, but are susceptible to erosion hazards.
$^{\oplus}$/A-(5)11	II, III	Algodones sandy loam, 0-1%	These soils are similar to the soil described above, but experience slight erosion hazards.
(1)1	IV	Gila clay	These soils are characterized by a slow rate of moisture penetration and are affected in some places by shallow water table or slight to heavy alkali accumulations. Their heavier textures require careful conservation-land use practices. They are moderately stratified, with thin layers of light and heavy-textured subsoils which restrict the moisture penetration to some extent.
(1)2	IV	Gila sandy clay	
(1)3	IV	Gila silty clay	
(1)11	IV	Gila sandy loam	The moisture penetration of this soil is moderate to rapid. Wind erosion is a primary problem. The subsoil is composed of mixed alluvial sands and gravels moderately stratified.
(3)1	IV	Pima clay	These are similar to the Gila soils described above. Some areas have a surface texture of extremely heavy, almost waxy, layer which is difficult to work. These soils are generally high in fertility and have moderate to good drainage. The primary limitations are the conservation-land use measures necessary for successful crop production.
(3)3	IV	Pima silty clay	
L(3)2	IV	Pima sandy clay, light subsoil phase	

Table B-2. Continued.

Map Symbol	General Location*	Soil Name	Soil Description
L(1)11	IV	Gila sandy loam, light subsoil phase	The surface layer of these soils is moderate to shallow in depth. The subsoil is a calcareous, light, single-grained coarse sand with occasional lenses of heavier material. Drainage is moderate to high. Water-holding capacity is moderate to low. These soils are considered to be low to medium in productivity.
L(1)7	IV	Gila loam, light subsoil phase	
L(1)6	IV	Gila silty clay loam, light subsoil phase	
L(1)5	IV	Gila sandy clay loam, light subsoil phase	
L(1)1	IV	Gila clay, light subsoil phase	
L(1)2	IV	Gila sandy clay, light subsoil phase	
L(1)10	IV	Gila fine sandy loam, light subsoil phase	
L(1)4	IV	Gila clay loam, light subsoil phase	
L(3)1	IV	Pima clay, light subsoil phase	

* I--Upper Rio Grande Region
II--Middle Rio Grande Region
III--Socorro Region
IV--Lower Rio Grande Region

APPENDIX B

Table B-3. Principal soils in productivity Group III, Rio Grande region, New Mexico

Map Symbol	General Location*	Soil Name	Soil Description
70/c	I	Fruitland sandy loam, 3-5 percent	This soil is similar to the Fruitland soils of Group II, but occurs on strongly sloping slopes. The permeability is rapid, runoff is medium, and erosion hazard is high.
80	I	Bluewing loamy fine sand	This soil occurs on nearly level to gently sloping slopes. It is relatively shallow, with rapid permeability, medium runoff, and moderate erosion hazard. The water-holding capacity and fertility are low.
81S	I	Bluewing loamy fine sand, saline	Similar to mapping unit 80, but exhibits salt concentrations that range from slight to moderate.
42	I	El Rancho sandy clay loam, sandy - Subsoil variant	This soil occurs on nearly level to gently sloping slopes. It differs from the El Rancho units of Groups I and II in that it is moderately deep and has a sand and/or gravel subsoil. Water-holding capacity is lower.
7/C	I	Harvey loam, 1-9 percent	This soil occurs on gently to strongly sloping slopes. It is moderately permeable and moderate to deep (36-60"). The fertility is low to moderate.
U/AC	I	El Rancho-Fruitland complex	This soil consists of about 65 percent El Rancho loam, 3-5 percent slopes, and 25 percent Fruitland sandy loam, 3-5 percent slopes. The remaining 10 percent is made up of small areas of Pojoaque-Rough Broken land complex. It is moderately permeable. The runoff is medium and erosion hazard is moderate. Depth is moderate to deep (36-60") and fertility is moderate.
41/C 44 41/D	I I I	El Rancho sandy clay loam, 3-5 percent	This soil occurs on strongly sloping slopes. The erosion hazard is high with some gullied land occurring in this unit.
23L	I	Pojoaque-Rough Broken land complex	This soil consists of about 50 percent Pojoaque soils and 40 percent Rough Broken land. The Rough Broken land occurs on complex hilly slopes and the Pojoaque soils occur interspersed throughout the Rough Broken land in no definite or repeating pattern. The soil is moderately permeable, runoff is very rapid and erosion hazard is high. Fertility is low.
Pc	II	Prewitt clay, 0-1 percent slopes	These soils resemble those of the Prewitt soils of Group II, but differ from them in having fine-textured materials. They have slower permeability, moderate salinity hazard, and poor workability.
Pg	II	Puerco clay, 0-1 percent slopes	These soils were derived largely from argillaceous shales but also from some sandstones. Both soils have slopes of 0 to 1 percent. The Puerco soils occur on the flood plains of intermittent streams. They have unusually hard, dense subsoils, which often have pronounced vertical shrinkage cracks. The subsoils are normally uniform in texture, but in places they contain thin strata of darker-colored coarser materials. They have slow to very slow permeability, may have moderate to severe, or slight to moderate, salinity hazard, depending upon the substratum, and generally poor workability.
Ph	II	Puerco clay, sandy substratum, 0-1 percent slopes	

Table B-3. Continued.

Map Symbol	General Location*	Soil Name	Soil Description
Pb	II	Preston-San Mateo complex	In this unit the Preston and San Mateo soils are so intricately mixed it was not practical to map them separately. A description of each follows: The Preston series, represented by Preston fine sand, 0 to 5 percent slopes, are sandy soils without developed profiles. The soils are porous, calcareous, and grayish-brown; they consist of transported material of mixed geological origin that has been deposited by wind. The San Mateo series consists of well-drained, calcareous, stratified alluvial soils occurring on the flood plains and low terraces along streams and rivers. They show little evidence of soil development other than slightly darker surface horizons, weak structure, or very weak and discontinuous horizons of lime accumulation.
3331/B-1	II	(unnamed)	These soils are medium-textured, have moderate permeability, and are usually considered deep (over 36 inches). They are limited by slight to moderate slopes, with slight erosion.
3331/C-1	II	(unnamed)	
3321/C-1	II	(unnamed)	
3231/C-1	II	(unnamed)	These soils are medium-textured, have slow to moderate permeability, and are deep (over 36 inches). They are limited by moderate to severe slopes.
4411/B-1	II	(unnamed)	These soils are fine textured, have rapid permeability in the subsoil, but have very slow permeability in the substratum. They are generally deep to moderately deep. Slopes are generally slight.
44M2/B-1	II	(unnamed)	
$^{+}$/A-(1)1-W	II, III	Gila clay, 0-1%	These soils are similar to those described in Groups I and II, but experience shallow water tables, light-textured subsoil phases, heavy subsoil phases, and slight to moderate erosion hazards. In many cases these soils have experienced deposition of materials, primarily silt, from irrigation waters, and some have experienced detrimental deposits from tributary arroyos.
$^{+}$/A-L(1)1-W	II, III	Gila clay, 0-1%, light-textured subsoil phase	
$^{+}$/A-H(1)1-W	II, III	Gila clay, 0-1%, heavy-textured subsoil phase	
$^{+}$/A-L(1)2-W	II, III	Gila sandy clay, 0-1%	
$^{+}$/A-(1)3-W	II, III	Gila silty clay, 0-1%	
$^{+}$/A-(1)4-W	II, III	Gila clay loam, 0-1%	
$^{+}$/A$_1$-(1)4	II, III	Gila clay loam, 0-1%	
$^{+}$/A-L(1)4	II, III	Gila clay loam, 0-1%, light	
$^{+}$/A$_1$-L(1)4	II, III	Gila clay loam, 0-1%, light	
$^{+}$/A-(1)5-W	II, III	Gila sandy clay loam, 0-1%	
$^{+}$/AA-H(1)5	II, III	Gila sandy clay loam, 1-3%, heavy phase	
^{PF}/A$_1$-(1)5	II, III	Gila sandy clay loam, 0-1%	
$^{+}$/A-(1)7-W	II, III	Gila loam, 0-1%	
$^{+}$/A-(1)10	II, III	Gila fine sandy loam, 0-1%	
$^{+}$/A$_1$-(1)10	II, III	Gila fine sandy loam, 0-1%	

Table B-3. Continued.

Map Symbol	General Location*	Soil Name	Soil Description
$^{+}$/A$_{1}$-L(1)10	II, III	Gila fine sandy loam, 0-1%, light phase	(Soil description similar to soils described in Table B-2)
$^{\oplus\,PF}$/AA$_{1}$-(1)10	II, III	Gila fine sandy loam, 1-3%	
$^{+}$/A-(1)11-W	II, III	Gila sandy loam, 0-1%	
$^{\oplus}$/AA-⊕(1)11	II, III	Gila sandy loam, 1-3%	
$^{+}$/A$_{1}$-L(1)11	II, III	Gila sandy loam, 0-1%, light phase	
$^{+RL}$/A$_{1}$(1)13	II, III	Gila fine sand, 0-1%	
$^{+N}$/AA-(1)14	II, III	Gila sand, 1-3%	
$^{\oplus}$/AA-0(1)14	II, III	Gila sand, 1-3%, gravelly phase	
$^{\oplus}$/AA$_{1}$-⊕(1)14	II, III	Gila sand, 1-3%	
$^{\oplus PF}$/A$_{1}$-0(1)14	II, III	Gila sand, 0-1%	
^{WU}/A-(1)UN	II, III	Gila undifferentiated, 0-1%	
^{o}/A-(2)1	II, III	Anthony clay, 0-1%	These soils are similar to those of the Anthony series described in Groups I and II, with the exception of having erosion problems, shallow water tables, and steeper slopes.
^{37}/AA-(2)1	II, III	Anthony clay, 1-3%	
^{o}/A-(2)5	II, III	Anthony sandy clay loam, 0-1%	
^{2RL}/AA-0(2)11	II, III	Sandoval sandy loam, 1-3%	These soils have the same general range in color, the same general conditions of relief and drainage, and a similar mode of formation as those of the Anthony series. They differ primarily in that they have been derived from finer-textured materials which have formed heavier-textured subsoils. The subsoils consist primarily of clay and sandy clay, with an occasional strata of lighter-textured material. Since the subsoils are of comparatively heavy texture, the moisture penetration is rather slow, and the water-holding capacity good. These soils are generally well adapted to irrigated agriculture, and with careful management, including weed eradication, crop rotations, and the incorporation of organic matter, good to excellent crop yields are possible. They are, in general, well drained, and alkali concentrations are negligible. The soils described in these mapping units are affected by high water tables and slight to moderate erosion hazards.
^{2RM}/AA-0(2)11	II, III	Sandoval sandy loam, 1-3%	
$^{+}$/A-(3)1-W	II, III	Pima clay, 0-1%	The soils of the Pima series differ primarily from those in the Gila series in the color of the surface soil and content of organic matter. The surface soil of the Pima series is a dark grayish-brown or nearly black, very often having a purplish and olive-green cast. This difference in color is due mainly to the development of this series under swampy and extremely poorly drained conditions, resulting in the accumulation of organic matter in the surface soil which extends to depths varying from 6 to 30 inches or more. This is underlain by the typical stratified Gila subsoil as described in other Gila series descriptions. This soil represents areas variously affected by alkali and drainage. Where it is well drained and free from harmful concentrations of alkali, it has high fertility and the yields of crops are good. However, a large percentage of this series is so affected and has resulted in from fair to poor crop conditions. Still other areas in this series have such a high water table, which is usually associated with toxic concentrations of alkali, that it has a low agricultural value.
$^{+}$/A-H(3)1	II, III	Pima clay, 0-1%, heavy phase	

Table B-3 Continued.

Map Symbol	General Location*	Soil Name	Soil Description
(1)15	IV	Gila loamy sand	These soils have moderate to low productivity. The moisture penetration is high to excessive. Wind erosion is a primary problem. Accumulation of alkali and shallow water tables are normally rare. These soils occupy the higher alluvial fans and are susceptible to flood damage. Slopes are moderate.
(1)13	IV	Gila fine sand	
(1)14	IV	Gila sand	
H(1)11	IV	Gila sandy loam, heavy subsoil phase	These soils are similar to those in Group II except for the heavy subsoil phase. The subsoil is usually heavy clay with a compact and almost impervious massive structure which extends for 6 to 8 feet. Internal drainage is impeded and perched water tables or high alkali accumulations are likely to occur.
H(1)10	IV	Gila fine sandy loam, heavy subsoil phase	
H(1)5	IV	Gila sandy clay loam, heavy subsoil phase	
H(1)1	IV	Gila clay, heavy subsoil phase	
H(1)3	IV	Gila silty clay, heavy subsoil phase	
H(1)4	IV	Gila clay loam, heavy subsoil phase	
H(3)1	IV	Pima clay, heavy subsoil phase	
I(1)11	IV	Gila sandy loam, impervious phase	These soils are similar to those in Group II except for the impervious layer which has the same effect as a full heavy subsoil phase. The moisture penetration is slow and badly restricted. Alkali accumulation and perched water tables are primary problems.
I(1)10	IV	Gila fine sandy loam, impervious phase	
I(1)5	IV	Gila sandy clay loam, impervious phase	
I(1)1	IV	Gila clay, impervious phase	
I(1)4	IV	Gila clay loam, impervious phase	
(6)14	IV	Anthony sand	These soils have generally shallow surface layers. They are generally medium to coarse-textured with high or excessive drainage, low water-holding capacity, and are susceptible to wind erosion. These soils generally occupy the higher slopes and mesas adjacent to the valley, but also occur in old stream channels and arroyo fans which extend into the valley. They are generally low in productivity and fertility.
(6)014	IV	Anthony gravelly sand	
(6)11	IV	Anthony sandy loam	
(6)011	IV	Anthony gravelly sandy loam	
(6)⊛11	IV	Anthony stony sandy loam	
(4)14	IV	Brazito sand	
(4)13	IV	Brazito fine sand	

* I--Upper Rio Grande Region
II--Middle Rio Grande Region
III--Socorro Region
IV--Lower Rio Grande Region