Managing Water Resources in New Mexico: Climate Trends and Cropping Patterns in the Lower Rio Grande

Cynthia Stokes

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MANAGING WATER RESOURCES IN NEW MEXICO: CLIMATE TRENDS AND CROPPING PATTERNS IN THE LOWER RIO GRANDE

by

Cynthia Stokes

A Professional Project Report Submitted in Partial Fulfillment of the Requirements for the Degree of
Master of Water Resources
Policy/Management Concentration
Water Resources Program
The University of New Mexico
Albuquerque, New Mexico
September 2007
The University of New Mexico
Albuquerque, New Mexico
September 6, 2007

COMMITTEE APPROVAL

The Master of Water Resources Professional Project Proposal of Cynthia Stokes is approved by the committee:

________________________________________________________________________  ________________
Chair                                                       Date

________________________________________________________________________

________________________________________________________________________
ACKNOWLEDGEMENTS

There are many people who helped me with this project. I would first like to thank David Henkel, Bill Fleming and Greg Lewis for agreeing to serve as my committee. Special thanks to Greg who gave me the inspiration for the project after my initial plans fell through, and to David for taking me on despite delays, procrastinations and vacations.

I received information and input from a great number of people from the professional arena as well as at home. The following lists of names are not in any particular order. From the New Mexico Office of the State Engineer; Greg Lewis, Lower Rio Grande team lead; John Longworth, Water Use and Conservation Bureau Chief; Peggy Barroll, Hydrology Bureau hydrologist; Sheldon Dorman, Lower Rio Grande Water Master District Water Master; Elizabeth Zeiler, Rio Grande Bureau; Molly Magnuson, Water Use and Conservation Bureau; Christina Knoftsker, Water Rights Division; David Green, Rio Grande Bureau. I also owe thanks to Robert Sengebush from INTERA, Inc. and Paul Neville from the Earth Data Analysis Center for their assistance with remote sensing details.

Finally, to my family, Paul, Laura, Paula, Pam and especially Samantha for their unending support and/or babysitting services.
ABSTRACT

The Lower Rio Grande basin is located in south-central New Mexico, an agriculturally significant region with an increasing population. Available water supply is used for irrigated agriculture, public water supply systems, commercial purposes, livestock watering, domestic wells, power generation, and industrial and mining purposes. Over time, consumptive use of irrigated water has increased, and the regional population is expected to grow. These increases in demand could put unsustainable stress on the limited supply of water in the Lower Rio Grande.

For this project, climatological and agricultural data were analyzed to determine if the growing season had lengthened since 1892, and it was shown that consumption of irrigated water by agriculture has increased in the Lower Rio Grande since 1953. Additionally, data from the climate and agriculture analyses were organized into a Geographical Information System and a geospatial representation of crop requirements was offered.

In response to extended drought conditions and increasing demand, the New Mexico Legislature passed legislation to allow the State Engineer to more timely administer the State’s water resources. This prompted the State Engineer to initiate a strategy named Active Water Resource Management. It is designed as a set of tools necessary to conduct priority administration; however, specific information is missing, and the Lower Rio Grande Water Master cannot perform his duties with the tools currently available to him. The geospatial tools presented at the end of this project will offer the Water Master a tool by which to monitor water use in the Lower Rio Grande.
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LIST OF ACRONYMS

AFA – acre-foot per acre
AWRM – Active Water Resource Management
BOR – U.S. Bureau of Reclamation
cfs – cubic feet per second
CIR – consumptive irrigation requirement
FDR – farm delivery requirement
EBID – Elephant Butte Irrigation District
Et - evapotranspiration
GIS – Geographic Information System
HSB – New Mexico Office of the State Engineer Hydrographic Survey Bureau
IBWC – International Boundary and Water Commission
ISC – New Mexico Interstate Stream Commission
LRG – Lower Rio Grande
NDVD – Normalized Difference Vegetation Index
OSE – New Mexico Office of the State Engineer
POU – place of use
PRISM – Parameter-elevation Regressions on Independent Slopes Model
RGP – Rio Grande Federal Irrigation Project
SWUA – Surface Water User’s Agreement
USGS – U.S. Geological Survey
WUC – New Mexico Office of the State Engineer Water Use and Conservation Bureau

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I. INTRODUCTION

Project Overview

The purpose of this project is to determine how climatological and agricultural data can be used to augment or enhance existing water resource management tools in New Mexico’s Lower Rio Grande (LRG). For the years 1892 to 2005, data indicate an overall warming trend with earlier spring thaws and later fall freezes. Climatological changes such as these could induce irrigators to use significantly more water on their crops, where perhaps water should be conserved. Historical agricultural data show that consumption of irrigated water and the acreage dedicated to water intensive crops have both increased since 1953. Additionally, population in the region has increased significantly since 2000 and is expected to double by the year 2040. New Mexico has a limited water supply and increasing demand; if climate and cropping patterns create water resource conditions that are undesirable or unsustainable, how do water managers address them?

The Lower Rio Grande Water Master has been hired by the New Mexico State Engineer to assure that irrigation water is fairly distributed in accordance with available water supply and priority dates. In order to accomplish this, the Water Master needs to know how much water an irrigator is entitled to, when his or her water right was established (priority date), and how much he or she applies to crops each year. Since adjudications are ongoing but incomplete in the Lower Rio Grande, the amount of water an irrigator is entitled to divert and the priority date of his or her water rights are largely unknown, as is the amount of water applied to specific tracts. Water use can be measured through groundwater meter readings and surface water gages but there are currently no
enforceable limits to an irrigator’s water use. Therefore, it is difficult for the State Engineer to conduct water rights administration in the Lower Rio Grande at this time.

Some of the challenges faced by water resource managers in the Lower Rio Grande are a longer growing season due to climate change; rapid population growth in the region; unreliable surface water supply, and an unknown volume of groundwater pumping, any of which could lead to water shortages. The New Mexico Legislature passed legislation in 2003 to allow the State Engineer to more timely administer the State’s water resources. In response, the State Engineer initiated a strategy named Active Water Resource Management (AWRM) to administer water rights in the absence of completed adjudications. AWRM is designed as a set of tools necessary to conduct priority administration, however few tools are currently available to the Lower Rio Grande Water Master. This project considers the potential of combining climatological and agricultural data into administrative tools, which could assist the Lower Rio Grande Water Master in managing water rights in the basin.

The objective of this project is to determine how to use geospatial climatological and agricultural data as an effective water management tool or set of tools to be used by the New Mexico State Engineer and his staff. The following sets of data were analyzed as a tactical step toward achieving this objective.

- Temperature and precipitation data collected since 1892 in tabular format, from Hydrosphere Resource Consultants, Inc.
- Oregon State University PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate data, 1895-2005
• Historical crop acreage of the New Mexico irrigation district present in the LRG, 1920-2004 obtained from the New Mexico Office of the State Engineer

• Crop pattern data in GIS (Geographical Information System) spatial format, 2000 obtained from the New Mexico Office of the State Engineer

The main findings were that the number of days between killing frosts has increased, and that more irrigation water could be applied outside of the primary irrigation season. Additionally, the acreage dedicated to water intensive crops has increased since about the middle of the century, causing total consumption of irrigated acreage to increase. Finally, the data analyzed in this project are presented in an example representing a water rights administrative tool.

**Project Organization**

A physical description of the Lower Rio Grande including topography, water resources, and soils and vegetation is presented in Chapter 2. The anthropogenic history is presented in Chapter 3, which describes Anglo and Mexican settlement in the region. This chapter explains some of the difficulties faced by irrigators before construction of the Rio Grande Project, what the Rio Grande Project is, and how agriculture has changed since its completion. Chapter 4 is the first of two parts of data analysis. It begins with an introduction to climate change and presents the two sets of climate data analyzed in this project, which are PRISM data, and historic climate data collected from the New Mexico State University weather stations. The second part of data analysis, Crop Requirements, is presented in Chapter 5. This chapter describes historical Lower Rio Grande cropping data and a GIS dataset acquired by the New Mexico Office of the State Engineer (OSE),
which represents Lower Rio Grande cropping patterns in 2000. Chapter 6 describes current water resource management strategies and tools, as well as their limitations and constraints. Finally, a summary and concluding remarks make up chapter 7, followed by recommendations in chapter 8. Chapter 9 is comprised of the reference cited and Appendices A through E contain additional graphical and technical information.
II. PHYSICAL DESCRIPTION

Area of Interest

The focus of this project is New Mexico’s Lower Rio Grande Basin (LRG), which extends along the Rio Grande from just below Caballo Dam in New Mexico to the Texas border. The Lower Rio Grande is a hydrologic boundary carved out of the Rio Grande Basin of Colorado, New Mexico and Texas, USA and Chihuahua, Coahuila de Zaragoza, Nuevo León and Tamaulipas, México. The Rio Grande originates in the San Juan Mountains of Colorado, and flows south through northern, central, and southern New Mexico to the Texas border. Approximately two miles northwest of El Paso, Texas, the river becomes the international border between the United States and México and follows that path until it empties into the Gulf of Mexico. The entire Rio Grande watershed is roughly 335,500 square miles, and the Lower Rio Grande measures less than two percent of that area (see Figure 1).

The Lower Rio Grande hydrologic basin is a small part of the Rio Grande basin and is located in south-central New Mexico. It is a surface water basin, which measures 2,291 square miles and contains agriculturally significant features in New Mexico. This basin extends from Caballo dam in Sierra County to the New Mexico-Texas state line in Doña Ana County. Here, the Rio Grande flows southeast across the Rincon and Mesilla valleys, and is diverted to the agricultural lands adjacent to the river.

The Lower Rio Grande administrative boundary (versus the hydrologic boundary) is also worth considering because of its use by the New Mexico State Engineer. It is an important part of the State Engineer’s efforts to administer water in the region and nearly contains the Lower Rio Grande hydrologic boundary, shown in Figure 2. This
administrative boundary covers 3,836 square miles and includes a large portion of the Jornada del Muerto Bolson.

Figure 1. Rio Grande Basin. The Rio Grande Basin (in green) drains surface water from three states and four municipalities in the southwest United States and eastern México to the Rio Grande/Río Bravo. The LRG hydrologic boundary is highlighted in orange. Source data: OSE.
Figure 2. LRG administrative and hydrologic boundaries. Source data: OSE.
Topography and Geology

A nearly level or gently sloping river valley is framed on the west and east by mesas, upland areas, and steep mountain ranges. Caballo dam is the northern boundary of the Lower Rio Grande hydrologic basin and the New Mexico-Texas state line is the southern boundary. Elevations range from 8,872 feet at Organ Peak, to almost 4,200 feet at Caballo dam, and finally to about 3,770 feet at the New Mexico/Texas state line; slopes range from less than one percent on the flood plains to seventy percent on the uplands and mountainsides where surface water drains to valley basins. Incised channels cross the uplands toward the Rio Grande, which is the primary perennial surface water source in the Lower Rio Grande hydrologic basin, with minor perennial waters in the Las Animas and Hot Springs basins. Selden Canyon links the Rincon Valley to the north and the larger Mesilla Valley in the southern section of the basin.

The study area lies within the Mexican Highland section of the Basin and Range physiographic province, and in the southern part of the Rio Grande rift tectonic province of south-central New Mexico. Although the Rio Grande rift is described at length elsewhere, it is fitting to mention its basic characteristics here. A rift is an elongated valley, which is created when earth’s crust stretches and thins. In New Mexico, the crust began to spread apart between 35 and 29 million years ago, and the resulting valley filled with sediments. The Rincon and Mesilla valley basins are “filled with up to several thousand feet of consolidated and
unconsolidated alluvial fill sediments of gravel, sand, silt and clay,” and make up the main groundwater bearing formations available to water users in the Lower Rio Grande.

From a regional climate perspective, the basin is located in the north-central Chihuahuan Desert. This terrestrial ecoregion is defined by the World Wildlife Fund as containing a series of basins and ranges where, “the climate includes a dry summer and occasional winter rains; mild frosts occur during autumn and winter. This Desert has more rainfall than other warm desert ecoregions, with precipitation ranging from 6 to 16 inches.”

**Water Resources**

The primary surface water supply in the Lower Rio Grande is the water stored and released from Elephant Butte and Caballo Reservoirs. All of the water released from these reservoirs is not utilized in New Mexico, and the surface water supply available is allocated exclusively for irrigated agriculture. Irrigated agriculture is the largest water use in the basin and surface water is often supplemented with groundwater to meet crop irrigation demands.

Groundwater in the Lower Rio Grande is extracted for public water supply systems, private domestic wells, industrial purposes, commercial purposes, irrigated agriculture, livestock watering, quarry mines, and power generation. Most of the demand is satisfied with withdrawals from the Mesilla Valley aquifer system, but a significant portion is taken from the Hueco Bolson and Jornada Bolson. Irrigated agriculture claims 90.11% of the surface water and groundwater used in the Lower Rio Grande, public water systems receive 6.81%, and the remainder is distributed to commercial, livestock, domestic wells, power, industrial, and mining uses.
Surface Water

The Rio Grande is the only perennial source of surface water in the Lower Rio Grande and except during significant storm events, intermittent stream flows from tributary creeks and arroyos do not normally reach the Rio Grande. Noteworthy tributaries are also located outside the Lower Rio Grande hydrologic boundary, south of Elephant Butte Reservoir. It is important to mention these ephemeral streams north of the study area because runoff often reaches the Rio Grande via these channels in summer months and contributes to Rio Grande flow; these streams are within the Lower Rio Grande administrative boundary.

Upstream Sources

The Rio Grande Project will be discussed in greater detail in the “Anthropogenic History” chapter, however it is appropriate to mention it here because it controls surface water supply water to the Lower Rio Grande. Runoff from winter snow pack in northern New Mexico and southern Colorado is the primary source of surface water to the Lower Rio Grande. Elephant Butte and Caballo dams control flows of the Rio Grande at this point. These dams, plus six smaller diversion structures and an extensive conveyance system that delivers irrigation water to acreage in New Mexico, Texas and México, are the chief components of the Rio Grande Project (RGP).

To get an idea of the quantity of surface water that reaches the region, please refer to Figures 3 through 6. The USGS has two gages at San Marcial, New Mexico; the Low Flow Conveyance Channel north and west of the Rio Grande and another located on the river floodway itself. Rio Grande flow is measured at these gage stations then stored in Elephant Butte and Caballo reservoirs until it is released for irrigation or, rarely, flood
control purposes. The data collected from the gages at San Marcial reveal the majority of surface water entering the region; gages below Elephant Butte and Caballo dams demonstrate the controlled discharge of surface water downstream. Figures 7 and 8 illustrate storage and release data obtained from the New Mexico Interstate Stream Commission. It is noteworthy to mention the peaks illustrated in 1942 and 1985 because the peaks coincide with a few of the actual spills of Elephant Butte Reservoir. An actual spill occurs when RGP storage in Elephant Butte and Caballo reservoirs reaches its capacity, and water either flows over the spillway crest at Elephant Butte Dam or releases are made to maintain flood storage capacity in Elephant Butte Reservoir in excess of downstream demands.¹⁰
Figure 3. Selected USGS gage station locations. Source data: OSE.
Figure 4. Daily Mean Rio Grande discharge below San Marcial, New Mexico. Data indicate runoff from upstream sources. Discharge peaked in 1986 for the years shown.\textsuperscript{11} Source data: USGS.

Figure 5. Annual Mean Rio Grande discharge below San Marcial, New Mexico. Data indicate runoff from upstream sources. Discharge peaked in 1986 for the years shown.\textsuperscript{12} Source data: USGS.
Figure 6. USGS gage data for the station below Elephant Butte Dam. The peaks in 1942 and 1985 illustrate actual spills of Elephant Butte Reservoir. Source data: USGS.
Figure 7. Storage and release data for Elephant Butte Reservoir. Source data from New Mexico Interstate Stream Commission (ISC) internal document.

Figure 8. Storage and release data for Caballo Reservoir. Source data from NMISC internal document.
### Annual Mean Discharge Summary

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Minimum Daily Flow (cfs)</th>
<th>Year</th>
<th>Maximum Daily Flow (cfs)</th>
<th>Year</th>
<th>Average Flow (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFCC @ San Marcial\textsubscript{a}</td>
<td>0</td>
<td>1977</td>
<td>1,148</td>
<td>1973</td>
<td>358</td>
</tr>
<tr>
<td>Rio Grande @ San Marcial\textsubscript{b}</td>
<td>0</td>
<td>1956</td>
<td>2,158</td>
<td>1986</td>
<td>667</td>
</tr>
<tr>
<td>Rio Grande below EB\textsubscript{c}</td>
<td>253</td>
<td>1964</td>
<td>2,665</td>
<td>1942</td>
<td>995</td>
</tr>
<tr>
<td>Rio Grande below Caballo\textsubscript{d}</td>
<td>284</td>
<td>1964</td>
<td>2,487</td>
<td>1942</td>
<td>926</td>
</tr>
</tbody>
</table>


**Tributary Flow**

In the mid-nineteenth century, Palomas Creek had a perennial flow all the way to the Rio Grande.\textsuperscript{14} Currently, there is no perennial stream in the Lower Rio Grande other than the Rio Grande, which indicates a reduction in available water supply. Numerous arroyos and ephemeral stream channels convey runoff in the direction of the river, and spring flows will reach the Rio Grande in normal supply years. Given the Lower Rio Grande is located within a desert, snow pack accumulation is negligible; precipitation is primarily in the form of thunderstorms, mostly between April and October. The current climatological normal (1971-2000) for precipitation ranges from 9 to 11 inches in the valley and up to 27 inches above Las Animas Creek (see Appendix C). Intense, convective storms generally occur from July to September, and it is during these events that surface water from precipitation can reach the Rio Grande by way of some intermittent streams. As a source to stream flow, USGS peak stream flow data in the Lower Rio Grande suggest that surface water resulting from precipitation is limited to mid to late summer months.
Peak stream flow is defined by the USGS as, “the maximum instantaneous discharge of a stream or river at a given location. It usually occurs at or near the time of maximum stage.” Peak stream flow is measured on intermittent streams by the USGS with stream flow gages. Two are located on Percha Creek (see Figure 3), and the most recent data available on the USGS web site are dated August 23, 2006. Data indicate that peak flows are the result of summer storms; except for a few days in October and November, peak stream flows occur in July, August and September where month and day are recorded. Graphs of data from two of those stations and their corresponding gage heights are shown on Figures 9 and 10. The greatest peak flow at the gage located at Percha Creek near Hillsboro, NM was measured in August of 1999; Percha Creek at Caballo Dam, NM recorded the greatest peak flow in September of 1972.

Compared to surface water provided by runoff from winter snow pack, contributions to the Rio Grande from precipitation are typically relatively small; precipitation in the Lower Rio Grande most often evaporates except after significant storm events. Additionally, a handful of wastewater treatment plants discharge treated groundwater into the Rio Grande. According to the New Mexico Lower Rio Grande Regional Water Plan, up to 19.1 MGD of treated wastewater can be discharged into the Rio Grande from municipal and other wastewater treatment plants.
Figure 9. Peak stream flow and gage height at USGS gage station, Percha Creek at Caballo Dam Near Arrey, NM. Numbers highlighted in blue are the maximum recorded peak annual stream flow for each station. Source data: USGS.

Figure 10. Peak stream flow and gage height at USGS gage station Percha Creek Near Hillsboro, NM. Numbers highlighted in blue are the maximum recorded peak annual stream flow for each station. Source data: USGS.

Relationship Between Surface Water and Groundwater

An interesting characteristic of the Lower Rio Grande is the relationship between the Rio Grande and the shallow groundwater basin beneath it. The Rio Grande and the
groundwater basin are hydrologically linked; depending on certain conditions, the Rio Grande can act as a losing or a gaining stream. Conover noted that the Rio Grande lost flow to groundwater seepage at four stretches, and gained flow from groundwater supply along three stretches of the river from Elephant Butte dam to Courchesne Bridge in El Paso. Average seepage losses in the Rincon and Mesilla valleys for the years 1930-1946 were 60.1 cubic feet per second (cfs). Thus, Conover concluded that, “on the whole the river replenishes the ground-water body rather than that the ground water replenishes the river.”

Seepage losses are due in part to drains, which were constructed to alleviate water logging and salinity problems on irrigated acres. The seepage loss from the river does not mean an actual loss of water from the valley, because the drain water is returned to the river downstream as excess irrigation water.

Groundwater

In the Lower Rio Grande, surface water and groundwater are basins hydrologically connected and physically behave as a single resource. For example, in some areas the Rio Grande gains base-flow from the shallow aquifer of the Lower Rio Grande during periods of low river flows. Additionally, irrigation canal systems and on-farm irrigation provide opportunities for recharge of the alluvial aquifers.

Groundwater basins (bolsons) important to the Lower Rio Grande include the Rincon bolson, the Mesilla bolson, and the Jornada del Muerto bolson (Figure 11). The main water bearing units (aquifers) of these bolsons consist of Santa Fe Group basin-fill, post-Santa Fe valley-fill (Rio Grande alluvium), or a combination of the two. The Rio Grande alluvium is also referred to as the Lower Rio Grande shallow aquifer or valley-fill aquifer, and it extends across the Rincon and Mesilla basins. Hawley notes that the
valley-fill aquifer “extends continuously from Elephant Butte and Caballo reservoirs, through the Rincon and Mesilla Valleys, to the Fort Quitman area at the lower end of the Hueco Bolson.”22 In the Lower Rio Grande, valley-fill is recharged by irrigated agriculture because of seepage from canals and laterals, and percolation from irrigated crops. Despite the potential of Lower Rio Grande aquifers and their current volume of stored water, much of the basin-fill is not being effectively recharged under warm-dry environmental conditions. Additionally, it has been estimated that only about two percent of the mean annual precipitation contributes to basin-fill recharge.23 Recent research in the region indicates that most of the groundwater in storage is thousands to tens of thousands of years old and was recharged during cooler and wetter periods more than five thousand years ago.24 Therefore, because discharge of basin-fill groundwater exceeds recharge, these aquifers are being mined. For additional information, please refer to Appendix E, Groundwater Hydrology.
Figure 11. LRG groundwater basins, or bolsons. Source data: OSE.
Soils and Vegetation

Surface soils within the Lower Rio Grande are of the typic aridic\textsuperscript{25} soil moisture regime.\textsuperscript{1} Please see Figure 12 and Table 2 for more detailed information regarding soils in the Lower Rio Grande as they relate to this project.

Natural vegetation patterns in the Lower Rio Grande reflect the prevailing arid climatic conditions. Due to the varied topography, marked differences in precipitation and soil conditions have shaped distinct zones of plant cover. Predictably, the most dramatic contrast is between what used to be the riparian forest of the Rio Grande flood plain and the much sparser Chihuahuan Desert type flora of the adjoining terrain.\textsuperscript{26} Lush agricultural fields have replaced the forest, yet the difference between the valley and the desert uplands is still striking. Only outside the boundaries of the Irrigation District does one still find extensive areas of natural vegetation.

Early explorers observed junipers and oaks on the hills bounding the Rio Grande Valley, while cottonwood, alder, ash, and walnut bordered Las Animas Creek and portions of Las Palomas and Cuchillo Negro Creeks.\textsuperscript{27} A few small and isolated patches of the originally extensive riparian forest remain today; these wooded areas include cottonwood, willow, desert broom, mesquite, and tamarisk.

On the margins of the river valley, irrigated crops grow within a few feet of desert plants such as sagebrush, arrow-wood, mesquite, white thorn, saltbush, creosote bush, cacti, and grama grasses. The creosote bush, which presently dominates the plains, is probably a successor to semidesert grasslands depleted by overgrazing.\textsuperscript{28} Additionally,\textsuperscript{30}

\textsuperscript{1} Aridic soil moisture regime "refers to the presence or absence either of ground water or of water held at a tension of less than 1500 kPa [kiloPascals] in the soil or in specific horizons during periods of the year. Ultimately, the aim is to determine the water available for plants throughout the year." Aridic refers to arid climate where the soil is usually dry and irrigation water is required for crop production.
piñon pine, juniper, scrub oak, mountain mahogany, Apache plume, salt bush and a number of different types of grasses has historically characterized the foothills of the mountains.\textsuperscript{29}

From 1844 to well into the twentieth century, wheat and corn were primary subsistence crops, while alfalfa and cantalopes became important cash crops.\textsuperscript{30} Secondary crops included chile, onions, tomatoes and at least a few acres of grains.\textsuperscript{31} Following completion of the Elephant Butte Dam in 1916, cotton, alfalfa, pecans, chile, lettuce, onions and grains have persisted as primary crops in the Lower Rio Grande. These crops are confined to the Rincon and Mesilla valleys where irrigation water is delivered primarily to lands within the Elephant Butte Irrigation District. Current agriculture crops and statistics will be discussed in greater detail in the “Crop Requirements” chapter.
Figure 12. Soils in the LRG as described by the NRCS. The composition of the soil type determines if it is appropriate for farmland. Source: NRCS and OSE.
<table>
<thead>
<tr>
<th>Series</th>
<th>Mean Annual Air Temp</th>
<th>Mean Annual Precipitation</th>
<th>Use</th>
<th>% Slope</th>
<th>Elevation (feet)</th>
<th>Frost-free days</th>
<th>Description</th>
<th>Native/Non-Irrigated Vegetation</th>
<th>Irrigated Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>53</td>
<td>8</td>
<td>Rangeled</td>
<td>0.5</td>
<td>3530 feet</td>
<td>601</td>
<td>NA</td>
<td>Climatic season is deep, well drained soils formed from alluvium, granite, quartzite, schist, and shale.</td>
<td>Native vegetation consists of creosote bush, sagebrush, and grasses.</td>
</tr>
<tr>
<td>Nevada</td>
<td>32</td>
<td>8</td>
<td>Rangeled</td>
<td>0.8</td>
<td>5280 feet</td>
<td>240</td>
<td>NA</td>
<td>Climatic season consists of very long, well drained soils formed from alluvium, glacial drift, and basalt.</td>
<td>Native vegetation consists of creosote bush, sagebrush, and grasses.</td>
</tr>
<tr>
<td>Wyoming</td>
<td>66</td>
<td>8</td>
<td>Rangeled</td>
<td>0.8</td>
<td>3600 feet</td>
<td>300</td>
<td>NA</td>
<td>Climatic season consists of very long, well drained soils formed from alluvium, glacial drift, and basalt.</td>
<td>Native vegetation consists of creosote bush, sagebrush, and grasses.</td>
</tr>
<tr>
<td>Arkansas</td>
<td>64</td>
<td>8</td>
<td>Irrigated</td>
<td>0.1</td>
<td>100 feet</td>
<td>300</td>
<td>NA</td>
<td>Various ecosystems of deep, well drained soils formed from alluvium, glacial drift, and basalt.</td>
<td>Grasses are common on upland areas and wetlands.</td>
</tr>
<tr>
<td>Arizona</td>
<td>53</td>
<td>8</td>
<td>Palouse</td>
<td>2.0</td>
<td>1400 feet</td>
<td>1800</td>
<td>NA</td>
<td>Palouse consists of deep, well drained soils formed from alluvium, glacial drift, and basalt.</td>
<td>Unprotected wetlands, shrubs, grasses, and trees.</td>
</tr>
<tr>
<td>Arizona</td>
<td>53</td>
<td>8</td>
<td>Palouse</td>
<td>2.0</td>
<td>1400 feet</td>
<td>1800</td>
<td>NA</td>
<td>Palouse consists of deep, well drained soils formed from alluvium, glacial drift, and basalt.</td>
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<td>8</td>
<td>Palouse</td>
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<td>Unprotected wetlands, shrubs, grasses, and trees.</td>
</tr>
</tbody>
</table>

Table 2: Soils series with characteristics that are considered to be “farmland of statewide importance” according to the NRCS. These soils are found primarily in the river valley or floodplain, however significant areas for grazing are located on the uplands and the Jornada del Muerto.
III. ANTHROPOGENIC HISTORY

Before 1900

Although agriculture is considered synonymous with irrigation in New Mexico, the traditional northern New Mexican system was considerably different in the Lower Rio Grande. Many settlers here had no land grants, and farming was an uncertain business because water control lay more with nature than with man. Land grants were requested prior to the Mexican War and the Treaty of Guadalupe Hidalgo; after the Lower Rio Grande region became part of the New Mexican territory, land that was not already claimed became public domain.

It is difficult to fully appreciate the obstacles faced by early irrigators in the Lower Rio Grande. Despite the presence of a major travel route—Camino Real de Tierra Adentro—through the valleys, no attempts were made to occupy valley lands for over 200 years. This can be attributed to hydrologic characteristics of the Rio Grande and the presence of hostile Indian groups in the area. Early settlers had to contend with floods, irregular water supply, Indian raids and war.

Settlement Patterns

Sierra County

Under Spanish and Mexican law, officials made grants to towns and other communities in the Lower Rio Grande region (Figure 13). Pedro Armendariz received his No. 33 grant in 1819, the southern portion of which covers what is now Elephant Butte dam. Armendariz cultivated crops in the river valley while sheep, cattle and horses grazed on adjacent hills until he was forced to abandon his projects in 1824. Early settlement in the northern part of the Lower Rio Grande begin again in 1857 and
continued into the 1870s during which time the Alamosa, Cañada Alamosa, Alamocita, Las Palomas, San José, San Albino and Cuchillo communities were established. Most of these sites are now beneath Elephant Butte and Caballo reservoirs.\textsuperscript{36}
Figure 13. LRG land grants. Land grants were confirmed between the years 1790 -1853. After the signing of the Treaty of Guadalupe Hidalgo, land in the United States not already claimed became public domain. Source data: OSE and New Mexico Resource Geographic Information System Program (RGIS).
Doña Ana County

The majority of early settlers in the Mesilla Valley originated from the El Paso Valley, where irrigated agriculture first appeared sometime between 1659 and 1661. As a result of devastating floods in 1827-1828, farmers from El Paso were unable to continue farming and relocated to the Mesilla Valley. They petitioned the Mexican government for land grants in what is now the Lower Rio Grande so that they might continue their agricultural way of life.

In 1843, a group of Mexican colonists established the Mesilla Valley’s first permanent agricultural village within the Doña Ana Bend Colony land grant. During the following ten years, La Mesilla, Las Cruces, Santo Tomás, Refugio de Los Amoles (La Union) and Picacho communities were established throughout the valley. Additionally, a completely developed irrigation system was functioning along Palomas Creek in 1867, which served the Rio Palomas community.

Subsequent to the Treaty of Guadalupe Hidalgo in 1848, the expansion of Mexican settlers in the Mesilla Valley resulted in virtually all of the Rio Grande floodplain between Las Cruces and El Paso being claimed by 1880. Economic growth and increased settlement were further stimulated by the completion of the Santa Fe Railroad from northern New Mexico to El Paso in 1881. Despite apparent progress, of the approximately 34,000 acres of irrigable land in 1885, only about 4,000 acres (12%) were actually cultivated.
Obstacles and Challenges

*Indian Raids*

Indian and Mexican or Euro-American conflict caused many to wonder why anyone would settle in such inhospitable territory. While it is not known how successful Pedro Armendariz’s crop production was, it is documented that Navajo raids compelled him to leave the region in 1824.\(^{43}\) In fact, the 130-mile stretch from San Antonio to Doña Ana remained uninhabited by Anglo settlers until 1857.

Several military forts were constructed in the 1850s to protect valley residents from the attacks of hostile Indian groups. Fort McRae was located north of the Lower Rio Grande administrative boundary and during years of adequate supply its archeological remains are usually below water at the southeastern boundary of Elephant Butte reservoir. Fort Fillmore was situated in the northern portion of the Brazito land grant and Fort Selden was located at the top of Selden Canyon, below the Rincon Valley. These forts served communities in the Mesilla Valley and today are tourist attractions in Doña Ana County.

Indian raids combined with unreliable water supply caused one observer to note in 1867, “it seems to be a mania with the Mexicans to locate on some small stream where a few acres of cultivable land can be found, and where the settlers are in danger every day of losing their lives by Indians.”\(^ {44}\)

*Availability of Water*

Three factors affected water supply prior to 1900: climate, upstream activity and diversion structures. Historic, modern, or future water availability in the Lower Rio Grande largely depends on climate. This topic will be discussed fully in the “Climate”
chapter, but it is necessary to mention it here as a determining factor of surface water supply for early irrigators. Seasonal precipitation and temperature in southern Colorado and central New Mexico will be above or below average by different degrees from year to year; to accurately predict the climate from one year to the next is difficult. Additionally, water availability in any downstream basin will be affected by upstream diversions, which may be used for irrigated agriculture. Finally, the structures required to divert water from the river or stream to fields must be in good condition and maintained on a regular basis.

Despite erratic Rio Grande flows, water supply was generally adequate for summer crops in the Mesilla Valley. On average, the river went dry once every ten years during the summer and could last a couple of weeks to several months. Prolonged water shortages caused occasional crop failures and the first major drought happened in 1879; it caused 2,500 acres served by Picacho ditch to be deserted.45 This event presaged a cycle of recurring droughts that threatened agriculture in the Lower Rio Grande along with the El Paso-Juarez valleys.

Throughout the 1880s, the region experienced repeated shortages of water from the Rio Grande. Less water in the river meant that fewer fields could be irrigated, and extensive areas of agricultural lands were being abandoned. Had it not been for the recurring water shortages, settlement of the Lower Rio Grande would likely have progressed much more rapidly. Ultimately, there was little prospect of future agricultural development or settlement expansion without significant improvements in water supply conditions.46 Even so, farmers must have adapted to the scarcity of irrigation water, because throughout the 1890s the irrigated acreage in Doña Ana County increased despite...
no significant improvement in the water supply. According to census data, however, the total number of irrigable acreage at the end of the nineteenth century was fewer than in the early to mid-1880s. Doña Ana County reported roughly 24,200 acres of improved land in 1880; by 1889 that number shrunk to 13,822 acres then rebounded to 21,870 acres by the turn of the century.⁴⁷

The summer and fall seasons of 1889 and 1893 stand out as particularly destructive to irrigated crops in the region. The Lower Rio Grande valleys and El Paso/Juarez valleys experienced water shortages so severe that there was no water in the Rio Grande for several months. Because water supplies had become increasingly less reliable, residents of both valleys began to explore their own options for water storage by means of a major dam.⁴⁸ While farmers in the El Paso/Juarez valley initially blamed expanded irrigation in the Mesilla valley, Lower Rio Grande farmers believed an increase of irrigated acreage in the San Luis Valley of southern Colorado was the cause of water shortages.⁴⁹

Even in the last two decades of the nineteenth century, drought conditions were relatively rare in the Lower Rio Grande compared to flooding. Data suggest that spring flooding occurred on an almost annual basis and often damaged diversion structures to the extent that crops could not be watered during the critical initial growth phase. Thus, water could not be diverted onto fields at crucial points, and facilities had to be rebuilt on an annual basis. Moreover, if floodwaters did not take out diversion structures such as canal headgates and throats, it was possible the rapid deposit of sediments could render them useless after the river water receded.⁵⁰
Flooding

While irrigated agriculture made living in the Lower Rio Grande possible, farmers were faced with daunting prospects during the irrigation season. They had to consider the probability of sufficient water supply for their crops, and the likelihood of catastrophic flooding which could wipe out their fields and homes.

Because the Rio Grande is an aggrading river, the riverbed tends to be filled with additional sediments with each passing year. Also, the main channel of the Rio Grande was broad and relatively shallow. The result of this combination was regular over-bank flooding along the Rio Grande that often caused destruction to diversion structures, fields and communities. Although the Rio Grande is currently canalized, the causes of flooding have remained unchanged since the 1800s.

The most common cause of flooding is from winter snow pack in the headwaters of the Rio Grande and in north-central New Mexico. While snow pack is also the most reliable source of surface water available to the Lower Rio Grande, above normal winter precipitation would have caused over-bank flooding in the spring. A second form of flooding results from local, high intensity thunderstorms, which predominantly take place July through September. These climatological processes caused flow in the Rio Grande to range from zero to 30,000 cfs or more in the valleys.

Flooding was common in the Lower Rio Grande, and floods in excess of 2,000 cfs discharge occurred almost annually. Lacking flood control and irrigation structures adequate to sustain these floods, canals were likely destroyed or damaged each year. There was a strong possibility that diversion structures would be damaged at precisely the time that water would be needed to begin producing crops.
It is estimated that floods exceeding 8,000 cfs occurred approximately 44% of the time between 1895 and 1960. Prior to construction of the Rio Grande Project, a flood of this magnitude would have destroyed diversion structures, canals and fields, often leaving families or entire communities destitute. Over-bank flooding at this scale would wipe out crops first by inundating the landscape with standing water, then by depositing silt and sand onto the fields after the waters had receded. In terms of agricultural production, floods of sufficient magnitude to have had adverse impacts occurred about every 7-8 years during the period 1680-1914.55

Channel Migration

As noted earlier, the Rio Grande river valley is underlain by an alluvial aquifer. The unconsolidated gravel, sand, silt and clay that makes up the alluvium is unstable and, depending on flood magnitude, can allow lateral migration of the river. Evidently, the Rio Grande was notorious for its frequent post-flood channel migration. The main channel of the river changed course at least eight times between 1844 and 1914. Figure 14 illustrates an example of one of these changes; the town of Mesilla, which was located on the west bank of the Rio Grande, suddenly found itself on the east side of the river following a massive flood in 1852. Mesilla residents found themselves on the American side of the river; previous to the flood they were on the Mexican side.56
Figure 14. A former path of the Río Grande. Before the federal government canalized the Río Grande and controlled its flow, it was a meandering river which, when discharge was high, would flood the valley and find a new course. Source data: OSE, RGIS
1900 to Present

The Rio Grande Project

A significant feature in the Lower Rio Grande is the Rio Grande Project (RGP), a federal project authorized by Congress under the Reclamation Act of 1902 to provide irrigation water to farms in Texas and New Mexico. The RGP includes diversion dams, a canal delivery system, and Elephant Butte Dam, the primary structure of the Project, which was completed in 1916 (Figure 15). A hydroelectric plant began generating power for the region in 1940. For more information about the RGP, visit the U.S. Bureau of Reclamation web site at http://www.usbr.gov/dataweb/html/riogrande.html.

The U.S. Bureau of Reclamation (BOR) is responsible for delivering surface water to two irrigation districts, one in New Mexico and another in Texas. The BOR allocates RGP water and operates Elephant Butte and Caballo reservoirs to provide water to New Mexico’s Elephant Butte Irrigation District and the El Paso County Water Improvement District No.1 in Texas for distribution to their constituents, such as farmers, municipalities and others. The 1905 Reclamation Extension Act established the guidelines to divide the water supply between the irrigation districts where 88,000 acres could be irrigated in New Mexico and 67,000 acres in Texas each year. Notably, an allotment of three acre-feet per acre is the standard farm delivery of irrigation water in the RGP during full supply years. The United States-Mexico Treaty of 1906 allotted 60,000 acre-feet annually of Rio Grande water to be delivered to the Acequia Madre in México except in years of extraordinary drought. In 1937, an important joint contract between the U.S. and the irrigation districts increased New Mexico’s irrigated acreage to 90,640 acres and Texas’ to 69,010 acres.
Figure 15. RGP dams and diversion structures in New Mexico. In New Mexico, the Rio Grande Project consists of Elephant Butte and Caballo dams, Percha, Leasburg and Mesilla diversion dams, and over 300 miles of canals, laterals, drains and wasteways. Source data: OSE.
The RGP is an important feature in the Lower Rio Grande because it helped solve many of the difficulties irrigators had to contend with. Prior to construction, farmers were plagued by problems such as unavailable irrigation water, salinization, insufficient drainage, and sediment deposition. Sources estimate that agriculture was affected to the extent that only one-third of the irrigable lands in the Mesilla Valley were actually under cultivation.\textsuperscript{57} Subsequent to construction of the dams and conveyance system of the RGP, the BOR reported an average 77,516 acres of irrigated acreage in the Rincon and Mesilla Valleys between the years 1920 and 2000.\textsuperscript{58}

The standard three acre-feet per acre allotment is not always what farmers in the Lower Rio Grande or El Paso receive to irrigate their crops. For example, the Elephant Butte Irrigation District’s allotment this year is two acre-feet per acre so far.\textsuperscript{59} To make up the difference, irrigators who have groundwater wells and the appropriate water right(s) may pump groundwater to supplement surface water deficiencies.

\textbf{Elephant Butte Irrigation District}

The Elephant Butte Irrigation District (EBID) presently manages water distribution to 90,640 assessed acres in New Mexico. This was not always the case. By 1908, there were eight community ditches operating in the Mesilla Valley alone. Community ditch associations populated by members of the community maintained these ditches, but they were often at odds with each other. As the RGP was being planned, a BOR official noted, “we would probably smooth out the local friction and at the same time get a system initiated that will be of great benefit to all in the future.”\textsuperscript{60} EBID took control overseeing water deliveries to farms below Elephant Butte Dam in 1918. It also took over sole responsibility repaying the federal government for a portion of the
construction costs associated with the RGP in New Mexico. In 1971 EBID made its final payment to the government for RGP construction costs and seven years later took over operation and maintenance of diversion dams, and canal and drainage systems in New Mexico. The EBID delivers RGP water to 90,640 water righted acres; the extent of the district covers close to all of the irrigable lands and is a fair representation of cultivated lands in the Lower Rio Grande.

**Agriculture and Crop Patterns**

The wishes of Lower Rio Grande and El Paso/Juarez farmers were granted when the RGP received congressional authorization in 1905. Although the population already residing in the Lower Rio Grande had previously requested assistance, it was the promotion of settlement under the terms of the Cary Act that ultimately pushed construction of the RGP. The irregular supply of irrigation water did not guarantee successful crop cultivation; in the Lower Rio Grande, it was necessary to provide potential settlers with an adequate livelihood such as farming or activities related to farming.

Unfortunately, few quantitative data are available on crop acreages in the Lower Rio Grande for pre-RGP years. We do know that during the ten-year planning and construction phase, crop patterns followed trends similar to the latter part of the nineteenth century. In the Mesilla Valley, approximately 60% of cultivated acres were planted in alfalfa, 20% in corn, 9% in wheat and other small grains, and about 11% to vineyards, orchards, gardens and other minor crops. Alfalfa was the favorite because it was easy to grow, required less work than most other crops, had a greater resistance to drought because of its deep roots, could generally be sold at a good price, and was a
source of food for livestock. Most farms kept at least one draft animal, and one milk cow. Additionally, the sale of animals and animal products were sold to raise money for items a farm did not produce, such as clothing, coffee, sugar, and salt. Livestock continued to have an important role in the local agricultural economy, with cattle, sheep and goats grazing in the woodlands along the river, in the foothills of the mountains, and on the mesas. Referring to RGP farms, a geographer from Southern Methodist University stated in 1931 that, “most of the alfalfa grown on the project today is used to feed work stock and dairy cattle.”

Fewer than 22,000 acres of improved land were available to farmers in the Mesilla Valley at the start of the twentieth century. By 1914 lands in cultivation in the Rincon and Mesilla Valleys had risen to 51,723 acres—6,701 in the Rincon Valley and 45,022 in the Mesilla. This increase was due to construction and operation of the Leasburg Project, located at the top of the Mesilla Valley and completed in 1908.

Between 1905 and the completion of the RGP in 1916, few “new” lands were cleared and put into cultivation. The Bureau of Reclamation’s history of the RGP states that 97,204 acres of irrigable land were available in the Rincon and Mesilla valleys in 1914, up from the 21,870 acres that had been available prior to planning or construction of the RGP. This increase is attributed to the reclaiming of agricultural fields that had been abandoned during the years of water shortages in the late nineteenth century. By 1916 most of the formerly abandoned lands had been reclaimed, and there was little land in fallow, though it was not until 1920 that valley farmers began to truly benefit from the RGP.
Prior to completion of the RGP, farmers were applying more than six acre-feet per acre of water to their fields, which resulted in highly alkaline soils and damaged perennial crops. For example, the BOR reported the duty of water for acreage served by the Leasburg Canal in 1915 to be 7.0 acre-feet per acre.\textsuperscript{69} BOR officials recognized the tendency of farmers to over-irrigate as early as 1909, at which time the “terms of the water delivered through the Leasburg Canal was measured and paid for on the basis of ten cents per acre-foot. This change from the lump basis of the previous year’s contract was made to encourage economy of the use of water.”\textsuperscript{70} The average amount of irrigation water applied to fields began to decrease following completion of the RGP. Causes for the decline in water use can be attributed to technology—such as a shift from flood irrigation to furrow irrigation methods—and changes in the crops that were being irrigated.\textsuperscript{71} Thus, in 1917 an average of three acre-feet per acre was argued to be sufficient to produce most of the major crops in the region.\textsuperscript{72} Alfalfa and grains continued to be the major crops because of the high prices received for those crops during the war years.\textsuperscript{73}

The consequences of water logging during the teens and a drop in farm prices caused RGP irrigators to reevaluate their crop choices in the 1920s. Alfalfa, which had been the leading cash crop for many years, lost much of its appeal because of declining yields from water logged fields. Such alfalfa plots had to be plowed, and perhaps leached, before they could be replanted with another crop. Grain crops have a shallow root system and generally have a greater tolerance for alkali soils. However, production costs were high, and the end of World War I resulted in the decline of farm prices, which made grain cultivation increasingly unprofitable.\textsuperscript{74}
1919 marks the widespread substitution of cotton, a drought tolerant crop, for the more water intensive crop alfalfa. On his farm near San Miguel, New Mexico, Lee Harlan planted twelve acres of cotton and enjoyed satisfactory yields, which encouraged other irrigators to plant cotton in 1920. Low prices kept most from replanting the following year, but in 1922 the prices received for cotton were double those of 1921 and sparked this decade’s trend of increasing agriculture profits due to the cultivation of cotton. At that time, cotton required only 1.5 acre-feet of water per acre, while the crop water requirement for alfalfa was 4.2 acre-feet per acre. This partly made it possible for the numbers of farms to increase between 1909-1931. Planting cotton rather than alfalfa saved a substantial amount of irrigation water and explains the increase in the numbers of farms and irrigated acreage while, at the same time, the overall amount of irrigation water requirements decreased.75

Prior to the introduction of cotton, alfalfa was the dominant crop in the Lower Rio Grande. The percentage of cultivated land planted in alfalfa was reduced almost 40 percent from 1919 to 1929. However, the total number of acres planted in alfalfa remained relatively constant. This discrepancy is explained by the increase of irrigated acreage during the 1920s because most of the 97,204 acres of irrigable land were not actually irrigated until cotton became popular. Alfalfa was cultivated for similar uses as before the completion of the RGP; most farmers grew alfalfa to feed their own livestock and surpluses were sold locally. Additionally, dairy farms were located near La Mesa and La Union, where alfalfa acreage was concentrated at that time to feed the local dairy livestock.76
The 1920s also marked the introduction of pecan trees in the Lower Rio Grande. A publicity campaign encouraged farmers to plant pecan trees on their properties for shade as well as the production of nuts. By 1929, over 1,700 pecan trees had been planted, although generally not in orchards at the time. Interest in pecans continued and the 1940 U.S. Census of Agriculture lists 1,563 acres in pecan orchards present in the Lower Rio Grande.77 It appears that acreage planted with pecan orchards increased sharply in the 1940s and continued to increase throughout the twentieth century. It is currently the dominant crop in the Lower Rio Grande. Cotton and alfalfa are also primary crops followed by vegetables, other forage crops, grains, hay and pasture, and miscellaneous crops.

Water user organizations have collected agricultural statistics from constituents and submitted them to the BOR since the early stages of RGP operations. EBID began reporting the acreage irrigated by surface water, which is and was supplied by the RGP, to the BOR in annual reports. These data are not complete, especially in the earlier years. For years with incomplete or missing data, estimates were calculated to fill in the gaps and present a complete dataset for the years 1920-2000.78 Figures 16-19 illustrate crop acreages irrigated by EBID for years 1920-2000. A second set of data for years 1953-2004 present the data somewhat differently and are displayed in figures 20-23 as reported to the BOR in annual reports.79 For this project, the 1920-2000 data are referred to as Dataset A, and the 1953-2004 data are named Dataset B.

Both datasets are significant not only for what they reveal about crop patterns, but also for elements the other is missing. Dataset A illustrates the explosion of acreage dedicated to cotton production in the 1920s as described above, the decline in post-
Depression years, and its peak in the 1950s. It also indicates the introduction of pecans in 1929; figures 16 and 20 demonstrate the gradual increase in the percentage of acres committed to pecan orchards. Additionally, figures 17-19 include data that represent the rapid increase in irrigated acreage in the Lower Rio Grande and the first year of fully developed acreage on the RGP in 1946. On the other hand, figures 21-23 show the sudden decrease in acreage irrigated with RGP supply in the years 2003-2004. The drop in the number of acres coincides with declines of discharge at San Marcial, discharge below Elephant Butte Dam, discharge below Caballo Dam, and particularly with end of month storage in acre-feet of Elephant Butte Reservoir (please refer to chapter II, pages 22-23, figures 4-7).

Another interesting difference can be seen in Figures 16 and 20 with regard to pecan dominance in the Lower Rio Grande. Specifically, Figure 16 demonstrates that the number of acres planted with pecans is second to forage crops; Figure 20 divides forage crops between alfalfa, hay, and other forage and reveals pecans as the predominant crop since 1998.

Figures 19 and 23 show that the number of cropped acres reported by EBID do not equal the number of irrigated acres by EBID. This is because many farmers cultivate multiple crops on the same tract of land, either concurrently or during different seasons. The number of double-cropped acreage is unknown because it is not reported to the BOR as double-cropped. The State Engineer relies on estimates calculated by hydrology experts to quantify double-cropped acreage.
Figure 16. Crop acreage irrigated with RGP supply for years 1920-2000 within the EBID boundary (Dataset A). Acreage irrigated by EBID as reported to the BOR in annual crop reports, except for those years where data are missing; data is estimated for the years 1922-1935. Source data: OSE.
Figure 17. Total acreage irrigated by EBID for 1920-2000 (Dataset A). Data are for lands within the EBID boundary. Acreage irrigated by EBID as reported to the BOR in annual crop reports, except for those years where data are missing; data is estimated for the years 1922-1935. In terms of total acreage, EBID has never irrigated the entire 90,640 acres authorized by the federal government. Source data: OSE.
Figure 18. EBID irrigated acreage for 1920-2000 by crop (Dataset A). Acreage irrigated by EBID as reported to the BOR in annual crop reports, except for those years where data are missing; data is estimated for the years 1922-1935. Data includes double cropped acres, thus reported acreage appears to exceed the 90,640-acre limit. Source data: OSE.
Figure 19. EBID irrigated acreage for 1920-2000 with estimated double cropped acreage (Dataset A). Acreage irrigated by EBID as reported to the BOR in annual crop reports, except for those years where data are missing; data is estimated for the years 1922-1935. Because farmers may cultivate multiple crops on the same plot, total reported acreage by crop numbers are misleading. For an accurate accounting of the number of acres to which RGP irrigation water was applied, do not include multi-crop acreage. Source data: OSE.
Figure 20. Irrigated crop acreage for years 1953-2004 within the EBID boundary (Dataset B). Acreage irrigated by EBID as reported to the BOR in annual crop reports. Data are missing for years 1959, 1969, and 1991. Source data: OSE.
Figure 21. Total acreage irrigated by EBID for 1953-2004 (Dataset B). Acreage irrigated by EBID as reported to the BOR in annual crop reports. Data are missing for years 1959, 1969, and 1991. The irrigated acreage began to drop significantly in 2003 with the onset of less-than-full-supply years. Source data: OSE.
Figure 22. Irrigated acreage for 1953-2004 by crop (Dataset B). Acreage irrigated by EBID as reported to the BOR in annual crop reports. Data are missing for years 1959, 1969, and 1991. Data includes double cropped acres. Source data: OSE.
Figure 23. Irrigated crop acreage for years 1953-2004 within the EBID boundary with estimated double cropped acreage (Dataset B). Acreage irrigated by EBID as reported to the BOR in annual crop reports. Data are missing for years 1959, 1969, and 1991. Source data: OSE.
Both datasets indicate an increase in the number of acres devoted to pecan orchards, and the significant presence of alfalfa or forage crops. This indicates a substantial percentage of water-intensive crops in the Lower Rio Grande. These high water use crops must be monitored in years of short water supply, because water resource managers in the Lower Rio Grande must ensure excessive water use does not compromise water availability to others and/or impair senior water right holders.

The 1980s and 1990s were extraordinarily wet and the surface water allocation, which will be described in more detail in the “Crop Requirements” section, reflects those conditions. Figure 24 illustrates that irrigators in the EBID received an unprecedented 24-year period of continuous full surface water supply. This may have affected their appreciation of drought and led to the decision to cultivate more pecans, a high-water-use crop, rather than crops with a more conservative water requirement. The information in Datasets A and B described above, and the EBID annual surface water allotment data originally came from the “Project Histories of the Rio Grande Project, 1912-1988.”

Figure 24. EBID surface water annual allotments of RGP water delivered to river headings by the BOR in acre-feet per acre. Source data: OSE.
EBID began reporting crop acreage as part of its agreement with the BOR; sharing information is a condition of receiving RGP surface water. The State Engineer relies on the annual reports provided to the BOR to determine acreage by crop and to calculate consumptive use based on those acreages.

**Water Use**

*Supply*

The primary surface water supply in the Lower Rio Grande is the water stored and released from Elephant Butte and Caballo Reservoirs. All of the water released from these reservoirs is not utilized in New Mexico, and the surface water supply available is allocated exclusively for irrigated agriculture. Irrigated agriculture is by far the largest water use in the basin and surface water is often supplemented with groundwater to meet crop irrigation demands.

Flow in the Rio Grande is highly variable and often there is not enough water for everyone. Because surface water is fully allocated, groundwater is used to supplement surface water for irrigation; however, competition for that resource is such that its supply will not sustain the growing demands on it. Any new uses of groundwater will need to be supplied from existing, legitimate water rights and transferring them to the new use. For example, a water right in place historically to use water for irrigation will need to be purchased by and transferred to a new use, perhaps by a municipality to satisfy future needs of a growing urban population.

*Demand*

Water use in the Lower Rio Grande is presently dominated by irrigated agriculture. The principal irrigation administrative authority in the Lower Rio Grande is
the Elephant Butte Irrigation District (EBID), which manages surface water deliveries to 90,640 assessed acres in the Lower Rio Grande. Acreage dedicated to pecan orchards are of particular concern to OSE water resource managers. Since pecan trees are a water-intensive crop and the number of acres devoted to pecan orchards is increasing at a substantial rate, the consumption of irrigation water has increased over time (Figure 25). This increase may create water shortages that impact individual senior water right holders and compromise federal obligations to deliver RGP surface water to Texas and México.

Figure 25. Consumption of irrigation water over time. Source data: OSE.

The principal non-irrigation water users in the Lower Rio Grande include the City of Las Cruces, numerous smaller communities and mutual domestic water user associations, and commercial/industrial users. According to the Lower Rio Grande Regional Water Plan, which comprises Doña Ana County, excluding portions of the Tularosa and Mimbres basins, the portion of Sierra County that is within the boundary of EBID, and a portion of the Hueco Bolson within Otero County, the population in the
region was 189,436 persons in 2000, and had increased almost 29% since the 1990 census (Table 3). Analysts predict the population will continue to increase and public water systems that currently rely solely on ground water (i.e., all non-irrigation users) will need to supplement their supply with surface water in order to meet demand.80

<table>
<thead>
<tr>
<th></th>
<th>1990 Population</th>
<th>2000 Population</th>
<th>Annual Rate of Change</th>
<th>2005 Population</th>
<th>Annual Rate of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sierra County, NM*</td>
<td>9,912</td>
<td>13,270</td>
<td>2.96%</td>
<td>12,815</td>
<td>-0.70%</td>
</tr>
<tr>
<td>Doña Ana County, NM*</td>
<td>135,510</td>
<td>174,682</td>
<td>2.57%</td>
<td>189,444</td>
<td>1.64%</td>
</tr>
<tr>
<td>El Paso, TX*</td>
<td>515,342</td>
<td>563,662</td>
<td>0.90%</td>
<td>598,590</td>
<td>1.21%</td>
</tr>
<tr>
<td>Ciudad, Juárez, MX**</td>
<td>798,499</td>
<td>1,218,817</td>
<td>4.32%</td>
<td>1,368,175</td>
<td>2.34%</td>
</tr>
</tbody>
</table>

Table 3. Population Statistics. Annual Rate of Change is the compounded growth rate for the given number of years. Source data: *www.census.gov **www.elpasotexas.gov

Groundwater in the Lower Rio Grande is extracted for public water supply systems, private domestic wells, industrial purposes, commercial purposes, irrigated agriculture, livestock watering, quarry mines, and power generation. Depending on the status of surface water supplyii, it is estimated that irrigated agriculture may use 55,000 acre-feet per year to 200,000 acre-feet per year (see figures 26 and 27). For example, only 35,286 acre-feet of surface water were delivered to EBID farms in New Mexico in 1964. This amounted to four acre-inches per acre versus the standard three acre-feet per acre and irrigators were encouraged to pump groundwater to meet demand. In 2000, 245,283 acre-feet were delivered to EBID farms.81 Most of the demand is satisfied with withdrawals from the Mesilla Valley aquifer system, but a significant part is taken from the Hueco Bolson and Jornada Bolson. Irrigated agriculture claims 90.11% of the surface water and groundwater used in the Lower Rio Grande, public water systems receive

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ii Irrigated agriculture is dependent on groundwater in the LRG, especially during years when surface water supply is insufficient to irrigate crops. Domestic wells, stock wells, municipal purposes, and industrial uses remain relatively constant.
6.81%, and the remainder is distributed to commercial, livestock, domestic wells, power, industrial, and mining uses.  

Las Cruces is the second largest city in New Mexico and growing, necessitating an increasing amount of water resources. The Lower Rio Grande’s growing population and the large, expanding metropolitan areas of El Paso, Texas and Ciudad Juarez, México will continue to place additional stress on resources that are already in short supply. The
populations that depend on water resources in the Lower Rio Grande include communities of Sierra and Doña Ana Counties in New Mexico, and the downstream users in the city of El Paso, Texas, and Ciudad Juárez in México. Projections in the Lower Rio Grande Regional Water Plan suggest that the Doña Ana County region will increase in population to as many as 538,970 persons by the year 2040 (Table 4). Consequently, public and private water needs could increase from less than seven percent of supply in 2004 to over sixteen percent in 2040 (figures 28 and 29). Since groundwater supplies are constrained, it has been recommended that surface water, which is fully allocated, will have to be utilized to satisfy municipal needs. Further, only about 2% of the mean annual precipitation contributes to recharge outside the inner river valley, and basin-wide groundwater use greatly exceeds this amount.

<table>
<thead>
<tr>
<th>Growth Scenario</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>189,436</td>
<td>243,425</td>
<td>288,458</td>
<td>341,822</td>
<td>405,060</td>
</tr>
<tr>
<td>High</td>
<td>189,436</td>
<td>266,252</td>
<td>336,809</td>
<td>426,063</td>
<td>538,970</td>
</tr>
<tr>
<td>Low</td>
<td>189,436</td>
<td>220,692</td>
<td>235,037</td>
<td>250,314</td>
<td>266,585</td>
</tr>
</tbody>
</table>

Table 4. Projected Population.
Figure 28. Current surface water and groundwater use in the LRG.\textsuperscript{86}

Figure 29. Future surface water and groundwater use in the LRG.\textsuperscript{87}
Administration

The geographic location of the Lower Rio Grande places considerable demands on the Rio Grande and its various managing entities in New Mexico; including interstate compact agreements to deliver water for irrigation to Elephant Butte Reservoir, international agreements to deliver water to México, and to make water available for public water supply systems, private domestic wells, power generation, commercial purposes and other uses in New Mexico.

In the Lower Rio Grande, surface water and groundwater are generally administered separately; however, the two systems are hydrologically connected and physically behave as a single resource. For example, the Rio Grande gains base-flow from the shallow aquifers of the Lower Rio Grande during periods of low river flows. Additionally, irrigation canal systems and on-farm irrigation provide opportunities for recharge of the alluvial aquifers. This interconnectivity also means that excessive groundwater pumping can prevent surface water from reaching downstream users. The risks of immoderate groundwater pumping are chiefly that the aquifers of the Lower Rio Grande will be mined and that surface water supply will be insufficient for downstream users entitled to their share of RGP water.

Surface water deliveries to México are the responsibility of federal governments, i.e. the BOR and the International Boundary Water Commission (IBWC). In addition, the BOR is responsible for delivering surface water to the irrigation districts within the RGP. Groundwater is administered by the OSE to protect senior surface water rights and to ensure that groundwater pumping does not compromise the RGP nor interfere with the federal obligation to deliver Rio Grande water to México and Texas.
Ever-increasing demand for water resources exacerbated by continued drought conditions in New Mexico caused New Mexico Legislature to pass legislation in 2003 to allow the State Engineer to more timely administer the State’s water resources. The legislation was codified as 72-2-9.1 (NMSA) and states in relevant part: “The legislature recognizes that the adjudication process is slow, the need for water administration is urgent, compliance with interstate compacts is imperative and the state engineer has authority to administer water allocations in accordance with the water right priorities recorded with or declared or otherwise available to the state engineer.” In response to this 2003 legislation, the State Engineer initiated a strategy named Active Water Resource Management (AWRM). Its purpose is to enable the State Engineer to administer water rights in the absence of completed adjudications. Priority of right is the basis of water administration in New Mexico and AWRM has been designed as a set of tools necessary to conduct priority administration. These tools include measuring and metering; rules and regulations; the designation of a water master and formation water master districts; and they are specific to each administrative basin in the state. The State Engineer has targeted the Lower Rio Grande as one of seven “priority basins” across the state for implementing AWRM, i.e., the need to implement AWRM tools in this basin is urgent. The Lower Rio Grande Water Master District was declared in December of 2004 and a Water Master was hired in March of 2005. The State Engineer also issued a Metering Order in December of 2004 requiring groundwater wells to have meters and in March 2006 the Lower Rio Grande Water Master completed his first inspection of groundwater wells. Basin-specific Rules and Regulations have been drafted by New
Mexico Interstate Stream Commission (ISC) and OSE staff and are currently being reviewed by the public.

In the Lower Rio Grande, RGP water is allocated expressly for irrigated agriculture and other uses of that water have traditionally been prohibited. In 2001, the Surface Water User’s Agreement (SWUA), supported by state legislation (NMSA 73-10-48) was formalized, enabling specified users to become constituents of EBID, allowing them to obtain irrigation water for non-irrigation purposes. These transfers can be either short- or long-term leases or outright sales.\textsuperscript{69}

Despite these efforts, institutional and economic barriers exist which discourage irrigators from investing in water conservation. One of these involves prior appropriation and beneficial use. For example, water rights protected under the law are limited to the amount of water that is diverted and put to beneficial use. This means that saved water cannot be sold to another party, and is at risk under the use-it-or-lose-it rule. Thus, the water right owner has no economic incentive to limit his or her water use or invest in water conservation.\textsuperscript{90}

Other institutional barriers on a larger scale include the shared carry-over storage of RGP water between New Mexico and Texas. Any carry-over, or unused irrigation water, that is available for the following year must be shared equally between New Mexico and Texas, regardless of whether both states contributed equally or at all to the volume of water. Additionally, the Rio Grande Compact and the 1906 U.S.-Mexico Treaty, which allocate Rio Grande water between Colorado, New Mexico, Texas and México, does not provide an institution to manage surplus Rio Grande water. For
example, if an upstream state wished to sell surplus water to a downstream state, it would not be permitted to do so.\textsuperscript{91}

A long history of water litigation and the threat of further litigation in the Lower Rio Grande have driven the OSE to protect its share of water resources. Most recently, since 2001 the Texas Attorney General has threatened litigation against the State of New Mexico over the quality and quantity of its share of Rio Grande surface water.\textsuperscript{92} In response, New Mexico acted proactively to protect its water entitlement by gaining a better understanding of the Lower Rio Grande hydrology and quantifying water use and quality. OSE and ISC staffs continue to work to safeguard New Mexico’s water resources.

Federal, state and local managers of Lower Rio Grande water resources are faced with competing water uses, limited water supply, barriers to water conservation, and threats of litigation. Much work needs to be done to address these challenges, as water supplies may not be able to sustain the increasing demands for them. AWRM and SWUA strategies are good examples of state and local solutions to very complex problems in the Lower Rio Grande; however, institutional barriers and few incentives to conserve water are still present in the basin.
IV. CLIMATE DATA

Agriculture may benefit from warmer temperatures and longer growing seasons in other parts of the United States; however in the Lower Rio Grande, most of the impacts of climate change on agriculture are expected to be harmful. The availability, delivery, management of and demand for water are dependent on climate. Warmer climate will likely result in less snow pack, more winter rain, and faster, earlier snowmelt. This increases the possibility of greater winter and spring flows, and the reduced ability to store floodwaters if the reservoirs fill to capacity and managers are forced to release water. Additionally, higher temperatures and increased evaporation could lower reservoir levels and stream flows in summer. As water supplies are constrained, irrigators will become more reliant on groundwater to supplement surface water, but less spring and summer recharge could reduce available groundwater. If climate changes bring drier and warmer climate, one could expect water supplies to be more limited while irrigated agriculture would require more water.

Climate in the Lower Rio Grande is arid to semi-arid with warm summers, mild winters, and warm spring and fall seasons. Precipitation is chiefly in the form of thunderstorms which normally occur during summer or early fall. Climatological normals are defined as the prevailing set of weather conditions calculated over a 30-year period and it is from this period that climate data is generally reported. The current climatological normal includes the years 1971-2000 and for these years precipitation has averaged between nine to eleven inches in the river valley and eight to twenty-six inches within the Lower Rio Grande hydrologic basin. These values were extracted from spatial data created by the PRISM (Parameter-elevation Regressions on Independent Slopes
Model) Group of Oregon State University, which has calculated climate datasets for the coterminous United States for the years 1895-2005. PRISM incorporates point data, a digital elevation model, and expert knowledge of complex climatic extremes, including rain shadows, coastal effects, and temperature inversions into four-kilometer resolution Arc/Info ASCII Grids. The NRCS, the USFS, and NOAA partly funded PRISM; it is the USDA’s official climatological data and can be downloaded from their website for any of the months or years between 1894-2007. Please see Appendix C for spatial climate data for the twentieth century.

**Climatological Normal**

The PRISM climate data was to be overlaid with Lower Rio Grande irrigated tracts, for the purpose of analyzing the different crop patterns and climate trends and the results placed into a database. Unfortunately, there was a problem with one or more of the programs used to manipulate the data and the resulting tables, which should have been populated with precipitation and temperature data, were empty when opened with a database program. It was at this point the decision was made to calculate the climatological normal values of the twentieth century because the data was complete when opened in ArcGIS. Graphical representations can be found in Appendix C. The assumption was that the values would increase as the century progressed. Then, the data would be compared with historical climate estimates for similarities.

Precipitation values were reconstructed using tree-ring research in southern New Mexico where extreme drought and unusually wet periods were calculated. These data show that since AD 800, the years between 1903-1921 was the third wettest period, and 1946-1961 (the 1950s drought) was the second worst drought, as indicated in Table 5.
Precipitation in the Lower Rio Grande basin is slightly higher 1911-1940, and precipitation decreases during the years that include the 1950s drought. Precipitation and temperature values generally increase in the latter part of the century, however averages of minimum temperature as well as low averages of maximum temperature remain relatively unchanged. This information suggests that while changing climate trends may enable irrigators to choose crops appropriate for warmer daytime temperatures, cooler nighttime temperatures will continue to be a factor.

<table>
<thead>
<tr>
<th>Climatological Period</th>
<th>Precipitation (inches)</th>
<th>Tmin ('F)</th>
<th>Tmax ('F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1901-1930</td>
<td>7</td>
<td>9</td>
<td>42</td>
</tr>
<tr>
<td>1911-1940</td>
<td>7</td>
<td>9</td>
<td>42</td>
</tr>
<tr>
<td>1921-1950</td>
<td>6</td>
<td>9</td>
<td>42</td>
</tr>
<tr>
<td>1931-1960</td>
<td>7</td>
<td>8</td>
<td>42</td>
</tr>
<tr>
<td>1941-1970</td>
<td>7</td>
<td>8</td>
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</tr>
<tr>
<td>1951-1980</td>
<td>7</td>
<td>9</td>
<td>42</td>
</tr>
<tr>
<td>1961-1990</td>
<td>7</td>
<td>10</td>
<td>42</td>
</tr>
<tr>
<td>1971-2000</td>
<td>8</td>
<td>11</td>
<td>42</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LRG Hydrologic Basin</th>
<th>Precipitation (inches)</th>
<th>Tmin ('F)</th>
<th>Tmax ('F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1901-1930</td>
<td>7</td>
<td>25</td>
<td>34</td>
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<td>1911-1940</td>
<td>6</td>
<td>28</td>
<td>35</td>
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<tr>
<td>1921-1950</td>
<td>6</td>
<td>27</td>
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</tr>
<tr>
<td>1931-1960</td>
<td>6</td>
<td>25</td>
<td>34</td>
</tr>
<tr>
<td>1941-1970</td>
<td>6</td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td>1951-1980</td>
<td>6</td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td>1961-1990</td>
<td>7</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>1971-2000</td>
<td>8</td>
<td>25</td>
<td>34</td>
</tr>
</tbody>
</table>

Table 5. Climate data gleaned from PRISM spatial data. Total precipitation; annual average minimum temperature, and annual average maximum temperature.

**Tabular Data**

In addition to spatial data, tabular data in the Lower Rio Grande has been collected since 1892 from the New Mexico State University weather station. It should be noted that the weather station at NMSU changed location slightly in the year 1959. These data were compiled for the purpose of determining the number of days of the
growing season for agricultural crops in the Lower Rio Grande over time. Not only do the data reveal that the number of days that comprise the growing season has increased, it shows that other parameters have increased as well. Simple trend lines illustrate tendencies, and from those future values were estimated. Please refer to Appendix B for graphs, which illustrate tabular data.

$$y = 0.3242x + 188.6$$

$$R^2 = 0.2547$$

Figure 30. Number of days between killing frosts in the LRG.

To determine the length of the growing season, 32°F was used as the bounding parameter. For this project, the last killing frost in spring and the first killing frost in fall are data points that are equal to or below 32°F. The growing season, or the number of days between killing frosts, has increased from an average 189 days in 1892 to an average 225 days in 2005 (Figure 30). Actual data points indicate the shortest growing season was 165 days in 1894, and the longest was 268 days in 2004. The average number of days between killing frosts for the period of record is 207 days.

A simple trend line indicated that the average number of days between killing frosts could reach 237 days by 2040. The root mean squared error (RMSE) was calculated as 32 days, thus the actual number of days would be somewhere between 205 and 269 days.
The temperature data collected from the NMSU weather station indicate an overall upward trend, especially in annual graphs. Monthly minimum temperature data is most erratic in the winter months; maximum temperature data is most erratic in the summer months. Average daily temperature by month suggests that the range of temperatures is quite irregular in warmer months, but the overall trend is increasing. Precipitation data do not indicate any significant trends and the evaporation data is incomplete for the period of record.

In sum, the climatological normal values data are interesting, but not entirely useful. On the other hand, the tabular data confirms the hypothesis that the growing season is getting longer in the Lower Rio Grande. The climatological normal values could be used to compare current climate parameters and their departure from normal, to historical parameters and their respective departures from normal. For example, the infamous drought of the 1950s had less precipitation and warmer temperatures than what was considered normal at the time. One could compare last year’s precipitation and temperature to what is the current climatological norm to determine if the droughts were
of a similar magnitude. The significant information that was gleaned from the tabular climate data was that the trend of the number of days per growing season in the Lower Rio Grande is increasing. Since the late 1800s, the growing season has lengthened and temperatures are somewhat warmer. This is a signal to water resource managers that irrigation will occur outside of the “regular” irrigation season more often. EBID’s primary irrigation season is generally March to October, however groundwater wells could pump water onto fields earlier in the spring and later in the fall if temperatures or the number of days between frosts continue to increase.
V. CROP REQUIREMENTS

Evaluating crop requirements and agricultural water use in the Lower Rio Grande is extremely important for effective water management in the Lower Rio Grande. This project emphasizes gathering historical cropping data, spatial cropping pattern data, and agricultural water use data as introductory steps. Organizing the data where crop irrigation requirements are assigned to individual tracts provides water use by crops located on individual farms as well as water use basin-wide.

Description of Data

Historical cropping data are discussed earlier in the “Agriculture and Crop Patterns” section and acreage over time is illustrated in figures 20-23, also referred to as Dataset B in this project.

To determine accurate agricultural tract boundaries in the Lower Rio Grande, the OSE Hydrographic Survey Bureau (HSB) conducted a hydrographic survey in the year 2000. Additionally, satellite imagery data were acquired and Parsons Engineering Science, Inc. completed windshield surveys the same year to establish which crops were being grown at the time. A spatial dataset was created that organized the observations from the windshield surveys into the agricultural tract boundaries determined by the HSB (figures 32 and 33). This spatial dataset offers a snapshot of cropping patterns in the Lower Rio Grande in 2000 and it serves as the base for the following evaluation.

Comparing the 2000 GIS data to crop data from annual reports (Dataset B), irrigated acreage is similar. For 2000, EBID reported 73,787 acres irrigated during the year; the 2000 GIS data comprises 74,023.18 acres irrigated within the EBID boundary. Conversely, 4,284 acres were reported as double cropped by EBID in annual reports, and
Figure 32. Crop patterns in the Rincon Valley. These data represent hydrographic survey boundaries and crop patterns observed during windshield surveys in 2000.
Figure 33. Crop patterns in the Mesilla Valley. These data represent hydrographic survey boundaries and crop patterns observed during windshield surveys in 2000.
1,910.71 acres are attributed to be double cropped within EBID in the 2000 GIS dataset. OSE hydrologists confirm that it is very difficult to ascertain the number of acres that are double cropped and more so to determine where those fields are located.

The “Second Public Draft of the Proposed Rules and Regulations Providing for Active Water Resource Management Administration of the Waters of the Lower Rio Grande Water Master District” define Consumptive Irrigation Requirement as:

The Consumptive Irrigation Requirement (CIR) is the quantity of irrigation water, expressed as a depth or volume, exclusive of effective rainfall, that is consumptively used by plants or is evaporated from the soil surface in the course of irrigation during one calendar year.

And Farm Delivery Requirement as:

The Farm Delivery Requirement (FDR) is the quantity of water expressed as an annual amount, exclusive of effective rainfall, that is delivered at the farm head gate, or is diverted from a source of water that originates on the farm itself, such as a well or spring, to satisfy the CIR of crops grown on a farm during the accounting period. FDR is calculated by dividing the CIR by the fraction of total annual irrigation water applied to a farm that is beneficially consumptively used by the crop.

The OSE Water Use and Conservation Bureau (WUC) calculated CIR for Lower Rio Grande crops grown in the year 2000 utilizing the SCS (now NRCS) Modified Blaney-Criddle Method (1970). These values are dependent on many factors such as the researcher, the method, climate values, and the geographic location and can be different for the same crop but different year, or method, or researcher, etc. The acre-feet per acre values utilized for this project were alfalfa, 3.49; corn, 1.38; chile, 2.21; cotton, 2.01; Christmas trees, 2.99; durum wheat, 1.07; fruit orchards, 3.56; vegetables, 2.01; vineyards, 2.10; hay, 3.02; herbs and spices, 1.92; irrigated native pasture, 3.02, irrigated improved pasture, 3.02; lettuce, 0.64; nursery stock, 2.32; onions, 1.78; pecans, 3.20; pistachios, 2.41 and sorghum, 1.64. For this project, alfalfa, pecans, hay and pasture
represent high-water use crops, and corn, wheat, lettuce and onion are shown to be low-water use crops.

For this project, WUC CIR values were assigned to cropping pattern data to find agricultural water use in the Lower Rio Grande basin. Because water needs have changed since RGP operation began, comparisons of the different FDR values diverted from the river to Lower Rio Grande farms since then, as well as a projection of future water use, were achieved and are discussed in the following sections.

**Farm Delivery Requirements**

The FDR became an issue soon after the Leasburg Project was complete in 1908. Irrigators were applying excessive amounts of water to their fields, thus created an unproductive environment to grow crops. An average allotment of 3.0 acre-feet per acre (AFA) per year of RGP water was argued to be sufficient to produce most of the crops in the region in 1917.\(^{102}\) This number was confirmed by the BOR in the 1970s when that organization concluded 3.0241 AFA per year satisfied irrigation requirements for RGP lands during normal supply years and annual allotments of that amount were diverted regularly beginning in the 1970s.\(^{103}\) The 3.0241 AFA per year annual allotment is currently the normal supply allotment to irrigation district farms; in years of less than normal supply a proportion of the 3.0241 AFA per year is calculated. For example, the allotment for EBID so far this year is 2.0 AFA. More recently, the OSE has proposed a basin-wide FDR of 4.0 AFA per year.\(^{104}\) Surface water allotment should be applied first, and the remainder may be pumped from groundwater wells with a valid water right. Some have objected to an FDR that is insufficient to cultivate high water use crops, usually pecans. To illustrate water use with multiple FDR values, 5.5 AFA per year was
chosen for pecans, and the remainder of the crops received 4.0 AFA per year. Finally, the FDR calculated from the WUC CIR values and a 72% on-farm efficiency rate was applied to crop patterns of the 2000 GIS data. The tables in Appendix D display the water use by crop in the Lower Rio Grande.

**Water Use Scenarios**

For this project, seven water use scenarios were identified, and the first was the crop patterns of 2000. The 2000 GIS data provide information regarding which crops were grown that year and how many acres were cultivated. The HSB survey tracts add up to 95,524.21 acres, of which 80,680.18 acres were irrigated in 2000 as attributed in the GIS data. Tracts that were not irrigated include fallow land, plowed idle ground, swamp, non-irrigated trees and water.

The second scenario is a minor change where vegetable crops were replaced by pecan orchards. This was based on the fact that row crops are more expensive to produce and could be replaced by more cost effective crops.105

Third, the number of acres committed to pecan orchards was doubled and the remaining crop acreage was reduced by roughly half. The reason for this was the expressed desire of some to “fill the valley” with pecan orchards.106

Fourth, the first year of complete data that followed the first year of fully developed crops supplied by the RGP was estimated utilizing crop acreage as reported to the BOR in annual reports. To get a picture of what the valley looked like when it was fully developed for the first time, the year 1953 was chosen. The actual first year of fully developed crops was 1946, however, that was a year in which agricultural data were
missing or incomplete. This is also an appropriate year to observe patterns during the severe drought of the 1950s.

The fifth situation is a representation of what the valley might look like without pecans. Cotton acreage was increased to about what it was in the 1920s, before the arrival of pecans and shortly after irrigators began to truly appreciate the benefits of the RGP supply of water.

Sixth, 2000 GIS data was reattributed with ArcGIS software; all agricultural tracts within urban boundaries (Las Cruces, Sunland Park, etc.) were changed to urban tracts, and no longer received irrigation water. This is a simplified method to address the transfer of agricultural water uses to urban or residential uses. As mentioned in earlier sections, surface water is fully appropriated, groundwater supplies must be extracted conservatively, and population in the Lower Rio Grande is expected to more than double in the next 30 years. Any new uses of groundwater will need to be legally and voluntarily transferred from existing water rights, likely from agriculture since it uses the greatest volume of water in the Lower Rio Grande.

Finally, a projection of what cropping patterns could look like in 2040 was estimated. Utilizing Dataset B, trend lines were established for pecans and alfalfa acreage, and the remaining crop acreages were figured as a percentage the pattern for 2000. The trend lines represent rates of growth for pecans and alfalfa; for pecans, a trend line that covers 1953-2004 with an $R^2$ value of 0.9473; for alfalfa, a slope was chosen that kept acreage relatively constant but with a low $R^2$ value. The best $R^2$ was 0.6381, and that trend was negative. Dairy is an important economic industry in the region, and
livestock crop receipts are greater than any individual agricultural crop, therefore alfalfa acreage is unlikely to change in the long run.\textsuperscript{107}
Figure 34. Crop patterns in the Rincon Valley with months of growing season overlaid and FDR labels. The numbers of days can be used instead of months, and maintained in a database to be viewed in report format. This data represents hydrographic survey boundaries and crop patterns observed during windshield surveys in 2000 and CIR calculated for 2000.
The tables in Appendix D compare cropping patterns and FDR values, which were named 1917 FDR, 1978 FDR, Proposed FDR, Multi-Value FDR and WUC FDR. With the exception of the First Year of Fully Developed Crops scenario, total acre-feet of required irrigation water for each scenario were in this order: the Multi-Value FDR, followed by the Proposed FDR, and then by the WUC FDR, the 1978 FDR, and finally the 1917 FDR had the lowest total acre-feet of water. The results of the First Year of Fully Developed Crops scenario seemed surprising at first. While the total cultivated acreage is greater than all but the projected scenario, the WUC FDR had the lowest total acre-feet of required irrigation water and the lowest average AFA of all the scenarios at 2.94 AFA. This was due to the high number of acres devoted to cotton, a water-thrifty crop.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Acreage</th>
<th>1917 FDR</th>
<th>1978 FDR</th>
<th>Proposed FDR</th>
<th>Multi-Value FDR</th>
<th>WUC FDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 Crop Patterns</td>
<td>80,680</td>
<td>242,041</td>
<td>243,985</td>
<td>322,721</td>
<td>358,510</td>
<td>281,634</td>
</tr>
<tr>
<td>Transfer Vegetables to Pecans</td>
<td>80,680</td>
<td>242,041</td>
<td>243,985</td>
<td>322,721</td>
<td>364,711</td>
<td>287,896</td>
</tr>
<tr>
<td>Increase Pecan Acreage</td>
<td>80,680</td>
<td>242,041</td>
<td>243,985</td>
<td>322,721</td>
<td>401,126</td>
<td>297,929</td>
</tr>
<tr>
<td>First Year of Fully Developed Crops</td>
<td>86,339</td>
<td>259,017</td>
<td>261,098</td>
<td>345,356</td>
<td>351,461</td>
<td>253,836</td>
</tr>
<tr>
<td>No Pecans, More Cotton</td>
<td>80,680</td>
<td>242,041</td>
<td>243,985</td>
<td>322,721</td>
<td>322,721</td>
<td>249,793</td>
</tr>
<tr>
<td>Convert Ag Areas to Urban</td>
<td>64,921</td>
<td>194,763</td>
<td>196,328</td>
<td>259,684</td>
<td>288,017</td>
<td>225,660</td>
</tr>
<tr>
<td>Projected to Year 2040</td>
<td>95,524</td>
<td>257,712</td>
<td>259,782</td>
<td>343,616</td>
<td>404,243</td>
<td>321,217</td>
</tr>
</tbody>
</table>

Table 6. Total acre-feet for each water use scenario. If EBID farms receive 250KAF per year of surface water in a normal supply year, crop requirements in excess of that volume would have to be supplied with groundwater (adjusted for regional precipitation).

A full diversion allocation of RGP water in New Mexico is 494,480 acre-feet per year. This amount should be diverted at river headings when Elephant Butte and Caballo reservoirs have a normal supply of water available. In reality, roughly 450,000 acre-feet are diverted at river headings. Subtracting operational spills and transport losses, EBID farms receive about 250,000 acre-feet of surface water per year during normal supply years to satisfy FDR. If a crop requires irrigation water in excess of a year’s surface
water supply, groundwater is pumped from the aquifers to satisfy demand. Table 6 shows that almost all of the scenarios after 1978, and a few from the 1917 and 1978 FDR scenarios, would require groundwater to supplement surface water in order to meet crop requirements.

The FDR values used for the water use scenarios were the best estimates of average irrigation water use in the Lower Rio Grande for their respective time periods, with the exception of the Multi-FDR and WUC FDR. This is based on the information mentioned under “Farm Delivery Requirements” section. The water use scenarios demonstrate an increase in irrigation water consumption because the same cropping patterns were estimated to use more water over time. Further, the WUC FDR values exceed the 1917 FDR and 1978 FDR values.

While these examples are generally hypothetical and created by extrapolation of current trends, they demonstrate the power of spatial data in an agricultural setting. Using the 2000 GIS data as a base, managers can see the place of use (POU), the FDR of each tract, and the number of days of the year it should have been applied (Figure 34). If spatial data were acquired annually, water resource managers would have a better idea of what is happening on the ground. Water depletions—not only from agricultural tracts, but also from riparian areas, parks, urban areas, and residential developments—could be calculated regularly and a historical record maintained in a database.
VI. WATER RESOURCE MANAGEMENT TOOLS

The climate and agricultural analyses in this project did not reveal a connection between a lengthening growing season and the types of crops farmers choose to irrigate in the Lower Rio Grande. They did show that the number of days per growing season for primary crops has increased and that over time the total consumption of irrigation water has increased to accommodate greater acreage of water intensive crops. These changes force effective management of water resources in the Lower Rio Grande to guarantee federal obligations downstream, protect senior water rights, and to safeguard aquifers from mining. This section will discuss existing management tools utilized by the OSE and its sister agency, the Interstate Stream Commission (ISC). The OSE is charged with administering water resources in the state, the objectives of the ISC are to ensure compliance with interstate stream compacts as well as investigating, protecting, conserving, planning and developing the waters of New Mexico.¹⁰⁸

Short Description of Water Resource Administration in New Mexico

Following fundamental principles found in Article XVI of the 1912 New Mexico Constitution, the State Engineer is responsible for the supervision, measurement, appropriation and distribution of the state’s water;¹⁰⁹ these are accomplished in part by recognizing and managing water rights. Adjudication is necessary to determine the extent of a water right—where the water is diverted, what it can be used for, where it can be used, how much can be taken, and when the water right came into existence. Mentioned previously, AWRM (Active Water Resource Management) is a strategy put in place to enable the State Engineer to administer water rights in the absence of completed adjudications, and the Lower Rio Grande has been selected as one of seven “priority
basins” across the state for implementing AWRM. The adjudication process began early in the 20th century but it was never completed; in 1986, EBID filed a lawsuit against the New Mexico State Engineer to force the State to file a lawsuit adjudicating water rights in the Lower Rio Grande stream system. Active adjudication of specific water right claims in the Lower Rio Grande began in 2000 and will continue for years to come. Without completed adjudications, the State Engineer must administer water rights with tools available to him. AWRM tools include the creation of a water master and water master districts; rules and regulations; measuring and metering, and they are specific to each administrative basin in the state.110

Water right claims identified by the Hydrographic Survey Bureau (HSB) are compiled into adjudication “subfiles.” Approximately 13,125 subfiles have been identified in the Lower Rio Grande, and 6,368 Offers of Judgment have been filed with the court. An Offer of Judgment is a document that informs the claimant of what the state thinks his or her water rights are, which he or she can accept or challenge in court. As of April 2007, 4,224 of the 6,368 subfiles served have been adjudicated, or just under one-third of the total number of subfiles.111 Recall that active adjudication began in 2000; therefore only 32% of the subfiles has been adjudicated in seven years. Incredibly, the adjudication process in the Lower Rio Grande is believed to be moving rapidly compared to other parts of the state. This lengthy process was the impetus to propose rules and regulations for the Lower Rio Grande and the FDR of four acre-feet per acre (which was the OSE best estimate of current average irrigation water use in the LRG). The OSE will continue the adjudication process; in the meantime, water use must be quantified and managed until it is complete.
In the Lower Rio Grande, a Water Master District has been declared, a Water Master has been hired, and the first inspection of groundwater wells in the Rincon and Mesilla valleys has been completed. This was the first step following the issuance of the Lower Rio Grande Metering Order, which requires groundwater wells—excluding domestic wells serving a single household, one-acre or less of non-commercial trees, lawn or garden, and livestock watering—to have flow meters for the purpose of measuring the volume of groundwater extracted. It must be emphasized that groundwater is administered by the OSE to protect senior surface water rights and to ensure that groundwater pumping does not compromise the RGP nor interfere with the federal obligation to deliver Rio Grande water to México. The BOR is responsible for delivering surface water to the irrigation districts within the RGP and surface water deliveries to México are the responsibility of the BOR and the IBWC. In short, the OSE is responsible for managing groundwater use in the Lower Rio Grande, and the federal government allocates surface water. However, an individual may be entitled to surface water or groundwater, or a combination of both, depending on his or her water right. Once a water right is established, those with the earliest date have the senior right, or priority, over junior water right holders; the State Engineer conducts priority administration when supply does not meet demand.

Rules and regulations are another set of tools available to the State Engineer under the AWRM strategy. The “Second Public Draft of the Proposed Rules and Regulations Providing for Active Water Resource Management Administration of the Waters of the Lower Rio Grande Water Master District” suggests the FDR be four acre-feet per acre annually. Further, section 19.25.16.403 states,
B. Groundwater diversions for irrigation of land assessed by EBID shall not exceed the difference between the farm delivery requirement and the surface water allotment, multiplied by the number of acres of irrigated land at the places of use served by the well(s), regardless of whether the surface water allotment is delivered.

C. Groundwater diversions for irrigation of lands irrigated with surface water but not assessed by EBID shall not exceed the difference between the applicable farm delivery requirement and the actual annual farm delivery of the surface irrigation water.

D. Annual groundwater diversion for irrigation of lands not irrigated with surface water or assessed by EBID shall not exceed the farm delivery requirement for those lands multiplied by the acreage of the place of use.\textsuperscript{112}

Basically, an irrigator cannot pump groundwater in excess of the FDR less the surface water applied for each acre of place of use. However, an irrigator can choose to fallow some of his or her acres and “stack” the irrigation water on remaining acres.

A scenario from the “Crop Requirements” chapter offers that the FDR for a single year could be 358,510AF (see Table 6). If the EBID farms receive 250,000AF of RGP surface water, 108,510AF would need to come from other sources to satisfy the agricultural demand. Depending on the volume of precipitation that falls on the fields, irrigators would pump groundwater to make up the difference. In years of drought, the total volume of RGP surface water may be only 50,000AF. Put simply, irrigators would need an additional 308,510AF of irrigation water to meet demand. If the State Engineer determines that users with senior water rights would be impaired or that the federal delivery of Rio Grande water would be threatened if an excessive volume of groundwater were extracted, junior water rights could be curtailed that year.

Measuring and metering water use in the Lower Rio Grande allows the State Engineer not only to ensure senior water rights, interstate and international agreements,
but also to track water depletions. An extensive collection of surface water flow gages measure and monitor flow in the Rio Grande, and in canals, laterals and drains. In the Lower Rio Grande, the EBID, BOR, and the U.S. Geological Survey maintain these gages. Groundwater monitoring wells are also maintained by the ISC to measure groundwater depletions and groundwater-surface water interconnectivity.

**Water Depletions**

Understanding water depletions, or consumptive use, is an important part of water resource investigations and adjudication activities. In addition to adjudication and administration activities, the State Engineer recognizes the need to extend the water supply for future generations, reduce the risk of water shortages, and improve the health of rivers and groundwater. The OSE maintains water use databases and analyzes crop, weather and other water use data to quantify water requirements for irrigation and other uses. This project considers agricultural depletions.

Different land surfaces consume water at different rates. Similarly, different crop types consume water at different rates. This is demonstrated in any of the tables in Appendix D, where the WUC FDR is different for each crop. Those numbers are the result of the Consumptive Irrigation Requirement (CIR), which is determined with crop and climate data and the SCS Modified Blaney-Criddle Method (1970). Components of that method include:

- Number of days of each month of the growing season
- Mean monthly temperature for each month of the growing season
- Inches of precipitation for each month of the growing season
- Monthly percentage of daytime hours of the year
• A calibrated crop coefficient
• A calibrated climate coefficient

These components are not usually computed for each year, and the OSE currently applies climate years 1950-1980 for the first three listed above. The monthly percentage of daytime hours of the year comes from a table based on latitude. The crop and climate coefficients also come from their own respective tables, and are calibrated to represent a particular region.

The SCS Modified Blaney-Criddle Method (1970) computes evapotranspiration (Et) for each crop type under the conditions mentioned above. When effective rainfall (Re) is subtracted from Et, the CIR is represented in acre-inches per acre. Effective rainfall is the amount of water stored in a plant’s root zone. Finally, FDR is calculated by dividing CIR by the percent on-farm efficiency, and for this project was presented in acre-feet per acre.

The State Engineer must administer water resources in the state while protecting New Mexico’s water future. CIR and FDR are important tools the OSE employs to address a variety of water supply and demand issues. Agricultural depletions must be determined to understand how much water is being used in the Lower Rio Grande, particularly when water supplies are low. Similarly, quantifying the volume of water that is sufficient to produce satisfactory yields is necessary not only to complete adjudications in the Lower Rio Grande, but also to highlight water intensive crops. The OSE continues to investigate new and existing tools and strategies to accomplish the responsibilities assigned to the State Engineer established by the New Mexico Constitution.
Limitations and Constraints

The OSE has made progress with the AWRM strategy, however limitations and constraints exist which prevent effective management in the Lower Rio Grande. These include the slow pace of implementing the Metering Order, metering and measurement shortfalls, incomplete and unverified agricultural data, and overlooked opportunities regarding climate data.

The groundwater meters the State Engineer has ordered irrigators to install are an important first step in the Lower Rio Grande. A system is not yet in place to manage groundwater data, although some irrigators have begun to report metered flows. It is expected to be years before a complete system is in place to collect, report, store and analyze metered groundwater flow data used for irrigation. This is in part because of the time required to design, accept, and implement such a system. Additionally, cooperation and coordination between the OSE and Lower Rio Grande farmers is not ideal at this point. Some farmers believe the State Engineer should not interfere with irrigation issues and do not recognize his responsibilities to manage it. A Water Master has been hired to assure that water is fairly distributed in accordance with available water supply and priority dates, or with the FDR decided upon in the Lower Rio Grande rules and regulations until water rights are completely adjudicated. The Lower Rio Grande Water Master and associated OSE staff are responsible for collecting, analyzing, and reporting groundwater data. Presently, the groundwater metering information held by the Lower Rio Grande Water Master is restricted to whether a well has a meter or not, though the Metering Order was issued almost three years ago in December 2004.
According to the Lower Rio Grande Water Master, Sheldon Dorman, the metering information he expects to receive from irrigators is the numerical reading from the meter, “exactly like the number on a car’s odometer.” Asked if irrigators would provide information such as where the irrigation water was applied (place of use) or on what crops, Mr. Dorman replied that irrigators either do not know, they would be resistant to share that information, or both. Additionally, Mr. Dorman expressed his need for place of use (POU) information someday, but that he understands it is currently difficult to obtain. Significant pieces of information that are unavailable to the Lower Rio Grande Water Master include how much water an irrigator is entitled to, how to determine when water use should be curtailed, and whether irrigators use water appropriately.

This project was not written to discuss precisely how agricultural depletions in the Lower Rio Grande are calculated; however, there are two base parameters that are of interest for this project. The cropping data reported by EBID to the BOR and the CIR data computed by OSE staff (including the WUC) are essential data to calculating water use, however there are constraints to their use. These data were discussed in the “Crop Requirements” section.

Lower Rio Grande cropping data are comprised of farms within the EBID boundary. This is a fair representation of agriculture use in the Lower Rio Grande; however, it is not complete because irrigation does occur outside of the District. Additionally, it is known that some thousands of acres are double-cropped each year, but not where, nor how many acres, nor which crops are grown. Rather, hydrologists and engineers estimate double-cropped acreage either by contract or within the OSE. Lastly,
the crop acreage reported by EBID is not verified by any agency. These are some of the rationale behind the acquisition of the 2000 GIS data discussed in the “Crop Requirements” section.

OSE staff relies on averaged climate data to calculate agricultural depletions. For example, the CIR discussed in this project uses climate data averaged over a 30-year time span to compute the Blaney-Criddle Method. Weather stations are scattered over the Lower Rio Grande basin and the New Mexico Climate Center provides detailed weather data daily. Since climate is variable in the Lower Rio Grande from year to year, it would make sense to use annual climate data. This is especially relevant because cropping data are reported on an annual basis. Evaluating agricultural depletions would be more accurate if the climate data corresponded more closely to the agricultural data.

The tools utilized by the OSE and ISC are useful, however limitations exist which prevent these agencies from effectively managing water resources in the Lower Rio Grande. In particular, the Water Master, who is in charge of the regulation of water use and distribution of irrigation water within the LRG Water Master District, is not equipped with the tools necessary to carry out AWRM.
VII. SUMMARY AND CONCLUSION

The purpose of this project was to investigate how climate and agriculture data can be used as water resource management tools in New Mexico’s Lower Rio Grande (LRG). The Lower Rio Grande is located in an arid climate where irrigated agriculture claims over 90% of the water used in the region, and the acreage committed to the cultivation of water intensive crops is expanding. Additionally, population growth in the region has increased significantly since 2000 and is expected to double by the year 2040. These increases in demand could create water resource conditions that are undesirable or unsustainable.

The New Mexico Legislature passed legislation in 2003 to allow the State Engineer to more timely administer the State’s water resources. In response, the State Engineer initiated a strategy named Active Water Resource Management (AWRM) to administer water rights in the absence of completed adjudications. AWRM is designed as a set of tools necessary to conduct priority administration, however few tools are currently available to the Lower Rio Grande Water Master. This project considered the potential of joining climatological and agricultural data into management tools, which could assist the Lower Rio Grande Water Master in managing water rights and monitoring water use in the Lower Rio Grande.

Climate data analyses were in two parts. The first was the geospatial PRISM data and second, the tabular data obtained from Hydrosphere Research Consultants, Inc. through the OSE. The results from the PRISM data analysis were disappointing because of programming flaws, but spatial data were sufficient to create climatological normal spatial datasets of the twentieth century. The climatological normal datasets were
interesting, if not very useful. These datasets were summarized and put into a table to compare changes over the twentieth century and their numbers indicate similarities to historic tree-ring data, but they are not strong. Thirty-year precipitation averages in the Lower Rio Grande Valley have increased since 1901, however basin-wide changes are slight. Thirty-year average maximum temperatures indicate warmer daytime temperatures between 1901 and 2000. There could also be some value when comparing current and historic climate parameters, such as departures from normal.

The analysis of the tabular data was most useful in that it did illustrate more numerous days between killing frosts in the Lower Rio Grande. The number of days between the last killing frost in spring and the first killing frost in fall determined the length of the growing season, where the bounding parameter was 32°F. Additionally, when the average, maximum and minimum temperature data were compiled and displayed in graphic format, they indicated an overall warmer trend.

Evaluating crop requirements and agricultural water use in the Lower Rio Grande is extremely important for effective water management. To demonstrate agricultural water use in the Lower Rio Grande, seven water use scenarios were identified for this project with historical cropping data, spatial cropping patterns, and consumption use values. The results of the scenario analysis demonstrated that based on the different FDR values over time, total consumption is increasing, and groundwater is necessary to supplement surface water even in normal supply years.

Although the scenarios were generally hypothetical, they demonstrated the power of spatial data in an agricultural setting. Using geospatial data, the place of use, FDR, the number of days of water application for each crop, and other relevant data can be put into
a visual format. If spatial data were acquired on a regular basis, water resource managers would have a better idea of what is happening on the ground throughout the year, every year. Agriculture water use, depletions from riparian areas and parks, and residential water consumption, could be calculated regularly and a historical record maintained in a database.

A longer growing season and warmer temperatures will enable an irrigator to apply water to crops more days of the year, which will lead to increased water use. Additionally, the rapid population growth in the region will require a greater amount of water for urban uses. Increased demand by all users will intensify the competition for limited water resources in the Lower Rio Grande and effective water resource management is necessary to measure, monitor and distribute the available supply.

The impetus for choosing this topic was climate data collected at New Mexico State University, which suggests the number of days between killing frosts has increased since the late 1800s. Will a longer growing season affect agriculture in the Lower Rio Grande? The answer to this question was unattainable with the climate and data analyses in this project. An irrigator would need to know how a change in crop type, water use, and appurtenant costs compare to the costs of existing practices. In addition to climate and cropping patterns, a researcher would need to know:

- Economic factors
  - Is there a market? An irrigator should know if there is a market for crops not currently being irrigated. These could include organic products, alternative fuels (ethanol) and the local grower’s markets.
Crop prices. The price received for crops should be high enough to warrant a change in crop type because profits are offset by production costs, labor costs, transportation costs, and the costs related to irrigating the land.

Available subsidies. If subsidies are available, an irrigator could consider changing his or her crop type so that some acres could be fallowed. This could present an opportunity to lease unused irrigation water.

Cost effectiveness of changing the crop type should also be considered. New crop types could require new methodologies where laborers would need to be trained, new irrigation technologies could require different equipment, or a different harvesting technology could require new machinery. Changing crop type may also reduce labor, irrigation, or harvesting costs.

New production costs could add to labor costs (training, number of laborers, hours per day). Additionally, a new crop may require automated harvesting when previously it was not. This could involve the purchase or rental of new equipment that may or may not be available locally.

Labor costs may increase or decrease as the result of new crop cultivation. Depending on the intensity of labor, wages paid to laborers may increase or decrease. For example, if fewer laborers with more expertise were required, wages would be
high, which could benefit the laborer and attract a workforce. Conversely, if crop production required many laborers who receive low wages, an irrigator may have trouble finding enough laborers. An available workforce is often difficult to find for irrigators in the LRG, because construction work is plentiful and pays higher wages.114

- Transportation costs could change if crop types change. Seeds or nursery stock may not be locally available, and markets where the new harvested crop would be purchased could be located at a further distance. Fuel prices and the availability of alternative fuels should also be considered.

- Climate factors
  - Will a change in crop type necessitate new water requirements? Versus existing crops, could a new crop type require more or less water? What will be the cost of ordering or pumping or leasing additional water? What could be earned from leasing or selling saved water by cultivated water-conservative crops?
  - Despite the trend of increasingly warmer average temperatures in the LRG, nighttime (minimum) temperatures can still be quite low. Equipment necessary to protect sensitive crops from winter frost, such as greenhouses, may cost more to an irrigator than the price received for the crop.
Yields. An irrigator will want to know if climate change will decrease yields of current crops, or if climate change will enable farmers to grow crops with yields that are superior to existing crops. This could be more expensive for a farmer if production and harvesting costs are high, or less expensive if the crops receive a high price.

Crop Value. Will climate change enable irrigators to cultivate high-value crops on fewer acres? Are those crops water-intensive or will they save water? Will climate change force irrigators to cultivate low-value crops on more numerous acres? Are those crops water-intensive?

- Cultural/Social factors
  - Traditional/subsistence farmers may not be willing to change crop type regardless of yields, profits or water conservation. Perhaps the OSE could provide educational materials of the benefits and costs to these irrigators if they exist.
  - Negative or positive impacts on neighbors either by pests, pollution, or water use may encourage irrigators to consider water-saving crops. These should be investigated and shared with irrigators as incentives to consider their crop choices.

- Agricultural factors
  - An irrigator may consider different crop types because a change could cause the farmer to earn more money, or because
he or she saves water. Knowing what is more important and why will assist the State Engineer when making decision regarding water conservation education and incentives.

- **Yield.** Historic and projected yields for crops with different water requirements in a changed or changing climate should be investigated. Additionally, the physical state of the land and soil and the ability to cultivate new or existing crops under a different climate must be determined.

- **Nuisance/pollution.** The potential for new pest infestation and the affect on crops, as well as the need for different pesticides and fertilizers could have direct costs to the irrigator utilizing them, as well as indirect costs well to other water users from pollution.

- **A crop’s reaction to warmer temperatures including daytime, nighttime, and average daily temperatures will need to be determined.** This would be necessary for existing and new crop types.

- **Does the crop maturity or yield depend on the growing season?**

- **Will a change in crop type make water formerly used to irrigate crops available for lease?**

John White of the NMSU Agricultural Extension office and Deborah Bathkey, a local climatologist in the Lower Rio Grande, have expressed an interest in answering questions regarding climate and agriculture. Of particular concern is the effect on pecans
grown in the region. The varieties grown in the Lower Rio Grande are sensitive to warmer nighttime temperatures because they require “chilling” at night. Without lower nighttime temperatures, pecan yields will be negatively affected. Miss Bathkey informed me that scientists from other parts of the country have been studying this subject extensively and will be sharing what they know with agronomists and climatologists in the Lower Rio Grande.

Water availability is an important subject in the Lower Rio Grande, and the success of water management strategies will depend on the tools used to carry them out. A comprehensive database populated with climate and agricultural data, and GIS software by which to view, analyze and report those data, would be valuable tools to the New Mexico Office of the State Engineer.
VIII. RECOMMENDATIONS

These recommendations were inspired by the 2000 GIS data mentioned throughout this project. The goals are to monitor basin-wide depletions and to highlight localized areas of intensive water use. Implementing a plan in which climate, agriculture and spatial data would be created on an annual basis would address many of the limitations and constraints mentioned previously. The following are recommendations for further study in the Lower Rio Grande.

Spatial Data

Spatial data relevant to agriculture and water use in the Lower Rio Grande are satellite imagery and GIS data. Satellite imagery data have been used extensively for many years for agricultural applications. These applications include determination of crop type, studying crop vigor and determining irrigated areas. Although crop types have not been determined in the Lower Rio Grande with satellite imagery so far, there are plans to accomplish this task soon. An example of spatial data used for quantifying crop acreage and patterns is the 2000 GIS data example from the “Crop Requirements” section.

Satellite imagery can come from a variety of sources, and Landsat is an appropriate example for this project. A Landsat satellite captures images of the earth’s surface that are generally well suited and widely used for regional monitoring of environmental change in vegetation and urbanization. The data are available at 14- to 16-day intervals, and 30- to 60-meter per pixel resolution. Thirty meters per pixel translates to roughly one-quarter acre on the ground. With the satellite imagery, the Normalized Difference Vegetation Index (NDVI) can be calculated and vegetation
characteristics on the ground can be measured. Specific signatures can be assigned to a
crop; with that information and the satellite imagery, a successful application can create
detailed agricultural data such as crop type and health. Satellite imagery can also provide
consumptive use (Et) data. This is particularly useful for managers who need to measure
basin-wide agricultural depletions. If the satellite Et data were viewed with GIS
software, or if a map was created which displayed the data spatially, one could see where
consumptive use is greatest in the Lower Rio Grande.

Recommendations

Landsat Data Acquisition

First, Landsat data should be purchased from a private contractor who has
calculated annual NDVI and Et values for the Lower Rio Grande. To calculate annual
NDVI, it is recommended that data should be collected and a composite created from
three passes of the satellite per season (spring, summer, winter, fall). For complete
coverage of the Lower Rio Grande, two scenes of the composite data are required.

Evapotranspiration Data Acquisition and Use

Satellite imagery that quantifies Et annually is an essential dataset for water
resource managers because it can inform managers how much water is required and/or
used by crops during each year. To calculate Et, two passes per season are adequate to
create an image composite. Again, for complete coverage of the Lower Rio Grande, two
scenes of the composite data are required and would be supplied by a contractor. Basin-
wide depletions are an important part of water resource investigations to quantify how
much water is being consumed in the Lower Rio Grande, and to provide information
necessary to complete adjudications. This information would be especially useful during
years of low water supply when ensuring interstate compacts and downstream obligations are more difficult to meet. Additionally, these data can be integrated with the GIS data for analysis with the crop patterns.

Field Surveys and Data Verification

The next step would be to complete windshield surveys of the basin every year to verify, correct, or fill in data gaps from the satellite imagery and NDVI calculations and to complete a spatial dataset of Lower Rio Grande cropping patterns. Perhaps some of this work could be done with OSE staff, but a contractor would complete the majority of the work. This step also includes organizing the crop observations into the hydrographic survey tracts spatial dataset furnished by the OSE. Subsequent steps would include attributing the survey tracts with data such as ownership information, if a groundwater well exists, and calculated FDR data. As it becomes available, additional data could be appended to the dataset. This could be whether that parcel has a right to be served by surface water only, groundwater only, or a combination of both. In the future, when ownership, FDR, water use and water right information are available, the OSE can view the data spatially, and compare how much irrigation water was actually applied versus what should have been applied in a given year.

The spatial data will not figure how much water has been diverted from any source (although that information could be entered and stored in a GIS); however, with the information in a visual format, managers can estimate if a crop will be irrigated outside of the primary irrigation season. EBID’s primary irrigation season, that is when surface water is distributed, is generally between March and October. This season is shorter in times of drought and it is not unusual for the season to expire in September. In
this case, the spatial data could highlight areas of concern where the Water Master may have to pay special attention.

An obvious application of the spatial data is to verify the EBID annual cropping data reported to the BOR. The satellite imagery, confirmed by the windshield surveys, could be a valuable quality assurance tool. Additionally, the windshield surveys could be utilized to find double-cropped acreage.

Obtain and Compile Climate Data

It is recommended to take advantage of available climate data to calculate annual CIR for the Lower Rio Grande. Data can be collected from a source such as the New Mexico Climate Center website, where all of the required parameters of the Blaney-Criddle Method (1970) are assembled and available to download from a variety of weather stations in the Lower Rio Grande. Annual CIR—versus a 30-year average—will portray the variable climate conditions of the Lower Rio Grande accurately.

It is also suggested to divide the Lower Rio Grande into climate zones because climate varies in different parts of the basin. This would be useful when calculating the Blaney-Criddle Method where the number of days of the growing season is dependent on the average monthly temperature and monthly precipitation. The PRISM Group data would be a useful tool to accomplish this because it indicates spatially where in the Lower Rio Grande average monthly temperatures are, as well as where monthly precipitation falls. For example, irrigation water should be applied to alfalfa when the mean monthly temperature equals or exceeds 50°F. This date will likely be different in the Rincon Valley than in the southern Mesilla Valley.
The agriculture and climate data necessary to create a geospatial tool are not difficult to obtain, and the crop water requirement method is not difficult to compute. Once the necessary data are put into a GIS, it is suggested the Water Master and his staff use the tool to monitor water use in the Lower Rio Grande. He is unable to administer water rights in part because there are currently no enforceable limits to an irrigator’s water use. Also, measurement and reporting of water use is incomplete. The absence of enforceable limits will be corrected when adjudications are complete, or when the Proposed Rules and Regulations Providing for Active Water Resource Management Administration of the Waters of the Lower Rio Grande Water Master District are promulgated and the basin-wide FDR is put in place. In the meantime, water use can be estimated and monitored both basin-wide and on a farm-by-farm basis. The following tool will be most useful to monitor water use on a farm-by-farm basis.
Figure 35. An example of spatial data as a water resource management tool. This is a simplistic example of how the spatial data could be used by OSE staff, including the Water Master.

**Water Master Tool**

Figure 35 is an example of agricultural data in a spatial format and a crude example of how water use data could be reported. The information offered would come from the data mentioned previously in this section including NDVI values computed from Landsat imagery and verified by windshield surveys, evapotranspiration data computed from Landsat imagery, CIR values computed with the Blaney-Criddle Method, detailed climate data, and hydrographic survey data. All of this information could be put into a database and organized in such a way that basin-wide or individual water-righted acreage could be displayed with detailed crop and water-use information. In this case, the farmer over-diverted irrigation water and that amount would need to be made up during the following accounting year.121 It is also possible to share the information with
the irrigator as incentive to conserve water or as an opportunity to lease unneeded water to water-short farmers or to municipalities with a Surface Water User’s Agreement (SWUA).

Data and Tool Use

The following are the suggested uses of the Landsat data, field data, and climate data, which should be collected, purchased and calculated on an annual basis. NDVI data will be used to indicate irrigated acreage and crop type in the region. Additionally, the fieldwork will provide crop type verification from windshield surveys. The second set of data derived from the Landsat imagery is the evapotranspiration data, which will indicate consumptive use in the Lower Rio Grande. Finally, climate data will be kept for an historical record, and more importantly to calculate the Blaney-Criddle Method (1970) in order to determine FDR. This will also require the NDVI crop type information. All information will be kept in a database and a GIS for rapid, simple used by OSE staff, as shown in Figure 35.

Benefits

Potential benefits to the Lower Rio Grande Water Master could be:

• Save time. The Water Master and his staff would not need to go into the field to make global farm observations. If there are areas of concern, a staff member could use the GIS tool to target an area, then go to the field for additional information if necessary.

• Place of use. With the information from the hydrographic survey, the OSE and the farmer will know how much land is potentially irrigated each
year. This information will also be helpful when irrigators fallow certain tracts and/or stack water on other tracts.

- **Water use.** The Water Master can compare and analyze estimated, actual, and/or illegal water use for each farm or water right. This will be most useful when adjudications are complete.

- **Target tracts that would likely have been irrigated outside of the primary irrigation season.** This would be useful or necessary when water supply is short and irrigators should not be pumping groundwater excessively. Additionally, Et data overlaid with the hydrographic survey tracts will inform the Water Master that irrigators are applying water to their crops, perhaps when he or she should not be.

- **Educational.** It would be simple to make a version of Figure 35 available to those who visit the district office, to inform the irrigator of what the State Engineer believes his or her water use was for a given year. This could serve to show an irrigator that surplus water could be leased or sold, and confirm water use.

- **For years of low water supply, irrigators with water-thrifty crops could be sought out as potential volunteers to lease their surplus water.**

- **Some irrigators use EBID’s conveyance system to transfer groundwater illegally to another POU.** The spatial tool will allow the Water Master to track that kind of behavior. For example, if a tract that should only receive one AFA of irrigation water is shown to have a high Et rate, that tract could be diverting water illegally.
• Water conservation and waste reduction. If an irrigator is over-diverting unnecessarily, as in Figure 35, the spatial tool could inform him or her that crops are being over-irrigated. If the irrigator limited water use to what is recommended using the spatial too, he or she could save money by not ordering as much water, or earn money by selling or leasing water that is not needed the following year.

**Costs**

The following are estimated costs associated with the recommendations. One staff person from the OSE was estimated to be sufficient to manage this project for the State Engineer per annum.\(^1\) The cost of the windshield surveys and appurtenant data cost $45,000 in 2000 and that is a fair estimate for this project.\(^2\) Lastly, the satellite imagery for the \(\text{Et}\) data costs roughly $30,000 for an adequate estimate of consumptive use for one year.\(^3\)

<table>
<thead>
<tr>
<th>Item</th>
<th>Price per year</th>
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<tbody>
<tr>
<td>One OSE staff person</td>
<td>$75,000</td>
</tr>
<tr>
<td>Windshield survey</td>
<td>$45,000</td>
</tr>
<tr>
<td>Satellite Imagery</td>
<td>$30,000</td>
</tr>
<tr>
<td>PRISM Data</td>
<td>Free</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$150,000</strong></td>
</tr>
</tbody>
</table>

Table 7. Costs associated with recommendations

In summary, climate and agriculture data could be put into a spatial format and used as a tool to provide crop and water use data. This information could be useful to the Water Master to compare and track estimated and actual water use on a farm-by-farm basis. Satellite data could be used to measure NDVI and \(\text{Et}\), and windshield surveys could verify the data. These data are also useful to verify the acreage reported by EBID to the BOR, and to measure basin-wide depletions. Climate data available on the web...
could be used to divide the Lower Rio Grande into climate zones and detailed climate data should be collected for the purpose of calculating the Blaney-Criddle Method (1970).

Further research of spatial data as additional water management tools for the purpose of measuring basin-wide depletions and to monitor water use at a farm-by-farm scale is recommended. Implementing strategies that incorporate spatial data will provide the OSE with a comprehensive and highly accurate database of water use data. Currently, the Lower Rio Grande Water Master is unable to administer water rights because a basin-wide FDR has not been agreed upon and adjudications are incomplete. A geospatial tool, which incorporates climatological data and agricultural data, would help the Water Master to monitor present water use, and administer water rights in the future.
8 Terracon, et al. 7-150.
9 Terracon, et al. 15.
10 King, Maitland 22-23
16 Terracon, et al., 6-80.
20 Conover 71-73.
21 Witcher, et al. 53.
23 Witcher, et al. 54.
24 Witcher, et al. 7.


27 Wilson 334-335.

28 Wilson 334-335.

29 Schönfeld La Mar 20-21.


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33 Wilson 342.

34 Schönfeld La Mar 22.


2 “GAO-01-330 Treaty of Guadalupe Hidalgo: Definition and List of Community Land Grants in New Mexico.”

36 Wilson 335.

37 Ackerly 4.

38 Ackerly 4.

39 Schönfeld La Mar 172.

40 Wilson 340.

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42 Ackerly 177.

43 Wilson 335.

44 Wilson 341-342.

45 Schönfeld La Mar 26.

46 Schönfeld La Mar 196-197.

47 Schönfeld La Mar 167.

48 Schönfeld La Mar 29-30.

49 Douglas R. Littlefield, Dividing the Waters of the Rio Grande, Ph.D diss, 1986, 44-46

50 Ackerly 38-39.

51 Ackerly 37-60.

52 Ackerly 38-39.


54 Ackerly 38-39.

55 Ackerly 38-64.

56 Ackerly 67.

57 Schönfeld La Mar 166-167.

58 Margaret Barrall 6 November 2006.

59 Diana M. Alba, “Farmers to see more water this season,” Las Cruces Sun-News, 18 June 2007, final ed.: 5A.


61 “About EBID: Recommended Reading from the General Manager.”

62 Ackerly 146.

63 Schönfeld La Mar 200-204.


66 Schönfeld La Mar 200.

Schönfeld La Mar 199-200


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Schönfeld La Mar 219.

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