Appendix E1

SSPA Middle Rio Grande Water Supply Study

Appendix E1. SSPA Middle Rio Grande Water Supply Study

The following report is an interim draft based on ongoing work of S.S.Papadopulos and Associates, Inc. and reflects work completed as of the date of this publication. This work has not yet been reviewed and accepted by the ISC and the Corps of Engineers. Updates to this work will be published at http://www.seo.state.nm.us/water-info/mrgwss/index.html

Middle Rio Grande Water Supply Study, Phase 3

INTERIM PARTIAL DRAFT

S.S. PAPADOPULOS & ASSOCIATES, INC.
Boulder, Colorado

August 6, 2003

Middle Rio Grande Water Supply Study, Phase 3

INTERIM PARTIAL DRAFT
This study is in progress. Interim results have not yet been reviewed by the Executive Steering Committee or by the Contracting Agencies.

Prepared for:

U. S. Army Corps of Engineers
Albuquerque District

Contract No. DACW47-99-C-0012

and

New Mexico Interstate Stream Commission

Prepared by:

Σ²Π **S.S. PAPADOPULOS & ASSOCIATES, INC.**
Boulder, Colorado

August 6, 2003

1877 Broadway, Suite 703, Boulder, Colorado 80302-5245 · (303) 939-8880

TABLE OF CONTENTS

Page

REPORT

TABLE OF CONTENTS (continued)

Page

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF APPENDICES

GLOSSARY

Actual Elephant Butte Effective Supply – the recorded flow of the Rio Grande at the gaging station below Elephant Butte Dam, adjusted for net changes in storage in the Elephant Butte reservoir during the year as determined by the Rio Grande Compact commissioners

Aquifer – a saturated zone of soil beneath the ground surface capable of yielding water to wells

Cone of depression – area immediately surrounding a well, where the groundwater elevation is lowered due to effects of pumping from wells

Conjunctive-use – use of a combination of water sources for water supply; i.e., use of surface water and groundwater

Consumptive irrigation requirement – the quantity of irrigation water that is consumptively used by crops or is evaporated from the soil surface within a designated period of time. The consumptive irrigation requirement is equal to the consumptive use minus the effective rainfall.

Consumptive use – the amount of water lost from the hydrologic system through evaporation, transpiration, and the building of plant tissue in a specified period of time.

Correlation analysis – involves the determination of the relationship between different processes. (For example, the likelihood that the flow of the Jemez River will be high if the Otowi native flow is high in a particular year.)

Credits and debits – the excess, or shortage, of surface water actually delivered, compared to the obligation, according to the Rio Grande Compact

Credit/debit balance – the end-of-the-year balance of credits and debits accrued under the Rio Grande Compact

Depletion – losses from the water supply for agricultural, domestic, riparian use or evaporation from open water surfaces

Depletion graphs – graphs showing the net depletion through a defined river reach; these graphs illustrate where net gains and losses are occurring

Deterministic – exhibiting behavior that can be described according to the laws of physics

Descriptive statistics – involves describing the nature of, and variability in, a population or set of events. (For example, the average, maximum, and minimum payout of a slot machine and how often it pays out.)

Double-mass curves – graphs depicting / comparing upstream and downstream cumulative flows within a defined reach of river versus time

Effective rainfall – rainwater available for use by plants; the portion of the rainfall event that does not flow overland into an arroyo or stream, infiltrate to the water table and contribute to aquifer recharge, or become lost to immediate evaporation from soils.

Elephant Butte Effective Index Supply – (also called *Elephant Butte Scheduled Delivery*) the delivery obligation at Elephant Butte, according to the Rio Grande Compact. The value of this delivery obligation is determined based on inflow conditions at the Otowi Gage.

Elephant Butte Scheduled Delivery – (also called *Elephant Butte Effective Index Supply*) the delivery obligation at Elephant Butte, according to the Rio Grande Compact. The value of this delivery obligation is determined based on inflow conditions at the Otowi Gage.

Ephemeral tributaries – rivers or streams that only flow during certain times of the year or under certain hydrologic conditions.

Evapotranspiration (ET) – the combined processes of simple evaporation and plant transpiration through which liquid water is converted to water vapor and lost to the atmosphere

Evapotranspiration rate – the rate at which evapotranspiration occurs. In this study, measured in acre-feet per acre per year

Farm delivery – The amount of water delivered to a farm for irrigation of crops.

[Water] Gains – increases in the water supply within a system or reach of a river. For example, gains to streamflow may occur due to precipitation, snowmelt, wastewater discharge, or agricultural return flow.

Metadata – Data about data. Metadata may include site identification information, spatial organization and reference, data quality, temporal data, entity and attribute information, distribution, and reference information.

Monte Carlo Analysis – The Monte Carlo method provides approximate solutions to mathematical problems by performing statistical sampling experiments. The method is useful for obtaining numerical solutions to problems which are too complicated to solve analytically. In the context of the work presented in this document, Monte Carlo Analysis means fitting individual flow and depletion terms with a *probability distribution*. Then, for each run of the model, a random number is generated for each probabilistic term, and that random number is used to select a value for the term from the term's probability distribution. Values for all terms are summed to give a final annual result. This is repeated 10,000 times to provide a distribution of outcomes. A given year's results have no influence on previous or future years.

Native water – Surface water from the Rio Grande and Chama River originating in Colorado and Northern New Mexico

Net Supply – Monthly diversions to irrigation canals reported by the irrigation district to the USBR

Otowi Index Supply – the recorded flow of the Rio Grande at Otowi Bridge, adjusted for storage in reservoirs constructed after 1929 and for trans-mountain diversions.

Perennial tributaries – rivers or streams that flow continuously throughout the year.

Probabilistic – (also called *stochastic*) exhibiting uncertainty that can be described using the laws of chance

Probability distribution fitting – the process of finding a curve or mathematical formula to describe a set of measured data

Quaternary alluvium – Generally unconsolidated geologic materials deposited by rivers during the Quaternary period of geologic time (within the past two million years).

Return flows – Water returning to the river after diversion into irrigation canals, including tail water from farms, drainflow or applied irrigation water seeping past the root zone to groundwater.

Rio Grande Compact – agreement passed by Congress in 1939 governing the delivery obligations of Colorado to New Mexico and New Mexico to Texas for waters of the Rio Grande basin.

Risk analysis – (also called uncertainty analysis) method for considering the combined effects of multiple probabilistic (uncertain) processes, and/or characterizing the range of possible outcomes

Salvaged evapotranspiration – a decrease in the evapotranspiration rate due to such factors as a decrease in availability of shallow groundwater to plants

San Juan-Chama Project water – Surface water from the Colorado River system delivered through the San Juan-Chama Project to the Rio Chama and thence to the Rio Grande

Santa Fe Group aquifer system – a deep complex of unconsolidated alluvial sediments along the Rio Grande that form an aquifer that is hydraulically connected with the Rio Grande.

[Water] Source – a resource for either surface or groundwater

Spill year – A year during which there is flow over the spillway at the Elephant Butte Reservoir (hypothetical spills may occur without an actual spill, given certain conditions, and are treated similarly under the Compact)

Static value – a term defined as a constant within the probabilistic water-budget model

Steady-state conditions – a system at equilibrium; conditions at which the system has stabilized

Storage – the amount of water existing in the interstices of a geologic medium as part of a groundwater system

Stream-connected aquifer – an aquifer with hydraulic connection with a surface water system. In a stream-connected aquifer, the pumping of groundwater will eventually reduce stream flow within the same basin

Trans-mountain diversions – Water diverted from drainage systems other than the Rio Grande, for use in the Rio Grande system (i.e., San Juan-Chama Project water)

USGS gaging stations – locations where the U. S. Geological Survey has installed equipment for monitoring of river level and flow rate

Waste – A term used in USBR monthly water distribution data sheets for water returned to the river through wasteways and drains

Water budget – A summary that shows the balance in a hydrologic system between water supplies to the system (inflow) and water losses from the system (outflow)

Water supply – the amount of water potentially available for use within a study area; this must account for both the hydrologic supply and the legal limitations imposed by water allocation agreements such as the Rio Grande Compact

Acronyms

AMAFCA – Albuquerque Metropolitan Arroyo Flood Control Authority

COE – U.S. Army Corps of Engineers

DEM – Digital Elevation Models

DRG – Digital Raster Graphics

EDAC – Earth Data Analysis Center

EPA – U.S. Environmental Protection Agency

ESC – Executive Steering Committee

FGDC – Federal Geographic Data Committee

GIS – Geographic Information Systems

HRAP – National Weather Service Hydrologic Rainfall Analysis Project

ISC – New Mexico Interstate Stream Commission

LUTA – Land Use Trend Analysis

MRGCD – Middle Rio Grande Conservancy District

NEXRAD – NEXt Generation Weather RADar System. A network of approximately 160 radar systems throughout the United States and at several overseas locations, which provide precipitation information. The system was installed by the National Weather Service, in conjunction with other agencies.

NPDES – National Pollution Discharge Elimination System

OSE – New Mexico Office of the State Engineer

PDSI – Palmer Drought Severity Index

USBR – U. S. Bureau of Reclamation

USGS – U. S. Geological Survey

URGWOM – Upper Rio Grande Water Operations Model

1.0 INTRODUCTION

1.1 Study History and Objectives

The Middle Rio Grande Water Supply Study was conducted by S.S. Papadopulos & Associates, Inc. (SSPA) to develop a quantitative and *probabilistic* description of the *conjunctive-use* groundwater and surface water supply available to the Middle Rio Grande region, under the constraints of the *Rio Grande Compact*. This study was initiated under U.S. Army Corps of Engineers (COE) Contract DACW47-99-C-0012 in 1999 and was jointly funded by the COE and the New Mexico Interstate Stream Commission (ISC). This study has assembled and evaluated water supply information and describes conditions relevant to maintaining compliance with the Rio Grande Compact.

This study has been conducted through three phases:

> *Phase 1: Development of a Work Plan, reflecting input from the contracting agencies and an Executive Steering Committee (SSPA, September 1999).*
>
> *Phase 2: Implementation of the Phase 1 Work Plan, with a report presenting the quantitative, probabilistic assessment of water supply from Cochiti to Elephant Butte (SSPA, 2000).*
>
> *Phase 3: Further refinement of the water budget and water supply quantification; additional technical analyses; and, support to regional planning groups.*

Phase 2 of this study culminated in a report entitled *Middle Rio Grande Water Supply Study* (S.S. Papadopulos & Associates, Inc., August 2000). In addition to the report, key products of Phase 2 included:

- A summary of available data in the Middle Rio Grande Basin;
- A bibliography of water-resource reference material;
- A discussion of previous *water budget and depletion* studies;
- Quantification of the impacts on flow of the Rio Grande from groundwater pumping;
- Quantification of the natural variability of water sources for the Middle Rio Grande region;
- A *risk analysis* evaluation of the water supply, identifying the range of expected water supply conditions;
- Evaluation of the probability of achieving compliance under the Rio Grande Compact, given present water demands; and,

- Evaluation of the probability of achieving compliance under the Rio Grande Compact, given a hypothetical alternative demand scenario.

Following the completion of Phase 2 of this study, additional funding became available to continue the work into a third phase. A plan of work was developed for Phase 3, which included data updates, additional technical analyses and some technical support to regional planning entities within the project study area. The goals of this third phase include:

- Updating and refining hydrologic functions in the probabilistic model to reflect new information;
- Refining climate-based dependencies for key water budget terms, including the development of climate dependency functions that were beyond the scope of work for Phase 2 analysis;
- Extending hydrologic functions to represent drought conditions;
- Reviewing long-term climate trends, using proxy-based reconstructions (i.e. tree rings) and ENSO (El Nino – Southern Oscillation) based projections for future changes, to further characterize potential variability in water budget terms;
- Developing an approach for handling antecedent conditions in functional relationships;
- Providing technical assistance to the Middle Rio Grande and Socorro-Sierra regional water planning groups in assessing the hydrologic impacts of chosen water planning alternatives on regional water use and on Compact deliveries.

This report describes the activities conducted in Phase 3, describes the updated probabilistic water budget and describes the evaluation of regional water planning alternatives.

1.2 Study Area

The *study area* for this project extends along the Rio Grande, north to south, from Cochiti Reservoir to Elephant Butte Reservoir, a distance of approximately 175 miles (Figure 1.1). This area, often termed the Middle Rio Grande region, is of greater extent than the *Middle Rio Grande Planning Region* (MRGPR) that extends through a portion of the Study Area. Upstream and downstream river gages that are associated with the study area include the Rio Grande at Otowi Bridge gage, upstream of Cochiti Reservoir, and the Rio Grande below Elephant Butte gage, downstream of Elephant Butte Reservoir. Water use within this reach is subject to limits set forth under the Rio Grande Compact, based on flow at the two above-mentioned gages. The study area includes groundwater within the *Quaternary alluvium* and the *Santa Fe Group* aquifer system.

The Study Area for this project was originally selected to support analysis of supply and demand by multiple entities in the Rio Grande Basin in the context of the Rio Grande Compact. While the study was envisioned to provide information and support to the *planning regions* within this area, the Study Area was not identified by the contracting agencies as being fully coincident with planning regions. The study area includes part of the Sangre y Jemez Regional Planning Region (SJPR), all of the Middle Rio Grande Planning Region (MRGPR) and a large area within the Socorro-Sierra Planning Region (SSPR). The SSPR is not fully encompassed within the Study Area, as the SSPR also includes areas of Sierra County south of Elephant Butte Dam, for example, a portion of the Rincon Valley, and the SSPR includes some areas in of Socorro and Sierra counties that lie to the west of the Albuquerque and Socorro basins, for example, the La Jencia Basin.

1.3 Study Approach

The water supply to the Middle Rio Grande region includes:

- Surface water from the Rio Grande and Chama River originating in Colorado and Northern New Mexico (*native flow*);
- Surface water from the Colorado River system delivered through the San Juan-Chama Project (*San Juan-Chama Project* water, or *trans-mountain diversions*);
- Tributary surface water, flowing to the Rio Grande from *perennial* and *ephemeral tributaries* between the Otowi gage and Elephant Butte Dam; and,
- Groundwater of the Albuquerque Basin, the Socorro Basin and other *stream-connected aquifer*s in communication with the Rio Grande.

This regional water supply, with the provisions of the 1938 Rio Grande Compact, is characterized by **variability** and **limitation**.

Variability is exhibited in the historic record of inflow components to the Middle Rio Grande region, including the mainstem inflow at the Otowi gage and tributary inflows. Figure 1.2 illustrates this variability with a graph showing the magnitude of the mainstem inflow at the Otowi gage from 1940 to 2002. Characterized with a mean value of approximately 1.1 million acre-feet per year over this period of 63 years, the annual supply varies considerably, with values throughout the range of 0.5 to 1.5 million acre-feet per year not uncommon.

Limitation on the useable supply for the Middle Rio Grande region is derived from physical and institutional bases. Figure 1.3 illustrates the portion of the Otowi inflow historically available for use in the Middle Rio Grande region. This graph shows the allocation of the gaged flow at Otowi (including trans-mountain diversion water) into the quantity available for use in the Middle Rio Grande region, and the quantity required to be delivered for use below Elephant Butte Reservoir. The portion of the Otowi inflow available to the Middle Rio Grande region is augmented by tributary inflow and groundwater. While these sources offer significant potential to increase or manage the supply, neither fully removes the effect of limitations on supply imposed by physical conditions and institutional constraints.

Quantification of variability in water supply components and recognition of Compact-based limitations are fundamental for the quantification of the water supply. Therefore, this study focuses on characterizing the variability in inflow supply components and in depletion components. This variability is tracked through the water budget for the study region to quantify the range of likely water supply conditions. The quantified water supply is the amount of water potentially available for use, or depletion, within the study area. This concept reflects both hydrologic limitations and legal limitations of the Rio Grande Compact.

The Middle Rio Grande water supply is quantified in this study using the historical variability of climate-dependent inflow components. To relate this supply to reach-specific demands, the available supply is compared to depletions under present river conditions, and under proposed regional water planning alternatives. The identification of depletions draws from past and in-progress water budget and depletion studies by other investigators. The probabilistic quantification of the water supply employs risk analysis tools. Using risk analysis tools, variability and correlations within the river system are used to determine the range of water supply conditions, including droughts and high supply years.

1.4 Executive Steering Committee Role

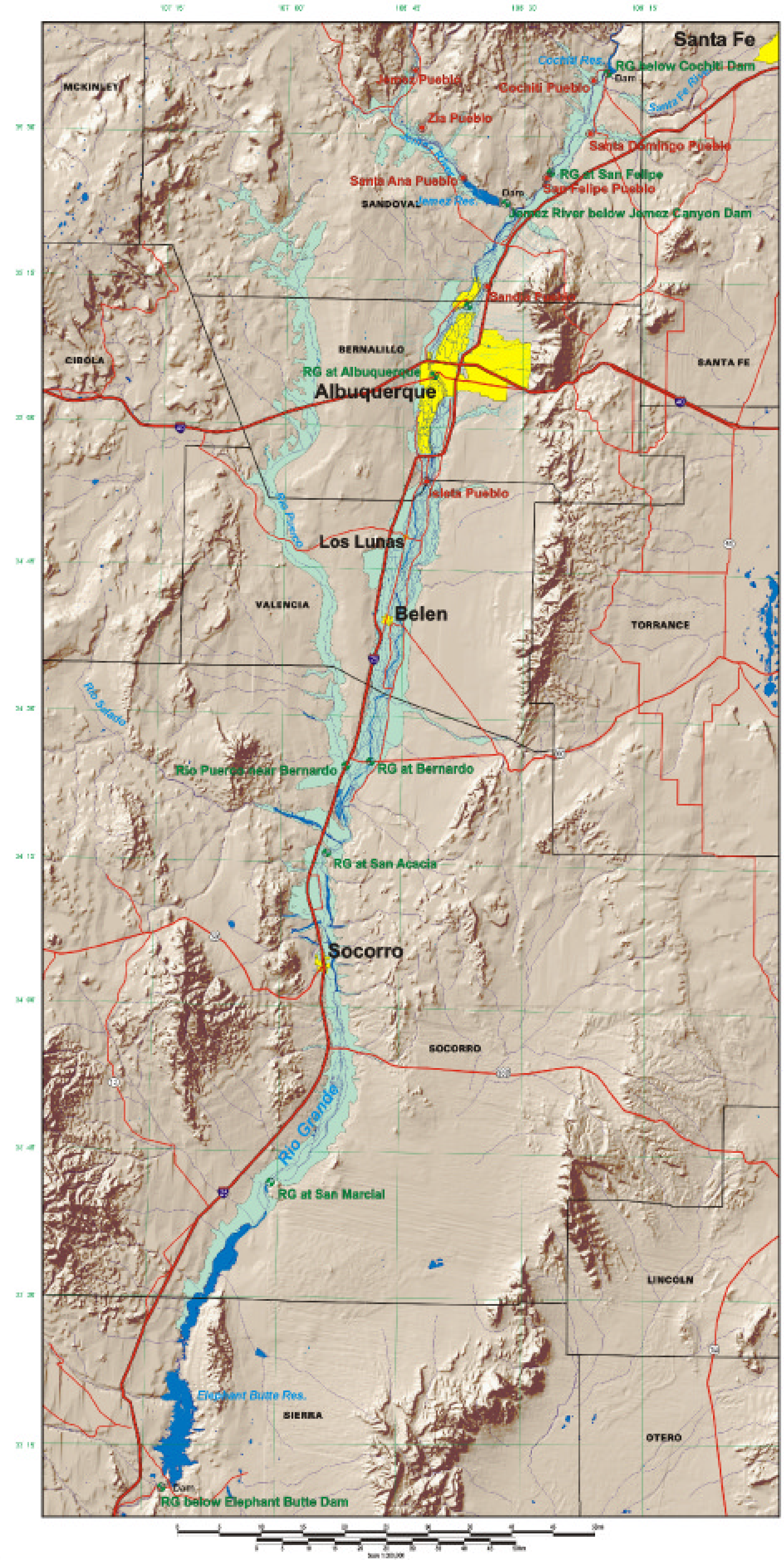
An Executive Steering Committee (ESC) was commissioned to provide technical advice and guidance regarding preparation of the Middle Rio Grande Water Supply. A Charter, signed by the New Mexico Interstate Stream Engineer and the District Engineer for the Albuquerque District, U.S. Army Corps of Engineers, sets forth the background, purpose, duties, chain of command, meetings and schedule and membership of the ESC. Accordingly, the ESC convened periodically with the study team. Phase 3 meetings included a kick-off informational meeting and Work Plan presentation in September 2001, progress meetings in September 2002 and October 2003, and a public meeting in the spring of 2004. The ESC included technical representatives from a diverse group of stakeholders and agencies within the Middle Rio Grande region. Agencies and groups invited to participate on the ESC are listed in Table 1.1. Several of the Committee members were provided insights throughout the study, and their assistance is gratefully acknowledged.

1.5 Report Organization

The main body of this report describes the procedures, results and work products of the study. Section 1 provides an introduction to the study and the report. Section 2 provides background information on topics of key importance to the study. Section 3 describes the available data and resources. Section 4 describes the conjunctive-use water supply to the Middle Rio Grande region in probabilistic terms. Section 5 describes regional planning support work done as part of the study. Section 6 describes implications of the study for future work and planning in the Middle Rio Grande region. The report also includes a glossary and a list of acronyms.

To maintain readability of the report, detailed technical material and supporting data are organized within several appendices. These appendices include the metadata database, summaries of key data sets, groundwater modeling details, statistical and risk analyses, and additional work products produced as part of the regional planning support work.

The project report is available for download from the project website, **http://www.ose.state.nm.us/water-info/mrgwss/index.html**. The project website also contains other project related material, including an illustrated summary of water budget data, metadata, bibliographic material and the project basemap.



Middle Rio Grande Water Supply Study

Figure 1.1
Map of Study Area: Cochiti Reservoir to Elephant Butte Reservoir

LEGEND

—	State Highway
—	U.S. Highway
—	Interstate
—	County Line
—	Perennial Stream/River
—	Intermittent Stream/River
—	Latitude/Longitude
🟨	City
🟦	Lake/Reservoir
🟩	Valley Alluvium
●	**Pueblo**
●	**Gage Station**

The purpose of the Middle Rio Grande Water Supply Study is to prepare a quantitative description of the conjunctive-use ground and surface water supply available to the Middle Rio Grande from Cochiti Reservoir to Elephant Butte Reservoir. This will be conducted under the constraints of the Rio Grande Compact and upstream Rio Grande basin water use with New Mexico. The Middle Rio Grande Water Supply Study will identify, assemble, and evaluate existing pertinent water supply and water budget data sets and present them in a form that can be used by regional water planning entities in the Middle Rio Grande. The product of the study will be used by others to develop and evaluate alternatives that reconcile projections of water demand with available water supply by the Interstate stream Commission in developing strategies to meet new Mexico's delivery obligations to Elephant Butte Reservoir uncer the Rio Grande Compact.

Sources: Base data compiled from USGS 1:100000k DLG and DEM files. Land use data provide by the Earth Data Analysis Center and was derived from the 1992 Land Use Trend Analysis study performed by the Bureau of Reclamation. Note:Land use coverages not available south (approx.) of 33 33'

S.S. PAPADOPULOS & ASSOCIATES, INC.
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Figure 1.2 Variability: Flow of Rio Grande at Otowi Bridge, 1940 to 2002

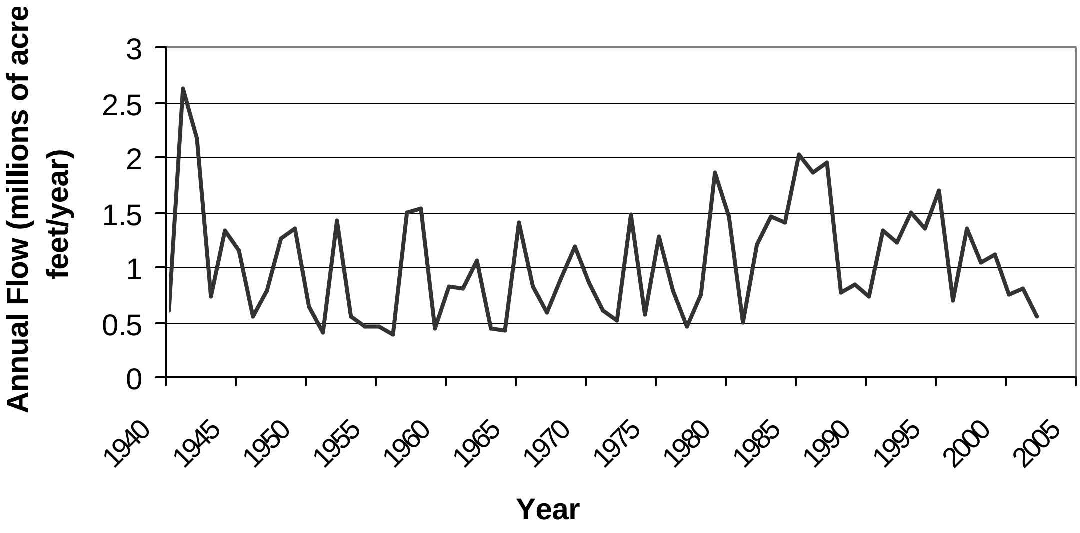

Figure 1.3 Limitation: Base Supply to the Middle Rio Grande Region (Rio Grande at Otowi Bridge minus Elephant Butte Scheduled Delivery)

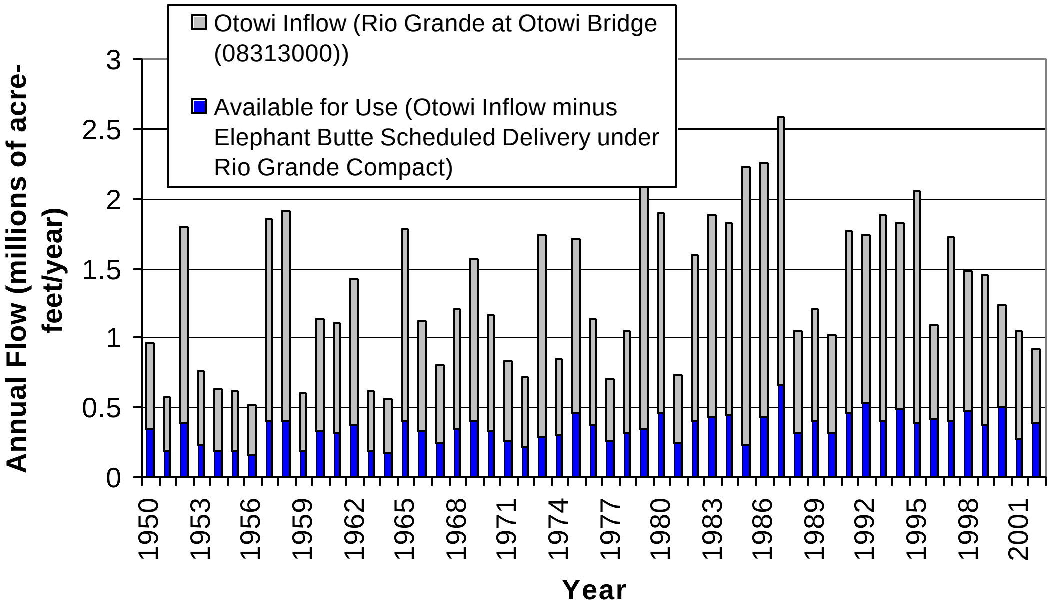

Table 1.1

Executive Steering Committee

The following entities were invited to participate on the Executive Steering Committee:

Alliance for the Rio Grande Heritage
Army Corps of Engineers
Bureau of Indian Affairs
Bureau of Reclamation
City of Albuquerque
JMC Farms
Middle Rio Grande Conservancy District
Middle Rio Grande Council of Governments
New Mexico Environment Department
New Mexico Interstate Stream Commission
New Mexico Office of the State Engineer
Pueblo of Cochiti
Pueblo of Isleta
Pueblo of Jemez
Pueblo of San Felipe
Pueblo of Santa Ana
Pueblo of Santo Domingo
Pueblo of Sandia
Pueblo of Zia
Rio Grande Restoration
Socorro-Sierra Planning Region
University of New Mexico, Department of Civil Engineering
U.S. Fish and Wildlife Service
U.S. Geological Survey
Mike Kernodle, Hydrogeologist
Frank Titus, Hydrogeologist

2.0 BACKGROUND

Background information is provided in this section on six topics important to this study. The first of these topics, regional water planning, describes the basic goals of the New Mexico's water planning process and the role SSPA played in assessing selected planning alternatives developed by the MRGPR and the SSPR. The second topic, the Rio Grande Compact, describes the interstate agreement underlying the delivery obligations downstream of the Study Area. The third, forth and fifth topics, groundwater-stream interaction, water budgets, and concepts of probability and risk analysis, describe technical concepts and analyses that are fundamental to the study approach. The sixth topic, climate variability in the period of record, outlines how the climate since 1950 relates to the climate of the past 1,000 years, as recorded in tree-rings, in particular focusing on whether recent climate is representative of past climates.

The background discussion in this section is provided as a primer, for readers less familiar with these concepts. In addition, the reader will find additional background resources in the annotated bibliography and list of web resources prepared for this study, available on the project website at **http://www.ose.state.nm.us/water-info/mrgwss/index.html**.

2.1 Regional Water Planning

In 1987, New Mexico's legislature enacted legislation to support regional water planning, *"Authorizing the Interstate Stream Commission to fund Regional Water Planning Efforts."* Regional water planning is being implemented to protect the water resources of the State with the goal of allowing stakeholders within a region to help determine the direction of water use within the region and between regions of the state. Planning regions are self-defined based on hydrological and political common interests.

The New Mexico legislature recognized and directed that water planning is most effectively done at the local level. However, since the state may decide to use the regional water plans as a basis for a state water plan, which can in turn influence litigation, water development, and legislation, consistency among plans was desired. The New Mexico Interstate Stream Commission published the *Regional Water Planning Handbook* (Handbook) in 1994 to guide the regional planning process (New Mexico

Interstate Stream Commission, 1994). The Handbook sets forth several required planning assumptions to be followed unless exceptions are adequately justified:

1. Public participation must be the significant factor in development of regional plans.
2. Plans are to be based upon existing water and related law, while suggestions for change may be noted.
3. All present and future water demands must be met with currently existing supplies of the region, unless exceptions are supported by analysis in the planning report.
4. Water conservation should be the first item considered among feasible water supply alternatives.
5. Population projects shall be based on Bureau of Business and Economic Research model, with any deviations from that model justified.

As part of Phase 3 of the Middle Rio Grande Water Supply Study, SSPA was tasked with providing specific technical assistance to the MRGPR and the SSPR. This assistance was to help the groups "develop the requisite understanding of the hydrology and water resources of their respective region necessary for the independent development of various water supply alternatives, and to evaluate the alternatives to ensure that they comply with the Compact" (MRGWSS Phase 3 Scope of Work). The SSPA Scope of Work excludes involvement in developing alternatives, as this is the function of the planning regions. Similarly, integration of technical evaluations into regional plans is the responsibility of the planning regions, as regional planning involves more factors than technical analysis. SSPA's role was limited to providing background information regarding supply, providing an assessment of the hydrologic impacts of the proposed alternatives, and evaluating each region's chosen water planning alternatives using the analysis tools described in this report. Results of this work are presented in Chapter 5.

2.2 Rio Grande Compact

Recognizing the need to formalize allocation of the Rio Grande among Colorado, New Mexico and Texas, in 1923, the U.S. Congress consented to negotiation of the Rio Grande Compact. The 1938 Rio Grande Compact was ratified by all three states and passed by the 76th Congress as Public Act No. 96 in 1939. The opening paragraph of the Compact summarizes its purpose and intentions:

> The State of Colorado, the State of New Mexico, and the State of Texas, desiring to remove all causes of present and future controversy among these States and between citizens of one of these States and citizens of another State with respect

> to the use of the waters of the Rio Grande above Fort Quitman, Texas, and being moved by considerations of interstate comity, and for the purpose of effecting an equitable apportionment of such waters, have resolved to conclude a Compact for the attainment of these purposes…. (McClure, T.M., M.C. Hinderlider, F.B. Clayton, and S.O. Harper, 1939. Rio Grande Compact.)

Among the Compact articles are specific delivery schedules, based on gaged stream flows and adjustments for storage of water in reservoirs. The delivery obligation of New Mexico is identified in Article IV. In this article, New Mexico's delivery obligation was scheduled based on flow conditions at Otowi, exclusive of the months of July, August and September. The original scheduled point of delivery was San Marcial, New Mexico, located upstream of the Elephant Butte Reservoir. (It should be noted that the Compact delivery point does not occur at the New Mexico – Texas stateline. Deliveries to "Texas" also serve New Mexico and Mexico users in the Lower Rio Grande basin of New Mexico).

The Compact schedule for New Mexico's delivery obligation was modified by a resolution in 1948 to incorporate the entire year and to change the location of the downstream index station. A revised delivery schedule was adopted, specifying the delivery obligation at Elephant Butte, based on conditions at Otowi. The delivery obligation at Elephant Butte is termed the *Elephant Butte Scheduled Delivery* (also sometimes termed *Elephant Butte Effective Index Supply*). The obligation is based on the annual value of the *Otowi Index Supply* (also sometimes termed *native inflow*). The Otowi Index Supply is defined as, "the recorded flow of the Rio Grande at the U.S.G.S. gaging station at Otowi Bridge… corrected for the operation of reservoirs constructed after 1929 in the drainage basin of the Rio Grande between Lobatos and Otowi Bridge." The resolution also indicates that the schedule is subject to adjustments for future changes in location of gaging stations, post-1929 depletions of the run-off above Otowi Bridge, and trans-mountain diversions. The difference between the Otowi Index Supply and the Elephant Butte Scheduled Delivery, plus surface or groundwater inflow between Otowi and Elephant Butte and San Juan-Chama transmountain diversion water, is the amount of surface water available for depletion in the Middle Rio Grande region. The relationship between Otowi Index Supply and Elephant Butte Scheduled Delivery is shown graphically on Figure 2.1. The percentage of the Otowi Index Supply that must be delivered at Elephant Butte increases with increasing water supply, ranging from 57% for a very low supply to over 86% for a very high supply year. The difference in Otowi Index Supply and Elephant Butte Scheduled Delivery reaches a maximum value of 405,000 acre-feet per year when the Otowi Index Supply exceeds 1.5 million acre-feet per year. In practical terms, the allocation of Otowi inflow to the Middle Rio Grande region is about 400,000 acre-feet in years with average or above-average supply, and less in years of below-average supply.

Other terms defined by the Rio Grande Compact include: the *Actual Elephant Butte Effective Supply*, which is the recorded flow of the Rio Grande at the gaging station below Elephant Butte Dam, adjusted for net changes in reservoir storage in the Elephant Butte Reservoir during the year; and the *Credit/Debit Balance*, which is the end of the year balance of *credits and debits* accrued under the Rio Grande Compact.

The Compact sets forth specific rules regarding the accumulation of credits and debits. No annual credits or debits are computed for years when a spill occurs from Elephant Butte Reservoir. Accrued credits spill first. Accrued debits are set to zero when water in excess of the accrued credits is spilled from storage.

Compliance with the Rio Grande Compact is mandated by law. Thus, the Compact has a definitive role in quantification of the regional water supply.

2.3 Concepts of Aquifer-Stream Interaction

In the Rio Grande Basin, groundwater is present at varying depths beneath the ground surface. The availability and suitability of groundwater in various locations depends on a number of factors, including the depth to groundwater, the quality of the groundwater, and the ease with which the aquifer yields groundwater to wells. These factors vary according to geologic conditions, land use, and intensity of groundwater withdrawals in an area. While the availability and suitability of groundwater is variable, all of the groundwater in the Quaternary alluvium and Santa Fe Formation (virtually all of the groundwater presently available to the Middle Rio Grande region) is considered to be *stream-connected*.

Conceptually, a stream-connected aquifer can be illustrated with a simple model of a bathtub filled with layers of gravel, sand, silt and clay, with a stream running across the surface from one end to the other. Consider the effect of removing water through a straw (a well) from the wetted gravel-sand-silt-clay (the aquifer) in the bathtub. The water level within the sands (and other sediments) of the tub, close to the straw, will be slightly lowered, and flow will be induced from the stream towards the straw. Likewise, the flow in the stream will be reduced and less water will flow out from the stream at the end of the tub. Similarly, in a stream-connected aquifer, pumping from wells in the aquifer will affect the flow of streams. Depending on the distance from the well to the stream, the geologic materials, and other factors, the effects of pumping on the stream may be immediate or may be delayed. For example, pumping effects from a distant or deeper well will be tend to be delayed, compared with pumping effects from a well closer to the river. Similarly, a well completed in sands and gravels will develop communication with the river more rapidly than wells completed in or beneath less permeable sediments, such as silt or clay. Regardless of the timing of impacts, eventually, the effects of pumping a stream-connected aquifer will be transmitted to the stream or river.

The impact on the river from pumping a stream-connected well increases with time until it reaches *steady-state conditions* and stabilizes. The steady-state reduction in stream flow may be less than 100% of the pumping rate if other sources or uses of water are intercepted. For example, pumping may result in decreased availability of shallow groundwater to plants, and a portion of the source may be attributed to *salvaged evapotranspiration*.

Before steady-state conditions are achieved, groundwater is partially obtained from storage. In other words, the amount of groundwater stored within pore spaces around the sand, gravel, or other aquifer materials, is reduced. As a result of the removal of groundwater from storage, the groundwater level is lowered, resulting in a *cone of depression* around the well or well field. While many consider the portion of pumped groundwater that is derived from storage to represent a source of water supply, separate from the stream supply, this characterization does not hold in a stream-connected aquifer unless pumping continues indefinitely. Once pumping ceases, the stream flow will continue to be impacted until the storage space is refilled. Thus, the original water obtained from storage is “borrowed”, to be repaid after pumping ceases.

The aquifers of the Middle Rio Grande region are stream connected. However, in the Albuquerque area, groundwater elevations have declined due to pumping and are presently below the elevation of the stream. Locally, the river and aquifer have become disconnected. This local disconnection results in additional delay in the time for pumping effects to be felt by the river. While local disconnection is an additional factor affecting the timing of pumping impacts on a stream, the characterization of aquifers in the Middle Rio Grande region as stream-connected remains functionally correct.

Because aquifers in the Middle Rio Grande region are stream-connected, the pumping of groundwater affects the Compact-limited water supply available to the region. In the long term, the groundwater resource functions as a regulating reservoir to the region, rather than as a separate source of water.

2.4 Water Budgets

The water budget describes the fundamental state of affairs for a hydrologic system. The water budget can be likened to a financial statement – quantification of inflows, outflows and changes in storage are analogous to income, expenses and changes in savings or mortgage balances. Quantification of the water budget is one of the primary activities conducted by hydrologists, resulting in a framework for evaluating water supplies and water use. Due to the value and limits of the water resource in the Middle Rio Grande region, the water budget has been studied and described by many investigators. Many of these studies have shed light on hydrologic processes, and have formed the basis for subsequent water resource policy.

The results of water budget studies from different investigations sometimes appear inconsistent. However, in many cases, water budgets address differently defined systems, different time periods, or have specific applications; hence, they are not amenable to direct comparisons with other water budgets. Regardless, the simplicity of the water budget invites comparison, and misunderstanding is not uncommon. In Phase 2 of this study, a review of several of the water budget evaluations found in the literature relating to the Middle Rio Grande region was undertaken. The water budgets were compared with respect to the study objective, spatial and time domains, physical domain and study approach. Profiles of each water budget study were provided in Appendix E of the Phase 2 report (SSPA, 2000) and provide a useful reference on this topic.

Through quantification of regional water inflows and demands, the regional water budget provides a foundation for regional water planning. This study presents a basin-wide water budget for the Middle Rio Grande region, delineated as described in Section 1.2. Elements of this basin-wide water budget can be applied by regional planners to their planning region, with some adjustments for non-coincident boundaries.

Water budgets are analytical tools that utilize estimates for many water budget terms. For this study, SSPA was directed to use best-available data in deriving a water budget. Original scientific study to quantify water budget terms was not within the scope of this study. Because available scientific data regarding water budget terms is evolving with time, the water budget likewise evolves. The water budget developed in Phase 2 (SSPA, 2000) has been supplanted with an updated water budget as described in this report, or, the Phase 3 water budget. Several important water budget terms have been revised based on updated data and evaluations provided by the U.S. Bureau of Reclamation (USBR), the U.S. Geological Survey (USGS) and the New Mexico Office of the State Engineer (NMOSE) and the NMISC in the three years since work in the earlier phase was conducted. Significant uncertainty remains in the estimation of several large water budget elements. As scientific studies continue to refine the quantification of terms such as crop and riparian consumptive use and ungaged tributary inflows, the water budget will be subject to further refinement.

2.5 Concepts of Probability and Risk Analysis

Hydrology, the science of the occurrence and distribution of water in time and space, involves the description of water inflows to, outflows from, and changes in storage within defined hydrologic systems. These hydrologic processes can be described using laws of physics, although fluctuations in some of these processes are best described using laws of chance. If causative factors for a hydrologic process are well understood and amenable to characterization, then that hydrologic process can be described *deterministically.* On the other hand, if causative factors are not known, are too great in number, or are too difficult to characterize, a *stochastic,* or *probabilistic,* description can be useful in characterizing the process. Many hydrologic processes exhibit probabilistic behavior.

The native inflow at Otowi is an example of a hydrologic input that can be described probabilistically. Although influenced by climate (i.e., snowpack, precipitation, temperature, etc.), the causative factors leading to a high- or low-flow year are themselves difficult to predict. The science of probability offers tools for describing processes seemingly governed by laws of chance. Probabilistic approaches are used in this study to better characterize hydrologic processes influenced by climatic-induced variability.

The probabilistic tools used in this study include *descriptive statistics, probability distribution fitting, correlation analysis* and *risk analysis*. These are very briefly described below. The application of these methods in this study are described more fully in Sections 4 and 5 and in their associated appendices.

Descriptive statistics involve describing the nature of, and variability in, a population or set of events. These statistics address questions such as, what is the average, maximum, or minimum payout of a slot machine, and how often does it pay.

Probability distribution fitting involves finding a curve or mathematical formula to describe the likelihood of experiencing a particular set of outcomes. For example, casinos set slot machines to operate according to a probability distribution that will achieve the desired result: a few big wins are needed to attract customers; a larger number of small wins are needed to satisfy players; but, on average, the casino must make a profit to stay in business. A probability distribution, as seen in Figure 2.2, can be graphed as a histogram (bar graph showing how often the outcome will fall into a specific range) or a function (a curve related to the probability of various outcomes).

Correlation analysis involves quantifying the similarity between different processes, allowing us to numerically answer questions such as "If the Otowi native flow is high in a particular year, how likely is it that the flow of the Jemez River will be high?" The numerical correlation between two data sets, such as the Otowi Index Supply and the Jemez River flow for 1950-2002, is generally referred to as an "r-value", and expressed as r=0.86. This implies that 86% of the variability in the Jemez River flow 1950-2002 time-series graph is also seen in the Otowi Index Supply graph for the same period.

Risk analysis, sometimes called uncertainty analysis, is a method for considering the combined effects of multiple probabilistic, or uncertain, processes. Risk analysis is the first step towards managing risk. From a protective point of view, it seeks to answer the question, what is the probability of a disastrous combination of events occurring? Risk analysis is a common tool in many industries, including finance, insurance and health care. Applied to water supply evaluation, risk analysis involves combining the probability distributions of each hydrologic process to find a probability distribution describing the overall water supply. Taking the analysis a step further, and combining the supply with assumed depletions, this process can be used to develop a probability distribution of achieving Compact credit or debit under certain conditions.

2.6 Climate Variability in the Period of Record

The water budget analysis presented in this report is based on the 1950-2002 period. This period was chosen because it is representative of present-day development conditions and is relatively well documented in terms of stream flow data, crop and riparian acreage values, reservoir storage and evaporation data. However, this leaves the questions, "Is this period representative of long-term average conditions, does it contain extremes we should know about, either droughts or wet periods, and do we believe it will be indicative of future conditions?" Two tools are applied to address these questions: tree ring records and climate forcing.

2.6.1. Tree ring reconstructions of past climate

Though measured stream flows in the Middle Rio Grande valley extend back no further than the late 1800s, tree-ring records can be used as a proxy for hydrologic and/or climatic conditions over the past 2000 years, allowing us to view the 1950-2002 period of record within the context of the historic regional climate. Two recent tree-ring climate reconstructions are available for the Middle valley, the El Malpais precipitation reconstruction (Grissino-Mayer, 1996), and the Middle Rio Grande Basin Palmer Drought Severity Index (MRG PDSI) reconstruction (Grissino-Mayer et al, 2002). The El Malpais precipitation reconstruction is based on Douglas fir and ponderosa pine found in the El Malpais National Monument near Grants, New Mexico (Figure 2.3), and covers 2,129 years from 136 B.C. to 1992 A.D. The MRG PDSI reconstruction is based on 3 tree-ring records: the El Malpais record, a record from the Magdalena Mountains west of Socorro, and a record from the Sandia Mountains east of Albuquerque. Conjunctively using records from all three sites, Grissino-Mayer et al. (2002) reconstructed the PDSI for New Mexico climate division 5, the Middle Rio Grande basin, for a period of 1,371 years from 622-1992 A.D. For both of these tree ring reconstructions, the author(s) has provided extensive analysis and ranking of drought and wet periods.

The analysis presented with the El Malpais reconstruction, though focused primarily on long-term (>100 year) trends, touches on decadal events. Grissino-Mayer (1996) notes "A long-term, above normal rainfall pattern began ca. AD 1791 and has lasted into the current century…. The reconstruction shows that two short-term drought periods occurred during AD 1890-1904 and AD 1945-1958. In general, however, rainfall during the last 200 years has been above normal, and has been steadily increasing since the early 1700s." This can easily be seen in Grissino-Mayer's (1996) Figures 4A and 4B, reproduced for this report as Figure 2.4A and 2.4B. Figure 2.4A shows the reconstructed annual rainfall in standard deviation units (above 1 indicates annual precipitation above the 84th percentile; below –1 indicates annual precipitation below the 16th percentile) smoothed with a 10-year spline that emphasizes decadal-scale climatic events. The 1950s drought can be easily seen as an extended period of values at or below –1 standard deviation units. Grissino-Mayer et al. (1997) rank the 1950s drought as the 19th most severe drought for the El Malpais in the 2,129-year record. Figure 2.4B shows the same data, smoothed with a 100-year spline that emphasizes century-scale events. Here, it is clear that climate since the 1800s has been extremely wet. However, even on a century-scale, the 1950s drought is clearly evident.

The analysis of the PDSI reconstruction for the Middle Rio Grande Basin focuses on events of 5 or more years. In their analysis, Grissino-Mayer et al. (2002) state "The reconstruction revealed over 60 multi-year periods (each >5 years in length) of either severe drought or extreme wetness. Notable among these were the five driest periods between 1571-1593, 1272-1297, ***1945-1963***, 701-712, and 1131-1151. The five wettest periods occurred between 1553-1557, 1627-1653, ***1978-1992***, 724-733, and 1377-1396." The extremity of both the 1950s drought and the extreme wet period post 1978 can be seen in Figure 2.5, which shows the MRG reconstructed PDSI, smoothed with a 10-year running average.

Data from the 1950-2002 period can be easily used to represent a wide range of climatic conditions. Both of the climate reconstructions show that the 1950s drought was a severe drought within the context of the past 1400-2100 years. They also show that MRG climate since the late 1970s has been wetter than anything previously on record. Fortunately, the 1950-2002 period also well-represents long-term average conditions. Table 2.1 shows the 1950-1992 and 622-1992 averages for both the El Malpais precipitation and the MRG PDSI reconstructions. The 622-1992 and 1950-1992 average PDSI are both equal to or nearly zero. The 622-1992 average annual precipitation is 14.59 inches; the 1950-1992 average annual precipitation is 15.49 inches. Clearly, for both reconstructions, particularly the PDSI, the 1950-1992 average is equal to the long-term average. The 1950-1992 and 1950-2002 periods also appear similar climatically. The Otowi Index Supply for 1950-1992 averaged 933,191 acre-feet per year; the Otowi Index Supply for 1950-2002 averaged 931,945 acre-feet per year.

In summary, the 1950-2002 period includes both a severe drought and an extreme wet period, and when averaged over the 52 years, represents long-term average conditions well.

2.6.2. Climate forcing and the Pacific Decadal Oscillation

Climate forcing can be used to look for climate cyclicity, which may provide an indication of upcoming conditions, though it does not constitute a climate prediction. It is generally accepted that New Mexican climate and precipitation are strongly influenced by El Niño/Southern Oscillation (ENSO) effects. Precipitation is frequently significantly above normal during El Niño years, and La Niña years are strongly correlated with drought.

New Mexican climate and precipitation are similarly influenced by Pacific Decadal Oscillation (PDO) effects. The Pacific Decadal Oscillation is a long-lived El Niño-like pattern of Pacific climate variability. The two climate oscillations, PDO and ENSO, have similar spatial climate fingerprints, but they have very different behavior in time. 20th century PDO "events" persisted for 20-to-30 years, while typical ENSO events persisted for 6 to 18 months.

The Pacific Decadal Oscillation is derived from monthly sea surface temperature anomalies in the North Pacific Ocean, poleward of 20 degrees latitude. Just as ENSO climatic variations occur as a result of anomalously warm and cool pools of water in the equatorial Pacific Ocean, PDO climatic variations occur on a decadal time scale as a result of anomalously warm or cool sea surface temperatures in the North Pacific Ocean, and over a larger spatial scale than ENSO. The North American climate anomalies associated with PDO are broadly similar to those connected with El Niño and La Niña, though generally not as extreme. Positive (warm, with warm water off the west coast of the Americas) phases of PDO are correlated with El Niño-like North American temperature and precipitation anomalies, while negative (cold, with cool water off the west coast of the Americas) phases of PDO are correlated with La Niña-like climate patterns (Mantua, 2000). As with ENSO, there is a strong correlation between the Pacific Decadal Oscillation and precipitation in New Mexico, with increased precipitation during the warm phase and decreased precipitation during the cold phase. During the last cold phase of the cycle (1947-1976) dry years outnumbered wet years[1] nearly four to one (55 to 15 percent of the years). During the warm phase of the cycle (1977-1997) wet years outnumbered dry ones three to one (43 to 14 percent) (Liles, web site).

The correlation between severe regional droughts in New Mexico and the cool phase of the PDO is strong. Figure 2.6 shows the reconstructed Pacific Decadal Oscillation index from 1650-1991 (Biondi et al., 2001), and severe regional droughts in the Middle Rio Grande region of New Mexico (Scurlock and Johnson, 2001). As can be seen, all 6 of the extended droughts that have occurred since 1650 have coincided with cool (negative) phases of the PDO. In particular, droughts have occurred during 4 of the 6 most negative (cool) excursions of the PDO.

Cool PDO regimes prevailed from 1890-1924 and again from 1947-1976, while warm PDO regimes dominated from 1925-1946 and from 1977 through the late-1990s. These periods correspond to the two periods of extended drought and two periods of above average moisture experienced by New Mexico in the past 100 years. Average

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[1] For both, “wet” and “dry” indicate years with precipitation 10% above or below the average precipitation measured from 1944 to 1997.

Otowi Index Supply for the latter three of these periods, shown in Table 2.1, illustrates the relationship between PDO phase and flow of the Rio Grande.

There is scientific evidence that the PDO shifted around 1998-1999 and we have entered the cool phase. If true, then New Mexico could be at the start of a 20-year extended period of drought, possibly similar to the 1950s drought.

2.6.3. Implications for the Middle Rio Grande Basin

Based on review of past climate, as captured in tree ring records, and of the climate forcing impact of the Pacific Decadal Oscillation in the Middle Rio Grande Basin, we can conclude the following:

- The 1950s drought, from 1945-1963, was the 3rd most severe drought of the past 1,371 years, equaled in its magnitude and duration only by the droughts between 1272-1296 and 1571-1593. (Based on the El Malpais precipitation reconstruction, the 1950s drought was the 19th ranked drought, in severity and duration, during the past 2,129 years);
- The 1978-1992 period is the third wettest multi-year period in the 1,371 year reconstruction (for the El Malpais precipitation reconstruction, the 1978-1992 period is ranked the wettest period of the last 2,129 years);
- Based on 20th century correlations between the PDO and MRG Basin drought and wet events, the apparent switch in the PDO in 1998 to it's cool phase would suggest extended drought conditions are returning to New Mexico.

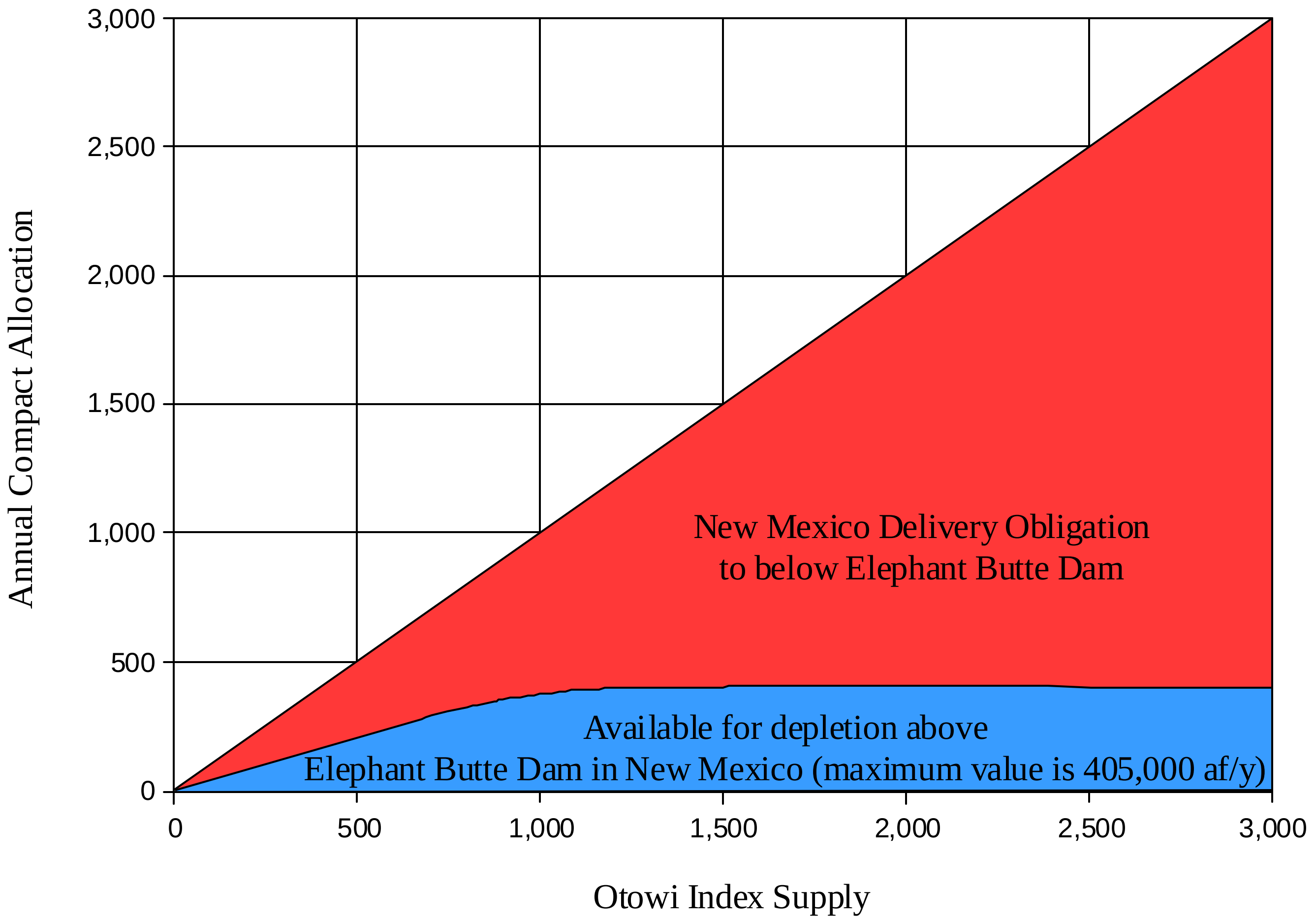
These conclusions imply that:

- The 1950s drought is an excellent period to work with for drought planning for the Middle Rio Grande Basin.
- In choosing a period of record to work with in preparing water budgets for the region, the 1950-2002 period is preferable to a shorter period during the same time span. Though on an annual basis, the 1950-2002 period includes an abundance of wet and dry years, and relatively few "average" years, when averaged over the 53 years of record, this period fairly well represents "average" conditions.
- Use of a shorter period of record for planning analyses, particularly the more recent 25-year period, should be done only with the recognition that this period has been significantly wetter-than-average. Without some adjustment for this bias in the record, water supply projections developed from the past quarter century will likely overestimate the long-term water supply.

Figure 2.1

Rio Grande Compact Allocation

(quantities in thousands of acre-feet)



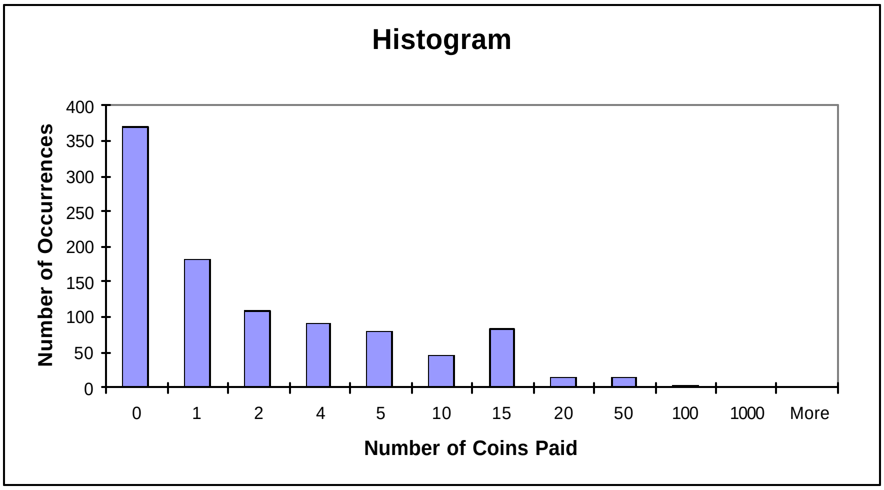
Tabulated values from Resolution Adopted by Rio Grande Compact Commission, 1948

(Quantities in thousands of acre-feet)

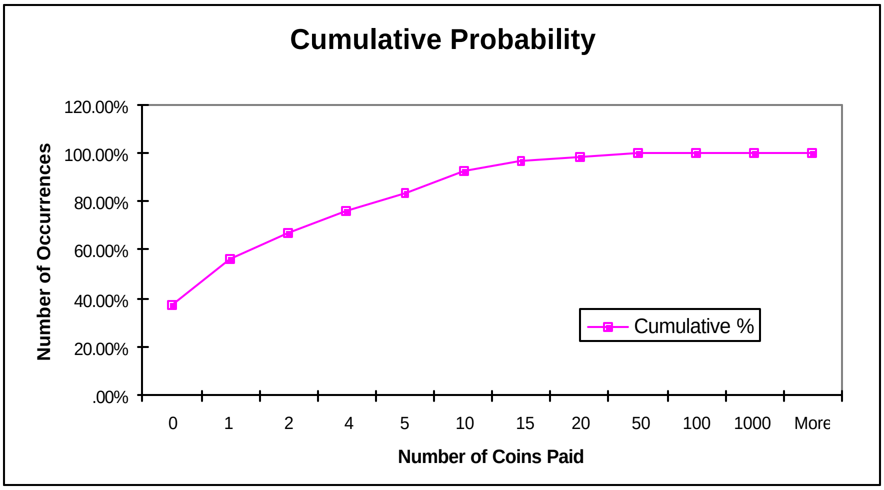
Otowi Index Supply	Elephant Butte Scheduled Delivery	Otowi Index Supply	Elephant Butte Scheduled Delivery
100	57	1,600	1,195
200	114	1,700	1,295
300	171	1,800	1,395
400	228	1,900	1,495
500	286	2,000	1,595
600	345	2,100	1,695
700	406	2,200	1,795
800	471	2,300	1,895
900	542	2,400	1,995
1,000	621	2,500	2,095
1,100	707	2,600	2,195
1,200	800	2,700	2,295
1,300	897	2,800	2,395
1,400	996	2,900	2,495
1,500	1,095	3,000	2,595

Figure 2.2

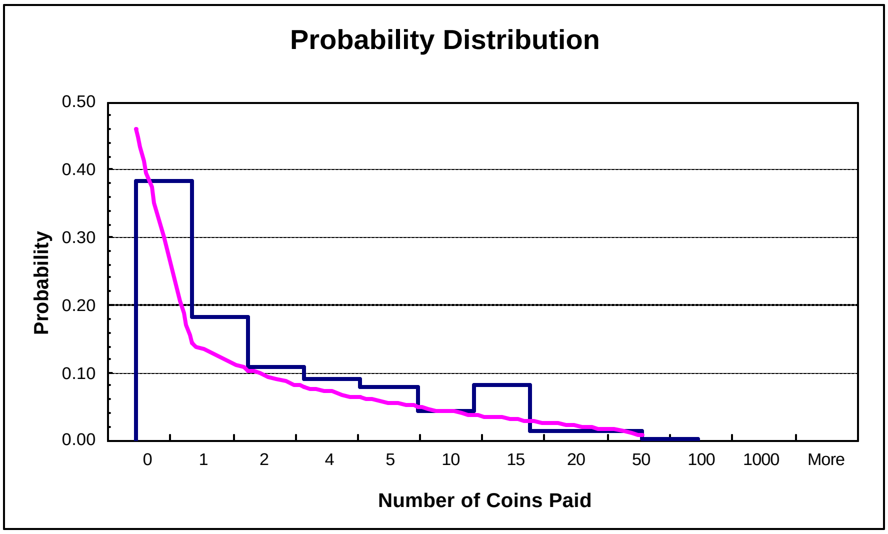
Probability Distribution Example



A histogram, is a type of bar graph which shows how often the outcome will fall into a specific range. (Here, how often a certain number of coins will be paid.)



A curve, or function, can be used to show the likelihood of experiencing a particular outcome. (Here, the likelihood of a certain payout.)



The probability distribution graph includes a histogram and a function of the predicted probable outcomes.

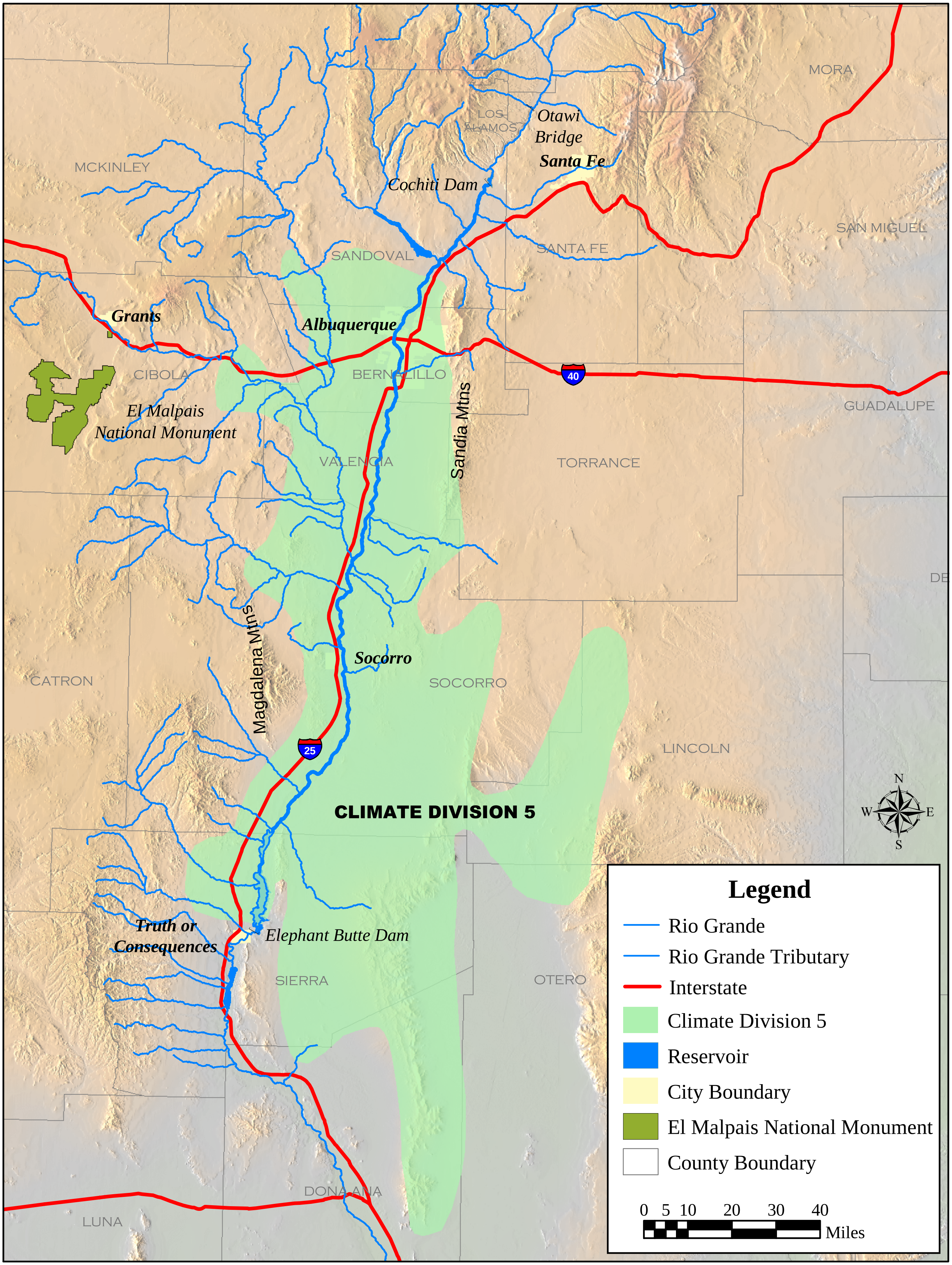


Figure 2.3. New Mexico Climate Division 5 and tree sampling sites

Figure 2.4
El Malpais precipitation reconstruction, in standard deviation units
A) Smoothed with a 10-year spline.
B) Smoothed with a 100-year spline.

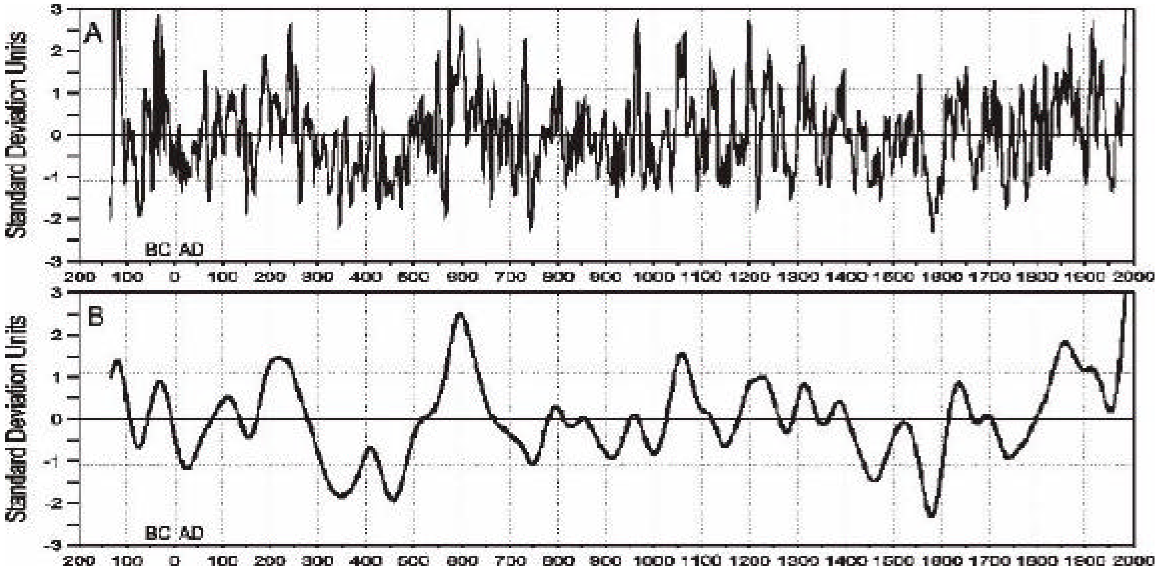
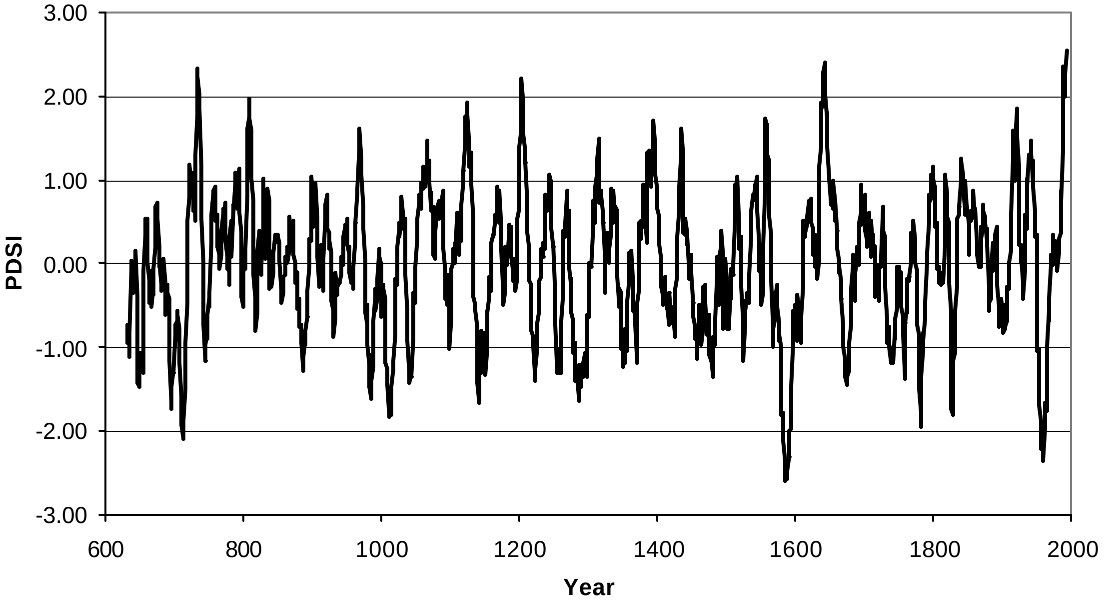


Figure from Grissino-Mayer, 1996

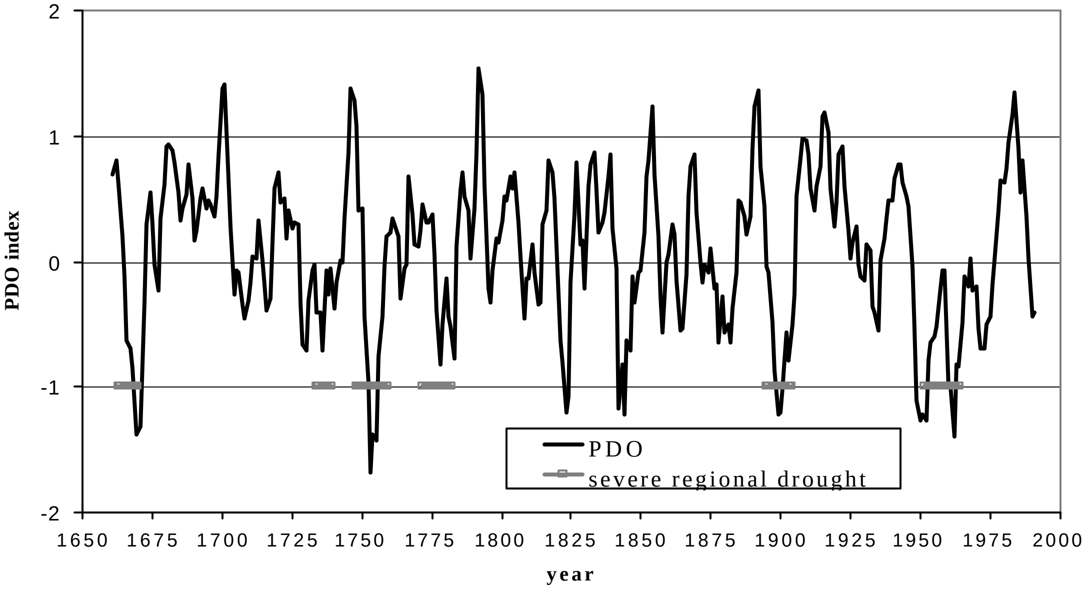
Figure 2.5
Middle Rio Grande Basin Palmer Drought Severity Index reconstruction; smoothed with a 10-year running average.



Data from Grissino-Mayer et al., 2002

Figure 2.6

Pacific Decadal Oscillation and Severe Regional Droughts in the Middle Rio Grande Basin



Reconstructed Pacific Decadal Oscillation index (Biondi et al., 2001), and extended droughts in the Middle Rio Grande. (Scurlock and Johnson, 2001). (Data from http://www.ngdc.noaa.gov/paleo/pubs/biondi2001/biondi2001.html)

Table 2.1

Average Otowi index flow for selected periods during the 1900s.

Year	Average Otowi index flow	% of 1919-1998 average	PDO phase
1950-1998	1,058,096	100	
1925-1945	1,146,418	108	Positive (warm)
1947-1976	824,647	78	Negative (cool)
1977-1998	1,171,159	111	Positive (warm)

3.0 AVAILABLE DATA AND RESOURCES

The water resources of the Middle Rio Grande region have been studied for over a century. Previous water resource studies relate to water supply, water demand, water storage, water conveyance, flood control and environmental issues. The number of investigating entities and breadth of investigator perspectives underscores the importance of water resources to this region.

Federal agencies conducting water resource evaluations in this region include the U.S. Geological Survey (USGS), the U.S. Bureau of Reclamation (USBR), the Army Corps of Engineers (COE), and the U.S. Fish and Wildlife Service. State agencies conducting water resource evaluations include the New Mexico Bureau of Mines and Mineral Resources, the New Mexico Interstate Stream Commission, the Department of Game and Fish, the New Mexico Office of the State Engineer, and the Environment Department. Other entities conducting studies include the Middle Rio Grande Conservancy District (MRGCD), the City of Albuquerque and other municipalities, the Bosque del Apache National Wildlife Refuge, the University of New Mexico, the New Mexico Institute of Mining and Technology, Sandia National Laboratories, Kirkland Air Force Base, and several water planning regions, counties and environmental groups. Other key players in the region include the pueblos of Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, Zia, Jemez and Isleta, and the Rio Grande Compact Commission, which is authorized by the Congress of the United States.

While previous studies have varied in focus and scope, in aggregate, they present a staggering amount of data and information on the water resources of the Middle Rio Grande. As part of this study, existing studies, reports and data sets were compiled and used in the analyses. The reports and data sets used in this work are discussed in the following sections.

3.1 <u>Data and Information Reconnaissance</u>

Data for Phase 3 analyses are based on the data sets and reports collected in Phases 1 and 2, and updated information where applicable. In Phases 1, Executive Steering Committee (ESC) members identified key studies and contacts for information on surface water, groundwater and water use in the Middle Rio Grande region. A data inventory survey form was distributed to ESC members and other contact persons to further identify information on available data and metadata. Follow-up interviews were conducted with agency representatives and key investigators regarding identified water resource data and studies. Key data sets and reports were requested and collected. The data and information gained during this reconnaissance phase were organized into a document database, a series of data sets, and a metadata database. For Phase 3, a key subset of these data sets was updated through the end of 2002. Where appropriate, revisions to source material and additional reports were included in the analyses.

3.2 Annotated Bibliography

The annotated bibliography was updated in this study phase to include new reports and reports pertaining to climate studies. The bibliography contains key documents related to the Middle Rio Grande region in the areas of surface and groundwater modeling; water budget studies and depletion analyses; hydrogeology, geology, water resource planning, management of biological resources, river operations, and regional paleo-climatology. A subset of this bibliography includes annotations summarizing report contents. The bibliography is accessible through the project website, at **http://www.ose.state.nm.us/water-info/mrgwss/index.html**.

3.3 Metadata Database

Metadata, or data about data, was requested from agencies or entities collecting or maintaining water resource data with relevance to this study. A metadata database was compiled in Phase 2 of this study. Metadata were catalogued and assimilated into broad categories as established by the Federal Geographic Data Committee (FGDC). These categories include identification information, data quality information, spatial data organization information, spatial reference information, temporal data information, entity and attribute information, distribution and metadata reference information. Data sets included within the metadata database are listed in Table 3.1. The metadata database, reflecting the Phase 2 work, is described in detail in Appendix A and is available for electronic access or download on the project website, at **http://www.ose.state.nm.us/water-info/mrgwss/index.html**.

Since the completion of Phase 2, some data described in the Phase 2 metadata database has been augmented by data origination entities through one or more of the following actions:

- Continued data collection and database maintenance: Gaged flow records and wastewater discharges are examples of data sets that continue to grow as additional data are generated.

- Installation of new gages resulting in new data locations: New data sets are being created with the addition of new flow gages. Most notable in this category are numerous additional gages installed by the MRGCD in the period between 1999 and 2003. These gages, identified on Table 3.2, have been installed with the objective of measuring all inflows to and outflows from the MRGCD. The MRGCD expects to continue to expand this network of gages over the coming years to better understand the irrigation system water budget and to support efforts for improved system efficiencies.

- Revision of data in public databases: For example, the USBR has recently conducted QA on the ET Toolbox reported consumptive use numbers, and has made changes to reported historic consumptive use.

- Updated scientific studies: For example, the USGS has developed a new groundwater model for the Albuquerque Basin, published in 2003.

A comprehensive update of the Phase 2 metadata database was not included in the scope of work for the Phase 3 study, however, where applicable to the Phase 3 analyses, updated or replacement data and metadata have been obtained. These data are identified and discussed in the following section.

3.4 Key Data Sets

Key data sets used in the Phase 3 study are described in this section, under the general categories of USGS flow data, wastewater discharge, Rio Grande Compact indices, *consumptive use* data and GIS coverages. These data sets are illustrated in Appendices B and C, which provide time-series plots of flow and consumptive use data. Figure 3.1 provides a schematic diagram indicating the relative location of selected gaging stations, major tributary inflows, and municipal wastewater returns in the study area.

3.4.1 USGS Flow Data

An initial review of *USGS gaging stations* identified 69 flow gaging stations within the Middle Rio Grande region that measure daily or peak discharge at river, canal, drain and tributary locations. From this list, active and discontinued stations were identified which met the following criteria:

- Stations on the Rio Grande, or adjacent canal, drain or other conveyance channels;
- Tributary stations at the most downstream (closest to confluence with Rio Grande) location monitored.

Stations on minor arroyos with gages at locations distant from the Rio Grande were excluded. The resulting set of 47 gaging stations is listed in Table 3.3, with identifying information and the period of record for the station. Metadata and time-series graphs of annual flow data calculated from the daily mean flows were provided in the Phase 2 report for most of these stations.

USGS gaging stations that are used in the basin-wide water budget include: Santa Fe above Cochiti Lake, Galisteo Creek below Galisteo Dam, Jemez River below Jemez River Dam, North Floodway, South Diversion Channel, Tijeras Arroyo near Albuquerque, Rio Puerco near Bernardo, and Rio Salado near San Acacia. These records have been updated through 2002 where possible. Time-series graphs of annual flow data calculated from the daily mean flows are provided in Appendix B for these 8 stations.

Other USGS gaging stations relevant to the basin-wide water budget include the Rio Grande at Otowi Bridge, the Rio Grande below Elephant Butte and the Rio Grande below Caballo. For the purposes of this study, adjustment of these records to account for changes in reservoir storage and for contributions of trans-mountain diversions is needed. Such adjustments are made annually by the Rio Grande Compact Commission, resulting in a secondary data set termed *Rio Grande Compact Data.* These data are discussed below in Section 3.4.3.

3.4.2 Wastewater Discharge

Monthly wastewater discharge records under Environmental Protection Agency (EPA) NPDES permits, for the municipalities of Albuquerque, Rio Rancho, Bernalillo, Los Lunas, Belen and Socorro, were obtained as electronic files from the EPA for the years of 1989 to 2002. The total wastewater discharge in 2002, comprised largely of wastewater from the City of Albuquerque, was 64,304 acre-feet. Time-series graphs of these records, as annual totals, are provided in Appendix B.

3.4.3 Rio Grande Compact-Based Indices and Records

The computed indices under the Rio Grande Compact include the Otowi Index Supply, the Elephant Butte Scheduled Delivery, the Elephant Butte Effective Supply and the End-of-Year Credit. These indices are published annually by the Rio Grande Compact Commission, along with the San Juan-Chama trans-mountain diversions. The definition and application of these indices are introduced in Section 2.2. Time-series graphs of each of these indices and the San Juan-Chama flows are provided in Appendix B.

The Rio Grande Compact indices control the useable supply to the Middle Rio Grande region. The Otowi Index Supply (native inflow) and the San Juan-Chama trans-mountain diversions represent the base upstream inflow to this region. This inflow, combined with surface water tributary inflow and net groundwater *gains/losses* in the Middle Rio Grande region, comprises the gross water supply to the region. The amount of water available for use within the Middle Rio Grande region, however, is determined after subtracting the downstream obligation, or Elephant Butte Scheduled Delivery, from the gross supply.

The Compact schedule sets forth a relationship between the Otowi Index Supply and the Elephant Butte Scheduled Delivery that provides for higher scheduled deliveries in years of higher flow. This relationship is not linear. Subtraction of the scheduled delivery from the Otowi Index Supply indicates that a maximum of 405,000 acre-feet per year is available for use within the Middle Rio Grande region (Figure 3.2). The actual supply to the region is equal to this difference, plus San Juan-Chama trans-mountain diversions, tributary inflow and net groundwater gains/losses.

The Compact credit or debit is calculated as the difference between the Elephant Butte Scheduled Delivery (the obligation) and the Actual Elephant Butte Effective Supply (representing the computed delivery), except in *spill years*, when no annual credit or debit is computed. Accrued credits and debits are set to zero when useable water is spilled from project storage. Figure 3.3 shows the history of credits and debits under the Rio Grande Compact. As seen in this figure, credits or debits were not computed for the spill years 1942, 1985 through 1988 and 1995.

Trans-mountain diversions of the San Juan-Chama Project were initiated in June 1971 to provide a supplemental water supply to contracting New Mexico entities. This Bureau of Reclamation project, authorized by Public Law 87-483, diverts water from three tributaries of the San Juan River in southwestern Colorado (the Navajo, Little Navajo and Blanco rivers), and delivers it through a series of tunnels across the continental divide to northern New Mexico. Project deliveries are measured at the mouth of Azotea Tunnel, which discharges into Willow Creek, a tributary to the Rio Chama. Project water is stored in Heron Reservoir on Willow Creek just above its confluence with the Chama. The total San Juan-Chama allocation, measured as releases from Heron Reservoir, is 96,200 acre-feet per year, of which 91,210 acre-feet per year is presently contracted. Included in this amount is 70,400 acre-feet per year contracted to entities within the Middle Rio Grande region, 5,605 acre-feet per year contracted to the City of Santa Fe and 5,000 acre-feet per year to maintain the recreation pool at Cochiti Lake, for a total contracted quantity for use between the Otowi gage and Elephant Butte of 81,005 acre-feet per year (NMISC, personal communication). San Juan-Chama water delivered for use in the Middle Rio Grande region is assessed a 2% conveyance loss between Heron Reservoir and the Otowi gage, as approved by the Rio Grande Compact Commission in 1979.

3.4.4 Consumptive Water Uses

Consumptive water uses in the Middle Rio Grande region include *evapotranspiration* by irrigated crops and riparian species; open water evaporation from the river, conveyance channels and reservoirs; and consumption of water for domestic, municipal and industrial use. Data sets for these consumptive uses have been obtained from sources described below, and are further documented in the metadata database

(Appendix A). Graphs summarizing data sets of consumptive use are provided in Appendix C.

3.4.4.1 Agricultural Consumptive Use

For six reaches in the region between Cochiti and San Marcial (Figure 3.4), daily consumptive use estimates for the years 1975 to 2002 are accessible through the USBR ET Toolbox web page at **http://www.usbr.gov/pmts/rivers/awards/ettoolbox.html**. These consumptive use estimates have been calculated by the USBR for mapped crops and riparian species within individual 4 km by 4 km cells corresponding to the National Weather Service Hydrologic Rainfall Analysis Project (HRAP) grid. For each cell, the USBR provides a term identified as "consumptive use", obtained by calculating daily potential evapotranspiration (ET) rates for each vegetation class using a modified Penman procedure, updated crop coefficients, and an updated solar radiation function (Al Brower, personal communication, May 2000). Crop and vegetation acreages are multiplied by their respective ET rates to calculate total daily consumptive use for each cell, and cells are summed to provide reach totals. In the calculation employed by the USBR for the ET Toolbox, uniform crop coefficients and vegetation acreages are employed, but climatic parameters are varied according to the climatic record.

Crop and vegetation acreages are based in part on the 1992 condition, calculated by the USBR utilizing aerial photography and 1992 Landsat TM satellite imagery, in coordination with a program of field verification. The acreages derived from this work were compiled by the USBR into a GIS database and are commonly referred to as the 1992 LUTA (land use trend analysis). This work is documented in the Middle Rio Grande Water Assessment Supporting Document No. 13 (Bell, et. al., 1994). The resulting GIS coverages were subsequently updated by the USBR to extend into areas to the south, and these extended land use coverages are available from archives at the Earth Data Analysis Center (EDAC). Metadata regarding the methods, date and other details of the land use extension have not been located. This combined coverage including the 1992 LUTA and the subsequent (undated) extension will be referred to as the 1992 LUTA/Extended land use coverage.

For this study, agricultural irrigated acreage for the reaches between Cochiti and San Marcial (reaches 1 and 3–6) were extracted directly 1992 LUTA/Extended GIS coverages obtained from EDAC[1]. These acreages were then used, in conjunction with reach-averaged potential ET rates (for the 1975-2002 period) derived from the ET Toolbox (January 2003 version) data, to calculate consumptive use (potential ET) values for each reach.

The average values for irrigated acreage and potential evapotranspiration rate, and the resulting calculated potential crop consumptive use, used in this study are shown in Table 3.4. These values include both irrigated lands within the MRGCD as well as other irrigated areas, for example areas irrigated by the La Joya Acequia, that reside outside of the boundaries of the MRGCD. Fallow and idle acreage is not included in the acreage totals. 1,706 acres of irrigated land within the Bosque del Apache are included within the San Acacia to San Marcial reach[2]. There is no irrigated agricultural acreage reported between San Marcial and the north end of Elephant Butte Reservoir. Consequently, ET Toolbox Reach 7, *San Marcial to Elephant Butte Reservoir*, is not included in these calculations.

The calculated consumptive use presented in Table 3.4 represents the potential, or theoretical, consumptive use for these crops, under the given climatic conditions, and assuming that optimal growth conditions are present. In reality, this level of use will not be obtained; actual consumptive use will reflect less than optimum growth conditions. An adjustment from potential to actual consumptive use for the water budget analysis is described in Section 4. Additionally, a portion of the consumptive use is supplied by precipitation, reducing the consumptive use that must be satisfied through irrigation (*consumptive irrigation requirement*). The ET Toolbox does not provide the estimated consumptive irrigation requirement, although a term labeled “daily water use” is provided. The “daily water use” provided in the ET Toolbox is not equivalent to a

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[1] These GIS coverages are used in lieu of acreages reported in the ET Toolbox, reportedly obtained by similar procedure from the same source material. Directly extracted values were not identical to those reported in the ET Toolbox, though total acreage for the entire Middle Rio Grande from Cochiti to San Marcial was nearly identical to that given in the ET Toolbox. At least some of the reach-by-reach difference is believed to be associated with the cell discretization utilized for the ET Toolbox. Although the ET Toolbox numbers are based on the LUTA/Extended data, the data is clipped to represent a slightly smaller grid than the original coverage, and land use is totaled by grid cell. At the reach breaks, cells that span two reaches are put in one of the two reaches.

[2] As shown in Table 3.4, the total irrigated acreage between Cochiti and San Marcial is 63,500 acres. If the Bosque del Apache acreage is removed, the remaining acreage is 61,794 acres, roughly equal to that presented in other studies for this region.

consumptive irrigation requirement, because of the procedure employed whereby *all* daily precipitation is subtracted from the daily consumptive use, resulting in negative daily water use where precipitation exceeds the consumptive use. Accordingly, a separate "effective precipitation" term is included in the water budget and modeling (Section 4.3.12).

Graphs showing the annual crop consumptive use used in the Phase 3 analyses are provided in Appendix C. The updated Phase 3 cropped acreages, potential evapotranspiration rates and potential consumptive use are not substantially different from the values obtained for Phase 2 of this study. However, as noted above, the consumptive use applied in the water budget analysis is adjusted to represent an estimate of "actual" versus "potential" consumptive use. This adjustment (Section 4) results in a significant reduction of agricultural demand in the basin-wide water budget.

3.4.4.2 Riparian and Open Water Consumptive Use

Riparian and open water acreage and potential consumptive use are treated as separate terms to facilitate assessment of planning alternatives that deal with only riparian or only open water. As for the agricultural acreage, riparian and open water acreages for reaches 1 and 3 – 6 were extracted directly from the 1992 LUTA/Extended GIS coverages archived by EDAC. The acreage in the *San Marcial to Elephant Butte Reservoir* reach (reach 7) was taken directly from the ET Toolbox and represents interpretation of IKONOS 2000 satellite imagery. Potential evapotranspiration rates were taken from the January 2003 ET Toolbox data for the reaches between Cochiti and San Acacia (reaches 1 and 3-5) and were averaged over the 1975 to 2002 period. For Reach 6, the average ET Toolbox riparian evapotranspiration rate was unexpectedly small, 3.03 acre-feet per acre. Given that the riparian vegetation in reach 6 is predominantly salt-cedar, and that the latest salt-cedar studies in New Mexico suggest that consumptive use is 4 acre-feet per acre (King and Bawazir, 2000; Bawazir, personal communication), an ET rate of 4 acre-feet per acre was used for Reach 6[3]. This rate was also used for Reach 7, which is also predominantly salt cedar.

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[3] The ET Toolbox uses one set of crop coefficients for Reaches 1-5, corresponding to a combined salt cedar and cottonwood acreage. Reach 6 is based on the 1999 USBR/US Fish and Wildlife Service GIS, which individually tallies salt cedar and cottonwood acreages. Consequently, for Reach 6 of the ET Toolbox, the

Tables 3.5 and 3.6 present the riparian and open water acreages, evapotranspiration rates, and potential consumptive use updated for Phase 3 of this study. There are significant differences between the reach-specific estimates of riparian and open water consumptive use obtained for this phase, and estimates obtained for Phase 2 (SSPA, 2000). The Phase 3 estimates of riparian and open water acreage for the *Central Avenue to Bernardo* and *San Acacia to San Marcial* reaches are substantially larger than those obtained from the ET Toolbox for Phase 2 of this study. The changes from values used in Phase 2 reflect revisions made to the ET Toolbox by the USBR in the past year.

As for the agricultural consumptive use, effective precipitation is not included in the riparian and open water consumptive use calculations. Graphs showing the annual riparian and open water consumptive use used in the Phase 3 analyses are provided in Appendix C.

3.4.4.3 Reservoir Evaporation

Reservoir evaporation represents a significant consumptive use in the Middle Rio Grande region. Calculated reservoir evaporation for Cochiti Lake, based on pan evaporation, climate data and reservoir area, was obtained from the U.S. Army Corps of Engineers. Evaporation from Cochiti Lake typically ranges between 5,000 and 8,000 acre-feet per year; however, evaporation in the range of 15,000 to 20,000 acre-feet per year was reported for the wet years 1985 through 1987. Evaporation for the Elephant Butte Reservoir is similarly calculated by the USBR. Evaporation from Elephant Butte Reservoir is highly variable due to the large range of surface area. Evaporation has ranged from less than 50,000 acre-feet per year to over 250,000 acre-feet per year during the past 50 years. These values do not include evaporative losses from the exposed portions of the reservoir, however. This is discussed further in Section 4.4.5.

Metadata for reservoir evaporation data is included in Appendix A; time-series graphs are include in Appendix C.

USBR obtained a second set of crop coefficients from Dr. Bawazir to calculate potential consumptive use for the two riparian types separately (Al Brower, USBR, personal communication). Given that these alterations result in consumptive use values significantly below those reported in the literature, and as obtained directly from Dr. Bawazir, we have chosen to use the literature values directly.

3.4.4.4 Groundwater Use

Groundwater use in the Albuquerque Basin was not independently evaluated as part of this study. Recent work has been conducted by the USGS to catalogue groundwater withdrawals as part of the USGS Middle Rio Grande study. This information has been incorporated into the USGS model of the Albuquerque Basin (McAda and Barroll, 2002). As represented in the 2002 USGS model, the current level of pumping in the Albuquerque Basin, from Cochiti Dam to San Acacia, is 150,474 acre-feet per year. Municipal pumping between San Acacia and San Marcial, as obtained from pumping reports from the City of Socorro and New Mexico Tech, was an additional 3,300 acre-feet per year for 2002. No records are available to allow quantification of agricultural pumping below San Acacia.

Other elements of the water budget with respect to the groundwater reservoir are incorporated through groundwater flow models. For example, precipitation is incorporated through the modeled recharge terms, and groundwater basin inflow and outflow are incorporated through model boundary designations. This study did not re-examine the hydrogeologic conditions or groundwater budget incorporated into available groundwater flow models.

For the Albuquerque Basin, this study used the USGS groundwater flow model (McAda and Barroll, 2002). This model is used to integrate and represent groundwater processes and aquifer-stream interactions. The groundwater model is a work product of long-term studies of the Middle Rio Grande Basin, undertaken by the USGS and cooperating agencies. Future changes to the model will likely occur, incorporating additional data as they are generated. The USGS Middle Rio Grande Study and work products are summarized at **http://nm/water.usgs.gov/publications/abstracts/wrir02-4200.html** .

For the Socorro Basin, this study used an interim version of the NMISC Socorro Basin model presently under development (Shafike, 2003, personal communication). This model was used to assess aquifer/stream interactions associated with municipal pumping in the Socorro area.

3.4.5 GIS Coverages

GIS *coverages* of vegetation, hydrography, geology, land use, transportation features, and property and municipal boundaries are available from many agencies. As part of the Middle Rio Grande Water Assessment (Hansen, and Gorbach, 1997) the USBR prepared coverages for county and MRGCD divisions. These coverages are available through the Earth Data Analysis Center (EDAC) in Albuquerque, a data clearinghouse for geographic data sets. The USBR produces and maintains other coverages, for example, geomorphology and flood related coverages that were not used in this study and have not been catalogued.

GIS coverages prepared by the USGS for use in developing the groundwater model of the Albuquerque Basin (Kernodle et al, 1995; McAda and Barrol, 2002) include hydrography, land cover, topography, faults, aquifer properties, recharge and water well locations for the State. Many of these coverages are not readily available and are considered internal working products. Other coverages including hydrography, land survey and geology are available to the public through the Earth Sciences Information Center as digital elevation models (DEM), digital line graphics (DLG) and digital *raster* graphics (DRG).

Other agencies collecting or maintaining GIS coverages include the Natural Resources Conservation Service (soil maps), the MRGCD (parcel boundaries and irrigation diversions), the U.S. Army Corps of Engineers (various, a catalogue of coverages is under development), the Environmental Protection Agency (watershed boundaries), and the Interstate Stream Commission. Digital orthophotos and satellite imagery coverages exist for much of the study region. Many GIS coverages are created for specific agency needs and are of unknown or undocumented quality and are not accompanied by adequate metadata.

GIS coverages obtained for use in this study are included on Table 3.1. In many cases, coverage-specific metadata were unavailable, rather, generalized metadata were applied to related sets of coverages.

Figure 3.1

Schematic of Major Diversions and Tributary Inflows: Rio Grande from Otowi to Elephant Butte

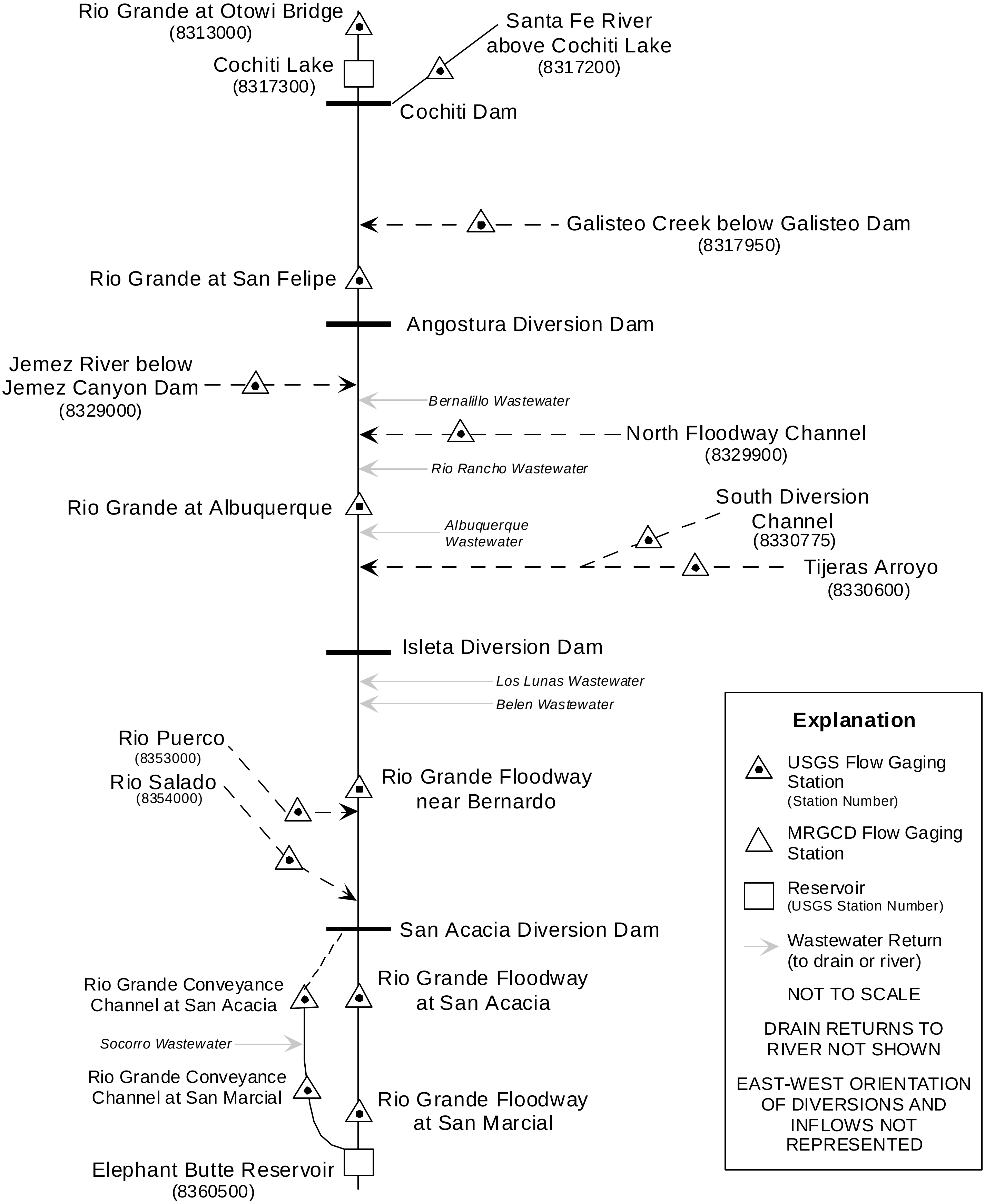


Figure 3.2 Net Supply (Otowi Index Supply minus Scheduled Delivery)
(Quantities in thousands of acre-feet)

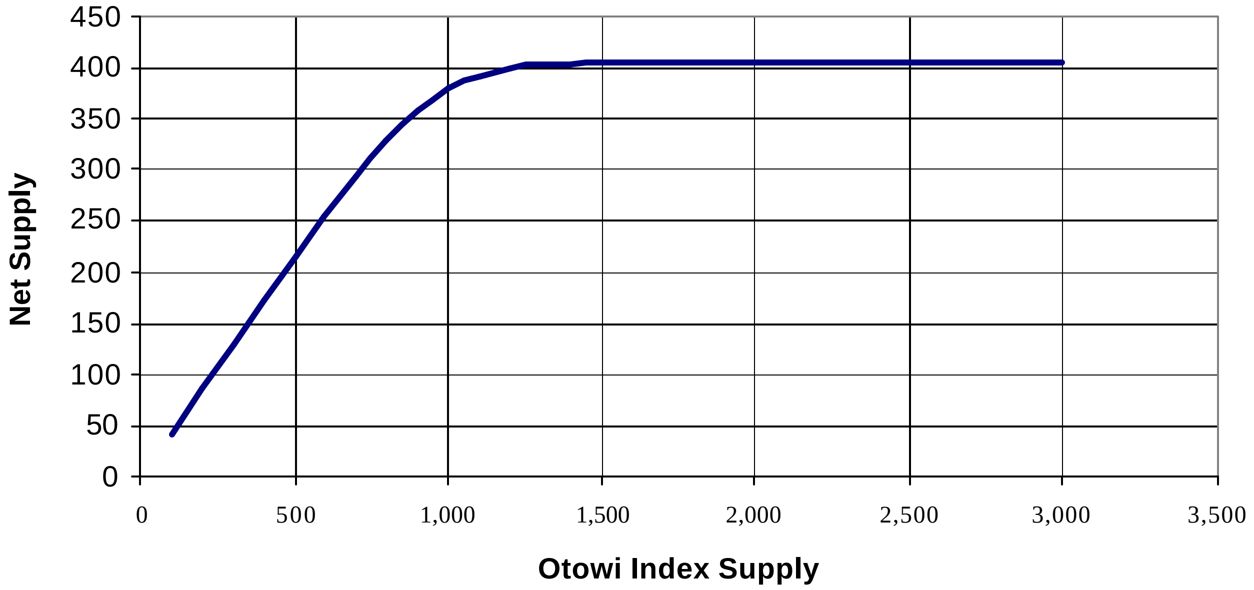
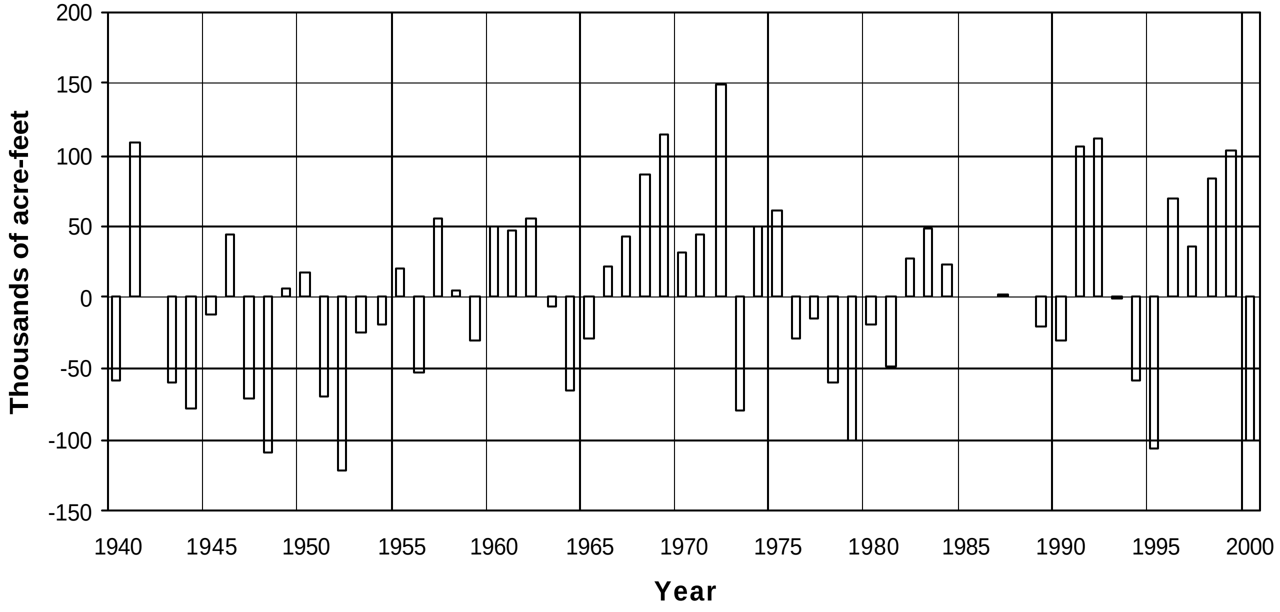


Figure 3.3 Rio Grande Compact Credit History



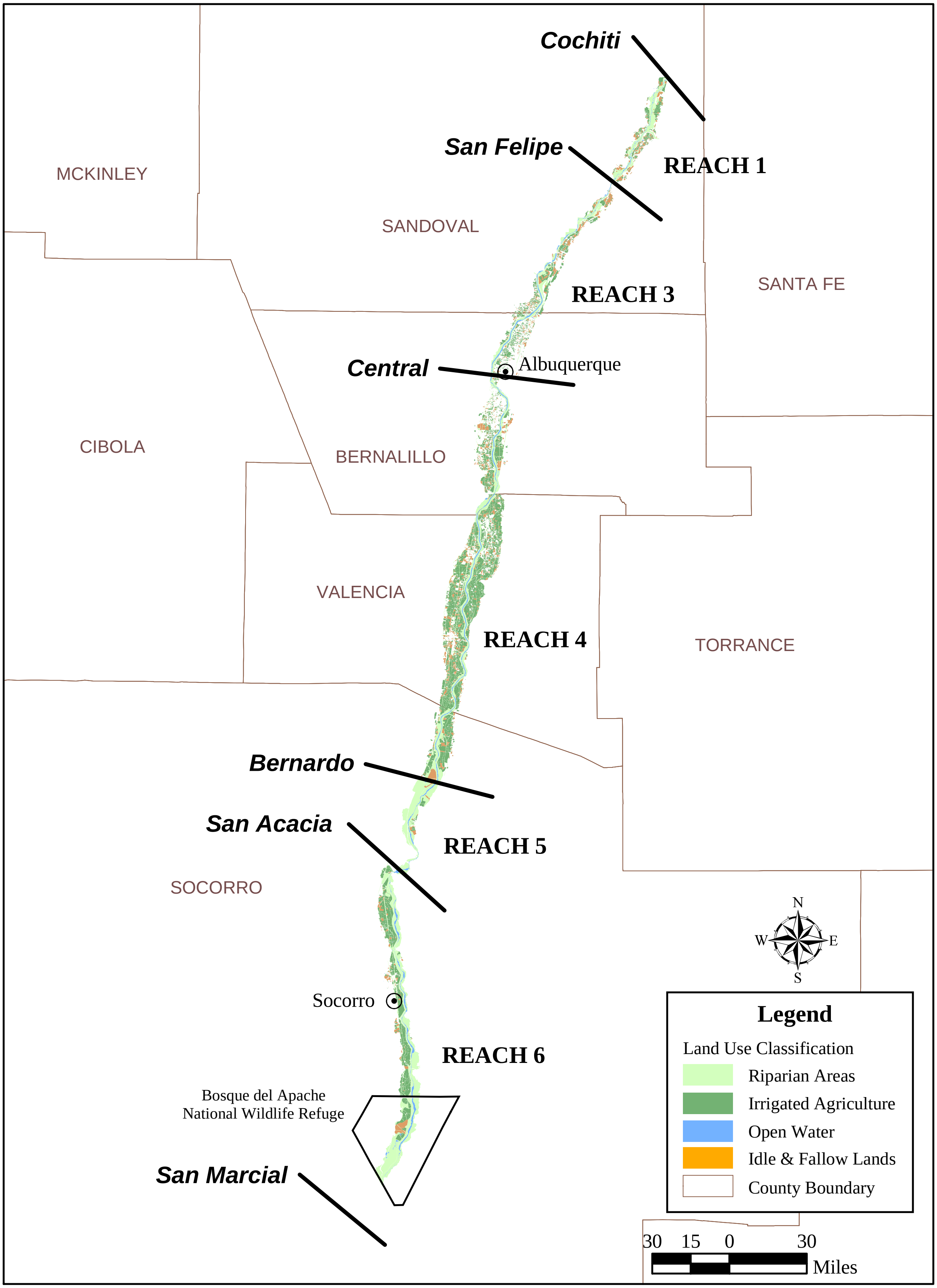


Figure 3.4. ET Toolbox reaches and 1992 LUTA/Extended agricultural, riparian, and open water acreages Cochiti to San Marcial

Table 3.1
Metadata Database: Summary of Included Data Sets

Time Series Data

USGS Gaging Stations, Flow:	Daily flow for each of 46 stations, including river, canals, drains and tributaries.
USGS Stations, Reservior Contents:	Daily contents, 2 stations, Cochiti Lake and Elephant Butte Reservoir
MRGCD Flow:	Daily flow at 13 stations, including canals, drains.
EPA records, wastewater:	Monthly NPDES discharge at Rio Rancho, Bernallilo, Albuquerque, Los Lunas, Belen, Socorro
Rio Grande Compact Data:	Rio Grande Compact Commission reported values for: Otowi Index Flow, Elephant Butte Scheduled Delivery, Elephant Butte Effective Supply, Trans-Mountain diversions, and Credit/Debit Balance
Crop Consumptive Use:	Daily crop use, for URGWOM reaches 1-5 from USBR ET Toolbox Daily crop use, for URGWIM reach 6 from USBR ET Toolbox
Riparian Consumptive Use	Daily riparian use, for URGWOM reaches 1-5, from USBR ET Toolbox Daily riparian use, for URGWOM reach 6, from USBR ET Toolbox
Cochiti Lake Evaporation	Daily evaporation, calculated by ACOE
Elephant Butte Evaporation	Daily evaporation, calculated by USBR
Groundwater Extraction	USGS groundwater model well file (as replicated in OSE model, well package)
Precipitation	Albuquerque WSFO Airport, New Mexico Historical Monthly Total Precipitation

Spatial Data

USGS Gaging Station Locations, for all active or discontinued gages on Rio Grande between Rio Grande at Otowi and Rio Grande below Elephant Butte; and, all active or discontinued gages for tributary flows at downstream location nearest to Rio Grande mainstem, point coverage

Land Use Area (from LUTA, USBR MRG Assessment), polygon and/or line coverages:

Vegetation classification for MRGCD Cochiti, Albuquerque, Belen, Socorro divisons, and San Marcial sub-area
Vegetation classification for Bernalillo County, Sandoval County, Valencia County, and Socorro County
Hydrography coverages for MRGCD Cochiti, Albuquerque, Belen, Socorro divisons, and San Marcial sub-area. (MRGCD drains, canals, river and portions of tributary inflow channels)
Hydrography coverages for Bernalillo County, Sandoval County, Valencia County, and Socorro County
Transportation coverages for MRGCD Cochiti, Albuquerque, Belen, Socorro divisons, and San Marcial sub-area
County boundaries for the State of New Mexico
Boundary of USGS Middle Rio Grande study area
Transportation line coverage for the State of New Mexico
CDP polygon coverage for the State of New Mexico (cities)

Federal land ownership for lands in the Middle Rio Grande region, polygon coverage

Natural hydrography for the State of New Mexico, line and polygon coveages

Digital geologic map of State of New Mexico – river alluvium

Shaded relief map of the State of New Mexico

1:1,000,000 BLM PLSS map of New Mexico

Hydrologic Unit Codes (HUC) for the State of New Mexico (watersheds: unit code, perimeter, area)

MRGCD Property Boundary Coverage (tax assessment parcel data layer)

Digital Hydrologic Reach map of New Mexico

Table 3.2

Existing Gaging Stations for Monitoring Key MRGCD Irrigation System Flows

Gage Name	Gage ID	Operator	Gage Purpose	Period of Record
Cochiti Division				
Cochiti East Side Main Canal	CCCN5	USGS	Canal Heading	1954 - present
Sili Main Canal	SILN5	USGS	Canal Heading	1954 - present
Approximately 10 - 14 return flow points	--------	---------	Returns to River	TBD
Cochiti Main at San Felipe	CMCCN	MRGCD	mid-reach	(1954) 1974 - present
Albuquerque Division				
Albuquerque Main Canal	ALBCN	MRGCD	Canal Heading	1974 - present
Atrisco Feeder Canal	ATFCN	MRGCD	Canal Heading	1974 - present
Algodones Riverside Drain	ALGDR	MRGCD	Return from Cochiti Div.	1974 - present
Lower San Felipe Drain Outfall	SNFDR	MRGCD	Return from Cochiti Div.	TBD
Arenal Main Canal	ARECN	MRGCD	Central Ave. X-Section	1974 - present
Armijo Acequia	ARMCN	MRGCD	Central Ave. X-Section	1958 - present
Atrisco Ditch	ATDCN	MRGCD	Central Ave. X-Section	1958 - present
Albuquerque Riverside Drain @ Central Avenue	ALBDR	MRGCD	Central Ave. X-Section	1954 - present
Corrales Main Canal	CORCN	MRGCD	West side feeder Canal	1974 - present
Upper Corrales Riverside Drain	UCRDR	MRGCD	Drain to River	2001 - present
Corrales Main Canal Wasteway	CORWW	MRGCD	Wasteway to River	1997 - present
Central Avenue Wasteway	CENWW	MRGCD	Wasteway to River	2000 - present
Atrisco Riverside Drain	ATRDR	MRGCD	Drain to River	1997 - present
Lower Corrales Riverside Drain	LCRDR	MRGCD	Derived drain to River	2000 - present
Albuquerque Riverside Drain	ARSDR	MRGCD	Drain to River	1997 - present
Sandia Lakes Wasteway	SANWW	MRGCD	Wasteway to River	2000 - present
Pajarito Lateral	PAJCN	MRGCD	Secondary Canal	2002/03 - present
Gun Club Lateral	GUNCN	MRGCD	Secondary Canal	2002/03 - present
Butte Lateral	BUTCN	MRGCD	Secondary Canal	Anticipated 8/03
Indian Lateral	INDCN	MRGCD	Secondary Canal	Anticipated 8/03

[1] This gage also forms the basis for estimating return flow to the river from this drain.

[2] Diversions from the Low Flow Conveyance Channel gaged intermittently by USGS.

[3] MRGCD has a new gage here beginning 2001.

TBD - the installation date has not yet been established.

Table 3.2 continued

Existing Gaging Stations for Monitoring Key MRGCD Irrigation System Flows

Gage Name	Gage ID	Operator	Gage Purpose	Period of Record
Belen Division				
Belen Highline Canal	BELCN	MRGCD	Canal Heading	1974 - present
Peralta Main Canal	PERCN	MRGCD	Canal Heading	1974 - present
Chical Lateral	CHICN	MRGCD	Canal Heading	1974 - present
Chical Acequia	CHACN	MRGCD	Canal Heading	1974 - present
Cacique Acequia	CACCN	MRGCD	Canal Heading	1974 - present
Lower San Juan Riverside Drain	LSJDR	MRGCD	Bernardo X-Section[1]	1974 - 2003; 2003 - present
Isleta Drain Outfall	ISLDR	MRGCD	Drain to River	Anticipated 2/04
Peralta Main Wasteway	PERWW	MRGCD	Wasteway to River	1999 - present
Feeder #3 Wasteway	FD3WW	MRGCD	Wasteway to River	2000 - present
Belen Riverside Drain	BELDR	MRGCD	Drain to River	2000 - present
New Belen Acequia Wasteway	NBLWW	MRGCD	Wasteway to River	Anticipated 2/04
Lower Peralta Riverside Drain #1	LP1DR	MRGCD	Drain to River	2001 - present
Lower Peralta Riverside Drain #2	LP2DR	MRGCD	Drain to River	2003
Sabinal Riverside Drain	SABDR	MRGCD	Drain to River	2001 - present
Storey Wasteway	STYWW	MRGCD	Wasteway to River	2003
San Francisco Riverside Drain	SFRDR	MRGCD	Drain to River	2003
Unit 7 Drain	UN7DR	MRGCD	Return to Socorro Division	2001 - present
Socorro Division				
Socorro Main Canal	SOCCN	USGS/MRGCD[3]	Canal Heading	2001 - present
Socorro Wasteway	SOCWW	MRGCD	Wasteway to LFCC	Anticipated 2/04
Brown Arroyo Wasteway	BRNWW	MRGCD	Wasteway to Brn. Arroyo	Anticipated 2/04
Socorro Riverside Drain at Bosque del Apache	SOCDR	MRGCD	end of MRGCD reach	2003
Socorro Main Canal South at Bosque del Apache	SMSCN	MRGCD	end of MRGCD reach	2003
San Antonio Ditch at Bosque del Apache	SADCN	MRGCD	end of MRGCD reach	2002
Elmendorf Drain at Bosque del Apache	ELMDR	MRGCD	end-reach	2003

[1] This gage also forms the basis for estimating return flow to the river from this drain.

[2] Diversions from the Low Flow Conveyance Channel gaged intermittently by USGS.

[3] MRGCD has a new gage here beginning 2001.

TBD - the installation date has not yet been established.

Table 3.3
Summary of USGS River, Conveyance and Tributary Gaging Stations

STATION NAME (upstream tributary and distant arroyo stations excluded)	Station Code	Station Number	Latitude	Longitude	County	Gage Datum (ft above NGVD)	Approximate Period of Record
Rio Grande At Otowi Bridge, Nm	R	8313000	355229	1060830	Santa Fe	5488.48	1885-1905, 1909-present
Cochiti East Side Main Canal At Cochiti, N. Mex.	C	8313500	353702	1061926	Sandoval		1954-present
Sili Main Canal (At Head) At Cochiti, N. Mex.	C	8314000	353710	1061928	Sandoval		1954-present
Rio Grande At Cochiti, New Mexico	R-d	8314500	353756	1061908	Sandoval	5224.7	1924-1970
Santa Fe River Above Cochiti Lake	T	8317200	353249	1061341	Santa Fe	5505	1970-present
Rio Grande Below Cochiti Dam, N. Mex.	R	8317400	353704	1061926	Sandoval	5226.08	1970 - present
Galisteo Creek Below Galisteo Dam, Nm	T	8317950	352756	1061257	Santa Fe	5450	1970-present
Rio Grande At San Felipe, Nm	R	8319000	352639	1062623	Sandoval	5115.73	1925 - present
Jemez River Below Jemez Canyon Dam,Nm	T	8329000	352324	1063203	Sandoval	5095.6	1936-1938; 1943-present
Rio Grande Near Bernalillo, N. Mex.	R-d	8329500	351705	1063545	Sandoval	5030.57	1941-1969
N Floodway Channel Nr Alameda N M	T	8329900	351158	1063553	Bernalillo	5015	1968-present
Rio Grande Nr Alameda, Nm	R-d	8329928	351054	1063920	Bernalillo		1989-1995
Corrales Riverside Drain Nr Corrales, Nm	D	8329930	351219	1063830	Bernalillo	4995	1996-present
Corrales Main Canal Outfall At Albuquerque, Nm	O	8329931	350941	1064027	Bernalillo	4990	1996-present
Rio Grande At Albuquerque, Nm	R	8330000	350521	1064047	Bernalillo	4946.16	1941 - present
Rio Grande At Rio Bravo Bridge Near Albuquerque,Nm	R-d	8330150	350159	1064023	Bernalillo		1991-1995
Tijeras Arroyo Nr Albuquerque, N. Mex.	T	8330600	350004	1063918	Bernalillo	5000	1951-1968, 1974-present
South Div Channel Abv Tijeras Arroyo Nr Albq, Nm	T	8330775	350009	1063902	Bernalillo	4930	1988-present
Tijeras Arroyo Bl S Div Inlet Nr Albuquerque, Nm	T-d	8330800	350009	1063941	Bernalillo	4933	1974-1988
Rio Grande At Isleta, Nm	R-d	8331000	345421	1064104	Valencia		1925-1929, 1936-1938
Belen Highline Canal Trib Nr Los Lunas, Nm	O-d	8331100	344920	1064910	Valencia	5250	
Rio Grande Near Belen, N. Mex.	R-d	8331500	343910	1064410	Valencia	4797.32	1941-1957
Abo Arroyo Trib. Near Blue Springs, N. Mex.	T	8331660	342647	1062946	Socorro	5960	1996-present
Rio Grande Conveyance Channel Near Bernardo, Nm	D	8331990	342452	1064811	Socorro	4720	1936-1937, 1964-present
Rio Grande Nr Bernardo, N. M.	R-d	8332000	342500	1064800	Socorro	4722.55	1936-1939, 1941-1964
Rio Grande Floodway Near Bernardo, Nm	F	8332010	342501	1064800	Socorro	4722.55	1936-1937, 1943-present
Lower San Juan Riverside Drain	D-d	8332030			Socorro		1954-1975
Bernardo Interior Drain Nr Bernardo,N. M.	D	8332050	342456	1064915	Socorro	4710	1936-1937, 1943-present
Rio Puerco Near Bernardo,Nm	T	8353000	342433	1065109	Socorro	4722.34	1939-present
Rio Salado Near San Acacia,Nm	T-d	8354000	341750	1065359	Socorro	4765	1947-1984
Socorro Main Canal North At San Acacia, Nm	C	8354500	341517	1065343	Socorro	4660.16	1936-present
Rio Grande Conveyance Channel At San Acacia, Nm	LFCC	8354800	341454	1065404	Socorro	4652.5	1954-present
Rio Grande Floodway At San Acacia, Nm	F	8354900	341523	1065318	Socorro	4654.5	1964 - present*
Rio Grande At San Acacia N M	R-d	8355000	341513	1065345	Socorro	4658.1	1936-1964
Nogal Arroyo Fwy Nr Socorro, Nm	T-d	8355200	340547	1065250	Socorro	4620	1969-1977
Arroyo De La Matanza At Socorro N M	T-d	8355300	340151	1065404	Socorro	4760	1969-1977
Rio Grande At San Antonio N M	R-d	8355500	335510	1065100	Socorro	4541.73	1951-1957
Socorro Main C S Near San Antonio, N. Mex.	C-d	8356000	335328	1065154	Socorro	4526.41	1937-1938, 1948-1971
San Antonio Riverside Drain Nr San Antonio, N M	D-d	8356500	335324	1065104	Socorro	4524.33	1948-1971
Elmendorf Int Dr Nr San Antonio N M	D-d	8357000	335212	1065139	Socorro	4518.9	1936-1938, 1948-1971
San Antonio Riverside Drain Nr San Marcial, N M	D-d	8357500	334431	1065528	Socorro	4487.12	1948-1971
Rio Grande Conveyance Channel At San Marcial, Nm	LFCC	8358300	334107	1065940	Socorro	4454	1958-1959, 1964-present
Rio Grande Floodway At San Marcial, Nm	F	8358400	334050	1065930	Socorro	4455.19	1964-present
Rio Grande At San Marcial N M	R-d	8358500	334050	1065930	Socorro	4455.19	1895-1964
Milligan Gulch Nr San Marcial N M	T-d	8358550	333937	1070525	Socorro	4720	1968-1978
Rio Grande At Narrows In Elephant Butte Res N M	R-d	8359500	332310	1070945	Sierra	4363.63	1951-1957
Rio Grande Below Elephant Butte Dam, Nm	R	8361000	330854	1071222	Sierra	4242.09	1915 - present

CODES:

R	River	O	Outfall
C	Canal	LFCC	Low Flow Conveyance Channel
D	Drain	F	Floodway
T	Tributary	d	Discontinued station

Table 3.4

Agricultural Consumptive Use

Reach	URGWOM Reach Number	Irrigated Acreage	Potential CU (af/year)	ET rate (af/acre/year)
Cochiti to San Felipe	1	2,963	10,572	3.57
San Felipe to Central Ave	3	7,000	27,025	3.86
Central Ave to Bernardo	4	39,601	157,314	3.97
Bernardo to San Acacia	5	446	1,547	3.47
San Acacia to San Marcial	6	13,490	51,320	3.80
Total		**63,500**	**247,778**	

Acreage values were taken from the 1992 LUTA/Extended GIS coverages directly; fallow and idle acreage is omitted. ET rate is taken from the January 2003 ET Toolbox data and represents the 1975-2002 average crop consumptive use.

Table 3.5

Riparian Consumptive Use

Reach	URGWOM Reach Number	Riparian Acreage	Potential Riparian CU, (af/year)	Riparian ET rate (af/acre/ year)
Cochiti to San Felipe	1	4,361	15,650	3.59
San Felipe to Central Ave	3	5,590	20,286	3.63
Central Ave to Bernardo	4	18,800	68,304	3.63
Bernardo to San Acacia	5	8,214	29,621	3.61
San Acacia to San Marcial	6	20,563	82,252	4.00
San Marcial to Elephant Butte	7	7,635	30,540	4.00
Total		**65,163**	**246,653**	

Acerages are taken directly from the 1992 LUTA/Extended GIS data. Open water ET rate is taken from the ET Toolbox for all reaches. Riparian ET rate is taken from the ET Toolbox for reaches 1 through 5; 4 acre-feet per acre is used for reaches 6 and 7. ET rate is taken from the January 2003 ET Toolbox data and represents the 1975-2002 average.

Table 3.6

Open Water Consumptive Use

Reach	URGWOM Reach Number	Open Water Acreage	Potential Open Water CU (af/year)	Open Water ET rate (af/acre/ year)
Cochiti to San Felipe	1	571	3,200	5.60
San Felipe to Central Ave	3	1,687	9,454	5.60
Central Ave to Bernardo	4	3,354	18,541	5.53
Bernardo to San Acacia	5	873	4,891	5.60
San Acacia to San Marcial	6	2,576	14,509	5.63
San Marcial to Elephant Butte	7	2,371	13,354	5.63
Total		**11,432**	**63,948**	

4.0 PROBABILISTIC WATER SUPPLY ANALYSIS

4.1 Water Supply Analysis Approach

Probabilistic water supply analyses were conducted to characterize the magnitude and variability of the conjunctive use water supply, including groundwater and surface water, to the Middle Rio Grande region (Study Area). A water budget model was assembled to serve as a template for the probabilistic water supply analysis. This water budget model is referenced to the Rio Grande surface water system, but integrates groundwater by incorporating externally calculated groundwater impacts on the surface water system. Because the analysis is referenced to the Rio Grande, the limitations of the Rio Grande Compact on the basin conjunctive use supply are readily incorporated.

The water budget model consists of supply terms, the primary sources of inflow into the Study Area, and demand terms, or depletions. Given that the goal of the study is to quantify supply, rather than river operations, transient changes in storage are not included in the analysis. The impact of long-term depletion of groundwater storage and the impacts of groundwater pumping on the Rio Grande is included through terms derived using groundwater models and groundwater studies. The USGS Albuquerque Basin groundwater model (McAda and Barroll, 2002) is applied in the Albuquerque Basin. Groundwater evaluations in the Socorro Basin are based on a model under development by the NMISC (Shafike, 2003, personal communications).

In this study, as in Phase 2 of the Water Supply Study, supply and demand terms are represented probabilistically where historic data exhibit variability and support the characterization of variability. For these water budget terms, the historic variability is fit with a probability distribution. In some cases, the historic record does not support probabilistic treatment; in these cases, a static value is selected to represent the term. Using the resulting probabilistic or static characterization of water budget elements, the water budget model simulates the water supply using a Monte Carlo analysis. The Monte Carlo analysis involves repeated simulation of the water budget model drawing from the component distributions. In each simulation, combinations of water budget terms are selected in random fashion, while maintaining the specified probability distributions and correlations. This process yields probability distributions for simulated water budget outcomes, including total inflow, total depletions and Compact credit/debit. Each run of the water budget model developed for this project, using the Monte Carlo approach, is based on 10,000 simulations. These simulations are also sometimes termed *events* or *realizations*.

4.2 Modeled Reaches for Regional Water Planning

To better accommodate the assessment of the regional planning alternatives, the probabilistic water budget model previously developed under Phase 2 was adapted to provide inflow and outflow at the Valencia-Socorro county line, corresponding with the southern boundary of the Middle Rio Grande Planning Region (MRGPR) and the northern boundary of the Socorro-Sierra Planning Region (SSPR). With this adaptation, the model is divided into three sections:

- Section 1 – Cochiti to Valencia-Socorro county line
- Section 2 – Valencia-Socorro county line to San Acacia
- Section 3 – San Acacia to Elephant Butte Reservoir (north end of the reservoir at high water)

The quantification of agricultural, riparian and open water consumptive use employed six reaches as used in the ET Toolbox (Section 3.4.4)[1], also sometimes referenced as "URGWOM reaches". These reaches are shown in Figure 3.4 and are identified as:

- Reach 1, Cochiti to San Felipe
- Reach 3, San Felipe to Central
- Reach 4, Central to Bernardo
- Reach 5, Bernardo to San Acacia
- Reach 6, San Acacia to San Marcial
- Reach 7, San Marcial to Elephant Butte Reservoir

To convert these reaches into the 3 model sections, Reach 4 was subdivided into two parts, Central to Valencia-Socorro county line, and Valencia-Socorro county line to Bernardo. Reaches and sub-reaches were then grouped into the three model sections as follows:

- Section 1: Otowi to Valencia-Socorro County Line – Includes Reach 1, Reach 3, and northern part of Reach 4 (Central to Valencia-Socorro county line). Also includes the area upstream of Reach 1, Otowi to Cochiti.

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[1] ET Toolbox Reach 2, Jemez Canyon, is omitted since it is out of the study boundaries.

- Section 2: Valencia-Socorro County Line to San Acacia – Southern part of Reach 4 (Valencia-Socorro county line to Bernardo) and Reach 5

- Section 3: San Acacia to Elephant Butte Dam – Reach 6 and Reach 7. Also includes the Elephant Butte pool area (and sometimes dry, exposed pool area) below Reach 7.

Use of these three sections in the analysis allows the agricultural, riparian and open water consumptive use to be considered for the region as a whole, for areas specific to planning regions, or broken at San Acacia, a boundary used in many other studies and therefore a useful intermediate point. Acreages and consumptive uses by model section are discussed further in Sections 4.4.3 and 4.4.4.

Water inflow and uses have been similarly subdivided to facilitate use of these model results by the regional planning entities. Additional nodes were added to the model to calculate inflow and outflow at the Valencia-Socorro county line. The water budget terms contained in the model sections above and below the Valencia-Socorro county line are identified in Table 4.1, where terms are grouped for model section 1 (above the county line) and for model sections 2 and 3 (below the county line).

The computed outflow/inflow at the Valencia-Socorro county line and combinations of water budget terms above and below this line are provided to assist the planning regions in identifying the physical supply pertaining to their regions. However, it is important to remember the county line does not equate to a "delivery" point under the Rio Grande Compact or under any other legal, quasi-legal, or administrative framework. The physical location of inflow does not imply "ownership" or constitute a "claim" to the inflow by a region. Water rights in New Mexico are acquired and governed by state statutes, and, in the Rio Grande Basin, depletion is limited by the Rio Grande Compact. The inflows and outflows within the sub-regions are provided to support understanding of the location and distribution of water potentially available to regions, as may be helpful to the regional planning process.

4.3 Probabilistic Characterization of Inflow Components

In preparation for the Phase 3 model update, all flow data, including wastewater return flows and reservoir evaporation data, were updated through 2002, and probability distributions were re-computed for each term. The evaluation of variability in the water budget terms and the selection of a probability distributuion to characterize this variability is discussed below. For some terms, distributions changed little, if any; from those used in Phase 2 of the WSS. For other terms, distributions changed significantly. Both Phase 2 and Phase 3 distributions are listed in Table 4.2.

4.3.1 Otowi Index Supply

The Otowi Index Supply represents the "native" flow at the Otowi gage, the portion of the flow not influenced by upstream storage conditions or trans-mountain diversions. This index is computed on a monthly basis by the Rio Grande Compact Commission and is reported annually in the Rio Grande Compact Commission Annual Report. The Commission computes the Otowi Index Supply by adjusting the gaged flow at Rio Grande at Otowi Bridge (08313000) to account for changes in upstream storage and to remove the fraction of gaged flow comprised of trans-mountain diversions. This procedure isolates the index from the impacts of water development, operations and management; thus, the index is considered representative of the "native" upstream supply to New Mexico on the mainstem of the Rio Grande. It is assumed that variability in this index represents variability in climatic conditions influencing the watershed yield.

The Otowi Index Supply was updated to the year 2002 (Figure 4.1). The resulting annual 1950-2002 data were fit using the BestFit software. The mean for this period is 931,945 acre-feet per year. The optimal distribution was a beta distribution, truncated at the maximum and minimum values seen in the 52 year input record, 254,800 and 2,171,126 acre-feet per year.

4.3.2 Trans-Mountain Diversions (San Juan-Chama Project water)

The magnitude of the trans-mountain diversions utilized in a given year is a function of the demand, the user's readiness to use the extra supply, and, inversely, the climate-dependent "native" supply. For the purpose of characterizing the variability of the trans-mountain diversions under present development conditions, the 1977 to 2002 period was selected to remove the variability of user readiness in the first few years after San Juan-Chama Project water became available (Figure 4.2). During the 1977 to 2002 period, the mean annual reported San Juan-Chama flow passing the Otowi gage is 71,569 acre-feet per year. A negative correlation of 0.58 was calculated between the native flow at Otowi and the trans-mountain diversion water; in years of greater native supply, less trans-mountain water was released to downstream San Juan-Chama contract holders. The 1977 to 2002 period was fit with a lognormal statistical distribution for inclusion in the model, truncated to the minimum and maximum flows observed during this time period. The correlation between San Juan-Chama and Otowi Index supply flows is implemented in the probabilistic water budget model by specification of an independent-dependent variable pair.

4.3.3 Santa Fe River Inflow

The flow at the most downstream station on the Santa Fe River, USGS gaging station 08317200, is representative of the inflow of this perennial tributary to the Rio Grande (Figure 4.3). Since the completion of Cochiti Dam, the Santa Fe River joins the Rio Grande at Cochiti Lake, immediately upstream of the dam. Flow in the Santa Fe River is comprised largely of wastewater flow from municipal usage in Santa Fe, and has gradually increased over the period of record in response to increasing population in the Santa Fe area, although the flow also responds to precipitation and operational events. Updating this record through 2002 is not possible, as the gage was discontinued in 1999. Lacking sufficient record to characterize variability, and on the assumption that, to large extent, this flow is a function of wastewater discharge, a static value is used for Santa Fe River inflow in the probabilistic water supply model. To estimate present development conditions, annual flow in the 6-year period 1993 to 1998 was averaged, yielding a value of 9,580 acre-feet per year.

4.3.4 Galisteo Creek

Galisteo Creek conveys intermittent run-off to the Rio Grande. The confluence of Galisteo Creek and the Rio Grande is located in the reach between Cochiti Dam and the San Felipe gage. This flow is measured at USGS gaging station 08317950, with a period of record extending from 1970 to 2002 (Figure 4.4). Data for the period of record were fit with a Weibull probability distribution function, truncated at zero and 20,000 acre-feet per year, two times the maximum observed flow for the period of record.

4.3.5 Jemez River

The Jemez River flows into the Rio Grande downstream of the San Felipe Pueblo and upstream of Bernalillo. The flow of the Jemez River is gaged below Jemez Canyon Dam at USGS gaging station 08329000; the flow at this station represents the inflow to the Rio Grande from the Jemez River (Figure 4.5).

Jemez River flow data was updated from 1950 through 2002 and refit with a new probability distribution. The optimal distribution was a beta, truncated at the maximum and minimum values seen in the 52 year input record, 7,739 and 122,908 acre-feet per year. Additionally, there is a correlation of 0.85 between the Jemez River flows and the Otowi Index Supply. Both the Jemez River and the Rio Grande above Otowi watersheds are located in the northern part of the state and include significant components of snowmelt.

4.3.6 AMAFCA Inflow

The AMAFCA inflow consists of intermittent run-off from the Albuquerque metropolitan area, collected through a network of channels constructed in the urban area. This inflow is comprised of flow gaged at three locations: the North Floodway Channel (08329900), the South Diversion Channel (08330775) and the Tijeras Arroyo (08330600) (composite record, Figure 4.6). The period for which records were available at these three gaging stations is 1988 to 2002. The optimal probability distribution for this term was a gamma distribution. The distribution was truncated at zero and 40,000 acre-feet per year, two times the maximum observed flow for the period of record.

4.3.7 Rio Puerco

The Rio Puerco conveys intermittent flow to the Rio Grande downstream of Bernardo (Figure 4.7). The period of record used to characterize variability at this station was 1950 to 2002. The optimal probability distribution for this term was a lognormal function. The distribution was truncated at zero and 230,000 acre-feet per year, two times the maximum observed flow for the period of record. The flow of the Rio Puerco is not correlated with the Otowi Index Supply. Though a portion of the Rio Puerco drainage basin lies in the northern mountains, annual flow is strongly influenced by rainfall events in its more southerly drainage basin.

4.3.8 Rio Salado

The Rio Salado conveys intermittent flow to the Rio Grande below San Acacia (Figure 4.8). Flow derived from the USGS gaging station at Rio Salado (08354000) has a continuous annual record ranging from 1948 to 1984. As in the Phase 2 modeling, the correlation between the Rio Salado and the Rio Puerco was evaluated for the overlapping period of record, 1950 to 1984, and the following linear regression was derived (units of acre-feet per year):

$$\text{Rio Salado Flow} = (\text{Rio Puerco Flow} * 0.303) + 1549$$

This regression was used to extend the period of record for the Rio Salado to 2002. The optimal probability distribution for the resulting time series was a lognormal. Flows were truncated at 0 and 160,000 acre-feet, two times the observed maximum flow.

The correlation between the Rio Salado and Rio Puerco flows for the 1950-1984 period is 0.56; the two rivers are in adjoining basins and share similar topography in their lower basins. This correlation was included in the model; the Rio Salado was modeled as dependent on the Rio Puerco, with a dependency of 0.56.

4.3.9 Ungaged tributaries; Westside and Eastside inflow

Inspection of the tributary gaging network and basin drainage characteristics in the Middle Rio Grande region suggest that significant ungaged tributary inflow likely occurs. On the west side of the Rio Grande, the ungaged tributary inflow includes the Rio Salado (formerly gaged) and inflow from tributaries to the south, including Tiffany Canyon, Milligan Gulch, Alamosa Creek and many smaller drainages that discharge directly to the Rio Grande or to Elephant Butte Reservoir. On the east side of the Rio Grande, ungaged tributary inflow includes Hell Canyon Wash, Canada Ancha, Abo Arroyo, Palo Doro Canyon and many smaller arroyos that drain to the Rio Grande.

Very little information is available concerning the magnitude of flows from these regions. No gaged records of any length exist for west-side arroyos below the Rio Salado, or for east-side arroyos below Albuquerque. To obtain an estimate of ungaged tributary inflow, drainage areas for the ungaged tributaries have been assessed and flow relationships assumed using relationships based on drainage or upland contribution areas for gaged tributaries. These values are considered placeholders and should be refined when better information becomes available.

Ungaged tributaries within Section 1 of the model are located on the east side of the Rio Grande within the Hell Canyon and the Manzano Mountains subareas as delineated by Anderholm (2001) in a study of mountain-front recharge. Although many arroyos in this area disappear as they traverse the boundary between upland areas and the basin (indicative of their contribution to mountain front recharge to groundwater), several larger arroyos continue to the Rio Grande. The drainage areas identified by Anderholm for these subareas correspond to the upland areas of the watershed adjacent to the basin margins, and are identified as 41,910 and 38,900 acres, respectively. Flow to the Rio Grande from these tributaries is estimated based on a relationship derived from the nearby Tijeras Arroyo. Though not entirely similar in topography or land use, absent other information, this method provides an approximation for use in this water budget. The upland drainage area for the Tijeras Arroyo is identified by Anderholm as 64,000 acres. The gaged flow at the Tijeras Arroyo near Albuquerque (08330600) averaged 330 acre-feet per year from 1982 to 1998. Using this information, tributary inflow of 420 acre-feet per year is estimated for the Hell Canyon and Manzano Mountain subareas into Section 1 of the water budget model. This value is input as a constant.

Ungaged tributaries entering the Rio Grande from the east in Section 2 of the model (county line to San Acacia) include the Abo Arroyo and arroyos of the Los Pinos Mountains subarea, as delineated by Anderholm (2001). These upland watershed for these subareas are 158,730 and 44,940 acres, respectively. A temporary gaging station on the Abo Arroyo near the mountain front indicated total streamflow of about 12,400 acre-feet per year for water year 1997. Anderholm indicates that most of the flow at the gaging station was runoff from intense summer thunderstorms, and that this value is estimated to be approximately 150% of the average, based on precipitation records for that year. Anderholm estimated, based on the frequency and magnitude of flows, that the annual infiltration of summer thunderstorm runoff is only about 900 acre-feet. Based on this estimate, he concluded that much of the streamflow measured at the mountain front discharges to the Rio Grande. Allowing for more typical precipitation conditions and for incidental losses due to evaporation and evapotranspiration, a placeholder value of 5,000 acre-feet per year is used for tributary inflow from the Abo Arroyo. The Los Pinos Mountains sub-area is drained by Palo Duro Canyon and is flanked by a number of smaller drainages. Absent further information, this sub-area is assumed to yield on average about 1,400 acre-feet per year to the Rio Grande. Together, the Abo and Los Pinos subareas are assumed to contribute an average of 6,400 acre-feet per year to the river system.

Numerous ungaged tributaries are present on both the west and east side of the Rio Grande in Section 3 of the Study Area (San Acacia to Elephant Butte). For these areas, runoff occurs via a large number of nearly parallel channels traversing the basin. Absent better information, the ungaged inflow from these areas is estimated using a direct relationship between the entire watershed area and gaged flows for the Rio Salado. The Rio Salado drainage is 883,197 acres, as reported by the USGS. The drainage areas of the Section 3 Westside and Eastside ungaged regions were evaluated based on a regional GIS coverage, and found to be 1,453,465 acres and 389,390 acres respectively (Figure 4.9).

The Rio Salado lognormal distribution was applied to the ungaged regions in Section 2 and Section 3, with multipliers derived from the information presented above. Similar to the method used to model the Rio Salado, the flows from the ungaged watersheds in Section 3 were modeled as dependent on the Rio Puerco. The Westside region was assigned a dependency of 0.4 and the Eastside region was assigned a dependency of 0.3. Dependencies were chosen to reflect increasing distance or characteristics from the Rio Puerco basin.

4.3.10 Base "Adjusted" Groundwater Inflow

Base "adjusted" groundwater inflow represents the net groundwater that would flow into or from the river under the present river-conveyance infrastructure conditions without pumping of groundwater, deep percolation of applied irrigation water, and riparian evapotranspiration. While not strictly physically-based, the base "adjusted" groundwater inflow is important as a baseline term to the water budget model. The base "adjusted" groundwater inflow term is included in the probabilistic model as a term representing the combination of stream-aquifer exchanges that would occur under steady-state conditions absent influences of pumping, irrigation and riparian use. This term can be conceptualized as representing the combination of mountain front recharge, basin inflow and recharge through tributary streams, absent natural incidental depletions in upland areas. The effect of pumping, irrigation and riparian use on the stream are calculated and tracked separately in the probabilistic water supply model.

Stream-aquifer interactions between Cochiti Dam and San Acacia were incorporated through external calculations made using the recently released USGS Albuquerque Basin groundwater flow model (McAda and Barroll, 2002). Net groundwater-stream exchanges calculated by the model for non-pumping conditions were adjusted to exclude irrigation percolation and riparian groundwater use, to reflect the adjusted baseline condition defined above. Details on the modeling analysis and adjustment procedure for calculating the baseline inflow are provided in Appendix E. This groundwater inflow component is handled as a static value in the probabilistic water budget model, under the assumption that year-to-year climatic-based variability is not significant for this term. Based on this analysis, the base adjusted groundwater inflow to the rivers and drains between Cochiti Dam and San Acacia was modeled as 49,940 acre-feet per year. This value is approximately 41,000 acre-feet per year less than was estimated with the groundwater model (Barroll, 1999) used in Phase 2, and largely reflects a reduction in estimated recharge to the Middle Rio Grande Basin supported by USGS studies cited by McAda and Barroll (2002).

For the region below San Acacia, the base adjusted groundwater inflow (defined under conditions of no pumping, no irrigation return flow, and no evapotranspiration) is approximated as equaling total groundwater recharge. For the Socorro and San Marcial basins, groundwater recharge is estimated as 16,500 acre-feet per year (Roybal, 1981). As for the reach above San Acacia, this inflow component is handled as a static value in the probabilistic water budget model.

4.3.11 Wastewater Return Flows

Monthly wastewater discharge records, under Environmental Protection Agency (EPA) NPDES permits, for the municipalities of Albuquerque, Belen, Bernalillo, Los Lunas, Rio Rancho and Socorro, were obtained as electronic files from the EPA for the years 1989 to 2002. Since 1998, wastewater return flow trends in the Middle Valley appear to have shifted, and reflect a declining trend (Figure 4.10). This trend is driven by the Albuquerque wastewater data and is assumed to result from water conservation efforts within the City of Albuquerque. The average return flow over the period from 1997 to 2002, or, 66,634 acre-feet per year, is assumed for the water budget model.

4.3.12 Effective Precipitation

Agricultural and riparian consumptive use is partially satisfied by effective precipitation, the portion of precipitation that does not run off or infiltrate and is therefore available for use by plants. In the water budget, potential consumptive use is partially offset by an assumed value for effective precipitation.

The effective precipitation is assumed to equal 4 inches per crop or riparian acre. This value is approximately 50% of the annual precipitation. This value is used as a placeholder; no rigorous studies were found on this topic applicable to the basin-wide scale of this study. Multiplying the assumed rate of effective precipitation by the crop, riparian and open water acreage (Section 4.4.3 and 4.4.4), the total effective precipitation for the water budget is calculated as:

- Cochiti to County Line: 24,648 acre-feet per year
  (44,291+24,565+5,088)acres *.3333 feet per year = 24,648 acre-feet per year

- County Line to Elephant Butte: 22,050 acre-feet per year
  (19,209+40,598+6,344)acres *.3333 feet per year = 22,050 acre-feet per year

4.4 Characterization of Depletions

4.4.1 Cochiti Reservoir Evaporation

Evaporation from Cochiti Lake occurs in response to reservoir surface area and climatic conditions. In general, water levels in Cochiti Reservoir are maintained at or near the recreation pool surface area of 1,200 acres, resulting in a relatively constant annual evaporative loss, with the exception of 1985, 1986 and 1987 when reservoir storage and evaporation were significantly higher. All three of these years were spill years. Accordingly, a probability distribution for Cochiti evaporation was derived from the 1976 to 2002 period of record, omitting 1985, 1986 and 1987. A normal distribution with an average of 6,708 acre-feet per year was developed from the remaining 24 years of data. This distribution is representative of Cochiti losses in all but spill years; during spill years Compact credit/debit status is zeroed, and increased evaporative losses from Cochiti become less significant.

4.4.2 Surface Water Depletions due to Groundwater Pumping

Surface water depletions due to groundwater pumping between Cochiti Dam and San Acacia were calculated using the recently released USGS groundwater model of the Albuquerque Basin (McAda and Barroll, 2002). A simulation of historical pumping was conducted through year 2000, with total pumping (estimated for the City of Albuquerque and other users in the Albuquerque Basin as part of the USGS modeling study) at the end of the simulation at 150,474 acre-feet per year. The model results indicate that depletions to surface water, including the river, drains and reservoirs, resulting from this pumping is 79,600 acre-feet per year for the "present condition" (i.e., given land use and development conditions occurring in the year 2000). This assessment is further described in Appendix F. This simulated impact differs somewhat from that of the Phase 2 study, reflecting changes in pumping rates, aquifer transmissivity and other parameters in the 2002 USGS model. Given the location of the wells within the Albuquerque Basin, these impacts are assigned to the *Cochiti to Valencia-Socorro county line* area (Section 1) of the probabilistic water budget model.

Groundwater depletions north of the area covered in the Albuquerque Basin model, between Otowi and Cochiti, are primarily a result of pumping by the City of Santa Fe. Santa Fe depletions, resulting from pumping at the Buckman Well Field, were assessed by the NMOSE in 2003 at a value of 2,587 acre-feet per year (Peggy Barroll, personal communication).

Groundwater depletions south of the area covered in the Albuquerque Basin model occur between San Acacia and Elephant Butte. A groundwater model for this area is currently under development by the NMISC (Shafike, personal communication). The current version of the NMISC model has been used to simulate the impact of the City of Socorro's municipal pumping on the stream system (drains and river). This simulation indicated that the lag time between pumping and the occurrence of stream impacts is relatively short, as is expected given the relative proximity of the wells to the river, and given the transmissivity of the aquifer. Therefore, impacts of pumping on the stream system are set as equal to groundwater withdrawal rates. The City of Socorro withdrawals are set at 3,300 acre-feet per year for present development conditions, based on data provided by the City of Socorro to the NMISC. The depletions are incorporated into the water budget model as a static value for a given point in time. A probability distribution function was not developed for groundwater depletions since climatic-induced variability in this term tends to be dampened by the aquifer over the time frame of stream impacts.

4.4.3 Agricultural Consumptive Use

Agricultural consumptive use is estimated for both irrigated lands within the MRGCD as well as other irrigated areas, for example the La Joya Acequia, that reside outside of the boundaries of the MRGCD. Calculated agricultural acreages, average potential evapotranspiration rates, and average potential consumptive use, by reach, are given in Table 3.3. The potential agricultural consumptive use obtained from the Penman method (ET Toolbox, 2003) is adjusted to obtain an estimate for actual consumptive use due to factors such as plant health and sub-optimal irrigation. This adjustment was implemented by multiplying the potential consumptive use by a factor of 0.75. The value of 0.75 was developed by comparison of ideal to actual crop yield for alfalfa in the MRGCD. Measured crop yields in the MRGCD in the latter half of the 1990s averaged about 5 tons per acre (MRGCD Crop Census Reports, 1956-1966, 1981-1999). In the Socorro District, maximum yields are on the order of 5-6 tons per acre for poor soils and 7-8 tons per acre for good soils (Darrel Reasner, NRCS, personal communication). Accordingly, a value of 7 tons per acre is used as a reasonable maximum yield for alfalfa within the Middle Valley, and alfalfa is used as the baseline crop by which to adjust consumptive use for all crops. The adjustment of 0.75 is derived from the ratio of the average measured yield of 5.1 tons per to the maximum yield of 7 tons per acre. The base ET rate, acreage, and consumptive use values, by model section, used in the probabilistic water budget model are given in Table 4.3.

The annual potential evapotranspiration rates (Appendix C), adjusted as described above, were used to fit a probability distribution to the agricultural consumptive use. The adjusted annual ET rates were multiplied by acreages from the 1992 LUTA/Extended GIS (Table 4.3), and the resulting data were fit with a normal distribution with an average of 185,848 acre-feet per year and a standard deviation of 9,101 acre-feet per year. This variability (shown in Figure 4.12) is minimal, and only reflects climate factors utilized in the ET Toolbox Penman calculation. Other variables, i.e., cropped acreage, crop type and crop vigor, were not captured in this exercise. These latter variables are likely to be significant, perhaps resulting in changes up to 20% of the average. However, inspection of agricultural records has not yielded sufficient information to identify or to characterize trends in these factors, or their relationship to overall supply conditions. Improved understanding of the variability in agricultural consumptive use would be worth pursuing in future studies.

Correlations between annual agricultural consumptive use and Otowi Index and Rio Puerco flows were calculated and a significant negative correlation was found with the Rio Puerco (r = -0.428); during times of higher Rio Puerco flows, agricultural consumptive use tends to be smaller, presumably because both respond to summer monsoon. This correlation was incorporated into the probabilistic water budget model.

4.4.4 Riparian and Open Water Consumptive Use

For riparian vegetation and open water, actual consumptive use is assumed to be equal to the calculated potential consumptive use. Therefore, no adjustment is made to scale down the calculated potential consumptive use as was implemented for crops. For riparian consumptive use, this assumption is based on the fact that riparian plants are typically able to deepen roots to obtain water in dryer periods, and therefore are less susceptible to supply and distribution conditions than are crops.

Correlations between annual riparian and open water consumptive use and Rio Puerco flows were significantly smaller than those found for agricultural consumptive use. In response to the low consumptive use correlations with measured flow, coupled with the relatively small annual variability in the annual consumptive use for either open water or riparian (shown in Figures 4.13 and 4.14) riparian and open water consumptive use were input as constants. The 1975-2002 average ET rate, acreage and consumptive use values, by model section are given in Tables 4.4 and 4.5.

4.4.5 Elephant Butte Reservoir Losses

Elephant Butte Reservoir (EB) evaporative losses include open water evaporation from the lake surface area and additional losses from exposed, drained reservoir areas. The exposed areas may include wet soil areas, marshy areas and areas re-colonized with riparian vegetation. The EB losses have been calculated to include losses from the lake and the exposed area.

The open water evaporative loss from the lake is calculated by, and has been obtained from, the USBR. Other relevant data, including average annual reservoir content and average reservoir elevation, have been obtained for the years 1950 to 2002 to support an analysis of the corresponding exposed area for less-than-full reservoir conditions. Using a digital elevation model (DEM) of the reservoir constructed from USGS 10-meter DEM quadrangles, total and northern basin reservoir surface areas were calculated as a function of reservoir content. Based on these acreage/content relationships, estimates of potential evaporative loss from northern basin exposed land as a function of reservoir content were made. 90% of exposed northern basin lands were assumed to experience evaporative losses; this value was based on vegetative coverage observed on July 23, 2003 on an airboat tour of the narrows, the lower portion of the north basin, and the upper portion of the south basin, and as shown on satellite images of the reservoir taken between October 1999 and February 2003. A consumptive use of 4 acre-feet per acre, used to represent the willow and salt cedar communities currently present in the north basin, was applied to this additional acreage. The additional exposed area losses were added to the calculated reservoir evaporative losses to produce a total loss for the reservoir (Figure 4.15).

For inclusion in the model, total Elephant Butte Reservoir losses were fit with a 9-class histogram and the histogram used as the input distribution for the model. The correlation between total Elephant Butte Reservoir losses and Otowi inflow is r = 0.46; this correlation was included in the model by specifying a dependency of 0.46 on the Otowi Index Supply.[2] Losses were truncated at the minimum and maximum values of the total evaporation, 79,370 and 265,949 acre-feet per year, respectively.

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[2] The correlation between this year's evaporative loss and last years Otowi Index Supply is slightly stronger, r=0.59, than the correlation between this year's Otowi Index Supply and this year's evaporative loss. However, because of how evaporative loss terms are selected, omitting this correlation has only a small impact on the resultant credit-debit for any given year, and virtually no impact on the overall probability distributions calculated as part of the model output.

4.5 Probabilistic Description of the Water Supply and Rio Grande Compact Credits/Debits Under Base Case Assumptions

Using the probabilistic and other characterizations described above, a risk analysis model representing the water budget was constructed for the Study Area. This model was implemented using the software @Risk, a spreadsheet-based model, with probability functions, correlations and other specified relationships used in place of fixed values (Appendix D). The model was operated using Monte Carlo procedures, which involved sampling and running the model 10,000 times, with sampling implemented in accordance with the specified probabilistic or other relationships (Appendix F). This section describes the application of this model to a Base Case, representing present development conditions. Section 5 will describe the application of this model to analysis of alternatives selected by the planning regions.

4.5.1 Base Case Assumptions

The Base Case Model is based on three primary assumptions that affect interpretation of the results. First, the model is based on the 1950-2002 period of record, and therefore models the water budget under the range of climate conditions as they occurred in the period 1950-2002. How these conditions represent past climate in the region is discussed in Section 2.6, and in supporting work products developed as part of the Water Supply Study work and included in Appendix I. Second, the model assumes “present day” development conditions, generally derived from data for the year 2000. For example, the magnitude of groundwater pumping and other water uses are based on present conditions. Third, the model provides a snapshot of how Year 2000 conditions are manifested “at present”. In other words, the Year 2000 Base Case model results do not reflect future lagged impacts of today’s pumping. Future lagged impacts would be the subject of a modified scenario and will be discussed later in this report.

The model does not project what will happen in any given year; rather, the model results describe the variation in water supply and in Compact credit/debit conditions that should be expected given present day development in the context of climate variability. Finally, changes in development or water use conditions are modeled as “alternatives”. The analysis of alternatives are reflected as changes from the Base Case described herein, and will be discussed further in Section 5.

4.5.2 Basin-Wide Probabilistic Description of Water Supply and Compact Credit/Debit

The probabilistic water supply model for the present condition was applied using the probabilistic description of water budget terms described above. The model results include probability distribution functions of the total inflow, total depletions, tributary inflow, Elephant Butte Reservoir losses, and the Compact-based credit or debit, assuming the Compact schedule of deliveries. Figures 4.16 through 4.24 illustrate the probability distributions resulting from the Base Case model run. The figures illustrate the magnitude of flows at various percentiles within the probability distribution, ranging from the 5th to the 95th percentiles. The 50th percentile indicates the mean flow. The 25th percentile illustrates at what value a flow would be exceeded 75% of the time. The 75th percentile illustrates at what value a flow would be exceeded 25% of the time. These figures can be used to identify what flow should be expected to occur, and can be used to assist regional planners in assessing the variability in supply conditions. Maximum and minimum values, along with mean, standard deviation, and percentile values, are given in Table 4.6.

Figure 4.16 shows modeled basin-wide total inflow, including mainstem and tributary inflow, and the remainder of this inflow available for depletion within the region once the Compact obligation is satisfied. Annual inflow to the region varies from less than 700,000 acre-feet per year to over 2,200,000 acre-feet per year, with an average of about 1,300,000 acre-feet per year. However, of this, only 475,000 to 890,000 acre-feet a year are available for use. The primary contributions to this inflow are from, in order of magnitude, the Otowi Index Supply (Figure 4.17), the San Juan-Chama inflow (Figure 4.18), Jemez River (Figure 4.19), the Rio Puerco, and the Rio Salado (Figure 4.20). Several of the smaller tributaries are also shown in Figures 4.19 and 4.20.

Figure 4.21 illustrates total regional depletions. Total depletions range from 670,000 to 850,000 acre-feet a year. Most of this variation is due to Elephant Butte losses. The variability in Elephant Butte losses can be seen in Figure 4.22; losses for the reservoir range from less than 86,000 acre-feet per year, when reservoir levels are low, to over 260,000 acre-feet per year when the reservoir is at full capacity. Given that available inflow ranges from 475,000 to 890,000 acre-feet per year, this means that

Elephant Butte losses can account for anywhere from 10% to 55% of the regional depletions in a given year. In contrast, modeled agricultural, riparian and open water consumptive use is relatively constant, ranging only from 481,000 to 512,000 acre-feet per year (Figure 4.23).

The average Compact credit/debit resulting from these inputs is a 64,000 acre-feet per year debit. The modeled Compact credit/debit, based on the input distributions described above, for year 2000 conditions, is shown in Figure 4.24. As can be seen, given the Base Case model assumptions, debit conditions occur below the 80th percentile, i.e., Compact deliveries are made or exceeded only 20 years out of every 100, and debits in excess of 100,000 acre-feet per year occur at the 35th percentile and below. This suggests that, absent active involvement in water management, the Middle Rio Grande Basin will be at significant risk of Compact violation.

Figure 4.25 provides a schematic of the mean available water supply in the Middle Rio Grande region. The mean values represented on this figure are the mean outcome from 10,000 realizations of the probabilistic water budget model, using the Monte Carlo analysis. The mean available supply represents supply to the basin, excluding the mean Elephant Butte Scheduled Delivery (Rio Grande Compact Obligation). Initiating the figure, the available portion of the Otowi Index Supply is shown as 306,000 acre-feet per year. This number is the difference between 930,000, the mean Otowi Index Supply from the probabilistic model simulations, and 624,000, the mean Compact Obligation obtained from the probabilistic model simulations. It should be noted that this value is not equal to the value that would be obtained directly from the Rio Grande Compact schedule corresponding to the mean Otowi Index Supply of 930,000 acre-feet per year (568,000 acre-feet per year). Because the Compact schedule is not linear, the mean value for the delivery Obligation cannot be derived from the Compact schedule using the mean value of the Otowi Index Supply. Assessment of Rio Grande Compact compliance using average terms will lead to erroneously favorable conclusions, unless the non-linearity of the Compact schedule is incorporated.

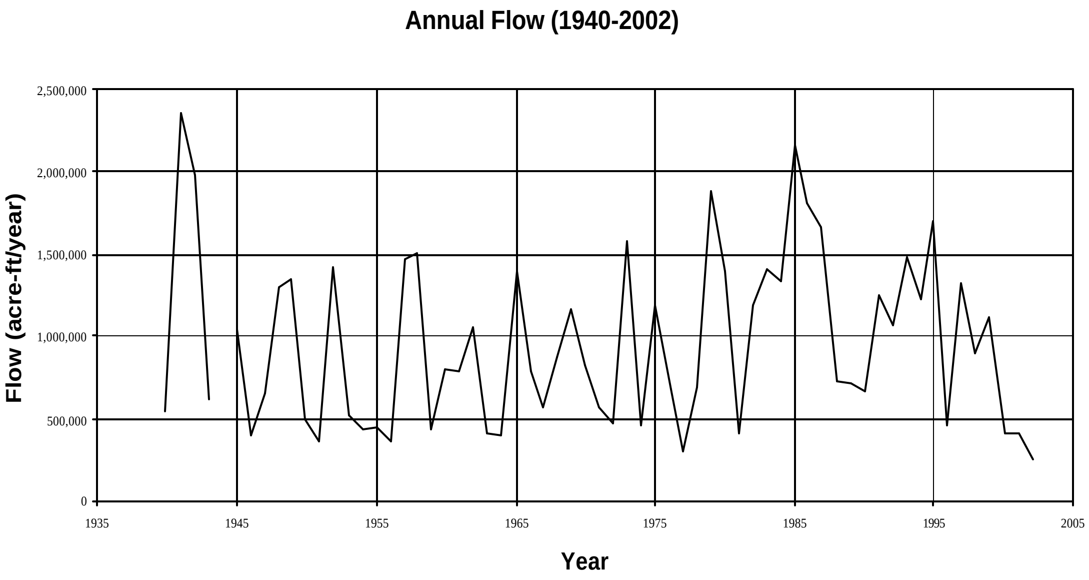
Figures 4.26 and 4.27 complete the picture with respect to the current disposition of the available supply. The pie graphs shown in these figures indicate the mean percentage of overall depletions occurring in various water use categories, according to the assumptions described in this and preceding sections. These graphs are based on the mean values of the model simulations. The percentages in the water use categories will vary to some degree, depending on climatic and water supply conditions in a given year. In particular, the reservoir evaporation is subject to a high degree of variation. The water use shown in Figures 4.26 and 4.27 does not include the full aquifer pumping currently ongoing in the basin; only stream depletions resulting from pumping are included. This means that about 70,000 acre-feet per year of aquifer storage depletions are not included in these figures.

4.5.3 Discussion

(Not yet available)

Figure 4.1

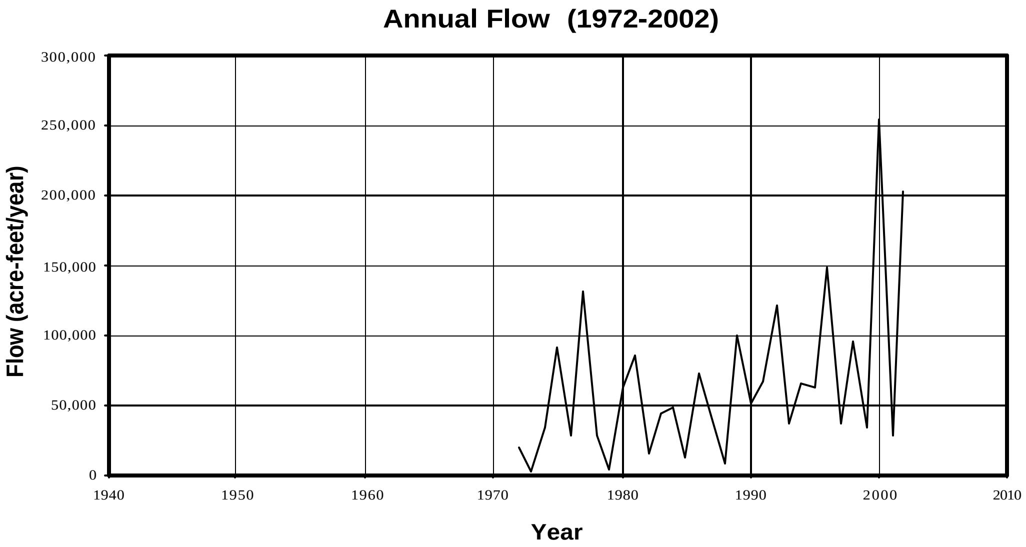
Otowi Index Supply



Title: Otowi Index Supply
Period of Record: 1940 - present
Data Source: Rio Grande Compact Commission
Comments: The Otowi Index Supply is computed on a monthly basis by the Rio Grande Compact Commission. The “native” flow at the Otowi Bridge gage is calculated by adjusting the gaged flow to add/subtract changes in upstream storage and to subtract the fraction of gaged flow comprised of trans-mountain diversions.

Figure 4.2

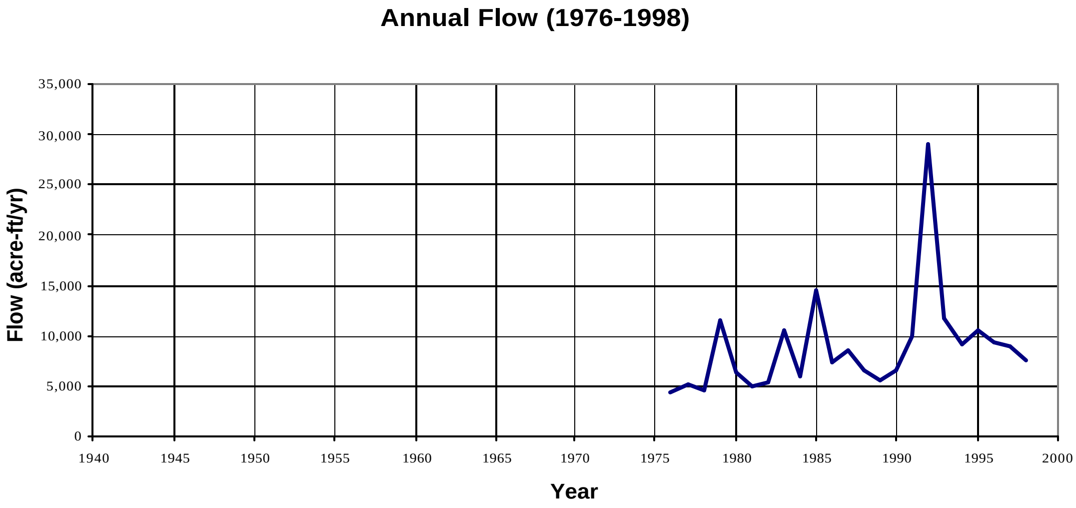
Trans-Mountain Diversions



Title: Trans-Mountain Diversions (San Juan-Chama)
Period of Record: 1972 - present
Data Source: Rio Grande Compact Commission

Figure 4.3

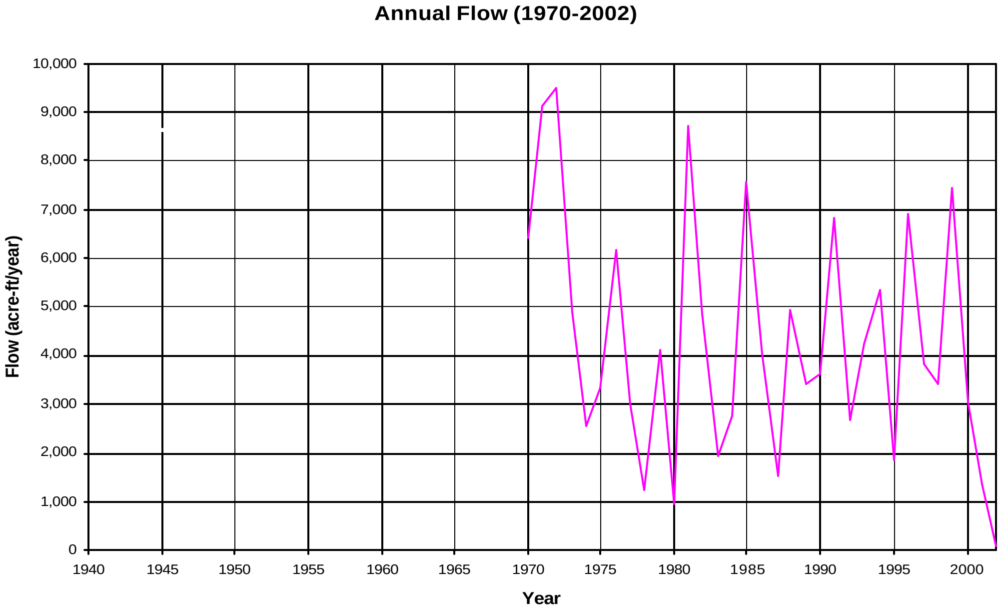
Santa Fe River



Station Name: Santa Fe River above Cochiti Lake
Station Number: 08317200
Latitude: 353249 N
Longitude: 1061341 W
Elevation : 5505 feet above NGVD
Period of Record: 1976 - 1998
Data Source: USGS

Figure 4.4

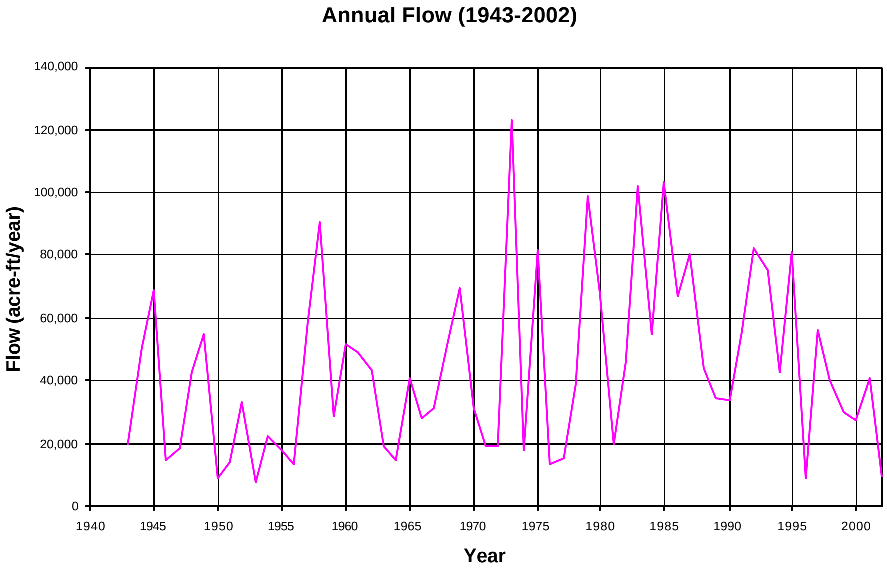
Galisteo Creek



Station Name: Galisteo Creek below Galisteo Dam
Station Number: 08317950
Latitude: 352756 N
Longitude: 1061257 W
Elevation : 5450 feet above NGVD
Period of Record: 1970 - present
Data Source: USGS

Figure 4.5

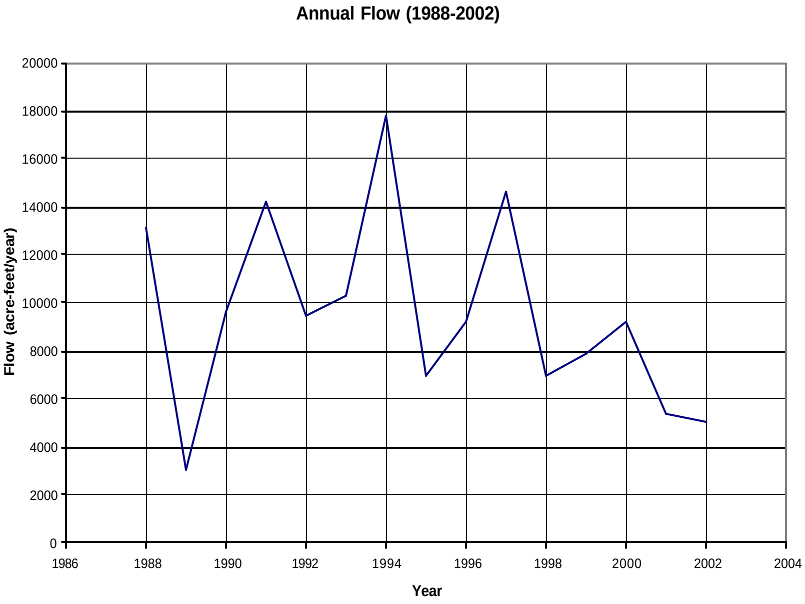
Jemez River



Station name: Jemez River below Jemez Canyon Dam
Station Number: 08329000
Latitude: 352324 N
Longitude: 1063203 W
Elevation: 5095.6 feet above NGVD
Period of Record: 1943 - present
Data Source: USGS

Figure 4.6

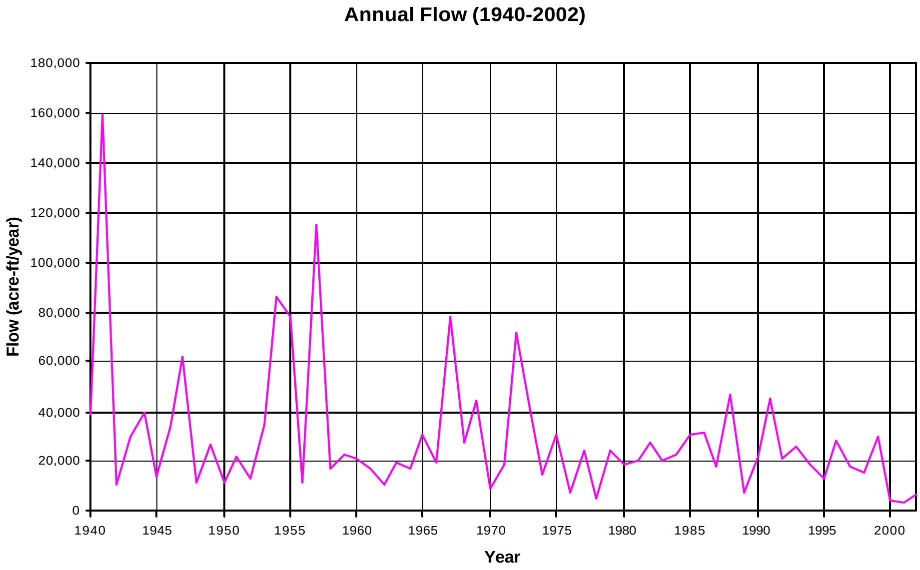
AMAFCA Inflow



Composite Flow: Albuquerque Metropolitan Arroyo Flood Control Authority channels to Rio Grande
Contributing Stations: 8329900, 8330775, and 8330600
Latitude: 351158 N, 350009 N, and 350004 N
Longitude: 1063553 W, 1063902 N, and 1063918 W
Elevation : 5015, 4930, and 5000 feet above NGVD
Composite Period of Record: 1988 - present
Data Source for Individual Stations: USGS

Figure 4.7

Rio Puerco



Station Name: Rio Puerco near Bernardo

Station Number: 08353000

Latitude: 342433 N

Longitude: 1065109 W

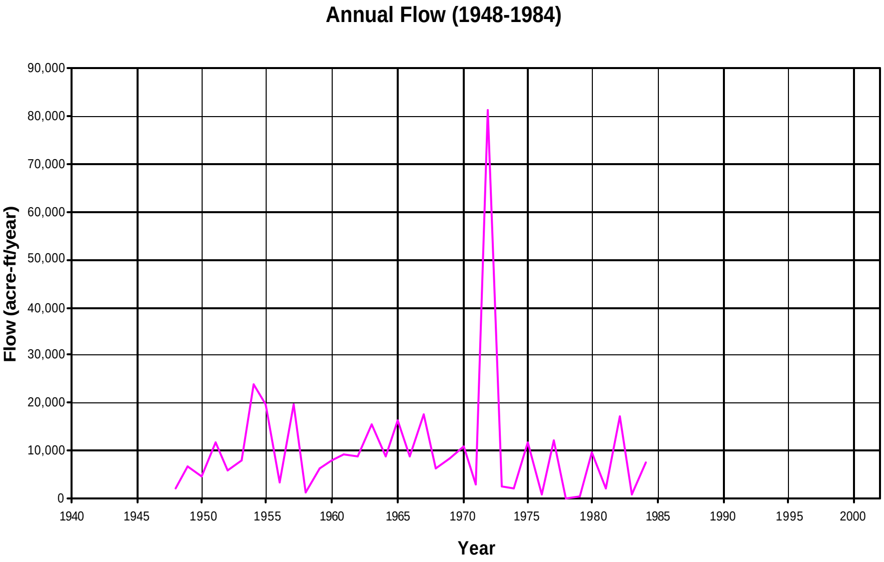
Elevation: 4722.34 feet above NGVD

Period of Record: 1940 - present

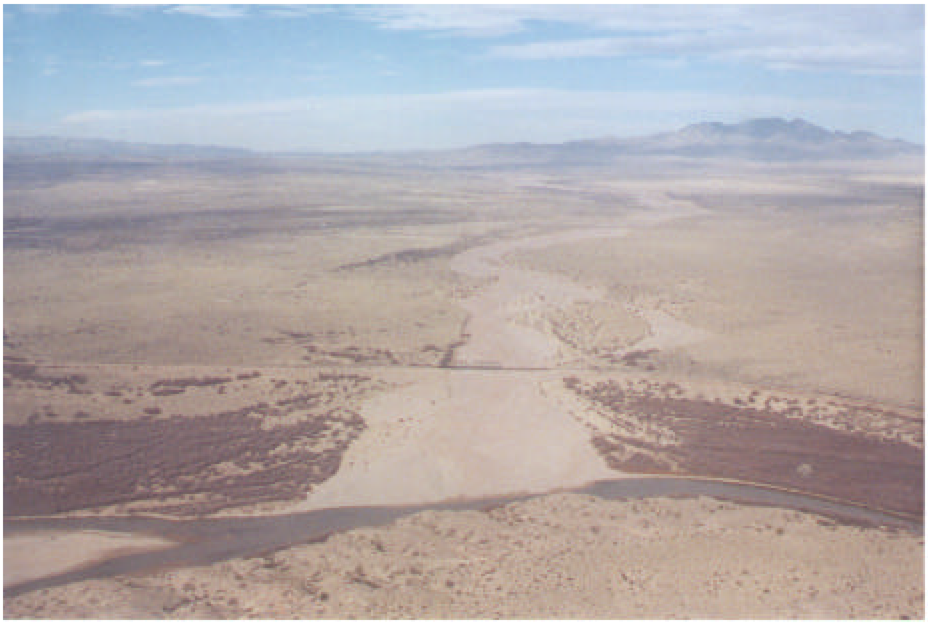
Data Source: USGS

Figure 4.8

Rio Salado



Station Name: Rio Salado near
San Acacia
Station Number: 08354000
Latitude: 341750 N
Longitude: 1065359 W
Elevation: 4765 feet above NGVD
Period of Record: 1948 - 1984
Data Source: USGS



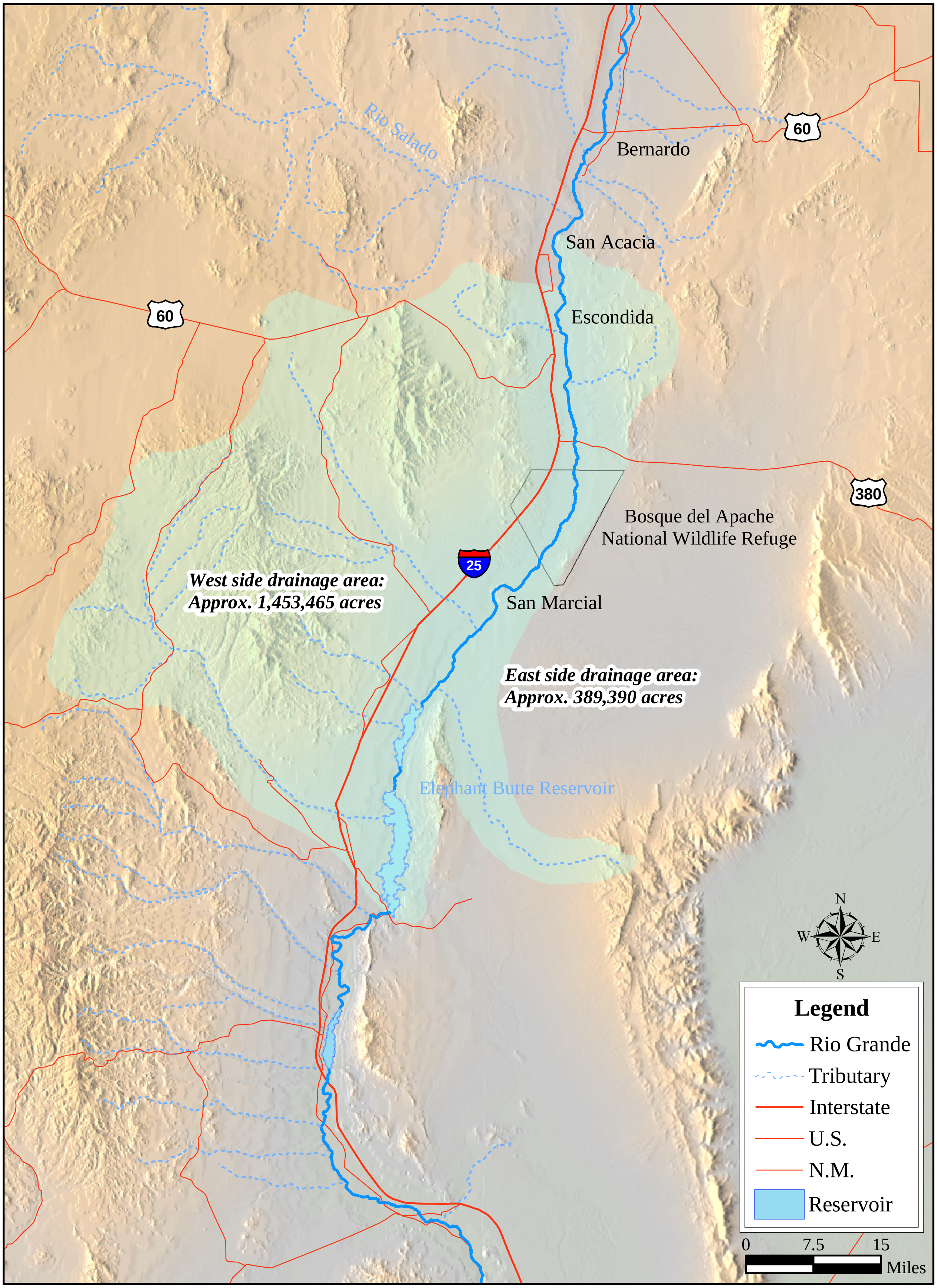
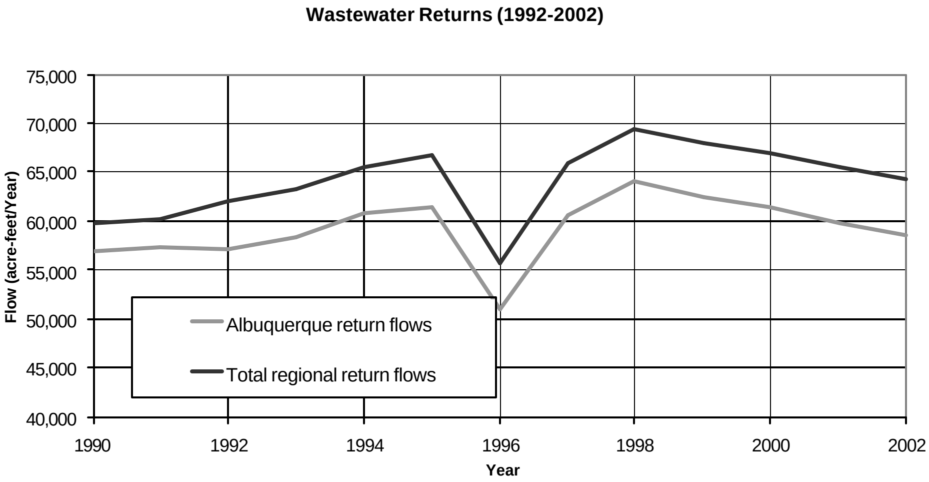


Figure 4.9 Ungaged Eastern and Western Tributary Basins South of Rio Salado

Figure 4.10

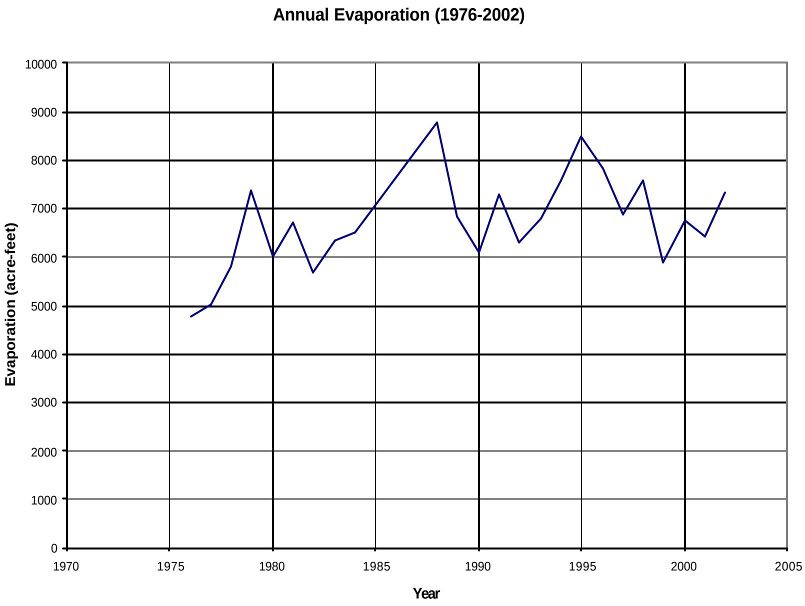
Wastewater Returns



Title: Wastewater Returns
Period of Record: 1992 - present
Data Source: USEPA
Comments: Composite of reported discharges under NPDES permits for cities of Albuquerque, Rio Rancho, Bernalillo, Los Lunas, Belen and Socorro

Figure 4.11

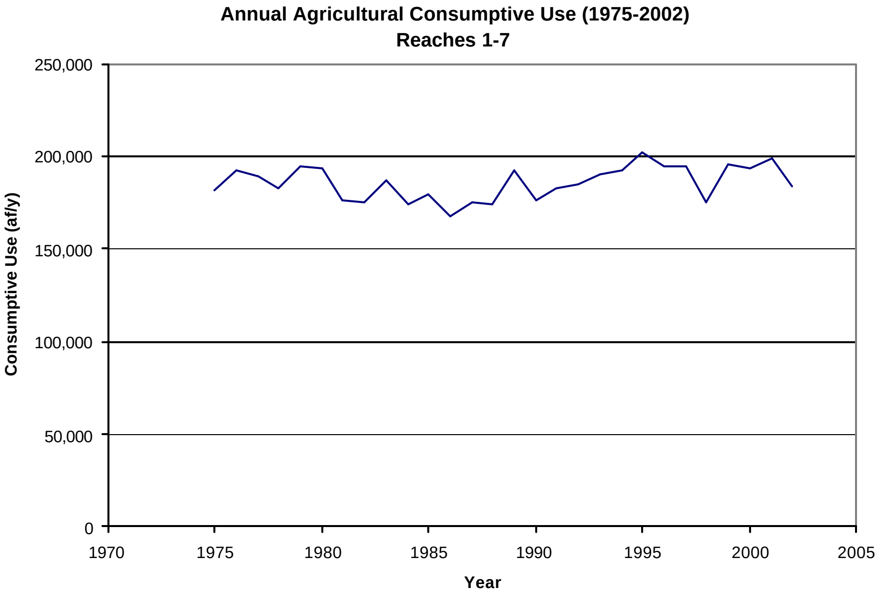
Cochiti Evaporation



Title: Evaporation from Cochiti Lake
Period of Record: 1976 - present
Data Source: U.S. Army Corps of Engineers

Figure 4.12

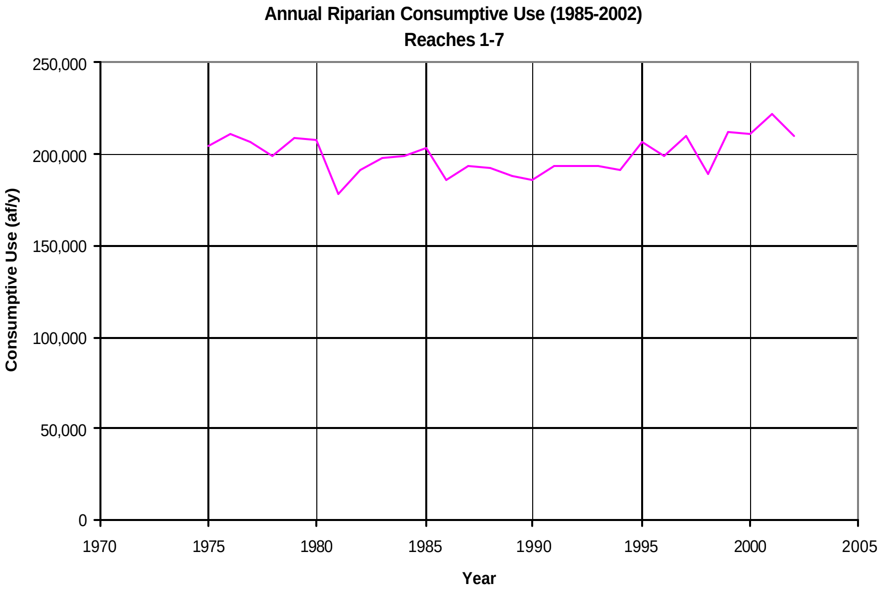
MRG Basin Agricultural Consumptive Use



Title: Agricultural Consumptive Use above San Acacia
Period of Record: 1975 - present
Data Source: USBR (ET Toolbox website, Jan. 2003)

Figure 4.13

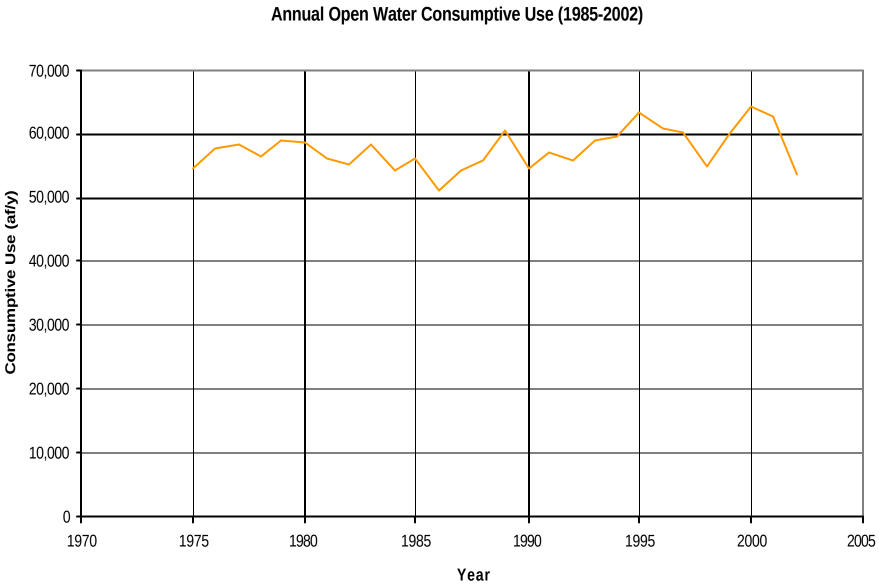
MRG Basin Riparian Consumptive Use

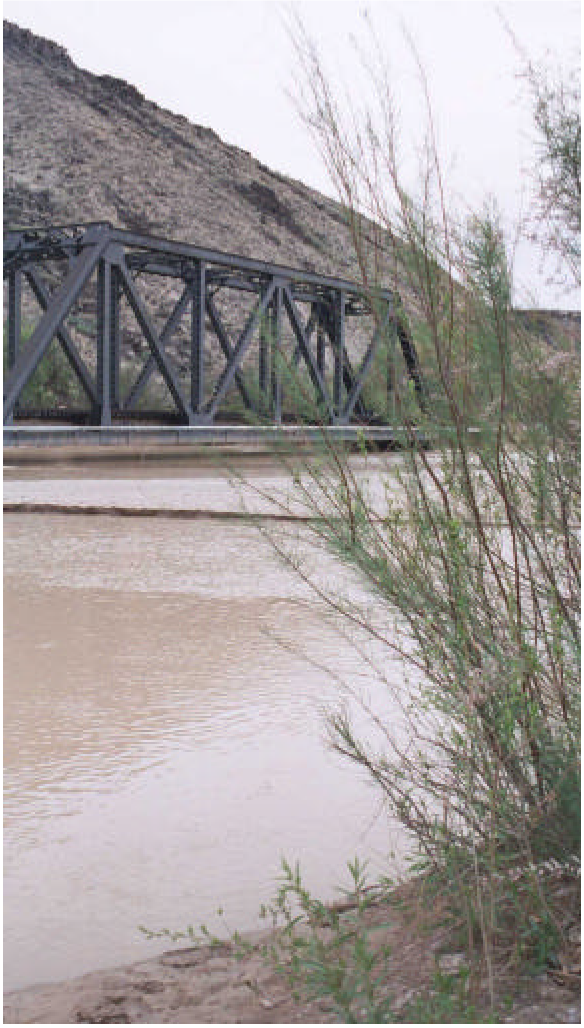


Title: Riparian Consumptive Use above San Acacia
Period of Record: 1975 - present
Data Source: USBR (ET Toolbox website, Jan. 2003)

Figure 4.14

MRG Basin Open Water Consumptive Use

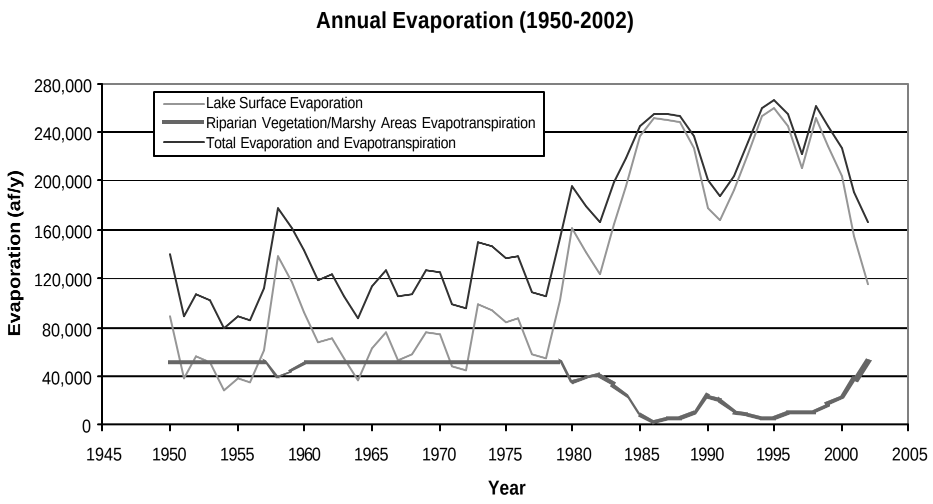




Title: Open Water Consumptive Use
Period of Record: 1975 - present
Data Source: USBR (ET Toolbox website, Jan. 2003)

Figure 4.15

Elephant Butte Evaporation



Title: Evaporation from Elephant Butte Reservoir
Period of Record: 1940 - present
Data Source: USBR

Figure 4.16

Modeled Basin-wide Total Inflow and Inflow Minus Compact Obligations

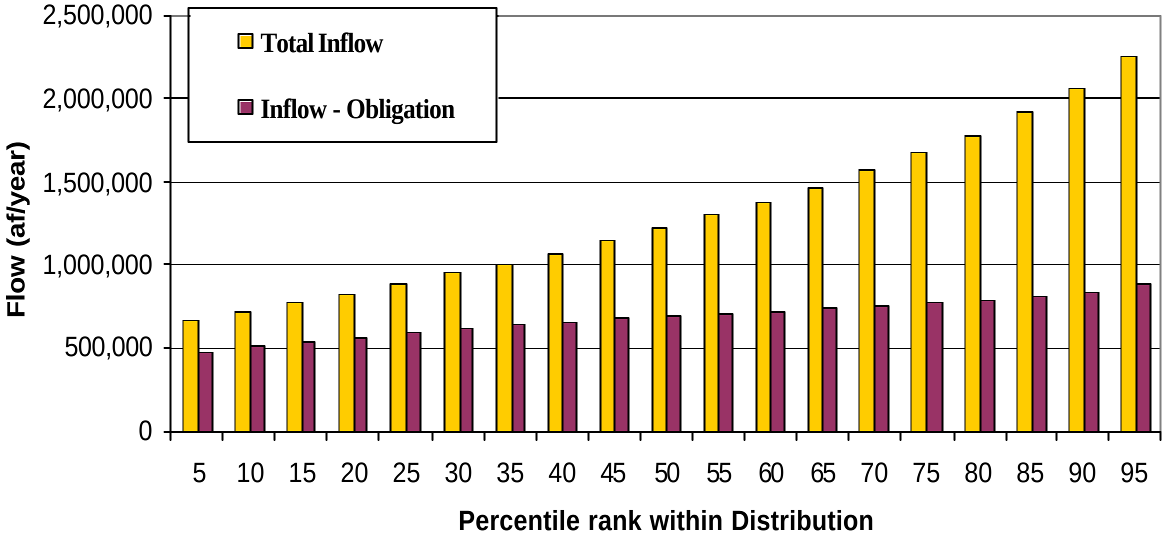


Figure 4.17

Modeled Otowi Index Supply

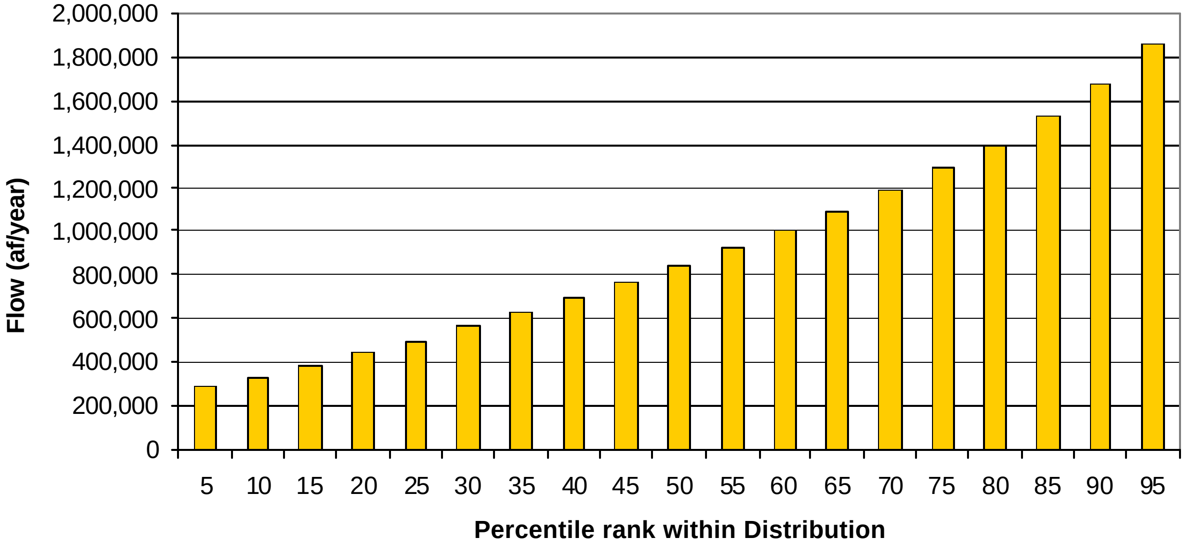


Figure 4.18
Modeled San Juan-Chama Project Inflow

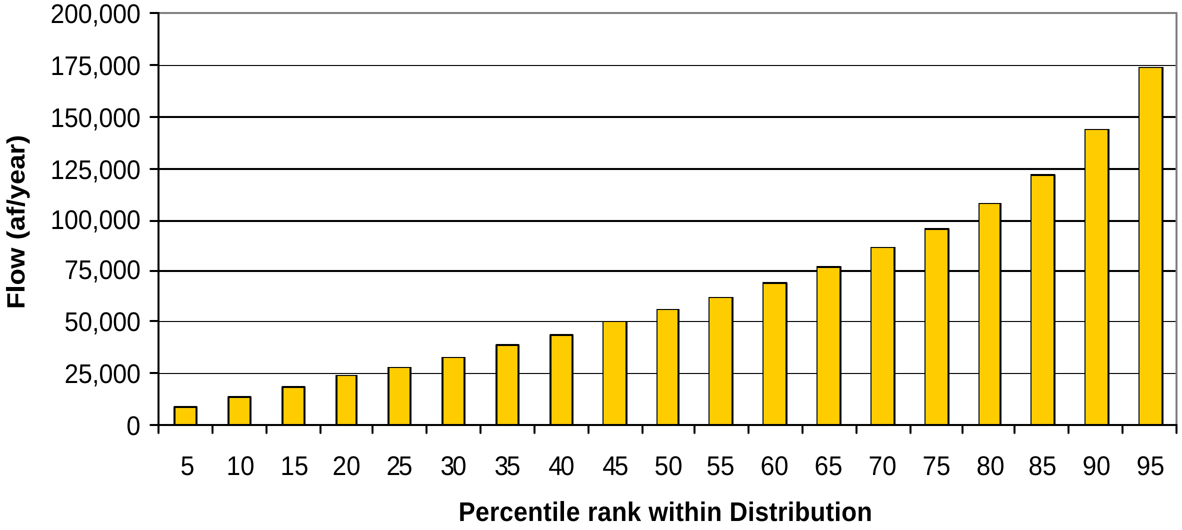


Figure 4.19
Modeled Section 1 Tributary Inflow

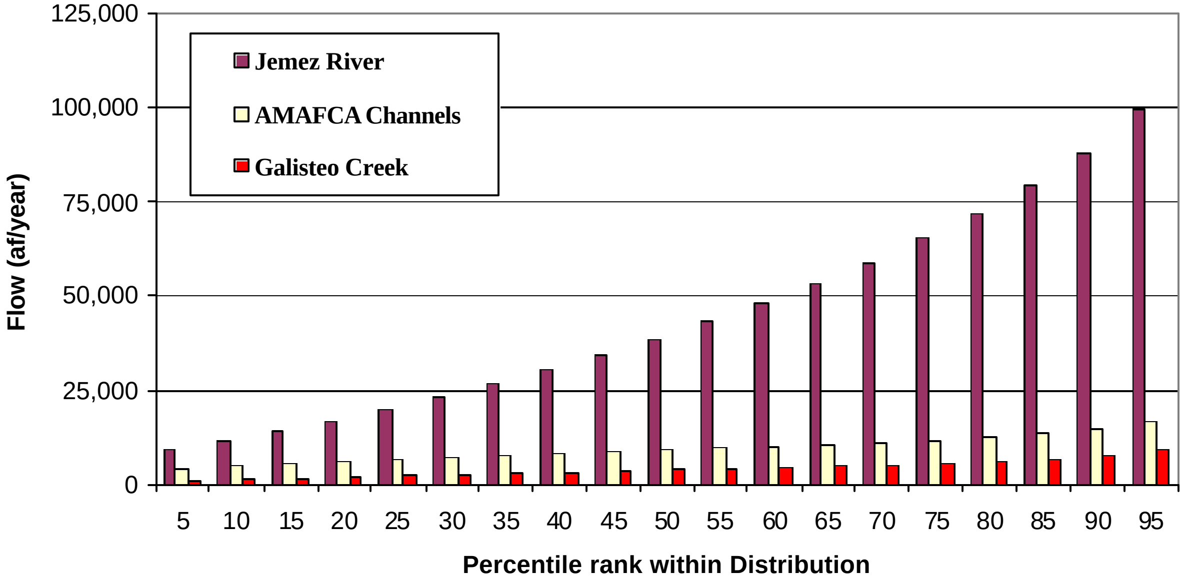


Figure 4.20
Modeled Sections 2 and 3 Tributary Inflow

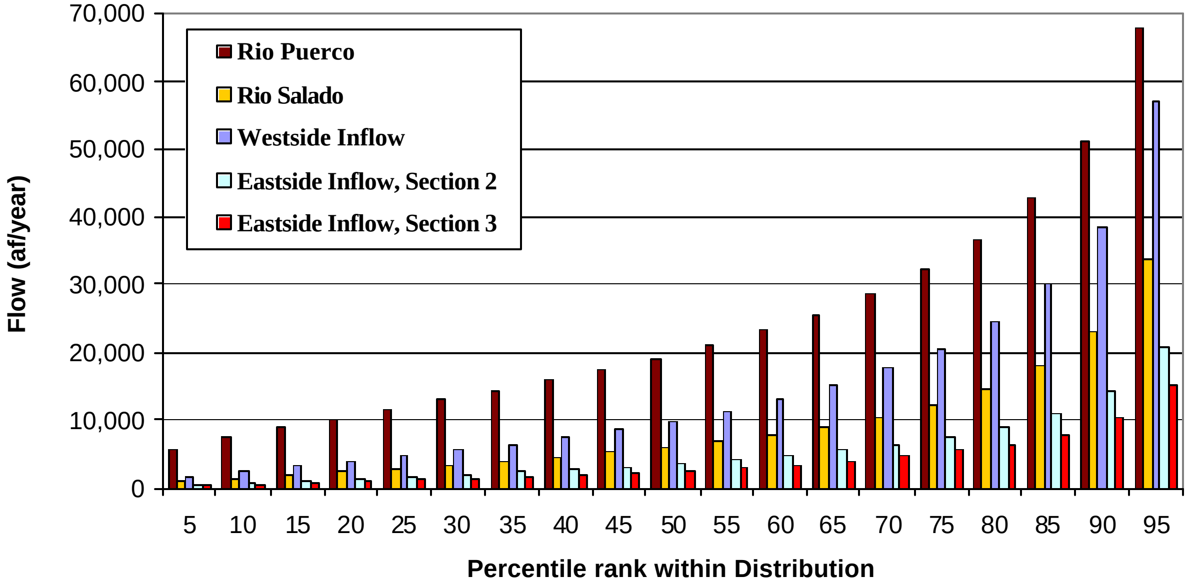


Figure 4.21
Modeled Basin-wide Available Inflow and Depletions

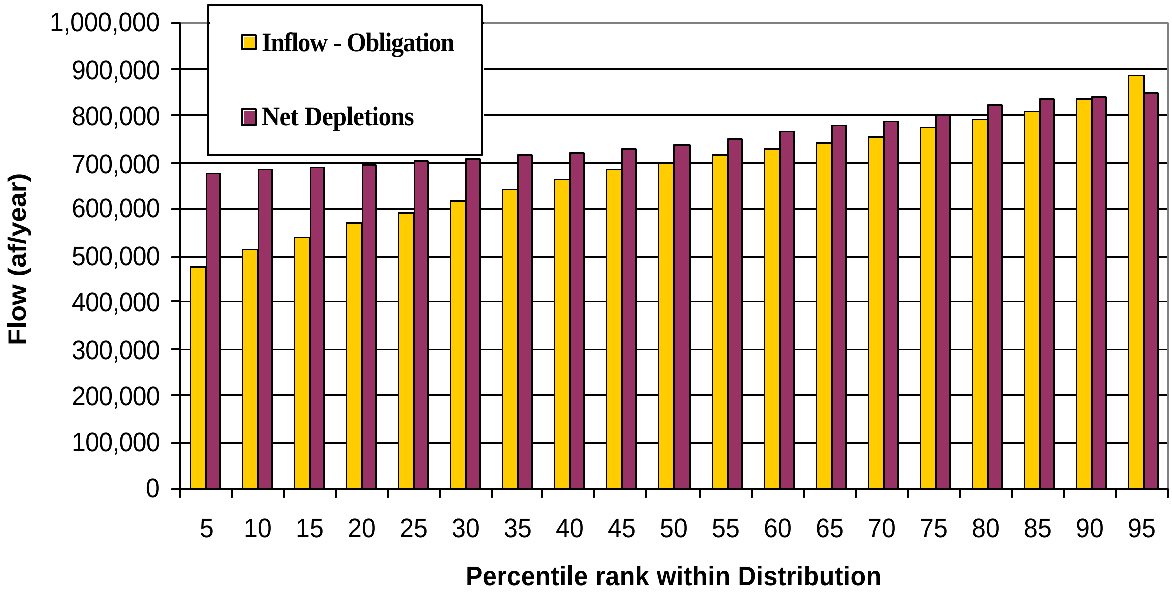


Figure 4.22
Modeled Elephant Butte Losses

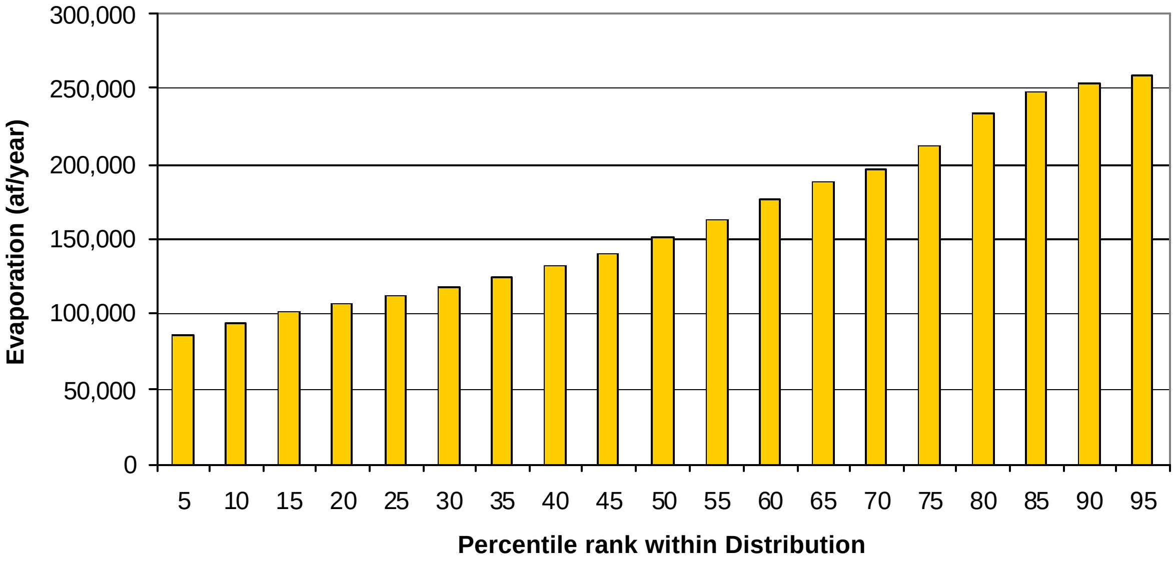


Figure 4.23
Total Agricultural, Riparian and Open Water Consumptive Use

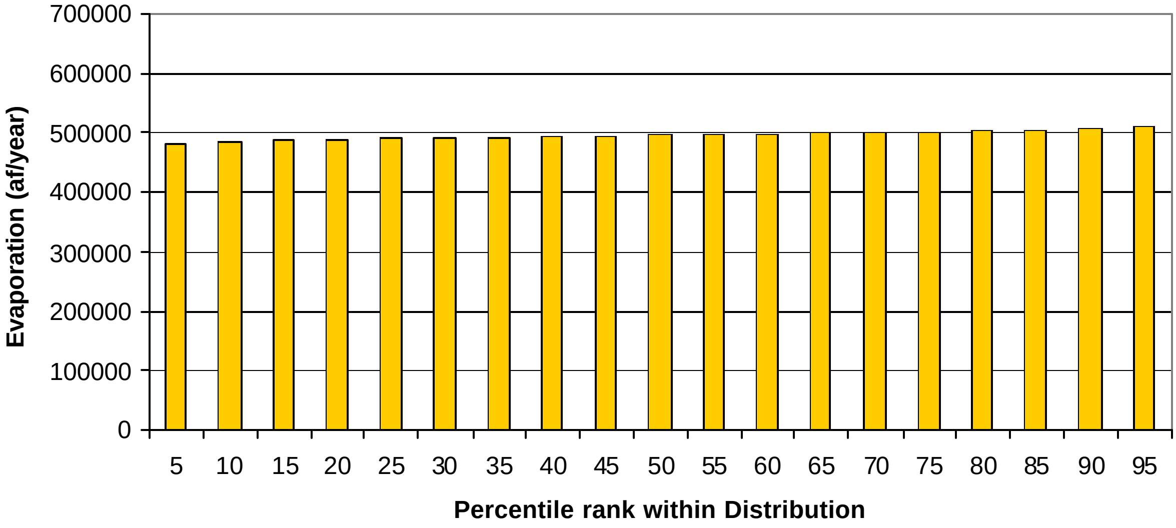


Figure 4.24
Base-Case Credit-Debit

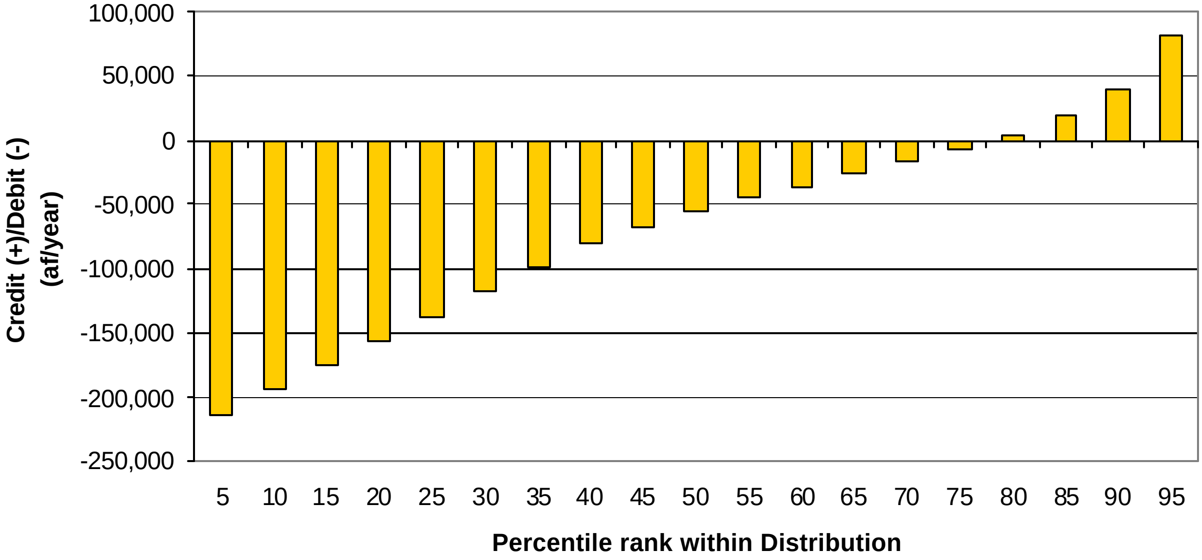
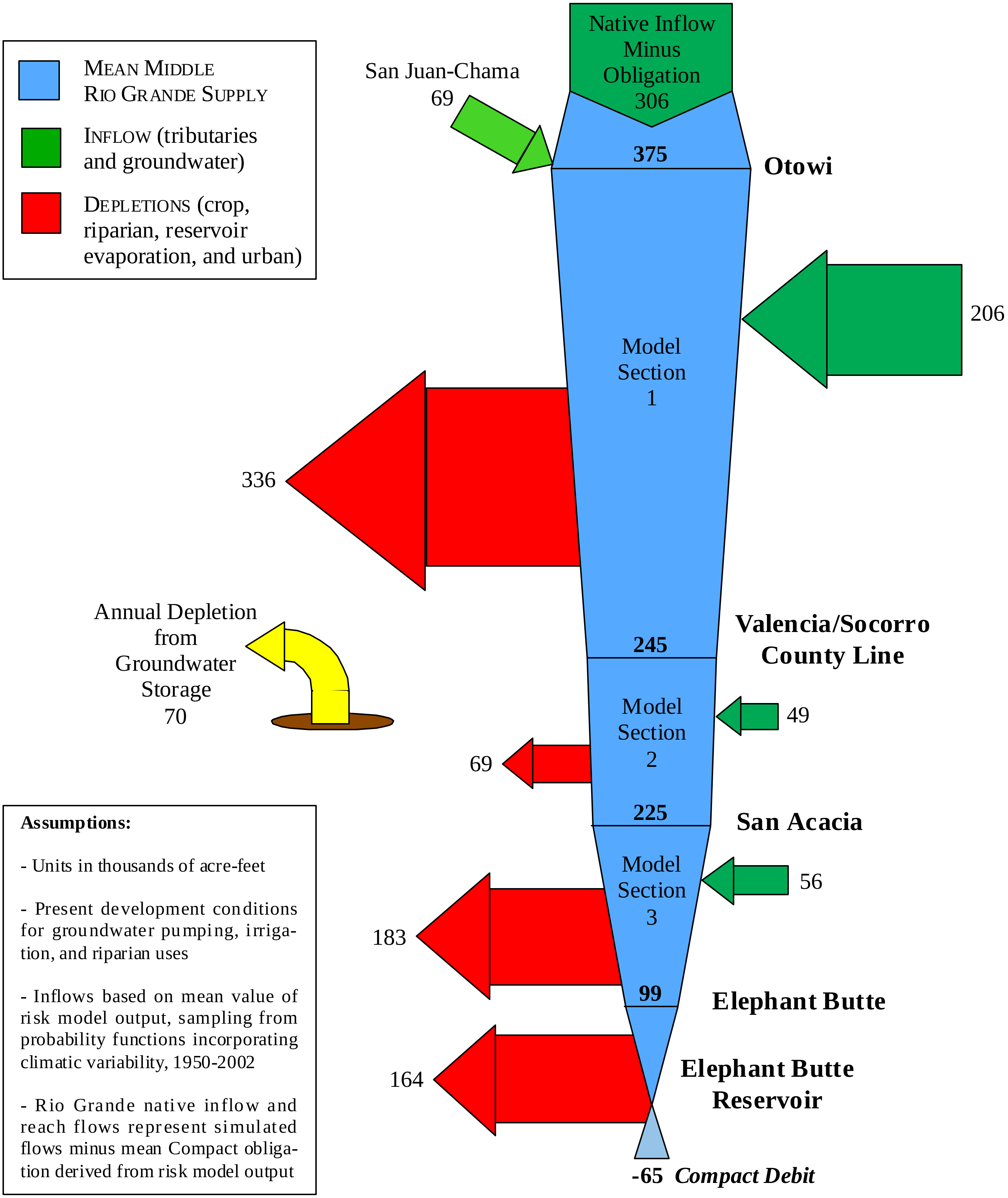


Figure 4.25

Mean Annual Middle Rio Grande Water Supply Under Present Conditions



Assumptions:

- Units in thousands of acre-feet

- Present development conditions for groundwater pumping, irrigation, and riparian uses

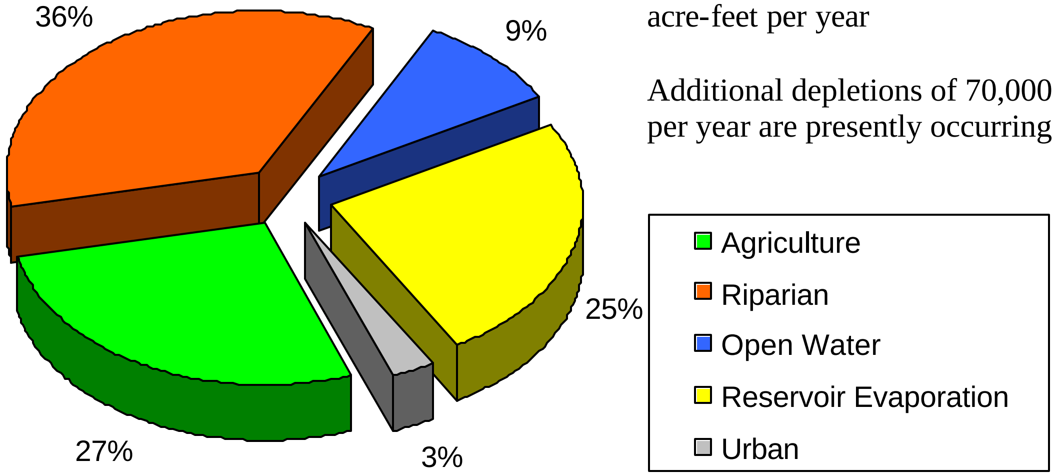
- Inflows based on mean value of risk model output, sampling from probability functions incorporating climatic variability, 1950-2002

- Rio Grande native inflow and reach flows represent simulated flows minus mean Compact obligation derived from risk model output

Figure 4.26

Summary of Mean Depletions, Grouped by Use

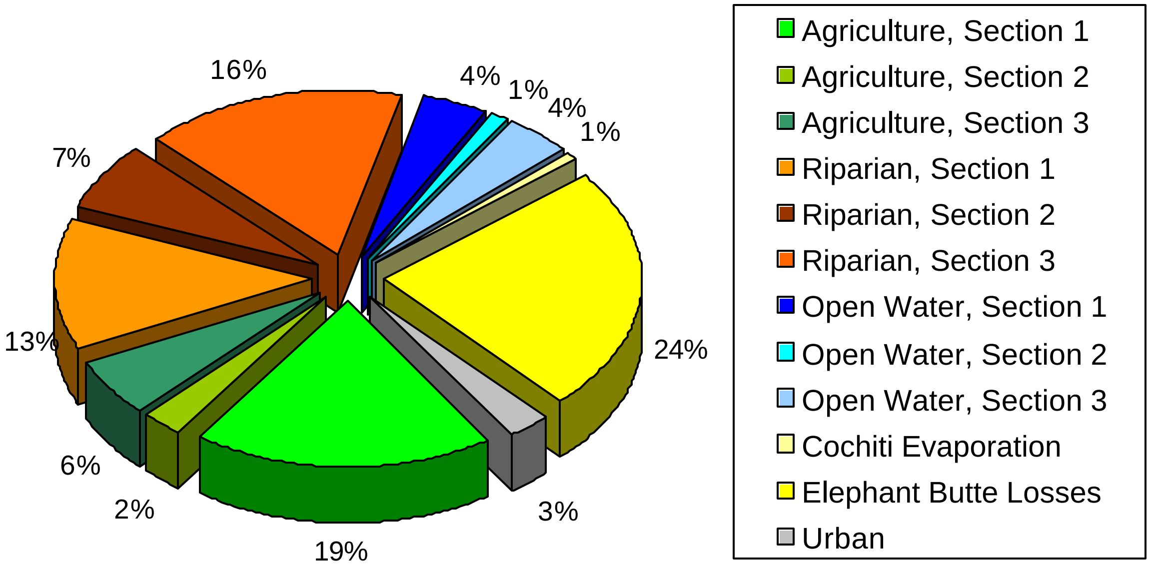
a) Mean depletions to River System (acre-feet per year)
(Year 2000 Land Use and Groundwater Development Conditions)



Note: Shown are percentages of total mean river depletions of approximately 685,400 acre-feet per year

Additional depletions of 70,000 acre-feet per year are presently occurring to aquifer

b) Mean depletions to River System (acre-feet per year), Detailed View



*Sections are:

Model section 1 – Cochiti to Valencia/Socorro county line
Model section 2 – Valencia/Socorro county line to San Acacia
Model section 3 – San Acacia to Elephant Butte Reservoir

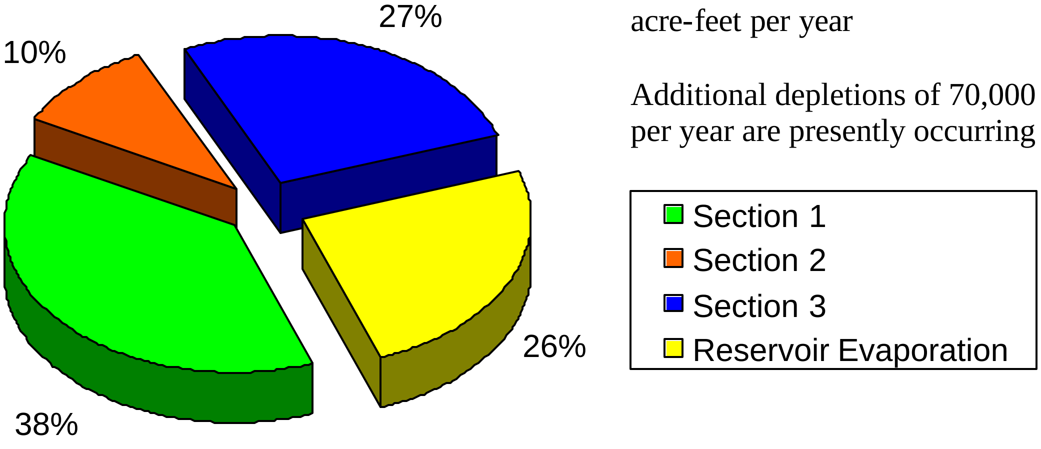
4.27

Summary of Mean Depletions, Grouped by Geographic Section*

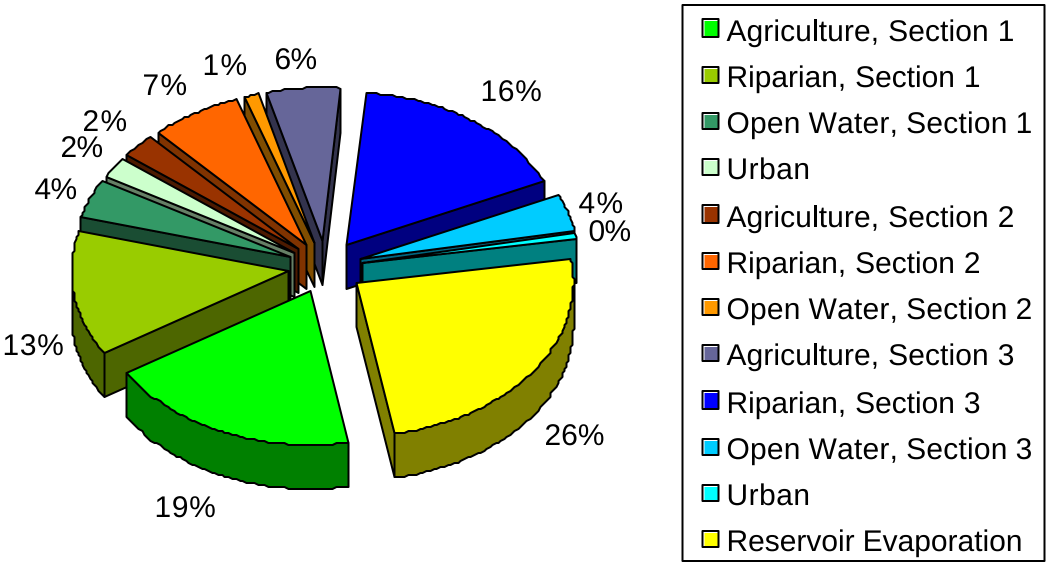
a) Mean depletions to River System (acre-feet per year)
(Year 2000 Land Use and Groundwater Development Conditions)

Note: Shown are percentages of total mean river depletions of approximately 685,400 acre-feet per year

Additional depletions of 70,000 acre-feet per year are presently occurring to aquifer



b) Mean depletions to River System (acre-feet per year), Detailed View



*Geographic sections are:
Model section 1 – Cochiti to Valencia/Socorro county line
Model section 2 – Valencia/Socorro county line to San Acacia
Model section 3 – San Acacia to Elephant Butte Reservoir

Table 4.1

Water Budget Flow and Depletion Terms

Adjusted Inflow, Model Section 1	Otowi Index Supply minus Obligation minus Elephant Butte Evaporation San Juan-Chama flow Santa Fe River above Cochiti Jemez River Galisteo Creek AMAFCA Channels Wastewater returns above county line Net groundwater inflow above San Acacia Effective precipitation above county line
Depletions, Model Section 1	Cochiti evaporation Santa Fe depletions Groundwater pumping depletions above county line Agricultural consumptive use above county line Riparian consumptive use above county line Open water consumptive use above county line Ungaged tributaries east of Rio Grande
Outflow from Model Section 1	Equals Adjusted Section 1 Inflow – Section 1 Depletions
Adjusted Inflow, Model Section 2 and 3	Section 1 Outflow Rio Puerco Rio Salado Wastewater returns below county line Ungaged tributaries west of the Rio Grande Ungaged tributaries east of the Rio Grande Net groundwater inflow below San Acacia Effective precipitation below county line
Depletions, Model Section 2 and 3	Groundwater pumping depletions below county line Agricultural consumptive use below county line Riparian consumptive use below county line Open water consumptive use below county line
Section 3 Outflow	Equals New Mexico Compact Credit/Debit

Note: Section 1 – Otowi to County Line
Section 2 – County Line to San Acacia
Section 3 – San Acacia to Elephant Butte

Table 4.2

Inflow and depletion terms, in acre-feet per year, used in the Phase 2 and Phase 3 modeling.

Inflow term	Phase 2 Distribution				Phase 3 Distribution			
	Distribution	m	s	Dependency	Distribution	m	s	Dependency
Otowi Index Supply	296500 + Beta(0.844,1.522) * 1872965	964,624	489,031		254000 + Beta(0.8735, 1.5947) * 1920000	930,084	493,352	
San Juan-Chama Project water	Static = 75,844				Gamma(1.545,46327, Truncate(0,255000))	68,613	51,348	-0.58 of Otowi Index
Santa Fe River above Cochiti	Static = 9,956				Static = 9,580			
Jemez River	7748 + Beta(0.807,1.631) * 115152	45,636	28,040	0.8805 on Otowi Index	(7740 + Beta(0.7933, 1.6992)* 115000)	44,750	28,726	0.85 on Otowi Index
Galisteo Creek	Gamma(3.44,1300, Truncate(928,9505))	4,469	2,360		Weibull(1.7365,4748, Truncate(0,20000))	4,225	2,509	
AMAFCA Channels	Uniform(3072,17845)	10,459	4,265		Gamma(5.62,1692, Truncate(0,36000))	9,519	3,999	
Effective precipitation, entire region	Static = 38,535				Static = 46,698			
Wastewater returns, entire region	Static = 68,941				Static = 66,734			
Rio Puerco	Pearson6(8.15,4.37,11609, Truncate(4753,115422))	30,966	27,107		Lognormal(25832,22432, Truncate(0,230000))	25,645	21,735	
Rio Salado	Pearson6(2.95,2.40,5343, Truncate(110,100000))	10,345	13,449	0.6688 on Rio Puerco	Lognormal(10542,15311, Truncate(0,160000))	10,393	13,830	0.56 on Rio Puerco
Ungaged Tributaties (Westside Inflow)	Pearson6(2.95,2.40,5343, Truncate(110,100000)) * 1.5	15,518		0.5 on Rio Salado	Lognormal(10542,15311, Truncate(0,160000))*1.65	17,090	21,560	0.4 on Rio Puerco
Eastside inflow, Section 1					Static = 420			
Eastside inflow, Section 2					Lognormal(10542,15311, Truncate(0,160000))*0.61	6,381	8,407	0.3 on Rio Puerco
Eastside inflow, Section 3	Pearson6(2.95,2.40,5343, Truncate(110,100000)) /1.02	10,552		0.5 on Rio Salado	Lognormal(10542,15311, Truncate(0,160000))*0.44	4,602	6,064	0.3 on Rio Puerco
Groundwater inflow above San Acacia	Static = 91,589				Static = 49,940			
Groundwater inflow below San Acacia	Static = 16,500				Static = 16,500			
Cochiti Evaporation	Loglogistic(4770,2482,2.46, Truncate(4770, 20220))	7,827	2,235		Normal(6708,977)	6,708	977	
Santa Fe GW pumping depletions	Static = 2,400				Static = 2,587			
GW pumping depletions above San Acacia	Static = 94,360				Static = 79,600			
Agricultural ET, entire region	Weibull distribution	248,096		-0.3622 on Otowi Index	Normal(185848, 9101)	185,848	9,101	-0.43 on Rio Puerco
Riparian and Open Water ET, entire region	Logistic distribution	246,500			Static = 310,410			
GW pumping depletions below San Acacia	Static = 2,507				Static = 3,300			
Elephant Butte Evaporation	Histogram(28254,260094, {7,12,7,3,3,3,1,3,3,7})	123,119	74,347	0.4965 on Otowi Index	Histogram(79360,265949, {7,10,7,5,4,6,2,3,9})	163,577	58,323	0.46 on Otowi Index

Mean (μ) and Standard Deviation (σ) given in af/y.

Table 4.3
Agricultural Consumptive Use

Model Section	Irrigated Agricultural Acreage	ET Rate (af/acre/y)	Potential CU (af/y)	Adjusted ET rate (af/acre/y)	Adjusted CU (af/y)
1 - Cochiti to Socorro County Line	44,291	3.93	173,965	2.95	130,473
2 - Socorro County Line to San Acacia	5,719	3.93	22,494	2.95	16,870
3 - San Acacia to Elephant Butte Res.	13,490	3.80	51,320	2.85	38,490

Table 4.4
Riparian Consumptive Use

Model Section	Riparian Acreage	ET Rate (af/acre/y)	Riparian CU (af/y)
1 - Cochiti to Socorro County Line	24,565	3.62	89,032
2 - Socorro County Line to San Acacia	12,400	3.62	44,829
3 - San Acacia to Elephant Butte Res.	28,198	4.00	112,792

Table 4.5
Open Water Consumptive Use

Model Section	Open Water Acreage	ET Rate (af/acre/y)	Open Water CU (af/y)
1 - Cochiti to Socorro County Line	5,088	5.52	28,106
2 - Socorro County Line to San Acacia	1,397	5.57	7,787
3 - San Acacia to Elephant Butte Res.	4,947	5.63	27,863

Table 4.6
Detailed Base-Case Model Statistical Output (Page 1 of 4)

Name	Total Inflow	Obligation	Inflow - Obligation	Net Depletions	Credit/ Debit	OTOWI Index Supply	San Juan - Chama	Jemez River
Mean	1,311,174	624,104	687,070	751,971	-64,901	930,084	68,613	44,750
Std Deviation	498,928	406,296	127,562	58,943	96,223	493,352	51,348	28,726
Minimum	513,628	144,796	368,670	642,763	-296,651	254,028	28	7,740
5%	668,038	165,359	474,289	673,806	-214,776	290,103	8,767	9,320
10%	721,335	191,242	510,440	682,367	-194,420	335,512	14,159	11,468
15%	772,970	220,119	539,516	688,731	-175,182	386,174	19,310	14,045
20%	829,354	253,733	568,715	694,967	-157,087	444,368	23,903	16,818
25%	886,207	286,883	593,033	700,924	-138,243	501,497	28,520	19,885
30%	949,621	324,036	617,528	706,432	-117,791	564,467	33,545	23,313
35%	1,009,334	364,854	642,052	713,392	-99,237	632,548	38,991	26,943
40%	1,072,671	407,156	662,613	721,287	-81,253	701,778	44,504	30,573
45%	1,148,055	453,250	682,252	729,863	-67,281	772,692	49,974	34,317
50%	1,228,124	504,640	698,604	739,797	-55,273	847,381	56,208	38,617
55%	1,302,363	561,962	713,749	751,973	-44,947	925,268	62,792	43,623
60%	1,379,327	622,709	727,475	765,269	-35,448	1,001,987	69,695	48,299
65%	1,466,984	697,424	741,136	776,535	-26,196	1,088,865	77,192	53,209
70%	1,569,495	788,582	757,262	786,717	-17,256	1,187,722	86,228	58,519
75%	1,674,796	891,741	771,511	800,862	-7,527	1,294,579	95,941	65,102
80%	1,784,627	994,712	789,086	820,636	3,779	1,398,699	107,364	71,997
85%	1,914,939	1,124,126	809,442	833,406	18,500	1,529,126	122,071	79,646
90%	2,067,530	1,274,158	835,774	841,563	40,230	1,679,158	143,722	88,241
95%	2,252,092	1,451,702	884,600	849,860	82,636	1,856,702	174,310	99,705
Maximum	2,787,037	1,763,029	1,388,173	879,642	620,268	2,168,029	254,489	122,448

Table 4.6
Detailed Base-Case Model Statistical Output (Page 2 of 4)

Name	Galisteo Creek	AMAFCA Channels	Rio Puerco	Rio Salado	Westside Inflow	Eastside Inflow, Section 2	Eastside Inflow, Section 3
Mean	4,225	9,519	25,645	10,393	17,090	6,381	4,602
Std Deviation	2,509	3,999	21,735	13,830	21,560	8,407	6,064
Minimum	38	924	913	93	219	35	25
5%	881	4,016	5,720	1,038	1,712	636	458
10%	1,337	4,830	7,466	1,508	2,511	935	675
15%	1,675	5,533	8,868	1,967	3,241	1,191	859
20%	2,012	6,126	10,252	2,398	4,022	1,489	1,074
25%	2,340	6,615	11,658	2,939	4,790	1,773	1,279
30%	2,627	7,103	13,077	3,477	5,618	2,087	1,505
35%	2,912	7,580	14,436	4,017	6,524	2,459	1,774
40%	3,200	8,005	15,891	4,595	7,556	2,817	2,032
45%	3,511	8,450	17,399	5,261	8,643	3,215	2,319
50%	3,819	8,965	19,122	6,031	9,901	3,690	2,662
55%	4,164	9,489	21,191	6,920	11,378	4,193	3,025
60%	4,510	9,974	23,234	7,858	13,147	4,811	3,470
65%	4,885	10,554	25,690	9,114	15,094	5,571	4,018
70%	5,257	11,167	28,657	10,528	17,650	6,495	4,685
75%	5,682	11,857	32,390	12,278	20,582	7,615	5,492
80%	6,197	12,607	36,578	14,520	24,498	8,988	6,483
85%	6,820	13,590	42,739	17,948	30,117	11,080	7,992
90%	7,661	14,811	51,197	23,032	38,534	14,322	10,331
95%	8,998	16,852	67,775	33,776	56,938	20,868	15,052
Maximum	17,119	34,182	220,113	159,293	262,398	95,135	68,622

Table 4.6
Detailed Base-Case Model Statistical Output (Page 3 of 4)

Name	Cochiti Evaporation	Agricultural ET, Section 1	Agricultural ET, Section 2	Agricultural ET, Section 3	Elephant Butte Losses base case	Elephant Butte Losses, SSPR Alternative 1A	Section 1 Adjusted Inflow
Mean	6,716	130,048	16,720	39,014	163,577	151,692	419,867
Std Deviation	971	6,436	827	1,931	58,323	63,343	74,869
Minimum	2,996	105,547	13,570	31,664	79,374	62,339	232,165
5%	5,085	119,380	15,349	35,814	86,331	69,859	294,841
10%	5,463	121,927	15,676	36,578	94,012	78,160	312,133
15%	5,718	123,463	15,874	37,039	101,644	86,257	322,484
20%	5,914	124,710	16,034	37,413	107,082	91,600	334,068
25%	6,070	125,752	16,168	37,726	112,256	96,684	349,005
30%	6,217	126,722	16,293	38,017	117,690	102,023	365,614
35%	6,352	127,577	16,403	38,273	124,644	107,952	387,051
40%	6,471	128,435	16,513	38,530	132,335	115,226	409,220
45%	6,601	129,228	16,615	38,768	139,950	122,427	429,214
50%	6,722	130,017	16,716	39,005	150,963	131,053	445,505
55%	6,834	130,865	16,826	39,260	163,101	147,233	454,825
60%	6,968	131,676	16,930	39,503	176,592	165,101	463,231
65%	7,101	132,514	17,037	39,754	187,810	180,577	470,268
70%	7,235	133,366	17,147	40,010	196,902	192,369	476,355
75%	7,382	134,314	17,269	40,294	211,999	210,184	481,764
80%	7,540	135,395	17,408	40,619	234,140	227,007	487,779
85%	7,722	136,667	17,571	41,000	247,794	241,922	495,607
90%	7,960	138,274	17,778	41,482	253,611	248,994	502,914
95%	8,275	140,676	18,087	42,203	259,690	256,386	511,221
Maximum	10,585	154,014	19,802	46,204	265,940	263,986	649,482

Table 4.6
Detailed Base-Case Model Statistical Output (Page 4 of 4)

Name	Section 1 Depletion	Section 1 Outflow	SSPR Inflow to Region	SSPR Depletion	SSPR Outflow (Equals Credit/Debit)	SSPR Inflow, All Alternatives	SSPR Outflow, All Alternatives
Mean	336,089	83,779	187,405	252,306	-64,901	223,995	-28,311
Std Deviation	6,514	75,085	96,518	2,758	96,223		
Minimum	312,500	-102,398	-44,768	241,805	-296,651	-3,030	-254,960
5%	325,344	-41,219	36,919	247,734	-214,776	76,734	-176,039
10%	327,841	-24,858	57,597	248,825	-194,420	96,461	-155,908
15%	329,414	-12,977	76,828	249,484	-175,182	115,178	-136,961
20%	330,673	-1,946	95,136	250,018	-157,087	132,972	-118,919
25%	331,777	12,731	114,321	250,465	-138,243	152,048	-99,947
30%	332,742	30,148	133,986	250,881	-117,791	171,896	-80,516
35%	333,616	51,456	152,952	251,247	-99,237	190,458	-61,898
40%	334,451	73,226	171,067	251,614	-81,253	206,680	-45,776
45%	335,286	93,713	184,979	251,954	-67,281	219,848	-32,650
50%	336,048	108,297	196,826	252,292	-55,273	230,910	-21,399
55%	336,918	118,453	207,254	252,656	-44,947	240,990	-10,807
60%	337,705	126,575	216,437	253,003	-35,448	251,410	-651
65%	338,563	133,533	225,569	253,363	-26,196	261,397	8,952
70%	339,401	139,879	234,611	253,728	-17,256	270,999	18,891
75%	340,419	145,909	244,387	254,134	-7,527	281,244	29,028
80%	341,472	152,222	255,991	254,598	3,779	292,309	39,843
85%	342,786	159,328	270,912	255,143	18,500	307,374	54,786
90%	344,401	167,212	293,032	255,831	40,230	329,161	76,415
95%	346,837	176,095	335,112	256,861	82,636	370,182	116,879
Maximum	361,201	300,515	878,921	262,577	620,268	920,486	661,833

5.0 REGIONAL WATER PLANNING ALTERNATIVES

A key element of the Middle Rio Grande Water Supply Study, Phase 3, involves providing technical support to the Middle Rio Grande Planning Region (MRGPR) and the Socorro-Sierra Planning Region (SSPR) in evaluation of their respective regional water planning alternatives. The areas of technical support includes assisting the regions in interpretation of hydrology and water resources relevant to their planning region, and evaluation of water supply alternatives developed by the regions, particularly with respect to overall basin-wide water supply and Rio Grande Compact limitations.

This section describes the analyses conducted of alternatives posed separately by each planning region, and joint evaluation of the combined alternatives from both regions. The analyses utilize the probabilistic water budget model described in Section 4, with modifications as needed to evaluate the proposed alternatives. Preliminary supporting work also has been provided to the planning regions periodically as they have worked to develop their alternatives. Supporting documentation produced during the alternative development period, where applicable, will be cited in the discussion in this section and is provided in Appendices G and H of this report.

5.1 Middle Rio Grande Planning Region

5.1.1 Background

5.1.2 Hydrologic Assessment of Alternatives

5.1.3 Modification of the Water Budget Model for Alternatives Analysis

5.1.4 Results of Quantitative Evaluation of Middle Rio Grande Planning Region Alternatives

5.2 Socorro-Sierra Planning Region

5.2.1 Background

In February of 2003, the Socorro-Sierra Planning Region (SSPR) finalized a list of 16 water planning alternatives. Of these 16, five alternatives involved changes to the regional water budget and were considered amenable to analysis using tools developed under this study. These alternatives are:

1. Evaporation control through reduced water surface areas in engineered and natural areas
2. Improve efficiency of surface water conveyance systems to agricultural land, including irrigation scheduling, metering, and ditch lining or piping
3. Improve on-farm efficiency
4. Control brush and weeds along water distribution systems and drains
5. Remove exotic vegetation (i.e. Salt cedar, Russian olive) on wide scale

Other alternatives were retained for evaluation by the SSPR and are not discussed in this section. A broader discussion of alternatives considered during the development process and a preliminary screening evaluation of many of these alternatives is contained within memoranda prepared for the SSPR, dated September 23, 2002 and March 7, 2003 (Appendix H). The March 7, 2003 memorandum provides preliminary quantitative estimates that were utilized by the SSPR in refining assumptions for the final alternatives posed for analysis and presented herein. Communications and review of subsequent preliminary analyses with the SSPR supported a process wherein some of the preliminary assumptions were refined to better reflect the alternatives being framed by the SSPR and to incorporate the local knowledge of the SSPR. A complete discussion of the alternatives, including those involving institutional controls, will be provided in the Socorro-Sierra Regional Water Plan, which is expected to be available by December 2004.

For the evaluation of the five alternatives identified above, the following analyses were performed:

- *<u>Preparation of Alternatives</u>*: Planning alternatives were evaluated to establish sensitivities and relationships between alternatives and between alternatives and other model parameters, with attention paid to how these sensitivities and relationships impact water consumption. Selected alternatives were grouped if appropriate.
- *<u>Model Set-Up and Analyses</u>*: Modifications were made to the basin-wide probabilistic water budget model to reflect the proposed alternatives. Additional modifications were made to the model to provide results in the context of the regional water supply and to include impacts on Compact obligations.
- *<u>Evaluation of Regional Water Budget Terms and their Variation</u>*: The regional water budget was evaluated as a subset of the basin-wide water budget to facilitate a comparison of supply and demand in the planning region. The various alternatives are described in terms of how they impact the regional water inflows (and outflows) and variations of these flows.

For this analysis, the downstream flow requirements (Compact obligation and anticipated Elephant Butte losses) were removed upfront from the upstream inflow to the study area. With this methodology, the "inflow" to the SSPR can be conceptualized as the Rio Grande flow at the Socorro county line, minus Compact obligation and Elephant Butte losses, plus inflows occurring below the county line. Though from a geographical or physical point of view some would characterize this quantity as *supply* to the Socorro-Sierra Planning Region, the validity of claims to such waters are subject to state laws of appropriation and the right to use waters will not strictly coincide with physical areas of inflow. The identification of regional water inflow in this report is described solely from a physical viewpoint.

5.2.2 Hydrologic Assessment of Alternatives

All five of the planning alternatives listed above were reviewed to assess hydrologic impacts on consumptive use. Alternative 1, evaporation control through reduced water surface areas, was subdivided into Alternatives 1A and 1B. Alternative 1A addresses reducing water surface areas and areas for potential riparian colonization in exposed portions of the Elephant Butte Reservoir north basin when the reservoir is at less than capacity. Alternative 1B addresses reducing water surface areas elsewhere in the planning region. Alternative 5 was subdivided into 3 options, A through C, based on the acreage of riparian vegetation removed, and the area from which it was removed. This subdivision is described in more detail under Alternative 5.

Alternative	Alternative Name
Alternative 1A	Evaporation control through reduced water surface areas in exposed portions of the Elephant Butte Reservoir
Alternative 1B	Evaporation control through reduced water surface areas elsewhere in the planning region
Alternatives 2, 3, and 4	Improve off-farm efficiency (includes irrigation scheduling, metering, ditch lining or piping) Improve on-farm efficiency Control brush and weeds along canals and drains
Alternative 5 – A, B, and C	Remove exotic vegetation on wide scale
All Alternatives – A, B, and C	Combined effects of Alternatives 1A, 1B, 2, 3, 4, and 5A/5B/5C

5.2.2.1 Alternative 1A: Evaporation Control in Exposed Areas of Elephant Butte Reservoir

Alternative 1A addresses evaporation control through reduction in open water evaporation and riparian colonization in exposed portions of the north basin of Elephant Butte Reservoir when reservoir levels are low. Drainage of a portion of the Elephant Butte delta and the exposed north basin is currently being undertaken by the State of New Mexico through construction of the Pilot Channel. As of July 23, 2003, this effort appears to have successfully drained several ponded areas in the portion of the north basin south of Nogal Canyon, and in general has improved flow and drainage in the areas where the channel has been completed. However, it appears that once areas are drained, or exposed by receding reservoir waters, salt cedar, and occasionally willow, colonize the area within about 3 months.

In implementing the SSPR Alternative 1A, drainage of the exposed portions of the northern basin, we have made the following assumptions:

- The state will complete the Pilot Channel through the north basin of Elephant Butte Reservoir, and will maintain the channel as long as the reservoir levels remain low;
- With the Pilot Channel in place, there will be little ponded water in the northern basin of the reservoir;
- In the absence of further intervention in the north basin, 90% of the exposed portion of the northern basin of Elephant Butte Reservoir is subject to colonization by riparian growth, with an evapotranspiration rate of 4 acre-feet per acre;
- With intervention[1], only 50% of the exposed portion of the northern basin of Elephant Butte Reservoir is subject to colonization by riparian growth, resulting in a savings of 1 acre-foot per acre of water (salt cedar, at a consumptive use of 4 acre-feet per acre, replaced with native vegetation at a consumptive use of 3 acre-feet per acre) over 40% of the total north basin acreage. Total north basin acreage is 14,196 acres (taken from DEM of reservoir – see section 4.4.5).

In the Base Case model analysis (Section 4), riparian evapotranspiration from the north basin area of Elephant Butte is included in the Elephant Butte Losses term. For the Base Case it is assumed that evapotranspiration losses occur on 90% of the exposed portion of the north basin. An alternate distribution was calculated for Alternative 1A under the

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[1] "Intervention" could be in the form of salt cedar removal and replacement with native riparian vegetation, or in the form of active drainage projects (i.e. lowering the Pilot Channel at the northern end of the reservoir so as to lower the water table in the area, potentially reducing riparian habitat).

assumption that intervention reduces evapotranspiration losses by 1 acre-foot per acre over 40% of the exposed north basin area, while 50% of the exposed north basin area continues to experience 4 acre-feet per acre of evapotranspiration.

5.2.2.2 Alternatives 1B: Evaporation Control Through Reduced Water Surface Areas Elsewhere in the Planning Region

In implementing the SSPR Alternative 1B, evaporation control through reduced water surface areas elsewhere in the planning region, the following assumptions are made:

- Open water acreage below the Socorro county line and the north end of Elephant Butte Reservoir is 6,344 acres;
- 10% of the open water acreage, or 634 acres, could be converted to native bosque;
- Open water evaporation for this area is 5.6 acre-feet per acre (average annual ET Toolbox ET rate for open water for the *Bernardo to San Acacia* and *San Acacia to San Marcial* reaches);
- Native bosque evapotranspiration for this area is 3 acre-feet per acre (King and Bawazir, 2000).

Based on these assumptions, the resulting water savings are 1,649 acre-feet per year.

5.2.2.3 Alternatives 2, 3, and 4: Improve Off-Farm Efficiency, On-Farm Efficiency, and Control Brush and Weeds Along Canals and Drains

Alternatives 2 through 4 include improvements in agricultural and conveyance efficiency through: irrigation scheduling, metering, ditch lining or piping; on-farm laser leveling of fields and lining of ditches; and controlling brush and weeds along canals and drains. These changes, though they have the potential to significantly reduce required river diversions, reduce canal seepage, and reduce on-farm water requirements (see discussion in Appendix H, March 7 2003 memo), will have little impact on crop consumptive use, the variable modeled in the basin-wide probabilistic water budget model[2].

The combined proposed changes in alternatives 2, 3, and 4 have the potential to reduce evapotranspiration from vegetation along the canals and drains, incidental

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[2] The water budget model operates on the premise that water "lost" to canal seepage and on-farm seepage is returned to the surface water system; it either flows into the drains and is returned directly, or flows to the shallow-groundwater system, which is in effective hydraulic connection with the river/drain system (physical connection is present over sufficient reaches that this mass balance is preserved although local areas of disconnection may result in some lag time for returns to the stream system).

evaporative losses from puddles in non-laser leveled fields, and evaporation from the water surfaces in the canals and drains. In the analysis of the regional water budget, these are relatively small terms; the combined impacts of implementation of Alternatives 2, 3, and 4 are estimated at 5% of the SSPR agricultural consumptive use[3], or 2,768 acre-feet per year.

5.2.2.4 Alternative 5: Removal of Exotic Vegetation

Removal of exotic vegetation has the potential to result in either significant consumptive use reduction, little change in consumptive use, or possibly even consumptive use increase depending on how it is implemented.

If areas are carefully chosen such that, with the addition of drainage, the water table can be lowered and the area cease to be riparian habitat, then once vegetation is removed and drainage installed, the area will become scrub or grassland with little or no direct evaporative loss. In this case, the evaporative savings will be on the order of 4 acre-feet per acre, the average evapotranspiration loss from salt-cedar (King and Bawazir, 2000). This may be possible in areas such as the east side of the Rio Grande north of San Antonio where arroyos no longer connect to the river and instead serve only to water large areas of salt cedar. Reconnection of the arroyos to the river might reduce salt cedar habitat along the eastern margin of the currently vegetated area. Some property owners in this area appear to be working on reconnecting arroyos to the river – if this re-engineering is combined with salt cedar removal, the area could prove a valuable test ground for the potential for this course of action to reduce salt cedar areas.

If non-native vegetation is removed but the water table remains high enough to support riparian growth, re-vegetation with native riparian plants is required to avoid re-colonization by non-native species. Removing non-natives and re-vegetating with native plants may result in evaporative savings on the order of 1 acre-foot per acre, reflecting a change from salt-cedar, at a consumptive use of 4 acre-feet per acre, to native bosque, at 3 acre-feet per acre (King and Bawazir, 2000). If the area is not re-vegetated with native riparian species, either non-natives will re-colonize the area, resulting in no water

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[3] Value based on the analysis presented in the memo of March 7, 2003, revised upward to take into account incidental depletions not previously quantified.

savings, or the water table may rise, resulting in saturated soils and standing water which evaporate at 5.6 acre-feet per year, thereby increasing consumptive use.

In analyzing this alternative, it is assumed that exotic vegetation removal in non-drainable areas will be accompanied by re-vegetation by native species. To adequately capture the potential variability in savings based on location of removal, and also to capture the possible range in acreage on which non-natives are eradicated, three options are evaluated:

- **Alternative 5A:** Removal of non-native vegetation from 4,060 acres (10% of the 40,598 riparian acres between the Socorro county line and the north end of Elephant Butte Reservoir at full capacity) in drainable areas, resulting in a decrease in consumptive use of 16,240 acre-feet per year (4 acre-feet per acre over 4,060 acres). It is assumed that the area can be drained sufficiently such that it will re-colonize only in native grasses and scrub, rather than riparian growth;
- **Alternative 5B:** Removal of non-native vegetation from 4,060 acres (10% of the riparian acreage between the Socorro county line and the north end of Elephant Butte Reservoir at full capacity), replaced with native vegetation, resulting in a decrease in consumptive use of 4,060 acre-feet per year (1 acre-foot per acre reduction in consumptive use);
- **Alternative 5C:** Removal of non-native vegetation from 20,300 acres (50% of the riparian acreage between the Socorro county line and the north end of Elephant Butte Reservoir at full capacity), replaced with native vegetation, resulting in a decrease in consumptive use of 20,300 acre-feet per year (1 acre-foot per acre reduction in consumptive use).

5.2.2.5 All Alternatives (1A, 1B, 2, 3, 4, and 5A/5B/5C)

A final evaluation, combining all five alternatives, is provided to look at the impacts of fully implementing all planning alternatives. Three versions of the full-implementation scenario, All Alternatives A, All Alternatives B, and All Alternatives C, are given corresponding to the three options for Alternative 5.

5.2.3 Modification of the Water Budget Model for Alternatives Analysis

The following changes were made to the water budget model to accommodate the SSPR alternatives:

1. All flows, water inputs, and consumptive uses were divided into above and below the Valencia/Socorro county line components;
2. Intermediate model calculations were made to quantify net inflow, regional demand, and net outflow for model sections above and below the county line;

3. Evapotranspiration losses for Elephant Butte Reservoir were recalculated to incorporate Alternative 1A, a new probability distribution was fit to the data, and the alternative distribution incorporated into the model.

These changes are described in more detail below.

The modeling done as part of the Middle Rio Grande Water Supply Study consists of two parts, the use of groundwater models other groundwater analyses to generate the base stream/aquifer exchanges and pumping-induced stream depletions; and, a probabilistic water budget model which integrates surface water inflows, groundwater effects, and consumptive use demands to determine regional Compact credit/debit. For the evaluation of the SSPR alternatives, changes were made only in the probabilistic model. None of the identified alternatives involve significant changes to groundwater conditions in the SSPR.

To provide the SSPR with inflow at the county line and consumptive use within the study area below the county line, agricultural, riparian, and open water consumptive use, effective precipitation, wastewater return flows, and tributary inflows were subdivided into above and below the Valencia/Socorro county line components. Groundwater inflow and pumping depletions obtained from the Albuquerque Basin model are assigned to the model section above the Socorro county line, to reflect the spatial distribution of the simulated pumping. Using the subdivided inflow and depletion terms, intermediate calculations were made to quantify net inflow, regional demand, and net outflow for the study area above and below the county line (Table 4.6). Inflow to the planning regions is “net” inflow, i.e., inflow minus water needed to satisfy the Compact Obligation and Elephant Butte Losses. Based on this convention, net outflow from the SSPR represents Compact credit/debit.

Within the probabilistic model, the agricultural, riparian, and open water consumptive uses, and the Elephant Butte losses required modification to represent implementation of the planning alternatives; all other terms remained as for the base case run. For Alternative 1A, a new probability distribution was prepared for the Elephant Butte Reservoir reflecting the revisions to the evapotranspiration losses in the north basin under implementation of the alternative. For Alternatives 1B and all three versions of Alternative 5 (A, B, and C), the changes imposed by implementation of the alternatives are to open water and riparian consumptive use. Since open water evaporation and riparian evapotranspiration are both included in the model as static values, no model run is required to evaluate these changes; evaluation of the alternative can be done by adjusting the SSPR demand and the resulting SSPR outflow by the acre-feet per year changes resulting from the alternatives.

For Alternatives 2, 3, and 4, implementation of the alternatives is modeled as a change in agricultural consumptive use. Agricultural consumptive use in the model is represented with a probability distribution to capture some variability due to climate-driven moisture conditions (in a wetter/cloudier season, the consumptive irrigation requirement will be lower than in a drier/hotter season). However, the combined impact of Alternatives 2, 3 and 4 are modeled as a static change. This was done for two reasons: a) the distribution used to represent agricultural consumptive use is very tight, with an average of 55,360 acre-feet per year and a standard deviation of less than 3000 acre-feet per year; and b) the average change in agricultural consumptive use resulting from implementation of the planning alternatives is 2,768 acre-feet per year. Given the nature of the agricultural consumptive use distribution and the size of the change in agricultural consumptive use resulting from implementation of the planning alternative, a modification to the algorithm of variability under the alternative would provide little benefit to the analyses.

5.2.4 Results of Quantitative Evaluation of Socorro-Sierra Planning Region Alternatives Analysis

As for the base-case scenario described in Chapter 4, the probabilistic model was run for 10,000 realizations. For each realization, water budget values were drawn from the probability distribution or otherwise specified values, for that term. Since Alternatives 1B, 2 through 4, and 5 were implemented as static changes, changes to the model were only required for Alternative 1A, and therefore only one model run was required to model the full suite of SSPR alternatives. Water budget results are presented for both the base-case and under the proposed SSPR alternatives. All flows terms are presented as net available water, with Compact deliveries and Elephant Butte Losses removed.

Table 5.1 shows the average, 10th percentile, and 90th percentile values calculated by the base case model for several water supply and demand terms, including adjusted inflow into each model section, depletions by model section, and outflow for the MRGPR and SSPR. The modeled distributions for these terms are shown in Figures 5.1 – 5.4.

Figure 5.2 shows the modeled outflow from model Section 1; this corresponds to the mainstem outflow from the MRGPR across the Valencia-Socorro county line. Flow is highly variable and ranges from –40,000 acre-feet per year to over 175,000 acre-feet per year. Negative flows in this context imply that depletions are exceeding available inflow at a given point. This may or may not result in a Compact debit, depending on the tributary inflows and depletions in the areas downstream of a given point. As can be seen, calculated (available) flows are negative below the 20th percentile at the Valencia-Socorro county line. Whether or not such a condition would result in a Compact debit is dependent on downstream inflows, and on how depletions are managed in both planning regions during a condition of low supply. Approaches to demand reduction or supply augmentation in times of drought are undergoing evaluation as part of the regional and state water planning process.

Figure 5.3 shows the modeled base case inflow to, and depletions for, model sections 2 and 3. As noted above, the depletions from the Elephant Butte Reservoir have been removed as a first step in this analysis, to isolate the available supply for alternatives analysis. Therefore, depletions shown in Figure 5.3 reflect only the crop, riparian and non-reservoir open water losses within Section 2 and 3. Inflow is highly variable, due both to the high variability in the Section 1 outflow, as well as high variability in inflow from Section 2 and 3 tributaries (Figure 4.20), while the depletions are nearly constant, varying only with the agricultural consumptive use. Inflow ranges from less than 37,000 acre-feet per year to over 335,000 acre-feet per year; depletions are about 250,000 acre-feet per year. In the current model simulation, demand is met only at the 75th percentile and above. Negative outflows from model Section 3 (Figure 5.4), corresponding to Compact debit conditions, occur at the 75th percentile and below.

The impacts of the proposed SSPR planning alternatives are shown in Table 5.3 and in Figures 5.5-5.7. The mean changes, by alternative, in model Sections 2 and 3 depletions resulting from implementation of the SSPR planning alternatives are given in Table 5.3. Since all but Alternative 1A represent static changes, no distributions are required for these terms to illustrate the range of possible outcomes. The range of impacts resulting from Alternative 1A is shown in Figure 5.5 (Table 4.6 provides maximum, minimum, standard deviation, and percentile values for this change in Elephant Butte Losses). Alternative 1A results in a mean reduction in depletions of 11,855 acre-feet per year. However, this reduction is greater when Elephant Butte losses are small (when the reservoir is at low levels, generally during dry periods), and smaller when Elephant Butte losses are large (during high reservoir levels, generally during wet periods).

The impact of full implementation of All Alternatives C on Section 2 and 3 depletions is shown in Figure 5.6. Demand is reduced at all percentiles; the reduction in demand is greater at the 5th percentile (41,200 acre-foot reduction in demand) than at the 95th percentile (30,100 acre-foot reduction in demand), resulting from the variation in reduction seen with Alternative 1A. Under full implementation of All Alternatives C, regional demand is now met at the 60th percentile and above. This can also be seen in the change in distribution of Section 3 outflow (Figure 5.7).

The point at which supply meets demand should be considered a relative, rather than absolute, measure. This model run does not take into account reduction in consumptive water use during droughts other than the reduction in Elephant Butte losses. In reality, shortages in supply would probably be shared equally between agricultural entities in the Middle Rio Grande Basin, thereby effectively increasing the Sections 2 and 3 inflow. The model currently fully satisfies the MRGPR and SSPR demand, regardless of inflow, by dipping into Compact delivery water and accruing a Compact debit for that year. The supply-meets-demand point, however, is useful as a relative tool to look at how changes in supply resulting from implementation of planning alternatives will affect the ability to meet demand. The modeled shift from the 75th to the 60th percentile in meeting demand is indicative of a shift in the ability of the region to satisfy demand during drier periods.

5.3 Combined MRGPR and SSPR Alternatives

Figure 5.1
Modeled Base Case Section 1 Inflow and Depletions

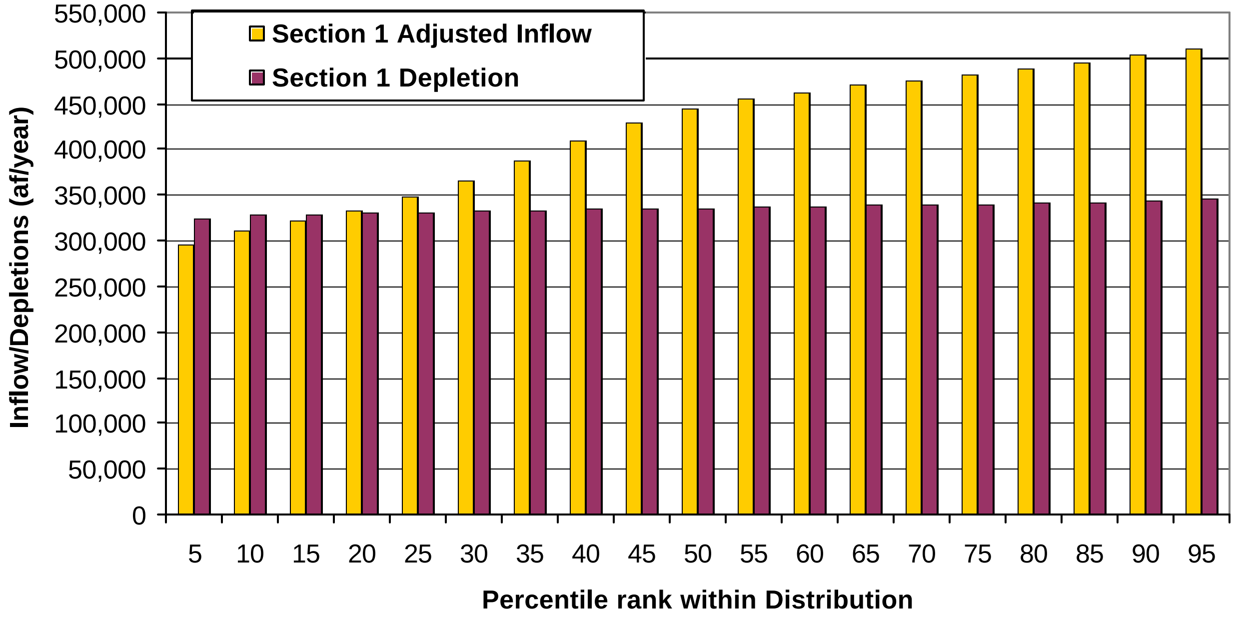

Figure 5.2
Modeled Base Case Section 1 Outflow

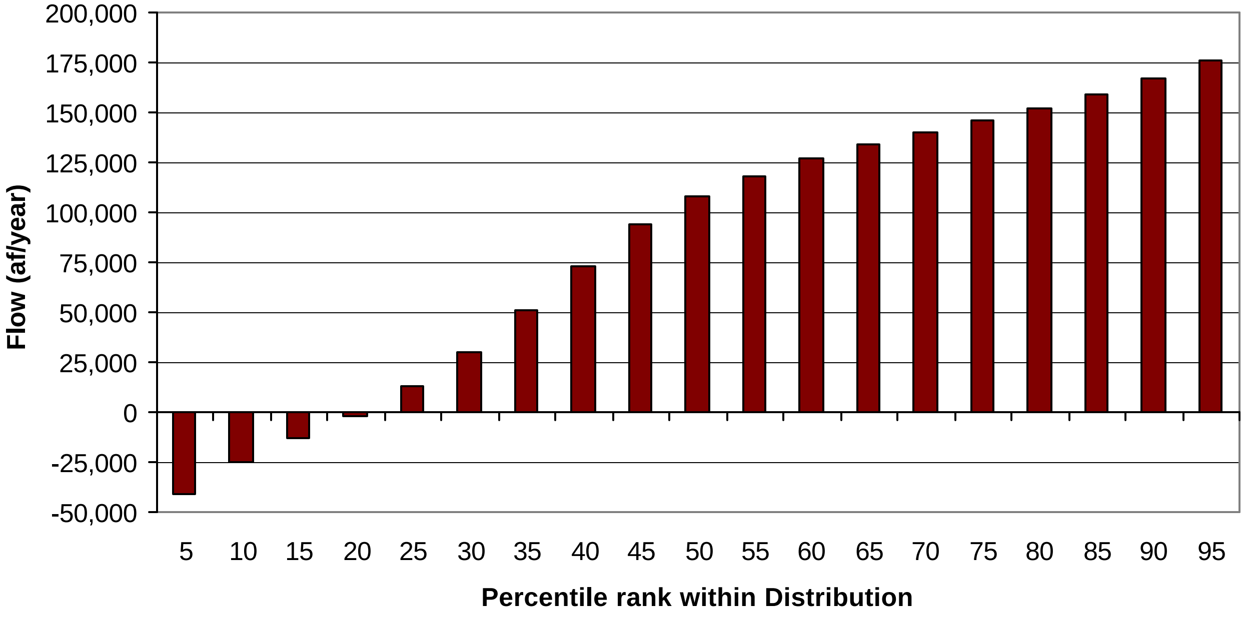

Figure 5.3
Modeled Base Case Sections 2 and 3 Inflow and Depletions

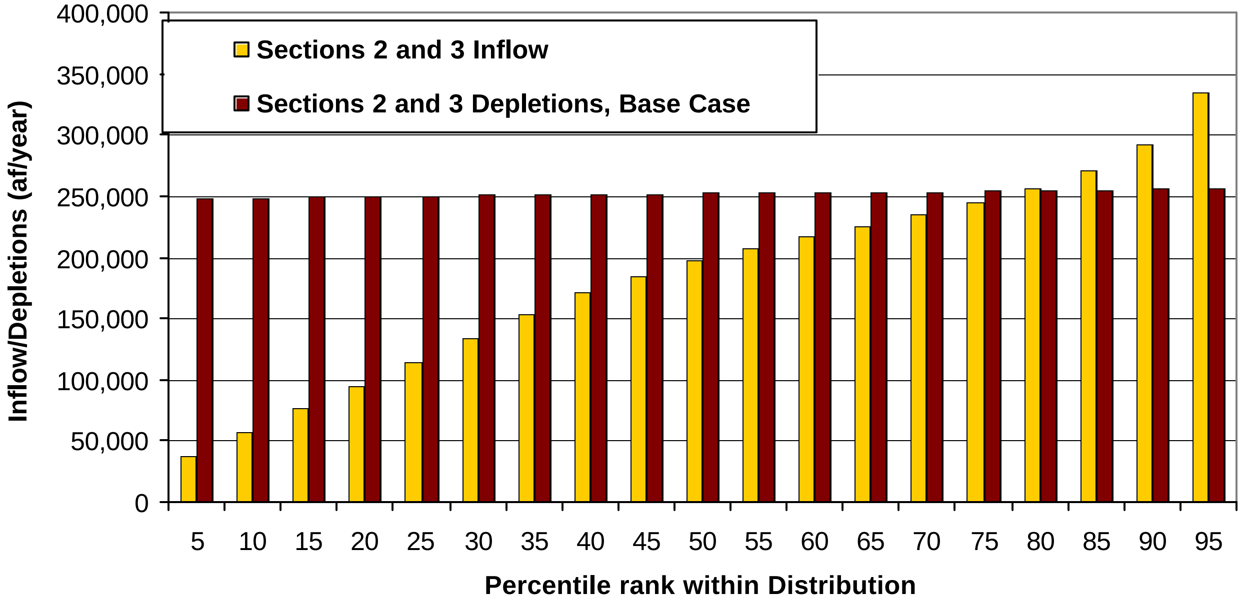

Figure 5.4
Modeled Base Case Section 3 Outflow

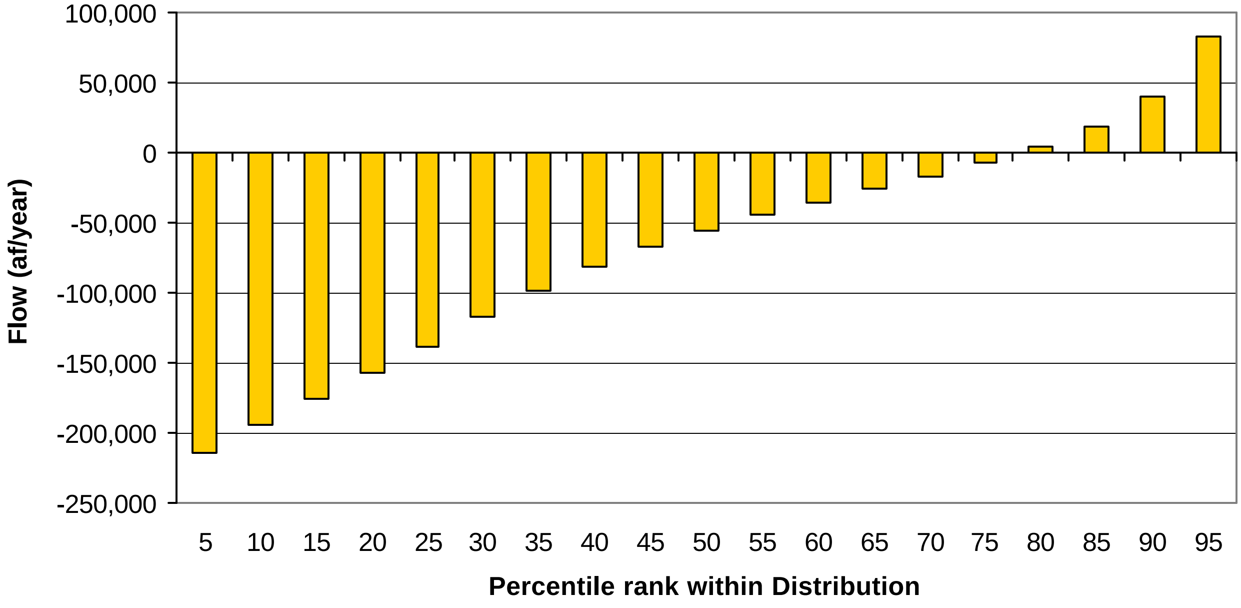

Figure 5.5
Modeled Elephant Butte Losses for the Base Case and Under SSPR Alternative 1A

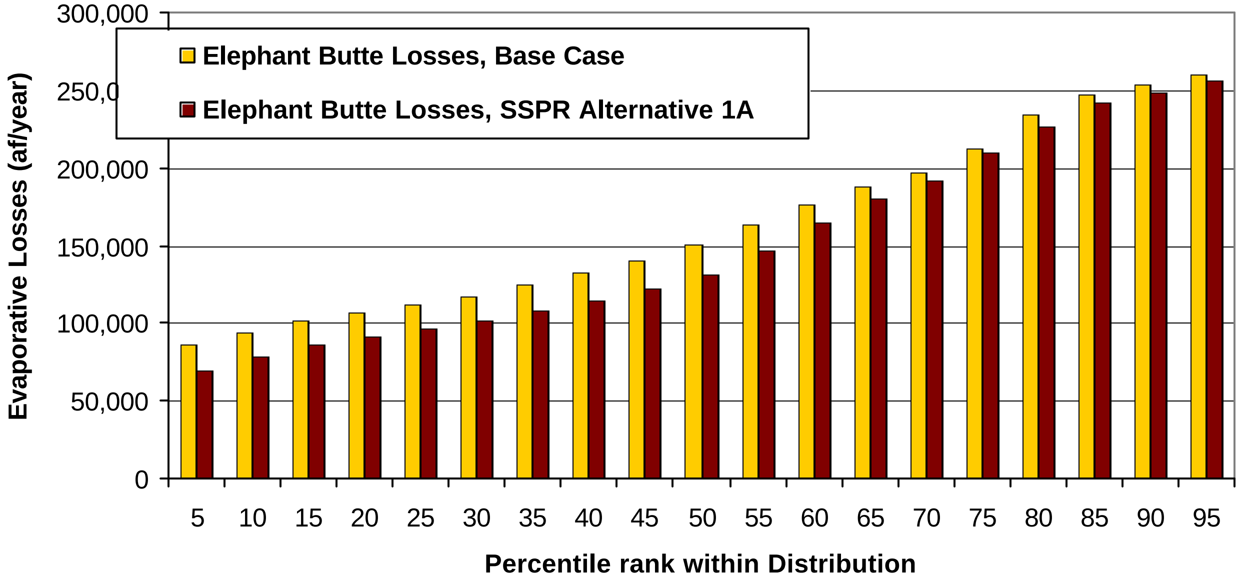

Figure 5.6
Modeled Base Case Inflow, and Depletions for the Base Case and Under SSPR All Alternatives C

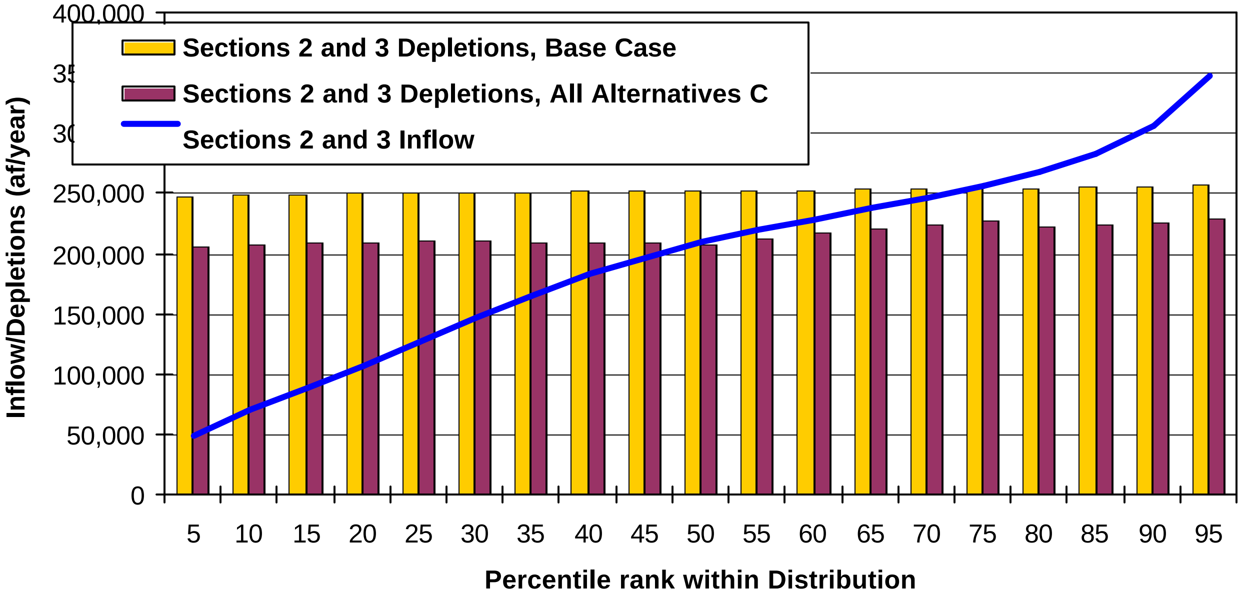

Figure 5.7
Modeled Section 3 Outflow for the Base Case and
Under SSPR All Alternatives C

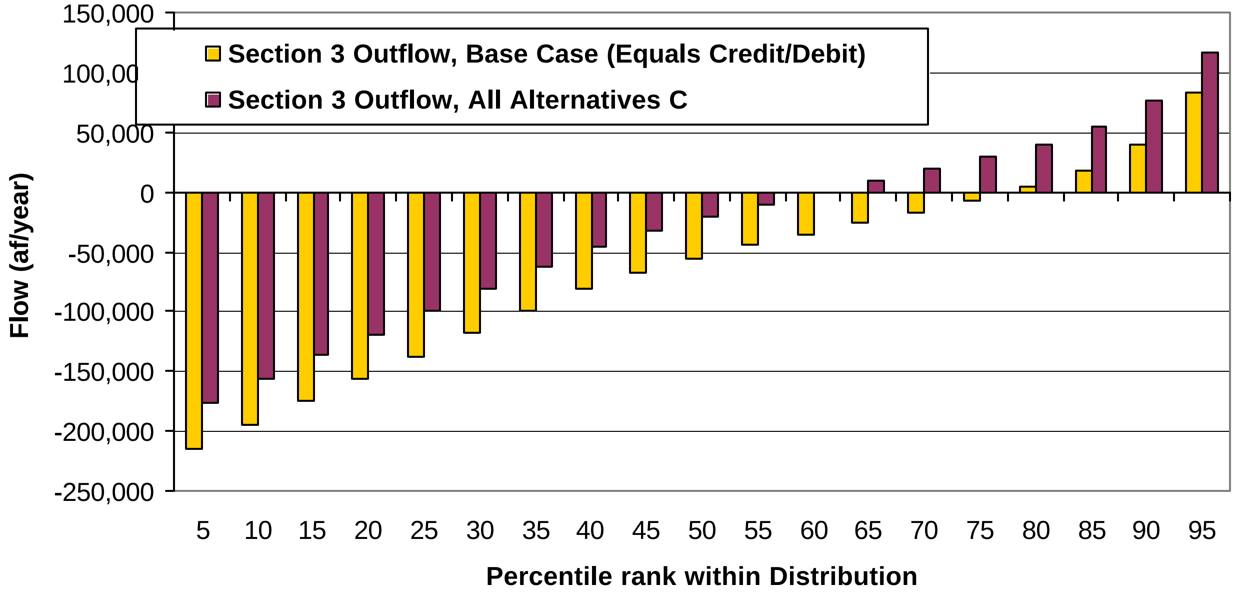

Table 5.1

Average, 10th and 90th percentile model values for inflow and depletion terms

Flow Term	10th percentile flows (af/year), 10,000 model realizations*	Average flow (af/year), 10,000 model realizations*	90th percentile flows (af/year), 10,000 model realizations*
Otowi Index Supply inflow at Otowi	335,512	930,084	1,679,158
Obligation	191,242	624,104	1,274,158
Total Inflow (Cochiti to Elephant Butte) - Obligation	510,440	687,070	835,774
Elephant Butte Losses	94,012	163,577	253,611
Adjusted Model Section 1 inflow**	312,133	419,867	502,914
Model Section 1 Depletion	327,841	336,089	344,401
Agricultural consumptive use, section 1	-121,927	-130,048	-138,274
Riparian consumptive use, section 1	-89,032	-89,032	-89,032
Open water Consumptive use, section 1	-28,106	-28,106	-28,106
Surface water depletions from groundwater pumping	-79,600	-79,600	-79,600
MRGPR Outflow = Adjusted SSPR mainstem inflow**	-24,858	83,779	167,212
Adjusted SSPR Total Inflow**	57,597	187,405	293,032
Rio Puerco inflow	7,466	25,645	51,197
Rio Salado inflow	1,508	10,393	23,032
Ungaged tributaries, westside	2,511	17,090	38,534
Ungaged tributaries, eastside section 2	935	6,381	14,322
Ungaged tributaries, eastside section 3	675	4,602	10,331
Wastewater inflow	966	966	966
Effective precipitation	22,050	22,050	22,050
Groundwater inflow	16,500	16,500	16,500
SSPR depletion	248,825	252,306	255,831
Agricultural consumptive use, section 2	-15,676	-16,720	-17,778
Agricultural consumptive use, section 3	-36,578	-39,014	-41,482
Riparian consumptive use, section 2	-44,829	-44,829	-44,829
Riparian consumptive use, section 3	-112,792	-112,792	-112,792
Open water Consumptive use, section 2	-7,787	-7,787	-7,787
Open water Consumptive use, section 3	-27,863	-27,863	-27,863
Surface water depletions from groundwater pumping	-3,300	-3,300	-3,300
SSPR outflow = NM Delivery Credit/Debit	-194,420	-64,901	40,230

* Base case model run - no regional planning alternatives included.

** Compact Obligation and Elephant Butte Losses removed. Also, the identified SSPR inflow and depletion terms are limited to those occurring within the Study Area.

Table 5.2

Middle Rio Grande Planning Region proposed planning alternatives

Alternative	Agricultural CU Change (af/year)	Riparian CU Change (af/year)	Open Water CU Change (af/year)	Municipal CU Change (af/year)	Reduction in Regional demand (af/year)
					0
					0
					0
					0
Planning alternatives not yet received from Middle Rio Grande Planning Region					0
					0
					0
					0
					0
					0

* Average reduction in agricultural, riparian, open water and municipal consumptive use as a function of each alternative.

Table 5.3

Socorro-Sierra Planning Region proposed planning alternatives

Alternative	Agricultural CU Change (af/year)	Riparian CU Change (af/year)	Open Water CU Change (af/year)	Change in Elephant Butte Losses (af/year)	Reduction in Regional demand (af/year)
Alternative 1A				-11,855	11,855
Alternative 1B			-1,649		1,649
Alternatives 2, 3, and 4	-2,768				2,768
Alternative 5A		-16,240			16,240
Alternative 5B		-4,060			4,060
Alternative 5C		-20,300			20,300
All Alternatives A	-2,768	-16,240	-1,649	-11,855	32,512
All Alternatives B	-2,768	-4,060	-1,649	-11,855	20,332
All Alternatives C	-2,768	-20,300	-1,649	-11,855	36,572

* Average reduction in agricultural, riparian, and open water consumptive use as a function of each alternative.

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S. S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

Memorandum

Date: March 7, 2003

From: Karen Lewis, Debbie Hathaway

To: Socorro-Sierra Regional Water Planning Group

Subject: **Selected Planning Alternatives –Analysis of Hydrologic Impacts**

Background

The Socorro-Sierra Regional Water Planning group has developed a short-list of water planning alternatives. By letter of January 24, 2003, the Socorro Soil & Water Conservation District requested that the ISC authorize SSP&A to provide a hydrologic analysis of these chosen alternatives. By letter of January 30, 2003, the ISC authorized SSP&A to analyze the noted alternatives (as part of work for the Middle Rio Grande Water Supply Study, Phase 3). This analysis includes:

- Quantitative estimates of changes in water consumption and qualitative estimates of changes in diversions resulting from implementation of the proposed alternatives
- An evaluation of sensitivities and relationships between alternatives and between alternatives and other model parameters, with attention paid to how these sensitivities and relationships will impact water consumption, availability, and, to limited extent, to timing of deliveries and diversions. Required modifications to the MRG WSS models resulting from these sensitivities and relationships will be outlined.
- Modification of the MRG WSS Phase 2 models to reflect the proposed alternatives and their sensitivities and relationships. Results will be provided in the context of regional water supply and impact on Compact obligations.
- A quantitative evaluation of surface water flow into the Socorro-Sierra region north of Elephant Butte Dam. This quantification will be based on the MRG WSS Phase 2 model, modified to provide a regional break at the county line such that all flows at and below that point can be evaluated. The evaluation will be presented in a probabilistic format.
- Riparian and agricultural consumptive use and open water evaporation for the Socorro-Sierra region north of Elephant Butte Dam, including evaporation for Elephant Butte reservoir, based on the information and data currently contained in the MRG WSS Phase 2 model.

This memorandum addresses the first bullet above, or, Task 1 described in the letter of January 30. The list of alternatives submitted to SSP&A for evaluation is provided below. Following the list is a quantitative evaluation of the hydrologic impacts of each item on the list, as well as a qualitative estimate of the changes in diversions that would result from implementation of each proposed alternative.

Socorro-Sierra Short-List Alternatives Identified for SSP&A Review

Socorro/Sierra has chosen 16 alternatives that they are pursuing in greater detail. Of these, six alternatives have been identified for hydrologic analysis by SSPA (1e, 3e, 3i, 4b, 4d, and 7b) and one was identified for comment (1d). The seven alternatives are:

1. 1e - Evaporation control through reduced water surface areas in engineered and natural areas
2. 3e - Improve efficiency of surface water conveyance systems to agricultural land, including irrigation scheduling, metering, and ditch lining or piping.
3. 3i - Improve on-farm efficiency
4. 4b - Control brush and weeds along water distribution systems and drains
5. 4d - Remove exotic vegetation (i.e. Salt cedar, Russian olive) on wide scale
6. 7b - Encourage retention of water within the planning region
7. 1d - Move water to higher elevation

Discussion of Hydrologic Impacts

The hydrologic impacts of these alternatives are reviewed at a detailed level. The goal of this review is to quantify changes to water consumption resulting from implementation of the alternative. Table 1 provides a quantitative water savings for each alternative, focusing on the opportunity to save (or gain) water from a consumptive perspective, and a qualitative assessment of changes in diversions; while changes in diversions without commensurate consumptive changes typically don't impact the basin supply (or ability to meet Compact obligations), there may be benefits to modifying diversions at a regional or local level, particularly when considering cost and environmental issues. Where possible, comments are offered in the text on technical, economic and political feasibility.

This memo is intended to provide regional planners with an assessment of hydrologic costs and benefits of each of the chosen alternative to the best of our current knowledge, and to aid planners in further refining their chosen alternatives to maximize the efficiency and success of the water planning process in the region.

For purposes of this analysis, we have used agricultural data for the Socorro Division of the MRGCD and riparian data from ET Toolbox reaches 5, 6 and 7. The Socorro-Sierra region, however, extends further north than either of these boundaries. Consequently, agricultural estimates are low; roughly 20% of the Belen division is contained within Socorro County, i.e. approximately 6,400 additional irrigated acres and 64 miles of canals. The crop acreage within the Socorro-Sierra County planning region, outside of the Socorro Division, will be estimated from GIS coverages as part of Task 3. Riparian values used in the calculations will be similarly adjusted in Task 3. However, the adjustment will not be as significant as that for crop acreage, because the bulk of the Middle Rio Grande mono-typical salt-cedar stands lie below Bernardo.

1 Evaporation control through reduced water surface areas in engineered and natural areas

Reduction of water surface areas, such as a reduction in the wetted area of the Elephant Butte delta and reduction of ponded areas between San Marcial and the reservoir, is important for efficient delivery of water to Elephant Butte Reservoir for meeting obligations under the Rio Grande Compact. Under current conditions, the open water and swamp portions in the delta are significant and result in high evaporative losses. There are also many open water areas in state and federal wildlife and game refuges within the Socorro-Sierra region. Reduction in these open water areas could also reduce water lost to evaporation. An analysis of the reduction in water depletion through evaporation available through implementation of this alternative is presented for two conditions:

A. Reducing evapotranspiration and evaporation from the Elephant Butte delta through channel construction and maintenance
B. Reducing open water areas within the counties' wildlife and game refuges

<u>Reducing evapotranspiration and evaporation from the Elephant Butte delta</u>

The LFCC provides drainage in the region from San Acacia to the delta, and was designed to improve the delivery of diverted river water and intercepted drainage water to the reservoir. Currently, the lower part of the LFCC through the delta area is not functioning as designed due to siltation and channel breaches. As a result, the water carried in the LFCC is deposited in marshy areas in the delta. Additionally, water in the river channel, whose bed elevation has significantly aggraded over past decades, spreads into the delta area, with much of it contributing to ponded or marshy areas. Field studies to support the characterization of the water budget in the delta area have not been conducted, but the following general statements can be made:

- Water from the LFCC and the river spread across the delta area. The disposition of these waters includes: seepage into the subsurface, open water evaporation, evapotranspiration by riparian vegetation, and surface flow to the reservoir through a network of smaller channels;
- Water in the shallow subsurface of the delta area has the following disposition, with relative quantities unknown: evaporation from wetted soils, riparian evapotranspiration, subsurface flow to the reservoir, interception by portions of the LFCC in places where the LFCC water surface lies below the shallow groundwater elevation.

A pilot channel is currently under construction to reconnect the river to the reservoir. This channel also intercepts a main area of spreading LFCC drainage in its planned downstream reach. The lower portion of the channel is on schedule for completion at the end of April 2003. The upper portion of the channel is partially complete, but the schedule for full completion is unclear. The intent of these channel maintenance activities is to provide a channel that can effectively carry spring run-off to the reservoir, thus, avoiding the spreading of floodwaters into the delta area. If these activities are successful, the delivery of water will return to what might be considered a "baseline condition", akin to what existed prior to the flooding and high waters that occurred in the 1980's. At present, the depth of the channel has not been designed to drain subsurface water to an elevation beyond the reach of riparian vegetation.

In evaluating this alternative, three scenarios are defined:

1) Failed or no maintenance: Conditions as in the past decade. Water from the LFCC and the river spread across the delta and extensive ponding occurs.
2) Successful pilot channel, effective maintenance of channel: Conditions returned to those as occurred prior to channel siltation in the 1980s; however, potential exists for significant riparian re-colonization during pool recession.
3) Deepening of the channel to increase drainage of saturated sediments in the delta and upper reservoir area. Consequent reduction in potential for riparian re-colonization.

For each scenario, it is assumed that the reservoir level is below the Narrows. The potential for reduction in water depletion under each scenario is discussed below and is roughly quantified. Table 1 summarizes the estimated reduction in depletion.

1) _Failed or no maintenance_. Under this scenario, open water evaporation occurs at essentially the same rate as would occur with a full reservoir throughout the delta area and the (drained) upper reservoir area. No savings occur. Water depletion under a less-than-full reservoir will exceed that which occurred prior to the 1980s.
2) _Successful pilot channel, effective maintenance of channel:_ Under this scenario, water depletions return to what some would term a "baseline condition" of normal operation. Water savings occur in two ways. First, spring run-off is routed quickly to the reservoir, rather than being held up through ponding, following a tortuous path through marshy areas and generally being subject to greater evaporation losses. Secondly, many ponded or marshy areas will dry, reducing open water evaporation. However, under this scenario, the groundwater elevation will likely still be within the reach of riparian vegetation. If colonization has been allowed to occur during recession, then evapotranspiration over a large area, potentially as large as the area previously covered by marshy conditions, may occur. The estimated (minimum) difference in water depletion between this scenario and scenario #1 is equal to the difference between open water evaporation and riparian evapotranspiration rates. Estimating annual average open water evaporation at 7 acre-feet per acre, and riparian evapotranspiration at 4 acre-feet per acre, this difference amounts to approximately 3 acre-feet per acre over the affected area. We don't have available data on the relative amounts of open water versus riparian vegetation in this area at present; nor do we have projections on how this will change upon completion of the pilot channel. The assumptions below should be refined if this analysis is critical in the decision making process. If we assume that presently, one half of the approximately 14,700 acres of the northern basin of Elephant Butte Reservoir, is characterized as marshy or ponded, and the other half consists of riparian area (50% marsh, 50% riparian as in scenario 1); and if the completion of the channel results in conversion of 75% of the open water area to riparian (scenario 2a, 12.5% marsh, 87.5% riparian), then, water depletion under this scenario is reduced by difference would amount to approximately 16,500 acre-feet per year. *It should be understood that this reduction in depletion from today's condition does not*

represent salvage or new water. In reality, this effort reduces excessive depletion that occurred due to the lack of effective channel maintenance over the past 18 years.

3) *Deepening of the channel to increase drainage of saturated sediments in the delta and upper reservoir area*: If the channel is deepened to drain surrounding delta and upper pool areas to the extent that it becomes difficult for riparian vegetation to colonize in areas exposed by reservoir recession, reduction in water depletion beyond the "baseline" level would result. The reduction would be equal to the difference between riparian evapotranspiration and bare ground evaporation (estimated at 1 acre-foot per acre for this calculation) in areas where depth to shallow ground water was adequately increased. Without field study of this area, it is not possible to know how deep channel excavation would need to be to accomplish adequate water table lowering nor is it possible to assess the feasibility. However, to enable discussion, we provide an estimate of hypothetical depletion reduction by assuming that riparian evapotranspiration would be limited to 50% of the exposed area, and drained ground will constitute the remaining 50% of the exposed area under the lowered water table scenario. Under these assumptions (scenario 3a), the change in water depletion, as compared to scenario 2a (87.5% riparian, 12.5% marsh), would be 22,050 acre-feet per year; or, as compared to scenario 1 (assumed present condition) would be 38,5990 acre-feet per year. This scenario, involving maintenance of drainage conditions (and reduction of marshy areas), may be problematic if Southwest Willow Flycatcher habitat develops in areas of the receding reservoir.

Table 1: Hypothetical evapotranspirative water use in the Elephant Butte northern basin under various scenarios.

Elephant Butte northern basin hypothetical evaporation/evapotranspiration (total area assumed is 14,700 acre-feet)				
	Marsh area (7 ac-ft/ac)	Riparian area (4 ac-ft/ac)	Barren area (1 ac-ft/ac)	Total ET (acre-feet)
Scenario 1	50%	50%		80,850
Scenario 2a	12.5%	87.5%		64,310
Scenario 2b		100%		58,800
Scenario 3a		50%	50%	42,260
Scenario 3b		20%	80%	23,520

Reducing open water areas within the counties' wildlife and game refuges

Open water evaporation from exposed open water bodies generally exceeds riparian evapotranspiration. Evaporation for small ponds shaded by trees and other growth, such as backwaters being constructed along the river for Silvery Minnow habitat, may have evaporation rates equal to or smaller than that of riparian vegetation.

Reduction in surface areas of these larger ponds could, therefore, result in reduced depletion for the region. Open water evaporation from Elephant Butte Reservoir is 7 feet per year; average open water evaporation for the San Acacia to San Marcial reach, as modeled in the ET Toolbox, is about 5.6 feet per year. Compared to evaporation rates of 4 feet per year for salt cedar and 3 feet per year for cottonwood, anywhere from 1.6 to 4 acre-feet of water per acre per year could potentially be saved by converting larger ponds to bosque.

A current number for acres of ponded areas between San Acacia and the Elephant Butte delta is unavailable. The ET Toolbox acreage for open water between Bernardo and the Elephant Butte Delta is 5,490 acres, this includes ponds, canals, drains, and river channel areas. For discussion purposes only, a rough estimate of hypothetical reduction in depletion follows. Further work is required to realistically assess these reductions via implementation of this option:

- Assume 30% of the open water acreage is stand-alone ponds (1,650 acres)
- Assume 20% of these could be replaced with native bosque (330 acres)
- The reduction in depletion would therefore range from 525 to 1,320 acre-feet per year.

The value of these areas to habitat and the ecosystem would need to be considered carefully if this option is pursued. This evaluation has not assessed the habitat value, but understands that many in this region favor the benefits provided by these open water areas. Furthermore, many, perhaps most, of these stand-alone ponds lie within state and federal wildlife and game refuges, and this issue is beyond the region's direct control.

2 Improve efficiency of surface water conveyance systems to agricultural land by implementing conveyance alternatives (e.g. concrete-lined ditches, pipelines), improving irrigation scheduling, and metering and managing surface water diversions and returns

Potentially large reductions in agricultural diversion demand are possible through improvements in irrigation efficiency. Irrigation-related consumptive use reductions will be minimal (only ensuing from reductions in incidental depletions associated with efficiency improvements). Reductions in diversion demand resulting from these changes would allow water to be retained in upstream storage reservoirs longer and provide timing advantages for irrigation (or ancillary needs/benefits). Reductions in consumptive use will both reduce the diversion demand and "save" water.

"Saved" water will not likely be directly available to the planning region; however, improvements to MRGCD efficiency will improve the ability of the MRGCD to provide a full supply to all irrigators, including those in this region. Because the basis of the MRGCD's permitted water right is irrigated agriculture, any water not needed for this purpose due to conservation efforts is assumed to belong "to the public and is subject to appropriation for beneficial use" (New Mexico statutes, 1978, 72-1-1). In the Rio Grande Basin, which is considered by the State Engineer to be fully appropriated, these waters would satisfy other established water rights (which may be subject to shortage), subject to the constraints of the Rio Grande Compact. In other words, these savings, while not likely available for transfer to a specific use within the region, avoid what could be construed as waste, and would benefit the entire region by more efficiently using the available water supply.

Canal Lining/Piping

Canal lining will result in a reduction in seepage losses from the canals, thereby requiring smaller diversions to convey water to farms than under present conditions. Canal lining will also result in a reduction in riparian growth along the canals, and a commesurate reduction in evapotranspirative consumptive use.

Lining all of the canals in the region would be expensive, and probably unnecessary; it is likely that the majority of canal seepage comes from a minority of the canals. For this analysis, we have chosen to look at lining 20% of the canals. This is a placeholder value. Results can be scaled for other percentages.

The reduction in canal seepage is:

- 133.9 miles of canals in the Socorro divisions (obtained from project GIS coverages and reported in the MRGCD Efficiency Study, Table I-1), multiplied by 1.5 to take into account small canals and laterals not counted in the original survey
- 2001 division supply of 138,713 acre-feet of water
- canal seepage of 20 percent of canal flow (USBR Estimate) equals 27,743 acre-feet of water
- assume lining canals reduces seepage by 80%
- resulting reduction in the diversion requirement is 4,440 acre-feet/year. If the leakiest canals were located and lined, this value might be increased.

We note that this reduction in seepage might result in effectively "new" water if the seepage is currently returning to the LFCC and is subsequently lost to evaporation in the delta – see item 1, Evaporation control.

The decrease in riparian consumption, based on the same lining of 20% of the canals, is:

- 133.9 miles of canals in the Socorro divisions (MRGCD Efficiency Study, Table I-1), multiplied by 1.5 to take into account small canals and laterals not counted in the original mileage survey
- Assume 20' riparian corridor (10' on either side of the canals)
- Assume 2' annual ET from existing riparian growth (based on the average annual ET of salt grass – USBR report, Determination of Soil Conservation Service Modified Blaney-Criddle Crop Coefficients in New Mexico, 1997), and an eradication of that corridor by lining the canal.
- Water savings will be approximately 195 acre-feet per year from reduced riparian usage.

Additionally, there may be canals/laterals or sections of canals/laterals in the division that could be abandoned. Abandoning canals will reduce seepage and ET losses to near 0 for that stretch.

Irrigation scheduling/metering and managing deliveries and river diversions and returns

All of these options have the potential to significantly reduce required irrigation diversions. These options may result in reductions in consumptive use, but consumptive use changes are primarily incidental.

River diversions and returns are now metered in the Socorro Division of the MRGCD with the exception of the LFCC and the river as they exit the division. Much of this metering is relatively new, and over the next few years will allow the region to better understand irrigational water diversions and consumptions, which in turn will aid in planning and provide insight into potential areas where water can be saved or conserved. Estimates of both potential changes in consumptive use and reduced diversion demands as a result of this metering are unavailable at this time. Gaging the LFCC would further improve knowledge of regional water allocation. Currently, the LFCC is only gaged at San Marcial.

Rotational water delivery would reduce required diversions by reducing the amount of time canals must be run full. However, no data is currently available to quantify the improvement in off-farm efficiency resulting from rotational delivery. We note that rotational delivery is already practiced in some areas in the Socorro Division at some times.

Metering farm deliveries would reduce on-farm demand, and therefore reduce diversion requirements. Metering has been found to increase farmer's efficiency with water by 10 to 20% in other irrigation districts (Fipps, *Potential Water Savings in Irrigated Agriculture for the Rio Grande Planning Region, Final Report*, Texas A&M University System, 2000). If the water required at the farm turnouts is reduced by 10 to 20%, required diversions are reduced by a minimum of 10 to 20% (for 2001, this would have meant a potential reduction in division diversions of 13,870 to 27,740 acre-feet). Depending on how the conveyance system is run in response to reduced on-farm demand, conveyance losses could also be reduced, further reducing diversion requirements.

3 Improve on-farm irrigation efficiency

Improvements in on-farm efficiency reduce diversion through the farm turnout primarily by reducing runoff and percolation to the aquifer. Smaller reductions are also effected through reducing ponding. Of these, only the smaller reductions (by reducing ponding) represent changes in consumptive use. Any other changes will impact required diversions only. As for prior alternatives, improvements to irrigation efficiency will improve MRGCD supply, and potentially increase water available for use in the Middle Valley at large, but may not make new water available for the region.

Most of the Socorro Division of the MRGCD is devoted to production farms, where laser-leveling and concrete lining of the on-farm ditches has already been done. Anecdotal evidence suggests that these improvements can reduce on-farm efficiency by 30%, and reduce turnout time to 25% of that previously required to irrigate the same acreage. This, in turn, reduces required diversions, makes rotational delivery far more efficient, and allows for increased off-farm efficiency.

Though many of the big production farms in the Socorro Division have already made efficiency improvements, some percentage of the district's irrigated lands remain unimproved. Focusing on improving these lands will boost district on-farm efficiency and allow for effective rotational delivery to these lands, further improving off-farm efficiency.

Laser-leveling can increase on-farm efficiency by about 30% (Darryl Reasnor, NRCS, personal communication). If we assume 30% of the Socorro Division is currently unimproved, we could then improve efficiency by 30% on 30% of the lands, or improve district on-farm efficiency by 9%. This, in turn, will allow for a minimum of a 9% reduction in required diversions. For 2001, this would have allowed for a reduction in diversions of about 12,500 acre-feet of water.

With the exception of laser leveling fields and improving on-farm ditches, any improvements to on-farm efficiency would likely be costly in relation to their potential to reduce diversions, and very costly in relation to their potential to reduce consumptive use.

4 Control brush and weeds along water distribution system and drains

Currently, the MRGCD is mowing 100% of the canals and drains in the Socorro Division. Canals are mowed at least 2 to 3 times per year, and drains at least once per year. Complete eradication of vegetation along the canals and ditches would result in bank destabilization – plant roots currently provide bank support. Consequently, a balance needs to be maintained between controlling growth via mowing and maintaining adequate root mass to stabilize the canal and ditch banks. The primary vegetation along the canals and drains is weeds and grasses (johnny grass, kosha weed, mustard weed, some noxious weeds) with the occasional patch of willow. (This information was obtained from Johnny Mounyo in the Socorro Division MRGCD office.)

Water usage by weeds and grasses is likely 2 feet per year or less (salt grass uses about 2 feet per year). Some water savings might be achieved by increasing the number of mowings, but it is likely to be small. Currently, the data doesn't exist that would allow us to quantify the potential savings from increased mowing frequency.

5 Remove exotic vegetation on a wide-scale

The ET Toolbox, version of January 2003, reports riparian acreage between Bernardo and San Acacia as 6,600 acres, between San Acacia and San Marcial as 16,200 acres, and between San Marcial and Elephant Butte as 7,600 acres (30,400 acres total). (Note: This version updates the ET Toolbox acreage reported in the August 2000 MRGWSS study of 31,934 acres).

Average consumptive use from 1985 to 1998 was estimated at 3.71 acre-feet per acre for San Acacia to San Marcia (ET Toolbox value). Applying this to the entire stretch from Bernardo to Elephant Butte, the resulting riparian usage is 112,784 acre-feet per year. Studies of riparian evapotranspiration currently suggest that an established bosque uses about 3 acre-feet per acre per year of water (King and Bawazir, *Riparian Evapotranspiration Studies of the Middle Rio Grande*, 2000). Based on these values, if salt cedar were removed and replaced with native bosque, the potential reduced depletion is 0.71 acre-feet per acre. Since most of the riparian acreage between San Acacia and the Elephant Butte delta is dominated by salt cedar, this potential reduced depletion can conceivably be applied to the total riparian acreage, resulting in a total reduced depletion of 21,584 acre-feet per year. If we consider controlling salt-cedar on only a portion of these lands, which might be more realistic, re-establishing native bosque on 10% of the lands (3,000 acres) would resulting in a reduced depletions of about 2,200 acre-feet of water per year.

Alternately, the region could focus on areas where salt cedar habitat can be eliminated. The benefit of eliminating habitat is that salt-cedar is replaced by scrub, rather than bosque, further reduces depletions. A potential area where this might work is on the east side of the Rio Grande below San Acacia. This area is a roughly 4 mile wide stretch of land that was once used for agriculture. This area was abandoned by the MRGCD when it became too waterlogged to plant. This area is cut off from the Rio Grande by a continuous levee, and is also the outlet for multiple arroyos, which, because of the levee, no longer connect to the river. The result is that significant amounts of water are released into this former farmland on a regular basis, maintaining a high water table and providing excellent conditions for salt cedar growth. It is likely that if the arroyos in this area were reconnected to the river, salt cedar habitat would be reduced. Work to reconnect the major arroyos to the river appears to have been recently started. If this land were drained such that some portion of it became inhospitable to riparian growth, the resulting water usage on the drained land would drop to roughly the effective precipitation, reducing depletions by roughly 3 to 3.5 acre-feet of water per acre annually. Maintenance of the drainage system would be required to prevent salt-cedar from re-vegetating the area. However, this maintenance is likely smaller than that required to keep salt-cedar from re-vegetating areas that support active riparian communities.

A developing area of riparian vegetation is in the now-exposed Elephant Butte northern basin. As mentioned in the first alternative, successful completion of the pilot channel is a critical step; however, additional drainage and maintenance would probably be required to substantially reduce the potential for riparian re-colonization.

There are several potential complications to controlling non-native vegetation. First, the removal of exotic vegetation may potentially conflict with Endangered Species Act over southwest willow-flycatcher habitat. Second, once non-native vegetation is removed, it will need to be maintained on a regular basis, or the area will need to be returned to more "natural" conditions such that non-natives have less advantage over native vegetation. Cost of on-going maintenance, in the former scenario, or the potential for increased water use resulting from re-engineering the area to recreate “natural” conditions, should be figured into the planning. Third, because non-native riparian vegetation, such as salt cedar, consume large quantities of shallow groundwater, to some extent they control shallow groundwater levels. Reconstruction and maintenance of the LFCC to ensure adequate drainage will be important to ensure that water-logging and evaporative losses are not exacerbated upon removal of salt cedar. Water table response and alternatives for water table elevation management should be built in to any vegetation removal plan.

6 Restrict transfer of water out of the planning region

Implementation of this option will allow the region to maintain it's current water supply. We are not aware of a mechanism for restricting water transfer out of the planning region, but would encourage the planning region to critically review any such proposals or transfer applications.

Transfers, within or beyond the planning region, must recognize hydrologic reality if the river is not to suffer detrimental impacts. Assessment of hydrologic reality includes quantification and comparison of incidental conveyance losses and return flows at both the "move-from" and the "move-to" locations. These assessments can be technically complex, and require evaluation of local hydrologic conditions throughout the impacted areas and river reaches. In many cases, a reduction in the diversion or consumptive use will be required to preserve the "status quo" water balance after the transfer occurs, to compensate for increased losses to the new point of use.

Transfers over large distances are particularly difficult to implement without risk to the existing hydrologic balance. First, certainty in evaluating comparative conveyance losses and return flows becomes more difficult to achieve when transfers occur across large distances, for example, as would occur with water transferred outside of the planning region. Second, some elements of the existing infrastructure are sensitive to the magnitude of use; for example, some canals require a given head or volume of water for efficient delivery. Substantial transfers out of one area may jeopardize the efficient continuation of present uses within the move-from area.

7 Storage of reservoir water at higher altitudes/latitudes

Moving storage of Elephant Butte Reservoir water to northern reservoirs has the potential to reduce total reservoir evaporation. Table 2, below, illustrates the potential reduction in evaporative loss for various reservoir storage scenarios. Reduction in evaporation in these scenarios, which are based on moving 100,000 acre-feet of storage from Elephant Butte to Abiquiu or Cochiti Reservoirs, which have lower evaporation rates than Elephant Butte as a result primarily of climate, range from 2,070 to 4,960 acre-feet. These calculations are based on current area-capacity tables for the specified reservoirs, and on measured annual pan evaporation rates, adjusted by a factor of 0.7 as is customary applied by the USBR and the ACOE in New Mexico. (These values are different from those in the DBS&A analysis presented to the Water Assembly, February 2003.)

Table 2: Reduction in evaporative loss resulting from moving water storage from Elephant Butte to Northern Reservoirs.

Elephant Butte Reservoir		Destination Reservoir		Evaporative loss reduction (acre-feet)
Storage Volume (acre-feet)	Water Moved (acre-feet)	Name	Volume Before Move (acre-feet)	
1,000,000	100,000	Cochiti	50,000	2,070
1,000,000	100,000	Abiquiu	50,000	4,420
2,000,000	100,000	Cochiti	50,000	2,610
2,000,000	100,000	Abiquiu	50,000	4,960

The values in Table 2 are based on differences in evaporation between Elephant Butte and the destination reservoir, at the specified reservoir levels. These values do not take into account potential changes in conveyance loss resulting from moving water to Elephant Butte on a different schedule than that now applied. Increases in conveyance loss, if water were released slowly during the summer rather than routed to Elephant Butte during the spring flood wave, could potentially exceed the water savings for all options shown above, resulting in a net water consumption rather than a water savings, and negatively impacting New Mexico's ability to meet Compact delivery requirements. Data is presently unavailable to precisely quantify the increase in conveyance losses during the summer, but may be available in the near future (ISC staff, personal communication).

The Table 2 water savings values also do not account for riparian colonization of, and subsequent evapotranspiration losses from, the newly exposed sediments in the Elephant Butte delta area resulting from shifting water upstream. Rough quantification of these losses is presented below:

- For a change in storage of 100,000 acre-feet, starting from a base storage of 1,000,000 acre-feet, reservoir surface area changes from 20,860 to 19,320 acres.
  - If we assume 40% of this is in the northern delta, this is 640 acres.
  - If this area were populated by riparian growth with an evapotransipiration rate of 4 acre-feet/acre, resulting losses would be 2,560 acre-feet.

- For a change in storage of 100,000 acre-feet, starting from a base storage of 2,000,000 acre-feet, reservoir surface area changes from 35,600 to 34,000 acres.
    - Using the above assumptions, resulting losses would be 2,464 acre-feet.

Table 2 water savings values should therefore be reduced by approximately 2,500 acre-feet (for the movement of 100,000 acre-feet of water) to account for delta evapotranspiration.

Additionally, there are many legal issues involved in implementing changes in reservoir storage. A complex suite of Congressional authorizations, and the Rio Grande Compact, control storage, releases and deliveries associated with both Elephant Butte and other reservoirs. These institutional controls are substantial; alteration of these institutional controls would be very time consuming and is beyond the scope of the regional planning process, though the region could lobby for changes.

Any reduction in evaporative depletions from changes to reservoir storage, assuming transit losses are not subsequently increased, effectively increase the amount of water available for other uses in the Middle Rio Grande (Cochiti to Elephant Butte) region. Under New Mexico water law, this water belongs "to the public and is subject to appropriation for beneficial use" (New Mexico statutes, 1978, 72-1-1). In the Rio Grande Basin, which is considered by the State Engineer to be fully appropriated, these waters would satisfy other established water rights (which may be subject to shortage), subject to the constraints of the Rio Grande Compact.

Table 2: Ranking of Hydrologic Impacts

A rough quantification of potential water savings resulting from each alternative, based on the assumptions outlined in the above text, is given below. Additionally, a qualitative hydrologic impact score is assigned for reduction in water diversions. The approximate water savings and diversion reduction scores do not reflect consideration of cost, feasibility, or other non-hydrologic constraints:

1 = no impact likely or not applicable
2 = modest improvements possible
3 = potentially helpful improvements
4 = potentially significant improvements
5 = potentially large improvements

Alt #	**Alternative description**	**Approximate Reduction in Depletion (acre-feet/year)**	**Score-Diversion**
1e	Evaporation control -reduced water surface areas	0 to 40,000	1
3e	Improve off-farm irrigation efficiency	200, not including seepage to LFCC	5
3i	Improve on-farm irrigation efficiency	Not quantifiable	3
4b	Control brush and weeds along water distribution system and drains	0	1
4d	Remove exotic vegetation on a wide-scale	2,200 (for 10% of lands)	2
7b	Restrict transfer out of the planning region	Not quantifiable	3
1d	Storage of reservoir water at higher alt./lat.	0 to 2,500, not including conveyance losses	1