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

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Agricultural Experiment Station, NMSU
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Engineering Experiment Station, NMSU
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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
Mr. Rowland Fife	U.S. Bureau of Reclamation
Mr. Wayne Cunningham	Elephant Butte Irrigation District
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ABSTRACT

An interdisciplinary approach to the solution of the water resource problems of the Upper Rio Grande region in New Mexico was centered around a socio-economic model, developed to represent the New Mexico economy, and 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, in the Rio Grande Region, both production and depletions are expected to exhibit the largest increase (59.7 percent and 47.4 percent, respectively). When a surface water constraint is imposed, the value of production is reduced by $18.1 million in 2020 and water depletions are expected to decrease about 18.1 percent by 2020. When a total water constraint is imposed, the value of production is decreased $4.1 million below that expected when using only a surface water constraint, and water depletions are reduced about 8.4 percent.

The Upper Rio Grande Region is expected to follow the general trend of the total Rio Grande region but at a lower growth rate. The expected increase in total value of production from 1970 to 2020 is 53.8 percent, employment 53 percent, and water depletions about 20 percent.

When a surface-water constraint is imposed, production is expected to be reduced $0.6 million in 2020, employment by 212 employees, and water depletions by 13,569 acre-feet. When an additional constraint is imposed on ground water in the URGR, production would be decreased $0.6 million in 2020, employment by an additional 212 employees, and water depletions by 13,497 acre-feet.

*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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AN ANALYTICAL INTERDISCIPLINARY EVALUATION OF THE UTILIZATION OF THE WATER RESOURCES OF THE RIO GRANDE IN NEW MEXICO: UPPER RIO GRANDE REGION

Robert R. Lansford, Shaul Ben-David, Thomas G. Gebhard, Jr., Willem Brutsaert, and Bobby J. Creel*

INTRODUCTION

This report represents an in-depth look at the water and related resources in the Upper Rio Grande Region (URGR) of New Mexico (Figure 1). Other reports have been prepared for the Middle Rio Grande Region (WRRI Report No. 022), the Socorro Region (WRRI Report No. 023), and the Lower Rio Grande Region (WRRI Report No. 024). These reports are viewed as basic data reports to supplement the overall report (WRRI Report No. 020, *An Analytical Interdisciplinary Evaluation of the Utilization of the Water Resources of the Rio Grande in New Mexico*, March 1973).

The Upper Rio Grande Region extends from the New Mexico-Colorado state line to Otowi Bridge and includes the counties of Rio Arriba, Taos, and Santa Fe; the Middle Rio Grande Region from Otowi Bridge to the Socorro-Valencia county line includes 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.

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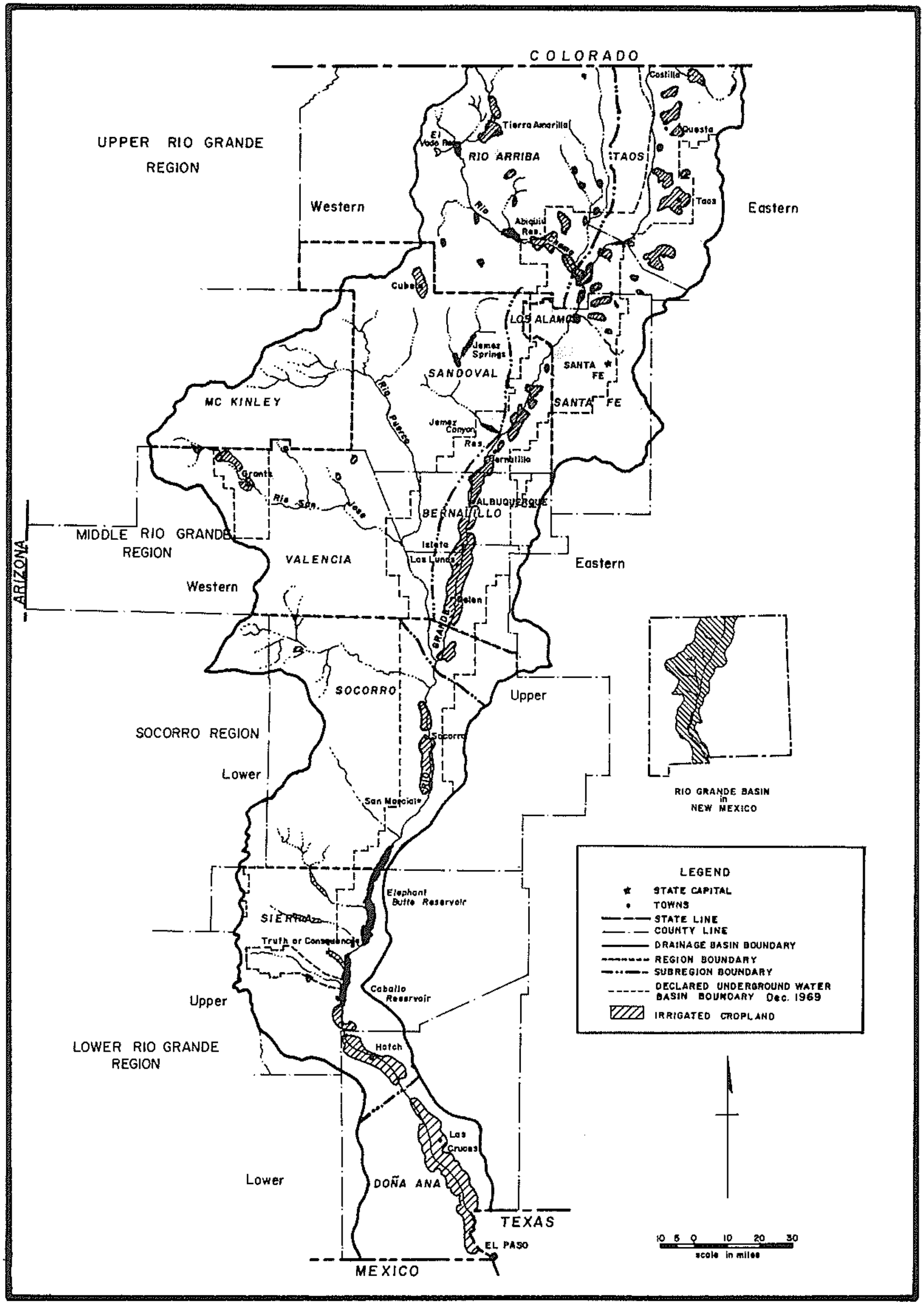

Figure 1. Rio Grande drainage basin in New Mexico, for this study.

GENERAL DESCRIPTION

The Upper Rio Grande Region includes all of Taos and Los Alamos Counties, most of Rio Arriba, and portions of Santa Fe, Mora, and San Miguel Counties (Figure 2). The URGR was further divided, for this study, into the eastern and western subregions. This division essentially separates the Rio Grande from the Rio Chama, its principal tributary. The western subregion includes the western portion of Rio Arriba County, and the eastern subregion includes Taos, eastern Rio Arriba and Santa Fe Counties (Figure 2).

The Upper Rio Grande Region is a large, sparsely populated area with major population centers at Santa Fe, Espanola, and Taos. A number of smaller communities dot the area. The principal irrigated areas are along the Rio Grande and its many tributaries in this Region.

Topography and Climate

The topography of the Upper Rio Grande Region is primarily mountainous, but relatively flat plains and valleys are common throughout. The Region is bordered on the north by the Colorado-New Mexico state line, on the west by the Continental Divide, on the south by the Middle Rio Grande Region, and on the east by the Sangre de Cristo Mountains.

The climate of the Upper Rio Grande Region is predominantly semi-arid in the lower elevations and semi-humid in the mountainous areas. Average annual temperatures in the Region range from 44 degrees Fahrenheit at Tierra Amarilla to about 50 degrees at Espanola (Table 1).

Precipitation ranges from over 15 inches in the mountainous areas to about 10 inches in the southern lower valleys. The average frost-free period at selected stations in the Region is from May 23 to September 30, or 130 days, but the period ranges from 146 days at Santa Fe to 100 days at Tierra Amarilla (Table 1).

Drainage Area

The Rio Grande, as it enters New Mexico, is flanked to the east by the southern extension of the Sangre de Cristo Mountains which maintain their high altitude as far north as the Glorieta Divide east of Santa Fe. On the

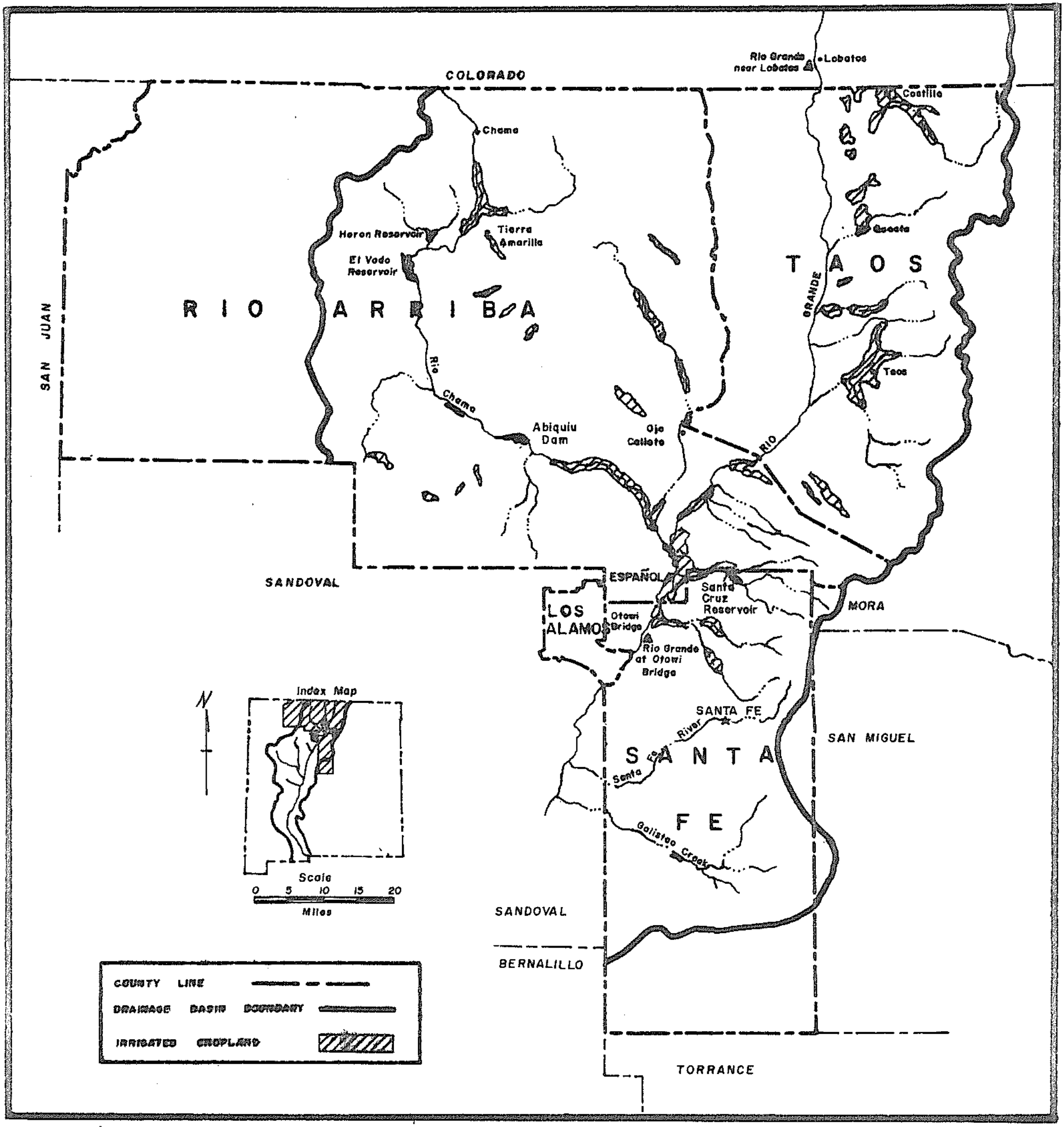

Figure 2. Map of the Upper Rio Grande Region in New Mexico.

Table 1. Eleven-year average temperature, total precipitation, and frost-free period for Tierra Amarilla, El Rito, Santa Fe, Espanola, Taos, and Cerro, New Mexico, 1960-70

Weather Bureau Station	Average Temperature	Total Precipitation	Frost-free Period Length	Frost-free Period Dates
	degrees F	inches	days	
Tierra Amarilla	43.9	15.97	100	June 8 - Sept. 16
El Rito	48.1	11.58	134	May 22 - Oct. 3
Santa Fe	48.9	15.05	146	May 18 - Oct. 11
Espanola	50.2	9.62	144	May 14 - Oct. 5
Taos	47.2	12.41	130	May 20 - Sept. 27
Cerro	44.4	11.01	123	May 27 - Sept. 27
Average	47.1	12.6	130	May 23 - Sept. 30

Source: United States Weather Bureau, *Climatological Data, New Mexico* (Annual Summaries), Vols. 64-74, 1960-1970.

west, the Conejos Range extends southward between the river and its principal New Mexico tributary, the Rio Chama, followed by the Jemez Mountains south of the Rio Chama. It is from this portion of the drainage area that the Rio Grande receives most of the water supply which originates in New Mexico.

The drainage area of the perennial Rio Grande at Otowi Bridge gaging station near the southern end of the URGR involves 14,300 square miles, approximately, of which 2,940 square miles are in the closed basin of the San Luis Valley, Colorado. The Rio Chama, the only perennial tributary of the Rio Grande in New Mexico, drains about 3,000 square miles of the URGR.

The Rio Grande flow at Otowi Bridge averages about 1,111,000 acre-feet per year; about 394,000 acre-feet per year come from the Rio Chama, as measured near Chamita, before flowing into the Rio Grande. The Rio Grande flow before entering New Mexico at Lobatos, Colorado, is about 436,900 acre-feet per year.

Snowmelt in Colorado and northern New Mexico and runoff from torrential summer rains constitute the Rio Grande river flow. A major component of this river flow comes through subsurface runoff, also called river accretion. It has been estimated (Winograd, 1959) that between 1948 and 1955, the annual accretion ranged from 10 to 55 percent of the flow in the river immediately upstream from Red River. During periods of low flow, this accretion has at times exceeded 90 percent of the flow at the Cerro gaging station. It is estimated that, on the average, the Rio Grande in the URGR gains about 5 to 6 cfs/mi.

Other tributaries to the Rio Grande are normally perennial, but with little flow, and are intermittent only in dry years: Examples are the Arroyo Hondo (20,290 acre-feet/year) and the Red River (57,310 acre-feet/year). Several arroyos of ephemeral nature only flow during torrential summer rainstorms.

Hydrogeology.

Structurally the URGR corresponds mainly to the Espanola Basin and partly to the southern end of the San Luis Basin. These basins, from 18 to 40 miles wide, are part of the Rio Grande depression and are also referred to as the Rio Grande trough (Figure 3). The trough is filled up with materials eroded from the bordering highlands and lava emitted from numerous volcanoes in the Region. This valley fill, also referred to as the Santa Fe formation, is closely related to the occurrence, movement, and quality of ground water. These sediments extend several thousand feet deep and consist mainly of sand and gravel. Below these sediments there may be hundreds or perhaps thousands of feet of sand and gravel of middle and early Tertiary age. The Santa Fe is, therefore, the major ground-water reservoir in Taos County.

Closely related, because of their interbedding, to the Santa Fe sediments are the alluvial deposits and andesite basalt lavas. These lavas also form the lava-capped plateaus in the area. Owing to their different water bearing capacities and water transmitting characteristics, the subsurface relations between these rocks directly affect the rate and direction of ground-water movement. The individual andesite-basalt lava flows are generally less than 50 feet thick and are locally interbedded with thin strata of volcanic ash. They occur in tabular sheets, often of large extent. Cooling causes fracturing, mostly vertical. Near the top of the lava flow are vesicles or bubbles formed by gases escaping from the cooling lava. Some vesicles are

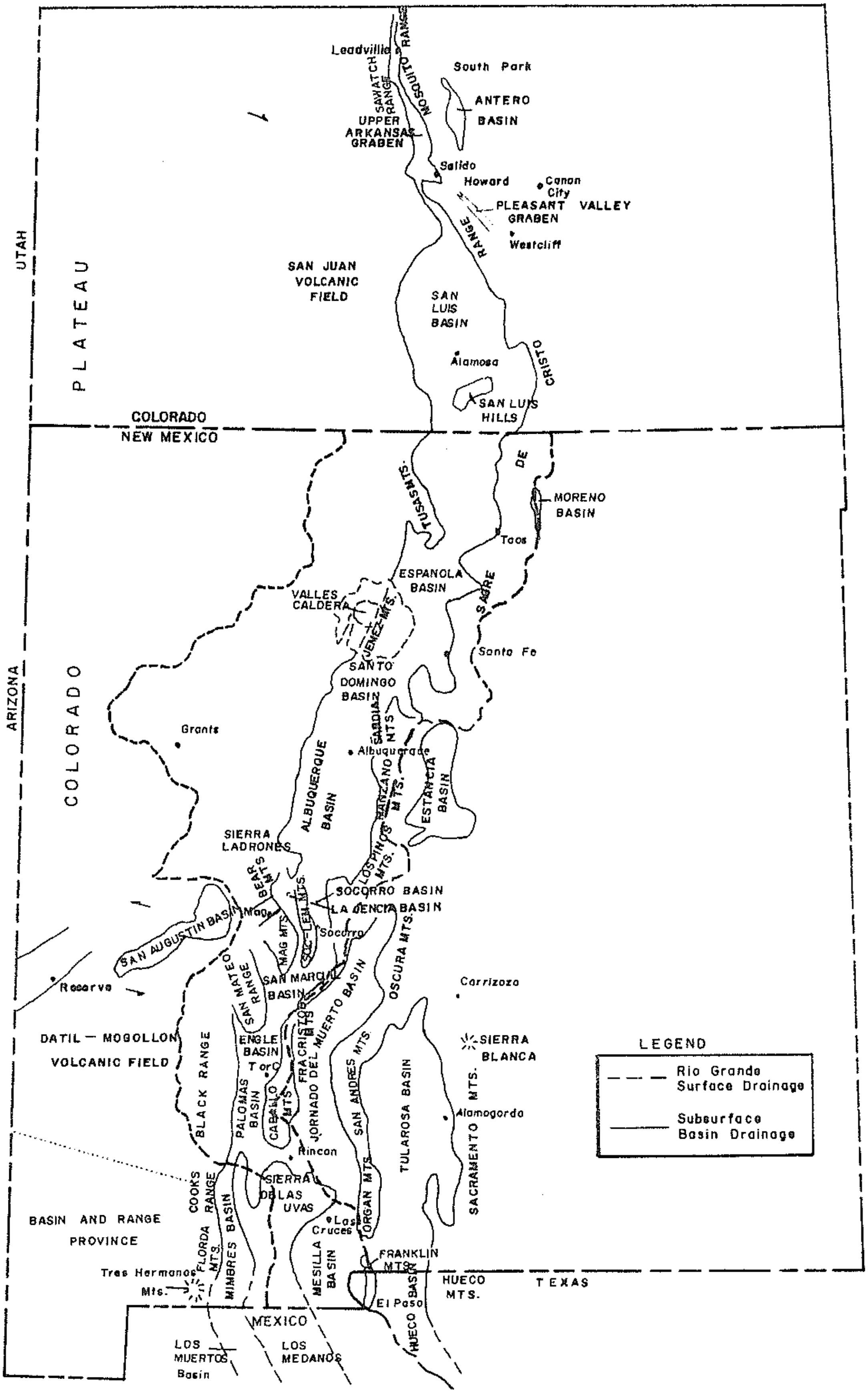

Figure 3. Generalized map of the Rio Grande Rift (after Chapin, 1971).

tabular but not well interconnected. Ground water also moves through this macro-fracturing system which is capable of transmitting large quantities of water. In short, although the individual portions of a lava flow are usually impermeable, its formational permeability is rather high.

Although Precambrian granite furnishes an intermittent supply of water to wells, at Tres Piedras for example, the Precambrian and middle Tertiary rocks which border the valley on the east and protrude above the plateau surface are, in general, insignificant with respect to water bearing capabilities.

An important hydrogeologic aspect in the URGR is a distinct river accretion. Winograd (1959) indicated, for example, that between the Colorado-New Mexico state line and the Red River, the Rio Grande gains about 96 cubic feet per second (70,000 acre-feet annually) from ground-water accretion. This accretion is closely related to the large formational permeability of the lava plateaus which permit natural ground-water recharge through rapid infiltration of rainfall. Therefore, the plateau surfaces have a poorly developed surface drainage system but are otherwise well-drained owing to the permeable nature of the lava flows lying at or near the surface.

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 irrigation districts which are formed in cooperation with the United States. Once a conservancy or irrigation district is formed it is a legally stable institution with broad powers to perform the purposes for which it was organized. The districts are able to borrow money, tax lands for the indebtedness, and charge for the water they deliver.

Surface Water

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. 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 acreages served by these individual ditch systems vary in size from a few acres to over 200.

Ground Water

The management of the ground-water resources 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 a ground-water basin. Nearly all of the irrigated cropland in the URGR is in a declared ground-water basin with only isolated tributary units outside of these basins (Figure 1). Therefore, the development of ground water is under the jurisdiction of the New Mexico State Engineer.

RESOURCES

Population

Table 2 presents a summary of the population of the URGR from 1950 to 1970, utilizing data from the Bureau of the Census. For the total URGR there has been a relatively small but steady growth rate; Santa Fe and Los Alamos Counties account for the greatest share of growth. This Region has undergone a shift from predominantly rural (58.2 percent rural in 1950) to predominantly urban (54.5 percent urban in 1970). This change is mainly due to the growth of urban centers in Taos and Rio Arriba Counties.

Basically there has been little change in total population for Rio Arriba and Taos Counties. These two counties decreased slightly in population from 1950-1960, but made up this loss, along with a small increase, by 1970. The most significant change in Rio Arriba's population has been the increase in the urban population and the resulting decrease in the rural population. Rio Arriba County was totally rural in both 1950 and 1960 census years, but by 1970 it had changed to 15 percent urban and only 85 percent rural. Although the figure given for Taos in the major cities section is above the urban requirement figure used by the Bureau of the Census, the Bureau does not consider it urban because that figure represents

Table 2. Urban and rural population* for the Upper Rio Grande Region, New Mexico, 1950-1970

Year and County	Urban	Percent Urban	Rural	Percent Rural	Total	Percent Change from Previous Census
1970						
Rio Arriba	3,902	15.5	21,268	84.5	25,170	4.0
Taos	0		17,516	100.0	17,516	9.9
Santa Fe	41,793	77.7	11,963	22.3	53,756	19.5
Los Alamos	15,171	99.8	27	.2	15,198	16.6
URGR	60,866	54.5	50,744	45.5	111,640	13.8
1960						
Rio Arriba	0		24,193	100.0	24,193	- 3.2
Taos	0		15,934	100.0	15,934	- 7.1
Santa Fe	34,676	77.1	10,294	22.2	44,970	17.9
Los Alamos	12,584	96.5	453	3.5	13,037	24.4
URGR	47,260	48.2	50,874	51.8	98,134	8.1
1950						
Rio Arriba	0		24,997	100.0	24,997	- 1.4
Taos	0		17,146	100.0	17,146	- 7.5
Santa Fe	27,998	73.4	10,155	26.6	38,153	23.8
Los Alamos	9,934	94.8	542	5.2	10,476	0.0**
URGR	37,932	41.8	52,840	58.2	90,772	21.5**

Major Cities	1950	1960	Percent Change	1970	Percent Change
Los Alamos (L.A.)	9,934	12,584	26.7	11,310	-10.1
White Rock (L.A.)	0	0		3,861	
Santa Fe (S.F.)	27,998	33,394	19.3	41,167	23.3
Espanola (R.A.)	1,446	1,976	36.7	4,528	129.1
Taos (T)	1,815	2,475	36.4	3,505	41.6

* County definition.
** Estimate.

the combined populations of three incorporated areas (Taos, Ranchos de Taos, and Taos Pueblo), none of which is over 2,500. Nevertheless, an urban center is developing in Taos County. This shift in population make-up is due to the decrease in agriculture and the increase in tourism and recreational activities in this area.

Santa Fe and Los Alamos Counties have shown a steady growth rate over the past two decades and the urban/rural composition has remained relatively stable (73.4 percent urban in 1950 and 77.7 percent in 1970 for Santa Fe, and 94.8 percent urban in 1950 and 99.8 percent in 1970 for Los Alamos). Both counties can expect to maintain this high proportion of urban make-up. Santa Fe County, as the center of growing state government activity and the major urban center in an increasingly popular tourist and recreation area, can expect to maintain a gradual but steady growth rate.

Table 3. Upper Rio Grande Region's percentage of New Mexico's urban and rural population, 1950-1970

URGR	Percent of Urban	Percent of Rural	Percent of Total
1950	11.0	15.5	13.3
1960	7.5	15.6	10.3
1970	8.5	16.5	10.9

Industrial Development

The URGR has long been entrenched in government activities. The state capital, located in Santa Fe County, and Los Alamos Scientific Laboratory have been, and will continue to be, the main components of the ever expanding government sector.

The recreational potential of this Region has only recently begun to be developed, but its effects are already being felt, especially in traditionally rural Rio Arriba and Taos Counties. The whole Region has experienced substantial growth in the trade, services, and real estate sectors, but Rio Arriba and Taos Counties have shown the most dramatic growth in these sectors. The Region's potential for recreation is tremendous because it is suitable for year-round recreational activities: skiing in the winter, and camping, hiking, and picnicking in the summer. Great increases are expected in the Trade, services, and construction sectors in Taos, Rio Arriba, and Santa Fe Counties to meet the needs of the influx of tourists and other visitors to the area.

Taos and Rio Arriba Counties have been traditionally agricultural, but agriculture is becoming less important as other industrial opportunities are developed. Two new businesses brought to this area recently are the Santa Fe Downs racetrack and the motion picture industry. Although these industries do not provide much direct employment, they are a great impetus to further development in the trade and services sectors.

Mining, one source of industrial potential which seemed to be declining, may increase again with the recent development of the Moly Corporation operations.

Employment

Table 4 presents employment data for the URGR for 1960 and 1970. For the Region as a whole there was a relatively large increase in the total work force (25.7 percent). Unemployment decreased in all counties except Los Alamos County. There was a substantial gain in non-agricultural employment, particularly in Taos and Rio Arriba Counties (58.7 and 78.7 percent increases respectively). The largest gains in this category were in the areas of wholesale and retail trade; real estate, finance, and insurance; and services; Taos and Rio Arriba Counties showed the largest percentage gains in these areas due to the growth of urban centers and the increase in tourism and recreational activities.

In those counties for which information is available, there is a decrease in Mining employment and Public utilities and transportation. The only exception is Los Alamos County which has a 113 percent increase in employment in the Public utilities and transportation sectors, possibly due to a greater demand for these services among a highly educated and fairly affluent population. Los Alamos is a special case in other employment sectors also. It shows a significantly larger increase in employment related to the Real estate, finance, and insurance sector than the other

Table 4. Employment[a] in the Upper Rio Grande Region, New Mexico, 1960-1970

Employment (County Definition) - ESC	Santa Fe 1960	Santa Fe 1970	Santa Fe Percent Change	Rio Arriba 1960	Rio Arriba 1970	Rio Arriba Percent Change	Taos 1960	Taos 1970	Taos Percent Change	Los Alamos 1960	Los Alamos 1970	Los Alamos Percent Change	Upper Rio Grande Region 1960	Upper Rio Grande Region 1970	Upper Rio Grande Region Percent Change
Total civilian work force	15,792	20,183	27.8	5,133	6,564	27.9	3,884	5,280	35.9	7,664	8,778	14.5	32,473	40,805	25.7
Unemployment	850	1,223	- [b]	1,129	1,085	- [b]	696	551	- [b]	126	228	- [b]	2,801	3,087	- [b]
Rate	5.4	6.1	- [b]	22.0	16.5	- [b]	17.9	10.4	- [b]	1.6	2.6	- [b]	8.6	7.6	- [b]
Employment	14,942	18,960	26.9	4,004	5,479	36.8	3,188	4,729	48.3	7,488	8,500	13.5	29,622	37,668	27.2
Non-ag. wage and salary	12,181	16,414	34.8	2,777	4,406	58.7	1,969	3,519	78.7	6,991	8,089	15.7	23,918	32,428	35.6
Manufacturing	593	697	17.5	267	372	39.3	190	181	- 4.7	- [c]	40	- [c]	- [c]	1,290[c]	- [c]
Contract construction	657	880	33.9	381	474	24.4	111	151	36.0	534	339	-36.5	1,683	1,844	9.6
Mining	170	135	-20.6	90	45	-50.0	109	- [c]	- [c]	- [c]	- [c]	- [c]	- [c]	- [c]	- [c]
Public utilities and transportation	759	660	-13.1	229	222	- 3.1	146	83	-43.2	22	47	113.6	1,156	1,012	-12.5
Wholesale & retail trade	2,443	3,332	36.4	520	753	44.8	450	664	47.6	340	530	55.9	3,753	5,279	40.7
Real estate, finance, and insurance	636	781	22.8	39	114	192.3	42	108	157.1	7	91	1200.0	724	1,094	51.1
Services and miscellaneous	2,347	3,532	50.5	455	969	113.0	384	1,394	263.0	1,514	1,329	-12.2	4,700	7,224	53.7
Government	4,577	6,397	39.8	795	1,458	83.4	537	937	74.5	4,574	5,713	24.9	10,483	14,505	38.4
All other Non-ag.	2,281	2,201	- 3.5	533	606	13.7	706	452	-36.0	496	411	-17.1	4,016	3,670	- 8.6
Agriculture	479	344	-28.2	694	467	-32.7	513	308	-40.0	0	0	0.0	1,686	1,119	-33.6

a Derived from ESC data
b Unemployment and associated rate are used for illustrative purposes; therefore, no percentage changes were needed.
c Undisclosed information; therefore, percentage changes not calculable.

counties, which may again be due to the particular character and demands of the Los Alamos population. In Los Alamos there is a large decrease (36.5 percent) in construction employment, whereas there is a general increase in the other three counties.

In general, the URGR seems to follow the same trends as other regions of the RGR. That is, there are substantial increases in non-agricultural employment and large decreases in agricultural employment. Since Santa Fe County contains the state capital, and Los Alamos County is totally dependent on the government sponsored scientific laboratory activities, it is not surprising that government (state, local, and federal) is the major employer in this Region. Of the four counties in this Region, Santa Fe has shown more stable but less spectacular growth. Los Alamos' differences have already been pointed out. Taos and Rio Arriba Counties demonstrate drastic changes in employment patterns. Although unemployment is still high in these counties there has been a great improvement over the 1960's rate. As noted previously, employment in sectors affected by tourism, recreation, and urbanization has increased dramatically.

Land

Within the Rio Grande drainage basin 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 drainage basin is reported in Table 5. Federal and state ownership account for about 43 percent of the total land area in the Rio Grande region (Table 5).

The URGR drainage area accounts for approximately 4.92 million acres (about 29 percent of the total land area within the Rio Grande region), of which 87,000 are irrigated. Within the URGR, federal ownership accounts for about 50 percent of the total land area. Within the Region the acreage of forest land controlled by the Forest Service accounts for about 36 percent of the total land area; land administered by the Bureau of Land Management (BLM) accounts for about 10 percent; defense, none; and other federal ownership about 4 percent. State ownership accounts for about 7 percent. Private ownership accounts for about 36 percent. Indian ownership accounts for about 7 percent. Inland water accounts for less than 1 percent of the total land area.

Table 5. Land ownership, in acres, in the Rio Grande drainage basin, New Mexico, 1971

Region and County[1]	Federal: Forest	Federal: BLM	Federal: Defense	Federal: Other	Federal: 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.

Irrigated Cropland. The reported irrigated cropland in this report is for the drainage basin and not for the entire four-county region. The irrigated cropland is located in a somewhat narrow strip along the rivers in the Upper Rio Grande Region (Figure 2). However, there are about 6,150 acres, chiefly in northern Taos County, supplied with ground water. In the western subregion of the drainage basin there are approximately 29,270 acres of irrigated cropland, about 55 percent (16,101 acres) of which are cropped. In the eastern subregion there are about 57,760 acres of irrigated cropland, about 65 percent (37,518 acres) of which are cropped.

In terms of acreage, other hays and native pasture were the most important crops, accounting for about 24 percent of the total irrigated cropland acreage in the Upper Rio Grande drainage basin. The other hays and native pasture account for over two-thirds of the cropped acreage in the western subregion, but less than one-third in the eastern subregion. Alfalfa was the most important crop in the eastern subregion of the drainage basin with about 32 percent of the cropped acreage (Table 6). Nearly all of the crops in the URGR were low income-generating crops, with the exception of vegetables and orchards.

Soil productivity. The soils of the Upper Rio Grange drainage basin are extremely varied, ranging from some highly productive alluvial valley soils to extensive, exceptionally low-productive mountain soils. The soils were derived from two general sources. The alluvial soils of the Rio Chama and Rio Grande flood plains were formed by material brought down by the rivers. The other soils of the mesas were formed of material from the adjacent mountains and are found on the alluvial fans extending into the valley and on the higher mesas and plateaus.

The largest percentage of the agricultural lands are on the alluvial soils of the Rio Grande, Rio Chama, and the tributary flood plains. These soils are relatively young compared with the soils of the valleys to the south which were formed of stratified alluvium of mixed origin, are predominantly deep, and moderately coarse to medium-textured. The principal soils are of the Fruitland, San Mateo, Ancho, and El Rancho series.

The soils occurring on the higher alluvial fans, terraces, and mesas are generally from unconsolidated old alluvium which is predominantly coarse

Table 6. Acres of irrigated cropland by use in the Upper Rio Grande Region, New Mexico, 1970

Land use	Western Subregion	Eastern Subregion			Upper Rio Grande Region	
	Rio Arriba	Rio Arriba	Santa Fe	Taos		
	acres	acres	acres	acres	acres	percent
Cotton	0	0	0	0	0	0
Alfalfa	3,812	2,364	1,616	8,162	15,954	18.3
Sorghum	0	0	4	0	4	0.0
Corn	184	319	129	468	1,100	1.3
Small grains	576	259	56	2,607	3,498	4.0
Improved pasture	488	1,233	773	5,650	8,144	9.4
Other hay and native pasture	10,889	1,312	171	8,838	21,210	24.4
Chile	5	88	27	0	120	0.1
Orchards	90	2,228	532	106	2,956	3.4
Spring lettuce	0	0	0	0	0	0
Fall lettuce	0	0	0	0	0	0
Spring onions	0	0	0	0	0	0
Fall onions	0	0	0	0	0	0
Misc. veg. & family gardens	57	103	121	352	633	0.7
Subtotal cropped acreage[a]	16,101	7,906	3,429	26,183	53,619	61.6
Diverted and fallow[b]	500	61	277	2,982	3,820	4.4
Prepared land	0	0	0	0	0	0
Subtotal Cultivated acreage[c]	16,601	7,967	3,706	29,165	57,439	66.0
Idle[d]	3,543	500	604	5,142	9,789	11.2
Out of production[e]	9,126	1,093	2,910	6,673	19,802	19.8
Total irrigated cropland[f]	29,270	9,560	7,220	40,980	87,030	100.0

a. 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.
b. Acreage of irrigated cropland which was not cropped under provisions of the Agricultural Adjustment Programs or had been tilled in the past two years.
c. 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.)
d. Irrigated cropland not actively farmed for the past two consecutive years but farmed within the past five years. (Includes suspended land which was not serviced by ground water.)
e. Irrigated cropland not actively farmed within the past five years.
f. 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 E.F. Sorensen, "Planted Cropland Acreage in New Mexico in 1969, 1970," *New Mexico Agriculture--1970*, Agricultural Experiment Station Research Report 195, New Mexico State Univ., Las Cruces, N.Mex., 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 Univ., Las Cruces, N.Mex., pp. 31-37, Tables 17 and 18.

to medium-textured and gravelly. They are normally gently sloping to moderately steep. The principal soils are of the coarser Fruitland, San Mateo, Pojoaque, Harvey, and Fernando series.

The soils were grouped into soil productivity groups according to their irrigation potential and capability. The acreage of irrigated cropland soils by productivity group is reported in Table 7.

Table 7. Acreage of irrigated cropland by soil productivity groups, Upper Rio Grande Region,[a] New Mexico, 1970

Soil Productivity Group[b]	Western Subregion		Eastern Subregion		Total	
	(acres)	(percent)	(acres)	(percent)	(acres)	(percent)
Group I	0	0.0	600	1.0	600	0.7
Group II	1,520	5.2	21,920	38.0	23,440	26.9
Group III	27,750	94.8	35,240	61.0	62,990	72.4
Total	29,270	100.0	57,760	100.0	87,030	100.0

[a]Acreage within the Rio Grande drainage basin.

[b]Soils included in each group are described in Appendix A.

Only a very small portion of the acreage is Group I soil. These soils occur primarily in the valley area near Espanola in Rio Arriba County (Figure 4). They are primarily loams of the Jocity and San Mateo series. They are level and deep and are considered to be highly productive. They are moderately permeable with good water holding capacity.

The Group II soils account for about 27 percent of the irrigated cropland in the Region (Table 7). They occur throughout the valley and plateau areas, primarily in the eastern subregion. In many cases they account for large tracts of land. These soils are similar to the soils in Group I, but are characterized by steeper slopes, shallower depths, and in some areas are affected by shallow water-tables and alkali accumulation. They consist primarily of the San Mateo, Doak, Fruitland, Manzano, Fernando, El Rancho, and Ancho series. In general, they include the coarser-textured and gravelly soils of the alluvial fans and the stratified soils of the valley. Some have

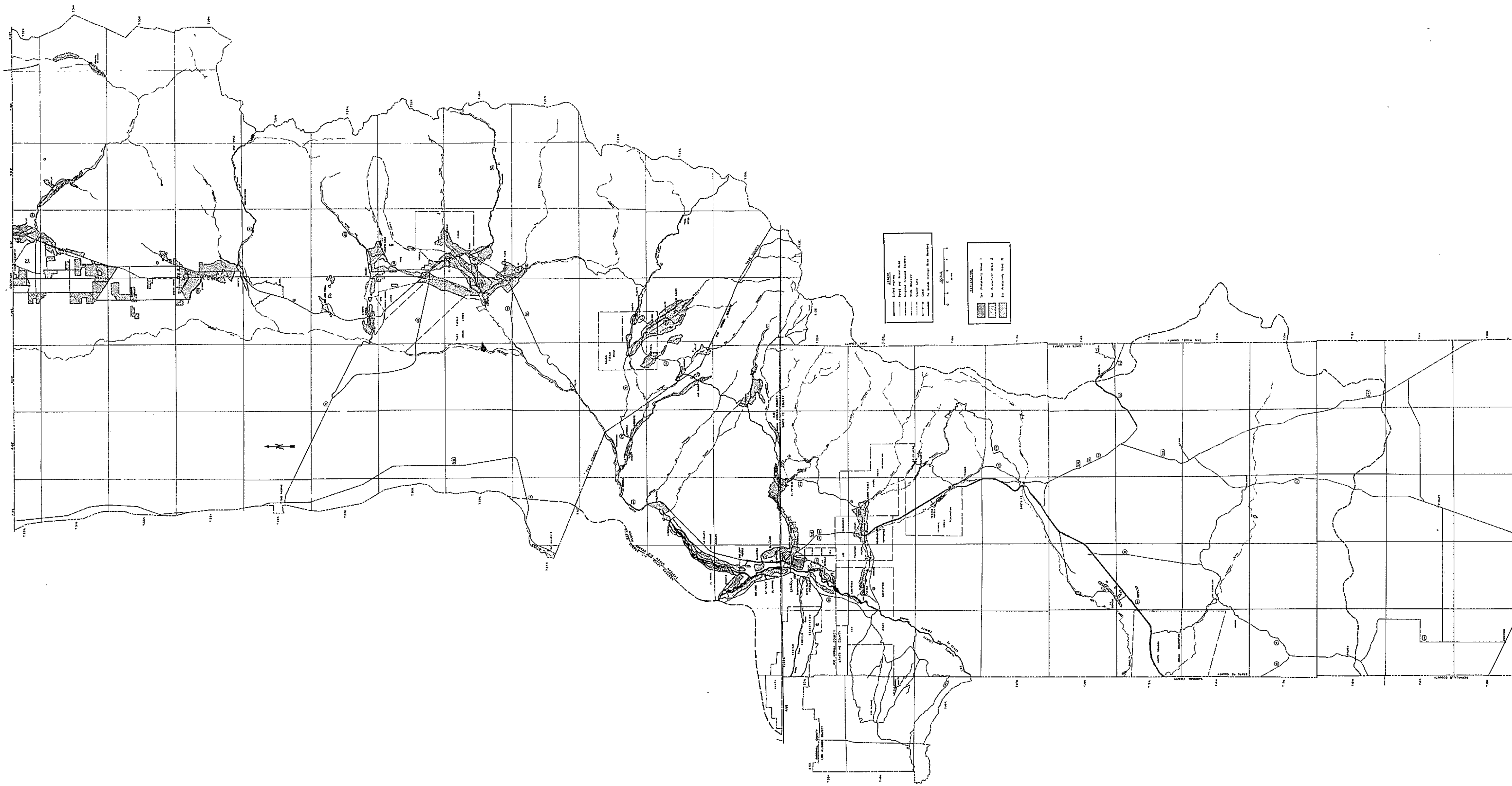

Figure 4. Soil productivity map, Eastern Upper Rio Grande Region, New Mexico.

moderately low to low permeability, others have moderately high to high permeability. Most are moderately susceptible to water erosion.

The Group III soils account for the largest percentage (72.4 percent) of the soils in the Region. They account for almost all of the soils in the western subregion (Table 7 and Figure 5). Their primary limitations are excessive slope, coarse textures, and shallow depth. The principal soils are of the Fruitland, Sheppard, San Mateo, Bluewing, El Rancho, Harvey, and Hondo series. This group also includes a large percentage of the idle and out-of-production acreage.

HYDROLOGIC DATA

The water supply of the upper Rio Grande Basin in New Mexico is generated by the melting snow in the Colorado and New Mexico mountains. New Mexico receives surface water from Colorado and also generates, through snowmelt, a large portion of the streamflow measured at the Otowi streamgage.

Surface Water

The surface-water resources of the upper Rio Grande basin come from snowmelt within the New Mexico portion of the basin and from Rio Grande waters delivered under the terms of the Rio Grande Compact, 1938. The Colorado obligation to deliver water to New Mexico is measured near Lobatos, Colorado, and is the sum of the supply indices for the Conejos River and the Rio Grande, minus ten thousand acre-feet. The supply index for the Rio Grande is the flow to be delivered to Lobatos as a varying percentage of the flow measured at the Del Norte station. Likewise, the supply index for the Conejos River is the flow to be delivered at the mouth of the Conejos River as a varying percentage of the flow measured at the Mogote station. The water used by Colorado above the Lobatos gage irrigates over 500,000 acres of land within the San Luis Valley. The total drainage area above Lobatos is 7,700 square miles, including 2,940 square miles of non-contributing drainage area in the San Luis Valley.

One of the reasons that the Rio Grande Compact, 1938, was enacted was to insure equitable apportionment of water between the states of Colorado, New

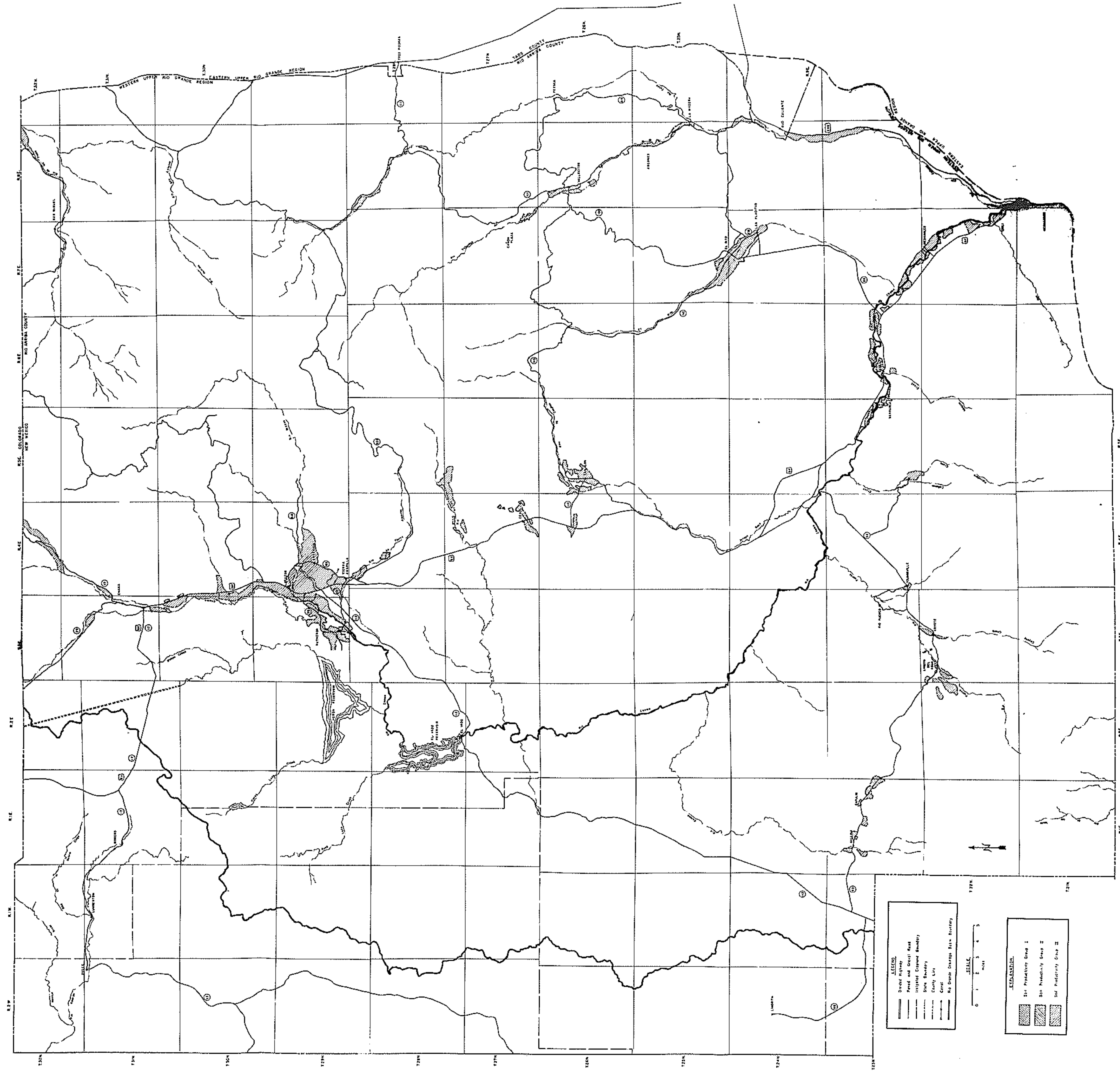

Figure 5. Soil productivity map, Western Upper Rio Grande Region, New Mexico.

Mexico, and Texas, and, thusly, restrict water consumption in Colorado. Colorado's management of its water has undergone many changes, and the flow of the Rio Grande has reflected these changes. The mass flow curve for the Rio Grande near Lobatos is shown in Figure 6. This curve could be segmented into several lines of different slopes to represent average flows for different time periods. Table 8 gives the average flows at Lobatos for different time periods. The period from 1958 to 1968 was selected as the base years to indicate streamflow values; the average inflow to New Mexico was 19,027 acre-feet per month, or 228,322 acre-feet per year. The average outflow from the URGR for the same time period (1955-1968) was 68,171 acre-feet per month, or 818,049 acre-feet per year, at Otowi Bridge (Table 9).

Table 8. Average monthly flows for the Rio Grande near Lobatos, Colorado

Period	Average Monthly Flow	Average Monthly Flow for March - October	Average Monthly Flow for November - February
	. . . .	acre-feet	. . . .
1900-1915	51,439	67,991	18,336
1916-1939	41,946	51,408	23,023
1940-1957	25,927	30,961	15,860
1958-1968	19,027	20,717	15,646
1900-1968	36,315	45,026	18,891
1916-1968	31,749	38,094	19,059
1940-1968	23,310	27,075	15,779

Most of the water available for consumptive use in the Upper Rio Grande Region is generated by precipitation in the mountains of the Region. Table 10 presents a comparison of the inflow from Colorado to the outflow of the Rio Grande as measured at Otowi Bridge. For the period 1958-1968, the flow at Lobatos, Colorado, was only 27.9 percent of the flow measured at Otowi Bridge, and the gain in flow between Lobatos and Otowi was 589,727 acre-feet (Figure 6). Based upon the flow measurements at Otowi Bridge between 1958 and 1968, the outflow from the Upper Rio Grande Region was 818,049 acre-feet.

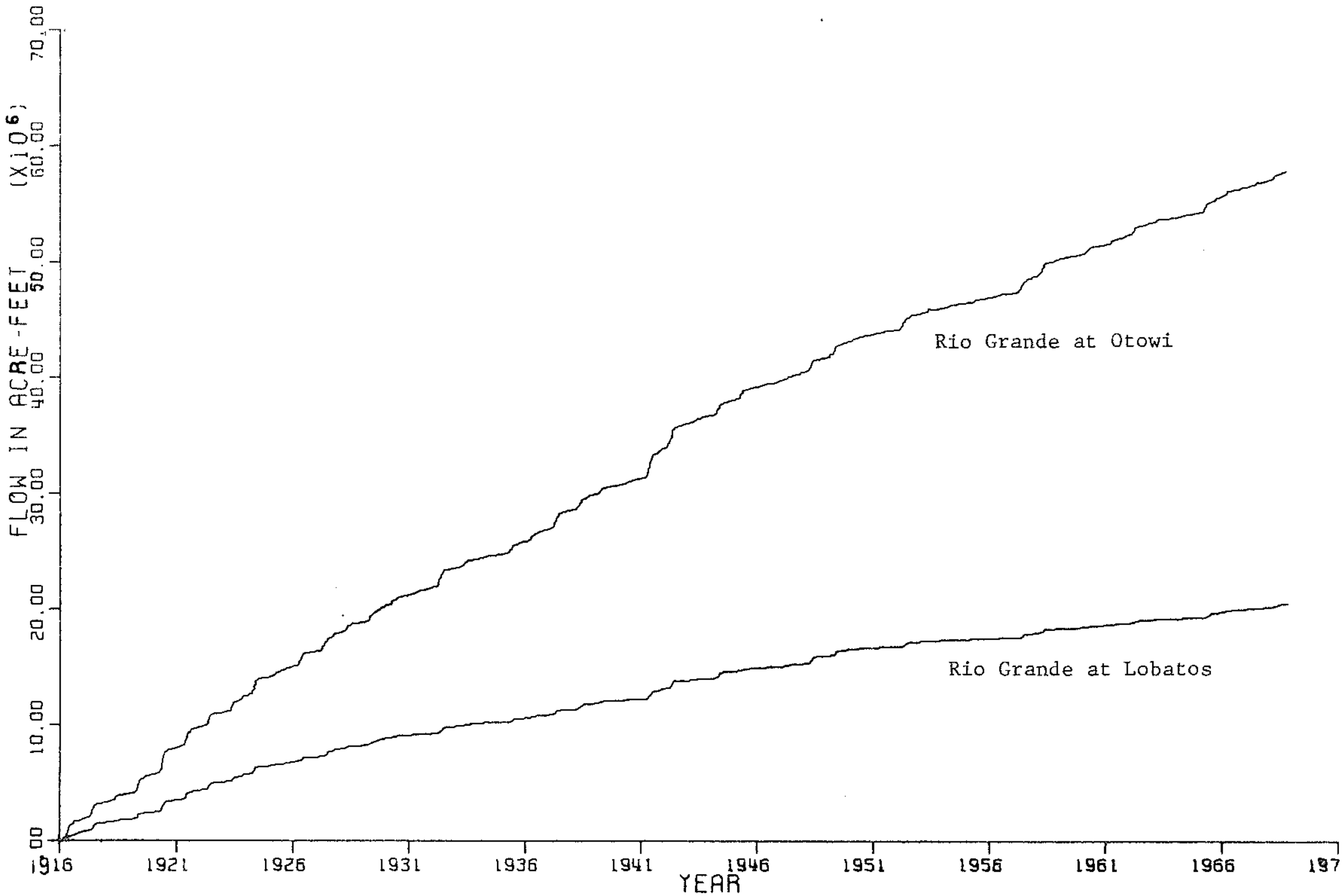

Figure 6. Mass flow curve for the Rio Grande at Lobatos and the Rio Grande at Otowi, 1916-1968

Table 9. Average monthly flows for the Rio Grande at Otowi Bridge, New Mexico

Period	Average Monthly Flow	Average Monthly Flow for March - October	Average Monthly Flow for November-February
	. . . .	acre-feet	
1916-1939	106,425	136,817	45,641
1940-1957	83,099	102,867	43,562
1958-1968	68,171	76,949	50,614
1916-1968	90,564	112,862	45,967
1940-1968	77,437	93,036	46,237

Table 10. Average monthly flows for the Rio Grande at Lobatos Colorado, and for the Rio Grande at Otowi, 1958-1968

Month	Lobatos	Otowi	Gain	Flow at Lobatos as percent of flow at Otowi
	. . . .	acre-feet		percent
January	13,395	38,568	25,173	34.7
February	16,151	41,965	25,814	38.5
March	22,366	62,499	40,133	35.8
April	25,415	119,279	93,867	21.3
May	42,659	173,943	131,284	24.5
June	40,179	107,605	67,426	37.3
July	12,783	43,338	30,555	29.5
August	11,099	53,375	42,276	20.8
September	4,555	28,434	23,879	16.0
October	6,682	27,120	20,438	24.6
November	19,101	68,607	49,506	27.8
December	13,937	53,316	39,379	26.1
Total	228,322	818,049	589,727	27.9

The net gain between Lobatos and Otowi Bridge was 589,727 acre-feet. The surface-water availability for the Upper Rio Grande Region is the sum of the outflow from the Region and the surface water consumed by irrigated agriculture within the Region. Table 11 is a compilation of these values.

The surface-water availability of the Upper Rio Grande Region is 886,762 acre-feet per year.

Table 11. Total surface water available for the Upper Rio Grande Region, New Mexico

	March - October	November - February	Yearly
	. . . .	. acre-feet . . .	. . . . .
Surface water outflow	615,593	202,456	818,049
Agricultural depletion	68,630	83	68,713
Total surface water available	684,223	202,539	886,762

Ground Water.

The Santa Fe formation is the major aquifer in the Region (Figure 7). 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 is encountered under water-table conditions at depths of 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 recently been developed in the URGR, with irrigation wells yielding 600 to 3000 gpm. 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 to 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

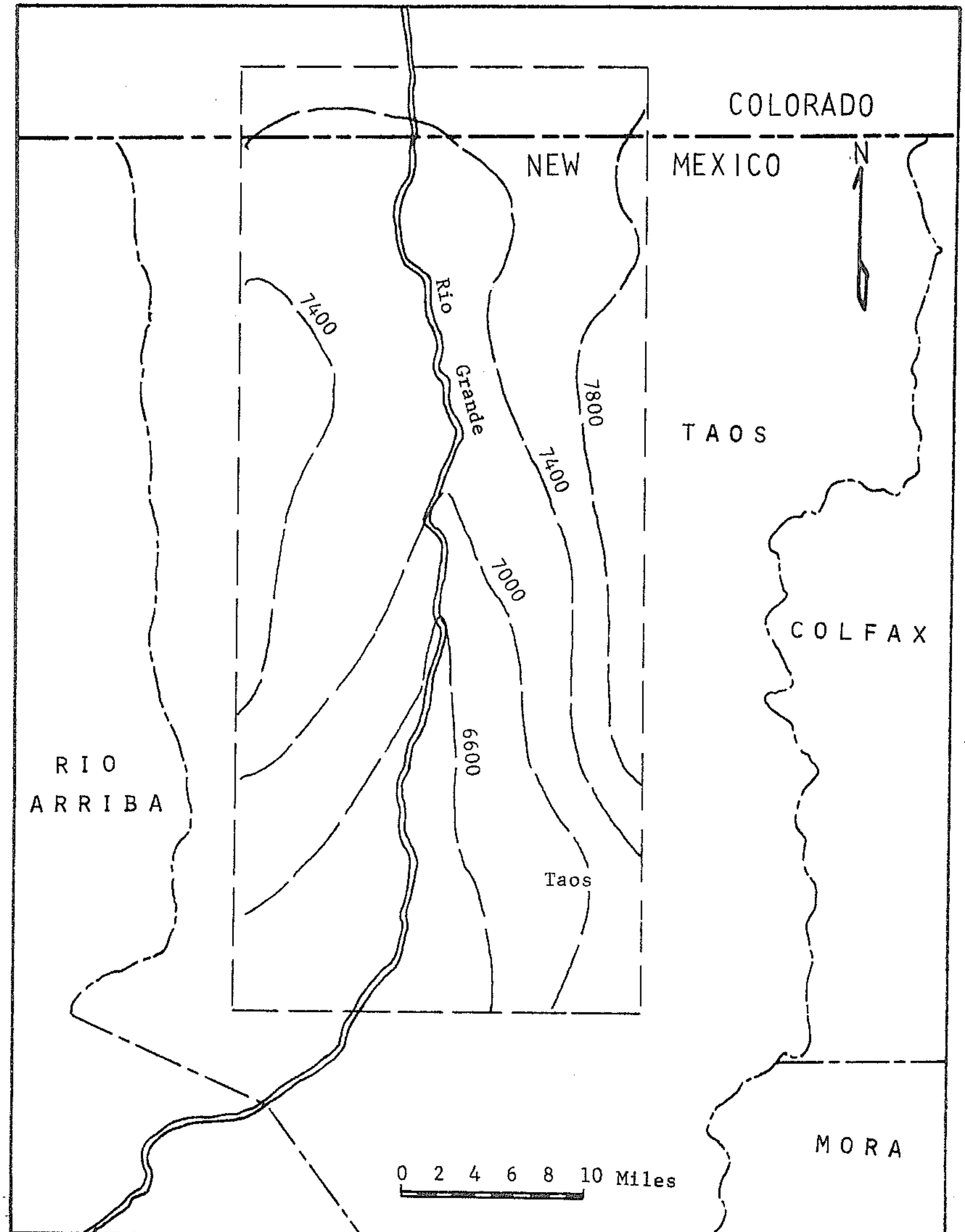

Figure 7. The Upper Rio Grande Region water-table contour map for 1965.

through the fractures under lower gradients than do the sediments which generally have a much lower permeability.

Surface water and ground water in the URGR 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 7) 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 water in the area far exceeds withdrawal rates. 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 7) with rather steep gradients almost perpendicular to the river, indicating natural recharge from the mountain sides and through the lava caps.

For the analysis of the surface-water ground-water interrelationship of the URGR, the mathematical simulator of this study uses 130 grid cells (10 X 13) and covers an area, shown on Figure 7, 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:

$$\Delta d = -0.5 \sqrt{d_n} + 29.1 \text{ LOG}_{10} (L + 0.2 \times 10^7) - 166.5$$

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

The applicability of this relationship is demonstrated through Figures 8 and 9. Figure 8 permits the calculation of the drop (-) or rise (+) of the water table, Δd, given the depth (d_n) of the water table at any time and the L-value. Figure 9 indicates a 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 pumpage after 20 years of present rate pumpage.

Water Quality

Surface water. The quality of the surface water of the Rio Grande reflects the use of the water upstream. Table 12 illustrates the general decline of the water quality along the Rio Grande during a recent year. Below Otowi Bridge, all ionic constituents increase and flow decreases. The consumption of water by agriculture tends to concentrate constituents. In addition, deep percolation and return flows to drains tend to compound the problem. Electrical conductivity (EC x 10^6 @ 25°C) and Sodium Adsorption 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 13 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.

Ground water. Ground water in the alluvial sediments is classified as "excellent to good" (Wilcox, 1948) for irrigation purposes. Results of chemical analyses (Winograd, 1959) indicate that this ground water is among

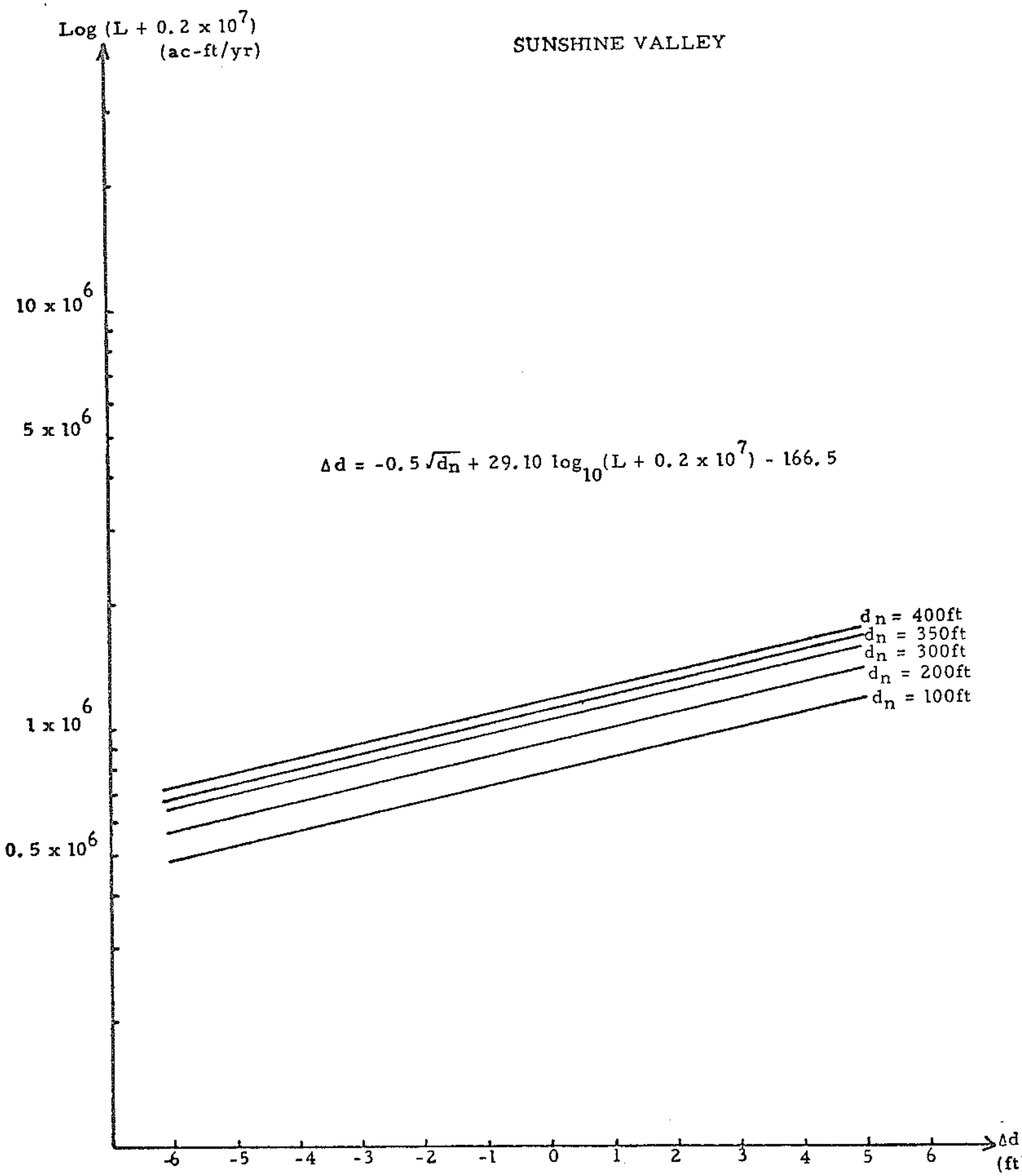

Figure 8. Expected declines in the water-table level in The Sunshine Valley utilizing varying depths to water, Upper Rio Grande Region, New Mexico

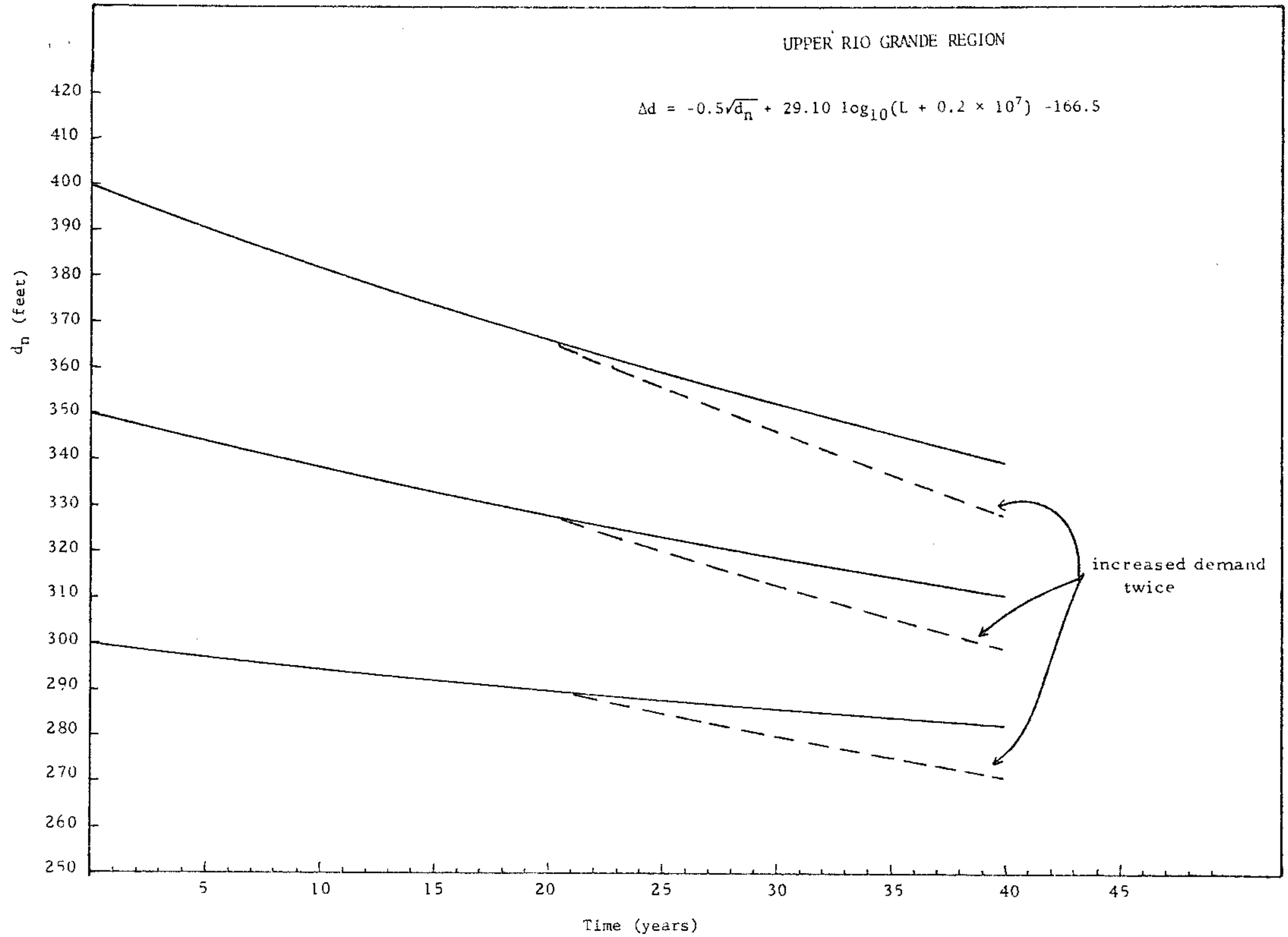

Figure 9. Depth (feet) to the water table [d_n] with respect to time for the Upper Rio Grande Region, New Mexico.

Table 12. 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 13. 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.

the best in the state, and its hardness ranging from 54 to 192 ppm does not interfere with use of this water for most purposes. No fluoride was detected in this analysis and nitrate content was very small. Total dissolved solids in the samples analyzed ranged from 100 to 300 ppm. Ground water within the lavas is not appreciably different from that within the alluvial sediment.

WATER DIVERSIONS AND DEPLETIONS

Irrigation

Irrigation water for the upper Rio Grande drainage basin comes primarily from surface sources. Ground water is used for about 5,200 acres in the Region. The surface water is supplied through the Santa Cruz Irrigation District, which serves the area around Espanola, and a large number of small private and community systems which divert surface water from the Rio Grande, the Rio Chama, and their many tributaries.

The upper Rio Grande drainage basin was divided into two sections: the eastern section includes Taos, Santa Fe, and eastern Rio Arriba Counties, and the western section includes western Rio Arriba County (Figure 2). The two areas essentially separate the Rio Grande from its principal tributary, the Rio Chama.

Surface-water quantity. The quantity of surface water available for the lands in the URGR has varied widely from year to year depending upon the precipitation and runoff. The season is normally short, beginning in early April and lasting through July. This essentially corresponds to the period of runoff, since there are virtually no storage facilities in the Region.

The San Juan-Chama diversion will provide for additional use of both surface and ground water in four units in the Upper Rio Grande Region. The four tributary units authorized are the Cerro unit, in northern Taos County; the Taos unit, also in Taos County; the Llano unit, in southern Rio Arriba County near Espanola; and the Pojoaque unit, in northwestern Santa Fe County. These four units will provide for an additional average annual diversion of about 27,700 acre-feet.

Ground-water quantity. Ground water used for irrigation in the upper Rio Grande drainage basin is relatively small compared to the quantities used in the Middle, Socorro, and Lower Rio Grande Regions. The largest use is in northern Taos County in the Sunshine Valley area where approximately 4,900 acres are served by ground water. Ground water is also used for about 320 acres in Santa Fe County.

Consumptive irrigation requirements calculated by the Blaney-Criddle formula (1962) on the basis of the 1970 cropping pattern for the lands in the eastern URGR are reported in Table 14. A total of about 48,267 acre-feet of irrigation water was necessary for crop consumption during the full season. Requirements calculated for the summer season, March through October, were about 48,075 acre-feet, and for the winter season, November through February, were about 192 acre-feet. These requirements are the quantities of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, required consumptively for crop production. They do not include surface evaporation or other economically unavoidable wastes normally associated with irrigation. A full water supply is assumed. The total irrigation requirements were estimated using a farm irrigation efficiency of 40 percent, and

Table 14. Seasonal and total consumptive irrigation requirements and irrigation requirements by crop for the cropped irrigated acreage in the Upper Rio Grande Region, New Mexico, 1970.

Crop	Consumptive Irrigation Requirements[a]			Irrigation Requirements[b]		
	Summer[c]	Winter[d]	Total	Summer[c]	Winter[d]	Total
	. . . . acre-feet			. . . acre-feet		
			Eastern Upper Rio Grande Region[e]			
Cotton	-	-	-	-	----	---
Alfalfa	18,359	-	18,359	45,898	----	45,898
Sorghum	5	-	5	13	----	13
Corn	986	-	986	2,465	----	2,465
Small grains	2,368	192	2,560	5,920	480	6,400
Improved pasture	10,506	-	10,506	26,265	----	26,265
Other hay and native pasture	11,486	-	11,486	28,715	----	28,715
Chile	128	-	128	320	----	320
Orchards	3,682	-	3,682	9,205	----	9,205
Spring lettuce	-	-	-	-	----	---
Fall lettuce	-	-	-	-	----	---
Spring onions	-	-	-	-	----	---
Fall onions	-	-	-	-	----	---
Misc. vegetables & family gardens[f]	555	-	555	1,388	----	1,388
Total	48,075	192	48,267	120,189	480	120,669
Weighted average	1.28	0.01	1.29	3.20	0.02	3.22

Crop	Consumptive Irrigation Requirements[a]			Irrigation Requirements[b]		
	Summer[c]	Winter[d]	Total	Summer[c]	Winter[d]	Total
			Western Upper Rio Grande Region[g]			
Cotton	-	-	-	-	----	---
Alfalfa	6,487	-	6,487	16,218	----	16,218
Sorghum	-	-	-	-	----	---
Corn	224	-	224	560	----	560
Small grains	493	-	493	1,233	----	1,233
Improved pasture	781	-	781	1,953	----	1,953
Other hay and native pasture	11,225	-	11,225	28,063	----	28,063
Chile	5	-	5	13	----	13
Orchards	116	-	116	290	----	290
Spring lettuce	-	-	-	-	----	---
Fall lettuce	-	-	-	-	----	---
Spring onions	-	-	-	-	----	---
Fall onions	-	-	-	-	----	---
Misc. vegetables & family gardens[f]	56	-	56	140	----	140
Total	19,387	-	19,387	48,470	----	48,470
Weighted average	1.20	-	1.20	3.01	----	3.01

a. The quantity of irrigation water, exclusive of precipitation, stores soil moisture, or ground water, that is required consumptively for crop production (Blaney and Hanson, 1965, p. 5).

b. The quantity of water, exclusive of precipitation, that is required for crop production, or the consumptive irrigation requirement divided by the irrigation efficiency (40 percent), (Blaney and Hanson, 1965, p. 5).

c. Months of March through October.

d. Months of November through February.

e. Includes all of Santa Fe and Taos Counties within the URGR drainage basin, and the following areas in Rio Arriba County: Rio Chama below Hernandez, Rio Grande below Dixon, San Juan and Santa Clara Pueblos, Chimayo and Truchas.

f. Also includes crops for which consumptive-use values were not available.

g. Includes the following areas in Rio Arriba County: Rio Chama below Abiquiu Dam and above Hernandez, El Rito, Ojo Caliente, La Madera-Vallecitos, Tierra Amarilla and vicinity, Rio Chama above Abiquiu Dam, Coyote, Cebolla, Conjilon, Canon Plaza, and Tres Piedras.

are also reported in Table 14. The total irrigation requirements for the summer season were 120,189 acre-feet, or about 3.20 acre-feet per cropped acre; for the winter season they were 480 acre-feet, or 0.02 acre-feet per cropped acre, for a total of 120,669 acre-feet, or 3.22 acre-feet per cropped acre.

Consumptive irrigation requirements for the western URGR calculated on the basis of the 1970 cropping pattern are also reported in Table 14. A total of about 19,387 acre-feet of irrigation water was necessary for crop consumption which was required only during the summer season. These requirements are likewise the quantities of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, required consumptively for crop production. They do not include surface evaporation or other economically unavoidable wastes normally associated with irrigation. A full water supply is assumed. The total irrigation requirements were estimated using a farm irrigation efficiency of 40 percent, and are also reported in Table 14. The total irrigation requirements for both the summer and total season were 48,470 acre-feet, or 3.01 acre-feet per cropped acre.

The surface-water diversions and deliveries in the Upper Rio Grande Region are not measured, and the quality of water used was not available. The same is true for the ground-water supplied areas. The calculated irrigation requirements, therefore, provide the best estimate of the total water depletions in the Region. However, in some areas, primarily those serviced by the smaller surface-water irrigation systems where the water supply was limited or available only during a shorter season, a full water supply was not available. In these cases, the irrigation water diversions and depletions estimated by the consumptive irrigation requirements of the crops were modified to account for a less than full supply. These estimated depletions are reported in Table 15.

Municipal and Industrial

Municipal water use depends primarily upon two factors: the number of urban water users, and the per capita use of water. Industrial water use depends partially on the number of employees and the per-employee use of water in the production of goods and services. Using figures from the State

Table 15. Irrigation requirements, availability of water supply, and calculated irrigation water diversions for the Upper Rio Grande Region, New Mexico, 1970

Area	Irrigation Requirements[a] (acre-feet)	Supply Availability[b] (percent)	Calculated Diversions (acre-feet)
Eastern Upper Rio Grande Region			
Taos County:			
Costilla	8,461	100	8,461
Sunshine Valley	12,263	100	12,263
Cerro	13,057	100	13,057
San Cristobal	1,316	100	1,316
Arroyo Hondo	5,641	100	5,641
Taos	26,992	100	26,992
Pilar	439	100	439
Penasco	16,922	50	8,461
Ojo Caliente	522	100	522
Sub-total	85,613	90	77,152
Rio Arriba County:			
Santa Cruz-Espanola	9,756	100	9,756
Alcalde-Velarde	4,534	100	4,534
Embudo	1,253	100	1,253
Truchas	4,429	50	2,214
Sub-total	19,972	89	17,756
Santa Fe County:			
Santa Cruz	3,875	100	3,875
San Ildefonso	1,786	100	1,786
Nambe-Pojoaque-Tesuque	8,409	50	4,204
La Cienega	773	100	773
Galisteo	115	50	57
Santa Fe	126	50	63
Sub-total	15,084	71	10,758
Total Eastern URGR	120,669	88	105,666
Western Upper Rio Grande Region			
Rio Arriba County:			
Rio Chama above El Vado	17,619	100	17,619
Rio Nutrias	1,523	50	762
Canjilon-Cebolla	4,471	50	2,236
Vallecitos	2,277	50	1,139
Ojo Caliente	1,590	100	1,590
El Rito	2,683	100	2,683
Gallina	2,070	50	1,035
Coyote	3,378	50	1,689
Rio Del Oso	83	50	42
Canones	745	50	373
Tusas	3,097	50	1,549
Rio de Los Pinos	588	100	588
Rio Chama below El Vado	8,346	100	8,346
Total Western URGR	48,470	82	39,651
Total Upper Rio Grande Region	169,139	86	145,317

a. Calculated total irrigation requirements based on average irrigation requirements per acre of total irrigated cropland.
b. Estimates of availability of surface-water supply.

Engineer Office, an estimate was made of water use for the urban population in 1960 and 1970 within each county. Municipal use includes more than urban population: light industrial as well as commercial activities within a region are dependent upon the municipal water supply. An estimate was made separately for this type of user, which includes the public sector composed of government and associated enterprises. Due to the lack of reliable primary data, these estimates should serve only as crude approximations to the actual water use within the URGR. The 9,000 acre-feet consumed represents a probable maximum during the years 1969 and 1970 for the four-county area.

Over 90 percent of the municipal and industrial water users obtained their supplies from ground-water systems. Very little surface water is diverted or depleted by any user other than agriculture.

Rural Domestic

Rural use of water is dependent upon the same two factors, population size (rural only) and the per capita use of water, as the urban population use. The 2,050 acre-feet of water consumed by the rural domestic population was assumed to be derived from ground water.

Livestock

Livestock use of water depends upon both use per animal within the region, and the number of, and evaporation from, stock ponds located in the region. To obtain a county estimate of the use of water by livestock, an inventory by Capener and Sorensen (1971) for both the number of livestock and the number of stock ponds was used.

Stock ponds are primarily supplied from surface water, but some livestock water comes from the ground supply. However, the most significant portion of water used can be assumed to be from surface supplies.

Between 1960 and 1970, there was no appreciable change in water consumption by livestock, but since 1960 the number of stock ponds increased. Consequently, only an estimate of livestock use was made for 1970.

The actual consumption by livestock was estimated to be 1,000 acre-feet in 1970 for the URGR: stock-pond evaporation was estimated to be 2,740 acre-feet. Irrigated pasture, for which no sale of commodity is involved, must be added to these figures. Approximately 57,000 acre-feet of water was used to irrigate pasture land for grazing by livestock. Therefore, in the URGR approximately 60,740 acre-feet was consumed each year in the late 60's by the livestock sector.

Recreation

There are no reservoirs in the URGR maintained solely for recreational use. Santa Cruz Reservoir does have recreational use and activity but was constructed for irrigation, flood control, and sediment abatement. Abiquiu Dam was constructed for flood control and sediment abatement with very little recreational potential. El Vado Reservoir was constructed primarily for irrigation and flood control but has extensive recreational use. Herron Reservoir was constructed as storage facilities for the San Juan-Chama diversion water. These reservoirs are expected to have extensive recreational use. However, the evaporation losses are charged to purposes other than recreation.

Non-beneficial

Each year a portion of the water supply of the URGR is lost through non-beneficial depletions. These losses are primarily in the form of evaporation from the surface-water areas and from evapotranspiration by phreatophytes.

Phreatophytes. The phreatophyte classification describes a distinct ecological group of desert plants that have adapted their root systems to survice in arid areas where the water table is between 5 and 30 feet below ground. The phreatophytes, which include salt cedar, saltgrass, cottonwood trees, and willow are found in areas such as the lower flood plain of arid river basins where it is difficult to account for the sources and interaction of surface and ground-water flow.

Phreatophytes, as defined by Blaney and Hanson (1965), are plants that habitually grow where they can send their roots down to the water table or to the capillary fringe immediately overlying the water table. Blaney and Hanson (1965) listed consumptive use of ground water by saltgrass as 29.3 inches per year, and for salt cedar 57.2 inches per year. The flood-plain areas of the Rio Grande and the Rio Chama in the URGR are generally covered with saltgrass and cottonwood (Figure 10). Cottonwood is the predominant type of phreatophyte in the URGR. The Bureau of Reclamation, in 1971, reported phreatophyte consumptive use in the URGR at nearly 18,300 acre-feet annually. The total area of phreatophytes in the URGR was estimated (U.S. Department of Interior, Bureau of Reclamation, 1971) at 5,650 acres.

Evaporation. Losses due to evaporation from reservoirs, lakes, and ponds affect the net water supply available. Studies of evaporation from storage reservoirs indicate that during long periods of deficient streamflow, reservoirs may yield, for useful purposes, as little as 50 percent of the total water supply. The primary evaporation loss in the URGR comes from rivers, streams, and the 10,700 acres of lakes. Phreatophyte losses, however, are far greater than evaporation losses.

ECONOMIC LAND CLASSIFICATION

An economic land classification of the 87,030 acres of irrigated cropland in the upper Rio Grande drainage basin was based on an adaptation of the Cornell system using soil productivity and irrigation water quality and quantity as the primary variables. This classification was conducted, primarily for use with the socioeconomic model, to provide basic information on the relative economic productivity of the irrigated cropland areas within the Region. The delineation of areas with slight, if any, moderate, and severe limitations provided information for the water and land resource reallocation criteria used in the model.

All of the irrigated cropland in the Upper Rio Grande drainage basin was considered to have severe limitations and was classed as economic land Class III (Table 16 and Figures 11 and 12). The primary reasons were low soil productivity, reduced water quantity, and extremely small farm size. The fields were small and irregular in shape as a result of the land division practices, terrain, and irrigation systems. Most of the farms were operated on a part-time basis, producing low income-generating crops. The farmsteads and buildings were generally old and in poor condition. Existing machinery and equipment was generally small and obsolete. The irrigation systems were

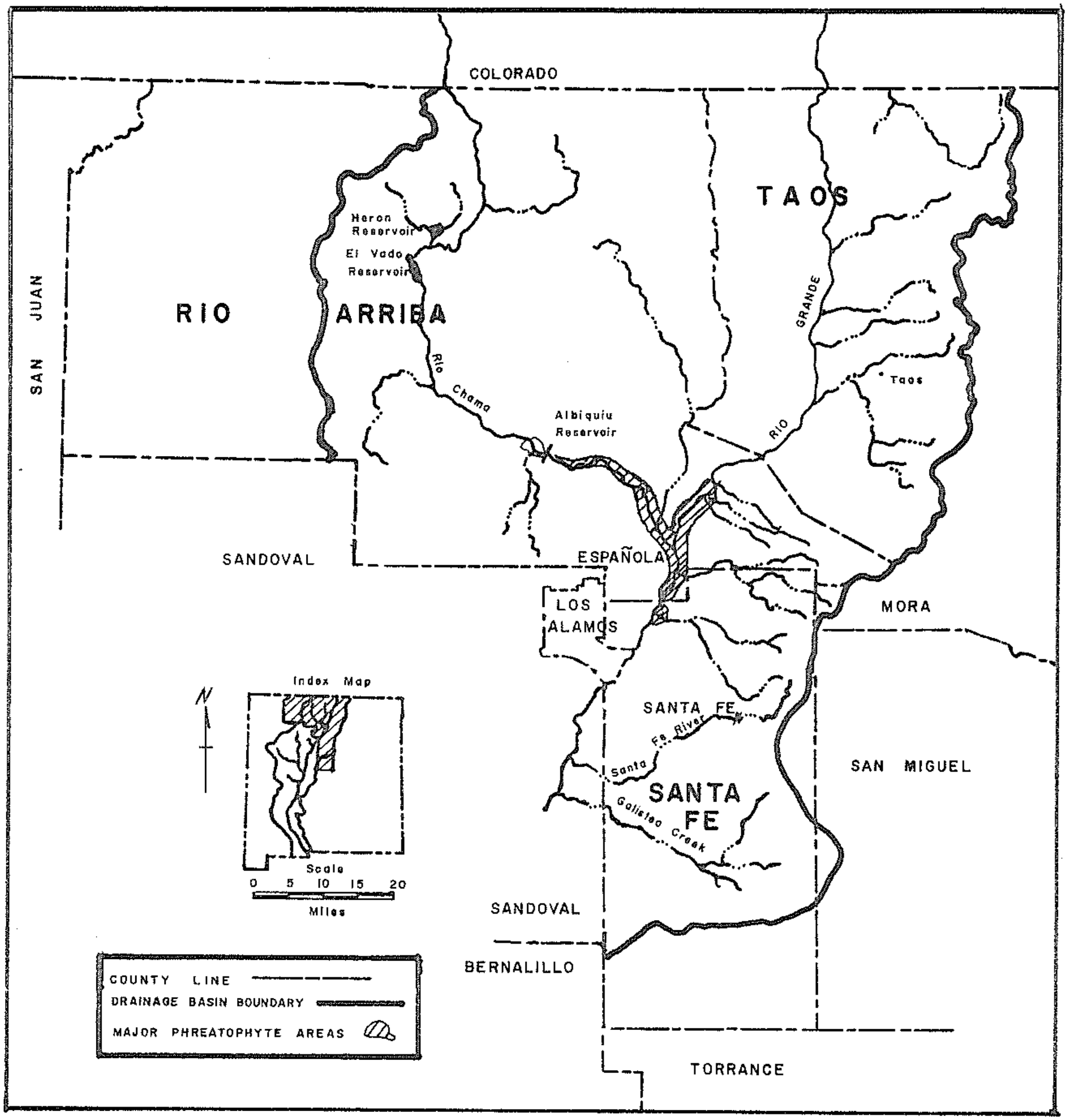

Figure 10. Major phreatophyte areas in the Upper Rio Grande Region, New Mexico.

normally small, poorly maintained, and inefficient. The water supply for most of the area was limited because of the seasonal nature of the runoff. Early spring runoff from the melting snow provided water for irrigation from about March through April, and summer rainfall runoff provided some irrigation water from July through September. In many cases the summer rainfall runoff only resulted in damage or destroyed the irrigation structures. Climatic conditions of the area also restricted the type of crops produced and the resulting yields. Alfalfa generally provided only about three cuttings for an average seasonal yield of 2-4 tons per acre. Other hay and pasture seasonal yields were approximately one ton for native hay and as much as two tons for timothy and other improved hays. These crops accounted for approximately 70 percent of the cropped acreage.

Table 16. Acreage of irrigated cropland by economic land classes, upper Rio Grande drainage basin, New Mexico

Economic Land Classification	Western Upper Rio Grande Region		Eastern Upper Rio Grande Region		Total	
	(acres)	(percent)	(acres)	(percent)	(acres)	(percent)
Class I	0	0	0	0	0	0
Class II	0	0	0	0	0	0
Class III	29,270	100.0	57,760	100.0	87,030	100.0
Total	29,270	100.0	57,760	100.0	87,030	100.0

The restrictions and limitations associated with the irrigated cropland areas in the Upper Rio Grande Region were considered extensive and significant in severely restricting the economic productivity and income generating potential of the Region.

Figure 11. Economic land classification map, Eastern Upper Rio Grande Region, New Mexico.

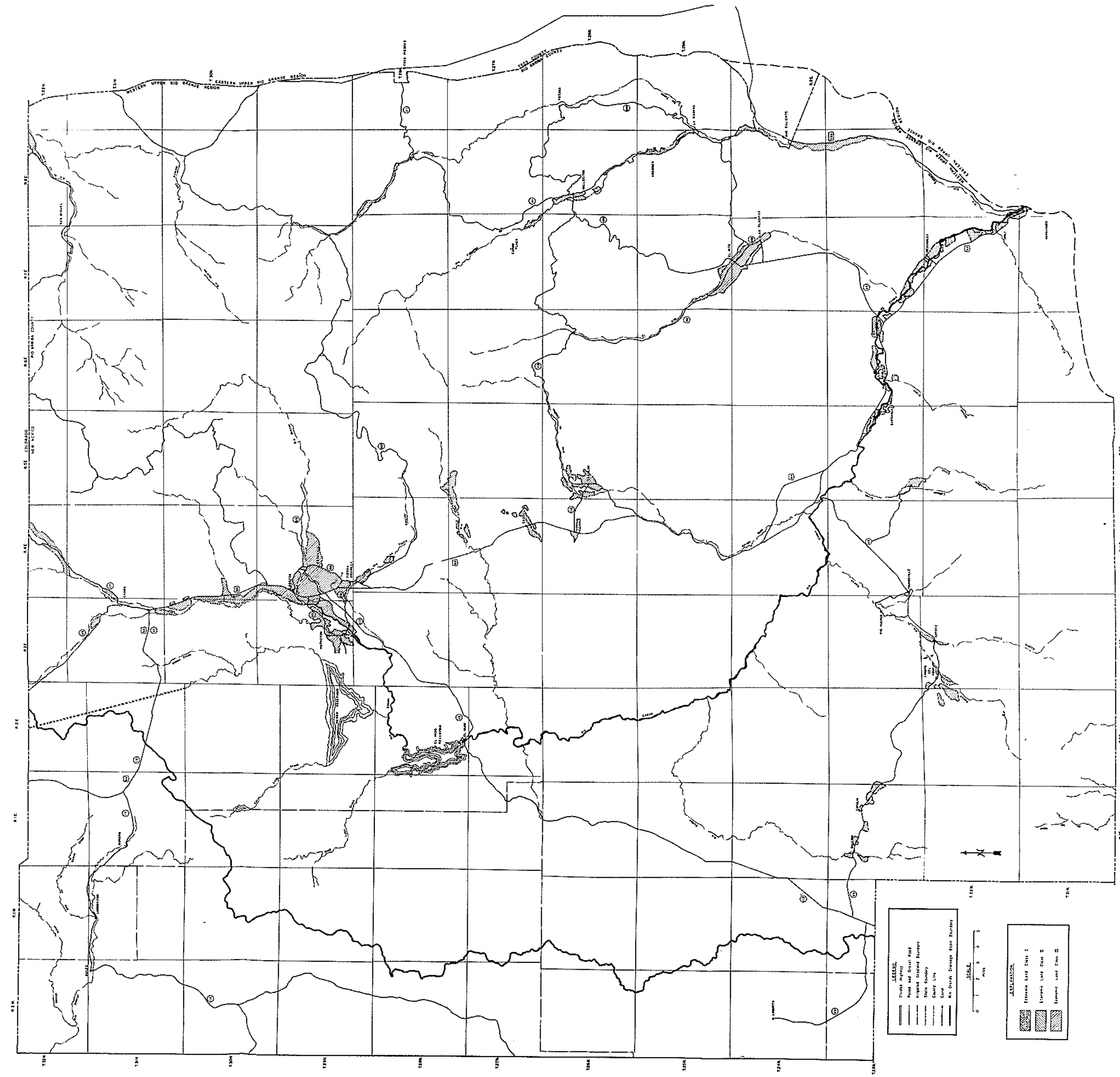

Figure 12. Economic land classification map, Western Upper Rio Grande Region, New Mexico.

THE SOCIO-ECONOMIC MODEL

The socio-economic model was used to simulate long-run production and water utilization patterns in the Rio Grande Basin under alternative assumptions. Because of the difficulty of obtaining population, industrial activity, and employment data by drainage basin they were incorporated into the socio-economic model on a county basis. Therefore, the results from the socio-economic model reflect economic activity and water depletions for all of Taos, Rio Arriba, Santa Fe, and Los Alamos Counties; portions of Rio Arriba and Santa Fe Counties outside of the Rio Grande drainage basin are included, but economic activity and water depletions for the small portions of Mora and San Miguel Counties that are within the Rio Grande drainage basin are excluded.

The URGR and the other three Regions constitute the total socio-economic simulation model. Direct interpretations of the results for only the URGR do not take into account the interactions with the other Regions; therefore, the URGR will be highlighted as a part of the total Rio Grande region analysis.

Each simulation process starts with the same basic optimal solution to the model, and continues with annual changes to satisfy the alternative conditions for a period of 50 years. The basic solution used 1970 conditions and closely approximates the actual production levels attained 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 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.

Basic Optimal Solution of the Model

The economy of New Mexico was represented in the model by twenty-four production sectors (Table 17). All sectors were defined in the model in units of one million dollars of production. Each sector had its own demands

Table 17. 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

*Source: New Mexico Bureau of Business Research, 1965
**Standard Industrial Classification

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 18 and 19 present some of the major results of the basic model and relate them to water utilization for both the total Rio Grande region and for the URGR. Table 18 presents levels of production for all 24 sectors measured in terms of output. *Medical and professional services* and *research and development* (sector 23) generated the largest value of production at $517.96 million, and *agricultural services* (sector 5) generated the smallest value of production at $4.95 million. Within the agricultural sector, *meat animals*, *dairy products*, *and poultry* (sector 1) accounted for about 49 percent of the agricultural value of production; *fruits and vegetables* (sector 4) about 23 percent; *cotton* (sector 3) about 10 percent; *food grains and feed crops* about 12 percent; and *agricultural services* about 6 percent. The *metals sector* (sector 6) accounted for about 76 percent of the total value of production for the mining industry, and *oil and gas* (sector 7) accounted for the remaining 24 percent. In the manufacturing sectors, *electrical, scientific instruments, and fabricated metal products* (sector 14) accounted for 27 percent of the value of production ($70.346 million); *lumber and wood products*, *concrete and stone products* (sector 12) 22 percent; *printing and publishing, miscellaneous manufacturing* (sector 15) 20 percent; *meat packing* and *dairy products* (sectors 8 and 9) 18 percent; and the remaining 13 percent included *grain mill and bakery products* (sector 10) 5 percent, *miscellaneous food* (sector 11) 5 percent, and *chemicals and petroleum refining* (sector 13) 3 percent. The *Services* sectors (sectors 22 and 23) accounted for about 40 percent of the total value of production; *Trade* (sectors 19 and 20) about 25 percent; *Transportation, communications, and utilities* (sectors 16, 17, and 18) about 14 percent; *Finance, insurance, and real estate* (sector 21) about 10 percent; and *Construction* (sector 24) about 10 percent.

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 71.2 percent in *retail auto, gas stations, 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.

The *Trades* and *Services* sectors represent about 82 percent of the employment within the Rio Grande region. *Wholesale trade, retail trade, gas stations, restaurants,* and *Services* (sectors 19, 20, 22, and 23) represent almost 60 percent of the total employment. Employment in *Manufacturing* accounts for about 10 percent of those employed in the RGR, primarily in *lumber and wood products*, and *concrete and stone products* (sector 12); *electrical machinery and equipment, scientific instruments, fabricated metal products* (sector 14); and *printing and publishing* and *miscellaneous manufacturing* (sector 15). These three sectors account for over 80 percent of the employment within the *Manufacturing* sectors. *Agriculture* represents about 7 percent of the RGR employment force, with about 38 percent employed in *vegetables and fruits* (sector 4), and about 33 percent in *meat animal and dairy production*.

Agricultural production accounted for 95 percent of the water depleted in the RGR with *food grains and feed crops* (sector 2) accounting for about 45 percent of the total depletions, and *cotton* (sector 3) accounting for another 27 percent. *Mining* sectors accounted for less than 1 percent, *Manufacturing* sectors only 0.3 percent, and *Trades and Services* 3.8 percent.

Table 19 magnifies the differences between the *Agriculture* sectors and all other producing sectors. While the *Agriculture* 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 95 percent of all the water used in production in the Rio Grande region. The *Trade and Services* sectors played the opposite role, using only 3.8 percent of all water depleted by the production sectors, but producing 78 percent of the total value of output and accounting for 81.9 percent of the total value added.

In the URGR the agricultural sectors produced the smallest portion of the subregion's total output (4.1 percent) and total value added (2.8 percent) percent), and also provided for one of the lowest employment rates (9.4 percent). *Agriculture* consumed the largest portion of the water used in production (93.8 percent of the URGR total). *Mining* (sectors 6 and 7), is more important in the URGR than in the total Rio Grande region, producing 13.3 percent of the total output, 15.3 percent of the total value added, and providing for 5.3 percent of the employment. The *Manufacturing* sectors are less important in the URGR than in the total Rio Grande region. The *Trade and Services* sectors in the URGR were similar to the total Rio Grande region, and the general relationships that exist for the total Rio Grande region are also expressed in the Upper Region; i.e., *Trade and Services* sectors were responsible for the largest portion of the total value of output (77.7 percent), but used only 3.6 percent of the water depleted. The single most important industry is *medical and professional services, research and development* (sector 23) accounting for almost 40 percent of the total value of production in the URGR.

In the agricultural sectors, *meat animal and dairy production* (sector 1) accounted for 80 percent of the value of production, 67 percent of the value added by *Agriculture*, provided almost 46 percent of the agricultural employment, and consumed about 46 percent of the agricultural water. *Food grains and feed crops* (sector 2) accounted for about 13 percent of the value of agricultural production, 20 percent of value added, 44 percent of agricultural employment, and 50 percent of the agricultural water consumed.

The single most important manufacturing sector in the URGR is *lumber and wood products* and *concrete and stone products* (sector 12), followed closely by *printing and publishing* and *miscellaneous manufacturing* (sector 15). These two manufacturing sectors account for 78 percent of the manufacturing value of production, 85 percent of value added, 72 percent of manufacturing employment, and 83 percent of the manufacturing depletions.

The single most important *Trade* and *Services* sector is *medical and professional services, research and development* (sector 23) comprising almost 50 percent of the value of production of *Trades and Services*, 46 percent of value added, but only 31 percent of the employment, and 47 percent of the water depletions used in *Trades* and *Services*. The location of the Los Alamos Scientific Laboratory in the URGR contributes significantly to sector 23. The next closest sector in value of production is *wholesale trade* and most *retail trade* (sector 19), but it contributes only 12 percent of the *Trades and Services* value of production followed by *contract construction* (sector 24) at 9 percent, and *motel, personal services*, and *business services* (sector 22) at slightly less than 9 percent. *Wholesale*

Table 18. Production, value added, employment, and water use by production sector in the Rio Grande Region, and in the Upper Rio Grande Region, 1970--basic optimal solution

Sector		Total Rio Grande Region: Value of Production ($1 million)	Total Rio Grande Region: Value Added ($1 million)	Total Rio Grande Region: Employment	Total Rio Grande Region: Water Depletions (acre-feet)	Upper Rio Grande Region: Value of Production ($1 million)	Upper Rio Grande Region: Value Added ($1 million)	Upper Rio Grande Region: Employment	Upper Rio Grande Region: Water Depletions (acre-feet)
Agriculture	1	41.839	14.351	2,346	79,888	13.503	4.632	864	50,552
	2	9.886	6.357	1,424	224,748	2.209	1.420	857	56,039
	3	8.574	5.264	233	134,180	0.000	0.000	0	0
	4	19.526	15.406	2,739	58,393	0.466	0.368	112	4.482
	5	4.950	3.024	454	59	0.814	0.497	59	10
Mining, Oil & Gas	6	81.785	52.342	1,731	2,977	36.077	23.089	897	1,652
	7	26.277	19.051	189	1,594	19.708	14.288	159	1,199
Manufacturing	8	20.651	3.655	273	62	0.281	0.050	3	1
	9	25.948	6.798	504	111	1.992	0.522	49	9
	10	14.277	4.183	537	20	0.000	0.000	0	0
	11	13.071	4.902	539	189	1.351	0.507	78	28
	12	56.155	26.730	2,332	854	9.020	4.294	299	150
	13	7.931	1.753	109	297	0.000	0.000	0	0
	14	70.345	29.615	4,018	157	1.204	0.507	126	2
	15	50.456	26.691	2,139	137	8.344	4.414	370	36
Trade & Services	16	109.842	72.935	5,004	274	10.468	6.951	240	26
	17	13.501	9.316	152	34	4.200	2.898	110	10
	18	104.925	68.201	4,518	4,484	16.871	10.966	604	806
	19	325.258	214.345	22,071	1,597	37.380	24.765	2,976	185
	20	98.281	69.976	11,298	579	14.817	10.550	1,769	79
	21	177.302	131.381	7,230	1,742	22.706	16.825	977	223
	22	151.463	88.303	13,158	1,940	28.163	16.419	2,831	400
	23	517.957	286.430	17,474	6,371	158.735	87.780	5,027	1,952
	24	172.462	71.744	9,559	3,039	29.416	12.237	1,697	518
	Total	2,122.660	1,232.753	110,030	523,722	417.925	243.979	20,104	118,358

Table 19. Production, employment, and water use for major sectors in the Rio Grande Region, and in the Upper Rio Grande Region, New Mexico--basic optimal solution

Major Sector	Total Rio Grande Region: Total Output ($1 million)	Total Rio Grande Region: Total Value Added ($1 million)	Total Rio Grande Region: Employment	Total Rio Grande Region: Total Water Depletions (acre-feet)	Upper Rio Grande Region: Total Output ($1 million)	Upper Rio Grande Region: Total Value Added ($1 million)	Upper Rio Grande Region: Employment	Upper Rio Grande Region: Total Water Depletions (acre-feet)
1. Agriculture	84.775	44.402	7,196	497,268	16.992	6.917	1,892	111,084
2. Mining, Oil & Gas	108.062	71.393	1,920	4,571	55.785	37.377	1,056	2,852
3. Manufacturing	258.834	104.327	10,451	1,826	22.192	10.294	925	225
4. Trade & Services	1,670.991	1,012.630	90,463	20,059	322.956	189.391	16,231	4,199
Total	2,122.660*	1,232.753*	110,030	523,722*	417.925	243.979	20,104	118,358*
	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)
1. Agriculture	4.0	3.6	6.5	94.9	4.1	2.8	9.4	93.8
2. Mining, Oil & Gas	5.1	5.8	1.8	0.9	13.3	15.3	5.3	2.4
3. Manufacturing	12.2	8.5	9.5	0.4	5.3	4.2	4.6	0.2
4. Trade & Services	78.7	82.1	82.2	3.8	77.3	77.7	80.7	3.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Does not add due to Rounding

trade and retail trade; *contract construction*; and *motel, personal services,* and *business services* represent 18, 11, and 18 percent of the employment, respectively, and combined account for 26 percent of the *Trades and Services* water depletions.

The regional distribution of water depletions by major production sectors and municipal and rural uses is presented in Table 20. 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 74.0 percent, where 16.5 percent of the total water use was for domestic purposes. The Upper Region was responsible for the second lowest water depletions in the Rio Grande region, utilizing only 22 percent of the total water available.

Water recreation demands in the Rio Grande region in the base year (1970) and the distribution of supply by origin are presented in Table 21. 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 21); in boating there is a net supply of 293,943 AOD (Table 21); and in fishing there is a net supply of 382,904 AOD (Table 21). The Upper Rio Grande Region supplies nearly all of the Upper Rio Grande Region's demand for water skiing, boating, and fishing. In addition, the URGR supplies 8,281 AOD's of out-of-state demand for water skiing, 15,673 AOD's of boating, and 162,706 AOD's of fishing, as well as 250,258 AOD's of fishing for the Middle Rio Grande Region.

Three Water Management Alternatives

The socio-economic model was used to estimate the effects of population growth on the distribution of production and water requirements in the Rio Grande region for the period 1970-2020. Regional population projections used

Table 20. Summary of depletions by major sector in the Rio Grande region (acre-feet)--basic optimal solution

Major Sector	Region: Upper	Middle	Socorro	Lower	Total Rio Grande Region
	. . . .	. . acre-feet	. . . . .	. . . . .	. . . .
Agriculture	111,084	125,795	38,061	222,328	497,268
Mining, Oil & Gas	2,852	1,500	108	111	4,571
Manufacturing	225	1,486	29	87	1,826*
Commercial Trade & Services	4,199	13,708	202	1,950	20,059
Municipal	3,862	25,568	407	4,362	34,199
Rural	2,042	2,527	203	1,051	5,823
Total	124,264	170,581	39,010	229,889	563,746*
	. . . .	. . percent	. . . . .	. . . . .	. . . .
Agriculture	89.39	73.74	97.57	96.71	88.21
Mining, Oil & Gas	2.30	0.88	0.28	0.05	0.81
Manufacturing	0.18	0.87	0.07	0.04	0.32
Commercial Trade & Services	3.38	8.04	0.52	0.85	3.56
Municipal	3.11	14.99	1.04	1.90	6.07
Rural	1.64	1.48	0.52	0.46	1.03
	100.00	100.00	100.00	100.00*	100.00

*Does not add due to rounding.

Table 21. Water-based recreation by Region, Rio Grande region--basic optimal solution

Supplying Region	Demanding Region: Upper	Middle	Socorro	Lower	Out of State	Total Supply
	. . . . (activity-occasion days)					
		WATER SKIING				
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
		BOATING				
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
		FISHING				
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

in the model were based on the New Mexico Bureau of Business Research county projections (BEA Projections) (Table 22). An increase in population affects the final demand for consumer projects, the labor force, as well as the direct demand for water for municipal and rural use. The model assumes government employment to be a function of population; therefore, it was determined but not reported in the following analyses.

An increase in the final demand will affect all 24 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.

Three alternative solutions of long-run production and water-use patterns, utilizing a linear 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 all future demands is not a realistic assumption. There are only limited opportunities for water importation to the Rio Grande Basin, i.e., the San Juan-Chama diversion. It is more likely that no additional surface water will be available in the foreseeable 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. In the model, surface and ground water are used in fixed proportions in the agricultural sectors, thus ground water cannot be substituted for surface water. The effect of limiting surface-water availability to 1970 levels (basic optimal solution) 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

Table 22. Population projections by Region, Rio Grande region, New Mexico, 1970-2020

Year	Region								Total Rio Grande Region
	Upper		Middle		Socorro		Lower		
	Total Population	% of Total	Total Population	% of Total	Total Population	% of Total	Total Population	% of Total	
1970	111,610	19.5	373,355	65.3	9,763	1.7	76,962	13.5	571,690
1980	123,372	19.3	4.9,897	65.6	10,870	1.7	85,630	13.4	639,769
1990	135,133	19.1	466,440	65.9	11,978	1.7	94,297	13.3	707,848
2000	146,895	18.9	512,982	66.1	13,085	1.7	102,965	13.3	775,927
2010	158,656	18.8	559,525	66.3	14,193	1.7	111,632	13.2	844,006
2020	170,418	18.7	606,067	66.4	15,300	1.7	120,300	13.2	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 (BEA Projections).

constraints imposed by the water laws of New Mexico, the mining of ground water may be restricted by authority of the State Engineer to declare a ground-water basin and close it to future development. Most of the Rio Grande region in New Mexico lies within declared basins. To maintain the base flow of the Rio Grande, increased pumping effects on the river must be offset by retiring surface-water rights. This alternative approximates the current administration of water resources in the Rio Grande region.

The third alternative is much more restrictive than the second alternative of imposing a constraint only on the surface water. This 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.

Additional diversions refer to the effect of pumpage upon the flows of 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.

In order to maintain interregional deliveries over time, the total surface-water availability in each Region was reduced annually to compensate for the additional effects of pumping upon the flow of the river.

Alternative 1: No water constraint. The long-run effects of population growth under the above assumptions are presented in Table 23 for the RGR and for the URGR. Table 23 presents the production levels, value added, employment, and water depletions 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. This amounts to an increase of more than

Table 23. Production, value added, employment, and water use by production sector in the Rio Grande Region, and in the Upper Rio Grande Region, 2020--no water constraint

Sector		Total Rio Grande Region				Upper Rio Grande Region			
		Value of Production ($1 million)	Value Added ($1 million)	Employment	Water Depletions (acre-feet)	Value of Production ($1 million)	Value Added ($1 million)	Employment	Water Depletions (acre-feet)
Agriculture	1	55.812	19.144	3,302	102,831	16.407	5.628	1,050	61,424
	2	14.502	9.325	2,004	332,144	3.100	1.993	1,203	78,643
	3	13.530	8.307	368	211,735	0.000	0.000	0	0
	4	25.812	20.366	3,629	77,802	0.645	0.509	154	6,204
	5	7.588	4.636	693	91	1.208	0.738	87	14
Mining, Oil & Gas	6	129.705	83.011	2,731	4,699	55.937	35.800	1,391	2,562
	7	41.219	29.884	296	2,499	30.556	22.153	247	1,859
Manufacturing	8	33.501	5.930	442	101	0.436	0.077	4	1
	9	41.866	10.969	814	179	3.088	0.809	76	13
	10	22.792	6.678	854	32	0.000	0.000	0	0
	11	20.971	7.864	864	303	2.092	0.785	121	43
	12	89.420	42.564	3,721	1,360	13.960	6.645	463	232
	13	12.868	2.844	177	482	0.000	0.000	0	0
	14	113.719	47.876	6,485	254	1.866	0.786	195	3
	15	80.783	42.734	3,424	219	12.934	6.842	574	55
Trade & Services	16	175.304	116.402	8,068	437	16.218	10.769	372	41
	17	21.588	14.896	245	54	6.512	4.493	180	16
	18	168.080	109.252	7,250	7,164	26.141	16.992	936	1,248
	19	522.722	344.473	35,423	2,567	58.175	38.337	4,607	286
	20	157.470	112.119	18,097	925	22.959	16.347	2,741	122
	21	284.080	210.503	11,577	2,791	35.108	26.015	1,510	345
	22	242.044	141.112	20,955	3,099	43.641	25.443	4,387	620
	23	838.294	463.576	28,442	10,311	246.115	136.102	7,794	3,027
	24	276.625	115.076	15,316	4,874	45.607	18.973	2,630	804
	Total	3,390.292	1,969.539	175,178	766,950	642.705	376.233	30,722	157,562

$1,267.6 million (59.7 percent) in the total value of output for the period 1970-2020.

Agricultural production is expected to increase only 38.3 percent ($32.5 million) in the Rio Grande region compared to an increase of 59.7 percent in total value of output. 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 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 expected increase varies from 58 percent for *cotton* (sector 3) to 32 percent for *vegetables and fruits* (sector 4), with *agricultural services* up 53 percent (sector 5), 47 percent for *food grains and feed crops* (sector 2), and *meat animals, dairy, and poultry* up only 33 percent (sector 1).

The total nonagricultural production is expected to increase by $1,235 million. The expected increase in agricultural production represents only 2.6 percent of the total increase in the value of production while it represents 85.2 percent of the additional water depletions required. The value of production for the *Mining* sectors is expected to increase about 58 percent from 1970 to 2020, *Manufacturing* up about 61 percent, and *Trades and Services* are expected to increase about 60 percent (Table 24).

Water depletions in the year 2020 for the Rio Grande region are expected to reach almost 830,000 acre-feet. This increase of 266,743 acre-feet over the depletions in 1970 will be required to meet the projected population needs in 2020. However, by 2020 an additional 83,000 acre-feet of surface water will be required to maintain the base flow of the river out of the region to Texas. Of the 266,743 acre-feet, the agricultural sectors will require 227,336 acre-feet, the remaining production sectors 15,769 acre-feet, and domestic needs 23,516 acre-feet. The increase in agricultural depletions will be met by utilizing 191,720 acre-feet of surface water and 35,616 acre-feet of ground water. All increases in surface water will be used by agriculture.

Table 24. Production, value added, employment and water use for major sectors in the Rio Grande Region and in the Upper Rio Grande Region, New Mexico, 1970-2020--no water constraint

		Total Rio Grande Region						Upper Rio Grande Region					
		Value of Production				Water Depletions		Value of Production				Water Depletions	
Year	Sector		Change from 1970	Value Added	Employment		Change from 1970		Change from 1970	Value Added	Employment		Change from 1970
		($1 million)	(percent)	($1 million)		(acre-feet)	(percent)	($1 million)	(percent)	($1 million)		(acre-feet)	(percent)
1970 (basic optimal solution)	Agriculture	84.775		44.402	7,195	497,268		16.992		6.917	1,891	111,084	
	Mining	108.062		71.393	1,920	4,571		55.785		37.377	1,056	2,852	
	Manufacturing	258.834		104.327	10,451	1,826		22.192		10.294	925	225	
	Trade & Services	1,670.991		1,012.630	90,463	20,059		322.956		189.391	16,231	4,199	
	Municipal & Rural	--		--	--	39,144		--		--	--	5,565	
	Total	2,122.660*		1,232.753*	110,030*	562,866*		417.925		243.979	20,104*	123,923*	
2020	Agriculture	117.244	38.3	61.778	9,997	724,603	45.7	21.360	25.7	8.868	2,495	146,285	31.7
	Mining	170.924	58.2	112.895	3,027	7,199	57.5	86.493	55.0	57.953	1,638	4,421	55.0
	Manufacturing	415.920	60.7	167.459	16,781	2,928	60.3	34.376	54.9	15.944	1,432	348	54.8
	Trade & Services	2,686.207	60.8	1,627.409	145,374	32,221	60.6	500.476	55.0	293.471	25,157	6,508	55.0
	Municipal & Rural	--		--	--	62,660	60.1	--		--	--	8,497	52.7
	Total	3,390.292*	59.7	1,969.539*	175,178*	829,610*	47.4	642.705	53.8	376.233*	30,722	166,059	34.0

*Does not add because of rounding.

In 1970 the Upper Rio Grande Region accounted for slightly over 19 percent of the total Rio Grande region's value of production and is estimated to remain fairly constant at slightly under 19 percent in 2020. *Trade and Services* accounted for about 78 percent of the value of production in 1970, *Agriculture* 4 percent, *Manufacturing* 5 percent, and *Mining* approximately 14 percent of the value of production in the Upper Rio Grande Region (Table 24). In the year 2020, *Trade and Services* are expected to remain constant at 78 percent, *Agriculture* constant at about 3 percent, *Manufacturing* constant at about 5 percent, and *Mining* to remain constant at about 14 percent of the value of production.

The economy of the URGR is expected to grow at a lower rate than that for the total Rio Grande region. The expected increase in total value of production from 1970 to 2020 is 53.8 percent compared to 59.7 percent for the total RGR. *Agriculture* is expected to increase at a lower percentage rate of growth, 25.7 percent for the URGR and 38.3 percent for the RGR, and the remaining sectors at a rate of about 55 percent for the URGR.

Employment in the URGR is expected to increase 53 percent from 1970 to 2020, with agricultural employment increasing 32 percent and the other sectors increasing about 55 percent.

Water depletions in the Upper Rio Grande Region in 1970 accounted for about 22 percent of the total Rio Grande region's water depletions but are expected to decrease slightly to about 20 percent in 2020. *Agriculture* is the largest water user, accounting for 90 percent of total depletion in the Upper Rio Grande Region in 1970 and about 88 percent in 2020.

<u>Alternative 2: Surface-water constraint</u>. Table 25 presents production levels, value added, employment, and expected water depletions by sector under the surface-water constraints for the Rio Grande region and for the URGR, and is summarized by major sector in Table 26. The Rio Grande regional value of production with a constraint would be $3,390.3 million, and $3,372.2 million without a surface-water constraint, thus the cost of imposing a surface-water constraint is $18.1 million (0.53 percent reduction. Direct *Agriculture* production would decrease $6.9 million, *Manufacturing* production would decrease $0.3 million, and *Trade and Services* are expected

Table 25. Production, value added, employment, and water use by production sector in the Rio Grande Region, and in the Upper Rio Grande Region, 2020--surface water constraint

Sector		Total Rio Grande Region				Upper Rio Grande Region			
		Value of Production ($1 million)	Value Added ($1 million)	Employment	Water Depletions (acre-feet)	Value of Production ($1 million)	Value Added ($1 million)	Employment	Water Depletions (acre-feet)
Agriculture	1	55.813	19.144	3,303	102,835	16.408	5.628	1,050	61,428
	2	8.127	5.226	1,261	196,466	2,565	1.649	995	65,071
	3	13.357	8.201	364	209,026	0.000	0.000	0	0
	4	25.812	20.366	3,629	77,802	0.645	0.509	154	6,204
	5	7.196	4.397	657	86	1.176	0.719	85	14
Mining, Oil & Gas	6	129.704	83.011	2,731	4,699	55.937	35.800	1,391	2,562
	7	41.218	29.883	296	2,499	30.556	22.153	247	1,859
Manufacturing	8	33.500	5.929	442	101	0.436	0.077	4	1
	9	41.866	10.969	814	179	3.088	0.809	76	13
	10	22.788	6.677	854	32	0.000	0.000	0	0
	11	20.971	7.864	864	303	2.092	0.785	121	43
	12	89.368	42.539	3,719	1,359	13.957	6.644	463	232
	13	12.849	2,840	177	481	0.000	0.000	0	0
	14	113.515	47.790	6,474	253	1.866	0.786	195	3
	15	80.772	42.728	3,423	219	12.933	6.842	574	55
Trade & Services	16	175.294	116.395	8,067	437	16.217	10.768	371	41
	17	21.582	14.892	245	54	6.512	4.493	180	16
	18	168.010	109.206	7,247	7,161	26.139	16.990	936	1,248
	19	522.539	344.353	35,411	2,566	58.169	38.333	4,606	286
	20	157.350	112.033	18,083	925	22.955	16.344	2,741	122
	21	283.816	210.308	11,566	2,788	35.098	26.008	1,510	345
	22	241.851	140.999	20,936	3,096	43.631	25.437	4,386	620
	23	828.282	458.040	27,955	10,188	246.114	136.101	7,794	3,027
	24	276.618	115.073	15,316	4,874	45.607	18.973	2,630	804
	Total	3,372.196	1,958.862	173,833	628,426	642.100	375.846	30,510	143,992

Table 26. Production, value added, employment, and water use for major sectors in the Rio Grande Region, and in the Upper Rio Grande Region, New Mexico, 1970-2020--surface water constraint

Year	Sector	Total Rio Grande Region: Value of Production ($1 million)	Total Rio Grande Region: Value of Production, Change from 1970 (percent)	Total Rio Grande Region: Value Added ($1 million)	Total Rio Grande Region: Employment	Total Rio Grande Region: Water Depletions (acre-feet)	Total Rio Grande Region: Water Depletions, Change from 1970 (percent)	Upper Rio Grande Region: Value of Production ($1 million)	Upper Rio Grande Region: Value of Production, Change from 1970 (percent)	Upper Rio Grande Region: Value Added ($1 million)	Upper Rio Grande Region: Employment	Upper Rio Grande Region: Water Depletions (acre-feet)	Upper Rio Grande Region: Water Depletions, Change from 1970 (percent)
1970 (basic optimal solution)	Agriculture	84.775		44.402	7,196	497,268		16.992		6.917	1,892	111,084	
	Mining	108.062		71.393	1,920	4,571		55.785		37.377	1,056	2,852	
	Manufacturing	258.834		104.327	10,451	1,826		22.192		10.294	925	225	
	Trade & Services	1,670.991		1,012.630	90,463	20,059		322.956		189.391	16,231	4,199	
	Municipal & Rural	--		--	--	39,144		--		--	--	5,565	
	Total	2,122.660*		1,232.753*	110,030	562,866*		417.925		243.979	20,104	123,923*	
2020	Agriculture	110.305	30.1	57.334	9,213	586,215	17.9	20.794	22.4	8.505	2,284	132,717	19.5
	Mining	170.922	58.2	112.894	3,027	7,199	57.5	86.493	55.0	57.953	1,638	4,421	55.0
	Manufacturing	415.629	60.6	167.336	16,767	2,926	60.2	34.372	54.9	15.943	1,432	348	54.8
	Trade & Services	2,675.342	60.1	1,621.299	144,827	32,088	60.0	500.442	55.0	293.447	25,156	6,507	55.0
	Municipal & Rural	--		--	--	62,660	60.1	--		--	--	8,497	52.7
	Total	3,372.196*	58.9	1,958.862*	173,833*	691,086	22.8	642.100*	53.6	375.846*	30,510	152,489*	23.0

*Does not add because of rounding.

to decrease \$10.9 million. The *meat animal, dairy,* and *poultry* sector (sector 1) would not be affected by surface-water constraint, but the value of production for *food grains and feed crops* (sector 2) would be decreased \$6.4 million, *cotton* (sector 3) reduced \$0.2 million, *fruits and vegetables* (sector 4) would be unchanged, and *agricultural services* (sector 5) down about \$0.4 million. In the *Services* sectors, *medical and professional*, and *research and development* (sector 23) is expected to decrease about \$10 million.

The level of employment in the Rio Grande region is expected to decrease by 1,344 employees in 2020 when a surface-water constraint is imposed. *Agriculture* production sectors (sectors 2, 3, and 5) are expected to account for 784 of these employees, with *food grains and feed crops* accounting for 88 percent of the decrease. *Services* production sectors are expected to account for 546 employees with sector 23 accounting for all employees.

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 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, and it is expected that 83,000 acre-feet of surface rights will be retired by 2020. Because of the additional San Juan-Chama diversion water, surface-water depletions are expected to increase until about the year 2000 and then decrease. However, the Socorro and Lower Regions are expected to have reductions in surface-water depletions well before the Upper and Middle Regions because they do not benefit from the San Juan-Chama project. The surface-water usage decreases in the 50-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 increased by 111,000 acre-feet (from the San Juan-Chama).

The decrease in ground-water depletions for agricultural use in the same years results from the fixed ground-surface water relationship assumed for agricultural production. This assumption was necessary in order to avoid surther surface-flow depletions which would take place if ground water were substituted for surface water in agricultural production.

Total water depletions are expected to increase only 22.8 percent and reach 691,086 acre-feet in 2020. This is 138,524 acre-feet less than the amount required where no water constraint was imposed. *Agriculture* accounts for 136,388 acre-feet of this reduction. The remaining 136 acre-feet reduction includes 2 acre-feet in *Manufacturing* and 134 acre-feet in *Trades and Services*.

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.

The value of production in the Upper Rio Grande Region in 2020 would be $642.7 million without a water constraint and $642.1 million when a surface-water constraint is imposed (Table 25). Direct agricultural production would decrease $0.6 million, and the indirect effects of agricultural production would account for less than $0.1 million decrease in services associated with agriculture. *Food grains and feed crops* (sector 2) accounts for 77 percent of the decrease in agricultural production.

Employment in the URGR would decrease from 30,722 with no water constraint to 30,510 with a surface-water constraint. Again, *Agriculture* would account for nearly all (99 percent) of the reduction in employment. The reduction in *food grains and feed crops* is expected to account for 98 percent of the total reduction in employment.

Surface-water depletions in the Upper Rio Grande Region in the base year 1970 did not approach the average annual availability because of the San Juan-Chama diversion project that is expected to supply additional surface water to the URGR. The average annual depletions in 2020 with a surface-water constraint would be 13,569 acre-feet less than under the condition of no water constraint. Reduced agricultural depletions account for all (13,569 acre-feet) of the reduced depletions.

Alternative 3: Surface and ground-water constraint. Production, value added, employment, and water depletions in this alternative for the Rio Grande region and the URGR are presented in Table 27 and summarized by major sector in Table 28. The cost of imposing the additional constraint on ground water is $4.1 million in 2020 compared with a surface-water only

Table 27. Production, value added, employment, and water use by production sector in the Rio Grande Region, and in the Upper Rio Grande Region, 2020--total water constraint

Sector		Total Rio Grande Region: Value of Production ($1 million)	Total Rio Grande Region: Value Added ($1 million)	Total Rio Grande Region: Employment	Total Rio Grande Region: Water Depletions (acre-feet)	Upper Rio Grande Region: Value of Production ($1 million)	Upper Rio Grande Region: Value Added ($1 million)	Upper Rio Grande Region: Employment	Upper Rio Grande Region: Water Depletions (acre-feet)
Agriculture	1	55.813	19.144	3,303	102,835	16.408	5.628	1,050	61,428
	2	5.990	3.852	989	144,070	2.033	1.307	789	51,575
	3	12.989	7.975	354	203,262	0.000	0.000	0	0
	4	25.812	20.366	3,629	77,802	0.645	0.509	154	6,204
	5	6.812	4.162	625	82	1.145	0.700	83	14
Mining, Oil & Gas	6	129.704	83.011	2,731	4,699	55.937	35.800	1,391	2,562
	7	41.217	29.882	296	2,499	30.556	22.153	247	1,859
Manufacturing	8	33.500	5.929	442	101	0.436	0.077	4	1
	9	41.866	10.969	814	179	3.089	0.809	76	13
	10	22.786	6.676	854	32	0.000	0.000	0	0
	11	20.971	7.864	864	303	2.092	0.785	121	43
	12	89.353	42.532	3,718	1,359	13.955	6.643	463	232
	13	12.836	2.837	176	480	0.000	0.000	0	0
	14	113.713	47.873	6,484	254	1.866	0.786	195	3
	15	80.769	42.727	3,423	219	12.933	6.842	574	55
Trade & Services	16	175.279	116.385	8,067	437	16.217	10.768	372	41
	17	21.578	14.889	245	54	6.512	4.493	180	16
	18	167.978	109.186	7,246	7,159	26.136	16.988	936	1,248
	19	522.462	344.302	35,406	2,565	58.164	38.330	4,606	286
	20	157.299	111.997	18,077	924	22.950	16.340	2,740	122
	21	283.706	210.226	11,562	2,787	35.088	26.000	1,510	345
	22	240.775	140.372	20,826	3,082	43.621	25.431	4,385	619
	23	828.277	458.036	27,955	10,188	246.114	136.101	7,794	3,027
	24	276.613	115.071	15,316	4,874	45.607	18.973	2,630	804
	Total	3,368.097	1,956.264	173,402	570,242	641.503	375.462	30,298	130,495

Table 28. Production, value added, employment and water use for major sectors in the Rio Grande Region, and in the Upper Rio Grande Region, New Mexico, 1970-2020 --total water constraint

		Total Rio Grande Region						Upper Rio Grande Region					
		Value of Production				Water Depletions		Value of Production				Water Depletions	
Year	Sector		Change from 1970	Value Added	Employment		Change from 1970		Change from 1970	Value Added	Employment		Change from 1970
		($1 million)	(percent)	($1 million)		(acre-feet)	(percent)	($1 million)	(percent)	($1 million)		(acre-feet)	(percent)
1970 (basic optimal solution)	Agriculture	84.775		44.402	7,196	497,268		16.992		6.917	1,892	111,084	
	Mining	108.062		71.393	1,920	4,571		55.785		37.377	1,056	2,852	
	Manufacturing	258.834		104.327	10,451	1,826		22.192		10.294	925	225	
	Trade & Services	1,670.991		1,012.630	90,463	20,059		322.956		189.391	16,231	4,199	
	Municipal & Rural	--		--	--	39,144		--		--	--	5,565	
	Total	2,122.660*		1,232.753*	110,030	562,866*		417.925		243.979	20,104	123,923*	
2020	Agriculture	107.416	26.7	55.499	8,900	528,050	6.2	20.231	19.1	8.144	2,076	119,220	7.3
	Mining	170.921	58.2	112.894	3,027	7,199	57.2	86.493	55.0	57.953	1,638	4,421	55.0
	Manufacturing	415.794	60.6	167.407	16,776	2,926	60.2	34.371	54.9	15.942	1,432	348	54.8
	Trade & Services	2,673.967	60.0	1,620.464	144,699	32,070	59.9	500.409	55.0	293.424	25,152	6,507	55.0
	Municipal & Rural	--		--	--	62,660	60.1	--		--	--	8,497	52.7
	Total	3,368.097*	58.7	1,956.264	173,402	632,904*	12.4	641.503*	53.5	375.462*	30,298	138,992*	12.2

*Does not add because of rounding.

constraint, and $22.2 million compared with the alternative without any constraint on water. Direct *Agriculture* production would decrease $2.9 million as a result of imposing the additional ground-water constraint, but *Mining* (sector 6) is expected to remain constant, and the indirect effects of reduced *Agriculture* production would account for the other $1.2 million in *Manufacturing, Trade,* and *Services* associated with agriculture. The affected *Agriculture* sectors are expected to be *food grains and feed crops*, $2.14 million; *cotton*, $0.37 million; and *agricultural services*, $0.38 million. However, annual agricultural production in 2020 is expected to be $22.6 million more than in 1970, and nonagricultural production is expected to be $1,225.8 million above the 1970 level.

The level of employment is expected to decrease by 481 employees when the additional constraint is placed on ground water. *Agriculture* production sectors (sectors 2, 3, and 5) are expected to account for 314 of these employees, with *food grains and feed crops* production accounting for 71 percent of the total decrease.

The increased demand for water by the nonagricultural sectors required a transfer of 47,166 acre-feet from surface rights to ground-water pumpage. The average annual depletion with a total water constraint is expected to be 58,182 acre-feet less than under the condition of a surface-water constraint only, and 196,706 acre-feet less than the alternative of no water constraint. *Agriculture* depletions are expected to decrease 58,165 acre-feet, and *Trade and Services* water depletions are expected to decrease 18 acre-feet when the additional ground-water constraint is added.

The cost of imposing the additional constraint on ground water in the Upper Rio Grande Region would be $0.6 million in 2020 compared with a surface-water constraint only, and $1.2 million compared with the alternative of no constraint on water. *Agriculture* production would account for $0.54 million of the $0.6 million of reduced production in 2020. *Food grains and feed crops* account for about 90 percent of the total reduction in production.

Employment in the URGR would decrease an additional 212 employees when the additional ground-water constraint is added. *Agriculture* employment would account for 208 of the employees, with 99 percent in the *food grains and feed crops* sector.

Total depletions in 2020 in the URGR are expected to decrease 13,497 acre-feet below that of a surface-water constraint only, and 27,066 acre-feet when compared with the alternative of no constraint on water. *Agriculture* depletions would account for all of the 13,497 acre-feet reduction in 2020.

Summary. In the previous discussion, three sets of water management 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 with a surface-water constraint. The third was an analysis of growth with both surface- and ground-water constraints. A summary of the solutions for these alternatives is presented in Table 29 for the total Rio Grande region and for the Upper Rio Grande Region.

Without a water constraint, value of production, employment, and water depletions in the Rio Grande region are expected to exhibit the largest increase (59.7 percent, 59.2 percent, and 47.4 percent, respectively.) The expected increase in value of production varies from 38.3 percent for *Agriculture* to 60.8 percent for *Trades and Services*. Water depletions are expected to increase 45.7 percent for *Agriculture*, 57.5 percent for *Mining*, 60.3 percent for *Manufacturing*, 60.6 percent for *Trades and Services*, and 60.1 percent for *Municipal and Rural* domestic purposes.

When a surface-water constraint is imposed, the expected value of production would be reduced by $18.1 million in 2020, employment by 1,344 employees, and water depletions by 138,523 acre-feet (16.7 percent) below the alternative of no water constraint (Table 29). Reduced *Agriculture* production would account for about 38 percent ($6.9 million) of the reduced value of production, and *Trades and Services* about 60 percent ($10.9 million). The level of employment in the RGR is expected to decrease by 1,344 employees in 2020. *Agriculture* production sectors are expected to account for about 58 percent and *Trades and Service* sectors about 41 percent. *Agriculture* water depletions are expected to represent about 85 percent of the total water depletion reduction when a surface-water constraint is imposed.

In 2020, when a total water constraint is imposed, value of production in the RGR is expected to be reduced to $3,368.1 million, decreased $4.1

Table 29. Summary of alternative solutions by major sectors in the Rio Grande Region, and in the Upper Rio Grande Region, New Mexico, 1970-2020

Alternative	Year	Major Sector	Total Rio Grande Region: Value of Production ($1 million)	Total Rio Grande Region: Value of Production Change from 1970 (percent)	Total Rio Grande Region: Value Added ($1 million)	Total Rio Grande Region: Employment	Total Rio Grande Region: Water Depletions (acre-feet)	Total Rio Grande Region: Water Depletions Change from 1970 (percent)	Upper Rio Grande Region: Value of Production ($1 million)	Upper Rio Grande Region: Value of Production Change from 1970 (percent)	Upper Rio Grande Region: Value Added ($1 million)	Upper Rio Grande Region: Employment	Upper Rio Grande Region: Water Depletions (acre-feet)	Upper Rio Grande Region: Water Depletions Change from 1970 (percent)
BASIC OPTIMAL SOLUTION	1970	Agriculture	84.775		44.402	7,196	497,268		16.992		6.917	1,892	111,084	
		Mining	108.062		71.393	1,920	4,571		55.785		37.377	1,056	2,852	
		Manufacturing	258.834		104.327	10,451	1,826		22.192		10.294	925	225	
		Trade & Services	1,670.001		1,012.630	90,463	20,059		322.956		189.391	16,231	4,199	
		Municipal & Rural	--		--	--	39,144		--		--	--	5,565	
		Total	2,122.660*		1,232.753*	110,030	562,866*		417.925		243.979	20,104	123,923*	
NO WATER CONSTRAINT	2020	Agriculture	117.244	38.3	61.778	9,997	724,603	45.7	21.360	25.7	8.868	2,495	146,285	31.7
		Mining	170.924	58.2	112.895	3,027	7,199	57.5	86.493	55.0	57.953	1,638	4,421	55.0
		Manufacturing	415.920	60.7	167.459	16,781	2,928	60.3	34.376	54.9	15.944	1,432	348	54.8
		Trade & Services	2,686.207	60.8	1,627.409	145,374	32,221	60.6	500.476	55.0	293.471	25,157	6,508	55.0
		Municipal & Rural	--		--	--	62,660	60.1	--		--	--	8,497	52.7
		Total	3,390.292*	59.7	1,969.539*	175,178*	829,610*	47.4	642.705	53.8	376.233*	30,722	166,059	34.0
SURFACE WATER CONSTRAINT	2020	Agriculture	110.305	30.1	57.334	9,213	586,215	17.9	20.794	22.4	8.505	2,284	132,717	19.5
		Mining	170.922	58.2	112.894	3,027	7,199	57.5	86.493	55.0	57.953	1,638	4,421	55.0
		Manufacturing	415.629	60.7	167.336	16,767	2,926	60.2	34.372	54.9	15.943	1,432	348	54.8
		Trade & Services	2,675.342	60.1	1,621.299	144,827	32,088	60.0	500.442	55.0	293.447	25,156	6,507	55.0
		Municipal & Rural	--		--	--	62,660	60.1	--		--	--	8,497	52.7
		Total	3,372.196*	58.9	1,958.862*	173,833*	691,086	22.8	642.100*	53.6	375.846*	30,510	152,489*	23.0
TOTAL WATER CONSTRAINT	2020	Agriculture	107.416	26.7	55.499	8,900	528,050	6.2	20.231	19.1	8.144	2,076	119,200	7.3
		Mining	170.921	58.2	112.894	3,027	7,199	57.2	86.493	55.0	57.953	1,638	4,421	55.0
		Manufacturing	415.794	60.6	167.407	16,776	2,926	60.2	34.371	54.9	15.942	25,152	348	54.8
		Trade & Services	2,673.967	60.0	1,620.464	144,699	32,070	59.9	500.409	55.0	293.424	24,972	6,507	55.0
		Municipal & Rural	--		--	--	62,660	60.1	--		--	--	8,497	52.7
		Total	3,368.097*	58.7	1,956.264	173,402	632,904*	12.4	641.503*	53.5	375.462*	30,298	138,992*	12.2

*Does not add because of rounding

million below the value obtained when only a surface-water constraint is imposed, and decreased by $22.2 million below the no-water-constraint alternative (Table 29). The level of employment is expected to decrease by 481 employees when a constraint is imposed on ground water. Again, *Agriculture* sectors account for 82 percent of the reduced employment.

Water depletions in the RGR are expected to decrease from 829,610 acre-feet without any water constraints to 632,904 acre-feet with a total water constraint, a 24 percent reduction. 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, Trades and 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 inter-regional 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 Upper Rio Grande Region is expected to follow the general trend of the total Rio Grande region but at a lower growth rate. The expected increase in total value of production from 1970 to 2020 is 53.8 percent. Employment is expected to increase 53 percent. Water depletions are expected to increase about 20 percent in 2020, with *Agriculture* accounting for 88 percent of total depletions in the URGR at that time.

When a surface-water constraint is imposed, the value of production is expected to be reduced $0.6 million in 2020, employment by 212 employees, and water depletions by 13,569 acre-feet. *Agriculture* production sectors would account for nearly all of the reduction in production, employment, and water depletions.

When an additional constraint is imposed on ground water in the URGR, value of production would be decreased $0.6 million in 2020, employment by an additional 212 employees, and water depletions by 13,497 acre-feet. *Agriculture* production sectors would account for over 95 percent of the expected reductions in production, employment, and water depletions.

The supply of water for water-based recreation is expected to be the highest under the alternative of no water constraint (Table 30), and reduced about 5 percent when a constraint is placed on the importation of surface water or mining of ground water. The major effect occurs on surface water where all of the water-based recreation occurs.

Table 30. 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

SOIL PRODUCTIVITY GROUPS IN THE UPPER RIO GRANDE REGION, NEW MEXICO

Group I.

Soils in productivity Group I have few limitations that restrict their use for irrigated crop production and are suited to a wide range of crops, especially those common to the Upper Rio Grande Region. 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.

Some of these soils have certain slight limitations which require more careful management practices; however, in most cases these corrective management practices are easy to apply. A very small portion of the irrigated acreage in the region occurs as Group I.

Group II

Soils in Group II have certain moderate restrictions that reduce their productive capabilities, require special management practices, or both. 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. These conditions are generally due to unfavorable soil characteristics, topography, erosion, or impeded drainage. Soils with light-textured subsoils and sandy textures were included in this Group. 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.

In some areas of the region, part of the soils in this Group have limited use because of a high water table and low permeability. Each distinctive kind of soil in Group II has one or more special managerial requirements for successful use. This Group accounts for about 27 percent of the irrigated acreage in the region.

Group III

The soils in productivity Group III have limitations which restrict their use for agricultural production. The character and properties of the soil itself were given the greatest consideration. The soils are primarily mountain soils of relative recent origin and in most cases are shallow, gravelly, and contain less organic matter.

This Group also 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.

This Group accounts for over 72 percent of the irrigated cropland in the Upper Rio Grande Region. It occurs in relatively large areas and is widespread throughout the region.

The above-described soil productivity groups and those described in Tables A-1, A-2, and A-3, were defined for purposes of this study and are not necessarily consistent with Soil Conservation Service Classification.

APPENDIX A

Table A-1. Principal soils in productivity Group I, Upper Rio Grande Region, New Mexico

Map Symbol	Soil Name	Soil Description
120	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	El Rancho clay loam, 0-1 percent	These soils are deep, moderately permeable, and occur on nearly level slopes. The erosion hazard is slight.

APPENDIX A

Table A-2. Principal soils in productivity Group II, Upper Rio Grande Region, New Mexico

Map Symbol	Soil Name	Soil Description
111	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 to 60"). Water holding capacity is low and fertility is low.
117 114/AB	Fruitland sandy loam, silty substratum, 0-3 percent	
122	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	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 43S	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.
362	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.

APPENDIX A

Table A-3. Principal soils in productivity Group III, Upper Rio Grande Region, New Mexico

Map Symbol	Soil Name	Soil Description
70/c	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	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	Bluewing loamy fine sand, saline	Similar to mapping unit 80, but exhibits salt concentrations that range from slight to moderate.
42	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	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	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.

Table A-3. continued

Map Symbol	Soil Name	Soil Description
41/C 44 41/D	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	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.