Supporting Document H-3

Middle Rio Grande Water Supply Study

Prepared by S.S. Papadopulos & Associates, Inc.

August 2000

Middle Rio Grande Water Supply Study

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

August 4, 2000

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

Middle Rio Grande
Water Supply Study

Prepared For:

U. S. Army Corps of Engineers
Albuquerque District

Contract No. DACW47-99-C-0012

And

New Mexico Interstate Stream Commission

Prepared By:

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

August 4, 2000

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

Executive Summary

Scope of Work

The Middle Rio Grande Water Supply Study develops 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. The Middle Rio Grande region in New Mexico extends along the Rio Grande, north to south, from Cochiti Reservoir to Elephant Butte Reservoir, a distance of approximately 175 miles (Figure ES-1). This study, conducted for the U.S. Army Corps of Engineers (COE) and the New Mexico Interstate Stream Commission (ISC), provides information to support regional water planning efforts for the Middle Rio Grande and describes conditions relevant to maintaining compliance with the Rio Grande Compact.

An Executive Steering Committee (ESC) was commissioned to provide technical advice and guidance regarding preparation of the Middle Rio Grande Water Supply. The ESC, including technical representatives of a diverse group of stakeholders and agencies within the Middle Rio Grande region, and interested observers, met periodically to review the progress of the study and to provide interim comments.

The regional water planning process focuses on five questions:

- What is the water supply?
- What is the water demand?
- What alternatives exist to meet demand with available supply, including water conservation?
- What are the advantages and disadvantages to these alternatives?
- What is the best plan and how will it be implemented?

This study addresses the first of these questions: characterization of the water supply. Other studies will be conducted by regional planning entities to address the remaining water planning questions.

Key products generated in this study include:

- 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, under a hypothetical alternative.

These products provide an up-to-date integration of past and on-going technical studies that can be used in the regional water planning process. This study differs from previous water supply studies in that it considers a range of water supply conditions, rather than average conditions, or conditions in specific years. The range of water supply conditions considered in this study reflects the climatic variability experienced in this region over the past 50 years.

Probabilistic Description of the Water Supply

In this study, a probabilistic water budget is developed for the stream system in the Middle Rio Grande region. Water inflows and uses are quantified to reflect both climatic variability and present development conditions. For each water budget term exhibiting climate dependency, the range and nature of this variability is described. Some water budget terms are predominantly influenced by land use or development conditions. These terms were quantified according to the present development condition.

Groundwater conditions are linked to the stream flow system using the groundwater model of the Albuquerque Basin. Through this approach, hydrologic processes occurring in the aquifer that have effects on the stream, for example, precipitation, recharge and groundwater pumping, are integrated into the water supply analysis.

The available water supply to the Middle Rio Grande region is constrained by the terms of the Rio Grande Compact. Figure ES-2 illustrates the quantity of Rio Grande inflow at Otowi that is available for use in the Middle Rio Grande region, and compares this to the amount designated for use below Elephant Butte Reservoir. The Middle Rio Grande region's share of the Otowi inflow is capped at about 400,000 acre feet per year when the inflow exceeds 1.1 million acre feet per year.

Reflecting the variability in water budget terms, including both Otowi inflow and other inflows to the region, a profile is derived of the *available* water supply (the water available for complete use, or depletion) in the Middle Rio Grande region. This profile accounts for the Rio Grande Compact delivery obligations (the Elephant Butte Scheduled Delivery) corresponding to the range of water supply conditions (as related to the Otowi Index Supply). A profile of the expected range of Compact credit/debit conditions is also developed, by subtraction of the estimated water depletions from the available supply, and comparison to Compact delivery requirements.

This analysis provides the *mean* (average) water supply conditions and the range of water supply conditions that are likely to occur given the climatic variability in flow. Figure ES-3 provides a schematic of the mean annual Middle Rio Grande water supply under present use conditions. This figure shows the available water supply at various points along the river, after deducting the Compact obligation from expected flows. This figure also shows the magnitude of depletions to the flow resulting from present water uses within each reach. As shown on this figure, given present uses in the basin, the available supply (including trans-mountain diversions and wastewater returns), on average, is virtually consumed within the Middle Rio Grande region. This analysis reflects the non-linearity of the Rio Grande Compact schedule, and appropriately handles the calculation of the average obligation for a range of conditions.

Figure ES-4 illustrates the relative magnitude of consumptive uses within the Middle Rio Grande region, under current land use and groundwater development conditions and assuming reservoir evaporation as averaged over the 1950-1998 period. An evaluation of the mean depletions occurring within the Middle Rio Grande region, given these assumptions, indicates that consumptive use by crops and riparian vegetation accounts for approximately 67% of the total use. Consumptive use by reservoir evaporation accounts for approximately 19% of the total, with the remainder of about 14% comprised of urban consumptive use. Of these uses, reservoir evaporation is subject to the largest variability. Evaporation from Elephant Butte Reservoir ranges from 10% to 30% of the overall basin depletion, depending primarily on the reservoir pool elevation and associated surface area.

While on average, the water supply is approximately equal to the present water demand, this study provides a measure of the variability in water supply conditions. Figure ES-5 illustrates the calculated credit/debit under the Rio Grande Compact as a *probability distribution function*. This type of graph is used to show how often a particular event will occur. In this case, the graph indicates how often the credit or debit will likely occur at various levels, given the climatic variability of water inflow and depletion terms. These analyses indicate that over the long term, debits are expected to occur nearly as often as credits, given the present water use conditions and the historic climatic variability.

The prognosis for water supply in future years, without significant intervention, is less favorable. The impact of current levels of groundwater pumping on the Rio Grande flow system continues to grow. Even without an increase in groundwater withdrawal rates, increased depletions will occur to the Rio Grande throughout the next 100 years, and beyond. While significant quantities of groundwater are available within aquifer storage, the water cannot be utilized without affecting the stream. An analysis of continuation of the present use conditions to the year 2040 indicates that debit conditions will occur more often than credit conditions.

An alternative scenario involving increased groundwater pumping was evaluated with the probabilistic model, to evaluate the impacts of approximately doubling the withdrawal of groundwater from the aquifer. Under this scenario, within 40 years the stream-referenced water supply is expected to diminish by about 43,000 acre-feet per year, resulting in even more frequent occurrences of Compact debit conditions. The probability distribution function for this hypothetical alternative is illustrated on Figure ES-6. Clearly, this alternative would not be acceptable without offsets from another water use sector. In addition, such an alternative would result in extreme water level declines and potentially poor groundwater quality.

The analyses conducted for this study illustrate the general magnitude of the available water supply, and its expected variability, assuming the degree of climatic variations observed during the past 50 years. These results provide a realistic framework for water resource planning. At the same time, it is useful to understand what is not represented in these results:

- This study does not model hydrologic conditions resulting from a specific sequence of annual conditions; in other words, predictions based on antecedent conditions are not provided.

- This study does not represent hydrologic responses to extreme events. While the available record includes both wet and drought periods, and the modeled inflow encompasses this range of conditions, the development of water-budget relationships for extreme conditions was beyond the scope of this study.

- This study does not provide localized evaluations of the water supply. Study assumptions are based on existing data sets, most of which are adequate for basin-scale water supply evaluations. In evaluating specific water supply alternatives as part of the water planning process, additional information will be needed to refine understanding of hydrologic conditions and relationships as they relate to proposed alternatives.

- This study does not provide a "turn-key" water planning model. The probabilistic water budget model presented in this study is based on a series of empirical relationships and specific simulations with the Albuquerque Basin groundwater model. Assumptions and structuring of the underlying models may require re-specification, depending on the parameters of an alternative selected for evaluation.

As the water planning process progresses to the stage of water supply alternative analysis, additional evaluations in some of the above-noted areas may prove useful.

Summary of Conclusions

Key water supply and hydrologic concepts illustrated or derived from this study, with implications for water planning are:

- On average, *the present water supply is barely adequate* (including San Juan-Chama Project water and groundwater withdrawals) to meet the present demands in the Middle Rio Grande region.

- *The water supply is highly variable,* due to the high variability in Otowi inflow and the high variability in evaporation from the Elephant Butte Reservoir.

- Given the variability of water budget terms, Rio Grande Compact *debit conditions are expected to occur nearly as frequently as credit conditions.*

- *Under conditions of increased water use in any sector, a reduction of water use from other sectors is requir*ed to maintain overall water supply balance, and to avoid increasing the likelihood of incurring Rio Grande Compact debits.

- The groundwater supply is not an independent, disconnected water supply. *Use of groundwater results in diminished flows of the Rio Grande* that will occur in the present and continue into the future.

- The location of groundwater well fields affects short-term timing of impacts to the river; however, *regardless of location, the impacts of groundwater pumping eventually reach the river and require offset*.

- *Recharge of groundwater from the stream system reduces the flow of the Rio Grande* available to meet obligations under the Rio Grande Compact.

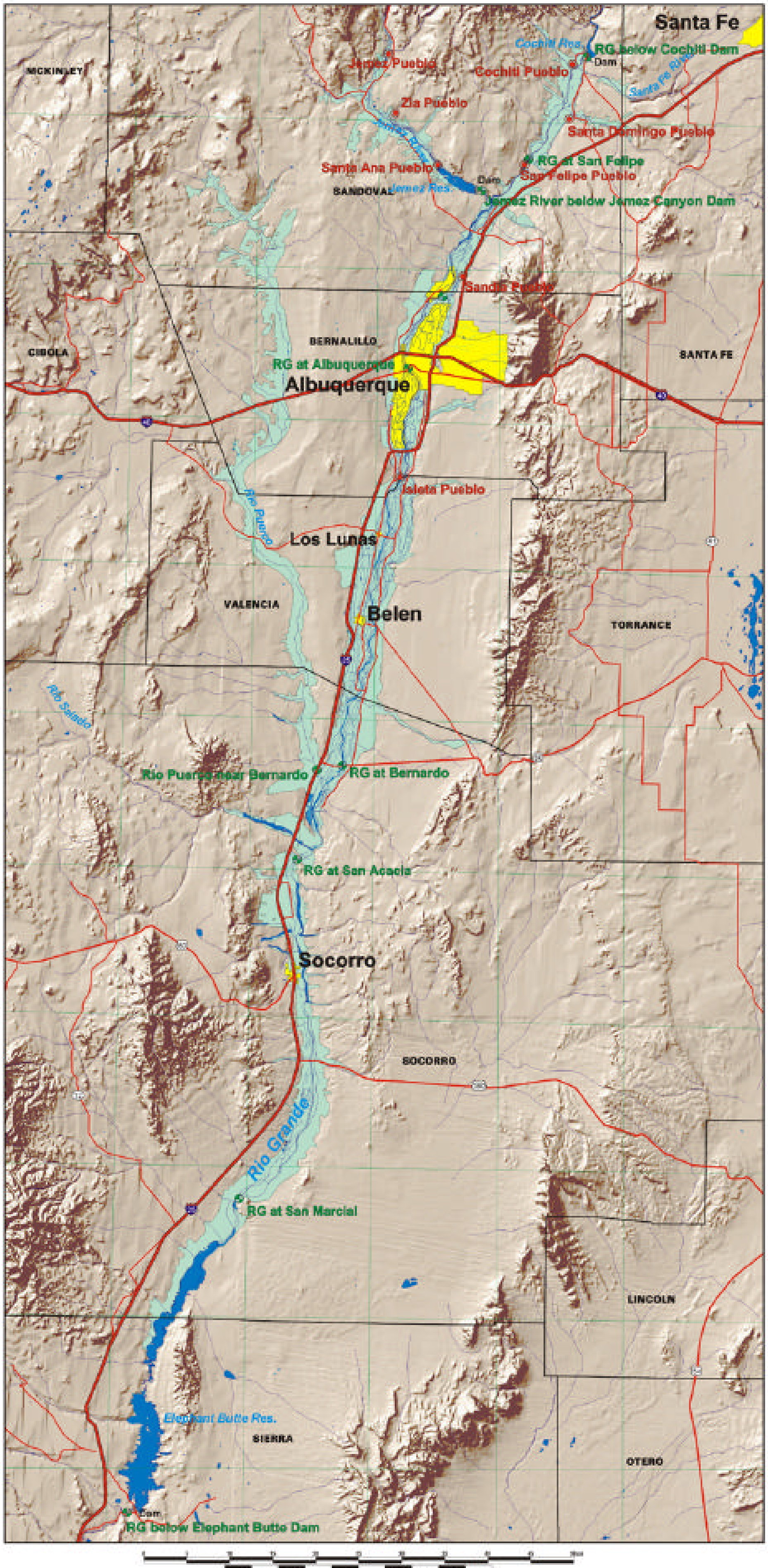
- *The water supply from Otowi to Elephant Butte is essentially a single supply*; water use in every sub-region of the Middle Rio Grande affects the water available to the entire region.

- *The water supply is only depleted by consumptive use*; reductions in diversions and return flows resulting in better delivery efficiency do not necessarily improve the water supply.

In summary, the water supply of the Middle Rio Grande is marked by limitation and variability. The successful water planning process will operate in recognition of these concepts.

Middle Rio Grande Water Supply Study

ES-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 under 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 32

S.S. Papadopulos & Associates, Inc.

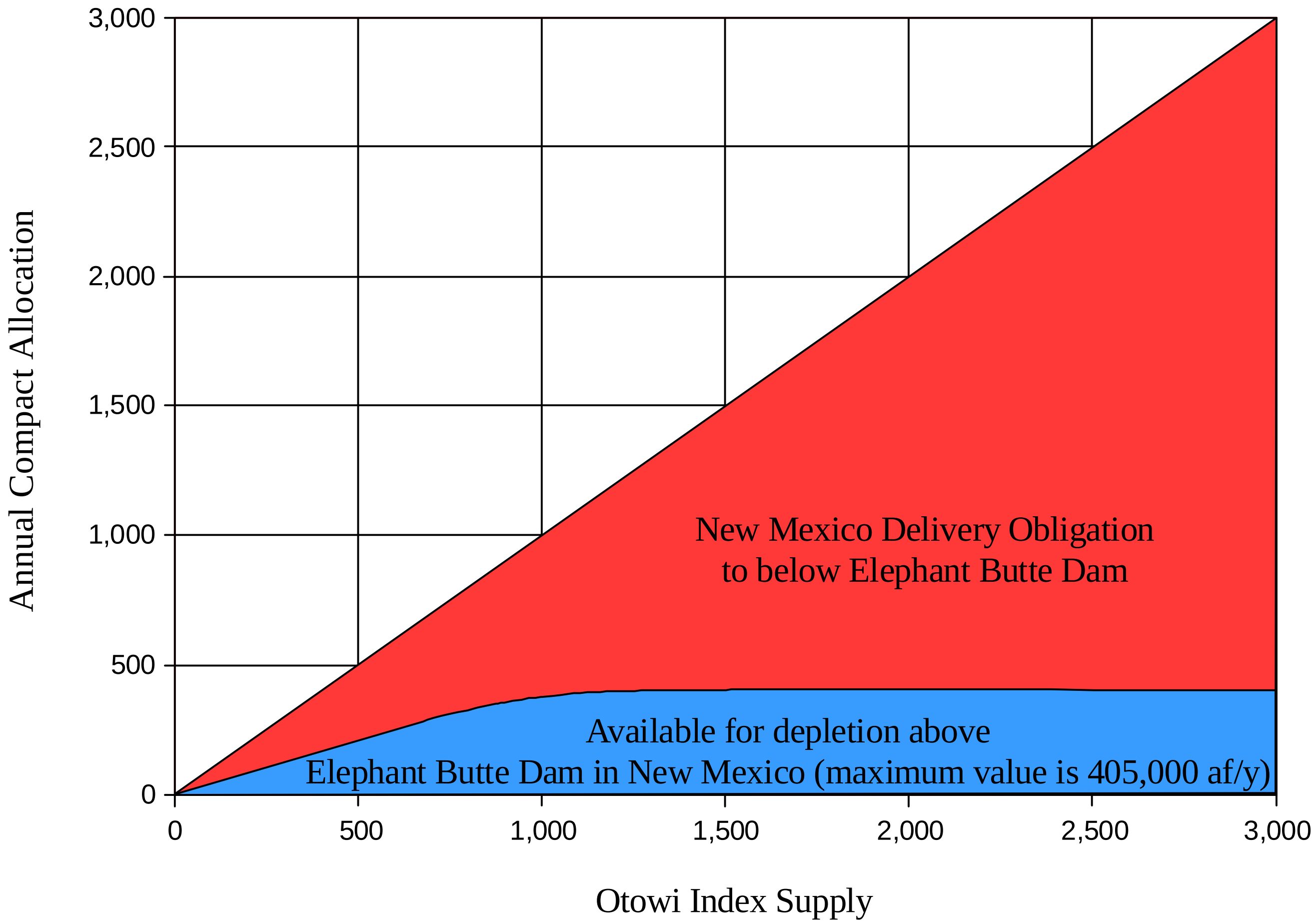
SS Consulting Group, Inc.

Revised 11/23/00

ES-2

Rio Grande Compact Allocation

(quantities in thousands of acre-feet)



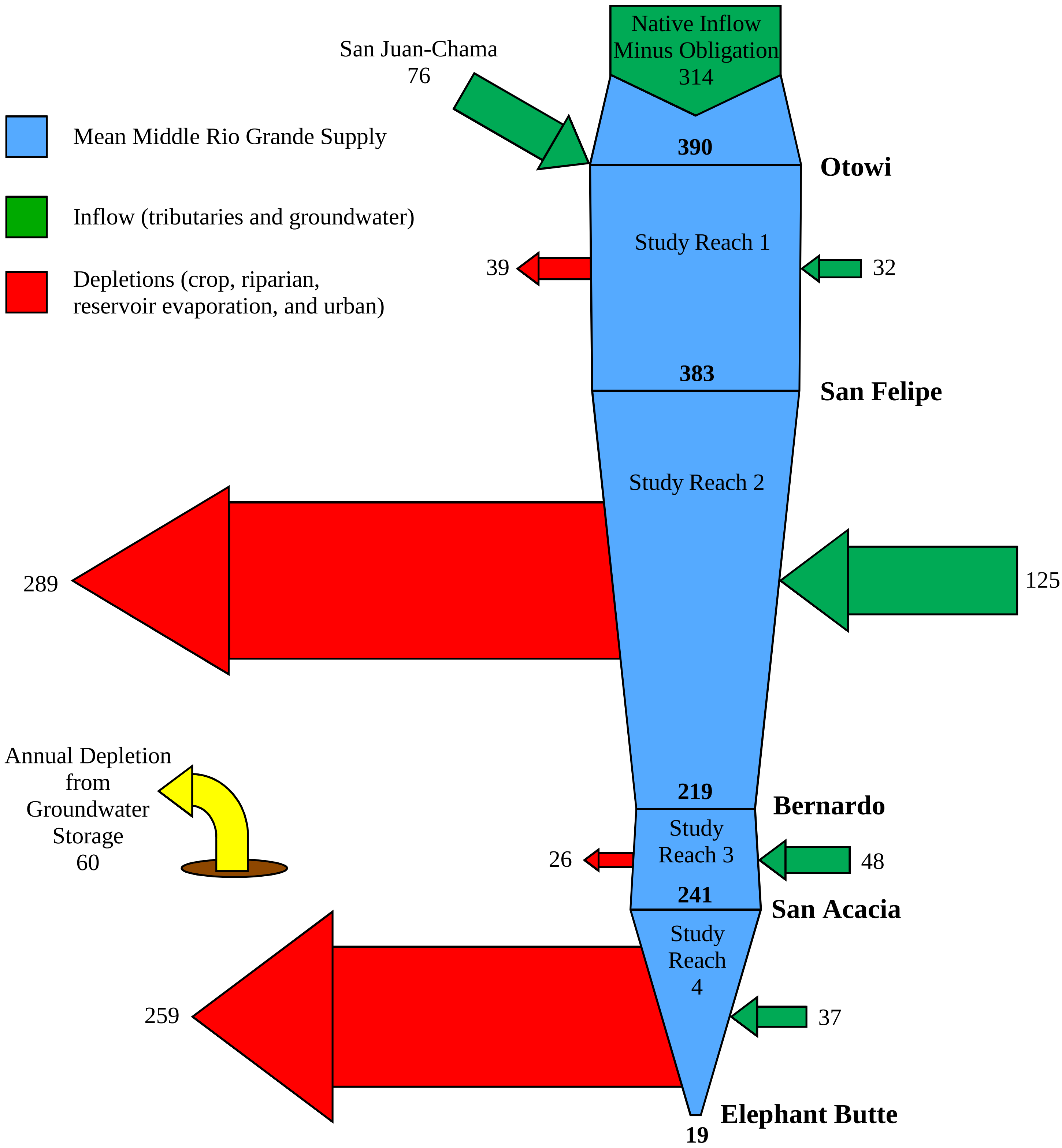
Tabulated values from Resolution Adopted by Rio Grande Compact Commission, 1948

(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

ES-3

Mean Annual Middle Rio Grande Water Supply Under Present Conditions, Excluding Elephant Butte Scheduled Delivery (in thousands of acre-feet)

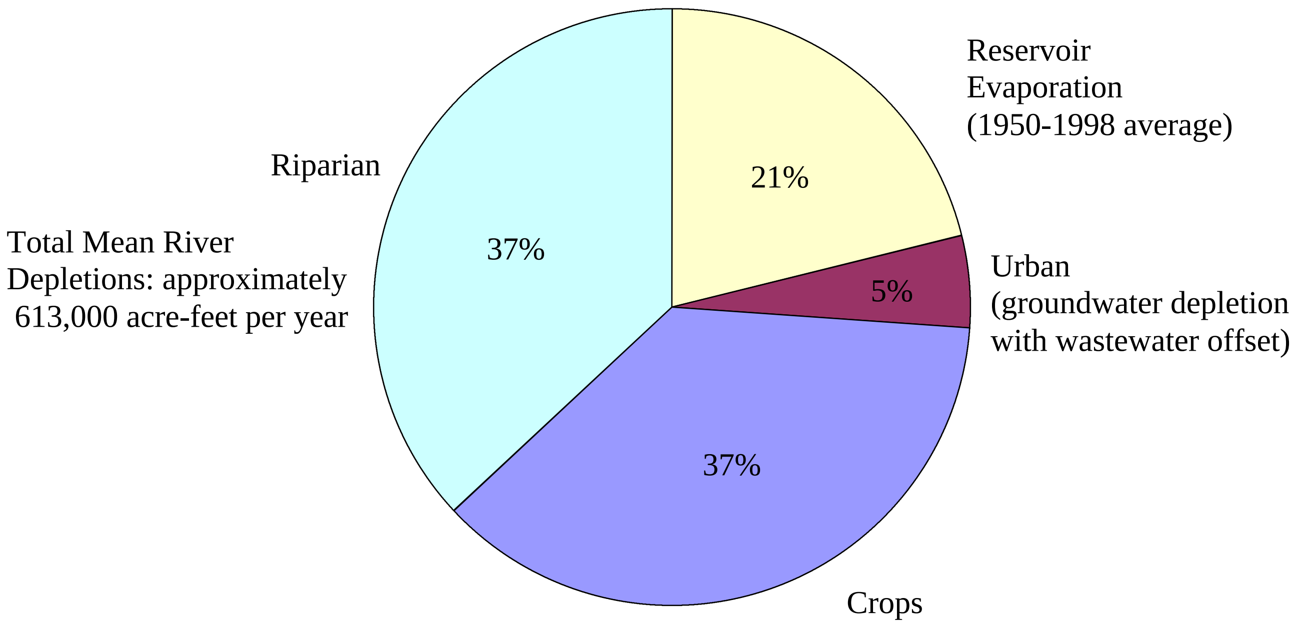


Assumptions:
- Present development conditions for groundwater pumping, irrigation, and riparian uses
- Inflows based on mean value of risk model output, sampling from probability functions incorporating climatic variability, 1950-1998
- Rio Grande native inflow and reach flows represent simulated flows minus mean Compact obligation derived from risk model output

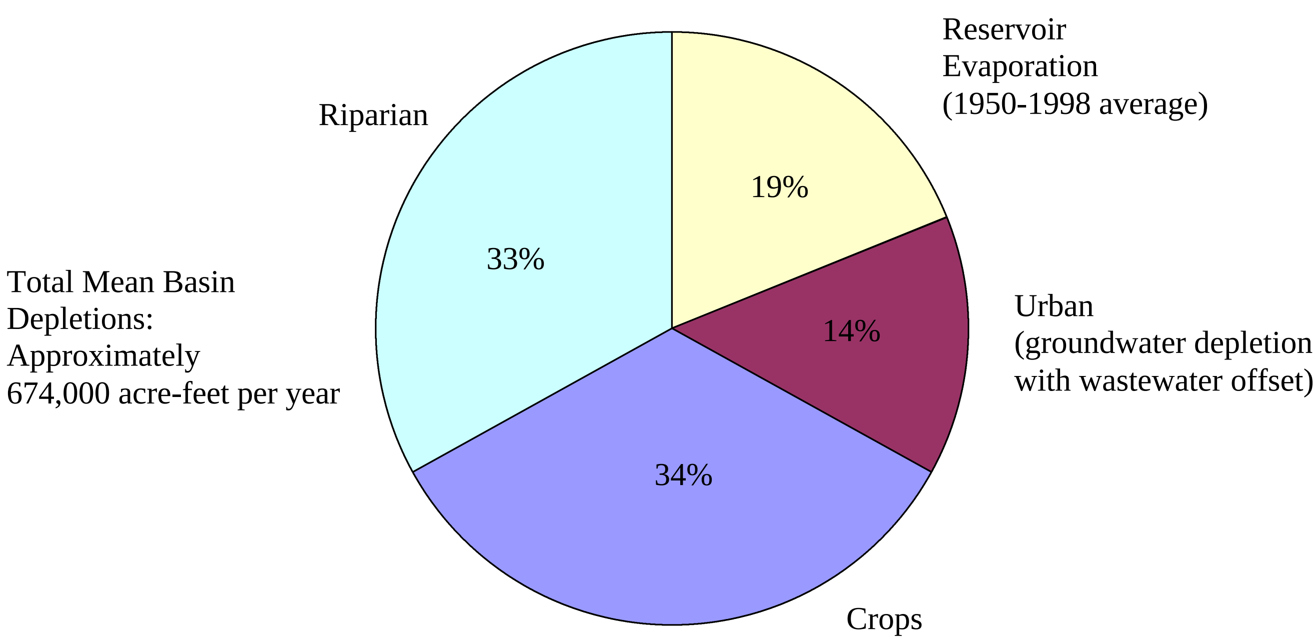
ES-4

Summary of Mean Depletions

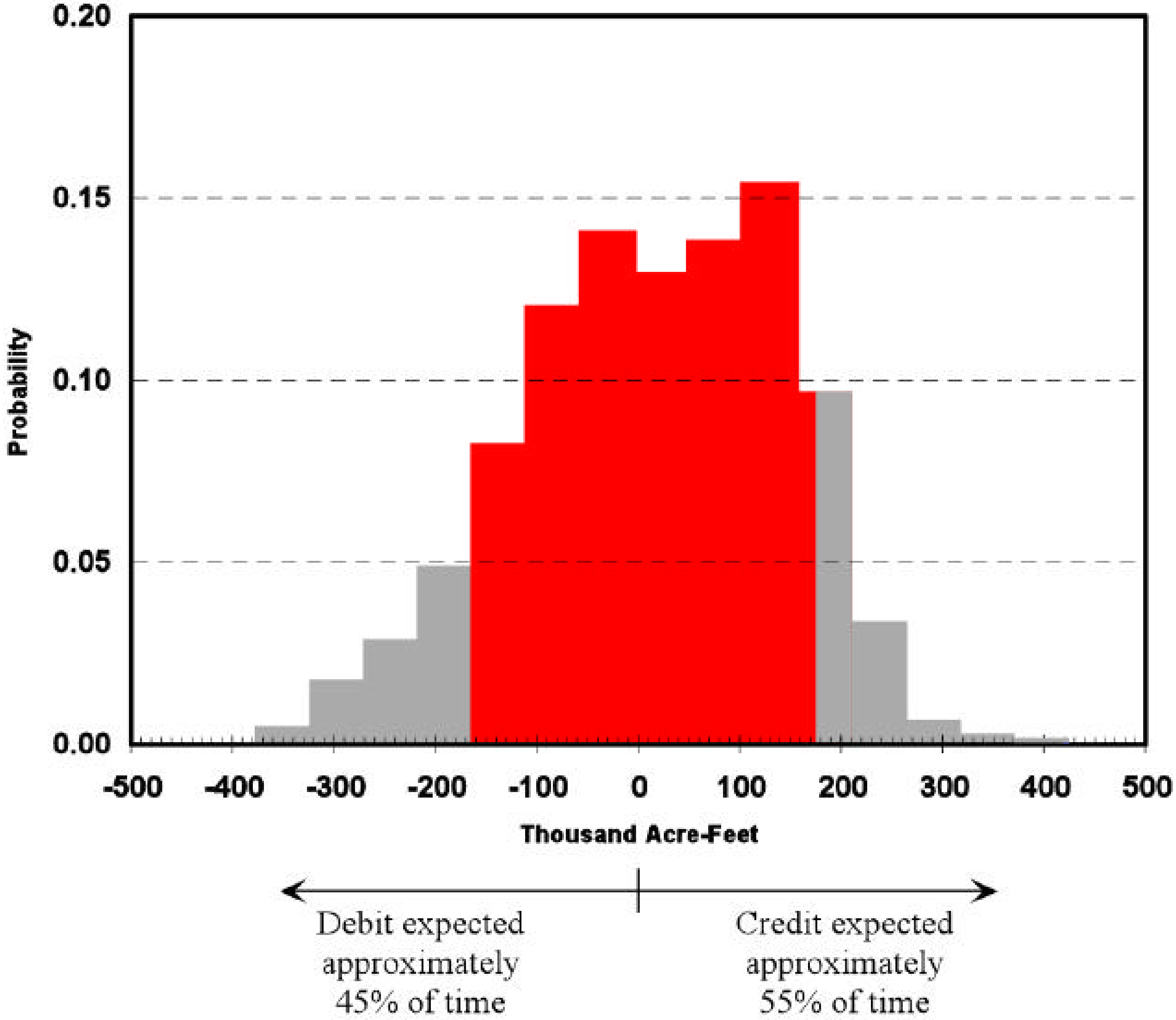
a) Mean depletions to river system under present land use and groundwater development conditions



b) Mean total Middle Rio Grande depletions (including depletion from groundwater storage),under present land use and groundwater development conditions

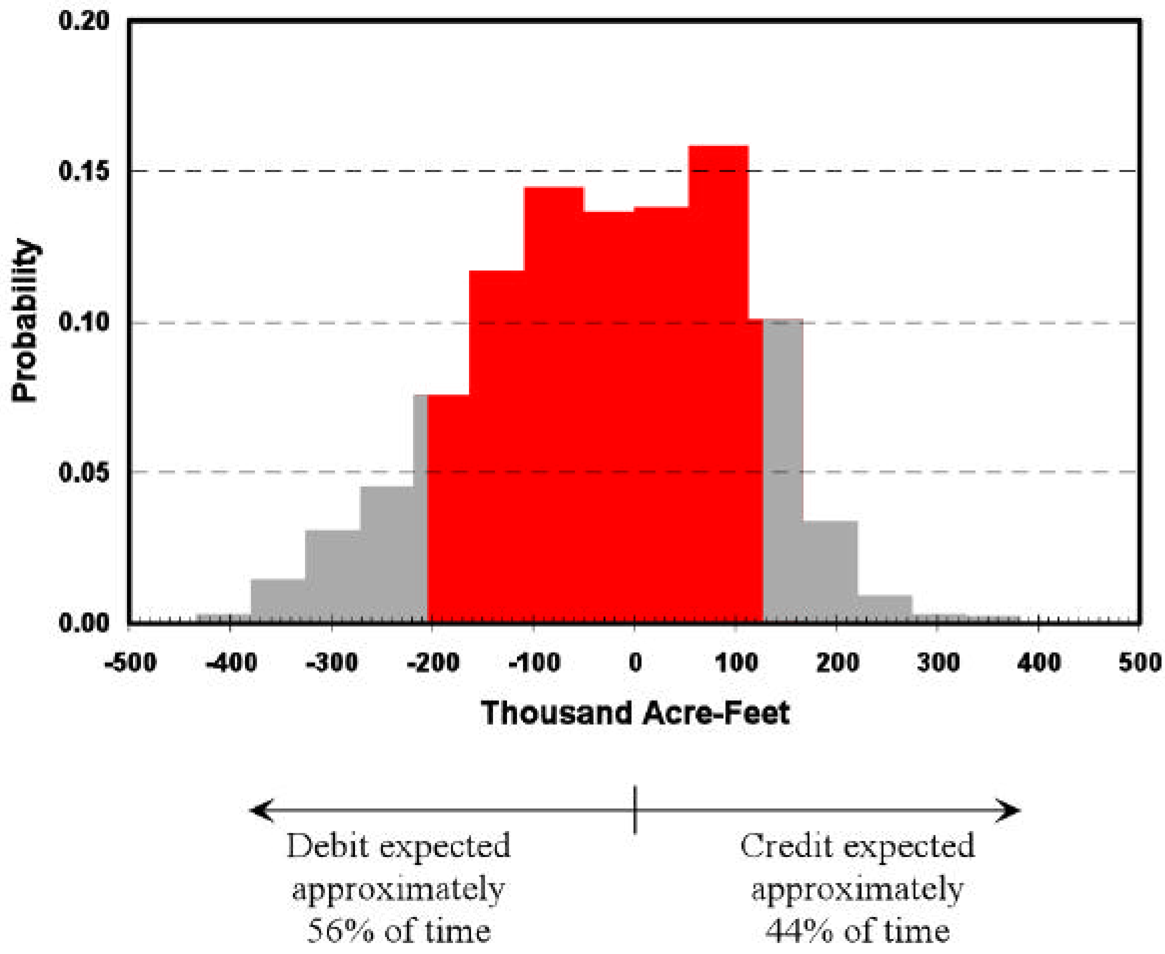


ES-5
Credit-Debit Probability Distribution
Present Development Condition, Year 2000



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area

ES-6
Credit-Debit Probability Distribution
Alternative Development Condition, Year 2040



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area

TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY ES-1

LIST OF FIGURES iv
LIST OF TABLES vi
LIST OF APPENDICES vii
GLOSSARY viii

REPORT

1.0 INTRODUCTION 1

1.1 Study Objectives 1
1.2 Study Area 2
1.3 Study Approach 2
1.4 Project Review 4
1.5 Report Organization 5

2.0 BACKGROUND 7

2.1 Rio Grande Compact 7
2.2 Concepts of Aquifer-Stream Interaction 10
2.3 Concepts of Probability and Risk Analysis 12

3.0 AVAILABLE DATA AND RESOURCES 15

3.1 Data and Information Reconnaissance 16
3.2 Document Database and Annotated Bibliography 16
3.3 Preparation of Metadata Database 17
3.4 Key Data Sets 17

3.4.1 USGS Flow Data and Composite Flow at River Cross-Sections 17
3.4.2 Middle Rio Grande Conservancy District Flow Records 19
3.4.3 Wastewater Discharge 21
3.4.4 Rio Grande Compact Indices 21
3.4.5 Consumptive Water Uses 22

3.4.5.1 Crop and Riparian Consumptive Use 23
3.4.5.2 Reservoir Evaporation 25
3.4.5.3 Groundwater Use 25

3.4.6 GIS Coverages 26

4.0 REVIEW OF WATER BUDGET AND DEPLETION STUDIES 28

4.1 Summary of River Depletions 29
4.2 Review of Water Budget and Depletion Studies 32

5.0 PROBABILISTIC WATER SUPPLY ANALYSIS 36

5.1 Water Supply Analysis Approach 36
5.2 Probabilistic Characterization of Inflow Components 38

5.2.1 Otowi Index Supply 38
5.2.2 Trans-Mountain Diversions (San Juan-Chama Project Water) 39
5.2.3 Santa Fe River Inflow 41
5.2.4 Galisteo Creek Inflow 41
5.2.5 Jemez River Inflow 42
5.2.6 AMAFCA Inflow 42
5.2.7 Rio Puerco Inflow 43
5.2.8 Rio Salado Inflow 43
5.2.9 Ungaged Tributary Inflow 44
5.2.10 Base "Adjusted" Groundwater Inflow 45

5.3 Probabilistic Characterization of Depletions 47

5.3.1 Cochiti Evaporation 47
5.3.2 Elephant Butte Evaporation 47
5.3.3 Groundwater Depletions 47
5.3.4 Wastewater Returns 48
5.3.5 Agricultural Consumptive Use 49
5.3.6 Riparian Consumptive Use 50
5.3.7 Reduction of Agricultural and Riparian Consumptive Use by Effective Precipitation 52
5.3.8 Downstream Delivery Obligation under the Rio Grande Compact 52

5.4 Water Supply Model Results 53

5.4.1 Basin-Wide Model, Annual Evaluation 54

5.4.1.1 Groundwater Inflow/Outflow Terms 54
5.4.1.2 The Probabilistic Water Supply under Present and Alternative Conditions 56

5.4.2 Reach-by-Reach Model, Annual Evaluation 57

6.0	IMPLICATIONS FOR REGIONAL WATER PLANNING		61
	6.1	Summary of Conclusions	61
	6.2	Implications for Regional Water Planning	65
	6.3	Areas for Continuing Investigation	67
7.0	REFERENCES		69

FIGURES
TABLES
APPENDICES

LIST OF FIGURES

1.1 Map of Study Area
1.2 Variability: Flow of Rio Grande at Otowi Bridge, 1940 to 1998
1.3 Limitation: Base Supply to the Middle Rio Grande Region (Rio Grande at Otowi Bridge minus Elephant Butte Scheduled Delivery)

2.1 New Mexico Delivery Schedule under the Rio Grande Compact
2.2 Probability Distribution Example

3.1 Schematic of Major Diversions and Tributary Inflows: Rio Grande from Otowi to Elephant Butte
3.2 Otowi Cross-Section
3.3 Cochiti Cross-Section
3.4 San Felipe Cross-Section
3.5 Bernardo Cross-Section
3.6 San Acacia Cross-Section
3.7 San Marcial Cross-Section
3.8 Elephant Butte Cross-Section
3.9 Cochiti Diversion
3.10 Angostura Diversion
3.11 Isleta Dam Diversion
3.12 San Acacia Dam Diversion
3.13 Net Supply (Otowi Index Supply minus Scheduled Delivery)
3.14 Rio Grande Compact Credit History

5.1 Otowi Index Supply
5.2 Trans-Mountain Diversions
5.3 Santa Fe River
5.4 Galisteo Creek
5.5 Jemez River
5.6 AMAFCA Inflow
5.7 Rio Puerco
5.8 Rio Salado
5.9 Cochiti Evaporation
5.10 Elephant Butte Evaporation
5.11 Wastewater Returns
5.12 Agricultural Consumptive Use above San Acacia
5.13 Agricultural Consumptive Use below San Acacia
5.14 Riparian Consumptive Use above San Acacia
5.15 Riparian Consumptive Use below San Acacia
5.16 Scheduled Delivery at Elephant Butte

5.17 River Depletions under Hypothetical Future Pumping Scenarios
5.18 Credit-Debit Probability Distribution Present Development Condition, Year 2000
5.19 Credit-Debit Probability Distribution Present Development Condition, Year 2040
5.20 Credit-Debit Probability Distribution Alternative Development Condition, Year 2040
5.21 Gross Water Supply at San Felipe Probability Distribution, Present Condition
5.22 Gross Water Supply at Bernardo Probability Distribution, Present Condition
5.23 Gross Water Supply at San Acacia Probability Distribution, Present Condition
5.24 Gross Water Supply at Elephant Butte Probability Distribution, Present Condition
5.25 Schematic: Middle Rio Grande Water Supply Under Present Conditions, Excluding Elephant Butte Scheduled Delivery (in thousand acre-feet)
5.26 Summary of Mean Depletions

LIST OF TABLES

1.1 Executive Steering Committee

3.1 Metadata Database: Summary of Included Data Sets
3.2 Summary of USGS River, Conveyance and Tributary Gaging Stations
3.3 MRGCD Diversion Gaging Stations, 1974 to 1995
3.4 Summary of MRGCD Water Distribution Data Reported to USBR
3.5 Comparison of MRGCD Reported Net Supply to Composite Diversions
3.6 MRGCD Irrigation System Delivery Efficiency
3.7 Crop and Riparian Acreage
3.8 Crop and Riparian Consumptive Use, Average from 1985-1998
3.9 Riparian and Wetland Community Types from San Marcial to Elephant Butte

4.1 Comparison of Agricultural and Riparian Consumptive Use Estimates in Water Budget Studies

5.1 Structure of Water Budget Model
5.2 Characterization of Water Budget Terms for Basin-Wide Model, Annual Evaluation
5.3 Mean Water Budget Summary by Reach

LIST OF APPENDICES

APPENDIX A	Metadata Database
APPENDIX B	Summary of Flow Data and Compact-based Flow Indices
APPENDIX C	Summary of Consumptive Use Data
APPENDIX D	Summary of Inflow-Outflow and Depletions Analysis
APPENDIX E	Profiles of Previous Water Budget and Depletion Studies
APPENDIX F	Probabilistic Analysis of Key Inflow and Outflow Water Budget Terms
APPENDIX G	Calculation of Groundwater Depletions and Base Groundwater Inflow
APPENDIX H	Use of Risk Analysis Model in Water Budget Evaluation

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, 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?)

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, what is the average payout of a slot machine, how often does it pay, what is the minimum and maximum payout?)

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

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 from the water system.

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.

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 reservoirs (constructed after 1929) and 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 the likelihood of experiencing a particular outcome

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

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

Salvaged evapotranspiration – a decrease in the amount of evapotranspiration occurring 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

Santa Fe Group aquifer system – a deep complex of unconsolidated alluvial sediments along the Rio Grande. These sediments form an aquifer that is hydraulically connection 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 to be 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 affect 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 within a river system where the U. S. Geological Survey has installed equipment for monitoring of river level and flow

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

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 Objectives

The goal of the Middle Rio Grande Water Supply Study is 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 is conducted under U.S. Army Corps of Engineers (COE), Albuquerque Division, Contract DACW47-99-C-0012, and is jointly funded by the COE and the New Mexico Interstate Stream Commission (ISC). This water supply study assembles and provides water supply information to support regional water planning efforts for the Middle Rio Grande and describes conditions relevant to maintaining compliance with the Rio Grande Compact.

The regional water planning process focuses on five questions:

- What is the water supply?
- What is the water demand?
- What alternatives exist to meet demand with available supply, including water conservation?
- What are the advantages and disadvantages to these alternatives?
- What is the best plan and how will it be implemented?

This study addresses the first of these questions: characterization of the water supply. Other studies will be conducted by regional planning entities to address the remaining water planning questions.

Key products generated in this study include:

- 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.

These products provide an up-to-date integration of past and on-going technical studies related to the water supply that can be considered by regional water planning entities as they frame water plans. This study differs from previous water supply studies in that it considers a range of water supply conditions, rather than average conditions, or conditions in specific years. The range of water supply conditions considered in this study reflects the climatic variability experienced in this region over the past 50 years.

1.2 Study Area

The Middle Rio Grande region in New Mexico extends along the Rio Grande, north to south, from Cochiti Reservoir to Elephant Butte Reservoir, a distance of approximately 175 miles (Figure 1.1). In terms of gaged flows, the Rio Grande at Otowi Bridge gage, upstream of Cochiti Reservoir, and the Rio Grande below Elephant Butte, downstream of Elephant Butte Reservoir mark the upstream and downstream limits of this study. The study area includes groundwater aquifers within the *Quaternary alluvium* and the *Santa Fe Group aquifer system*.

1.3 Study Approach

The present 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, primarily located in the Albuquerque Basin, but also located in *stream-connected aquifer*s immediately north and south of the Albuquerque Basin.

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 1998. Characterized with a mean value of approximately 1.1 million acre-feet per year, visual inspection of this graph shows that 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 water) between 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 limited 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, the study approach focuses on characterizing the variability of inflow supply components and depletion components. This variability is tracked through the water budget for the study region, to quantify the range of likely water supply conditions. The water supply quantified 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 and development conditions. 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 Project Review

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. During Phase 1 of the project (June through September, 1999), meetings included a kick-off informational meeting and a Work Plan presentation. During Phase 2 (November 1999 through August 2000), meetings included progress meetings in February and May, and a public meeting in July. The ESC included technical representatives of a diverse group of stakeholders and agencies within the Middle Rio Grande region; interested observers also attended meetings of the ESC. Agencies or groups invited to participate on the ESC are listed on Table 1.1. Many of these entities were actively involved 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 this study. Section 1 provides an introduction to the study and the report. Section 2 provides background information on three topics of key importance to this study. Section 3 describes the available data and resources utilized in this study. Section 4 discusses previous water budget and depletion studies, and compares and contrasts their conclusions. Section 5 describes the conjunctive-use water supply to the Middle Rio Grande region in probabilistic terms, as derived under this study. Section 6 describes implications of this study for future work and planning in the Middle Rio Grande region. To maintain readability of the report, detailed technical material and supporting data are organized within several appendices to this report. These appendices include the metadata database, summaries of key data sets, profiles of previous water budget studies, groundwater modeling details and statistical and risk analyses.

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. The illustrated summary of water budget data provides a map-based set of navigation points leading to time-series graphs, metadata, probability distribution functions, photos and other information related to the water supply study.

2.0 BACKGROUND

Background information is provided in this section on three topics important to this study. The first of these topics, the Rio Grande Compact, describes the interstate agreement underlying the delivery obligations downstream of the Middle Rio Grande region. The second and third topics, groundwater-stream interaction, and probability and risk analysis, describe technical concepts that are fundamental to the study approach. 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 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; and, that deliveries to "Texas" also serve New Mexico and Mexico users supplied with water stored in the Elephant Butte Reservoir).

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, is the amount of surface water available for depletion in the Middle Rio Grande region. The scheduled relationship between Otowi Index Supply and Elephant Butte Scheduled Delivery is shown graphically on Figure 2.1. According to this schedule, 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. Under this schedule, 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 *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 *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.

2.2 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 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*.

The concept of 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 percentage of water withdrawn from a well that results in decreased stream flow will increase with time, until stabilizing, or reaching *steady-state conditions*. 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, as the distance between the pumping locations and the connected reaches of the stream are increased. 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.

2.3 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. The above-mentioned hydrologic processes can be described using laws of physics; although fluctuations in some of these processes can be 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, that is, they can be characterized using laws of chance.

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. A more detailed discussion of these procedures is included in Appendices F and H.

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

Probability distribution fitting involves finding a curve or mathematical formula to describe the likelihood of experiencing a particular outcome. For example, casinos set slot machines to operate according to a *probability distribution* that will achieve the desired outcome. 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 on 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 the description of similar relationships between different processes. For example, 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?

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.

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 include the pueblos of Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, Zia, Jemez and Isleta; and the Rio Grande Compact Commission, authorized by the Congress of the United States.

While the 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, several activities were conducted to review, assimilate and document available material from these studies. These activities are discussed in the following sections.

3.1 Data and Information Reconnaissance

This activity was initiated at the project kick-off meeting with the Executive Steering Committee (ESC). During this meeting, 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 key data sets and a metadata database, as described below.

3.2 Document Database and Annotated Bibliography

A document database, or bibliography, was prepared that includes citations for reports with potential relevance to the study. The objective of this task was to include 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 and river operations. 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 Preparation of Metadata Database

Metadata, or, data about data, was requested from agencies or entities collecting or maintaining water resource data with relevance to this study. Metadata was 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 on Table 3.1. The metadata database 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**.

3.4 Key Data Sets

Key data sets obtained for consideration in this study are described in this section, under the general categories of USGS flow data, MRGCD flow data, wastewater discharge, Rio Grande Compact indices, *consumptive use* data and GIS coverages. These data sets are represented 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 gaging stations, major tributary inflows and major diversions in the study area.

3.4.1 USGS Flow Data and Composite Flow at River Cross-Sections

An initial review of *USGS gaging stations* identified 69 flow gaging stations within the Middle Rio Grande region, measuring 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 and 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 on Table 3.2, with identifying information and the period of record for the station. Time-series graphs of annual flow data calculated from the daily mean flows are provided in Appendix B for most of these stations. Metadata has been developed using information provided by the USGS for each of the 47 gaging stations and is provided in Appendix A.

The combined surface water supply in the river and the adjacent channels can be seen by examining the composite flow at several transects along the river, or river cross-sections. River cross-sections with a relatively long period of recorded total flow include the locations at Otowi, Cochiti, Bernardo, San Acacia, San Marcial and below Elephant Butte. Neglecting some small components of unmeasured flow, San Felipe can be added to this list. Profiles of these cross-sections, including time-series graphs of the composite flow, are provided in Figures 3.2 through 3.8. Changes in conveyance channel configuration and gage location are reflected in the selection of gaging stations included for the composite record. The contributing stations for various time periods are noted on the figures. The composite flow indicates the amount of surface water in the combined river and irrigation conveyance system during the period illustrated, and indicates overall supply conditions. Changes in the supply, or depletions through the reaches, will be discussed in Section 4.0.

3.4.2 Middle Rio Grande Conservancy District Flow Records

Historically, the MRGCD has gaged major diversions to the irrigation conveyance system, select drain returns and mid-system streams. Records of the flow at these points were obtained from the MRGCD. These records consist of handwritten tables of recorded daily flows at 13 stations, for the period of 1974 to 1995. These stations are listed on Table 3.3. The MRGCD was unable to locate similar records for the years prior to 1975, although it was thought that they might exist in warehoused boxes. Not catalogued at present, these voluminous materials were not searched.

More recently, the MRGCD has embarked on an expanded monitoring program, with the goal of measuring additional diversion points within the irrigation system and measuring all outfall and drain return flows. Additionally, the MRGCD is implementing an electronic data storage and retrieval system.

The historical flow data were summed to obtain the total recorded flow in canals at their headings near major diversion dams: Cochiti, Angostura, Isleta and San Acacia. The sum of the recorded flows, termed "composite diversion", is shown on Figures 3.9 to 3.12. These totals were derived from an electronic rendition of the paper records referenced above, implemented by the multi-agency Upper Rio Grande Water Operations Model (URGWOM) study team. The "composite diversion" shown for each dam represents the reported amount of water diverted, with the exception of the Socorro Diversion, which also includes unmeasured return flows from the Unit 7 Drain. The composite diversions do not represent the amount of water consumptively used to meet crop demand within the MRGCD. A significant portion of the diverted water returns to the river through outfalls or drains, while some of the diverted water percolates to the aquifer. Additionally, some of the diverted water is consumed by riparian plants, and some is lost to evaporation.

A similar record of MRGCD diversions is reflected in the Water Distribution Reports, submitted to the USBR on an annual basis by the MRGCD. These records, prepared for each division within the MRGCD, include *net supply* (monthly diversions to major canals), estimated *waste* (water returned to the river through wasteways and drains), estimated *loss* (defined as evaporation, phreatophyte consumption and seepage to groundwater) and estimated *deliveries to farms*. Table 3.4 provides a summary of these records. The reported net supply is understood to represent the sum of diversions for the major MRGCD divisions. As with the composite diversions, the net supply does not represent the amount of water used in the MRGCD to meet crop demand, as much of this water is returned to the river system. Similarly, the farm delivery does not represent crop consumptive use, as *return flow* from farms occurs back to the hydrologic system (i.e., tail water or percolation to groundwater).

Table 3.5 compares the total MRGCD diversions computed using data portrayed in Figures 3.9 to 3.12 with the totals provided on the USBR Water Distribution Reports. Differences in these figures have not been reconciled as part of this study, but may be explained by further examination of the records.

An average delivery efficiency of 30.3% is calculated, reflecting the water delivered to farms divided by the net supply (Table 3.6). The on-farm efficiency and overall system efficiency cannot be calculated from data provided. Questions regarding irrigation district usage, distribution efficiency and scheduling will be more amenable to study in the near future, with the expansion of the MRGCD monitoring network.

3.4.3 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 1998. The total wastewater discharge in 1998, comprised largely of wastewater from the City of Albuquerque, was 68,941 acre-feet. Time-series graphs of these records, as annual totals, are provided in Appendix B.

3.4.4 Rio Grande Compact Indices

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 trans-mountain diversions and supporting data for derivation of the indices. The definition and application of these indices are introduced in Section 2.1, above. Time-series graphs of each of these indices are provided in Appendix B.

The Rio Grande Compact indices control the supply to the Middle Rio Grande region. The Otowi Index Supply (native inflow) and the 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 3.13). The actual supply to the region is equal to this difference, plus 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 3.14 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.

3.4.5 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 further documented in the metadata database (see

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

3.4.5.1 Crop and Riparian Consumptive Use

Crop and riparian consumptive use data were obtained from the USBR, as developed in the ET Toolbox project (Brower and Hartzell, 1998), for the region from Cochiti to San Marcial. For the reach from San Marcial to the Elephant Butte Reservoir, consumptive use was estimated based on provisional acreages for riparian and wetland vegetation classes provided by the USBR.

For six reaches in the region between Cochiti and San Marcial, daily consumptive use estimates for the years 1985 to 1998 are accessible through the USBR NEXRAD web page at **http://www.usbr.gov/rsmg/nexrad**. These 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. The consumptive use was calculated by applying a modified Penman procedure, using updated crop coefficients for salt cedar and cottonwood, and an updated solar radiation function (Al Brower, personal communication, May 2000). In the calculation, uniform crop coefficients and vegetation class acreages have been employed, but climatic parameters were varied according to the climatic record.

For this study, the daily consumptive use by crop or riparian groups have been aggregated within river reaches to obtain total monthly and annual crop or riparian estimates. The riparian class includes open water evaporation from the Rio Grande, canals and drains. Graphs showing the annual consumptive use derived for reaches above and below San Acacia, for crops and riparian uses, are provided in Appendix C. A summary of the acres assumed by the USBR for the consumptive use calculations is provided in Table 3.7. A summary of the calculated consumptive use, averaged for the period 1985 to 1998, is provided in Table 3.8. The average crop and riparian consumptive uses for the region above San Acacia are 191,567 and 155,078 acre-feet per year, respectively. The average crop and riparian consumptive uses for the reach below San Acacia are 56,520 and 49,452 acre-feet per year, respectively.

The calculated consumptive use presented on Table 3.8 represents the theoretical consumptive use for these crops, under assumed climatic conditions. However, 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 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.

For the reach from San Marcial to Elephant Butte, consumptive use for riparian and wetland (including open water) vegetation classes were assigned using provisional acreage estimates developed by the USBR (Larry White, personal communication, April, 2000). The acreages assigned to several vegetation and wetland classes for this reach are summarized on Table 3.9. A total of approximately 11,000 riparian and open-water acres are assumed for the area from San Marcial to the edge of the Elephant Butte Reservoir. The consumptive use for these acreages has not yet been incorporated into the ET

Toolbox, using the modified Penman approach, as described for the URGWOM reaches 1-6. For the purpose of this study, consumptive use in this reach has been estimated by applying a consumptive use factor derived from the ET Toolbox data for the San Acacia to San Marcial riparian classes. This consumptive use factor is 3.71 acre-feet per acre, without adjustment for effective precipitation.

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

3.4.5.3 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 (Kernodle et al, 1995; Kernodle, 1998), and is reflected in the Office of the State

Engineer (OSE) version of this model (Barroll, 1999). As represented in the OSE model, the current level of pumping in the Albuquerque Basin is 156,800 acre-feet per year.

Other elements of the water budget with respect to the groundwater reservoir are incorporated into the groundwater flow model. 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 the flow model. This study used the existing flow model 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 new work products are summarized on the website **http://rmmcwet.cr.usgs.gov/public/mrgbhome.html**.

3.4.6 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) 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. As part of this study, specific metadata were developed where possible and are provided in Appendix A.

4.0 REVIEW OF WATER BUDGET AND DEPLETION STUDIES

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 along the Middle Rio Grande, 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.

Water budget results 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. This study undertakes a review of several of the water budget evaluations found in the literature relating to the Middle Rio Grande region. These water budgets are discussed in terms of the study objective, spatial and time domain, physical domain and study approach. Comparisons are made where appropriate; more importantly, reasons for not comparing some of the past studies are noted.

Depletion analyses represent one of the approaches frequently employed in conducting water budget studies, and involve estimation of depletion terms through evaluation of other, more easily measured terms. Applied to flow conditions in the river, depletion analyses identify reach gains or losses by evaluating the difference between upstream and downstream points along a reach. The review of water budget studies in this section also discusses river depletion studies.

Section 3 of this report summarized available data for key water budget components, including inflow components and outflow (consumptive use) components. As previously noted, these flow data are summarized graphically in Appendices B and C. River depletions, by reach, can readily be derived from the flow data. Reach-specific river depletions obtained from the flow data are described briefly in Section 4.1, below, to provide additional background for the discussion of water budget and depletion studies. Section 4.2 provides a discussion and integration of previous water budget and depletion studies.

4.1 Summary of River Depletions

River depletions by reach are described in this section, based on the sum of flow at channels crossing river cross-sections for annual and sub-annual time periods. Discriminating the causes of historical changes in reach depletions can be complex, and in some cases, difficult, due to limited historical data. This study, focusing on the present supply condition, does not undertake an analysis of the historical conditions beyond a descriptive level. However, generalized observations regarding historical conditions are noted in this section, for general background purposes.

For this study, composite flow at the river cross-sections at Otowi, Cochiti, San Felipe, Bernardo, San Acacia, San Marcial and Elephant Butte (Figures 3.2 to 3.8) have been reviewed. Composite flows at these cross-sections have been used to create *double-*

mass curves and *depletion graphs* for each reach, annually, and for each of three sub-annual periods. For these analyses, the sub-annual periods are described as:

Winter – November, December, January, February

Spring - March, April, May, June

Summer – July, August, September, October.

These graphs are provided in Appendix D and illustrate the general relationships among flows between reaches.

The double-mass curves show the cumulative flow at the upstream and downstream section for the reach, with data points representing successive years. In viewing these graphs, a change in the slope of the graphed line indicates a change in the inflow-outflow relationship for the reach. A steeper slope indicates a period of reduced reach depletions; conversely, a flatter slope indicates a period of increased reach depletions.

The depletion graphs show the difference between the upstream and downstream flow for the reach cross-sections, and illustrate where and when reach gains and losses are occurring. Because these graphs are based on composite flow at cross-sections, and include the flow in adjacent canal, drains or conveyance channels, they are indicative of overall supply conditions and reach depletions, as opposed to in-stream river flow and riverbed gains or losses.

Review of the double-mass curves and depletion graphs supports the following general observations:

<u>Cochiti to San Felipe (1956 to 1998)</u>

- Depletions typically range between 0 and 50,000 acre-feet per year,

- Gains occur during the winter season for the post-1970s. This is presumably due to seepage from Cochiti Reservoir past the gage on the Rio Grande below Cochiti.

San Felipe to Bernardo (1965 to 1998)

- Depletions typically range between 0 and 180,000 acre-feet per year,
- Some association of lower depletions in years of higher supply, particularly in spring, is apparent,
- Cumulative trends reflect reduced depletions since the mid-1980's,
- Winter gains occur through most of period, and are more pronounced in 1990's.

Bernardo to San Acacia (1965 to 1997)

- Depletions and gains occur, both typically ranging up to 50,000 acre-feet per year,
- Cumulative trends indicate a slight average gain in this reach,
- Gains are evidenced particularly during summer, likely associated with the flows of the Rio Puerco and Rio Salado.

San Acacia to San Marcial (1940 to 1998)

- Depletions typically range between 50,000 and 150,000 acre-feet per year,
- Cumulative annual trends suggest reduced depletions beginning in the 1960's
- Cumulative trends for winter flow suggest reduced depletions from about 1960 to mid-1980s, resulting in cumulative increased delivery during this period of over 1 million acre feet,
- Cumulative trends for spring flow suggest a relatively constant pattern of spring depletion,
- Cumulative trends for summer flow suggest reduced depletions from about the mid-1950s to the end of record.

Similar graphs are included for the reaches above Cochiti and below San Marcial. However, without accounting for changes in reservoir storage in these reaches, these analyses do not reflect reach depletions.

The double-mass curves and depletion graphs provide a general characterization of the past occurrence and magnitude of depletions to the Middle Rio Grande water supply, in various reaches. Changes in depletions reflected in the composite flows at river cross-sections reflect a combination of changes in land use conditions, water conveyance infrastructure, operational conditions and loss relationships under variable supply conditions. The identification of specific cause-effect relationships resulting in historical depletion trends is beyond the scope of this study. However, a more detailed evaluation of these records and understanding of cause-effect relationships will be important in evaluating future water supply alternatives in subsequent water-planning studies. Several potential cause-effect relationships are identified by Turney (1991) in a review of depletion trends.

4.2 Review of Water Budget and Depletion Studies

Water budgets and depletion studies have been developed as part of several investigations, including the Rio Grande Joint Investigation (U.S. National Resources Committee, 1938); a 1947 study by the Rio Grande Compact Commission; the U.S. Geological Survey study of the geohydrologic framework of the Albuquerque Basin (Thorn et al., 1993); the Middle Rio Grande Water Assessment [U.S. Bureau of Reclamation (USBR), 1995, 1997]; and the Middle Rio Grande Water Assembly Action Committee (presentation handouts, various authors). The New Mexico State Engineer Office has prepared water-use and depletion summaries for various regions of the state, including the Rio Grande Basin (Wilson, and Lucero, 1997). Depletion analyses and related topics have been presented by the ISC (Turney, 1991) and water budget reviews have been prepared by the Alliance for Rio Grande Heritage (Kelton, 1998) and others. These studies, conducted at different times and for different objectives, provide insight into many aspects of the surface and groundwater hydrologic budget in this region. Profiles of these water budget and depletion studies are included in Appendix E.

In general, the previous water budget and depletion studies represent a progression of understanding of the relationships within the Middle Rio Grande region. Prepared at different points in time, with the benefit of increasing data in later years, and analyzing highly variable conditions over differing time frames, the previous studies are not strictly comparable.

The Rio Grande Joint Investigation (U.S. National Resources Committee, 1938) provides a detailed analysis of 1936 conditions, including crop acreages, estimated consumptive use, diversions, stream inflows, evaporation and groundwater conditions. A comprehensive undertaking, this study provided the foundation for the apportionment of the Rio Grande under the Rio Grande Compact. Comprehensive stream gaging and other investigations were conducted in 1936 and 1937, to support this investigation and to augment the previous record.

Depletion and water budget analyses developed for this study were based on the period 1890 to 1935. Two stations with relatively long periods of record were the Rio Grande at Otowi Bridge and Rio Grande at San Marcial. Records from 1890 to 1935 indicate mean annual flows of 1.35 and 1.13 million acre feet, respectively. These values from the pre-Compact years are considerably higher than the mean annual Otowi Index Supply of 0.96 million acre-feet for the period 1950 to 1997 (the Otowi Index Supply in this later period is comparable to the Rio Grande at Otowi Bridge in the pre-1935 period). Water budgets and depletion analyses derived under the Rio Grande Joint Investigation, valuable from a historical perspective, are difficult to apply to evaluation of current and future water supply conditions. Changes in conveyance infrastructure and land use patterns have altered the water budget framework within the Middle Rio Grande region since the Joint Investigation. In addition, conditions described in the Joint Investigation represent water supply conditions based on a shorter record and marked by higher water supplies than seen on average in recent decades.

Water budget studies published in the past decade have been examined in some detail for the purposes of this study, as they reflect the current development condition and provide perspective useful in characterizing the present water supply. A comparison of these studies (Thorn, 1993; Gould, 1997; MRG Assembly, 1999) indicates general consistency in system understanding, but differences in quantification of individual water budget terms. Differences in inflow terms occur primarily due to the use of different time frames. Given the large variability in flow conditions, the quantification is very sensitive to the selected time frame. Other differences occur due to the domain of the hydrologic system analyzed. For example, a water budget referenced to the stream system will be different from a budget referenced to a composite stream-groundwater system. Other than these easily reconcilable differences, the primary difference in published water budgets relates to the quantification of consumptive use from agricultural crops, riparian vegetation and open water evaporation.

Differences in quantification of consumptive use among several water budget evaluations are summarized in Table 4.1. Typically in water budget studies, the consumptive use term of interest is that amount of water depleted from the surface water or groundwater system to satisfy the crop consumptive use and incidental depletions. This quantity is equal to the crop consumptive use, minus the effective precipitation that satisfies some of the consumptive use. Joint Investigation and USBR ET Toolbox estimates, shown on Table 4.1, are not adjusted to remove the portion of consumptive use satisfied by effective precipitation, and are not strictly comparable to other tabulated estimates. However, they are provided for general comparison purposes. The estimates reported by Gould (1997) are based on detailed calculations using the modified Blaney-Criddle method, conducted as part of the Middle Rio Grande Water Assessment (Gould, 1997). The estimates provided by the USBR ET Toolbox are based on detailed calculations using a modified Penman approach. Further analysis of the consumptive use estimates is needed to develop comparable data sets and examine the nature of their differences. Initial work in this area should include adjustment of modified Penman calculated consumptive use to account for effective precipitation; and, calibration to historic yields to account for water supply, crop condition, or other limits on consumptive use.

5.0 PROBABILISTIC WATER SUPPLY ANALYSIS

5.1 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. 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 through externally calculated stream-aquifer interactions. Since the analysis has been 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 all identified inflow representing the water supply and outflow components representing depletions to the supply. Given that the goal of this study is quantification of supply (as opposed to an evaluation of river operations) short-term, transient changes in storage are not included in the analysis. Examples of short-term, transient changes in storage not included are seasonal fluctuations in shallow aquifer water levels, and year-to-year changes in storage within surface water reservoirs. However, long-term depletion of groundwater storage is implicitly considered in the analysis. Given this approach, the mainstem inflow component consists of the Otowi Index Supply and trans-mountain (San Juan-Chama Project) water. To the extent that reservoir storage is increased or decreased in upstream reservoirs in a given year, the modeled supply will vary from the actual supply. The structure of the simple water budget model is described on Table 5.1.

To quantify the probabilistic water supply, the simple water budget model is evaluated with a risk analysis procedure. Instead of assigning a fixed value to each element of the water budget, each element is described in probabilistic terms, based on the variability and correlations represented in the historical data record. Using the probabilistic characterization of water budget elements, the water budget model simulates the resulting water supply using a Monte Carlo analysis. In this analysis, the water budget is simulated 10,000 times. In each simulation, combinations of water budget terms are selected in random fashion, while user-identified probability distributions and correlations are preserved. This process yields probability distributions for simulated water budget outcomes. In this analysis, the simulated water budget outcomes include total inflow, total depletions and Compact credit/debit. The modeling procedures are described in more detail in Appendix H.

The probabilistic water supply model is based on records representing the period from 1950 to 1998. The initial date of 1950 was selected to conform the period of evaluation to a period with consistent administrative rules under the Rio Grande Compact. The end date of 1998 conforms to the end of the period of record for most data sets compiled during this study. For water budget components exhibiting climate dependency, the 1950 –1998 period was used to develop probabilistic descriptions of the water budget term. If the record during this period was incomplete, correlations were developed in some cases to create synthetic data sets to complete the records over the 1950-1998 period. For water budget components influenced largely by development conditions, as opposed to climate conditions, a representative value was determined based on recent conditions. The handling of each water budget component for input to the probabilistic water supply model is discussed in the following sections and is summarized in Table 5.1. A more detailed description of the probability distribution function-fitting procedure, including statistics and significance testing can be found in Appendix F.

5.2 Probabilistic Characterization of Inflow Components

5.2.1 Otowi Index Supply

The Otowi Index Supply represents the "native" flow at the Otowi gage, or, that 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 add/subtract changes in upstream storage and to subtract 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.

To characterize the variability in the Otowi Index Supply, annual data spanning the period of 1950 to 1998 were grouped into 10 classes and used to fit a probability distribution function. A Beta distribution with parameters α_1 = 0.84 and α_2 = 1.52 was obtained, based on goodness-of-fit tests. The time series data, a histogram representing the grouped annual Otowi Index Supply data and the fitted Beta distribution are illustrated on Figure 5.1.

5.2.2 Trans-Mountain Diversions (San Juan-Chama Project Water)

Trans-mountain diversions of the San Juan-Chama project were initiated in June 1971, to provide a supplemental water supply to New Mexico entities contracting for this water. 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. 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.

The magnitude of the trans-mountain diversions utilized in a given year is a function of the demand condition, the user's readiness to use the extra supply, and, inversely, the climate-dependent "native" supply. To characterize the supply of San Juan–Chama Project water under present development conditions, the records of the Rio Grande Compact Commission were reviewed. The amount of trans-mountain diversion water within the gaged flow of the Rio Grande at Otowi is calculated and reported by the Rio Grande Compact Commission in annual reports. A time series graph of the annual trans-mountain diversion flow calculated at Otowi is shown on Figure 5.2.

For the purpose of characterizing the variability of the trans-mountain diversions under present development conditions, the post-1976 period was selected to remove the variable of user readiness in earlier years. Further excepting the Elephant Butte spill years, 1985-1988, a negative correlation of 0.66 was calculated between the native flow at Otowi and the trans-mountain diversion water. In other words, in years of greater native supply, less trans-mountain water was released to downstream San Juan-Chama contract holders, presumably because in these years, there was less of a need to augment the native supply. However, because of the relatively small number of years available for this correlation, and because operations and demands are difficult to separate from supply conditions for this flow component, this correlation may not be the best representation of the present condition. Furthermore, present trends towards optimization of available trans-mountain supply via sale or lease suggests that the variability in this inflow term may be lessening under present conditions. Handling this term as a *static value* is considered more representative of the present condition than would be represented with a correlation based on the past variability. The arithmetic mean of the annual reported values for trans-mountain diversions at Otowi for the recent period, 1990 to 1998, is 75,844 acre feet per year. This average is assumed as representative of the "present development condition" and is handled as a static value in the probabilistic water budget model.

5.2.3 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. Since the completion of Cochiti Dam, the Santa Fe River joins the Rio Grande at Cochiti Lake, immediately upstream of the dam. Flow from the Santa Fe River is profiled on Figure 5.3. Flow in the Santa Fe River is comprised largely of wastewater flow from municipal usage in Santa Fe. Through the period of record, this flow has generally increased with increasing population in the Santa Fe area, although the flow also responds to precipitation and operational events. To reflect present development conditions, the recent period of 1993-1997 was selected as a representative period. The average flow for this period is 9,956 acre-feet per year; this value is used as a "static" value to represent the present condition in the probabilistic water supply model.

5.2.4 Galisteo Creek Inflow

The 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 1998 (Figure 5.4). Correlations with the Otowi Index Supply and with precipitation at Albuquerque were evaluated as possible means of extending the period of record, but deemed unsatisfactory for this purpose. A Gamma probability distribution function, constructed from 10 class intervals over the period of record, was fit with parameters $\alpha = 3.44$ and $\beta = 1301$.

5.2.5 Jemez River Inflow

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 generally represents the inflow to the Rio Grande from the Jemez River. A time series plot of the Jemez River flow, a histogram representing data within ten flow classes, and a fitted probability distribution function are shown on Figure 5.5. The probability distribution function is a Beta function with parameters $\alpha_1 = 0.81$ and $\alpha_2 = 1.63$.

The watersheds yielding water to Jemez River and to the Rio Grande above Otowi are both located in the northern part of the state, and both include significant components of snowmelt. Correlation of the annual flow of the Jemez River to the Otowi Index Supply was evaluated, and indicated that these two variables are highly correlated (Appendix F). This correlation is implemented in the probabilistic water budget model by specification of an independent-dependent variable pair, using a correlation matrix.

5.2.6 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). The period for which records were available at three gaging stations is 1988 to 1998 (Figure 5.6). Although clearly affected by climatic variability, this period of record is too short to support statistical distribution fitting procedures. A uniform probability distribution across the observed range of 3,073 to 17,843 acre-feet per year was assumed. The uniform distribution assumes that any value within this range is equally probable.

5.2.7 Rio Puerco Inflow

The Rio Puerco conveys intermittent flow to the Rio Grande downstream of Bernardo. The period of record used to characterize variability at this station is 1950 to 1998 (Figure 5.7). A Pearson VI probability density function was fit to the grouped data, with shape and scale parameters of $\alpha_1 = 8.15$, $\alpha_2 = 4.37$, and $\beta = 11{,}609$. Not surprisingly, the flow of the Rio Puerco is not correlated with the Otowi Index Supply. Whereas the Otowi Index Supply is largely comprised of snowmelt from northern areas, the Rio Puerco flow is primarily derived from rainfall events in its more southerly drainage basin.

5.2.8 Rio Salado Inflow

The Rio Salado conveys intermittent flow to the Rio Grande below San Acacia. Annual flow derived from the USGS gaging station at Rio Salado (08354000) has a continuous annual record ranging from 1948 to 1984 (Figure 5.8). A correlation between the Rio Salado and the Rio Puerco was evaluated for the overlapping period of record of 1950 to 1984. The following linear regression equation was derived (assuming units of acre feet per year):

Rio Salado Flow = (Rio Puerco Flow *0.303) + 1549

This regression was used to extend the period of record for the Rio Salado to 1998. From the resulting time series of the Rio Salado, a Pearson VI probability distribution was derived, with a mean of 11,923 acre feet and standard deviation of 18,092 acre feet.

Correlation between the Rio Puerco and Rio Salado flow was implemented in the probabilistic water budget model by specification of an independent-dependent variable pair, using a correlation matrix (Appendix F).

5.2.9 Ungaged Tributary 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 south of Socorro in a region defined by the USGS as Hydrologic Unit 13020211, or the Elephant Butte Reservoir Unit. This unit includes drainage from portions of Catron, Sierra and Socorro counties, primarily on the west side of the Rio Grande, extending from the divide of the Rio Salado drainage basin on the north to approximately the location of Truth or Consequences. Additionally, this unit includes a smaller area on the east of the Rio Grande. Some of the more prominent drainages on the west included within this unit are Tiffany Canyon, Milligan Gulch and Alamosa Creek. Numerous smaller arroyos lead directly into the Rio Grande or Elephant Butte Reservoir, flowing in a southeasterly direction off the flanks of the Magdalena Mountains and the San Mateo Mountains. The land area in this Hydrologic Unit is approximately 2,103 square miles.

To obtain an estimate of ungaged tributary inflow from the Elephant Butte Hydrologic Unit to the Rio Grande, a relationship to gaged tributary inflow from the adjacent Rio Salado Hydrologic Unit is developed by direct scaling of contributing drainage areas. The land area of the Rio Salado Hydrologic Unit (13020209) is reported as 1,403 square miles. The land area ratio of the Elephant Butte Unit to the Rio Salado Unit is 2,103 square miles/1,403 square miles, or, 1.5. By this procedure, the ungaged tributary inflow from the Elephant Butte Unit will be computed as 1.5 times the tributary inflow of the Rio Salado, assuming a 50% correlation.

Additional ungaged tributary inflow likely occurs, particularly from the eastside, north of the Elephant Butte Hydrologic Unit. This region lies within the Rio Grande Hydrologic Unit (13020203), with a land area of 3,211 square miles. A direct scaling method for estimating recharge within this area is not used because a significant portion of run-off from this unit is included in gaged tributaries of AMAFCA, Galisteo Creek and the Jemez River; and, because length and slope characteristics of ungaged tributaries in this area suggest the occurrence of higher rates of infiltration and less direct flow to the river. Drainages within this area include Hell Canyon Wash, Canada Ancha, Abo Arroyo and numerous smaller arroyos. Information to support a reasoned estimate of flow from these areas to the Rio Grande has not been developed. However, to avoid omission of this inflow component, a "place-holder" estimate of 10,000 acre feet per year mean inflow is assumed for this region, approximately equal to that of the Rio Salado. Variability for this inflow is based on the probability distribution function derived for the Rio Salado, assuming 50% correlation.

5.2.10 Base "Adjusted" Groundwater Inflow

Base "adjusted" groundwater inflow represents the net groundwater that would flow into or from the river, under conditions of the present river-conveyance infrastructure, without pumping of groundwater, without deep percolation of applied irrigation water, and without riparian evapotranspiration. While not strictly a physically based component, this component 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 occurring under steady-state conditions absent influences of pumping, irrigation and riparian use. The effect of pumping, irrigation and riparian use on the stream are calculated and tracked separately within the structure of the probabilistic water supply model.

The base "adjusted" groundwater inflow term for the area between Cochiti and San Acacia is quantified using the New Mexico Office of the State Engineer (OSE) version of the Albuquerque Basin groundwater flow model (Barroll, 1999). This model is based on the groundwater flow model previously developed by the USGS (Tiedeman et al, 1998; Kernodle, 1998; Kernodle et al, 1995). Net groundwater-stream exchanges calculated by the model for non-pumping conditions are adjusted to exclude irrigation and riparian impacts, to reflect the baseline condition defined above. Details on the modeling analysis and adjustment procedure for calculating the baseline inflow are provided in Appendix G. 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.

Absent a model for the region below San Acacia, the baseline groundwater inflow in this region (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 16,658 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.

5.3 Probabilistic Characterization of Depletions

5.3.1 Cochiti Evaporation

Evaporation from Cochiti Lake occurs in response to reservoir surface area and climatic conditions. Using records of calculated evaporation provided by the U.S. Army Corps of Engineers for the period 1976 to 1998, we fit a loglogistic distribution with the following parameters: location parameter γ = 4770 (acre feet; minimum), shape parameter α = 2482 (acre feet), and shape parameter β = 2.46. The historical record and fitted distribution function are illustrated on Figure 5.9.

5.3.2 Elephant Butte Evaporation

Calculated evaporation from the Elephant Butte Reservoir for the period 1950 to 1998, obtained from the U.S. Bureau of Reclamation, is illustrated on Figure 5.10. Evaporation from Elephant Butte Reservoir occurs as a function of surface area and climatic conditions. The surface area increases during periods of above-average water supply, and reflects water supply and demand conditions occurring over a period of several years. While the surface area is partially dependent on past conditions, the surface area is also partially correlated to the present year's water supply condition. A correlation to Otowi Index Supply was developed to represent this relationship. The Elephant Butte evaporation, under present conditions, is represented in the probabilistic water budget model through sampling according to the histogram representing the 1950 to 1998 period, and a correlation to the Otowi Index Supply.

5.3.3 Groundwater Depletions

Groundwater depletions from pumping in the Albuquerque Basin are computed for present conditions and for future conditions, using the OSE version of the

Albuquerque Basin groundwater flow model (Barroll, 1999). The assumed present and future conditions are discussed in Section 5.5, below, and additional model details are provided in Appendix G.

Groundwater depletions north of the area covered in the Albuquerque Basin model occur between Otowi and Cochiti. Depletions in this area from pumping by the City of Santa Fe are estimated as 2,400 acre-feet per year by the OSE. Groundwater depletions south of the area covered in the Albuquerque Basin model occur between San Acacia and Elephant Butte. Absent a model or more detailed calculations for this area, these depletions are approximated as equal to the total groundwater withdrawals for Socorro County. These withdrawals, including those of the Socorro Water System and several small water systems, are reported as 2,507 acre-feet per year by the OSE (Wilson, and Lucero, 1997).

The depletions are assumed as a static value for given points in time and specified development conditions. The assumed static value represents the lagged impact of groundwater pumping on net groundwater-stream exchanges, at an assumed point in time. A probability distribution function is not developed for groundwater depletions, as any climatic-induced variability in this term tends to be dampened by the aquifer over the time frame of stream impacts.

5.3.4 Wastewater Returns

Wastewater returns conveyed to the Rio Grande have been quantified for six major municipalities: Albuquerque, Belen, Bernallilo, Los Lunas, Rio Rancho, and Socorro. These returns are illustrated on Figure 5.11. To reflect the present development condition, a static value of 68,941 acre feet per year, representing the composite wastewater return for 1998, is assumed. In evaluating a hypothetical future development condition, this number is increased by 50% of the assumed additional municipal usage. In the probabilistic water budget model, this term is represented as a negative outflow term, or, a credit to depletions.

5.3.5 Agricultural Consumptive Use

Historical agricultural consumptive use estimated by the USBR ET Toolbox (May, 2000) for the period 1985 to 1998 forms the basis for this depletion term in the probabilistic water budget model, for the region from Cochiti to San Marcial.

To extend the record and incorporate some element of climatic variability over the target period of record for this analysis, the 1985 to 1998 annual time series data were correlated to a contemporaneous precipitation record from Albuquerque. This analysis was conducted separately for consumptive use above and below San Acacia. This analysis did not yield strong correlations; regardless, these relationships were used in "placeholder" fashion to overlay an element of variability on these water budget terms. Future work to refine historical and present consumptive use estimates may result in data that can be used to define and quantify better consumptive use relationships.

For the area above San Acacia (URGWOM reaches 1-5), the following linear regression equation was developed and used to extend the record:

Agricultural CU, acre-feet = (Precipitation, in.* -2,088.72) + 212,858

The resulting time series was then subjected to the probability distribution fitting. The fitted distribution for agricultural consumptive use most closely resembled a continuous Weibull distribution with a shape parameter α = 33.4 and scale parameter β = 197,963

The USBR estimated consumptive use, a histogram representing the extended data set and the fitted probability distribution function are illustrated on Figure 5.12.

For the area below San Acacia (URGWOM reach 6), the following linear regression equation was developed and used to extend the record:

Agricultural CU, acre-feet = (Precipitation, in. * -623.60) + 62,873

The resulting time series was then subjected to the probability distribution fitting. The fitted distribution for agricultural consumptive use most closely resembled a continuous Weibull distribution with a shape parameter of $\alpha = 33$ and scale parameter $\beta = 57{,}471$. The USBR estimated consumptive use, a histogram representing the extended data set and the fitted probability distribution function are illustrated on Figure 5.13.

5.3.6 Riparian Consumptive Use

Historical riparian and open water (river and conveyance channels) consumptive use estimated by the USBR ET Toolbox (May, 2000) for the period 1985 to 1998 forms the basis for this depletion term in the probabilistic water budget model for the reach from Cochiti to San Marcial. Consumptive use for the reach from San Marcial to Elephant Butte was estimated from provisional riparian and wetland acreages obtained from the USBR (Larry White, personal communication, April, 2000). To extend the record and incorporate some element of climatic variability over the target period of record for this analysis, the 1985 to 1998 annual time series data were correlated to a contemporaneous precipitation record from Albuquerque. As with correlations developed for agricultural use, these relationships are best viewed as "placeholders", to be refined as better information becomes available. This analysis was conducted separately for consumptive use above and below San Acacia.

For the area above San Acacia (URGWOM reaches 1-5), the following linear regression equation was developed and used to extend the record:

$$\text{Riparian CU, acre-feet} = (\text{Precipitation, in.} * -570.51) + 160{,}951$$

The resulting time series was then subjected to the probability distribution fitting. The fitted distribution for riparian and open water consumptive is a logistic probability distribution, with mean parameter α = 156,008 acre-feet and shape parameter β = 1,851. The USBR-estimated riparian consumptive use, a histogram representing the extended data set and the fitted probability distribution function are illustrated on Figure 5.14.

For the area below San Acacia (URGWOM reach 6), the following linear regression equation was developed and used to extend the record:

$$\text{Riparian CU, acre-feet} = (\text{Precipitation, in.} * -134.67) + 50{,}845$$

The resulting time series was then subjected to the probability distribution fitting. The fitted distribution for agricultural consumptive use most closely resembled a continuous logistic distribution with mean parameter α = 49,679 acre-feet and shape parameter β = 56. The USBR estimated consumptive use, a histogram representing the extended data set and the fitted probability distribution function are illustrated on Figure 5.15.

For the reach between San Marcial and Elephant Butte, a static value was assumed for consumptive use based on riparian and wetland acreages estimates developed by the USBR (Table 3.9) and using a consumptive use factor of 3.71 acre feet per acre.

5.3.7 Reduction of Agricultural and Riparian Consumptive Use by Effective Precipitation

The agricultural and riparian consumptive use, calculated as described above, is partially satisfied by effective precipitation. The consumptive irrigation requirement, needed for this analysis, is derived by subtraction of effective precipitation from the consumptive use. Although the ET Toolbox provides a "daily water use", this value reflects the subtraction of total precipitation, rather than effective precipitation. The "daily water use" thus derived is not used in the water supply model, because it would underestimate the consumptive irrigation requirement. For this study, the effective precipitation is assumed to equal 4 inches per crop or riparian acre. Using this assumption, effective precipitation is calculated as 38,497 acre-feet per year for the combination of agricultural and riparian acreages in the region from Cochiti to San Marcial (Table 5.1). The effective precipitation reduces the crop and riparian consumptive use by this amount. This estimate would benefit from more detailed analysis and is considered a "place-holder" in this study.

For the estimated consumptive use in the reach between San Marcial and Elephant Butte, the assumed effective precipitation is subtracted from the consumptive use factor of 3.71 acre feet per acre, to obtain an adjusted factor of 3.38 acre-feet per acre. The modeled riparian depletion in this reach is calculated directly with this adjusted factor.

5.3.8 Downstream Delivery Obligation under the Rio Grande Compact

The probabilistic water supply model can be used to compute the "available" supply, given constraints of the Rio Grande Compact; or, the Rio Grande Compact credit/debit, assuming specified probability distribution functions for inflow and outflow components. For these calculations, downstream obligation under the Rio Grande Compact (Elephant Butte Effective Index Supply) is specified for the assumed inflow condition (Figure 5.16). The inflow condition is represented by the Otowi Index Supply. Within the water budget model, a "look-up" table and interpolation rule is provided to determine the Compact-based obligation (Elephant Butte Effective Index Supply) for any specified Otowi Index Supply, resulting in the schedule illustrated on Figure 2.1.

5.4 Water Supply Model Results

Using the probabilistic and other characterizations described above, a risk analysis model representing the water budget was constructed. This model was implemented using the software *@Risk*, a spreadsheet-based model, with probability functions, correlations or other specified relationships used in place of fixed values (Appendix F). 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 H). The key evaluation conducted with this tool was a basin-wide evaluation of annual conditions. This evaluation was conducted using three scenarios for groundwater use:

1) Present Condition, Year 2000: This scenario assumes the present development condition, in terms of groundwater pumping and other water uses, and evaluates impacts in the year 2000.

2) Present Condition, Year 2040: This scenario assumes continuation of the present development condition, in terms of groundwater pumping and other water uses, and evaluates the impacts as they would occur in the year 2040.

3) Alternative Development Condition, Year 2040: This scenario assumes an alternative development condition, reflecting an increase in groundwater pumping, and evaluates the groundwater impacts as they would occur in year 2040.

The scenario assumptions and results are discussed further in section 5.4.1, below. A reach-by-reach evaluation was conducted to further explore the present condition. These evaluations are described in sections 5.4.2, below.

5.4.1 Basin-Wide Model, Annual Evaluation

For the annual, basin-wide evaluation, the inflow and outflow terms were generally characterized as described above. The specific relationships utilized for each water budget term are summarized on Table 5.1. The water budget terms were described identically for each of the three scenarios, with the exception of the groundwater inflow/outflow and wastewater discharge terms.

5.4.1.1 Groundwater Inflow/Outflow Terms

For the scenarios modeling the present development condition, pumping was set in the model at the levels identified for 1999 in the OSE Albuquerque Basin model. The total amount of groundwater withdrawals assumed for 1999 is 156,800 acre-feet per year. These withdrawals represent the sum total of estimated pumping presently occurring, and are distributed throughout the model according to actual well locations, depths, and pumping rates.

For the alternative scenario, a hypothetical pumping distribution is assumed, whereby existing pumping is increased as follows. First, pumping from the existing wellfields is increased to the amount estimated by the OSE to represent "full use of existing claimed water rights", for a total withdrawal of 217,600 acre-feet per year from existing wellfields. Second, an additional 100,000 acre-feet per year is assumed to be withdrawn from the Albuquerque Basin. Thus, under the alternative scenario, a total of 317,600 acre-feet per year is withdrawn from the aquifer. In developing this alternative scenario, several potential locations for the additional withdrawals were considered. Appendix G provides details on these modeled scenarios. For this alternative, pumping from the Albuquerque area, as well as from an extended region south of Albuquerque on the eastside of the basin, was modeled. Figure 5.17 indicates the impacts of various levels of groundwater withdrawal on the river. This figure illustrates the increasing amount of river depletions over time, resulting from groundwater pumping. These model simulation results indicate that there is little difference in the timing or magnitude of depletions with the two alternative assumptions concerning wellfield placement. The expanded pumping in the Albuquerque area benefits from a short-term delay in impacts, probably due to present disconnected stream-aquifer conditions in this area. However, over time, the river depletions from pumping in the Albuquerque area are essentially the same as would occur if this pumping is dispersed further to the south. In both cases, the impact on the river increases from about 100,000 acre-feet per year in the first year, to about 220,000 acre-feet per year by Year 2040, and about 260,000 acre-feet per year by Year 2100. The location of the assumed wellfields and the water level declines associated with these alternatives are provided in Appendix G.

The assumption of the alternative increased pumping conditions is made for the purpose of demonstrating how the water supply model can be used to evaluate alternative development scenarios, and to illustrate the scale of long-term aquifer-stream interactions. These stream-aquifer interactions must be considered in any conjunctive use water supply evaluation that involves groundwater pumping. These results illustrate the surface water penalty incurred when obtaining long-term water supplies from groundwater in a stream-connected aquifer. Clearly, with limits on surface water supply set by the Rio Grande Compact, these impacts would require offset by reducing water use from other sectors.

5.4.1.2 The Probabilistic Water Supply under Present and Alternative Conditions

The probabilistic water supply model for the present and alternative condition was applied using the probabilistic description of water budget terms described above. The model results include probability distribution functions of the total inflow, the total depletions and the Compact-based credit or debit, assuming the Compact schedule of deliveries. Figures 5.18 through 5.20 provide the probability distribution functions of the modeled Compact-based credits or debits, for the present condition in the years 2000 and 2040, and for the alternative condition in the year 2040. These probability distribution functions illustrate the wide range in conditions that can be expected given the variability and relationships among water budget components exhibited in the past 50 years. Reflecting varying degrees of stream impacts from groundwater pumping, the mean Compact credit under each scenario is summarized as:

- **Present Development, 2000:** **Credit of 13,500 acre-feet per year**
- **Present Development, 2040:** **Debit of 14,300 acre-feet per year**
- **Alternative Development, 2040:** **Debit of 29,800 acre-feet per year**

The mean credit or debit only portrays part of the information from these analyses. Of equal interest, the probability distribution indicates the range of values that are likely to occur at various probability levels. Inspection of the probability distribution for present development, Year 2000, conditions (Figure 5.18) indicates that a debit condition should be expected nearly half the time. Further, this distribution suggests that debits and credits exceeding 50,000 acre-feet per year are not uncommon. Thus, despite expecting credit conditions on average, one should expect to experience debit conditions in many years. Compact rules limit the accumulation of debits; a sequence of poor years could easily result in violation, even under the most favorable of these three scenarios.

5.4.2 Reach-by-Reach Model, Annual Evaluation

To characterize the probabilistic water supply at intermediate points within the Middle Rio Grande, the water supply model was operated under the present condition using a reach-by-reach approach. The intermediate points considered in this analysis are San Felipe, Bernardo and San Acacia. This model consists of four linked models, one for each of the following reaches:

- Reach 1: Otowi to San Felipe
- Reach 2: San Felipe to Bernardo
- Reach 3: Bernardo to San Acacia
- Reach 4: San Acacia to Elephant Butte

The analysis procedure for the reach-by-reach linked models is similar to that described for the entire basin. However, specific inflow and outflow distributions are assigned to the specific sub-reach model within which they occur. For the reach-by-reach model, groundwater inflow and groundwater depletions were re-calculated with the model, using post-processing routines to apportion the flows among the reaches. The crop consumptive use, riparian consumptive use and effective precipitation were apportioned among reaches based on the corresponding acreage within each reach, using acreage coverages as estimated by the USBR for the ET Toolbox application.

The upstream inflow for Reach 1 is described in terms of the appropriate probability distribution functions for Otowi Index Supply and trans-mountain diversions, as in the basin-wide model. The result of the Reach 1 simulation is a probability distribution function for the gross water supply at San Felipe. This result is illustrated on Figure 5.21. The probability distribution function at San Felipe then becomes the upstream inflow to Reach 2. Other inflows and depletions within Reach 2 are specified as for the basin-wide model. Progressing downstream, the outflow distribution for reaches 2 and 3 become the inflow distributions for reaches 3 and 4. The gross water supply probability distribution functions for Bernardo, San Acacia and Elephant Butte, derived by these models are shown on Figures 5.22 to 5.24. Water budget details for these reach-by-reach evaluations are shown on Table 5.3.

Figures 5.21 to 5.24 represent the theoretical distribution of gross water supply, or, approximately, the flow in the river system at intermediate points. However, included within the quantified flow is the scheduled delivery at Elephant Butte. Therefore, the quantity of water shown is not equivalent to the available supply to the region. Subtraction of the scheduled delivery would give a measure of the available supply.

Figure 5.25 provides a schematic of the mean available water supply in the Middle Rio Grande region. The mean available supply is obtained by subtracting the mean Elephant Butte Scheduled Delivery (Rio Grande Compact obligation), based on model output (10,000 simulations using the probability distribution functions), from the modeled mean flow at San Felipe, Bernardo, San Acacia and Elephant Butte (as reflected in probability distribution functions shown on Figures 5.21 to 5.24). Initiating this process, the available portion of the Otowi Index Supply is shown as 314,000 acre-feet per year. This number is the difference between 964,000, the mean Otowi Index Supply from the probabilistic model simulations, and 650,000, the mean Elephant Butte Scheduled Delivery obtained from the probabilistic model simulations. It is interesting to note that the mean of the modeled Elephant Butte Scheduled Delivery is 650,000 acre-feet per year, as opposed to a value that would be obtained directly from the Rio Grande Compact schedule corresponding to the mean Otowi Index Supply of 964,000 acre-feet per year (593,000 acre-feet per year). Because the Compact schedule is not linear, the mean value for the Elephant Butte Scheduled Delivery cannot be derived from the Compact schedule using the mean value of the Otowi Index Supply. In simple terms, working with average conditions in the context of the Rio Grande Compact is not a straightforward process. 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.

Figure 5.26 completes the picture with respect to the current disposition of the available supply. The pie graphs shown on this figure 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. Reservoir evaporation in the Elephant Butte Reservoir has fluctuated dramatically between a range of 28,000 and 260,000 acre-feet per year throughout the period evaluated.

Groundwater depletions reflected in the probabilistic water supply model and shown on Figure 5.6 are derived from groundwater model evaluations conducted with the Albuquerque Basin model (Appendix G). For a present total groundwater withdrawal of 156,800 acre feet per year, the resulting stream depletion (in year 2000) is 94,400 acre-feet per year, with about 68,000 of this offset by wastewater returns. For the most part, the remainder of the groundwater withdrawn, or about 60,000 acre-feet per year, is removed from aquifer storage.

6.0 IMPLICATIONS FOR REGIONAL WATER PLANNING

6.1 Summary of Conclusions

This study quantifies the water supply to the Middle Rio Grande region, considering groundwater and surface water resources, the depletion of water under existing conditions and constraints represented by the Rio Grande Compact. The water budget developed in this study describes the water supply and expected Compact credit/debit conditions in a probabilistic context, incorporating climatic-induced variability in water budget terms.

The probabilistic water budget approach taken for this study is referenced to the stream and near-stream hydrologic flow system. Water inflow and depletion, referenced to this flow system, were quantified to reflect climatic variability and present development conditions. The probabilistic characterization of water inflow terms is based on climatic variability observed over the past 50 years, where data were available. For each water budget term exhibiting climate dependency, a probability distribution function was developed to characterize the range and nature of this variability. Some water budget terms are predominantly influenced by land use or development conditions. These terms were quantified according to the present development condition.

Processes occurring in the basin-wide groundwater flow system are linked to the stream flow system using the groundwater model of the Albuquerque Basin. Through this approach, a multitude of complex hydrologic processes occurring in the basin with indirect or lagged impacts on the stream, for example, precipitation, mountain front recharge and groundwater pumping, are integrated into the water supply analysis. The quantification of groundwater processes occurs within a modeling framework that is based on a very detailed characterization of basin hydrogeology, i.e., representing the occurrence of hydrogeologic units, faults, aquifer properties and their configuration.

Based on the quantified water budget terms for the stream system and linked groundwater system, a probabilistic water-supply model was used to simulate the conjunctive-use water supply and demand conditions. This analysis resulted in a probabilistic characterization of the conjunctive-use water supply in the Middle Rio Grande region. Through identification of the Rio Grande Compact delivery (Elephant Butte Scheduled Delivery) corresponding to the simulated water supply conditions (Otowi Index Supply), a profile was derived of the *available* supply and of Compact credit/debit conditions according to water use assumptions.

This analysis indicates that under present development conditions, and assuming that San Juan-Chama Project water is included in the supply to the region, on average, Compact requirements are satisfied. However, due to the large variability in inflow conditions, and the large variability in evaporation from Elephant Butte Reservoir, Compact credits/debits are expected to vary over a wide range; with debits occurring nearly as frequently as credits.

The prognosis for water supply in future years, without significant intervention, is less favorable. The impact of groundwater pumping on the Rio Grande flow system continues to grow. Even without an increase in groundwater withdrawal rates, increased depletions will occur to the Rio Grande throughout the next 100 years, and beyond. While significant quantities of groundwater are available within aquifer storage, the water cannot be utilized without affecting the stream. Furthermore, cessation of pumping does not arrest the occurrence of stream impacts. The flow of the Rio Grande will be diminished for many years, as it loses water to replenish the previously depleted groundwater reservoir.

An alternative scenario involving increased groundwater pumping was evaluated with the probabilistic model, to evaluate the impacts of approximately doubling the withdrawal of groundwater from the aquifer. Under this scenario, within 40 years the stream-referenced water supply is expected to diminish by about 43,000 acre-feet per year, resulting in more frequent occurrences of Compact debit conditions. Clearly, this alternative would not be practical without offsets from another water use sector.

An evaluation of the depletions occurring within the Middle Rio Grande region under current use conditions indicates that consumptive use by crops and riparian vegetation accounts for approximately 67% of the total use. Consumptive use by reservoir evaporation accounts for approximately 19% of the total, with the remainder of about 14% comprised of urban consumptive use. Of these uses, reservoir evaporation is subject to the largest variability. Evaporation from Elephant Butte Reservoir ranges from 10% to 30% of the overall basin depletion, depending primarily on the reservoir level and associated surface area.

This study is based on a vast quantity of data and incorporates understanding gained through numerous complex technical investigations conducted by multiple agencies and individuals, particularly in the recent decade. Regardless, specific numbers for water budget terms quantified in this study are subject to uncertainty due to difficulty in measurement or the imprecision of estimation procedures. Undoubtedly, estimates will be refined as future work occurs. This uncertainty in estimation of water budget terms has not been formally evaluated – however, judgment suggests that the overall uncertainty in mean projected values for the available water supply or resulting occurrence of Compact credit/debit is on the order of 50,000 acre-feet per year. Despite uncertainty in the specific mean projected values, the relative conclusions regarding range of variability and general relationships among water supply and demand terms are considered representative of basin conditions, and should be used as a planning basis in the development of regional water plans.

The analyses conducted for this study illustrate the general magnitude of the available water supply, and its expected variability, assuming the degree of climatic variations observed during the past 50 years. These results provide a realistic framework for water resource planning. At the same time, it is useful to understand what is not represented in these results:

- This study does not model hydrologic conditions resulting from a specific sequence of annual conditions; in other words, predictions based on antecedent conditions are not provided.

- This study does not represent hydrologic responses to extreme events. While the available record includes both wet and drought periods, and the modeled inflow encompasses this range of conditions, the development of water-budget relationships for extreme conditions was beyond the scope of this study.

- This study does not provide localized evaluations of the water supply. Study assumptions are based on existing data sets, most of which are adequate for basin-scale water supply evaluations. In evaluating specific water supply alternatives as part of the water planning process, additional information will be needed to refine understanding of hydrologic conditions and relationships as they relate to proposed alternatives.

- This study does not provide a "turn-key" water planning model. The probabilistic water budget model presented in this study is based on a series of empirical relationships and specific simulations with the Albuquerque Basin groundwater model. Assumptions and structuring of the underlying models may require re-specification, depending on the parameters of an alternative selected for evaluation.

As the water planning process progresses to the stage of water supply alternative analysis, additional evaluations in some of the above-noted areas may prove useful.

6.2 Implications for Regional Water Planning

Key water supply and hydrologic concepts with implications for water planning are:

- On average, *the present water supply is barely adequate* (including San Juan-Chama Project water and groundwater withdrawals) to meet existing uses.

- *The water supply is highly variable,* due to the high variability in Otowi inflow and the high variability in evaporation from the Elephant Butte Reservoir.

- Given the variability of water budget terms, Rio Grande Compact debit conditions are expected to occur nearly as frequently as credit conditions.

- *Under conditions of increased water use in any sector, a reduction of water use from other sectors is requir*ed to maintain overall water supply balance, and to avoid increasing the likelihood of incurring Rio Grande Compact debits.

- The groundwater aquifer in the Albuquerque Basin does not provide an independent, disconnected water supply. *Use of groundwater results in diminished flows of the Rio Grande* that will occur in the present and continue into the future.

- The location of well fields affects short-term timing of impacts to the river; however, regardless of location, the impacts of groundwater pumping eventually reach the river and require offset.

- Recharge of groundwater from the stream system reduces the flow of the Rio Grande available to meet obligations under the Rio Grande Compact.

- *The water supply from Otowi to Elephant Butte is essentially a single supply*; water use in every sub-region of the Middle Rio Grande affects the overall regional water supply.

- *The overall water supply is only depleted by consumptive use*; reductions in diversions and return flows resulting in better delivery efficiency do not necessarily improve the water supply.

Recognition of these water supply and hydrologic concepts is key to the development of successful water plans and water supply alternatives. In addition, these concepts suggest areas for exploration in the framing of alternatives under the water planning process.

- Management of variability in supply: The water supply is highly variable. To maximize the availability of water supply to meet water needs and the Compact obligations, the maintenance, development and use of storage capacity within the hydrologic system is critical. Enhanced storage in surface reservoirs and within the aquifer should be seriously evaluated in water planning alternatives seeking to maximize the available water supply. Groundwater storage would provide benefits of reduced evaporative losses to the basin, in addition to increased storage capacity. Mechanisms for storage of excess water under the Compact in "spill" years, although infrequent, would be worth evaluation. Conversely, the occurrence of flow variability is a legitimate objective with respect to some planning goals; in this case, the available water supply will not likely be maximized – this trade-off should be recognized.

- Reduction of non-beneficial and non-desirable uses: Local definition of water uses, in realistic hydrologic terms, is needed to identify non-beneficial or less-desirable uses that can be shifted to other more desirable use sectors. Many traditional "non-beneficial" uses, i.e., phreatophyte consumption and evaporation from in-stream flows, are desirable as part of an overall strategy addressing environmental goals, for example, riparian or fish habitat. However, these consumptive uses are significant and require careful evaluation—raising questions to be answered in the alternative evaluation phase of the planning process. Which phreatophyte uses bear benefits worth maintaining, at the cost of water supply to other sectors; and, vice versa? Perhaps easier to address, would be the question of depletions from reservoir evaporation. Should alternatives be framed that reduce the significant water loss via evaporation from the Elephant Butte Reservoir?

- Accommodation of Increased Water Needs and Evaluation of Trade-Offs: Increased water demands are anticipated in the Middle Rio Grande region. The characterization of future water demands is the subject of separate water planning studies for the Middle Rio Grande, including water plans being developed by local planning regions. Increased future demand may be seen in many use sectors. Clearly, under the constraints of the Rio Grande Compact, increased demands in all water use sectors cannot be satisfied, and trade-offs must occur to maintain the overall water balance of supply and demand. In evaluating trade-offs under future alternatives, careful evaluation of incremental consumptive use changes due to change in the diversion location, conveyance dynamics and the change in use will be required.

In summary, the water supply of the Middle Rio Grande is marked by limitation and variability. The successful water planning process will operate in recognition of these concepts.

6.3 Areas for Continuing Investigation

This water supply study has reviewed voluminous technical material relating to water resources of this region, developed over decades. Based on this review and the analysis of the information available to dates, continuing investigation in the following areas is recommended:

- Quantification of Crop and Riparian Consumptive Use: Crop and riparian consumptive represents approximately two thirds of the overall basin depletions. Clearly, understanding the magnitude and variability in these water use sectors is critical to understanding the overall water balance. The estimated consumptive use used in this study was derived by the USBR, based on detailed and state-of-the-art techniques. However, researchers familiar with this work note that significant continuing work in this area is needed. The consumptive use estimates referenced in this study should, and are expected to, undergo careful scrutiny and refinement. This work should be expedited to the extent possible. Detailed representation of changes in consumptive use given riparian community maturity, density and supply conditions, as well as species mix, should be considered in the demand and alternatives analysis phase of water planning. Evaluation of the historic record to better characterize the contribution of effective precipitation to meet consumptive use also is needed.

- Evaluation of Reservoir Evaporation as a Function of Incremental Storage: The evaporation from Elephant Butte Reservoir increases at a greater rate than incremental storage, raising the questions of cost vs. benefit. Although governed by legal-administrative constraints that may be difficult to modify, an assessment of the hydrologic conditions related to this significant depletion would be worthwhile to the water planning process.

- Characterization of Bank Storage/Stream Interactions below San Acacia: To some extent, the storage of water in sediments adjacent to the river and

Elephant Butte Reservoir, affects the available water supply in a given year, as well as shallow water conditions available to riparian communities and undergoing direct evaporation. An expanded network of monitoring wells and flow measurements in this region is recommended to quantify hydrologic processes and conveyance options in this area.

- Continuation of Hydrogeologic Studies and Modeling in the Albuquerque Basin and the Socorro Region: The USGS continues to update and refine the groundwater model of the Albuquerque Basin. In addition to updating hydrogeologic structure and parameter characterizations, continued evaluation of water budget processes reflected by the model is recommended. Recharge, evapotranspiration and stream gains/losses should continue to be evaluated in the context of updated independent studies in these areas. Similarly, additional work to characterize groundwater conditions in the Socorro region is recommended. Groundwater-stream interactions in the region from San Acacia to Elephant Butte are not well-characterized or understood.

- Enhanced Water Flow Measurements: Critical to understanding water supply is the measurement of water inflow and outflow. This study supports the expansion of the MRGCD monitoring network, currently underway. The measurement of all inflows and outflows to this system would enhance understanding of the irrigation district water budget. This study also recommends improved monitoring of tributary inflows to the Rio Grande, as these flows represent a non-trivial portion of the water budget.

- Continuation of Water Operations Modeling: Water operations modeling under development in the URGWOM program will address a number of important questions not addressed by the present study. The URGWOM model will provide a detailed look at where and when water will be present in the river system according to operational conditions. This information will be useful in evaluating details of some of the alternatives considered in the planning process. However, the URGWOM model may require separate versions to evaluate some alternatives involving future conditions not represented by the existing model assumptions.

7.0 REFERENCES

BARROLL, P, 1999 **Draft Documentation for the Administrative Groundwater Model for the Middle Rio Grande Basin,** New Mexico Office of the State Engineer.

BROWER. L.A., and C.L. Hartzell, 1998, **Agricultural Water Resources Decision Support System (AWARDS),** Proceedings, 14th Technical Conference - 1998, U.S. Committee on Irrigation and Drainage.

GOULD, J.L., 1997, **Rio Grande conveyance loss investigation Isleta to San Acacia,** U.S. Bureau of Reclamation, Albuquerque, New Mexico.

HANSEN, S., and C. GORBACH, 1999, **Middle Rio Grande Water Assessment Final Report: Middle Rio Grande Water Assessment,** United States Bureau of Reclamation, Albuquerque area office.

KERNODLE, J.M., D.P. MCADA and C.R. THORN, 1995, **Simulation of ground-water flow in the Albuquerque basin, central New Mexico, 1901-1994, with projections to 2020,** United States Geological Survey Water-Resources Investigations Report 94-4251, and the City of Albuquerque Public woks Department.

KERNODLE, J.M. 1998, **Simulation of ground-water flow in the Albuquerque basin, Central New Mexico, 1901-1995, with projection to 2020**, U.S. Geological Survey Open-File Report 96-209.

McCLURE, T.M., M.C. Hinderlider, F.B. Clayton, and S.O. Harper, 1939. **Rio Grande Compact.**

MIDDLE RIO GRANDE WATER ASSEMBLY, ACTION COMMITTEE, 1999, **Middle Rio Grande Water Budget, Where water comes from, & goes, & how much, Averages for 1972-1997**, Middle Rio Grande Water Assembly, Inc., Albuquerque, New Mexico.

ROYBAL, F.E., 1991, **Ground-Water Resources of Socorro, New Mexico,** U.S. Geological Survey Water-Resources Investigation Report 89-4083.

THORN, C., D. MCADA, and J. KERNODLE, 1993, **Geohydrologic framework and hydrologic conditions in the Albuquerque Basin, Central New Mexico,** U.S. Geological Survey Water-Resources Investigation Report 93-4149.

TIEDEMAN, C., J.W. KERNODLE, and D. MCADA, 1998, **Application of nonlinear-regression methods to a ground-water flow model of the Albuquerque basin, New Mexico,** U. S. Geological Survey Water-Resources Investigation Report 98-4172.

TURNEY, P., 1991, **Rio Grande depletion analysis: A presentation to the New Mexico section of the American Water Resources Association conference on Rio Grande basin hydrology,** Interstate Stream Commission.

U.S. BUREAU OF RECLAMATION, 1995, **Middle Rio Grande water assessment: Estimates of consumptive use requirements for irrigated agriculture and riparian vegetation, Volume I and Volume II,** Middle Rio Grande Water Assessment, supporting document no. 6, U. S. Bureau of Reclamation Albuquerque area office.

U.S. BUREAU OF RECLAMATION, U.S. ARMY CORPS OF ENGINEERS, U.S. GEOLOGICAL SURVEY, U.S. FISH AND WILDLIFE SERVICE, BUREAU OF INDIAN AFFAIRS, INTERNATIONAL BOUNDARY and WATER COMMISSION, 1997, **Upper Rio Grande Operations Model plan for development.**

U.S. NATIONAL RESOURCES COMMITTEE, 1938, **The Rio Grande joint investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937; regional planning part VI,** U.S. National Resources Committee, Regional Planning U.S. Government Printing Office.

WILSON, B.C., and A.A. LUCERO, 1997, **Water Use by Categories in New Mexico Counties and River Basins, and Irrigated Acreage in 1995**, New Mexico State Engineer Office Technical Report 49.

LIST OF FIGURES

1.1 Map of Study Area
1.2 Variability: Flow of Rio Grande at Otowi Bridge, 1940 to 1998
1.3 Limitation: Base Supply to the Middle Rio Grande Region (Rio Grande at Otowi Bridge minus Elephant Butte Scheduled Delivery)

2.1 New Mexico Delivery Schedule under the Rio Grande Compact
2.2 Probability Distribution Example

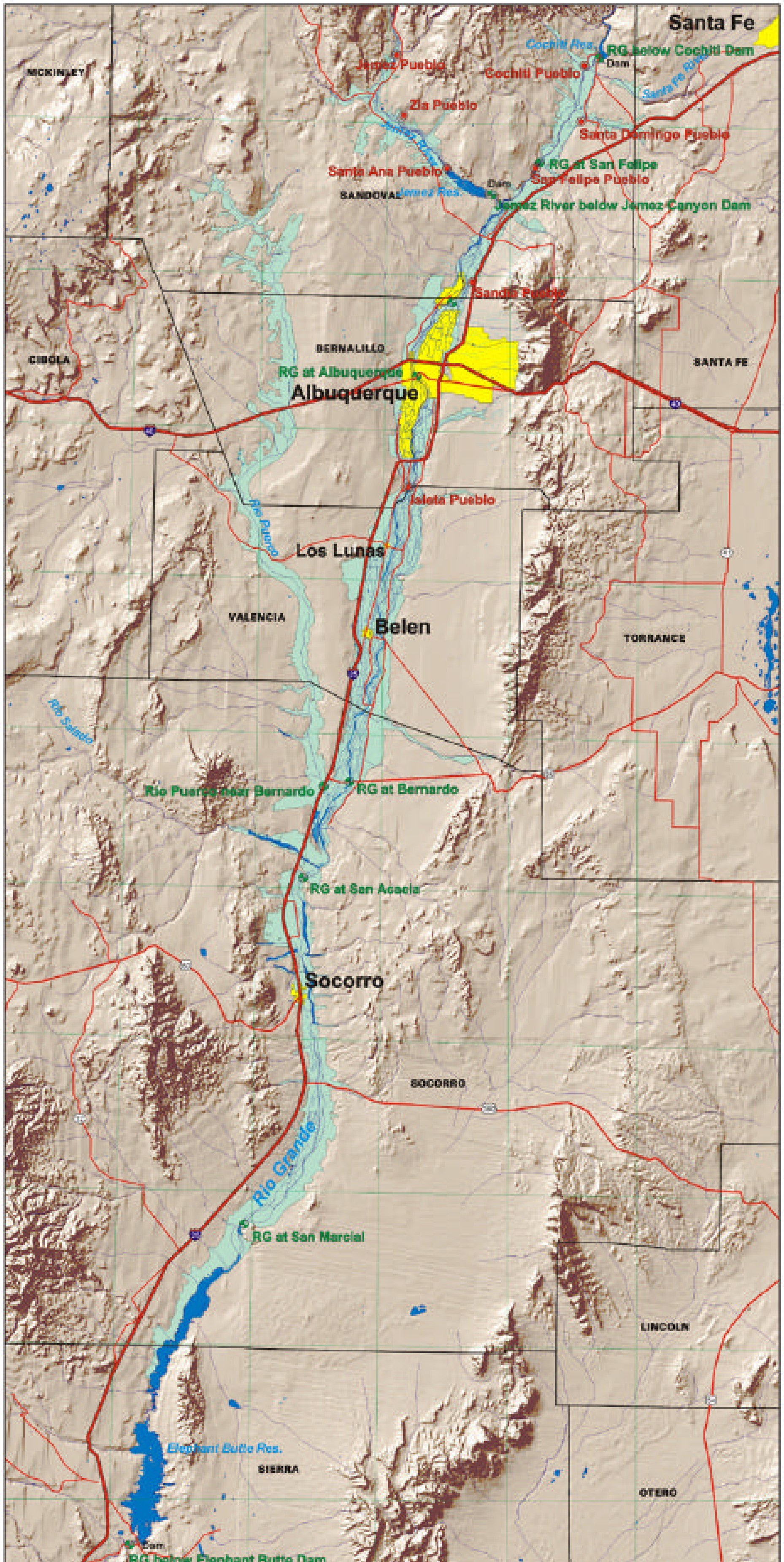
3.1 Schematic of Major Diversions and Tributary Inflows: Rio Grande from Otowi to Elephant Butte
3.2 Otowi Cross-Section
3.3 Cochiti Cross-Section
3.4 San Felipe Cross-Section
3.5 Bernardo Cross-Section
3.6 San Acacia Cross-Section
3.7 San Marcial Cross-Section
3.8 Elephant Butte Cross-Section
3.9 Cochiti Diversion
3.10 Angostura Diversion
3.11 Isleta Dam Diversion
3.12 San Acacia Dam Diversion
3.13 Net Supply (Otowi Index Supply minus Scheduled Delivery)
3.14 Rio Grande Compact Credit History

5.1 Otowi Index Supply
5.2 Trans-Mountain Diversions
5.3 Santa Fe River
5.4 Galisteo Creek
5.5 Jemez River
5.6 AMAFCA Inflow
5.7 Rio Puerco
5.8 Rio Salado
5.9 Cochiti Evaporation
5.10 Elephant Butte Evaporation
5.11 Wastewater Returns
5.12 Agricultural Consumptive Use above San Acacia
5.13 Agricultural Consumptive Use below San Acacia
5.14 Riparian Consumptive Use above San Acacia
5.15 Riparian Consumptive Use below San Acacia
5.16 Scheduled Delivery at Elephant Butte
5.17 River Depletions under Hypothetical Future Pumping Scenarios
5.18 Credit-Debit Probability Distribution Present Development Condition, Year 2000

5.19 Credit-Debit Probability Distribution Present Development Condition, Year 2040
5.20 Credit-Debit Probability Distribution Alternative Development Condition, Year 2040
5.21 Gross Water Supply at San Felipe Probability Distribution, Present Condition
5.22 Gross Water Supply at Bernardo Probability Distribution, Present Condition
5.23 Gross Water Supply at San Acacia Probability Distribution, Present Condition
5.24 Gross Water Supply at Elephant Butte Probability Distribution, Present Condition
5.25 Schematic: Middle Rio Grande Water Supply Under Present Conditions, Excluding Elephant Butte Scheduled Delivery (in thousand acre-feet)
5.26 Summary of Mean Depletions

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 under 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 32'

S.S. Papadopulos & Associates, Inc.

SS Consulting Group, Inc.

Revised 11/23/00

Figure 1.2 Variability: Flow of Rio Grande at Otowi Bridge, 1940 to 1998

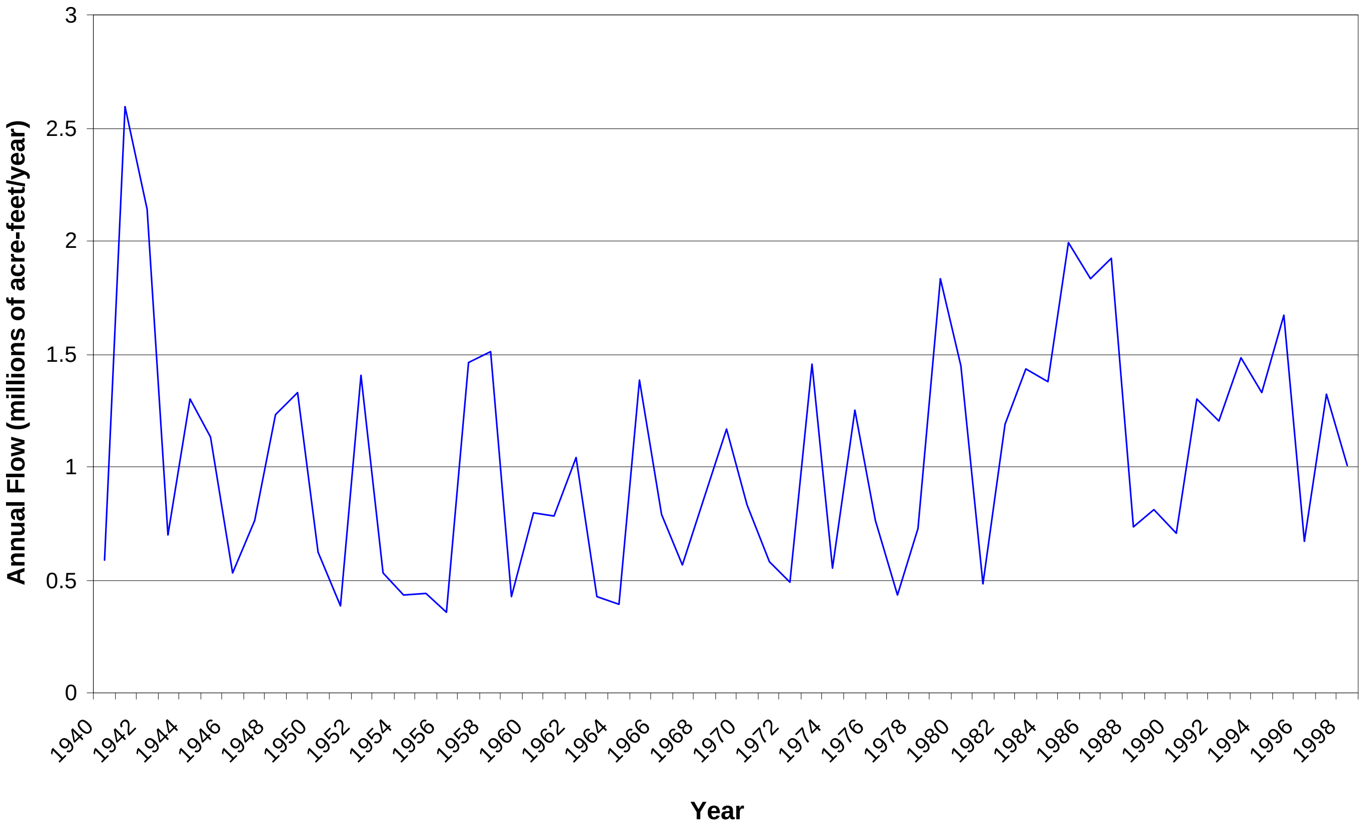


Figure 1.3 Limitation: Base Supply to the Middle Rio Grande Region (Rio Grande at Otowi Bridge minus Elephant Butte Scheduled Delivery)

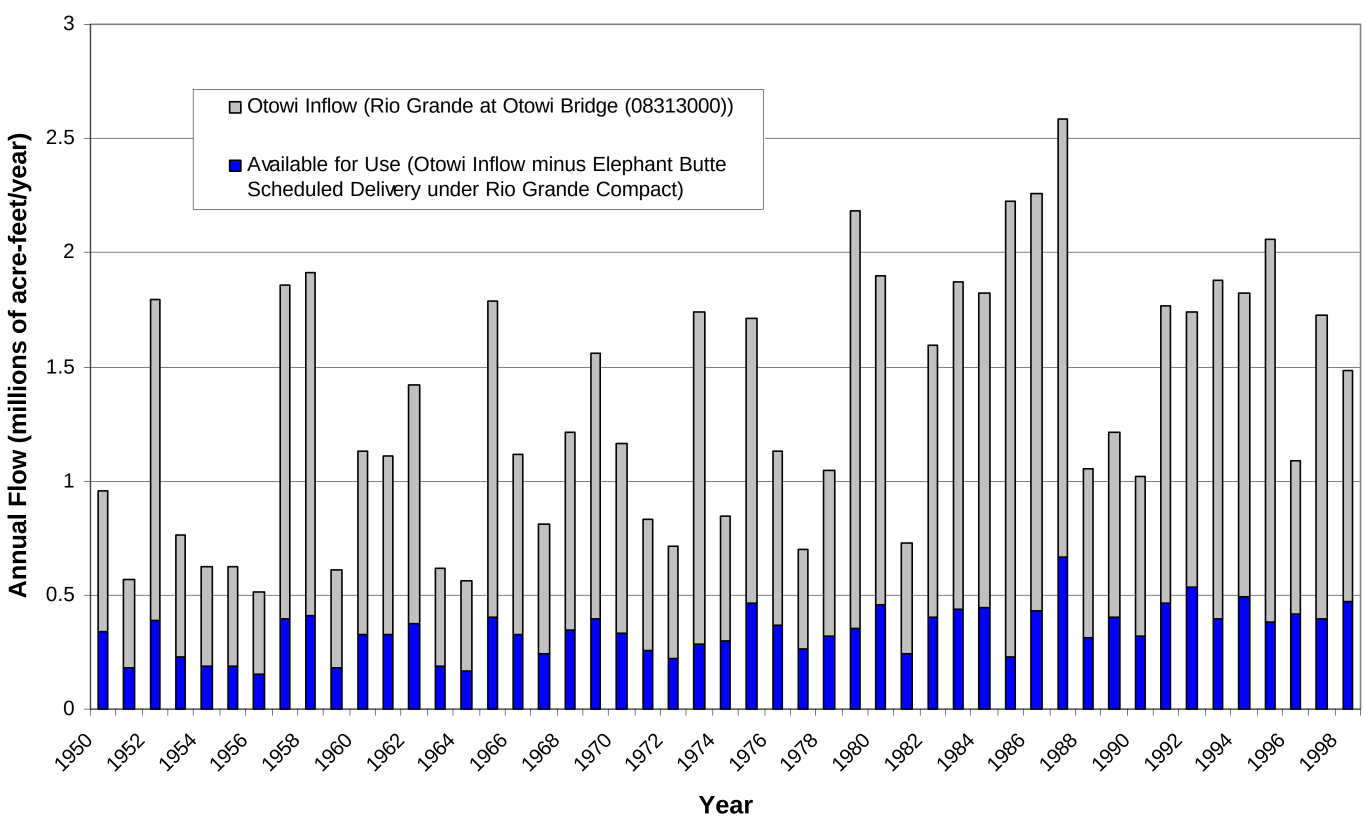
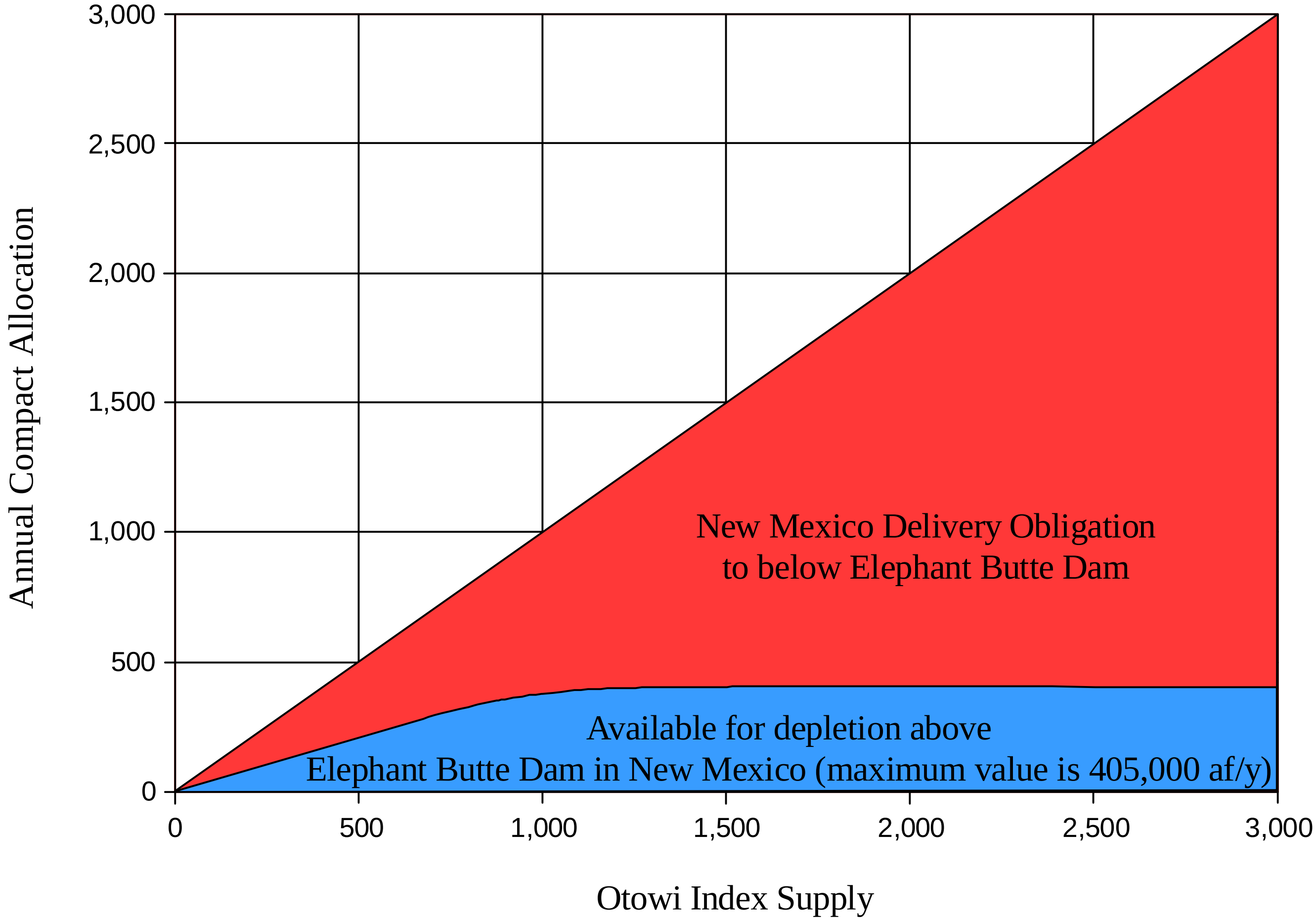


Figure 2.1

Rio Grande Compact Allocation

(quantities in thousands of acre-feet)



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

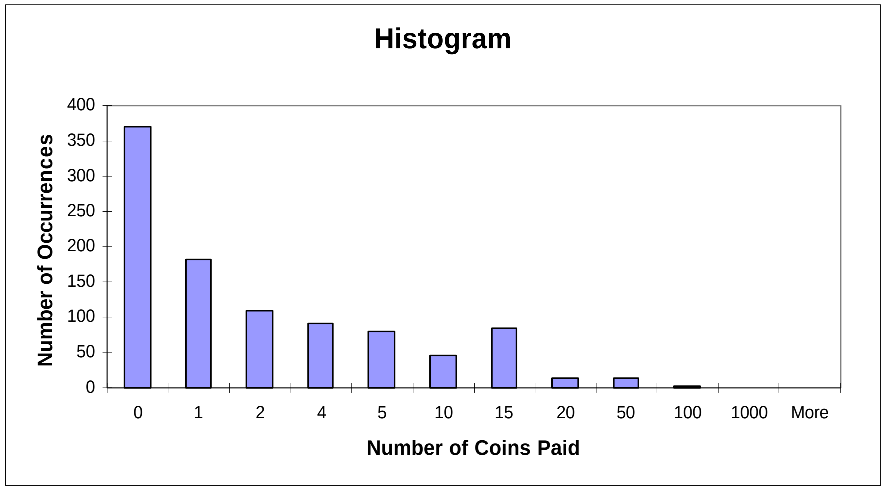
(Quantities in thousands of acre-feet)

Otowi Index Supply	Elephant Butte Scheduled Delivery
100	57
200	114
300	171
400	228
500	286
600	345
700	406
800	471
900	542
1,000	621
1,100	707
1,200	800
1,300	897
1,400	996
1,500	1,095

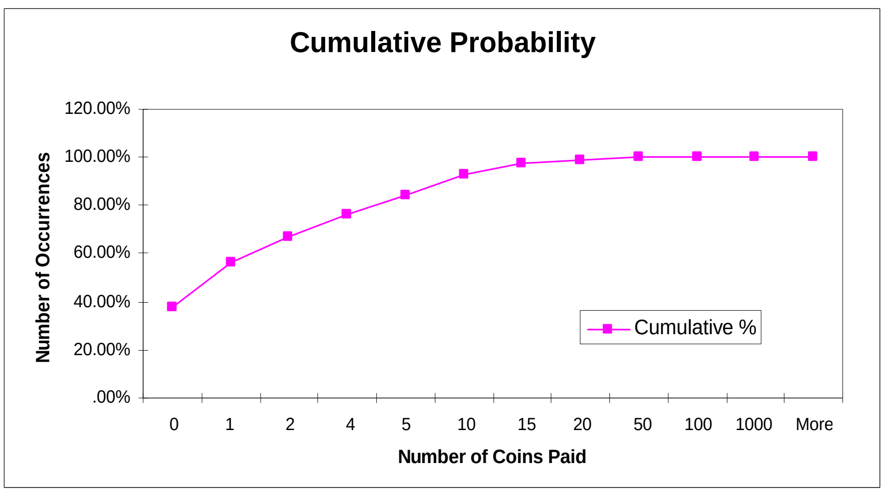
Otowi Index Supply	Elephant Butte Scheduled Delivery
1,600	1,195
1,700	1,295
1,800	1,395
1,900	1,495
2,000	1,595
2,100	1,695
2,200	1,795
2,300	1,895
2,400	1,995
2,500	2,095
2,600	2,195
2,700	2,295
2,800	2,395
2,900	2,495
3,000	2,595

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.

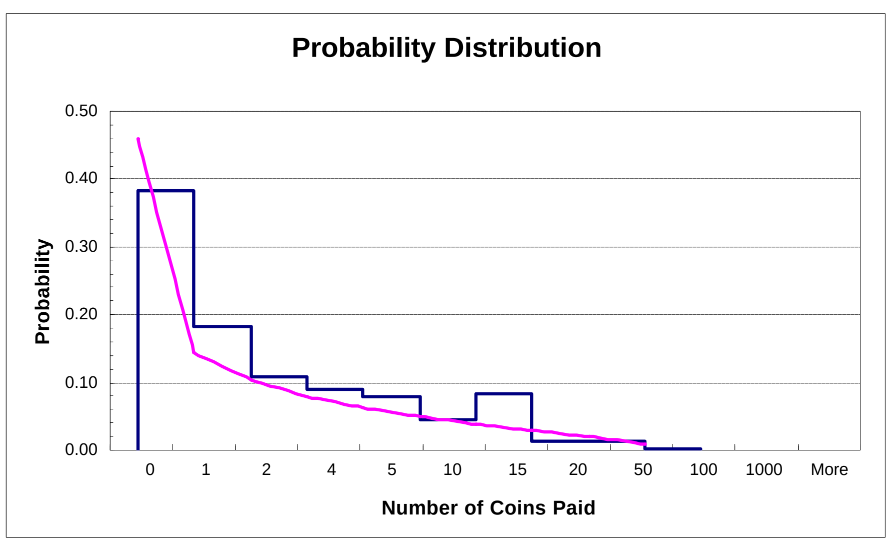


Figure 3.1

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

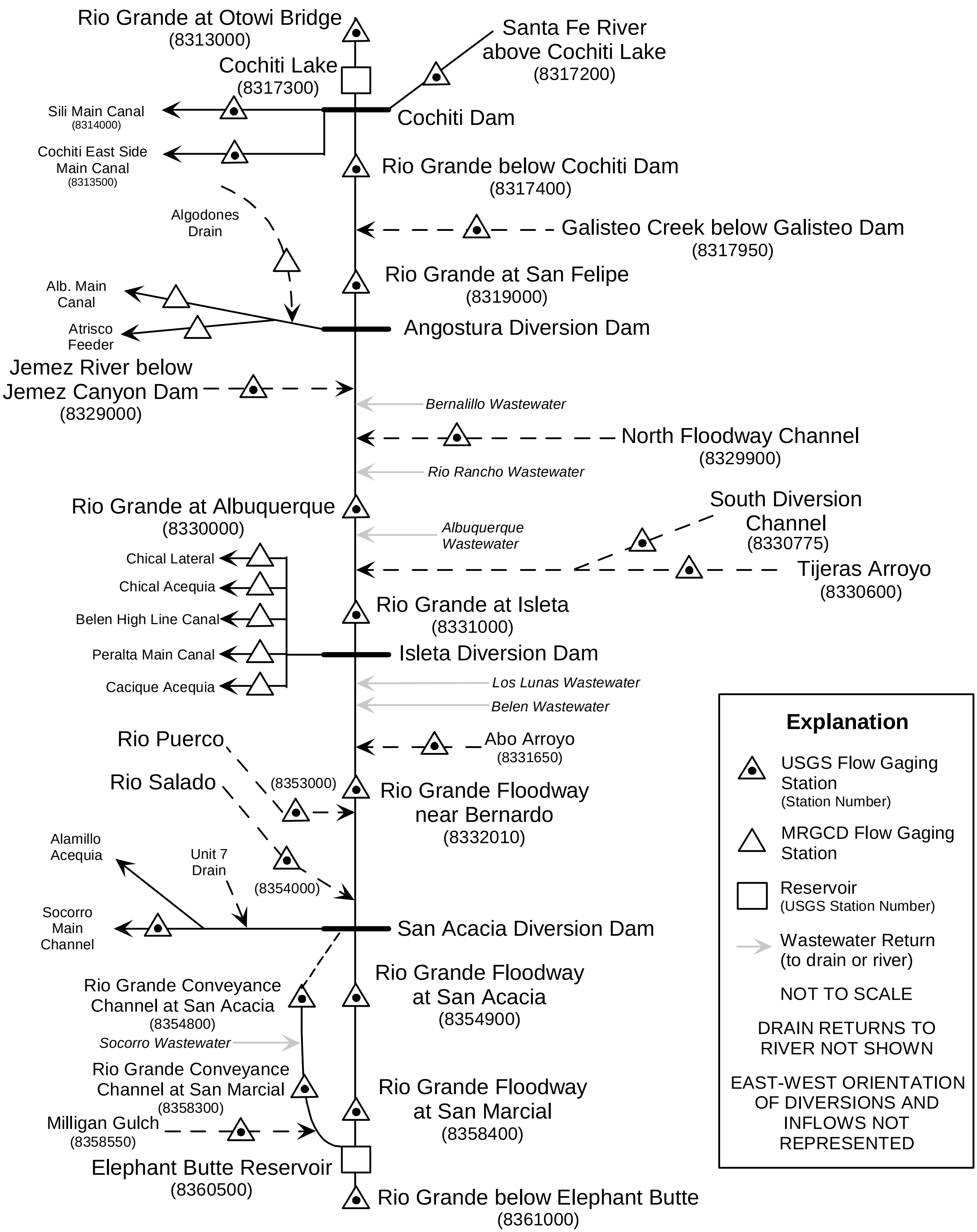
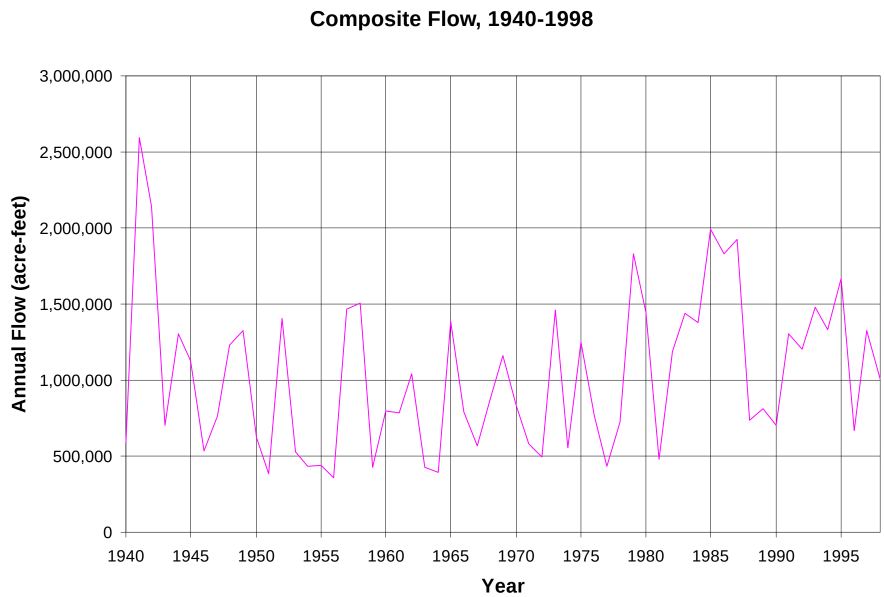


Figure 3.2

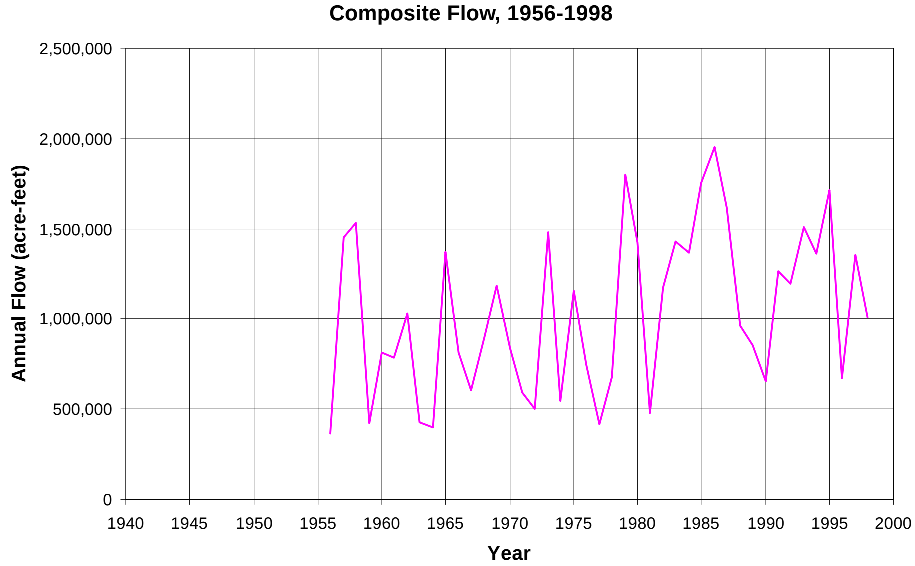
Otowi Cross-Section



Contributing Station:
Rio Grande at Otowi Bridge (08313000)

Figure 3.3

Cochiti Cross-Section

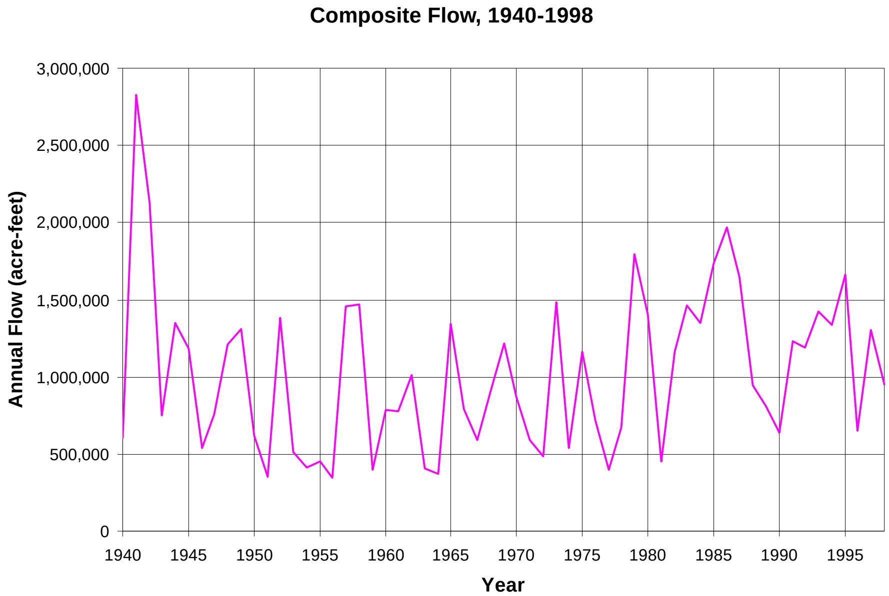


Contributing Stations:

1956-1970	Sili Main Canal at Cochiti	(08314000)
	Cochiti East Side Main Canal	(08313500)
	Rio Grande at Cochiti	(08314500)
1971-1998	Sili Main Canal at Cochiti	(08314000)
	Cochiti East Side Main Canal	(08313500)
	Rio Grande below Cochiti Dam	(08317400)

Figure 3.4

San Felipe Cross-Section

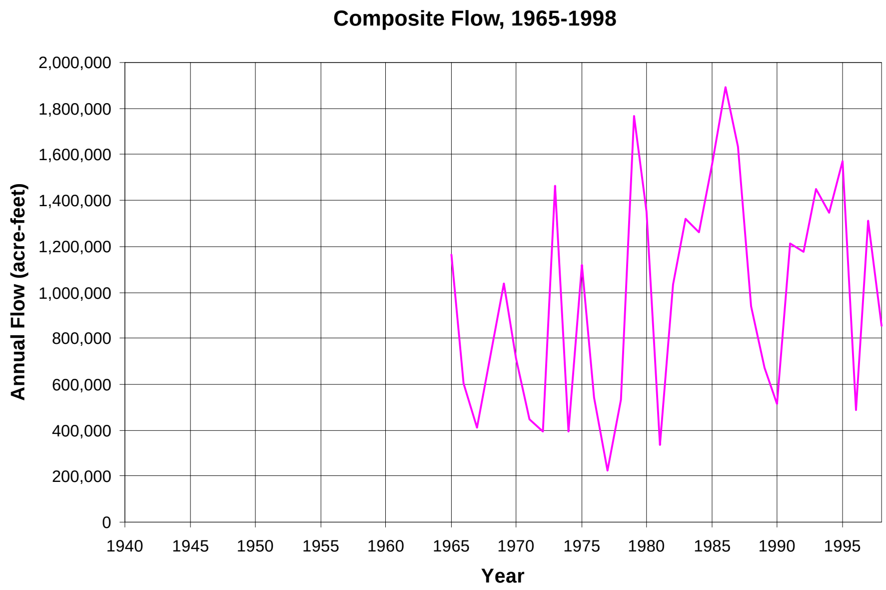


Contributing Station:
Rio Grande at San Felipe (08319000)

Comments: Some ungaged flow in Cochiti Eastside Main Canal and San Felipe eastside acequia bypasses this station

Figure 3.5

Bernardo Cross-Section

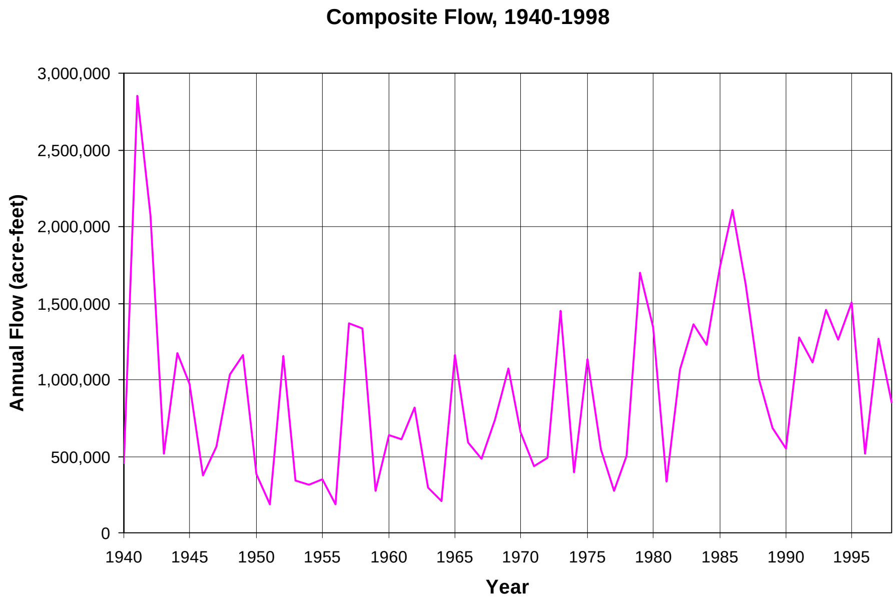


Contributing Stations:

1965-1998	Rio Grande Conveyance Channel near Bernardo	(08331990)
1965-1998	Rio Grande Floodway near Bernardo	(08332010)
1965-1998	Lower San Juan Riverside Drain near Bernardo	(08332030)
1965-1998	Bernardo Interior Drain near Bernardo	(08332050)

Figure 3.6

San Acacia Cross-Section

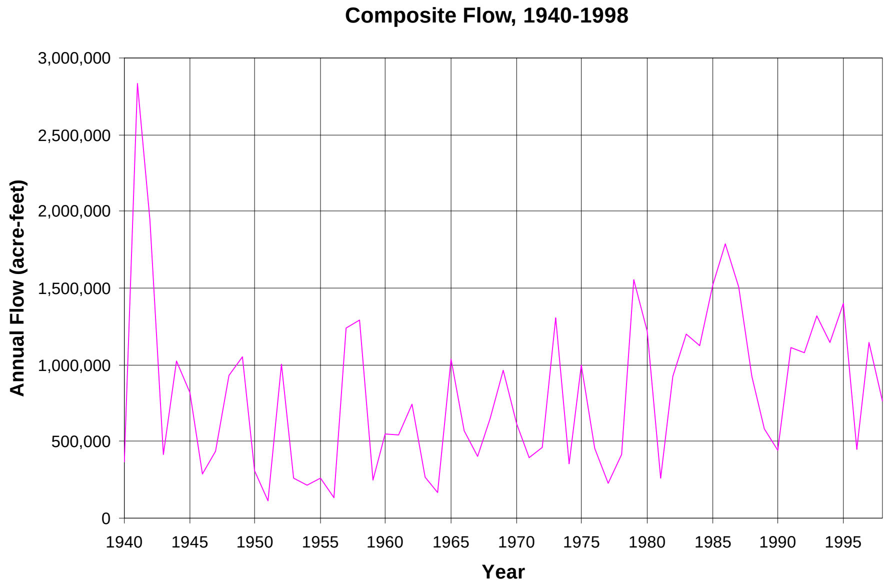


Contributing Stations:

1940-1963	Rio Grande at San Acacia	(08355000)
1964-1998	Rio Grande Conveyance Channel	(08354800)
	Rio Grande Floodway at San Acacia	(08354900)
	Socorro Main Canal	(08354500)

Figure 3.7

San Marcial Cross-Section

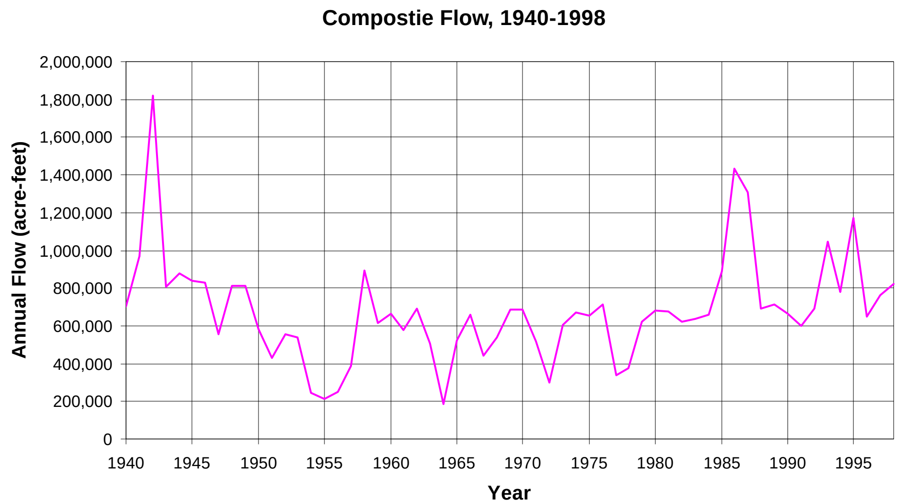


Contributing Stations:

1940-1963	Rio Grande at San Marcial	(08358500)
1964-1998	Rio Grande Conveyance Channel at San Marcial	(08358300)
	Rio Grande Floodway at San Marcial	(08358400)

Figure 3.8

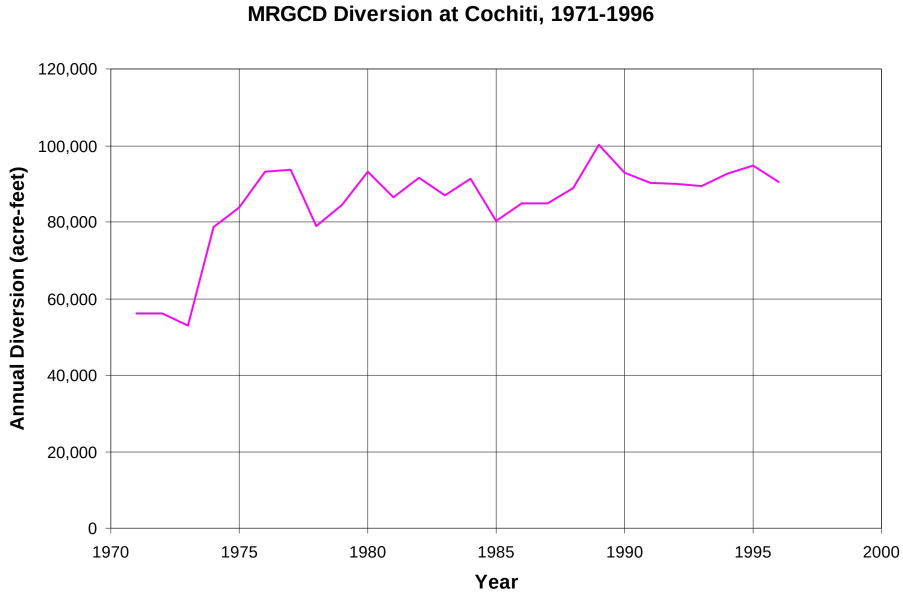
Elephant Butte Cross-Section



Contributing Station:
Rio Grande below Elephant Butte Dam (08361000)

Figure 3.9

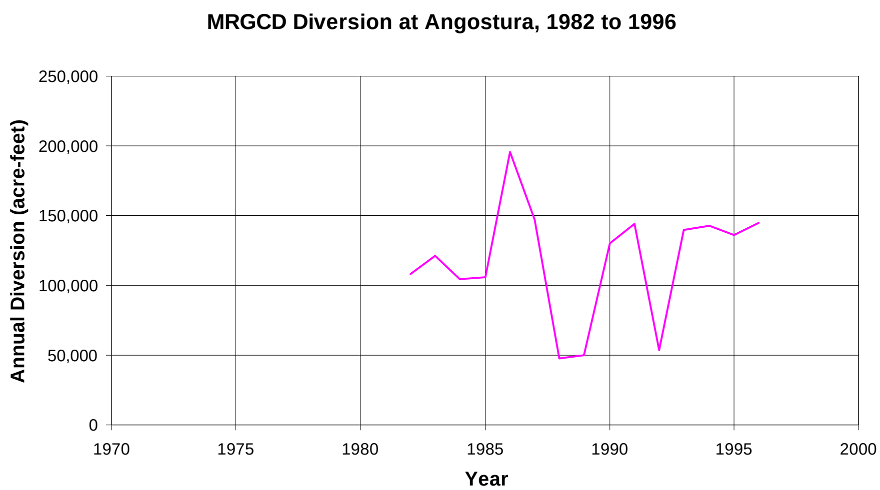
Cochiti Diversion



The MRGCD Composite Diversion at Cochiti represents the sum of gaged diversions to Sili Main Canal and Cochiti East Side Canal. This composite is a measure of annual diversions, and does not reflect irrigation consumptive use or return flows to the river or aquifer.

Figure 3.10

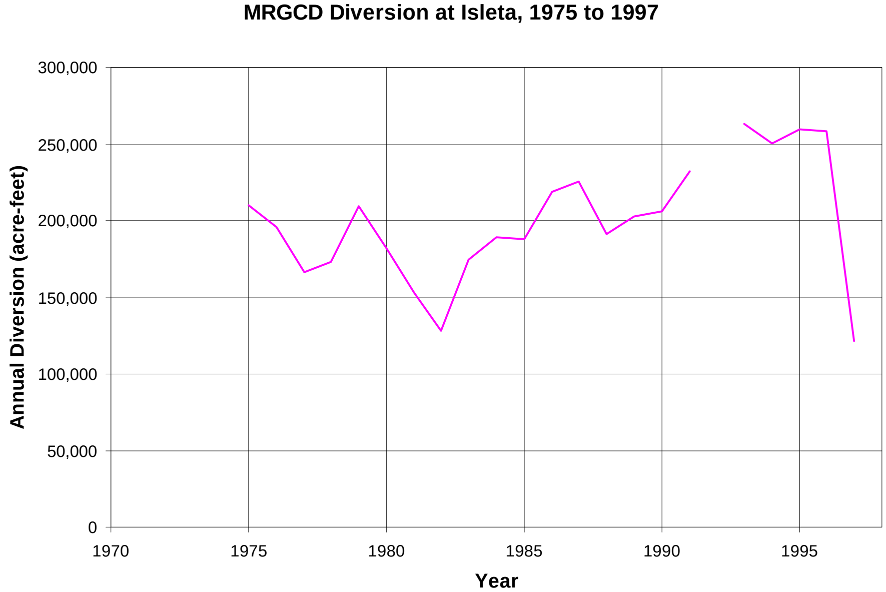
Angostura Diversion



The MRGCD Composite Diversion at Angostura represents the sum of gaged diversions to Albuquerque Main Canal and the Atrisco Feeder, minus the flow of the Algodones Drain, which is included in the gaged canal flow. This composite is a measure of annual diversions, and does not reflect irrigation consumptive use or return flows to the river or aquifer.

Figure 3.11

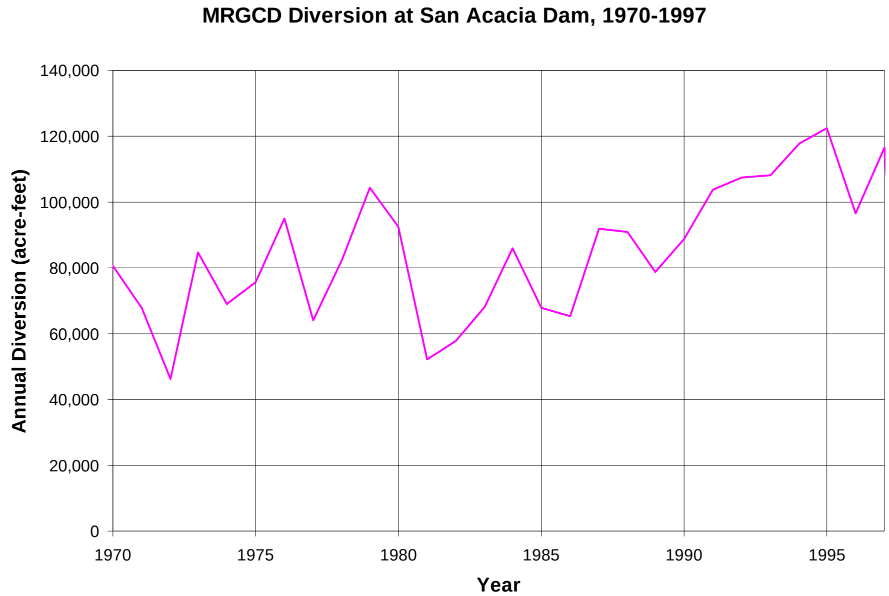
Isleta Dam Diversion



The MRGCD Composite Diversion at Isleta represents the sum of gaged diversions to Chical Lateral, Cacique Acequia, Peralta Main Canal, Belen Hi Line Canal and Chical Acequia. This composite is a measure of annual diversions, and does not reflect irrigation consumptive use or return flows to the river or aquifer.

Figure 3.12

San Acacia Diversion



This graph of the MRGCD diversion at San Acacia represents the gaged diversions to the Socorro Main Canal. This is a measure of annual diversions, plus ungaged return flows from the Unit 7 drain, and does not reflect irrigation consumptive use or return flows to the river or aquifer.

Figure 3.13

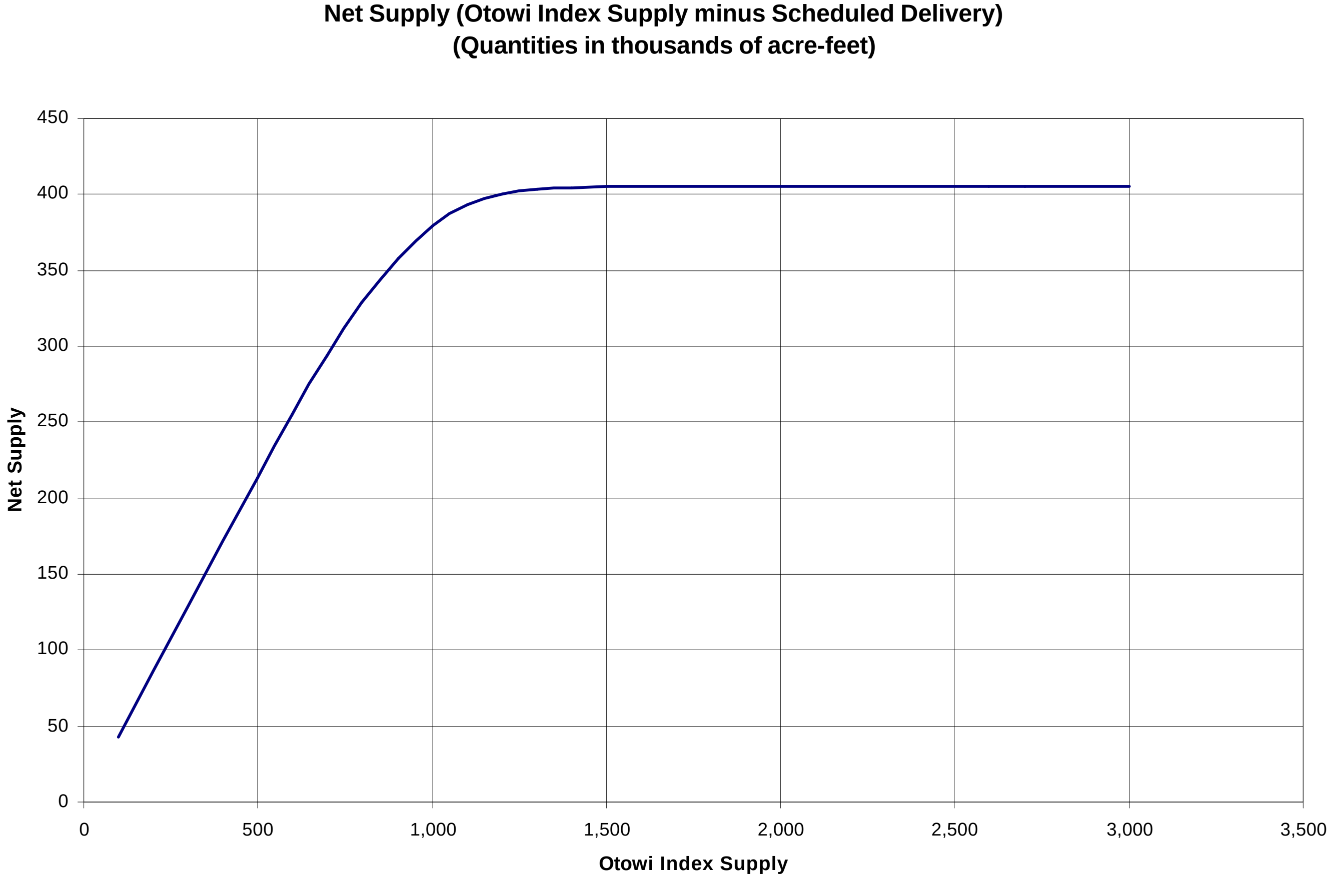


Figure 3.14

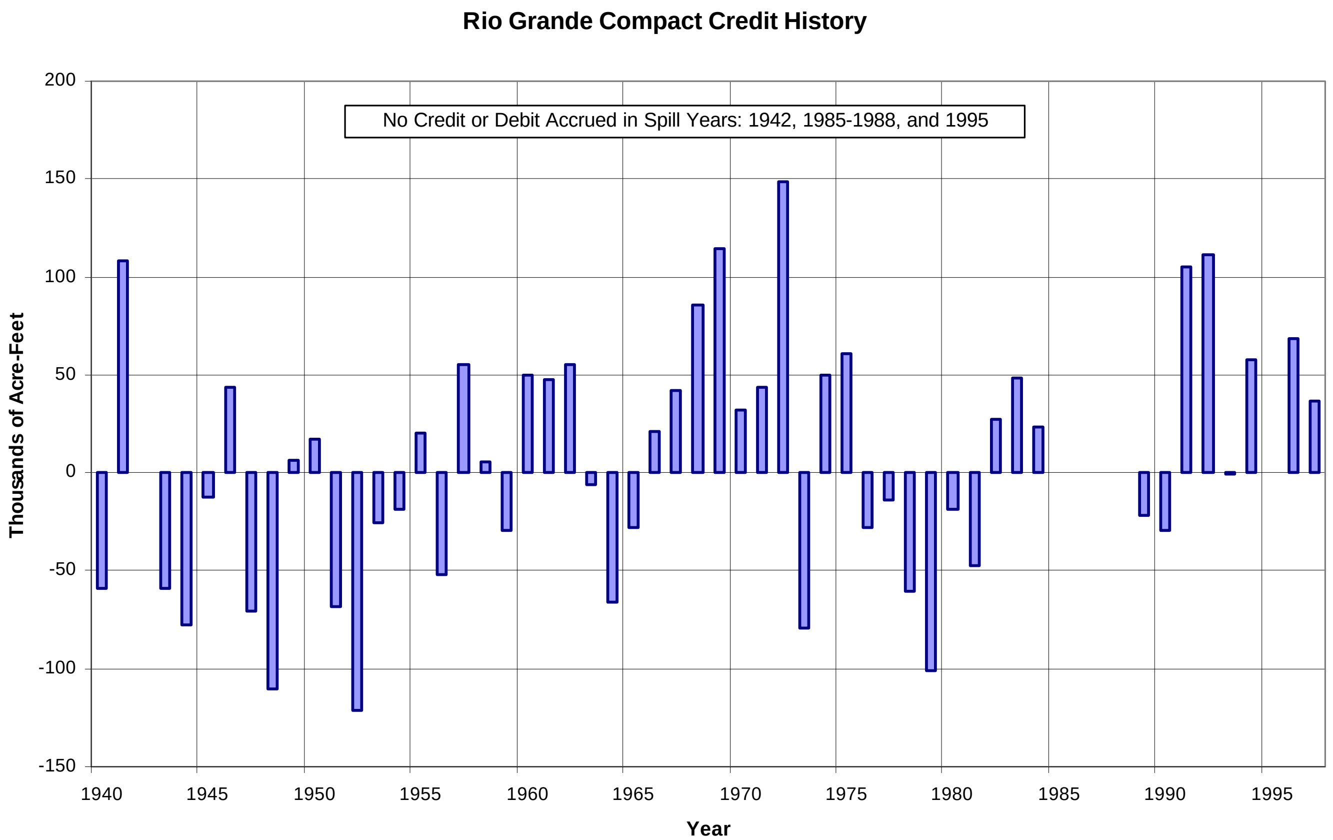
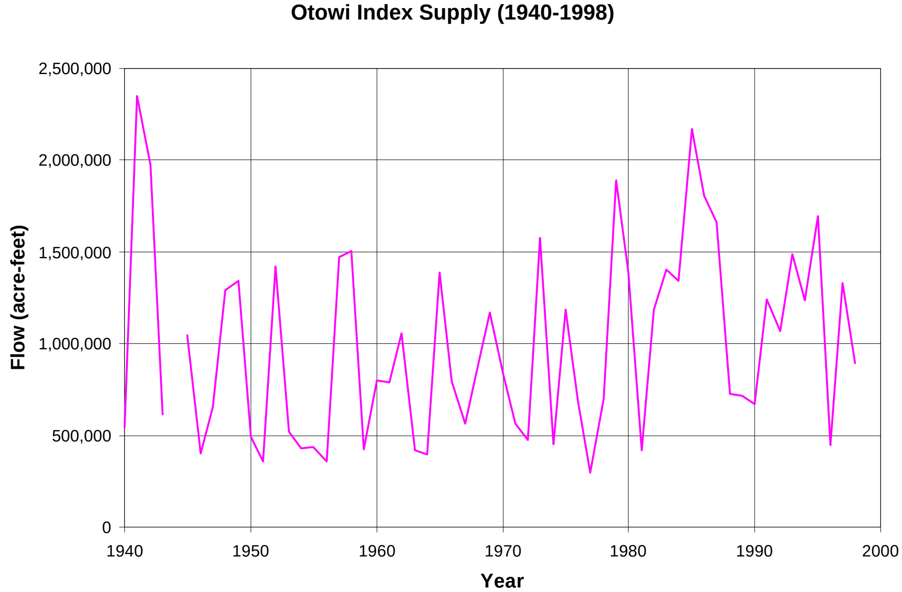


Figure 5.1

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.

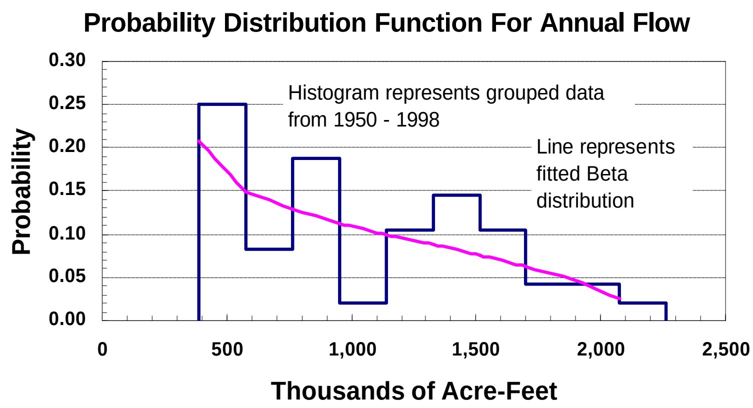
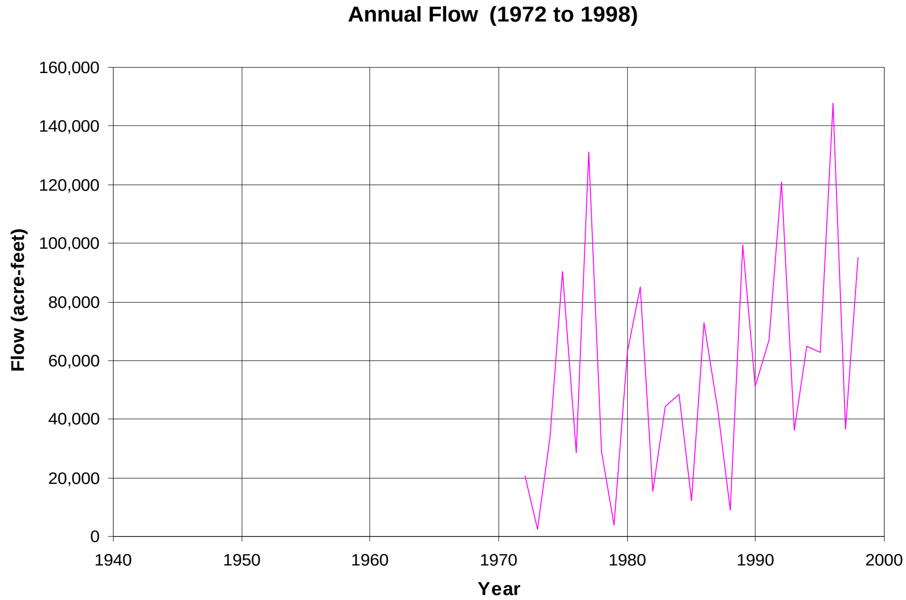


Figure 5.2

Trans-Mountain Diversions

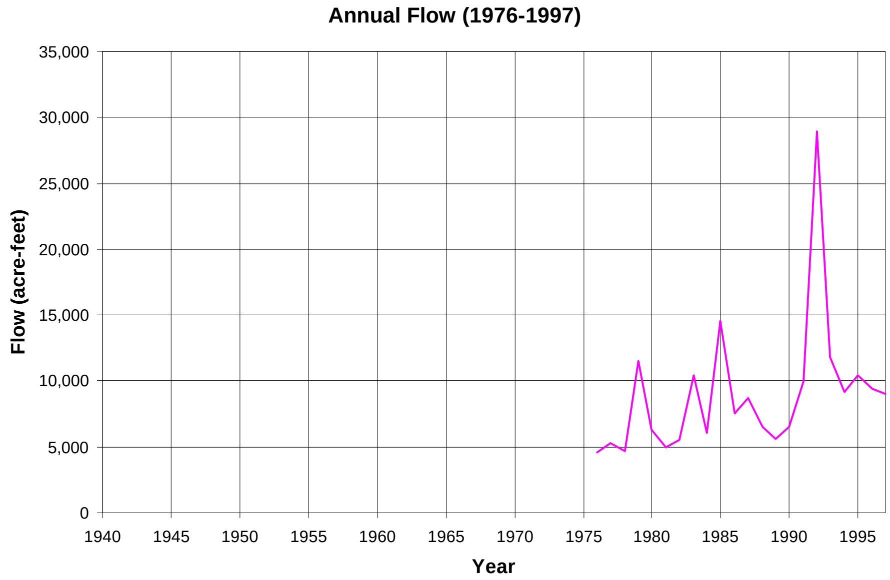


Title: Trans-Mountain Diversions (San Juan-Chama)
Period of Record: 1972 - present
Data Source: Rio Grande Compact Commission

Probability Function:
Due to demand-dependency and the short period of record, a probability function was not developed for use in the probabilistic water supply model. Rather, a mean value of 75,844 acre feet per year, derived from the 1990 to 1998 period, was employed to represent this inflow component under current development conditions.

Figure 5.3

Santa Fe River

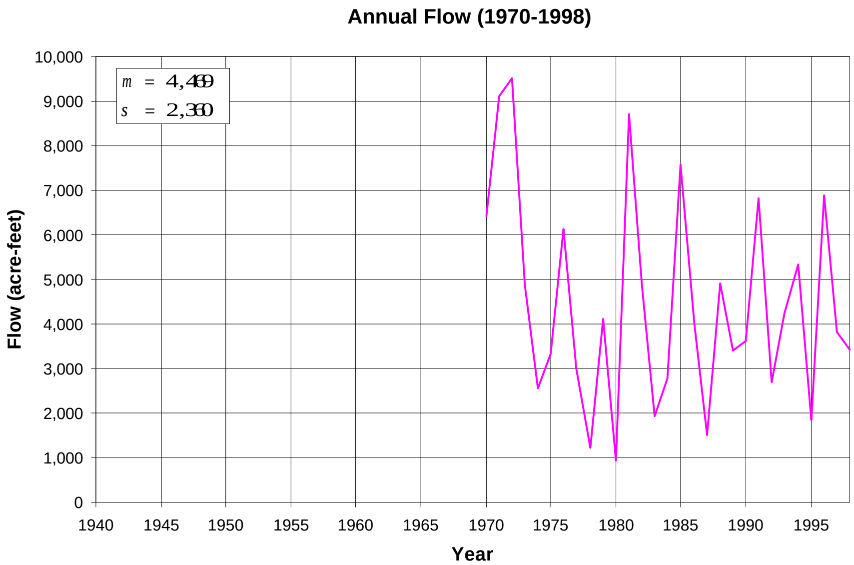


Station Name: Santa Fe River above Cochiti Lake
Station Number: 08317200
Latitude: 353249 N
Longitude: 1061341 W
Elevation : 5505 feet above NGVD
Period of Record: 1976 - present
Data Source: USGS

Probability Function:
Comprised to large extent by population-based wastewater returns, and influenced by operation of water supply reservoir, a probability function was not developed for this inflow term. The mean annual flow for the years 1993 to 1997, of 9,956 acre feet per year, is assumed to represent present development conditions in the water supply model.

Figure 5.4

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

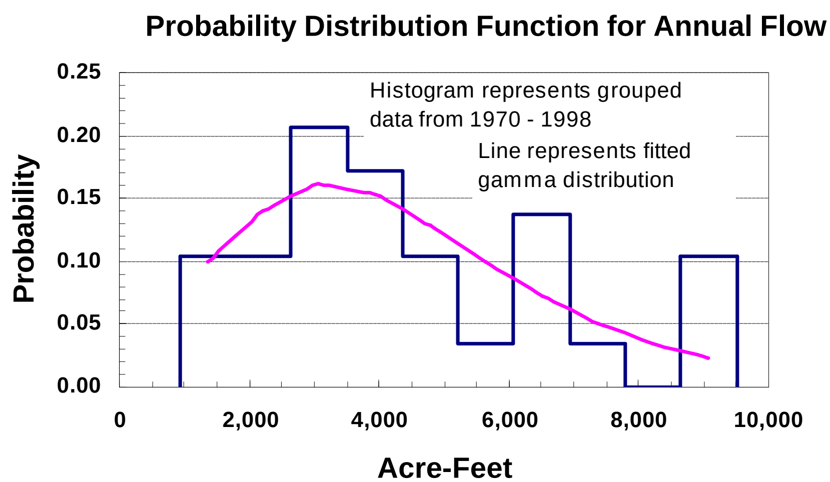
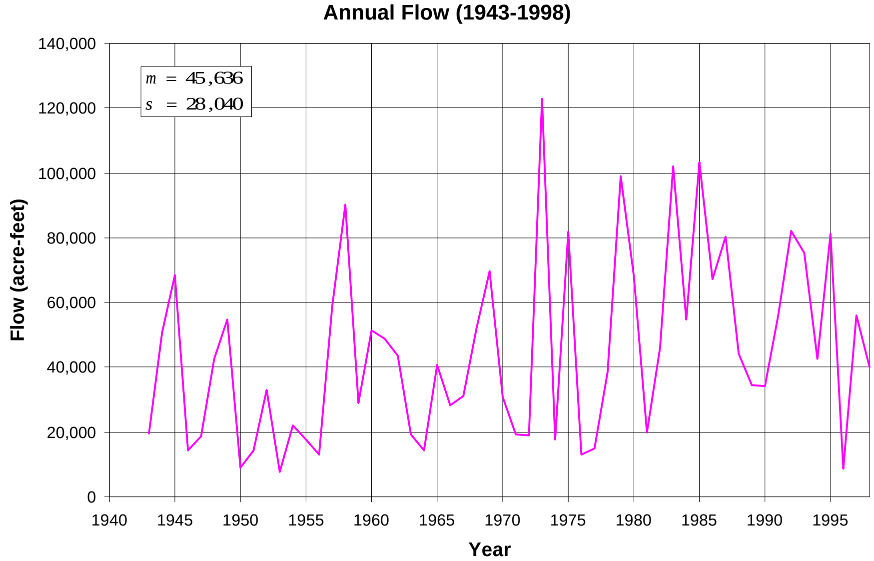


Figure 5.5

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

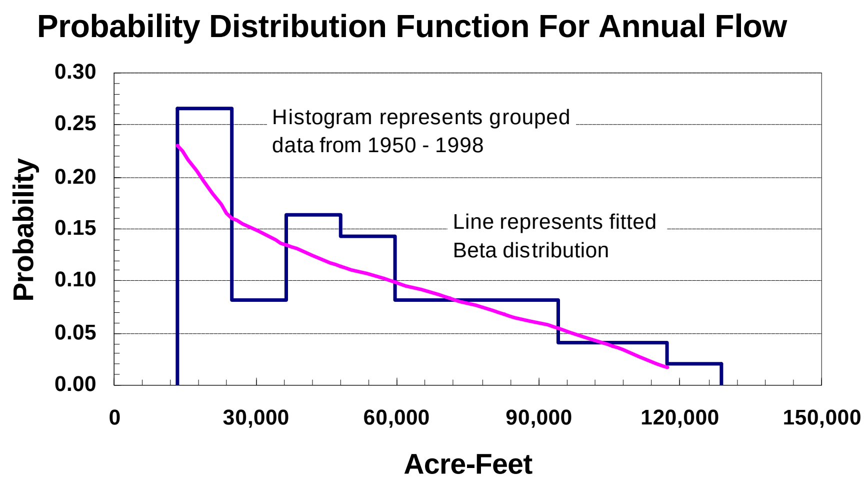
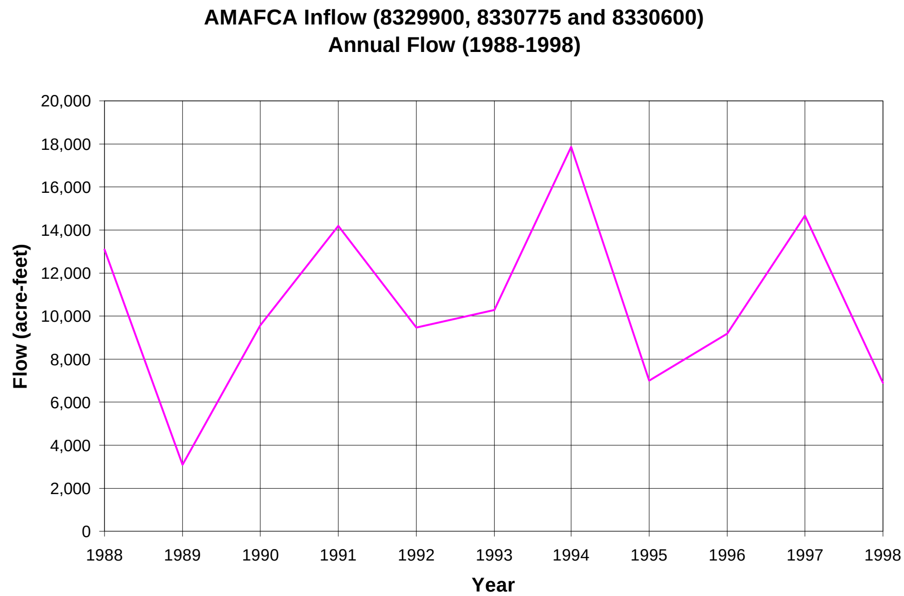


Figure 5.6

AMAFCA Inflow

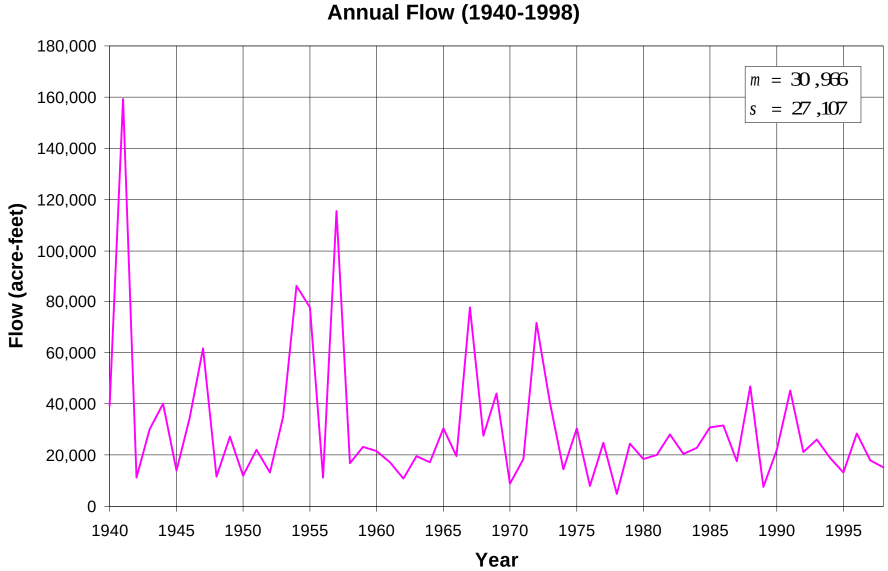


Composite Flow: Albuquerque Metropolitan Arroyo Flood Control Authority channels to Rio Grande
Contributing Stations: 8329900, 8330775, and 8330600
Latitude: 351158 N, 350009 N, and 350004 N
Longitude: 1063553 W, 1063902 N, and 1063918 W
Elevation : 5015, 4930, and 5000 feet above NGVD
Composite Period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

Probability Function:
A simple uniform probability distribution with the minimum and maximum of 3,072 and 17,845 acre feet per year, respectively, for the short period of record was employed.

Figure 5.7

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

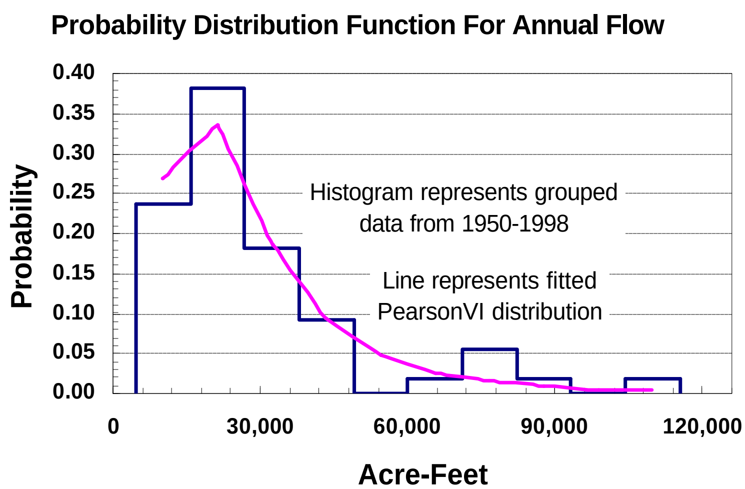
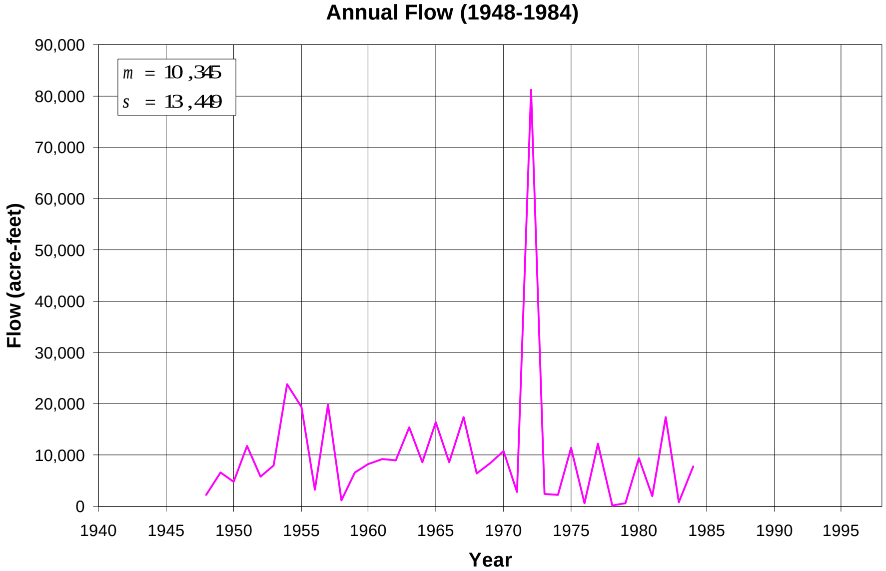


Figure 5.8

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

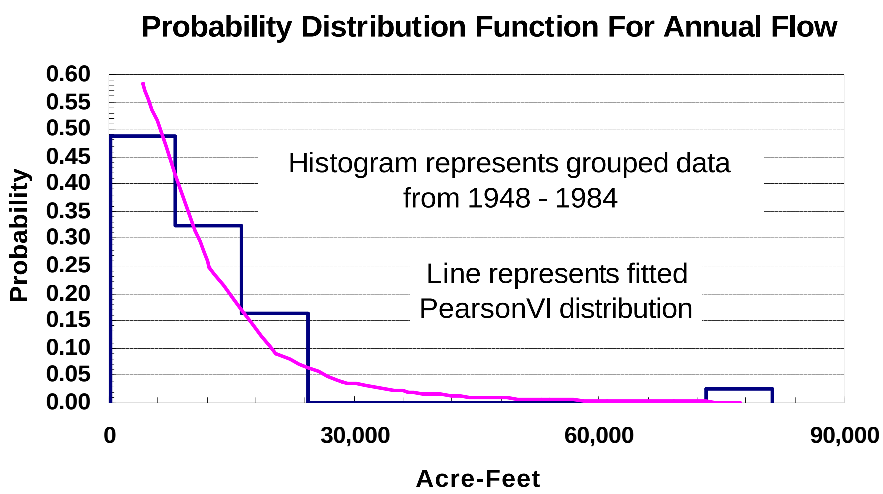
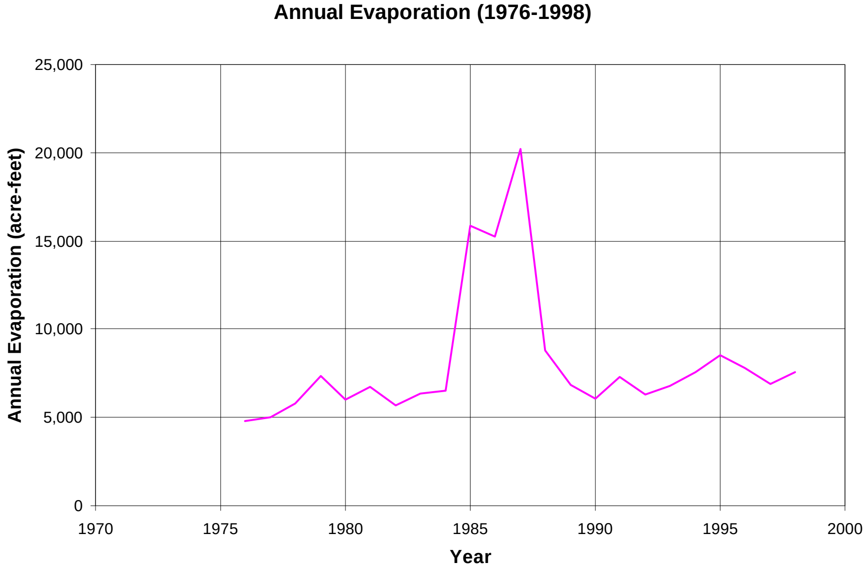


Figure 5.9

Cochiti Evaporation



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

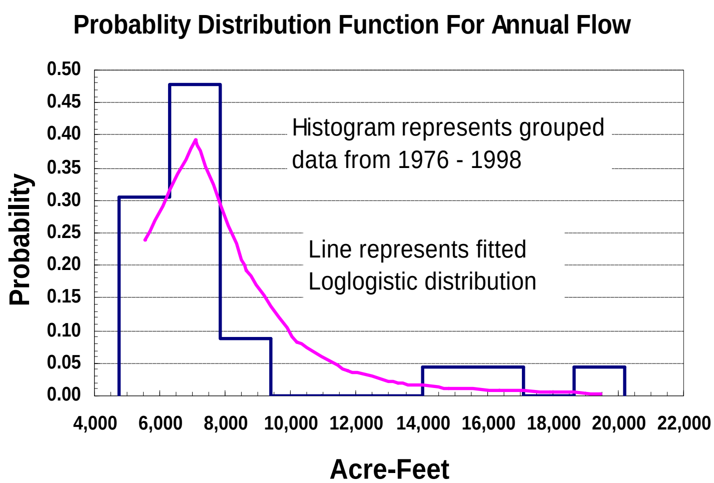
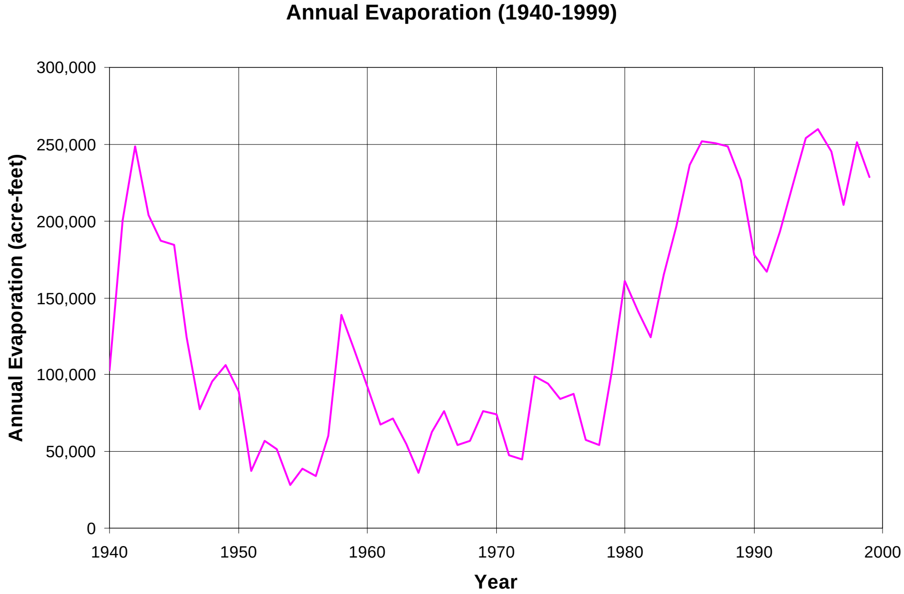


Figure 5.10

Elephant Butte Evaporation



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

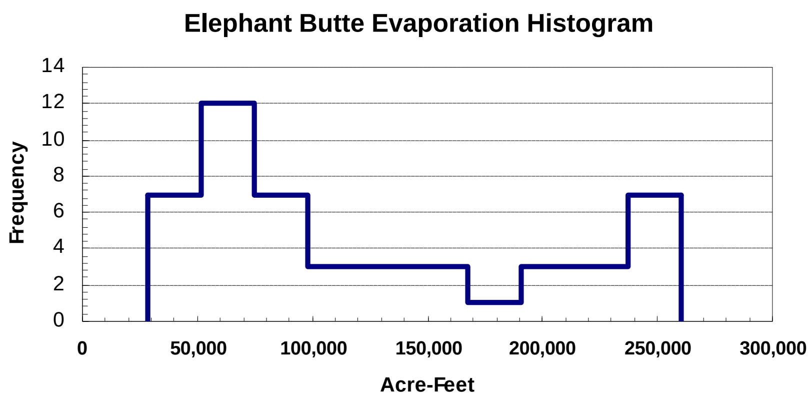
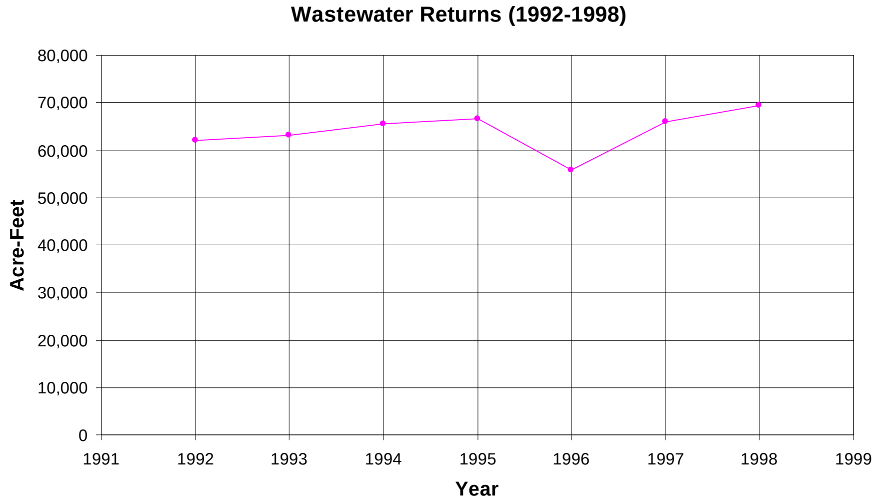


Figure 5.11

Wastewater Returns

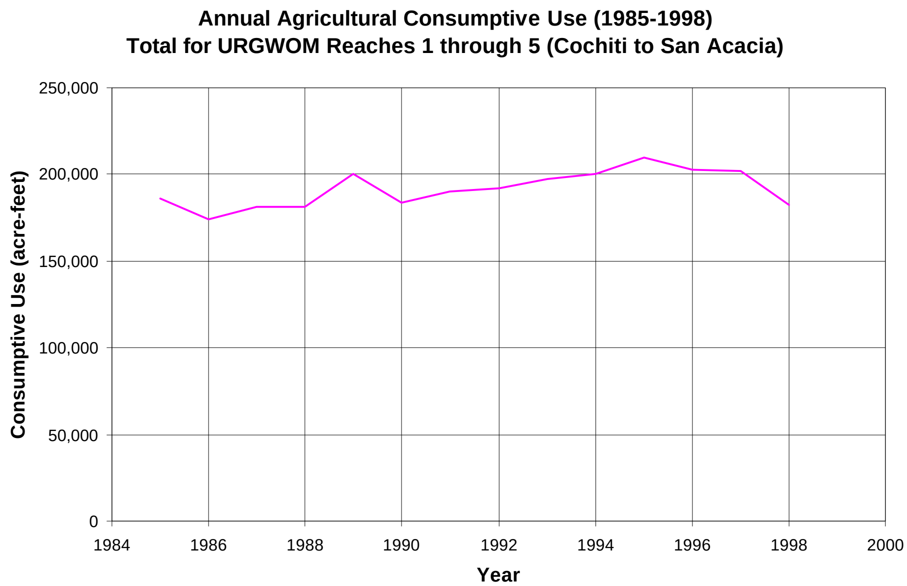


Title: Wastewater Returns
Period of Record: 1992 - present
Data Source: USEPA
Comments: Composite of reported discharges under NPDES permits for cities of Albuquerque, Rio Rancho, Bernalillo, Los Lunas, Belen and Socorro

Probability Function:
Reflecting population-based water usage, a probability function was not developed for this water budget term. To reflect the present development condition, a static value of 68,941 acre feet per year, representing the composite waste water return for 1998, is assumed for the water supply model.

Figure 5.12

Agricultural Consumptive Use above San Acacia



Title: Agricultural Consumptive Use above San Acacia
Period of Record: 1985 - present
Data Source: USBR (ET Toolbox website, May 2000)

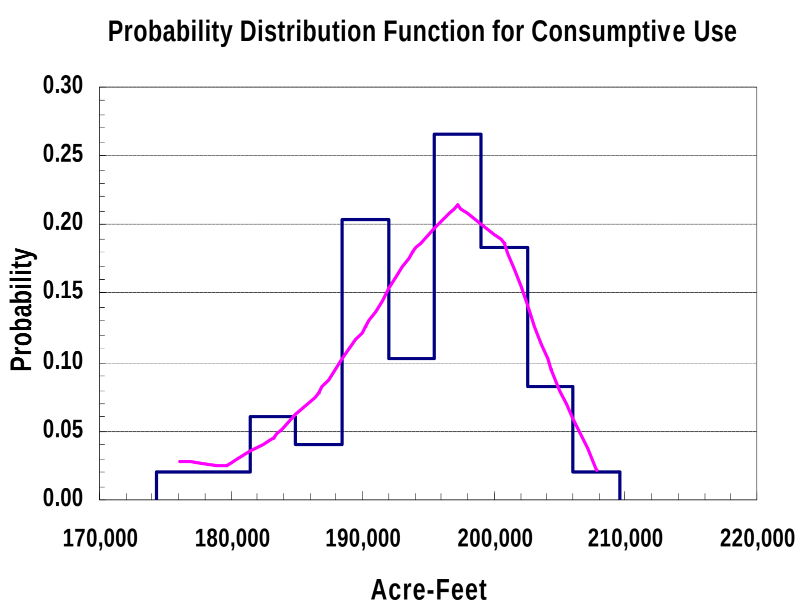
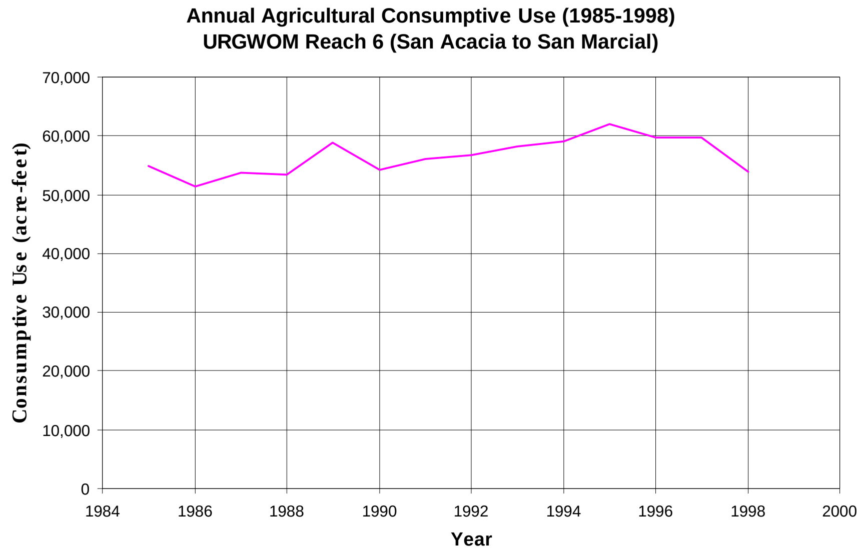


Figure 5.13

Agricultural Consumptive Use below San Acacia



Title: Agricultural Consumptive Use below San Acacia
Period of Record: 1985 - present
Data Source: USBR (ET Toolbox website, May 2000)

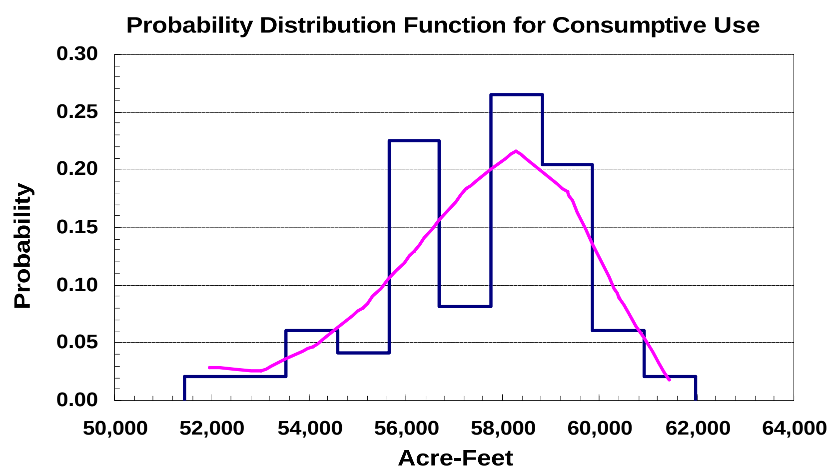
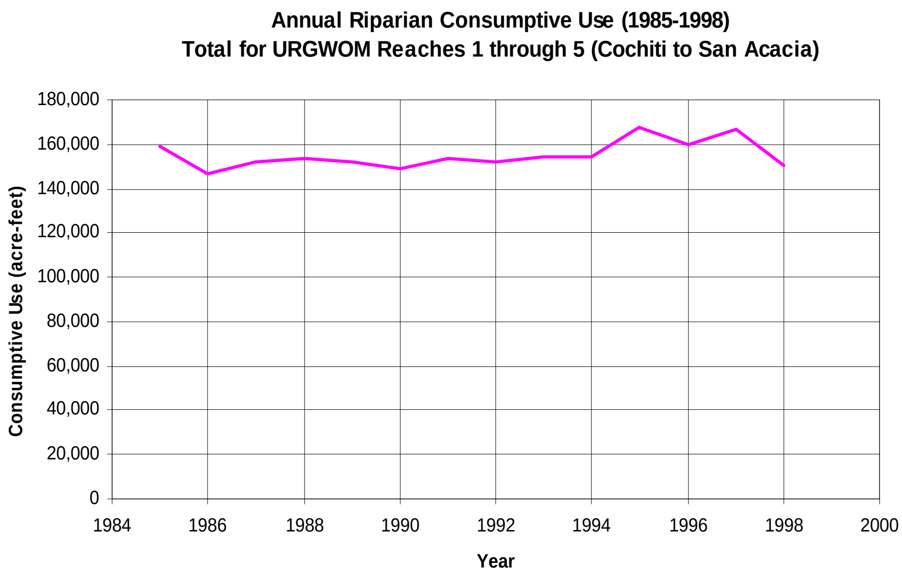


Figure 5.14

Riparian Consumptive Use above San Acacia



Title: Riparian Consumptive Use above San Acacia
Period of Record: 1985 - present
Data Source: USBR (ET Toolbox website, May 2000)

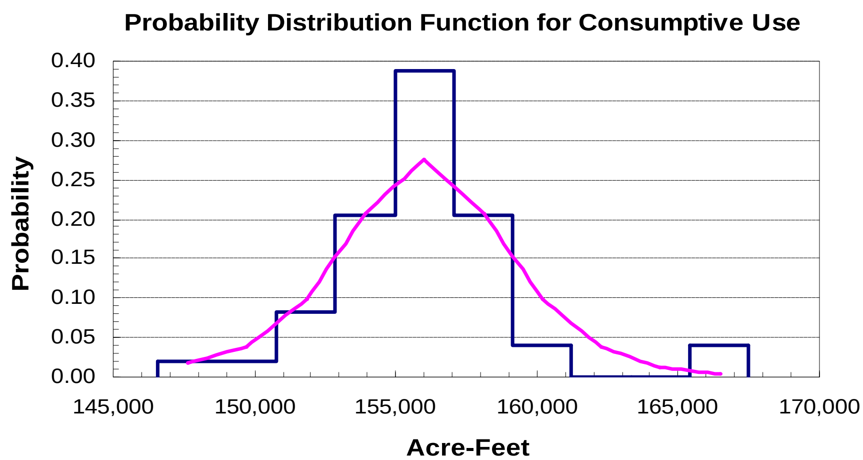
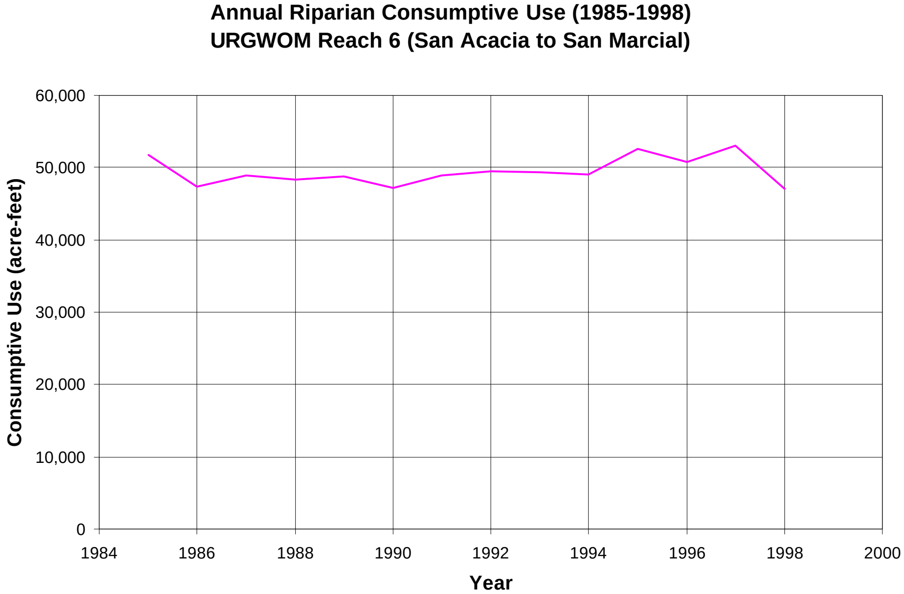
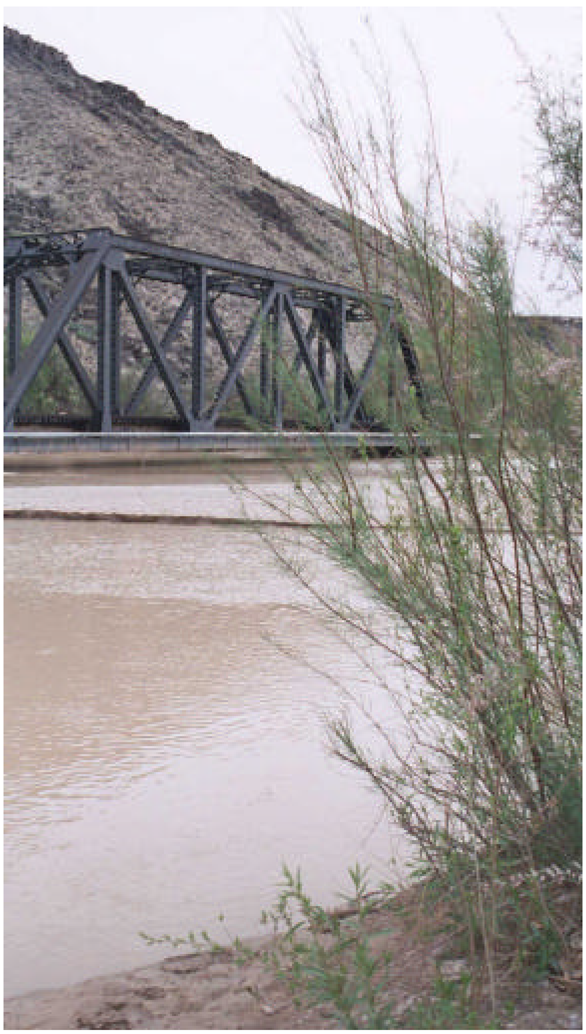


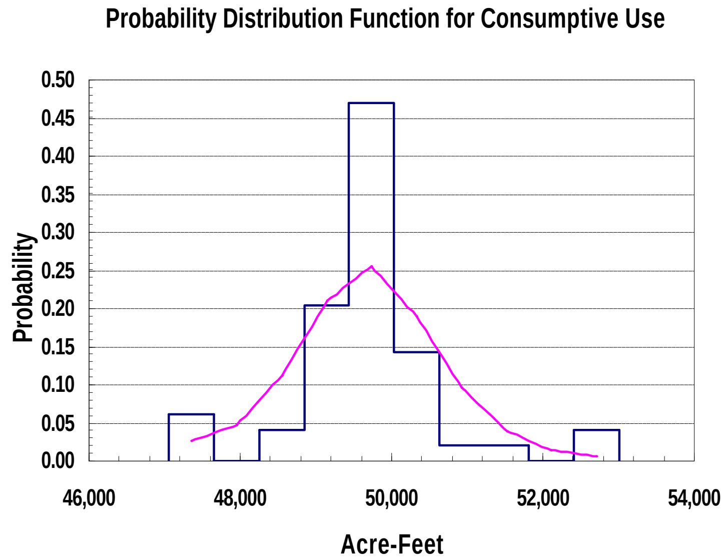
Figure 5.15

Riparian Consumptive Use below San Acacia





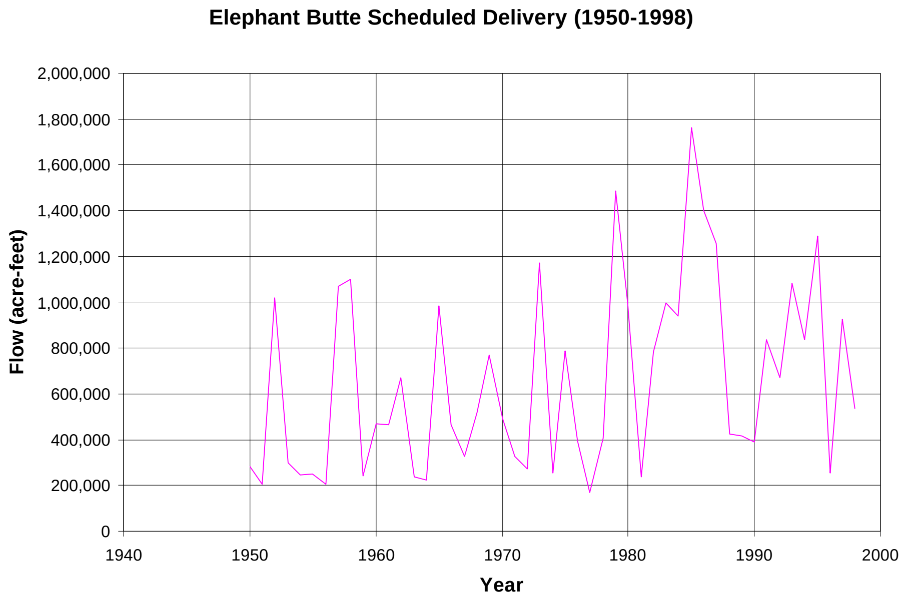
Title: Riparian Consumptive Use below San Acacia
Period of Record: 1985 - present
Data Source: USBR (ET Toolbox website, May 2000)

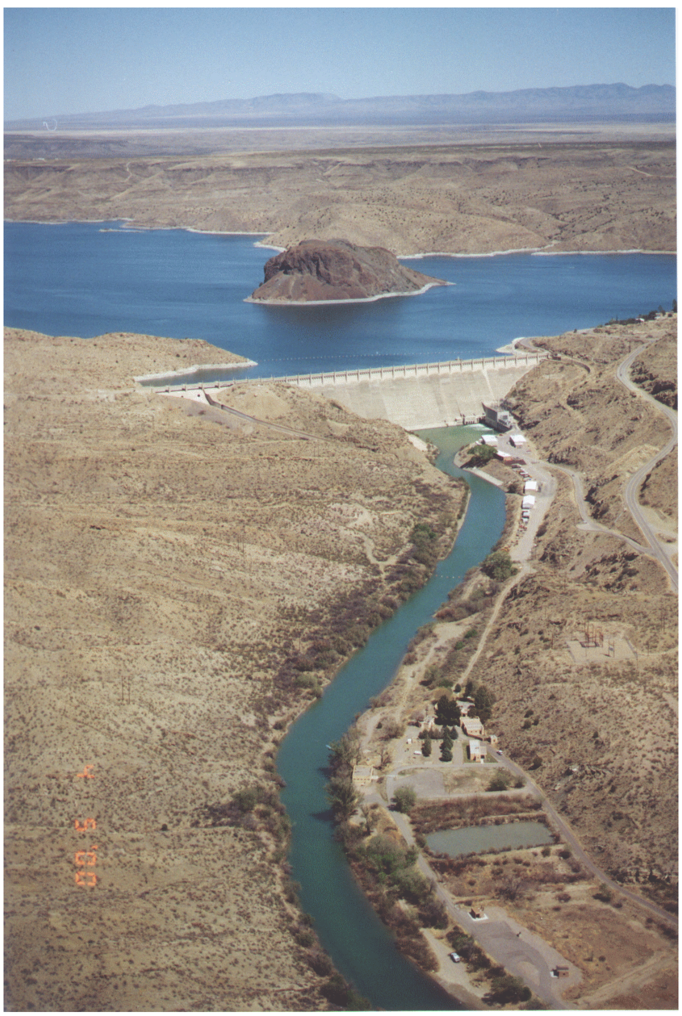


Note: Additional riparian consumptive use between San Marcial and Elephant Butte is assumed for 11,300 acres at a rate of 3.7 acre-feet per acre.

Figure 5.16

Scheduled Delivery at Elephant Butte





Title: Scheduled Delivery at Elephant Butte
Period of Record: 1948 - present
Data Source: Rio Grande Compact Commission
Note: Prior to 1948, alternate accounting procedures were used; the obligation under those procedures is not shown.

Probability Function:
The Rio Grande Compact identifies a specific delivery obligation ("Elephant Butte Scheduled Delivery") to correspond to any specific Otowi Index Supply. Therefore, for the water supply model, the obligation is not based on a probability function; rather, a "look-up" table and interpolation rule is provided to determine the Compact-based obligation for any specified Otowi Index Supply.

Figure 5.17

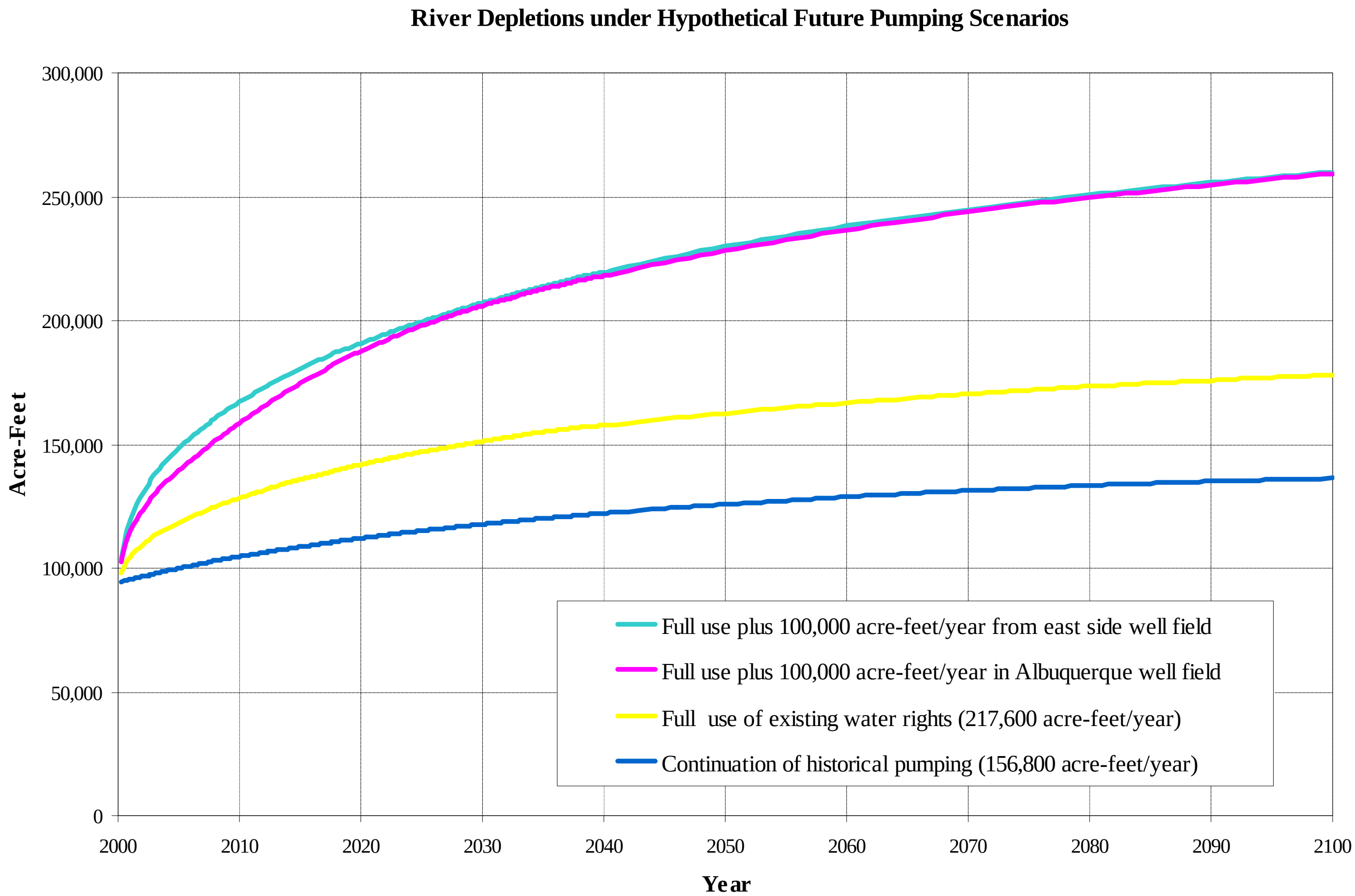
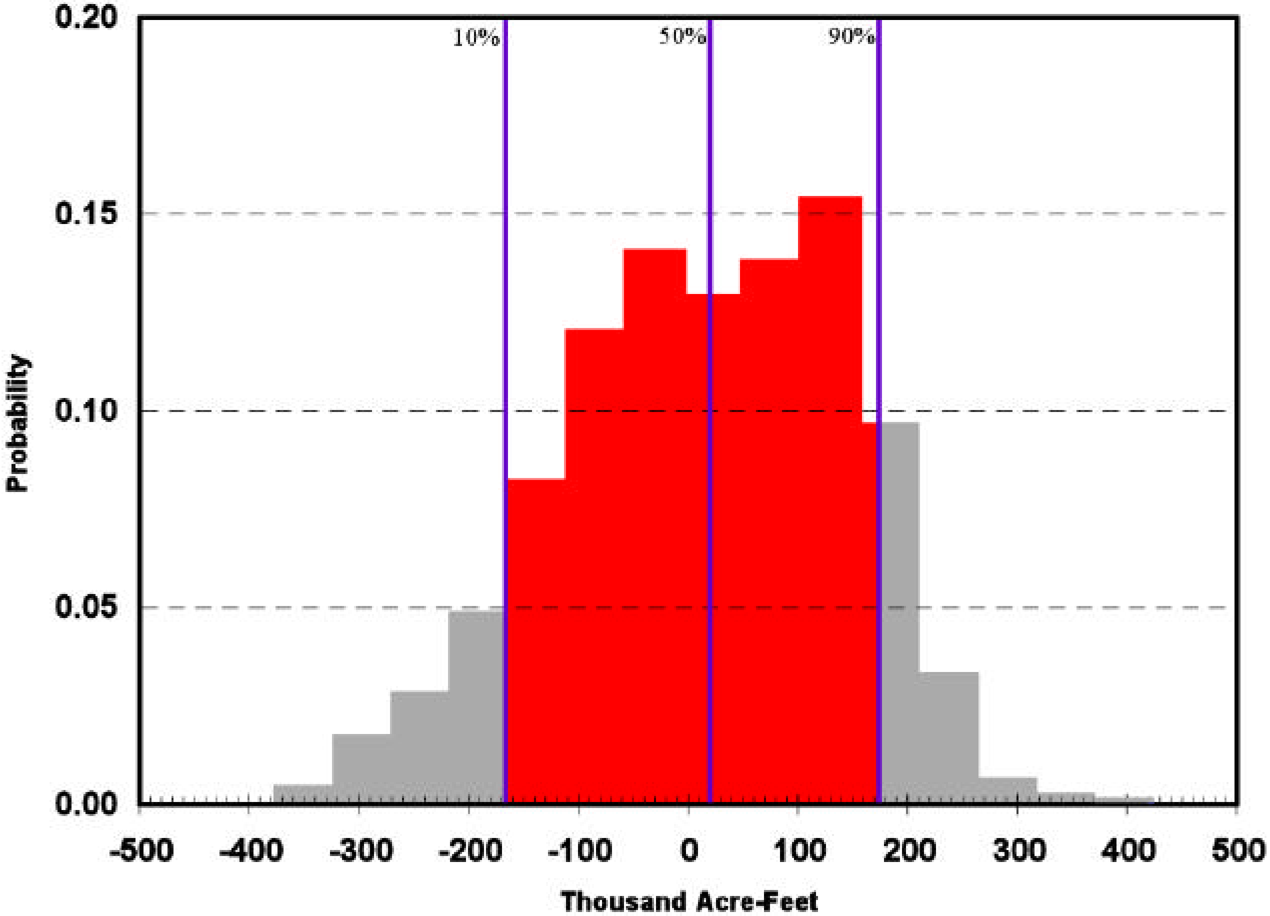

River Depletions under Hypothetical Future Pumping Scenarios
300,000
250,000
200,000
150,000
100,000
50,000
0
Acre-Feet
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Full use plus 100,000 acre-feet/year from east side well field
Full use plus 100,000 acre-feet/year in Albuquerque well field
Full use of existing water rights (217,600 acre-feet/year)
Continuation of historical pumping (156,800 acre-feet/year)

Figure 5.18

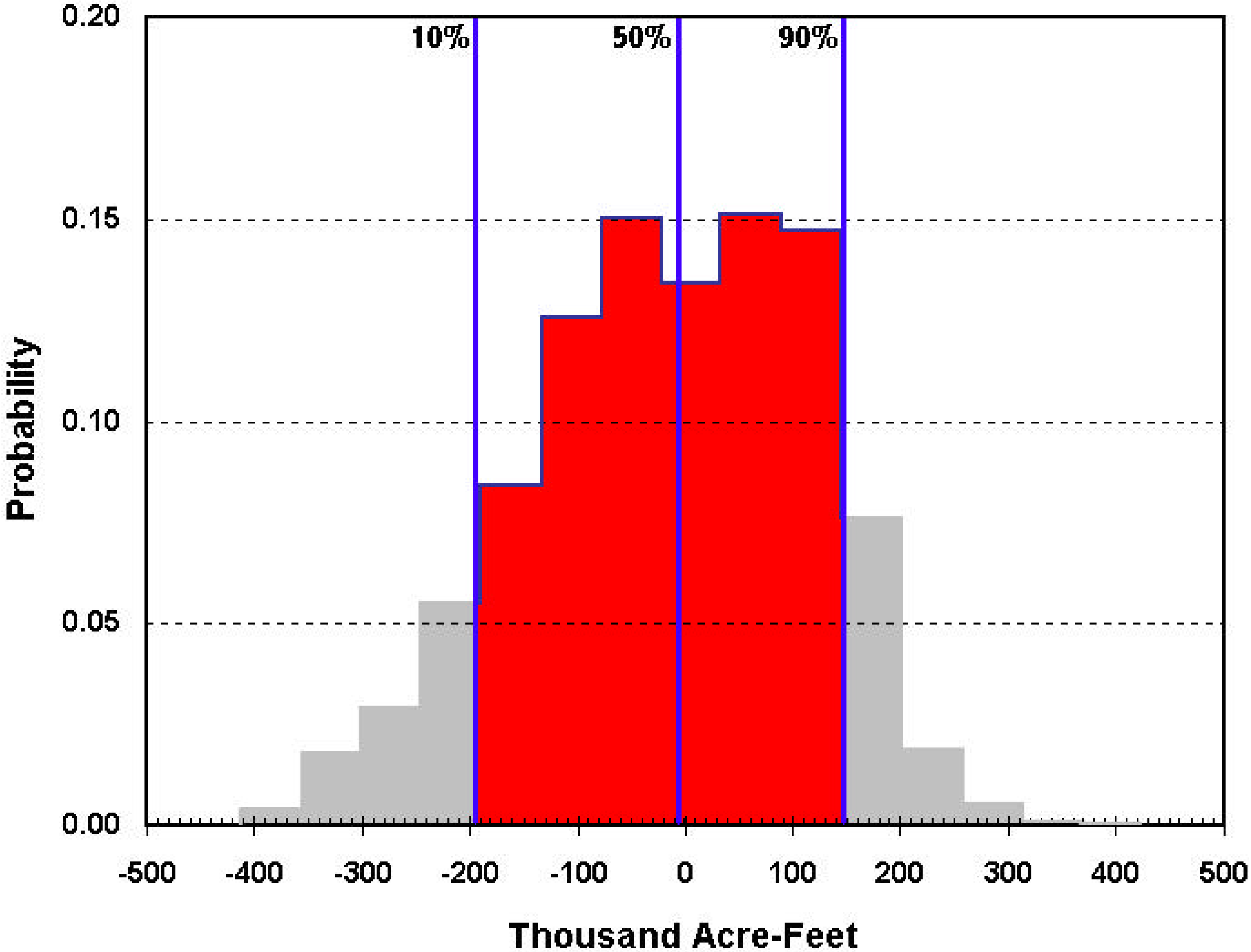
Credit-Debit Probability Distribution
Present Development Condition, Year 2000



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area.

Figure 5.19

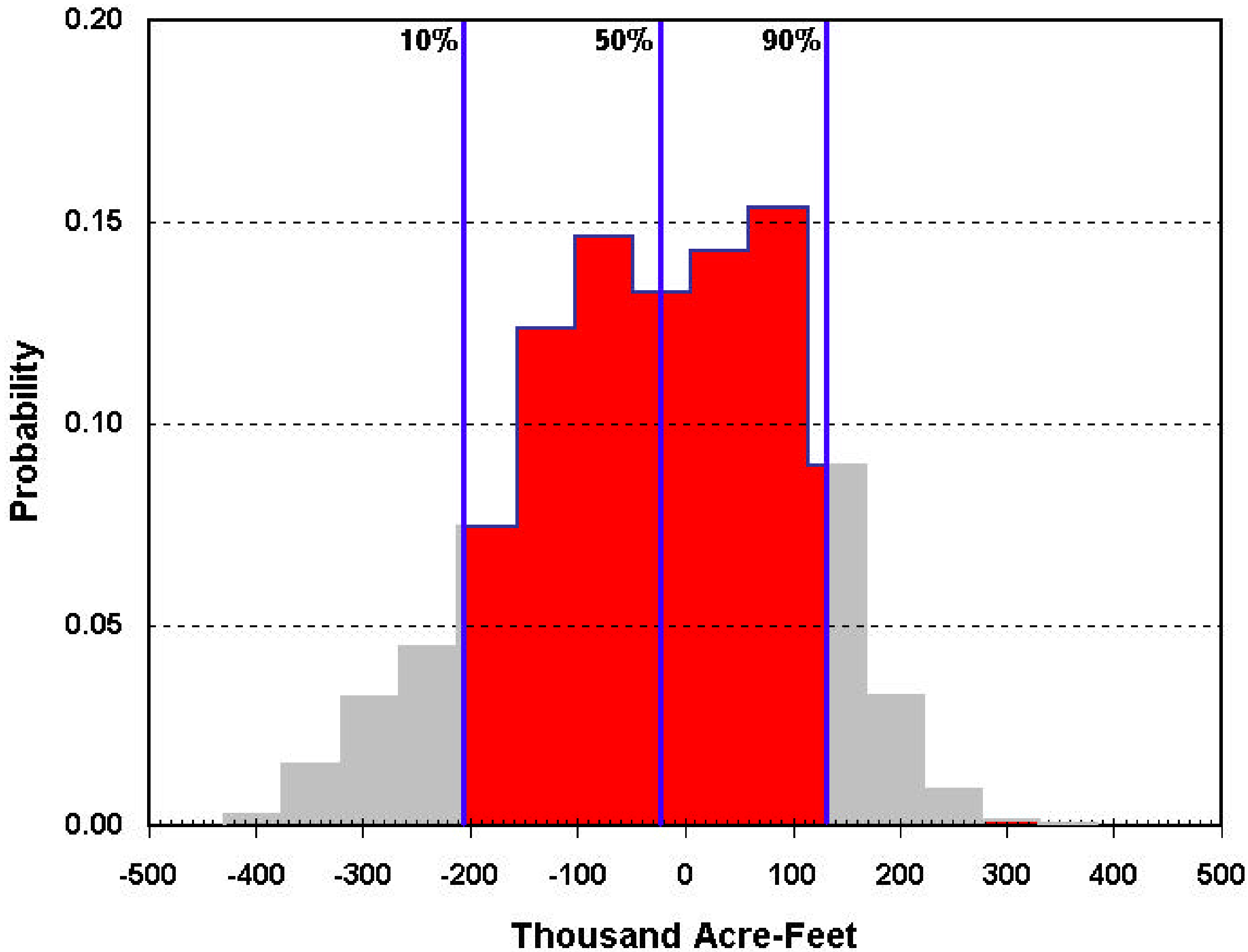
Credit-Debit Probability Distribution
Present Development Condition, Year 2040



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area.

Figure 5.20

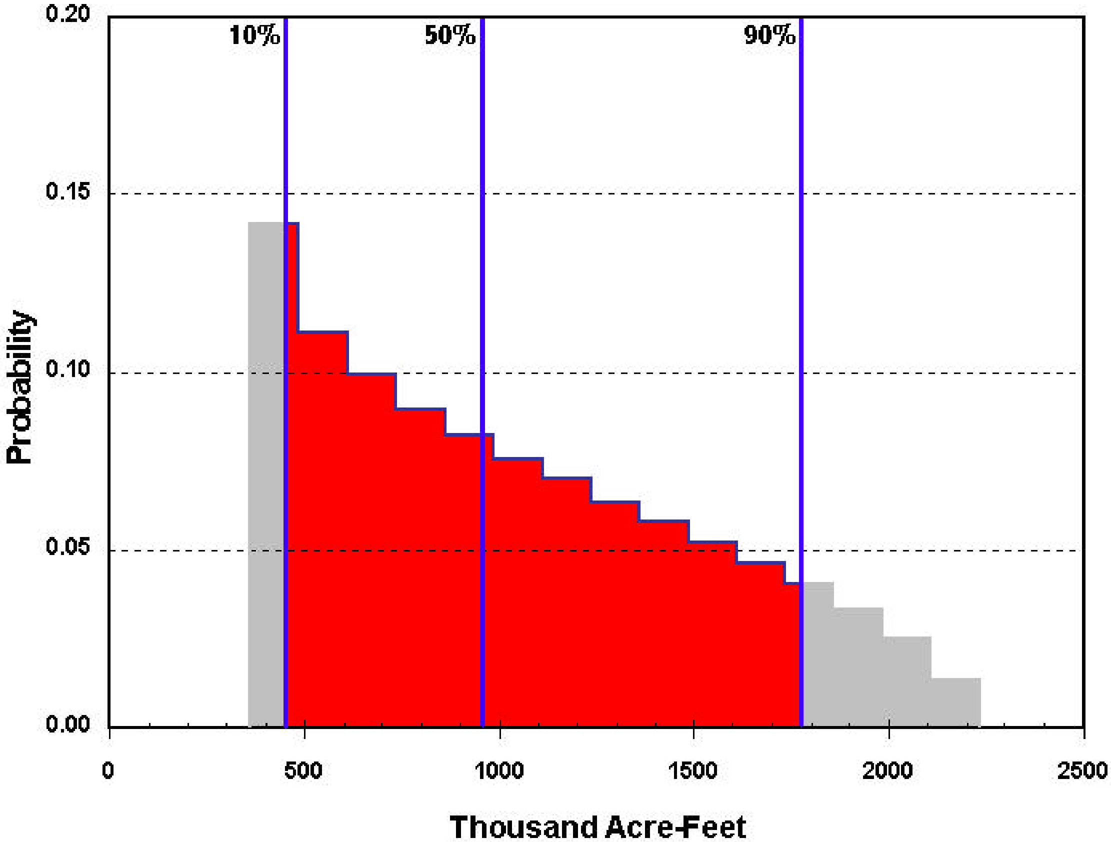
Credit-Debit Probability Distribution
Alternative Development Condition, Year 2040



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area.

Figure 5.21

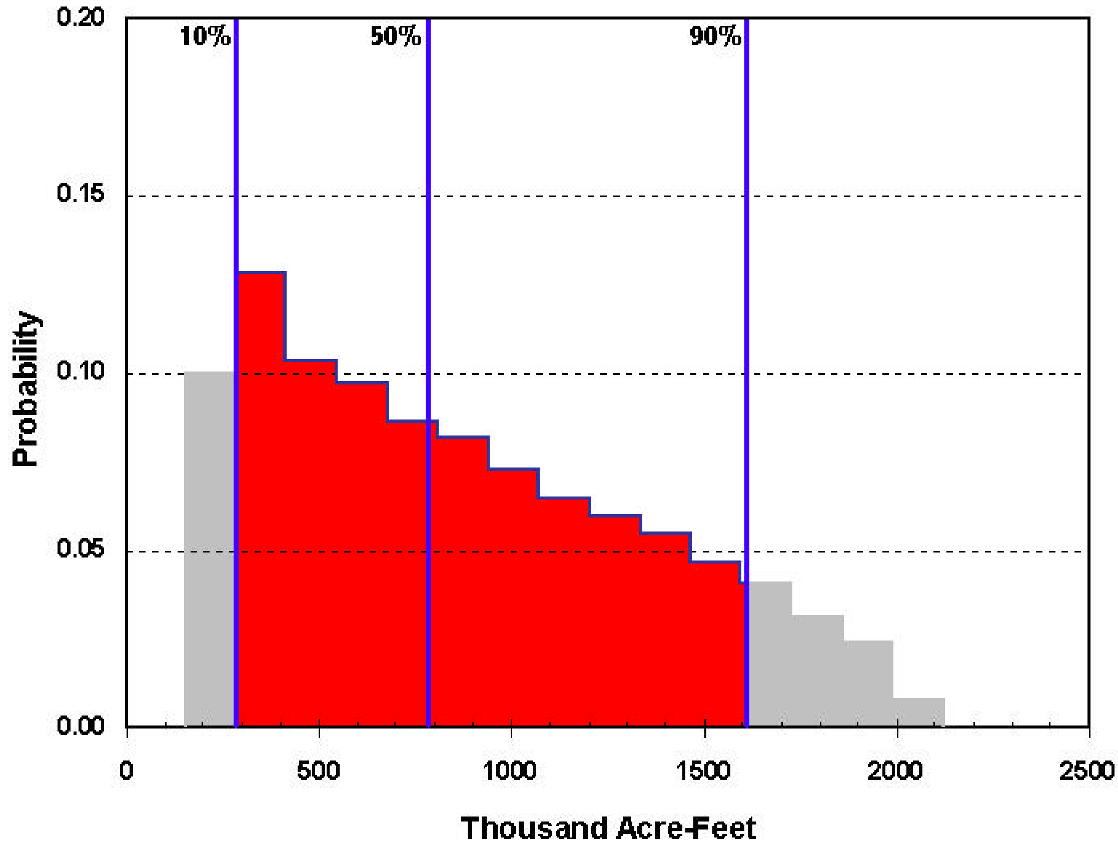
Gross Water Supply at San Felipe
Probability Distribution, Present Condition



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area.

Figure 5.22

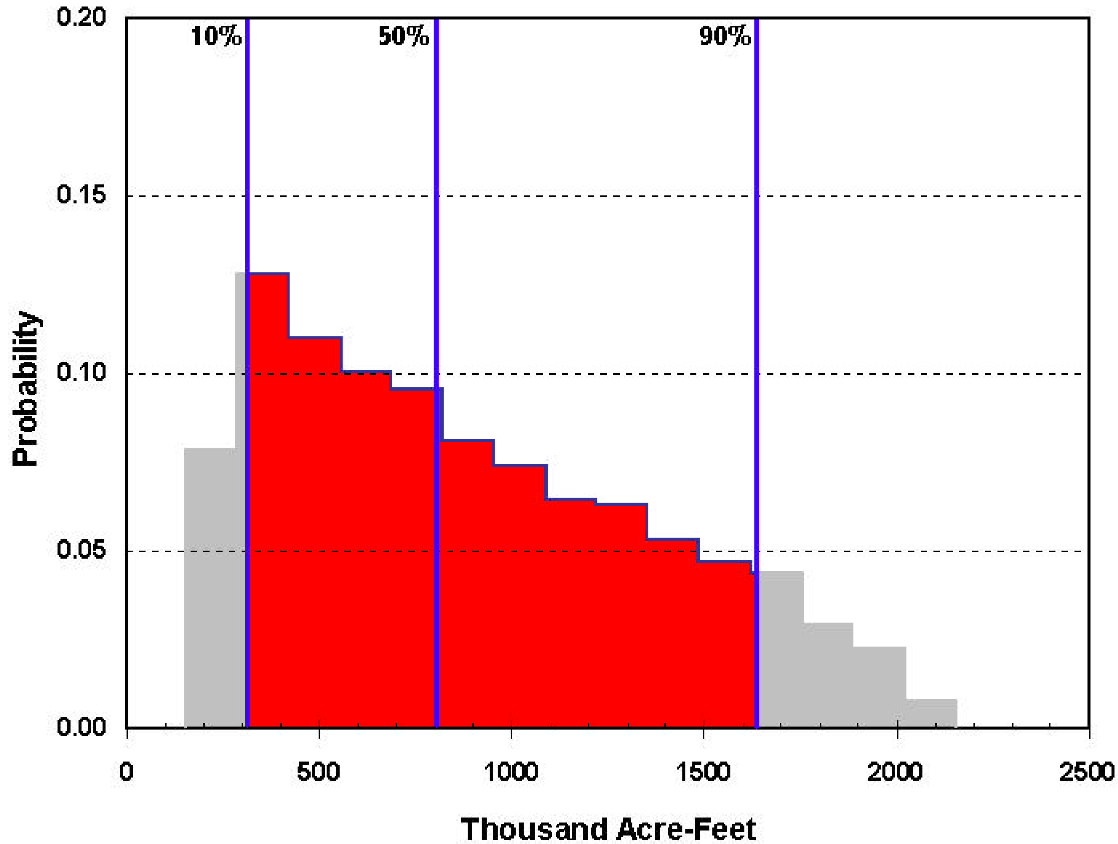
Gross Water Supply at Bernardo
Probability Distribution, Present Condition



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area.

Figure 5.23

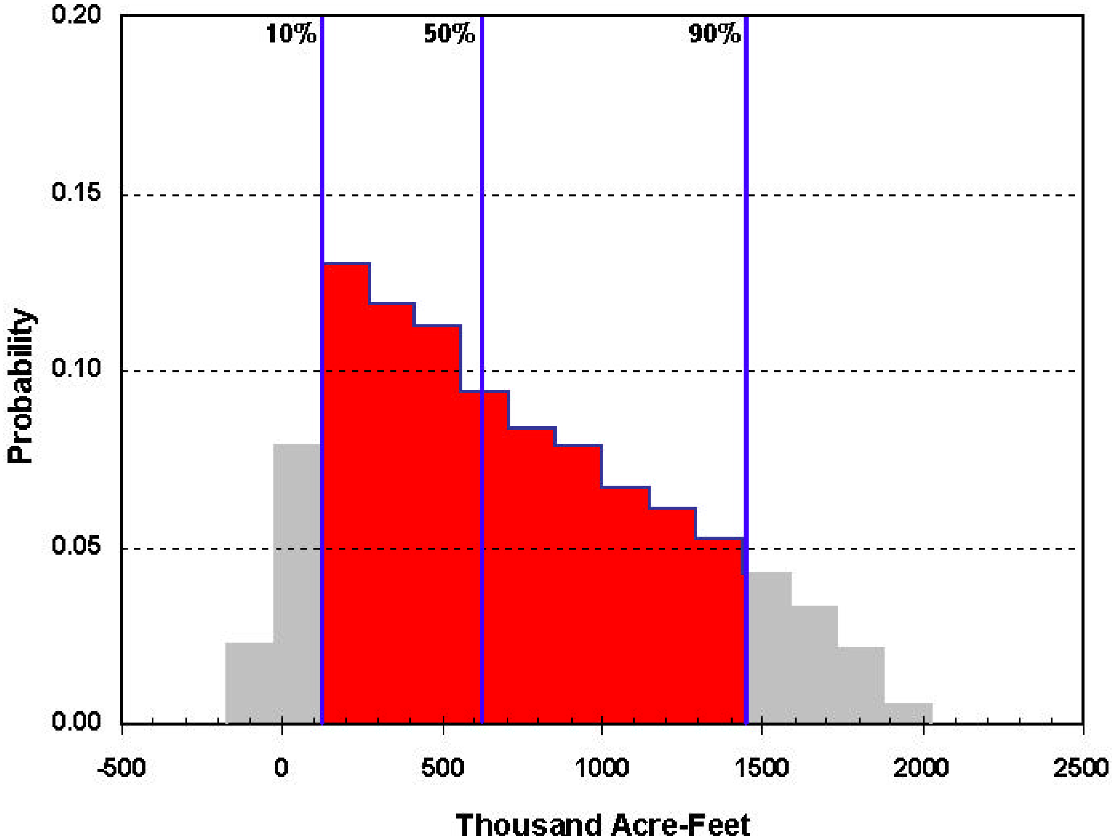
Gross Water Supply at San Acacia
Probability Distribution, Present Condition



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area.

Figure 5.24

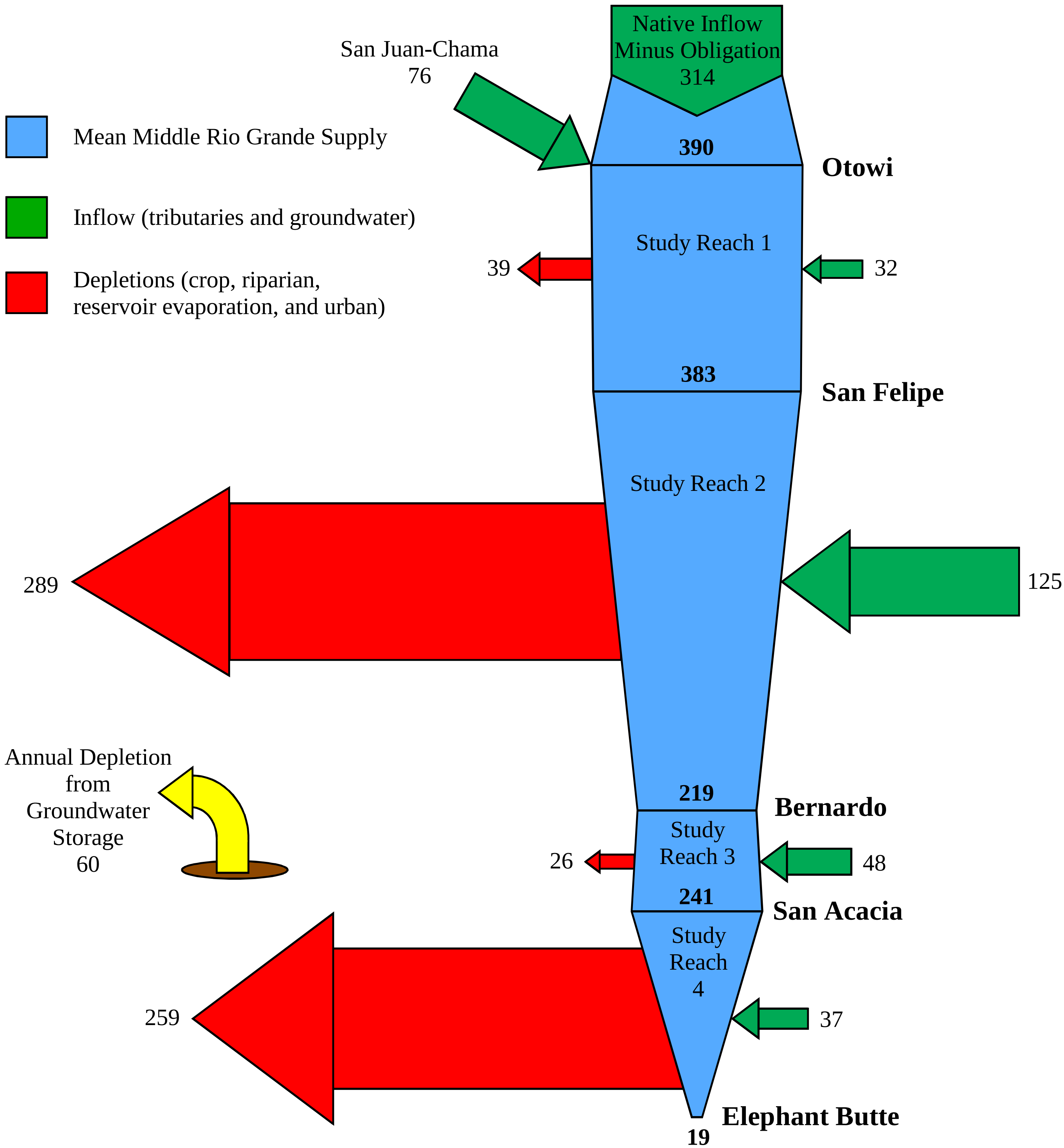
Gross Water Supply at Elephant Butte
Probability Distribution, Present Condition



Some model assumptions may not apply under extreme conditions, particularly affecting results in gray area.

Figure 5.25

Mean Annual Middle Rio Grande Water Supply Under Present Conditions, Excluding Elephant Butte Scheduled Delivery (in thousands of acre-feet)



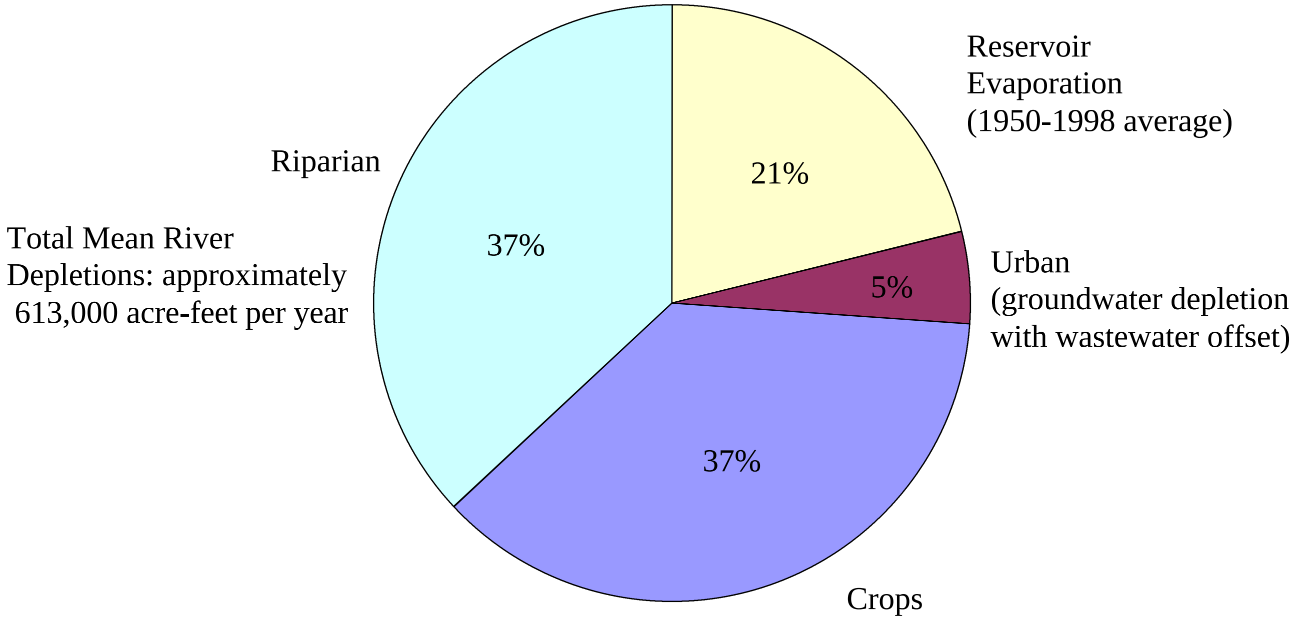
Assumptions:

- 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, 1950-1998
- Rio Grande native inflow and reach flows represent simulated flows minus mean Compact obligation derived from risk model output

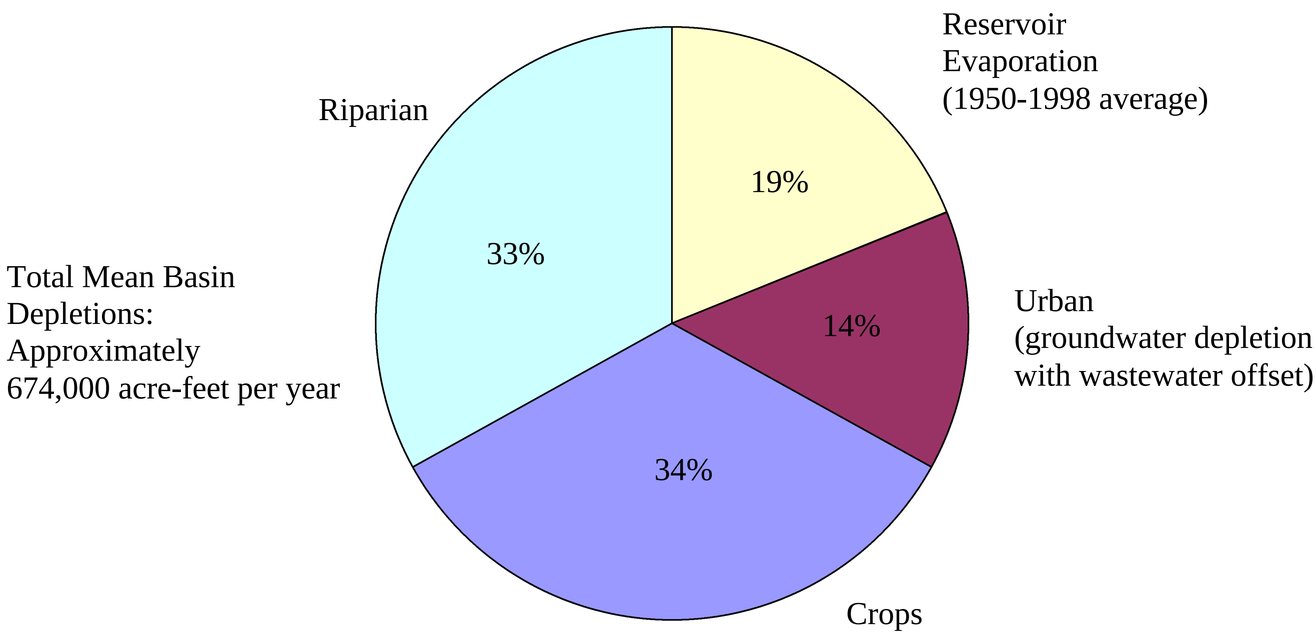
Figure 5.26

Summary of Mean Depletions

a) Mean depletions to river system under present land use and groundwater development conditions



b) Mean total Middle Rio Grande depletions (including depletion from groundwater storage), under present land use and groundwater development conditions



LIST OF TABLES

1.1 Executive Steering Committee

3.1 Metadata Database: Summary of Included Data Sets
3.2 Summary of USGS River, Conveyance and Tributary Gaging Stations
3.3 MRGCD Diversion Gaging Stations, 1974 to 1995
3.4 Summary of MRGCD Water Distribution Data Reported to USBR
3.5 Comparison of MRGCD Reported Net Supply to Composite Diversions
3.6 MRGCD Irrigation System Delivery Efficiency
3.7 Crop and Riparian Acreage
3.8 Crop and Riparian Consumptive Use, Average from 1985-1998
3.9 Riparian and Wetland Community Types from San Marcial to Elephant Butte

4.1 Comparison of Agricultural and Riparian Consumptive Use Estimates in Water Budget Studies

5.1 Structure of Water Budget Model
5.2 Characterization of Water Budget Terms for Basin-Wide Model, Annual Evaluation
5.3 Mean Water Budget Summary by Reach

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
Retired hydrologist, Mike Kernodle
Retired hydrologist, Frank Titus

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

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 3.3

MRGCD Diversion Gaging Stations, 1974 - 1995[1]

Cochiti Division (Cochiti Dam)
(none- gaged by the USGS)

Albuquerque Division (Angostura Diversion Dam)
Albuquerque Main Canal
Atrisco Feeder Canal
Algodones Riverside Drain [2]

Belen Division (Isleta Diversion Dam)
Chical Lateral
Chical Acequia
Belen Highline Canal
Peralta Main Canal
Caique Acequia

Socorro Division (San Acacia Diversion Dam)
(none – Socorro Main Canal gaged by the USGS)

1) This table summarizes MRGCD gages related to measurement of diversions at major headings, with paper records typically spanning the period 1974 to 1995. Additional gaging stations have recently been and continue to be added to the MRGCD network. Other MRGCD gaged stations with some historic record include

Arenal Main Canal:	relates to flow at Central Avenue cross-section
Albuquerque Riverside Drain:	relates to flow at Central Avenue cross-section
Armijo Acequia:	relates to flow at Central Avenue cross-section
Lower San Juan Riverside Drain:	relates to flow at Bernardo cross-section
Corrales Main Canal:	secondary heading in Albuquerque Division
Cochiti	additional gage near tail end of canal

2) Diversions at Angostura are computed by addition of Albuquerque Main and Atrisco Feeder, minus Algodones Riverside Drain. (The drain empties into major diversion canal about 300 yards prior to bifurcation into Albuquerque Main and Atrisco Feeder).

Table 3.4

Summary of MRGCD Water Distribution Data Reported to USBR

Year*	Net Supply (acre-feet)	Operational Spills (acre-feet)	Transportation Losses (acre-feet)	Delivered to Farms (acre-feet)
1976	550,110	179,190	195,310	175,610
1979	547,726	178,586	209,878	159,262
1980	513,465	169,363	205,306	138,796
1981	475,590	154,160	189,740	131,690
1982	434,790	129,580	155,820	149,390
1983	465,330	193,230	101,360	170,740
1984	525,883	171,360	192,920	148,410
1985	476,744	187,860	163,540	117,530
1986	631,228	221,220	203,110	141,620
1987	644,490	176,300	205,670	206,700
1988	614,800	163,020	201,000	179,390
1989	593,307	187,300	198,670	178,680
1990	562,771	166,990	177,310	162,430
1991	554,450	185,900	192,120	176,430
1992	599,890	210,030	204,200	185,660
1993	609,050	213,160	200,970	194,920
1994	606,030	219,120	209,570	177,340
1995	617,530	214,920	203,970	198,640
1996	618,419	216,447	204,079	197,894
1997	653,872	228,855	215,778	209,239
1998	679,266	237,744	224,158	217,365
1999	612,120	214,242	202,000	195,589
Average	**572,130**	**191,754**	**193,476**	**173,333**

*records prior to 1975 and 1977-1978 were not located for this study, but should be available in USBR archived files

NOTE: For comparison purposes, 1936 diversions are reported as 619,989 in Table 72, Rio Grande Joint Investigation, 1938 for 59,159 irrigated acres

Table 3.5

Comparison of MRGCD Reported Net Supply to Composite Diversions

Year	Net Supply Reported to USBR (acre-feet)	Composite MRGCD Diversions (acre-feet)
1976	550,110	
1979	547,726	
1980	513,465	
1981	475,590	
1982	434,790	385,742
1983	465,330	451,266
1984	525,883	470,751
1985	476,744	442,141
1986	631,228	564,762
1987	644,490	549,040
1988	614,800	418,340
1989	593,307	431,551
1990	562,771	517,144
1991	554,450	570,210
1992	599,890	
1993	609,050	600,109
1994	606,030	603,396
1995	617,530	613,071
1996	618,419	590,244
1997	653,872	
1998	679,266	
1999	612,120	

Table 3.6

MRGCD Irrigation System Delivery Efficiency

Year	Net Supply (acre-feet)	Delivered to Farms (acre-feet)	System Delivery Efficiency
1976	550,110	175,610	0.319
1979	547,726	159,262	0.291
1980	513,465	138,796	0.270
1981	475,590	131,690	0.277
1982	434,790	149,390	0.344
1983	465,330	170,740	0.367
1984	525,883	148,410	0.282
1985	476,744	117,530	0.247
1986	631,228	141,620	0.224
1987	644,490	206,700	0.321
1988	614,800	179,390	0.292
1989	593,307	178,680	0.301
1990	562,771	162,430	0.289
1991	554,450	176,430	0.318
1992	599,890	185,660	0.309
1993	609,050	194,920	0.320
1994	606,030	177,340	0.293
1995	617,530	198,640	0.322
1996	618,419	197,894	0.320
1997	653,872	209,239	0.320
1998	679,266	217,365	0.320
1999	612,120	195,589	0.320
Average System Delivery Efficiency:			**0.303**

Table 3.7

Crop and Riparian Acreage[1]

Reach	URGWOM Reach Number	Crop Acres	Riparian Acres
Cochiti to San Felipe	1	2,869	5,146
Jemez River	2		1,971
San Felipe to Central Avenue	3	7,085	8,388
Central Avenue to Bernardo	4	38,389	15,931
Bernardo to San Acacia	5	438	7,298
San Acacia to San Marcial	6	14,770	13,323
TOTAL		63,551	52,057

[1] Acreages from USBR ET Toolbox, based on 1992 LUTA coverage for URGWOM reaches 1 - 5. Riparian acres for reach 6 estimated from USBR/Forest Service 1999 aerial photographs; crop acres for reach 6 estimated by USBR from MRGCD crop reports and Fish and Wildlife crop reports (Al Brower, personal communication, May 4, 2000)

Table 3.8

Crop and Riparian Consumptive Use, Average from 1985 - 1998

Reach	URGWOM Reach Number	Crop Consumptive Use (acre-feet/year)	Riparian Consumptive Use (acre-feet/year)
Cochiti to San Acacia			
Cochiti to San Felipe	1	10,221	20,529
Jemez River	2	0	9,624
San Felipe to Central Avenue	3	27,468	33,812
Central Avenue to Bernardo	4	152,396	63,921
Bernardo to San Acacia	5	1,491	27,191
Total above San Acacia	1 - 5	191,576	155,078
San Acacia to Elephant Butte			
San Acacia to San Marcial	6	56,520	49,452
San Marcial to Elephant Butte			41,971
TOTAL		248,096	246,500

Note: Consumptive Use for URGWOM reaches 1 through 6 derived from ET Toolbox. Consumptive use for San Marcial to Elephant Butte estimated assuming 11,313 acres (Table 3.9) and consumptive use factor based on San Acacia to San Marcial of 3.7 acre-feet per acre. These estimates do not reflect adjustment for effective precipitation.

Table 3.9

Riparian and Wetland Community Types from San Marcial to Elephant Butte

Plant Community	Total Acreage
Mature Cottonwood Forest	358
Mature Willow Forest	84
Mid-aged cottonwood-willow or saltcedar-Russian Olive Stands	415
Monotypic saltcedar stands	2,385
Young successional stage stands	2,113
Emergent marsh	427
Open water	2,870
Dead flooded saltcedar	1,118
Wet meadow	1,543
Total	11,313

[1] Vegetation acreage represent provisional estimates provided by Larry White, USBR, 4-21-2000.

Table 4.1

Comparison of Agricultural and Riparian Consumptive Use Estimates in Water Budget Studies

	Agricultural		Riparian and Open Water		
	above San Acacia (acre-feet)	below San Acacia (acre-feet)	above San Acacia (acre-feet)	San Acacia to San Marcial (acre-feet)	San Marcial to Elephant Butte[f] (acre-feet)
RGJI, 1938 (1936-1937 Condition)	139,300[d]	20,700[d]	326,334	185,088	114,796[d]
Thorn, 1993 (1974-1992 Average)	120,900		146,500		
Gould, 1997 (1993)	98,600		205,400[a]		
MRG Assembly, 1999 (1972-1997 Average)	100,000	[c]	195,000[b]	[c]	
USBR ET Toolbox, 2000 (1985-1998 Average)	191,600[d]	56,500[d]	155,000[d]	49,400[d]	41,858[d]
Wilson, 1997 (1995)	139,700 (total)[e]				

[a] Consists of 135,600 riparian and 69,800 open water

[b] Includes 135,000 riparian and 60,000 open water for reach Otowi to San Acacia

[c] Assumes total 100,000 for both agricultural and riparian/open water below San Acacia (excluding Elephant Butte evaporation)

[d] Not adjusted for effective precipitation

[e] Total project depletion for surface water (114,133 acre-feet) and groundwater (25,208 acre-feet) and non-MRGCD (323 acre-feet) for Sandoval, Bernalillo, Valencia and Socorro counties

[f] Reservoir evaporation not included

Table 5.1

Structure of Water Budget Model

Inflow Terms

Otowi Index Supply
San Juan-Chama Water
Santa Fe River
Galisteo Creek
Jemez River
AMAFCA Inflow
Rio Puerco
Rio Salado
Ungaged tributary inflow
Groundwater inflow
M&I wastewater return flow

Outflow Terms

Reservoir evaporation
Irrigation consumptive use
Riparian consumptive use
Outflow to groundwater

Table 5.2

Characterization of Water Budget Terms for Basin-Wide Water Supply Model, Annual Evaluation

Water Budget Term	PDF or Value	Variable Type[1], Comment
Gaged (Computed) Inflow		
Otowi Index Supply	Beta distribution	Independent
San Juan-Chama Water	75,855 af/y	Static
Galisteo Creek	Gamma distribution	Independent
Jemez River	Beta distribution	Dependent (Otowi Index)
AMAFCA Channels	Uniform	Independent
Rio Puerco	Pearson VI	Independent
Rio Salado	Pearson VI	Dependent (Rio Puerco)
Ungaged Tributary Inflow		
Elephant Butte Unit	Pearson VI	Dependent (Rio Salado)
Eastside	Pearson VI	Dependent (Rio Salado)
Base Adjusted Groundwater Inflow[2]		
Above San Acacia	91,589 af/y	Static
Below San Acacia	16,500 af/y	Static
Rio Grande Compact Obligation		
	Table look-up	Dependent (Otowi Index)
Depletions[3]		
Crop Consumptive Use	Weibull	Independent
Riparian Consumptive Use	Logistic	Independent
(Effective Precipitation)	-38,535 af/y	Independent
Cochiti Evaporation	Loglogistic	Independent
Elephant Butte Evaporation	Histogram – record	Dependent (Otowi Index)
Groundwater, Santa Fe	2,400 af/y	Static
Groundwater, above SA	94,360 af/y	Present condition, year 2000
	122,158 af/y	Present condition, year 2040
	218,076 af/y	Alternative condition, 2040
Groundwater, below SA	2,507 af/y	Static
(Wastewater Discharge)	-68,941 af/y	Present condition
	-149,315 af/y	Alternative condition (50% of increased withdrawals plus present value)

1 Variable Type: Independent variables are selected based on value or PDF. If noted as dependent, correlation to noted variable was characterized.

2 Base adjusted groundwater inflow represents net stream-aquifer exchanges under hypothetical conditions of no pumping, no irrigation recharge and no riparian evapotranspiration.

3 Depletion terms noted in parentheses are negative values that reduce the actual depletion from an associated term. (Wastewater returns are associated with groundwater pumping and reduce the effective depletion from groundwater use; and, effective precipitation on crop and riparian acres reduces these consumptive uses.)

Table 5.3

Mean Annual Water Budget Summary by Reach

Mean Annual Values in acre-feet/year	REACH				
	1	2	3	4	Total
	Otowi to San Felipe	San Felipe to Bernardo	Bernardo to San Acacia	San Acacia to Elephant Butte	Otowi to Elephant Butte
Mainstem Inflow	964	1033	869	892	964
San Juan-Chama Water	76	0	0	0	76
Tributary Inflow	14	61	38	20	133
Adj. Base Groundwater Inflow[1]	18	64	10	17	109
TOTAL INFLOW	**1073**	**1158**	**918**	**928**	**1282**
Crop Depletions	10	180	1	57	248
Riparian Depletions	21	107	27	88	243
(Effective Precipitation)[2]	-3	-24	-3	-9	-39
Reservoir Evaporation	8	0	0	123	131
Groundwater Depletion	3	94	0	3	100
(Wastewater Returns)	0	-68	0	-1	-69
TOTAL DEPLETIONS	**39**	**289**	**26**	**259**	**613**
REACH OUTFLOW	**1033**	**869**	**891**	**669**	**669**
SCHEDULED DELIVERY[3]	**650**	**650**	**650**	**650**	**650**
MEAN AVAILABLE SUPPLY[4]	**383**	**219**	**241**	**19**	**19**

1 Adjusted Base groundwater inflow represents groundwater inflow under base conditions of no pumping, no irrigation recharge and no evapotranspiration. Reductions to this base inflow are independently derived and subtracted from water budget as depletions.
2 Effective precipitation is estimated as a reduction to crop and riparian consumptive use for reaches from Cochiti to San Marcial. (Effective precipitation is included directly in consumptive use term below San Marcial.)
3 Scheduled delivery is the mean value of risk model output from 10,000 simulations of Otowi Index Flow according to climate-based probability distribution function.
4 Mean Available Supply is the supply at reach endpoints after subtracting the scheduled delivery.

APPENDIX A
Metadata Database

Table of Contents

Page
Introduction……………………………………………………………………………6
Metadata……………………………………………………………………………….6
Water Resource Data Types……………..……………………….……….……...6
Data and Metadata Attributes…………………………………………………7
Water Resources Data and Metadata Sources………………………………...….7
Metadata Database
Metadata Standards……………..…………………………………………………..8
Structure………..……………………………………………………………....…8
Tools…….…..…………………………………………………………………..….9
FGDC Metadata Elements…………..……………………….…………………..9
Summary of Included Datasets……..……………………..……………….....12

Metadata Records

Spatial Data Sets
USGS Middle Rio Grande Study Area Boundary

New Mexico Shaded Relief Map

1:100,000 BLM PLSS Map of New Mexico

New Mexico County Boundaries

New Mexico Cities Map

MRGCD Property Boundaries
Property Boundaries, Middle Rio Grande Area (MRGCD), New Mexico

Federal Land Ownership for Lands in the Middle Rio Grande Region

Digital Geologic Map of the State of New Mexico – River Alluvium

Hydrologic Unit Codes (HUC) for the State of New Mexico

Digital Hydrologic Reach Map of New Mexico

Key USGS Gaging Stations - Middle Rio Grande Water Supply Study

Hydrography Coverages
Hydrography for New Mexico (line)

Hydrography for New Mexico (polygon)
Hydrography for Cochiti Division
Hydrography for Albuquerque Division
Hydrography for Belen Division
Hydrography for Socorro Division
Hydrography for San Marcial Sub-Division
Hydrography for Sandoval County
Hydrography for Bernalillo County
Hydrography of Valencia County
Hydrography for Socorro County

Vegetation Coverages

Vegetation Classification for Cochiti Division
Vegetation Classification for Albuquerque Division
Vegetation Classification for Belen Division
Vegetation Classification for Socorro Division
Vegetation Classification for San Marcial Sub-Division
Vegetation Classification for Sandoval County
Vegetation Classification for Bernalillo County
Vegetation Classification for Valencia County
Vegetation Classification for Socorro County

Transportation Coverages

New Mexico Transportation
Transportation for Cochiti Division
Transportation for Albuquerque Division
Transportation for Belen Division
Transportation for Socorro Division
Transportation for San Marcial Sub-Division

Time Series Data Sets

USGS Gaging Stations

USGS Annual Peak Discharge at 08331700 - Abo Arroyo Trib. Near Scholle, N. Mex
USGS Annual Peak Discharge at 08355200 - Nogal Arroyo Fwy Nr Socorro, Nm
USGS Daily Mean Discharge at 08313000 - Rio Grande At Otowi Bridge, Nm
USGS Daily Mean Discharge at 08313500 - Cochiti East Side Main Canal At Cochiti, N. Mex
USGS Daily Mean Discharge at 08314000 - Sili Main Canal (At Head) At Cochiti, N. Mex.
USGS Daily Mean Discharge at 08317200 - Santa Fe River above Cochiti Lake, NM
USGS Daily Mean Discharge at 08317400 - Rio Grande Below Cochiti Dam, N. Mex.

USGS Daily Mean Discharge at 08317950 - Galisteo Creek Below Galisteo Dam, Nm
USGS Daily Mean Discharge at 08319000 - Rio Grande At San Felipe, Nm
USGS Daily Mean Discharge at 08329000 - Jemez River Below Jemez Canyon Dam,Nm
USGS Daily Mean Discharge at 08329500 - Rio Grande Near Bernalillo, N. Mex.
USGS Daily Mean Discharge at 08329900 - N Floodway Channel Nr Alameda N M
USGS Daily Mean Discharge at 08329928 - Rio Grande Nr Alameda, Nm
USGS Daily Mean Discharge at 08329930 - Corrales Riverside Drain Nr Corrales, Nm
USGS Daily Mean Discharge at 08329931 - Corrales Main Canal Outfall At Albuquerque, Nm
USGS Daily Mean Discharge at 08330000 - Rio Grande At Albuquerque, Nm
USGS Daily Mean Discharge at 08330150 - Rio Grande At Rio Bravo Bridge Near Albuquerque,Nm
USGS Daily Mean Discharge at 08330600 - Tijeras Arroyo Nr Albuquerque, N. Mex.
USGS Daily Mean Discharge at 08330775 - South Div Channel Abv Tijeras Arroyo Nr Albq, Nm
USGS Daily Mean Discharge at 08330800 - Tijeras Arroyo Bl S Div Inlet Nr Albuquerque, Nm
USGS Daily Mean Discharge at 08331000 - Rio Grande At Isleta, Nm
USGS Daily Mean Discharge at 08331100 - Belen Highline Canal Trib Nr Los Lunas, Nm
USGS Daily Mean Discharge at 08331500 - Rio Grande Near Belen, N. Mex.
USGS Daily Mean Discharge at 08331990 - Rio Grande Conveyance Channel Near Bernardo, Nm
USGS Daily Mean Discharge at 08332000 - Rio Grande Nr Bernardo, N. M.
USGS Daily Mean Discharge at 08332010 - Rio Grande Floodway Near Bernardo, Nm
USGS Daily Mean Discharge at 08332030 - Lower San Juan Riverside Drain, NM
USGS Daily Mean Discharge at 08332050 - Bernardo Interior Drain Nr Bernardo,N. M.
USGS Daily Mean Discharge at 08353000 - Rio Puerco Near Bernardo,Nm
USGS Daily Mean Discharge at 08354000 - Rio Salado Near San Acacia,Nm
USGS Daily Mean Discharge at 08354500 - Socorro Main Canal North At San Acacia, Nm

- USGS Daily Mean Discharge at 08354800 - Rio Grande Conveyance Channel At San Acacia, Nm
- USGS Daily Mean Discharge at 08354900 - Rio Grande Floodway At San Acacia, Nm
- USGS Daily Mean Discharge at 08355000 - Rio Grande At San Acacia N M
- USGS Daily Mean Discharge at 08355300 - Arroyo De La Matanza At Socorro N M
- USGS Daily Mean Discharge at 08355500 - Rio Grande At San Antonio N M
- USGS Daily Mean Discharge at 08356000 - Socorro Main C S Near San Antonio, N. Mex.
- USGS Daily Mean Discharge at 08356500 - San Antonio Riverside Drain Nr San Antonio, N M
- USGS Daily Mean Discharge at 08357000 - Elmendorf Int Dr Nr San Antonio N M
- USGS Daily Mean Discharge at 08357500 - San Antonio Riverside Drain Nr San Marcial, N M
- USGS Daily Mean Discharge at 08358300 - Rio Grande Conveyance Channel At San Marcial, Nm
- USGS Daily Mean Discharge at 08358400 - Rio Grande Floodway At San Marcial, Nm
- USGS Daily Mean Discharge at 08358500 - Rio Grande At San Marcial N M
- USGS Daily Mean Discharge at 08358550 - Milligan Gulch Nr San Marcial N M
- USGS Daily Mean Discharge at 08359500 - Rio Grande At Narrows In Elephant Butte Res N M
- USGS Daily Mean Discharge at 08361000 - Rio Grande Below Elephant Butte Dam, Nm

Middle Rio Grande Conservancy District Gaging Stations

- MRGCD Daily Mean Flow at Algodones Riverside Drain
- MRGCD Daily Mean Flow at Albuquerque Main Canal
- MRGCD Daily Mean Flow at Albuquerque Riverside Drain
- MRGCD Daily Mean Flow at Atrisco Feeder
- MRGCD Daily Mean Flow at Chical Lateral
- MRGCD Daily Mean Flow at Chical Acequia
- MRGCD Daily Mean Flow at Belen Highline Canal
- MRGCD Daily Mean Flow at Peralta Main Canal
- MRGCD Daily Mean Flow at Cacique Acequia
- MRGCD Daily Mean Flow at Arenal Main Canal
- MRGCD Daily Mean Flow at Armijo Acequia
- MRGCD Daily Mean Flow at Corrales Main Canal
- MRGCD Daily Mean Flow at Lower San Juan Riverside Drain

Wastewater Discharge
- Wastewater Discharge for Bernalillo
- Wastewater Discharge for Rio Rancho
- Wastewater Discharge for Albuquerque
- Wastewater Discharge for Los Lunas
- Wastewater Discharge for Belen
- Wastewater Discharge for Socorro

Reservoir Evaporation
- Evaporation from Cochiti Lake
- Evaporation from Elephant Butte Reservoir

Daily Consumptive Use Estimates for Reaches 1-5

Daily Consumptive Use Estimates for Reach 6

USGS Reservoir Contents
- USGS Reservoir Contents for 08317300 - Cochiti Lake Near Cochiti Pueblo, NM
- USGS Reservoir Contents for 8360500 - Elephant Butte Reservoir at Elephant Butte, NM

Albuquerque Airport Total Precipitation
- Albuquerque WSFO Airport, New Mexico Historical Monthly Total Precipitation

Rio Grande Compact Data

Administrative Groundwater Model for the Middle Rio Grande Basin

Introduction

The purpose of the Middle Rio Grande Water Supply Study is to prepare a quantitative description of the conjunctive-use groundwater and surface-water supply available to the Middle Rio Grande from Cochiti Reservoir to Elephant Butte Reservoir, under the constraints of the Rio Grande Compact and the upstream Rio Grande basin water use within New Mexico. This study is based on analysis of surface-water and groundwater data.

As part of this work, available water resource data sets with potential relevance to the study have been catalogued. These water resource data sets have been developed over a period of many years by federal, state, regional and municipal governmental entities, and others. A metadata database has been constructed to document background information about the water resource data sets. This information, or, “data about data”, includes descriptions of the content, quality, condition and other appropriate characteristics of the data. The metadata database serves as a reference for this study and subsequent studies. This compilation will provide information to investigators evaluating the suitability of diverse water resource data sets to their particular needs.

Metadata

Metadata are data about data. They provide the description of a particular data set that identifies it’s contents and usefulness: metadata answer the questions of who, what, when, where, why, and how about every component of the data set being documented. Additionally, metadata maintains the integrity of the data set as it is utilized and provides a reference as to the quality and suitability of the data set.

Water Resource Data Types

Water resource data sets can be categorized into several major groups. These include groundwater data, surface water conveyance data (rivers, canals, drains), water use data (surface and groundwater; agricultural, riparian, municipal, industrial), and reservoir data (storage, evaporation). Within each of these groups, two types of datasets will be encountered: spatial data and time series data. Spatial data consists of geographic data that is generally utilized by a Geographical Information System (GIS) such as ArcInfo or ArcView but can also exist as basic maps in a variety of formats. Time series data is any data that measures a specific value over time. Each data set includes several intrinsic attributes, in addition to data characteristics related to quality, condition and source.

Data and Metadata Attributes

Data attributes typical of time series water resource data include the station location, measured value, date of measurement, unit of measurement, measurement device and comments which may have been made at the time of measurement describing conditions encountered. Typical data attributes of spatial data include boundaries, waterways, vegetation, roads, geology and points of interest.

The information conveyed in each type of dataset is different and, therefore, the associated metadata is different. Spatial metadata consists of information that is relevant to executing and understanding the specific program file or coverage. For example, information on vectors, latitude and longitude resolution, and ellipsoids would be included. Time series metadata includes information such as the entity being measured and time period and frequency of content, unit of measurement, measurement device and accuracy.

Despite the differences in information, the two types of datasets share many of the same metadata attributes. Metadata attributes relevant to both spatial and time series water resource data sets for the purpose of this and subsequent water supply studies include identification information (title, area covered, keywords, purpose, access), data quality information, spatial reference information, entity and attribute information, distribution information and reference information.

Water Resources Data and Metadata Sources

Data sources for water resource datasets are diverse. For the Middle Rio Grande region, key sources of original data are the U.S. Geological Survey, the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, the Environmental Protection Agency, the Middle Rio Grande Conservancy District, and the City of Albuquerque. In addition to these entities, data has been developed by numerous private parties, local governing bodies and universities. Data has been developed by Indian pueblos; however, unless published, these data are considered confidential by the pueblos and are not available to this study.

The formalization of metadata into a standardized reporting format is a relatively new concept. Many data sources do not maintain formal metadata, and metadata can only be partially reconstructed from available information. For recent data sets, metadata is more widely available. Metadata is noticeably lacking for historical data, especially for time series data. Data sets spanning long periods of record have been collected under differing conditions, with different levels of accuracy and precision making the quality of the data difficult to determine. In some instances, generalized metadata are applied to multiple and diverse data sets with the result of metadata limited in practical value.

Metadata Database

The metadata database for this study was compiled by the SSPA study team based on formalized metadata when available and, more frequently, through personal communication with the distributing agency. An initial survey was distributed to the agencies and groups associated and familiar with the Middle Rio Grande requesting the identification of data sets collected and maintained by the respondent. Following review of survey responses and review of other published and other unpublished information, data and metadata requests were submitted to the source agencies. In many cases, after receiving data sets, more than one follow-up interview was conducted to obtained metadata known to agency employees. This metadata database is based solely on the information provided by the source agencies and is not intended to provide a complete metadata reference for all data sets utilized in the Middle Rio Grande Water Supply Study. Further investigation into metadata attributes of various data sets is warranted.

Metadata Standards

The most recognized and current publication of geospatial metadata is the Federal Geographic Data Committee (FGDC) "Content Standards for Spatial Metadata" (FGDC-STD-001-1998). This standard was selected as being the most desirable standard for both the management and generation of geospatial and time series metadata for the Middle Rio Grande Water Supply Study data sets. The FGDC Content Standard helps data users determine what data are available, whether those data meet their specific needs, how to acquire it, and how to transfer it between computer systems. It also provides a mechanism for data generators to share their products with others. Efficient data sharing speeds completion of projects, improves the quality of research and decision-making, and reduces costs by minimizing the duplication of effort. While this standard may appear complex and cumbersome to many, and the application to time series data unjustified, this level of standardization will facilitate future appropriate use of data sets incorporated into or generated by this study. This metadata standard, however, will include many fields for which metadata is unavailable, for a number of data sets relevant to this study. In these cases, the metadata are simply specified as unknown, unavailable or not determined.

Structure

The FGDC Metadata Standard is composed of sections, compound elements, and data elements. Sections are the main divisions of the Standard. The Sections contain the data elements and compound elements and are like the "chapters" of the Standard. The Metadata Standard contains seven main sections and three supporting sections. The main sections of the standard are summarized as follows:

1. **Identification** - General information about the data set.
2. **Data Quality -** Information about the quality of horizontal and vertical positions, and the attributes assigned to geographic features.
3. **Spatial Data -** Organization information about the data types contained in the data set.
4. **Spatial Reference -** Information about the coordinates used to describe locations in the data set.
5. **Entity and Attribute -** Names, definitions, and other information about the features and their attributes found in the data set.

6. **Distribution -** Information about how the data set is distributed.
7. **Metadata Reference -** Metadata about the metadata file. This section contains information about the metadata file itself.

Additionally, the content standards define three 'floating' minor sections.

8. **Citation -** This section contains a structure to create a bibliographic reference to a data set.
9. **Time Period -**This section contains three structures for expressing dates and times.
10. **Contact -** This section contains information used to contact someone to ask questions about the metadata file or the data set.

Tools

Numerous public domain and commercially available database tools currently exist for the generation and management of geospatial metadata. These tools preclude the necessity for creating or customizing a database application specifically for this purpose. Spatial Metadata Management System from RTS Enabling Technology was selected based on the following considerations in the evaluation and selection of database tools for the generation and management of metadata for the water supply study:

- Compliance with the FGDC Content Standards for Digital Geospatial Metadata;
- Compatible for use on Windows 95/98/NT platform computers;
- Ease of use for generators not familiar with the content standards;
- Ability for multiple organizations to access the metadata base over a wide area network;
- Costs associated with the acquisition, implementation and maintenance of the database;
- Data import and export capabilities; and,
- Database Security.

FGDC Metadata Elements

The FGDC content standard consists of a hierarchy of metadata elements, or fields, available for specifying information about the data. The following element list provides a summary of the kind of metadata that populates the database, for the datasets with fairly complete existing metadata, for example, recently produced GIS coverages. Datasets lacking in formal metadata were described according to information obtained from the source. Although many fields remain unpopulated, the standardization of available information should still prove useful. The metadata elements are described below, according to the seven primary sections of the standard.

Section 1 - Identification Information

- Citation Information
  - Originator

- Publication Date
- Publisher
- Title
- Edition
- Online Linkage
- Description
  - Abstract
  - Purpose
  - Supplemental Information
- Time Period of Content
  - Beginning Date
  - Ending Date
- Progress
- Maintenance and Update Frequency
- Spatial Domain
  - West Bounding Coordinate
  - East Bounding Coordinate
  - North Bounding Coordinate
  - South Bounding Coordinate
- Theme Keyword(s)
- Place Keyword
- Access Constraints
- Use Constraints
- Contact Information
  - Contact Person
  - Contact Organization
  - Address Type: mailing and physical address
    - Address
    - City
    - State or Province
    - Postal Code
    - Country
    - Contact Voice Telephone
    - Contact Facsimile Telephone
    - Contact Electronic Mail Address
- Browse Graphic
  - Browse Graphic File Name
  - Browse Graphic File Description
  - Browse Graphic File Type
- Native Data Set Environment

Section 2 - Data Quality Information

- Attribute Accuracy Report
- Logical Consistency Report
- Completeness Report
- Positional Accuracy Report
- Horizontal
- Vertical
- Lineage
- Source Information

    - Publication Date
    - Title
    - Edition
    - Publication Place
    - Publisher
    - Online Linkage
    - Type of Source Media
    - Source Citation Abbreviation
- Process
    - Process step
    - Process date
    - Process contact

Section 3 - Spatial Data Organization Information

- Direct Spatial Reference Method
- Point and Vector Object Information
- SDTS Point and Vector Object Type
- Point and Vector Object Count

Section 4 - Spatial Reference Information

- Horizontal Coordinate System Definition
    - Latitude Resolution
    - Longitude Resolution
    - Geographic Coordinate Units
    - Horizontal Datum Name
    - Ellipsoid Name
    - Semi-Major Axis
    - Denominator of Flattening Ratio
- Vertical Coordinate Definition

Section 5 - Entity and Attribute

- Entity and Attribute (For Each Entity)
    - Entity and Attribute Overview
    - Entity Type Label
    - Entity Type Definition
    - Attribute Label
    - Attribute Definition

Section 6 - Distribution

- Contact Person
- Contact Organization
- Address Type
- Address
- Country
- Contact Voice Telephone
- Contact Facsimile Telephone
- Contact Electronic Mail Address

- Distribution Liability

Section 7 - Metadata Reference Information

- Metadata Date
- Contact Person
- Contact Position
- Contact Organization
- Address Type: physical address
  - Address
  - City
  - State or Province
  - Postal Code
  - Country USA
  - Contact Voice Telephone
  - Contact Facsimile Telephone
  - Contact Electronic Mail Address
- Metadata Standard Name
- Metadata Standard Version

Summary of Included Data Sets

This summary represents the data collected and used in the Middle Rio Grande Water Supply study. The metadata database consists of 105 different records, including both spatial and time series data sets.

Time Series Data

USGS Gaging Stations, Flow:	46 stations, daily discharge
USGS Stations, Reservoir Contents:	2 stations, Cochiti Lake and Elephant Butte
MRGCD Gaging Stations, Flow:	13 stations, daily discharge
EPA records, wastewater:	6 primary cities: Rio Rancho, Bernallilo, Albuquerque, Los Lunas, Belen, Socorro; monthly total discharge
Rio Grande Compact Data:	from Compact annual reports, the following: Otowi index flow Obligation at Elephant Butte Delivery at Elephant Butte Trans-Mountain Diversions Credit/Debit Balance
Crop Consumptive Use:	by reach, for all crops, from ET Toolbox
Riparian Consumptive Use:	by reach, for all riparian types, from ET Toolbox

Cochiti Lake Evaporation:	Army Corps of Engineers
Elephant Butte Evaporation:	U. S. Bureau of Reclamation
Groundwater Extraction:	USGS, model files (as replicated in OSE model, well package, final time step, historical run)
Precipitation:	Albuquerque WSFO Airport, New Mexico Historical Monthly Total Precipitation

Spatial Data

USGS Gaging Station Locations, for stations identified by SSPA as meeting the following description:

> All active or discontinued gages on Rio Grande between Rio Grande at Otowi and Rio Grande below Elephant Butte; all active or discontinued gages for tributary flows at downstream location nearest to Rio Grande mainstem.

Land Use Area (from LUTA, USBR MRG Assessment), polygon coverages:

Vegetation classification for MRGCD Divisions as follows:
- Cochiti Division
- Albuquerque Division
- Belen Division
- Socorro Divison
- San Marcial Sub-area

Vegetation classification for counties as follows:
- Bernalillo County
- Sandoval County
- Valencia County
- Socorro County

Hydrography coverages, including MRGCD drains, canals, river and portions of tributary inflow channels for MRGCD Divisions (as listed above) and counties (as listed above)

Transportation coverages for the MRGCD divisions (as listed above).

County boundaries for the State of New Mexico, line coverages

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

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

MRGCD Property Boundary Coverage

APPENDIX B
Middle Rio Grande Water Supply Study
Summary of Flow Data and Compact-based Flow Indices

This appendix includes time-series graphs for flow data compiled and evaluated as part of the Middle Rio Grande Water Supply Study. Flow data include USGS gaged records for river stations, tributaries (including AMAFCA inflows), canal diversions and drain flows; flow indices computed under the Rio Grande Compact; MRGCD records of canal and drain flows; and wastewater inflow reported by municipalities to the EPA. Metadata for source data sets is provided in Appendix A. Time-series graphs in this appendix represent annual values at individual stations; composite annual values at selected cross-sections; and, composite annual values representing total diversions at MRGCD diversion points. In some cases, the available record precedes the period evaluated for this study and presented on time-series graphs. The period of record for each station is included with metadata in Appendix A. The annual values were derived from source data employing the following procedures:

USGS gaged river flows: Annual average flow was derived from mean daily flow reported in the source data set. Reported mean daily flow in cubic feet per second was converted to acre-feet per year by summation and unit conversion. The source data flagged missing daily flows. In these cases, we did not compute an annual average flow, and a break in the record is observed.

USGS gaged canal flows: Annual average flow was derived from mean daily flow reported in the source data set. Reported mean daily flow in cubic feet per second was converted to acre-feet per year by summation and unit conversion. The source data typically flagged missing daily flows. In some cases, zero flow in the non-irrigation season was not distinguished from missing data. Annual average flow was computed assuming missing data during the non-irrigation season represented zero flow.

MRGCD canal and drain flows: These records were compiled electronically as daily values by the URGWOM team (personal communication, April Fitzner) from MRGCD paper records. Daily values from the URGWOM files were cumulated and converted to obtain monthly and annual values in acre-feet per year. MRGCD paper records were obtained for this study and used to spot-check the content of URGWOM files.

Wastewater Inflow: Source data sets consisted of monthly reported flows in cubic feet per second. The reported monthly flows were summed and converted to obtain annual flow in acre-feet per year.

Compact-based Indices: The Otowi Index Supply, trans-mountain diversions, Elephant Butte scheduled delivery, Actual Elephant Butte Effective Supply, and New Mexico Credit History reflect annual values reported in the Rio Grande Compact Commission Annual Reports.

Annual Flow at USGS Rio Grande Gaging Stations

Figure B-1.1	Rio Grande at Otowi Bridge	(08313000)
Figure B-1.2a	Rio Grande at Cochiti	(08314500)
Figure B-1.2b	Rio Grande below Cochiti Dam	(08317400)
Figure B-1.3	Rio Grande at San Felipe	(08319000)
Figure B-1.4	Rio Grande at Albuquerque	(08330000)
Figure B-1.5	Rio Grande Floodway near Bernardo	(08332010)
Figure B-1.6	Rio Grande Conveyance Channel near Bernardo	(08331990)
Figure B-1.7	Rio Grande near Bernardo	(08332000)
Figure B-1.8	Rio Grande Conveyance Channel at San Acacia	(08354800)
Figure B-1.9	Rio Grande Floodway at San Acacia	(08354900)
Figure B-1.10	Rio Grande at San Acacia	(08355000)
Figure B-1.11	Rio Grande Conveyance Channel at San Marcial	(08358300)
Figure B-1.12	Rio Grande Floodway at San Marcial	(08358400)
Figure B-1.13	Rio Grande at San Marcial	(08358500)
Figure B-1.14	Rio Grande below Elephant Butte Dam	(08361000)
Figure B-1.15	Rio Grande near Bernalillo	(08329500)
Figure B-1.16	Rio Grande at Rio Bravo Bridge near Albuquerque	(08330150)
Figure B-1.17	Rio Grande near Alameda	(08329928)
Figure B-1.18	Rio Grande at San Antonio	(08355500)
Figure B-1.19	Rio Grande at Isleta	(08331000)
Figure B-1.20	Rio Grande at Narrows in Elephant Butte Reservoir	(08359500)

Annual Flow at USGS Gaged Tributaries, station nearest to confluence with Rio Grande

Figure B-2.1	Santa Fe River near Santa Fe	(08316000)
Figure B-2.2	Santa Fe River above Cochiti Lake	(08317200)
Figure B-2.3	Galisteo Creek below Galisteo Dam	(08317950)
Figure B-2.4	Jemez River below Jemez Canyon Dam	(08329000)
Figure B-2.5	North Floodway Channel	(08329900)
Figure B-2.6	South Diversion Channel above Tijeras Arroyo near Albuquerque	(08330775)
Figure B-2.7	Tijeras Arroyo near Albuquerque	(08330600)
Figure B-2.8	Tijeras Arroyo below South Diversion Inlet near Albuquerque	(08330800)
Figure B-2.9	Rio Puerco near Bernardo	(08353000)
Figure B-2.10	Rio Salado near San Acacia	(08354000)

Annual Flow at Canal Headings, reported by USGS

Figure B-3.1	Cochiti East Side Main Canal at Cochiti	(08313500)
Figure B-3.2	Sili Main Canal at Cochiti	(08314000)
Figure B-3.3	Socorro Main Canal North at San Acacia	(08354500)

Annual Flow at Drains, reported by USGS

Figure B-4.1	Bernardo Interior Drain near Bernardo	(08332050)
Figure B-4.2	San Antonio Riverside Drain near San Marcial	(08357500)

Figure B-4.3 Elmendorf Interior Drain near San Antonio (08357000)
Figure B-4.4 San Antonio Riverside Drain near San Antonio (08356500)

Combined Flow at MRGCD Diversion Points

Figure B-5.1 MRGCD Diversion at Cochiti Dam
Figure B-5.2 MRGCD Diversion at Angostura Dam
Figure B-5.3 MRGCD Diversion at Isleta Dam
Figure B-5.4 MRGCD Diversion at San Acacia Dam
Figure B-5.5 Total of MRGCD Recorded Canal Diversions

Composite Flow at Middle Rio Grande Cross-Sections

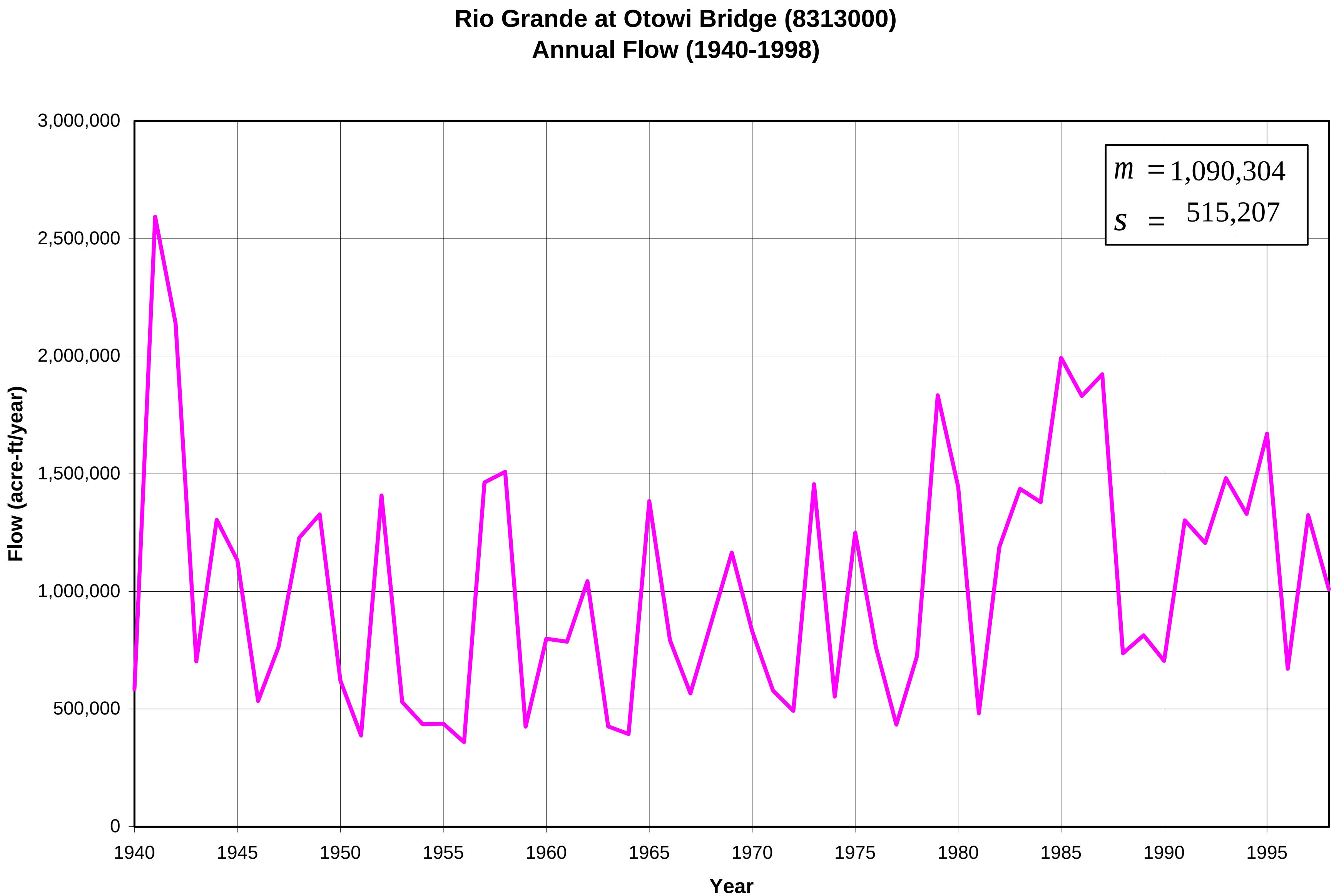
Figure B-6.1 Composite Flow at Cochiti Cross-Section
Figure B-6.2 Composite Flow at San Felipe Cross-Section
Figure B-6.3 Composite Flow at Bernardo Cross-Section
Figure B-6.4 Composite Flow at San Acacia Cross-Section
Figure B-6.5 Composite Flow at San Marcial Cross-Section

Wastewater Discharge

Figure B-7.1 Wastewater Discharge at Rio Rancho, Bernalillo, Los Lunas, Belen and Socorro
Figure B-7.2 Wastewater Discharge at Albuquerque

Compact Based Indices

Figure B-8.1 Otowi Index Supply
Figure B-8.2 San Juan Chama Transmountain Diversions
Figure B-8.3 Elephant Butte Scheduled Delivery
Figure B-8.4 Elephant Butte Effective Supply
Figure B-8.5 Rio Grande Compact: New Mexico Credit History



10/3/00

Figure B-1.1

8313000_yearly

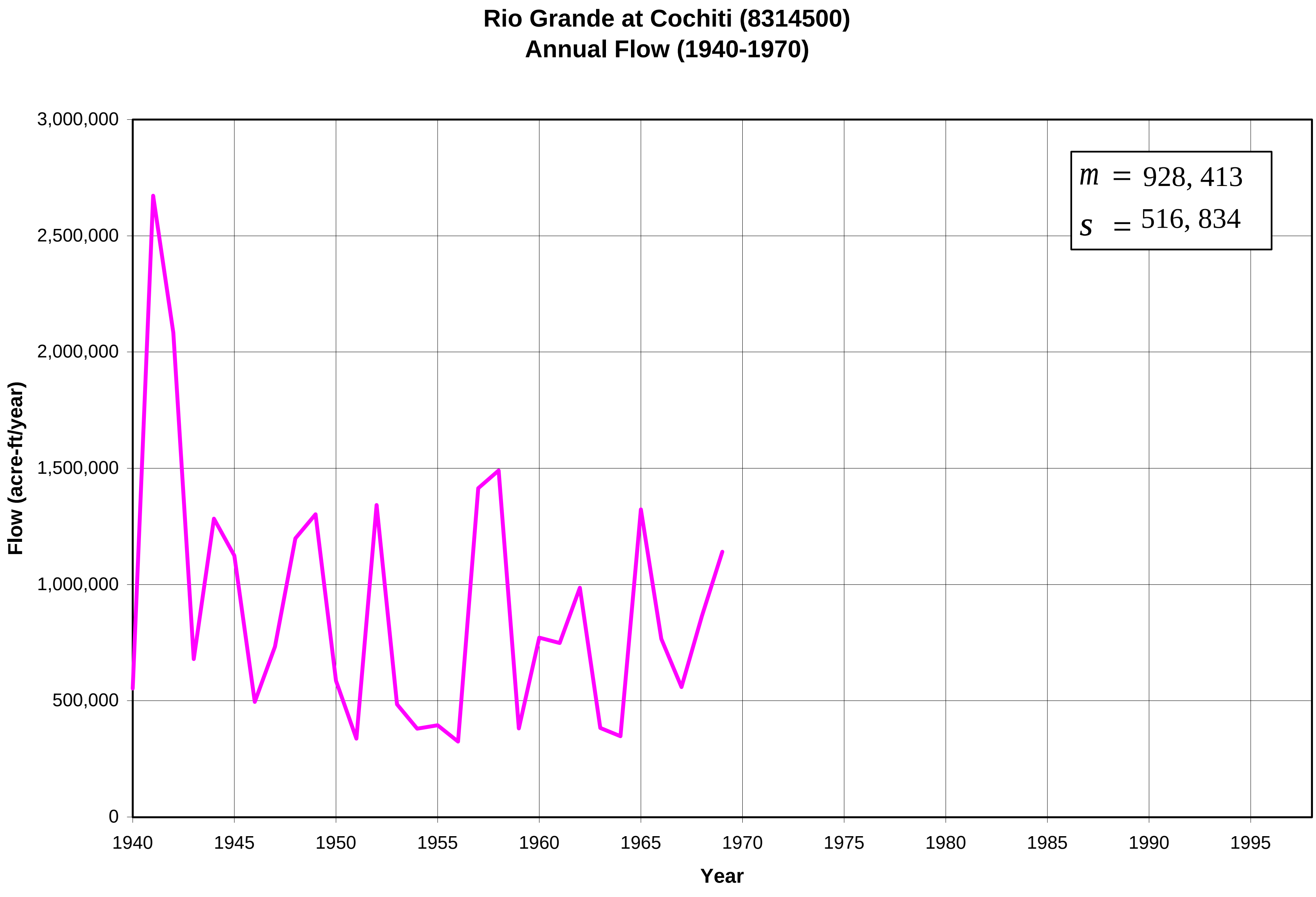

Rio Grande at Cochiti (8314500)
Annual Flow (1940-1970)
Flow (acre-ft/year)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
m = 928, 413
s = 516, 834

Figure B-1.2a

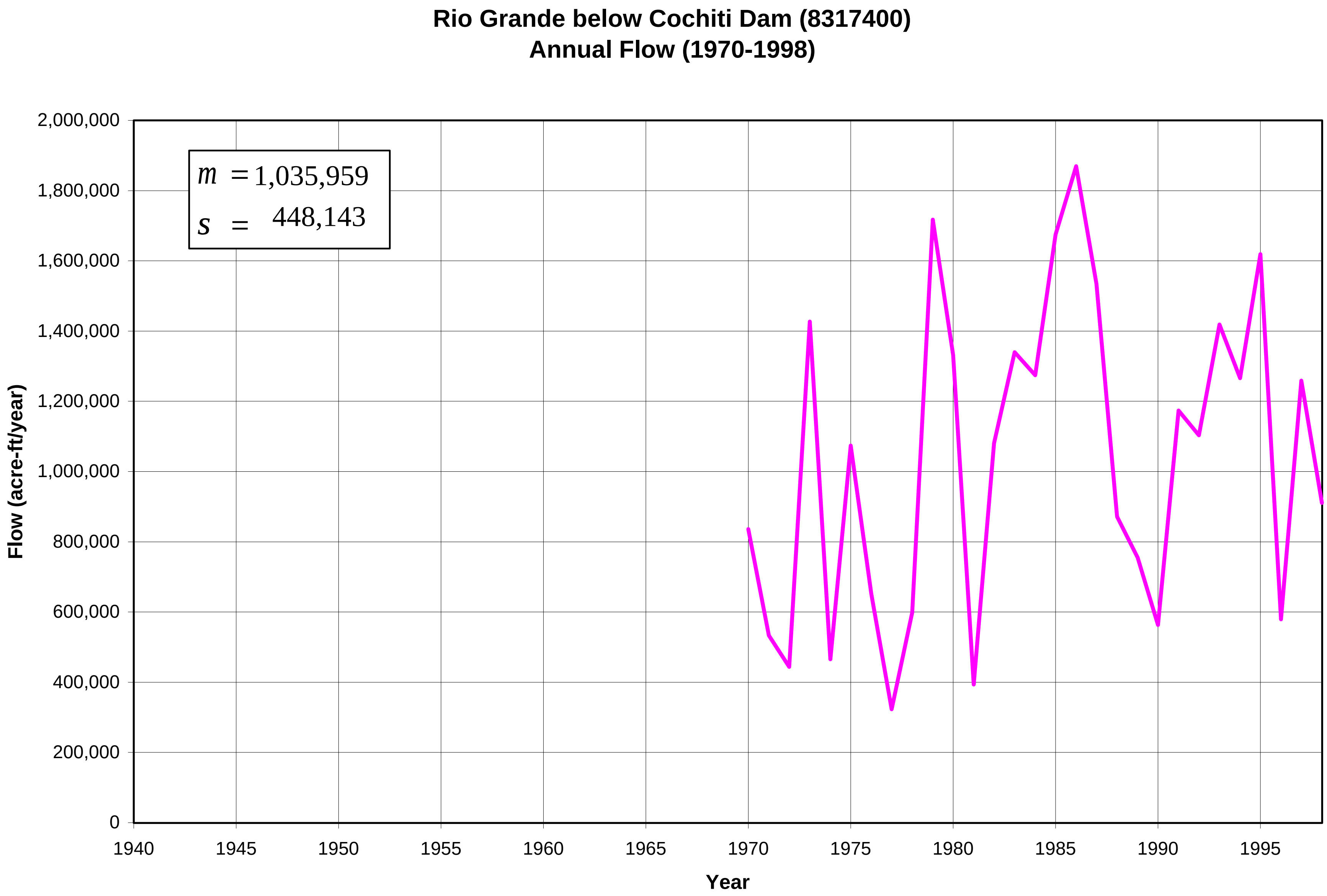
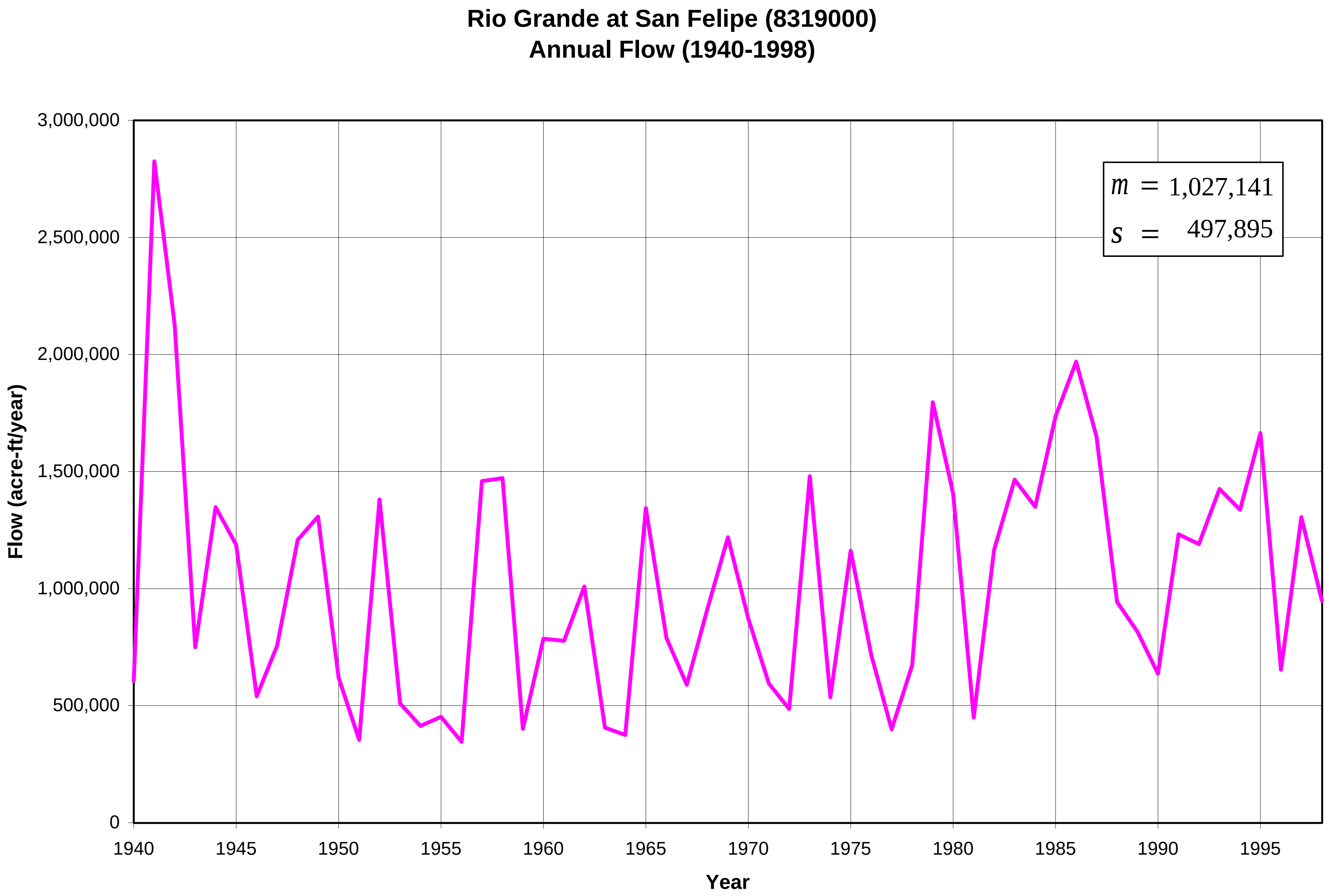

Rio Grande below Cochiti Dam (8317400)
Annual Flow (1970-1998)
m = 1,035,959
s = 448,143
Flow (acre-ft/year)
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year

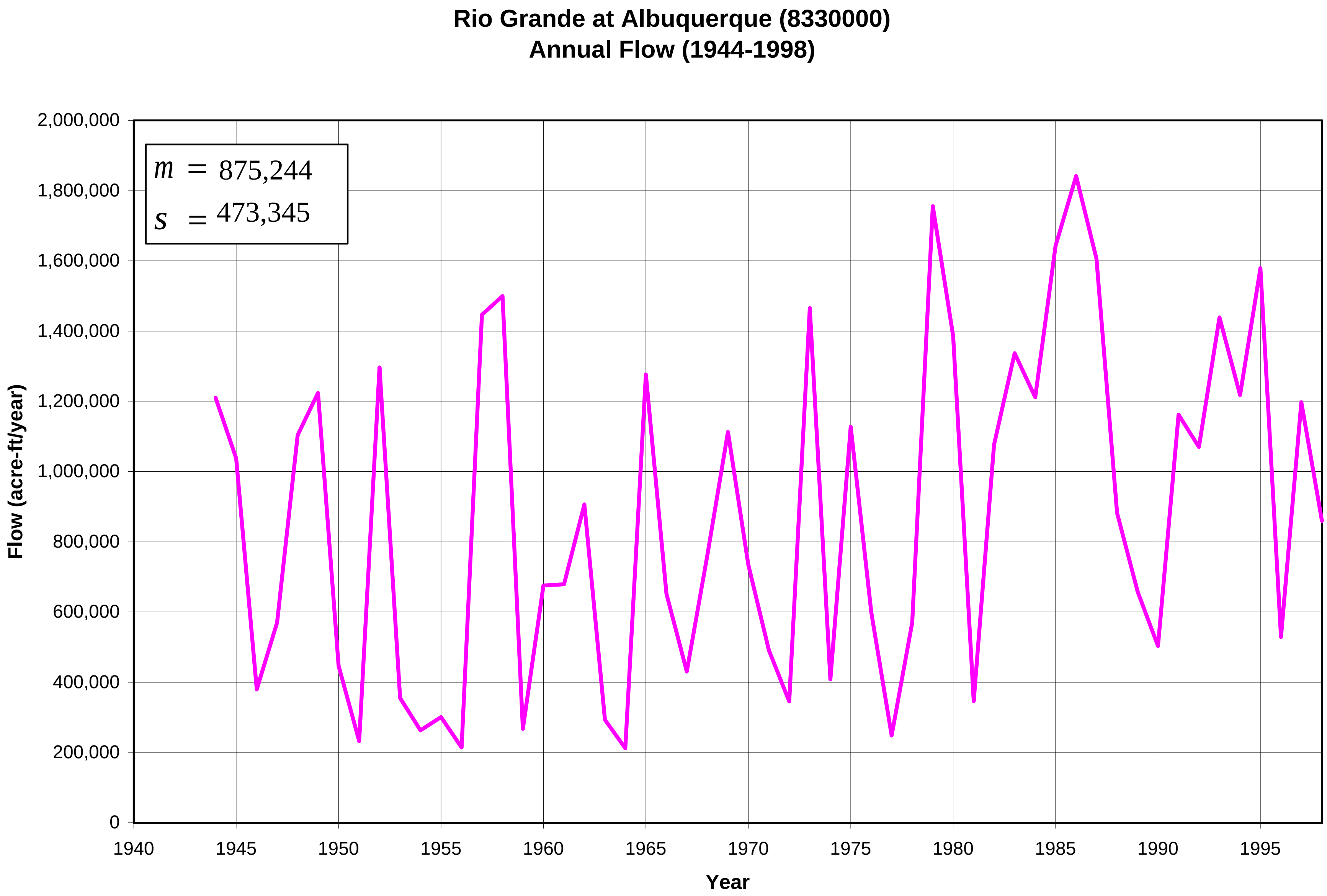
Figure B-1.2b



10/3/00

Figure B-1.3

8319000_yearly

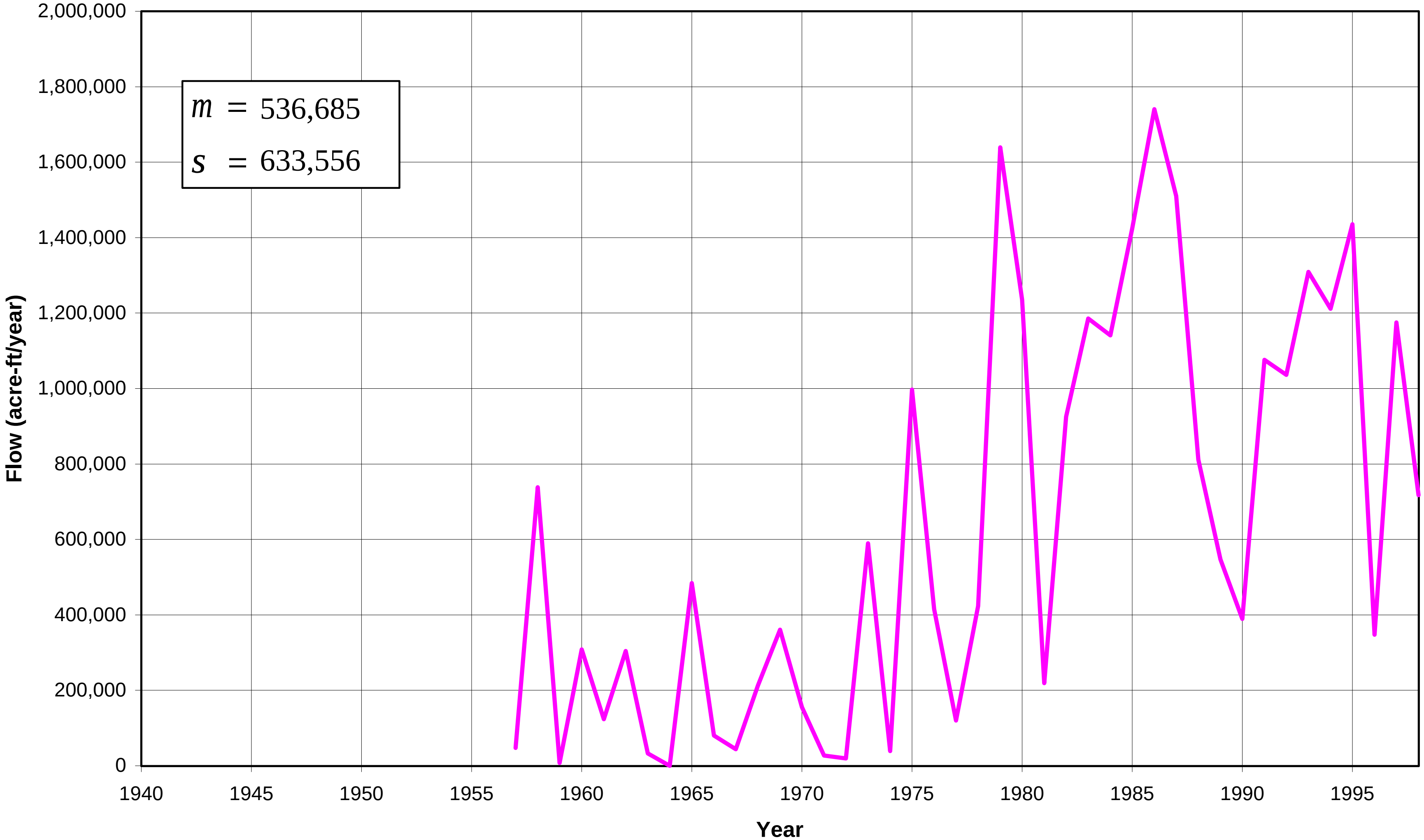


10/3/00

Figure B-1.4

8330000_yearly

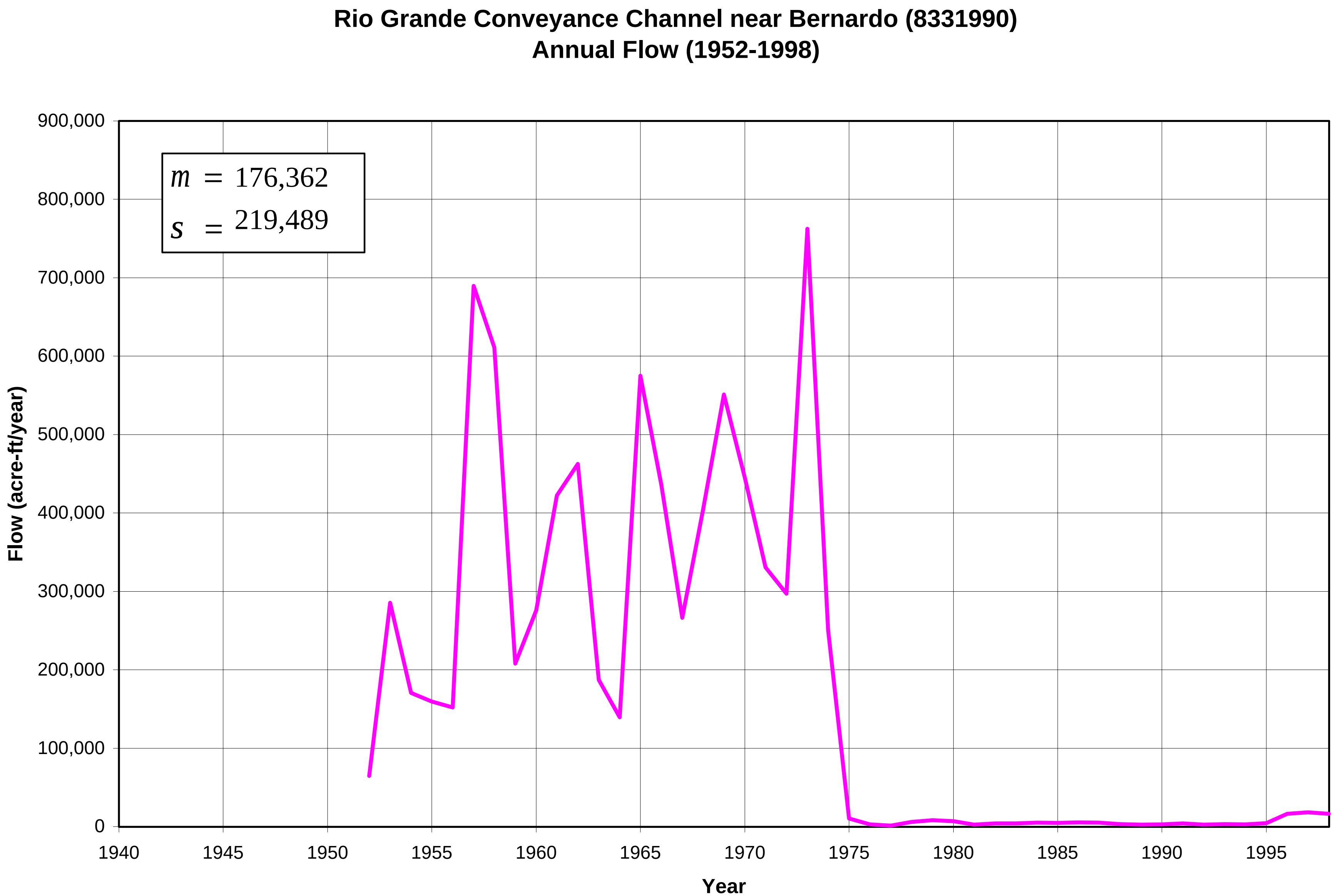
Rio Grande Floodway near Bernardo (8332010)
Annual Flow (1957-1998)



10/3/00

Figure B-1.5

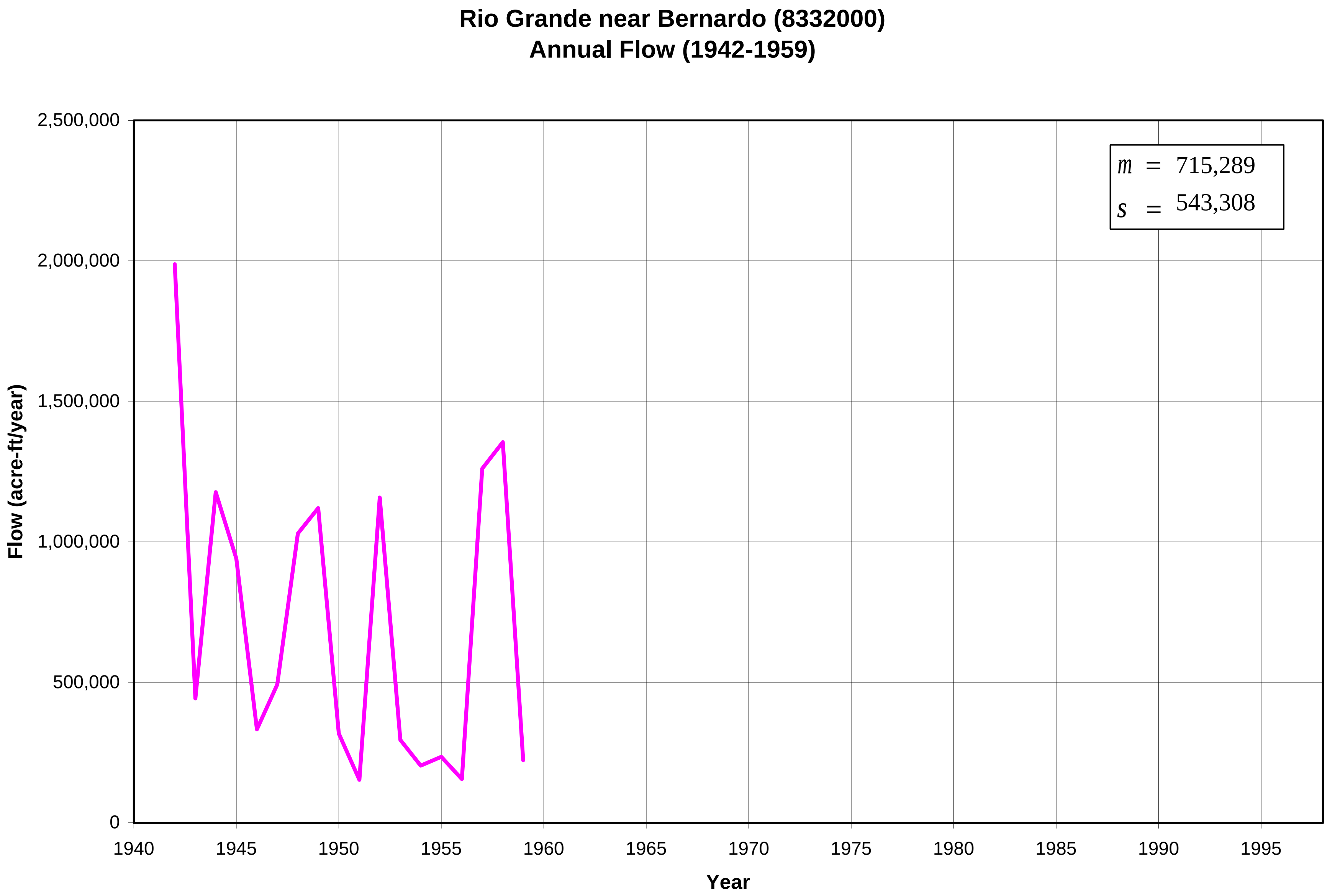
8332010_yearly



10/3/00

Figure B-1.6

8331990_yearly



10/3/00

Figure B-1.7

8332000_yearly

Rio Grande Conveyance Channel at San Acacia (8354800)
Annual Flow (1958-1998)

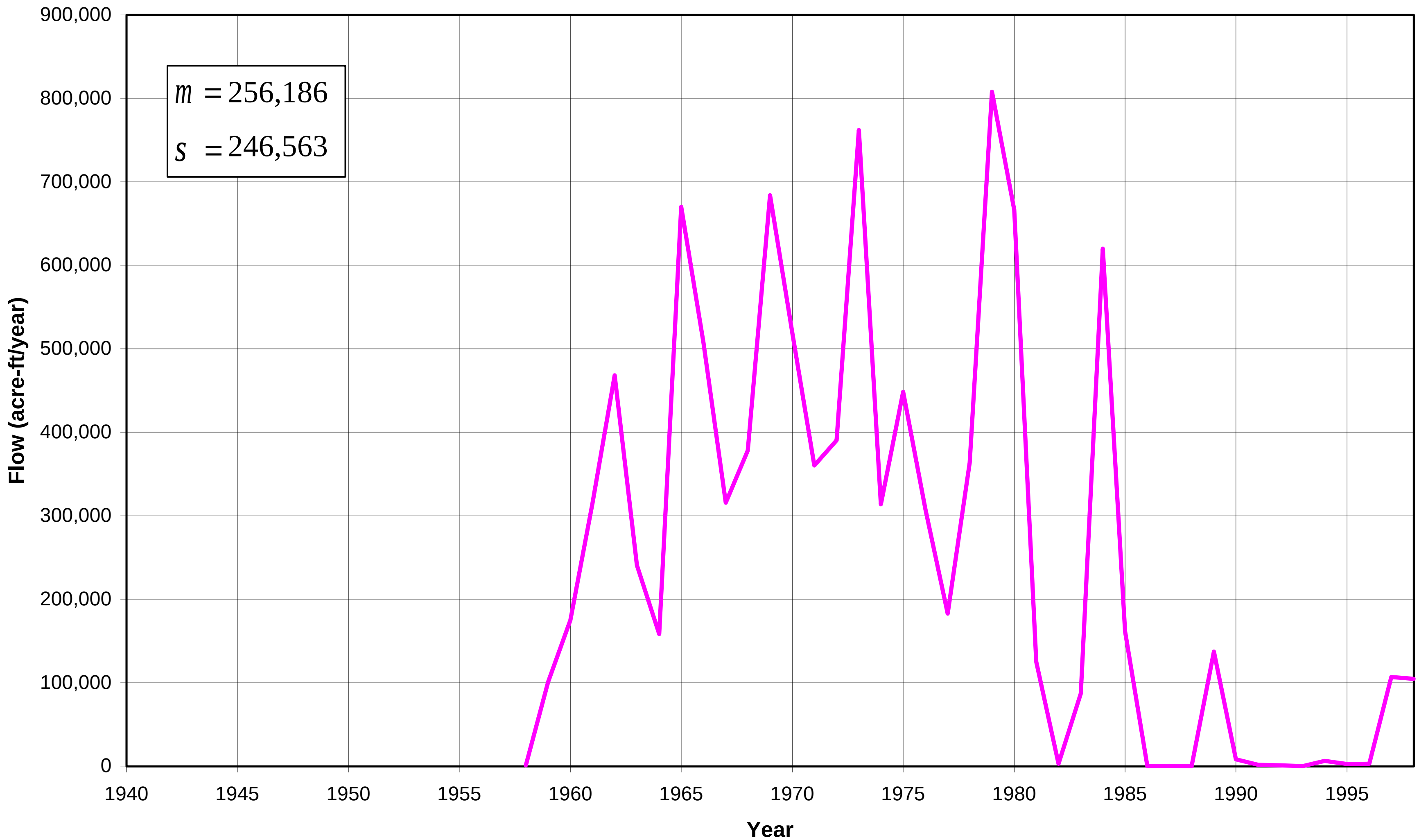


Figure B-1.8

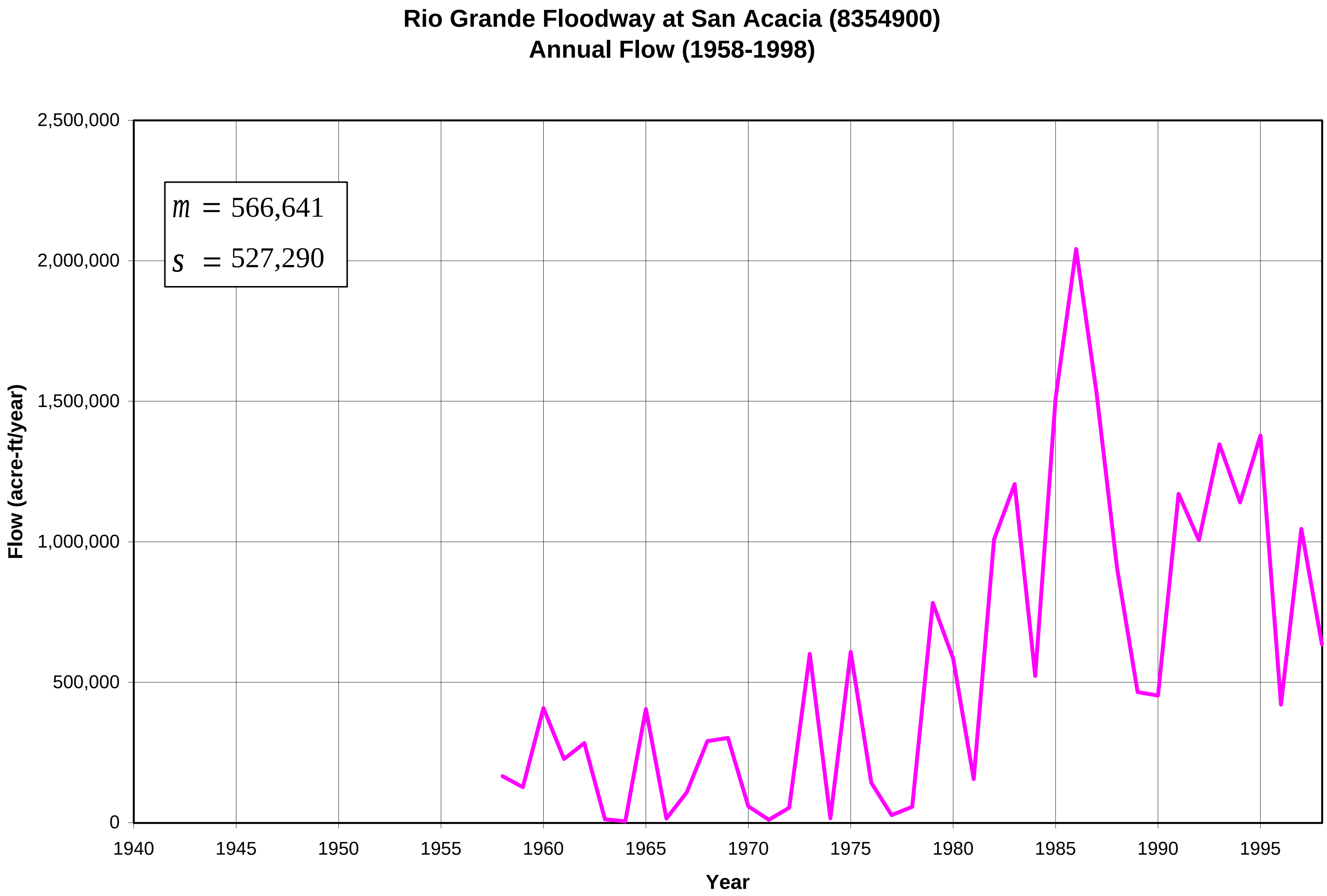

Rio Grande Floodway at San Acacia (8354900)
Annual Flow (1958-1998)
m = 566,641
s = 527,290
Flow (acre-ft/year)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year

Figure B-1.9

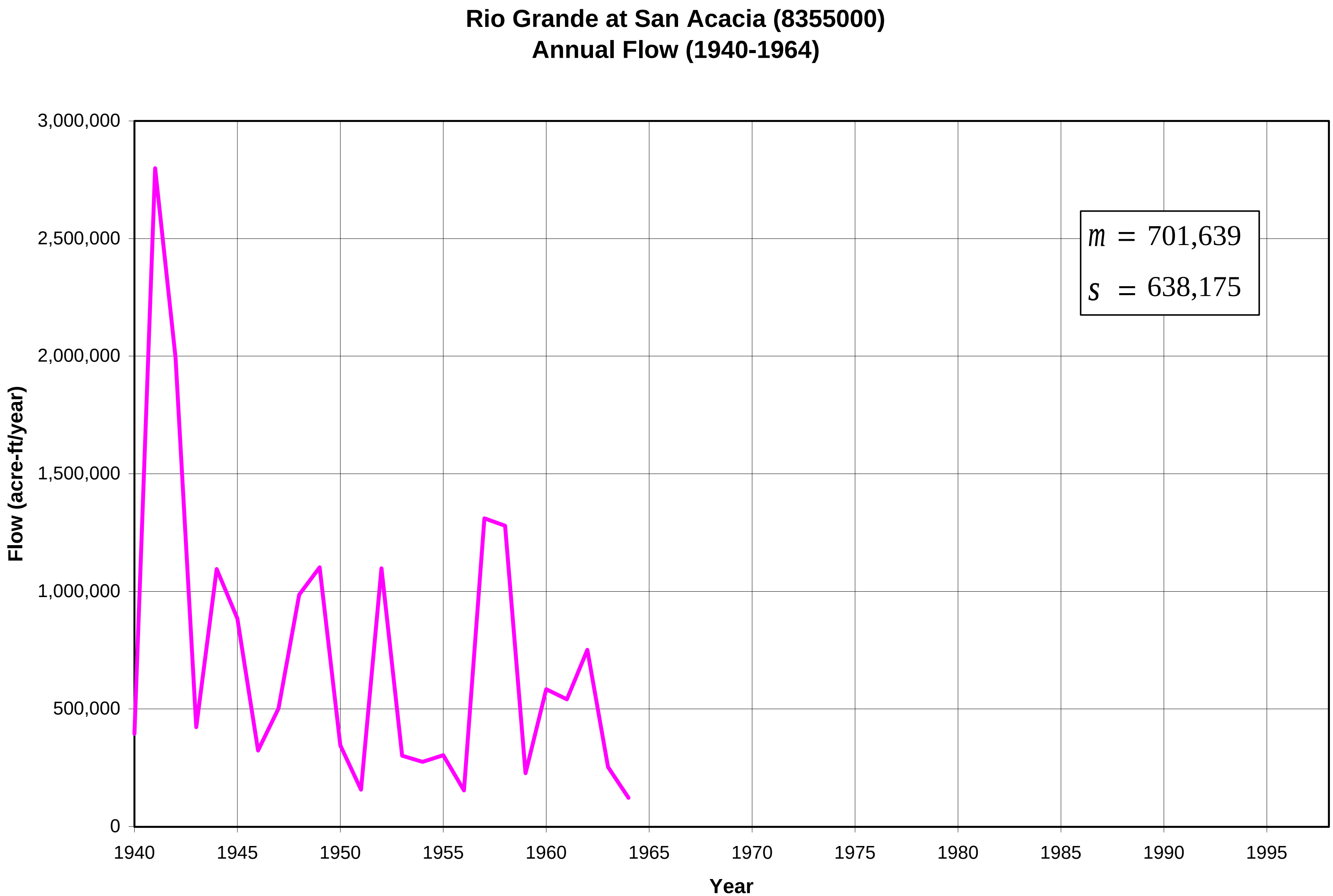
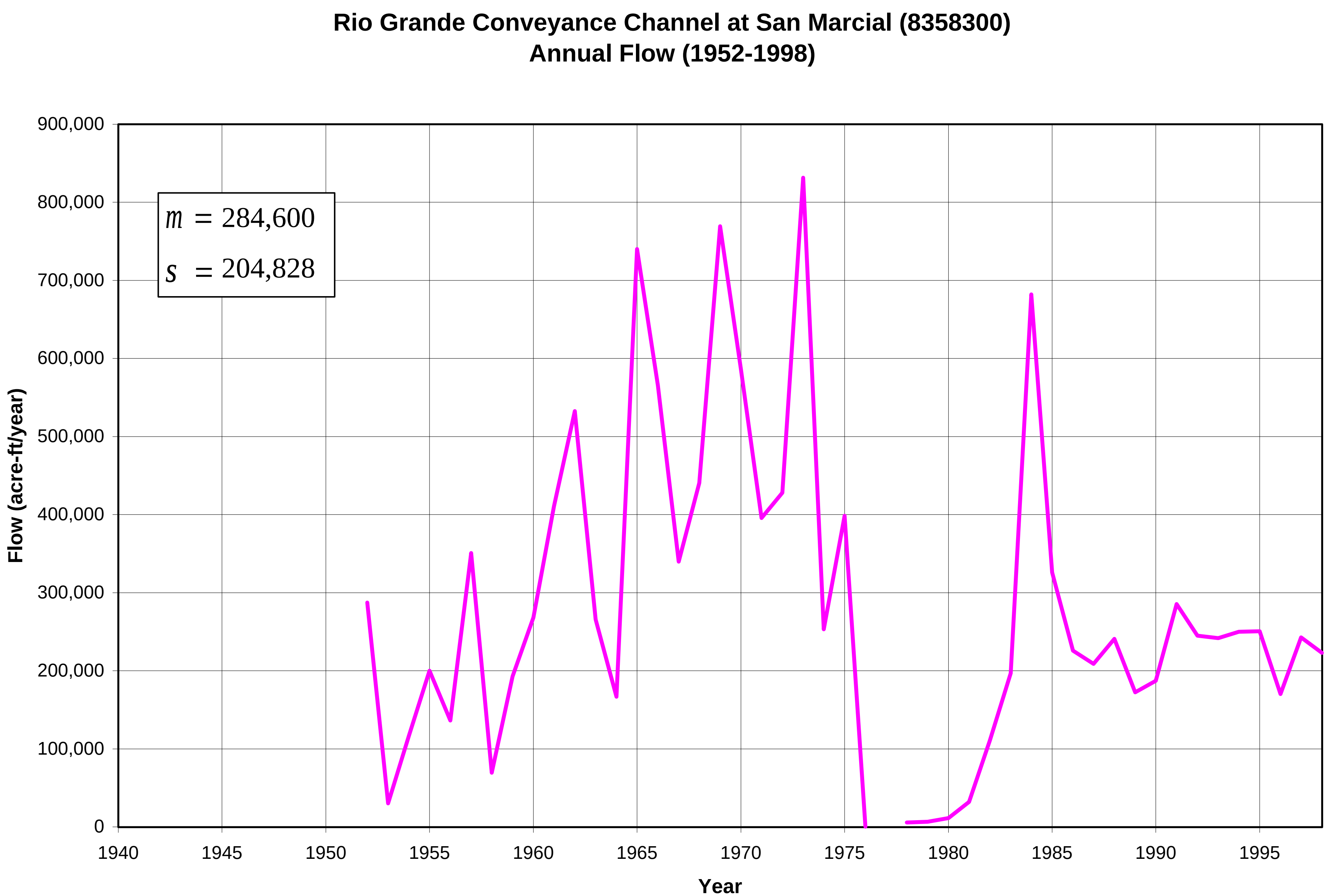

Rio Grande at San Acacia (8355000)
Annual Flow (1940-1964)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Flow (acre-ft/year)
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
m = 701,639
s = 638,175

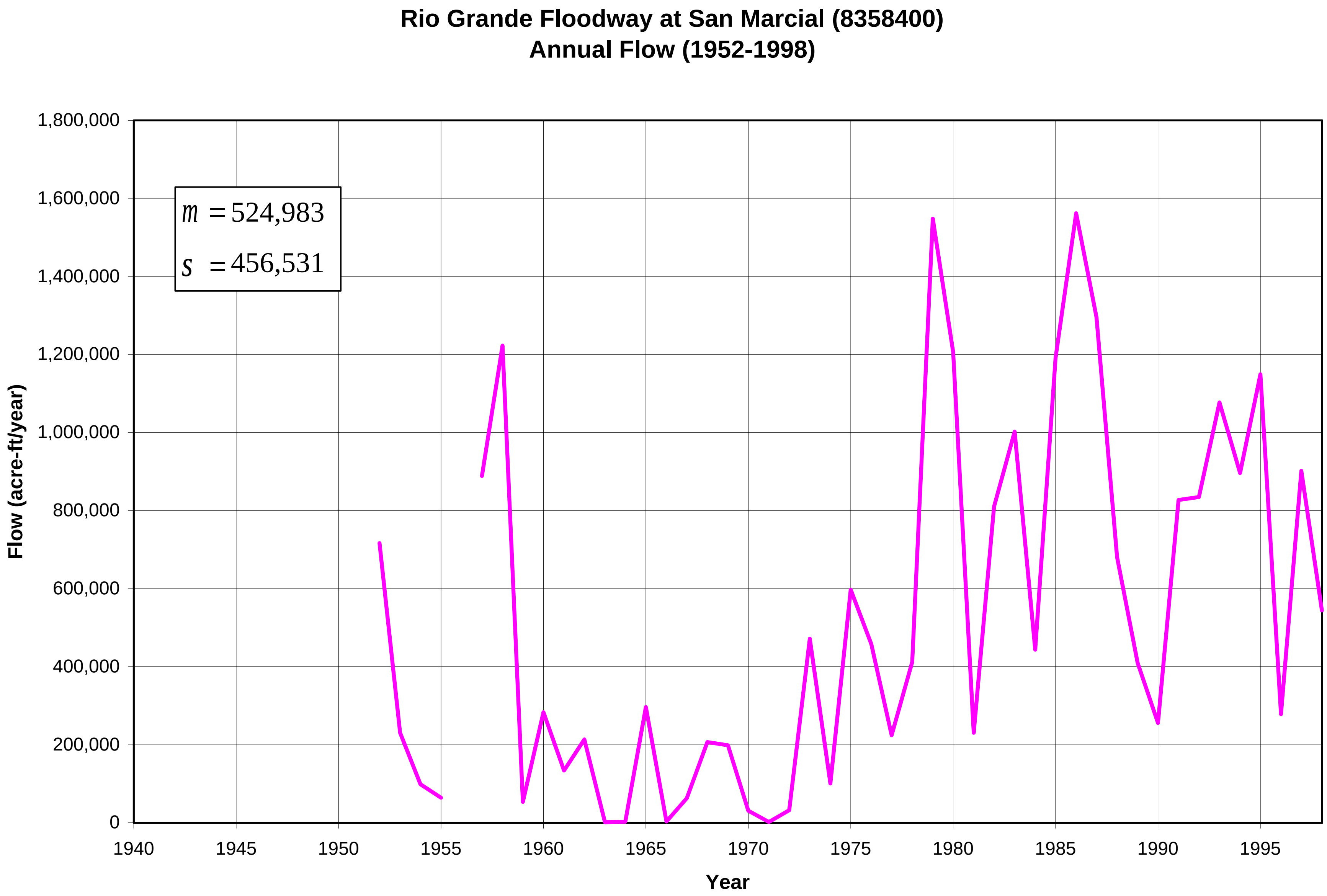
Figure B-1.10



10/3/00

Figure B-1.11

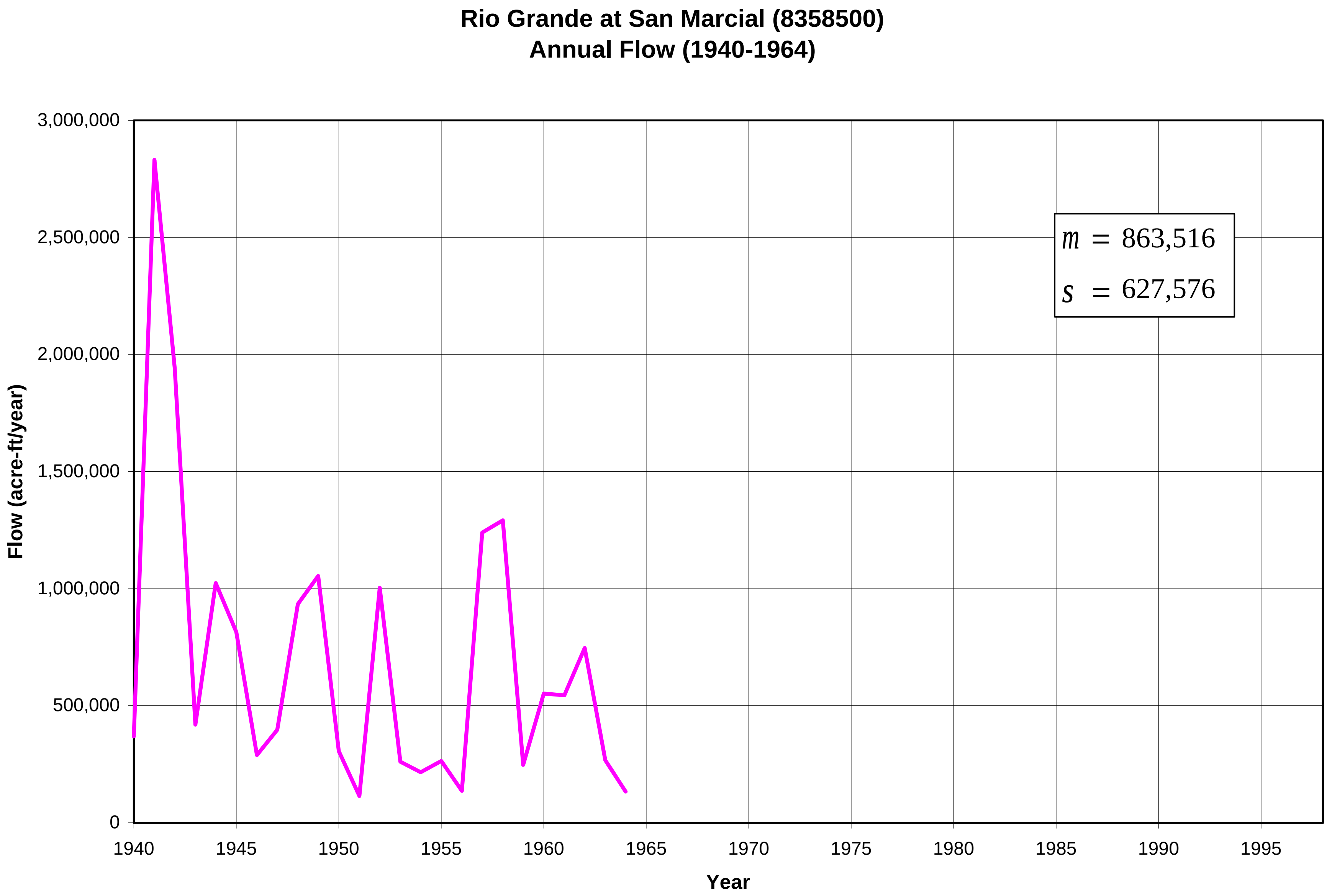
8358300_yearly



10/3/00

Figure B-1.12

8358400_yearly



10/3/00

Figure B-1.13

8358500_yearly

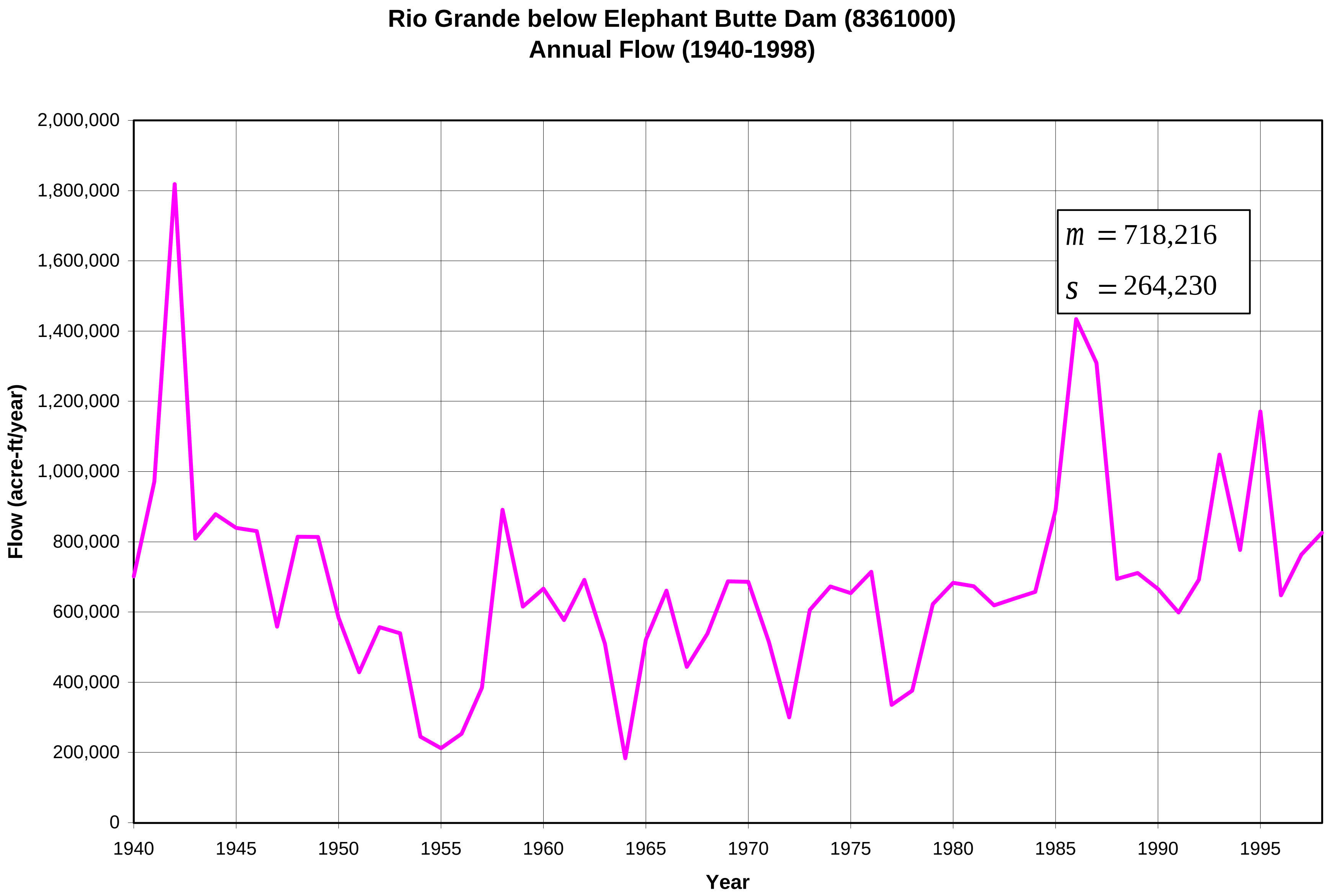
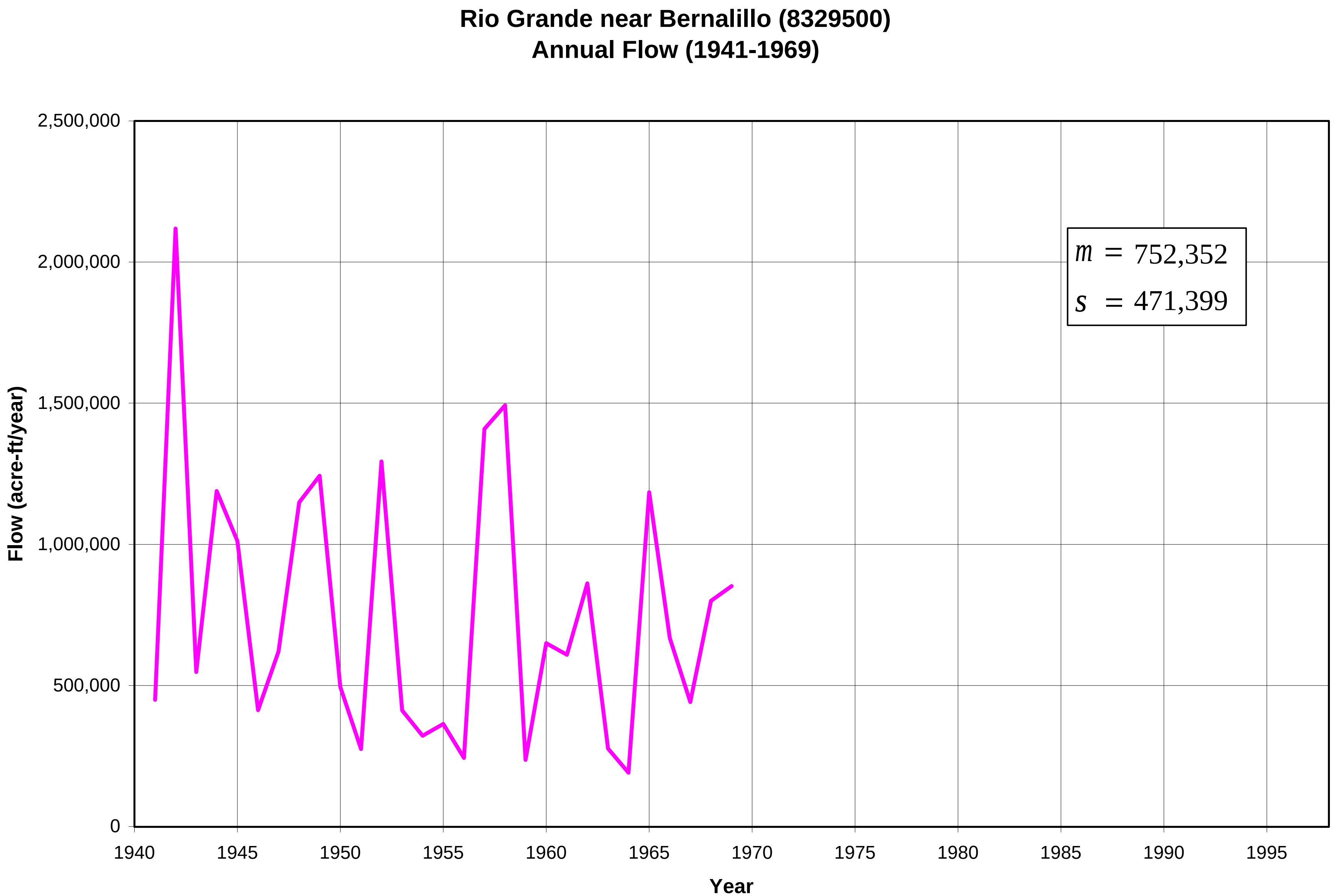
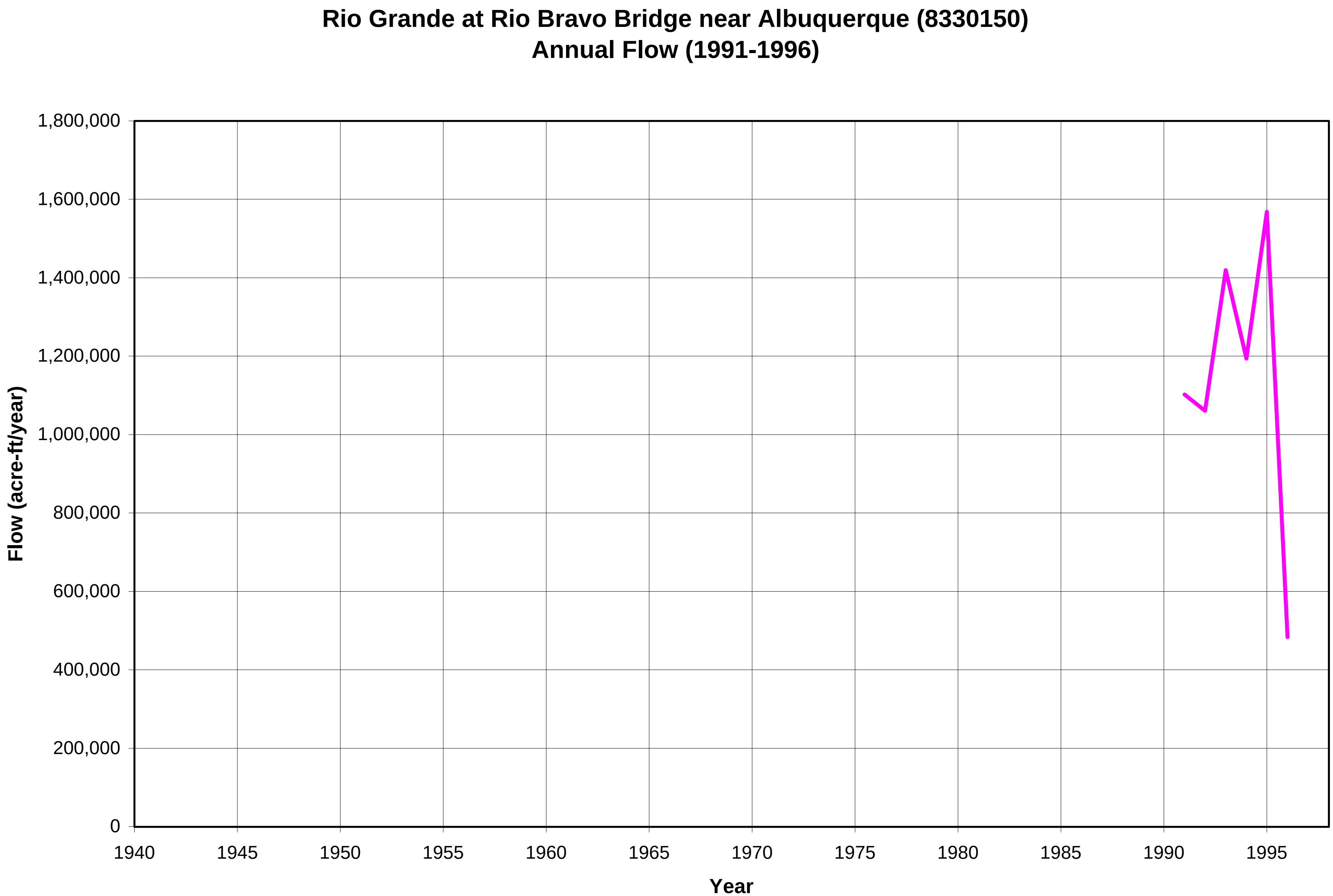

Rio Grande below Elephant Butte Dam (8361000)
Annual Flow (1940-1998)
m = 718,216
s = 264,230
Flow (acre-ft/year)
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year

Figure B-1.14

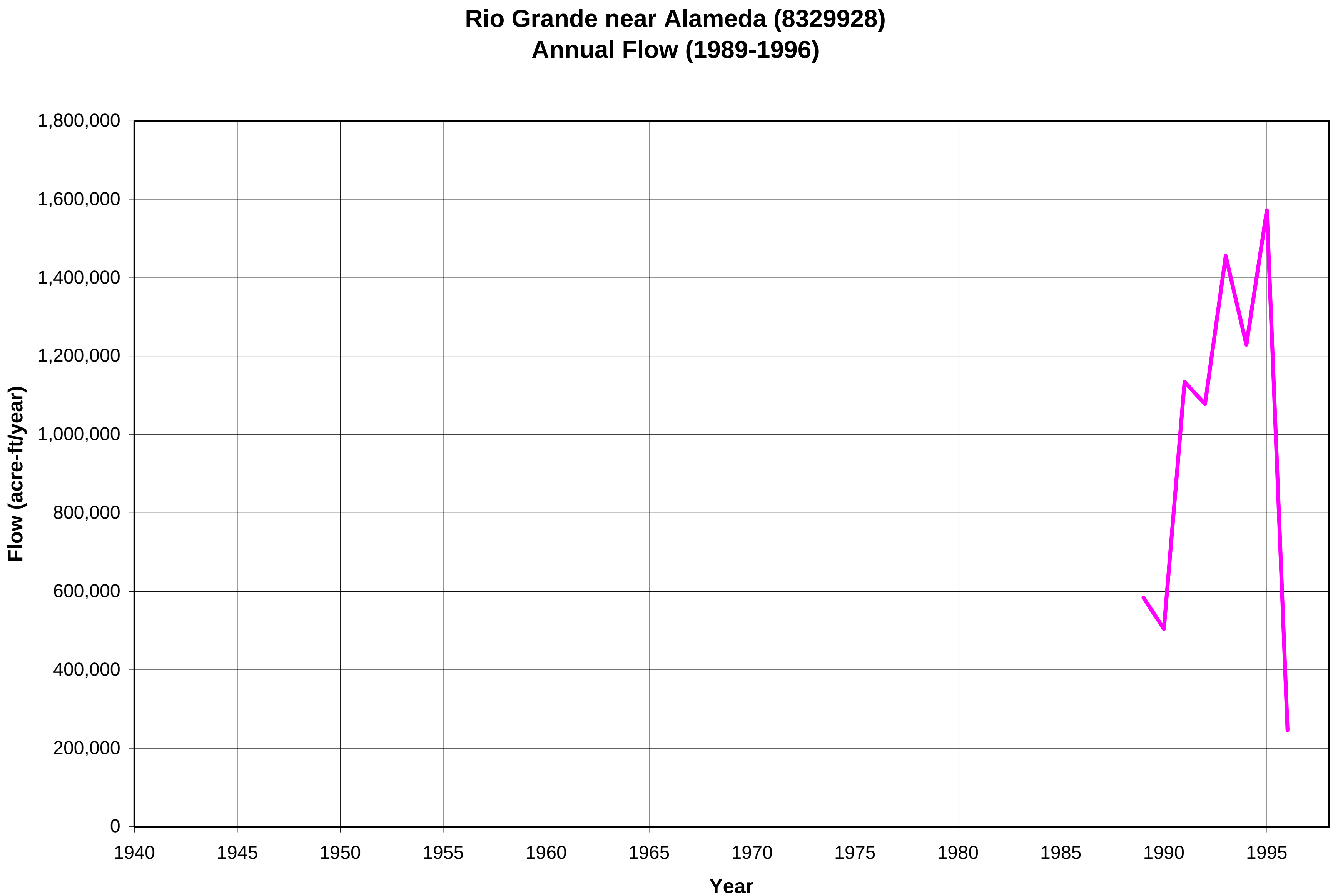

Rio Grande near Bernalillo (8329500)
Annual Flow (1941-1969)
Flow (acre-ft/year)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
m = 752,352
s = 471,399



10/3/00

Figure B-1.16

8330150_yearly



10/3/00

Figure B-1.17

8329928_yearly

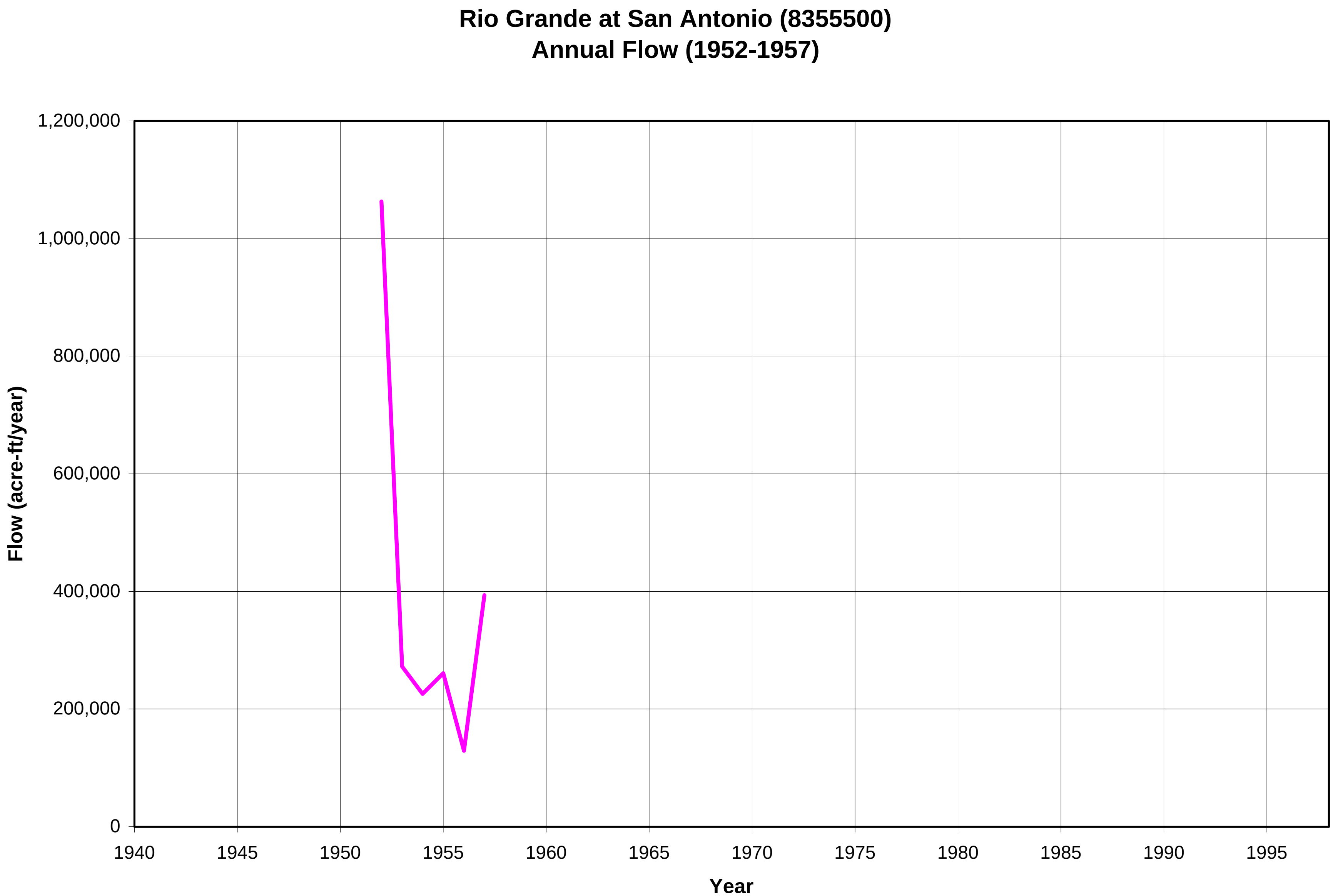

Rio Grande at San Antonio (8355500)
Annual Flow (1952-1957)
Flow (acre-ft/year)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year

Figure B-1.18

Rio Grande at Isleta (8331000)
Annual Flow (1995-1997)

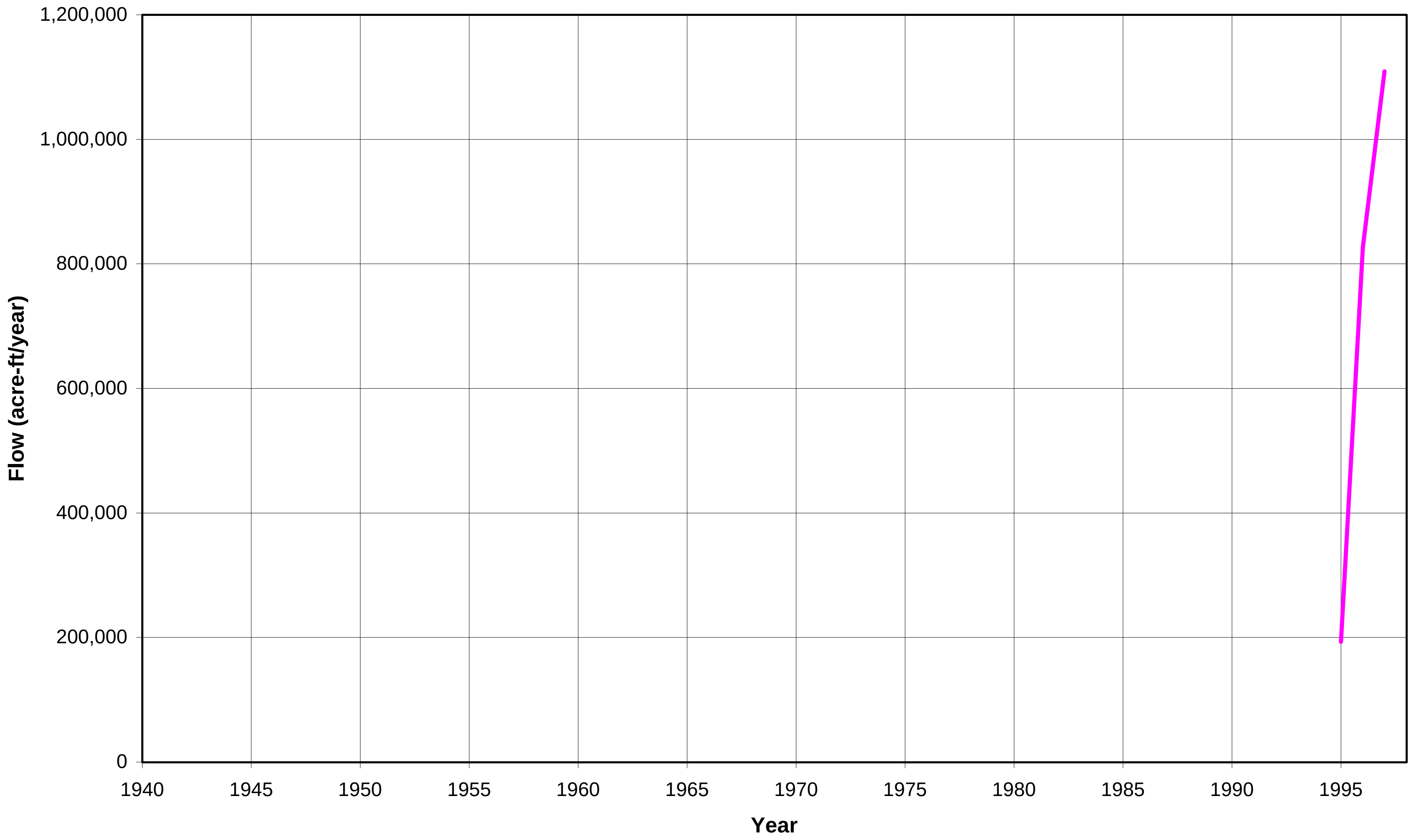
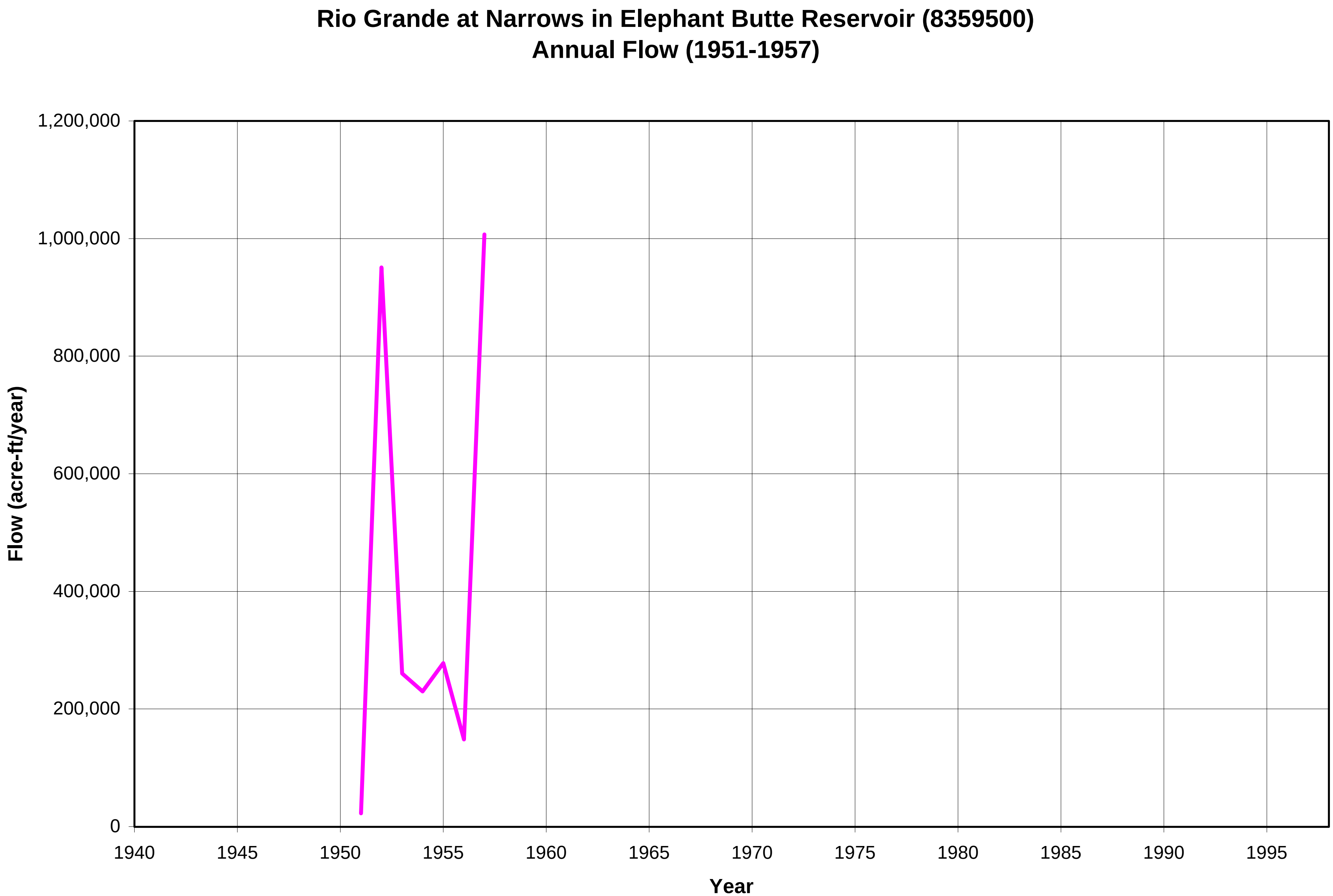


Figure B-1.19



10/3/00

Figure B-1.20

8359500_yearly

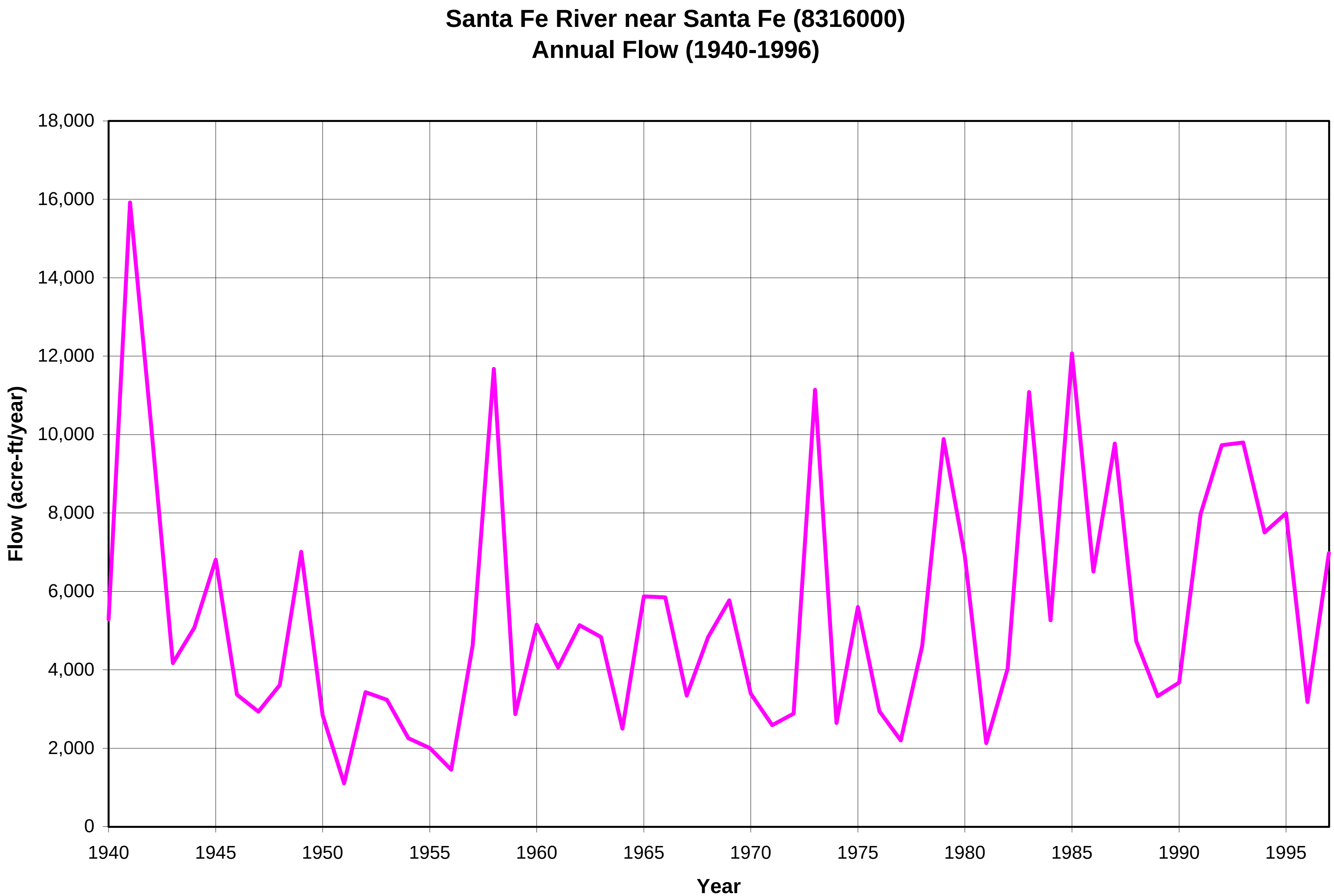
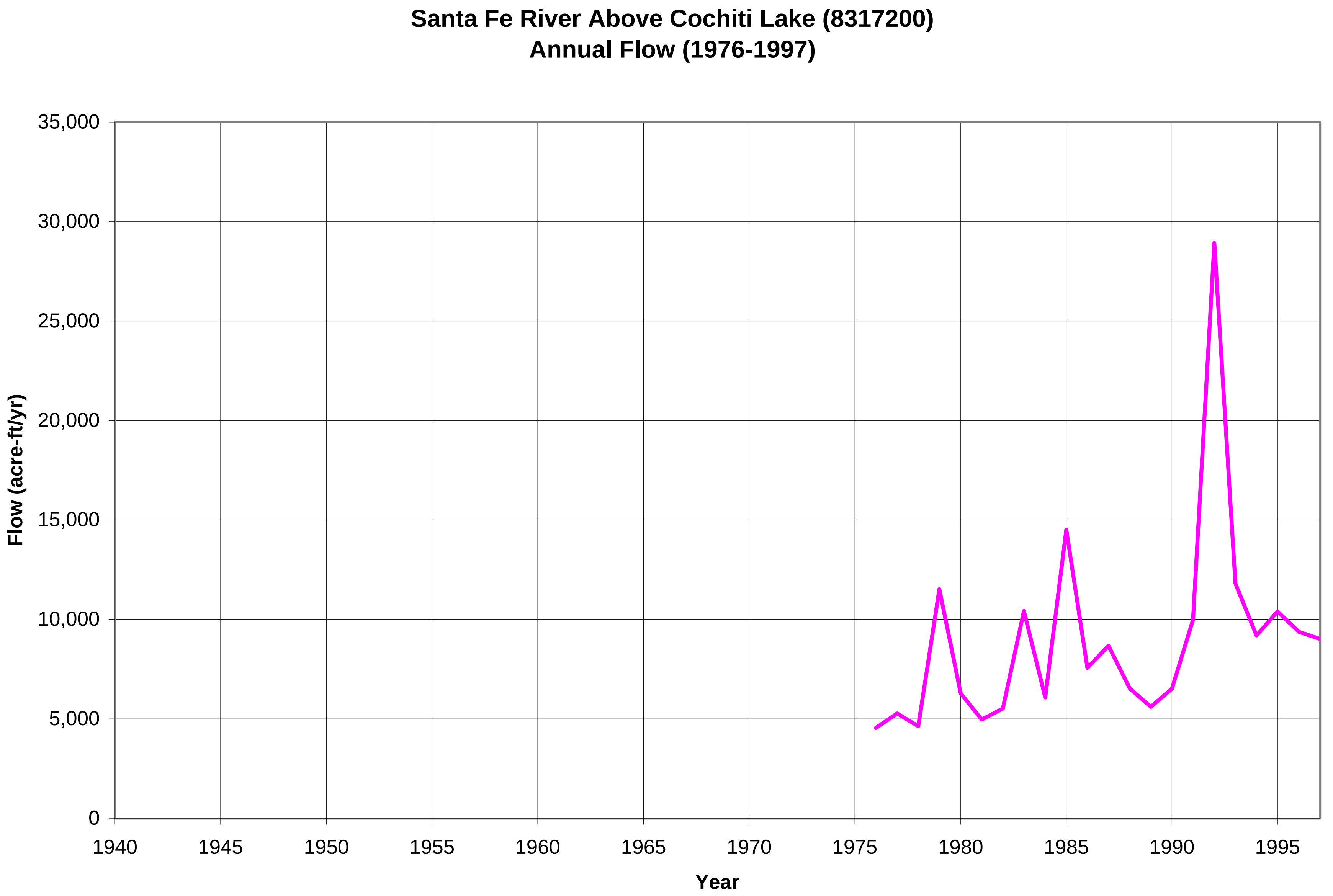

Santa Fe River near Santa Fe (8316000)
Annual Flow (1940-1996)
Flow (acre-ft/year)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year

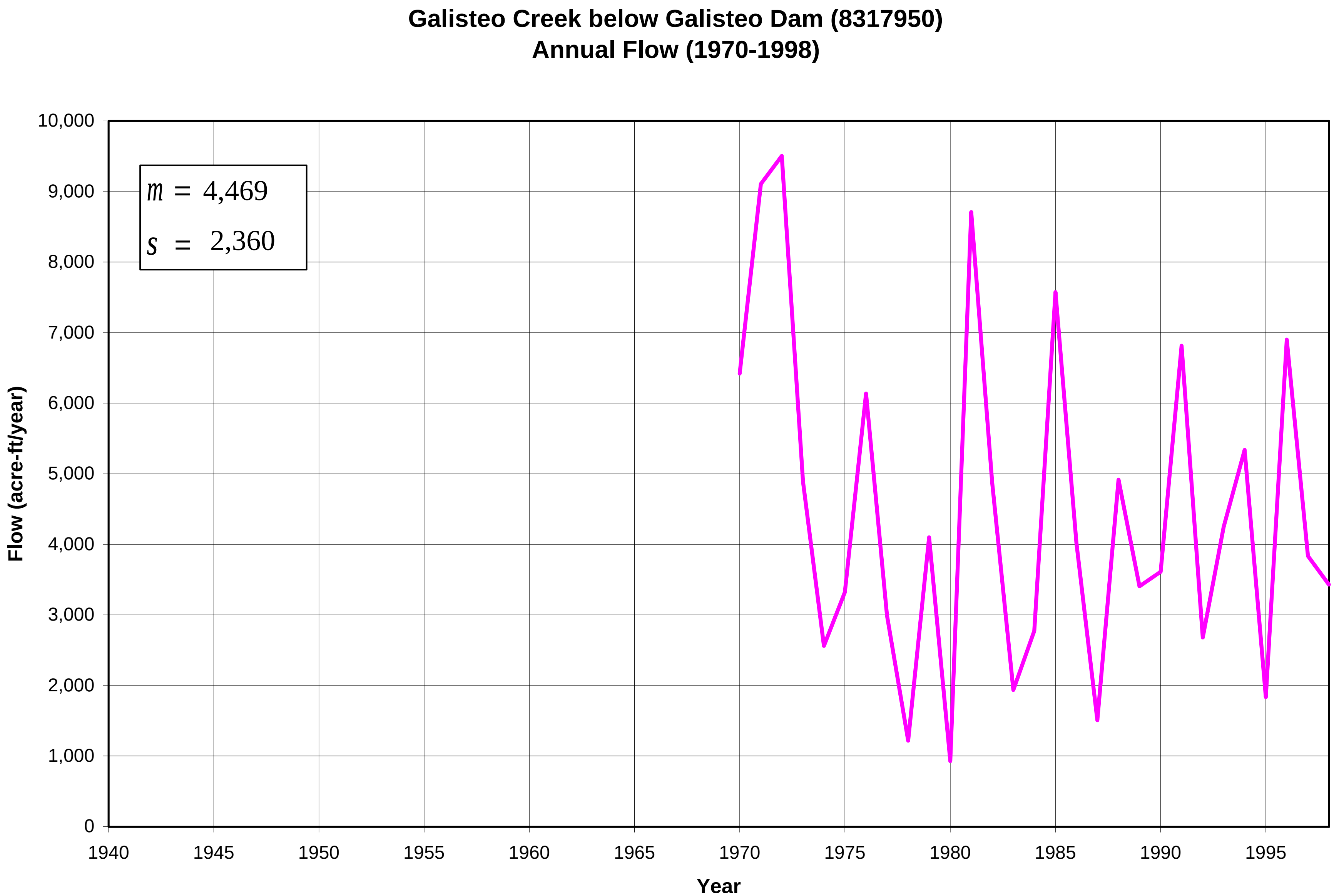
Figure B-2.1



10/3/00

Figure B-2.2

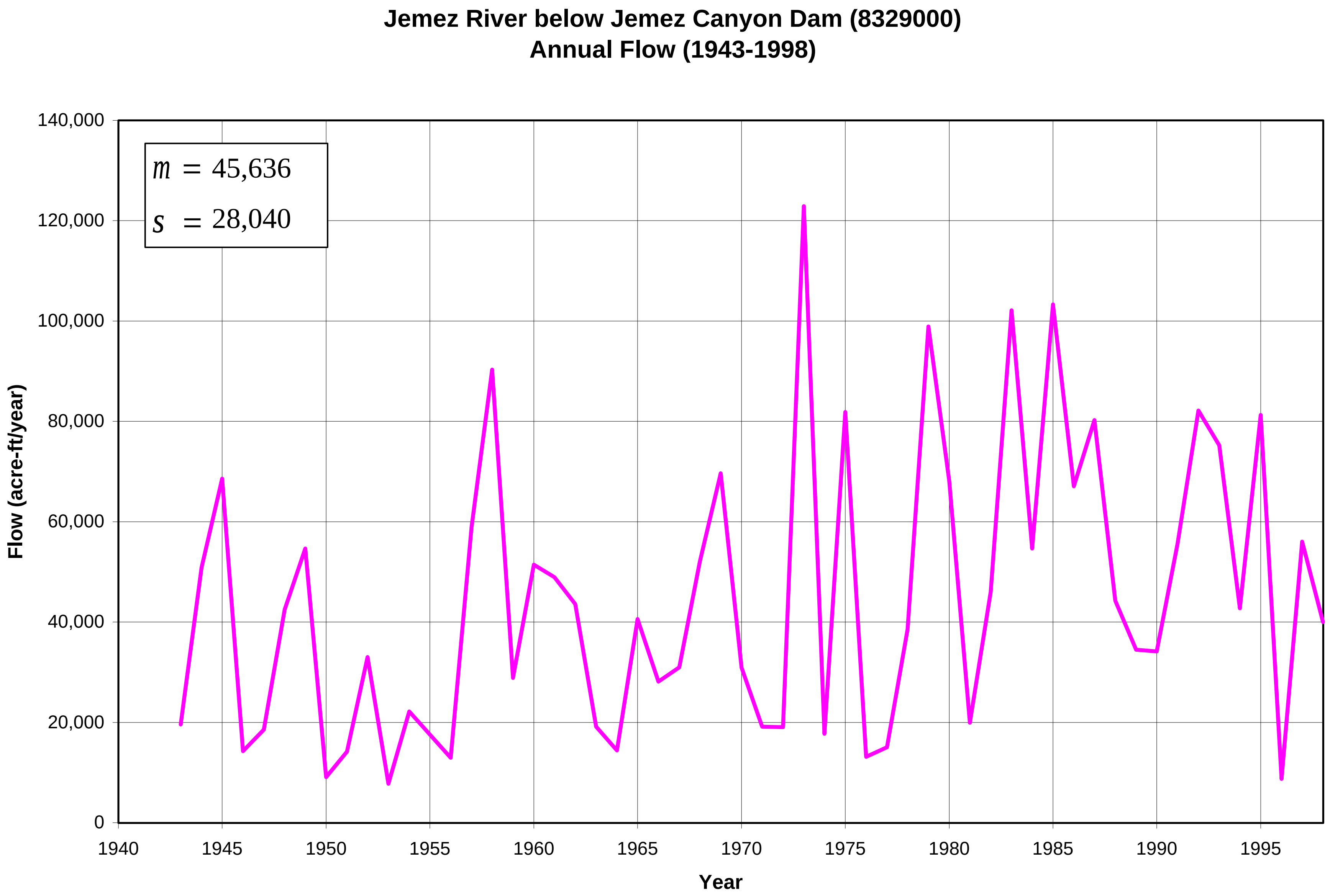
8317200_yearly



10/3/00

Figure B-2.3

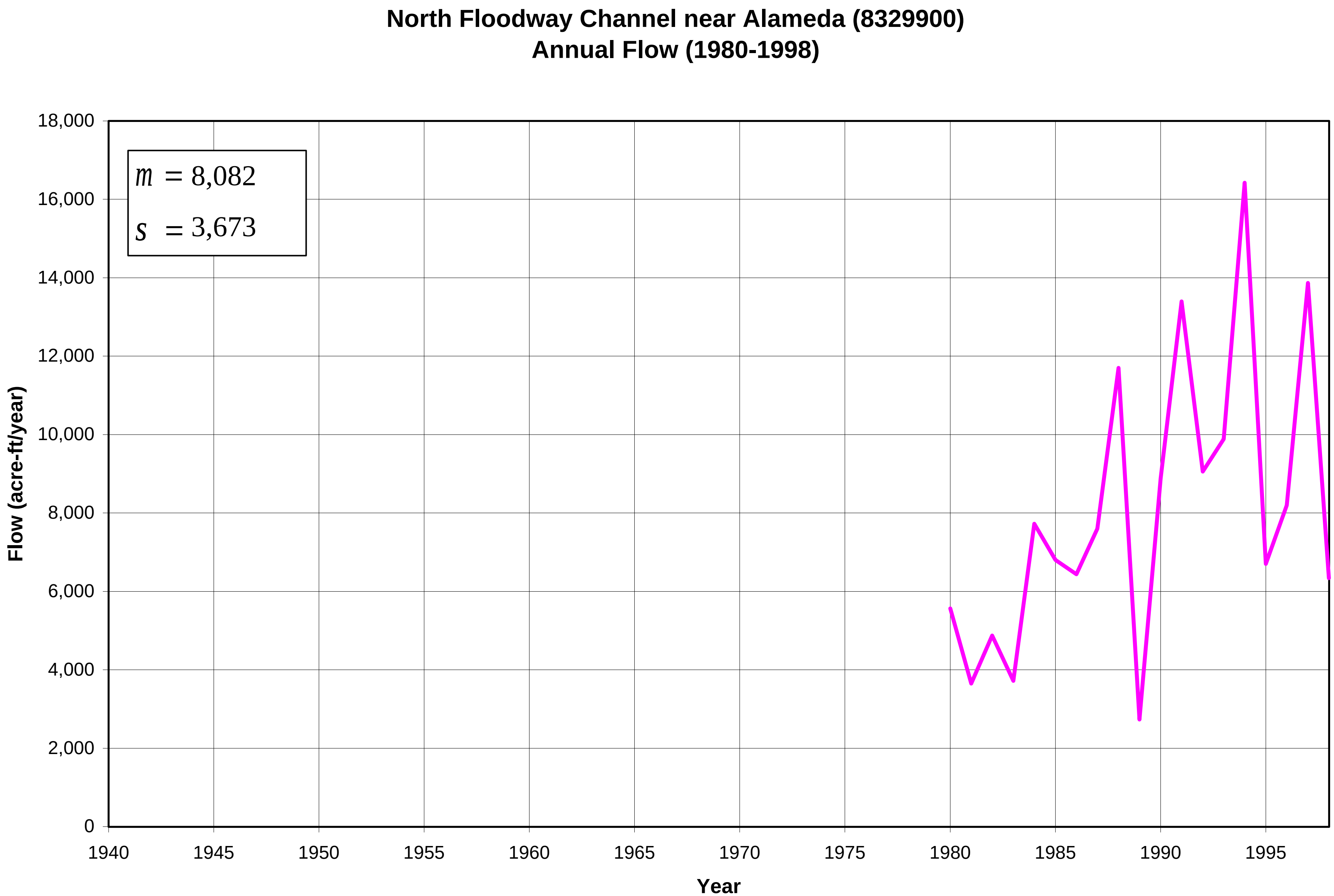
8317950_yearly



10/3/00

Figure B-2.4

8329000_yearly



10/3/00

Figure B-2.5

8329900_yearly

South Diversion Channel above Tijeras Arroyo near Albuquerque (8330775)
Annual Flow (1988-1998)

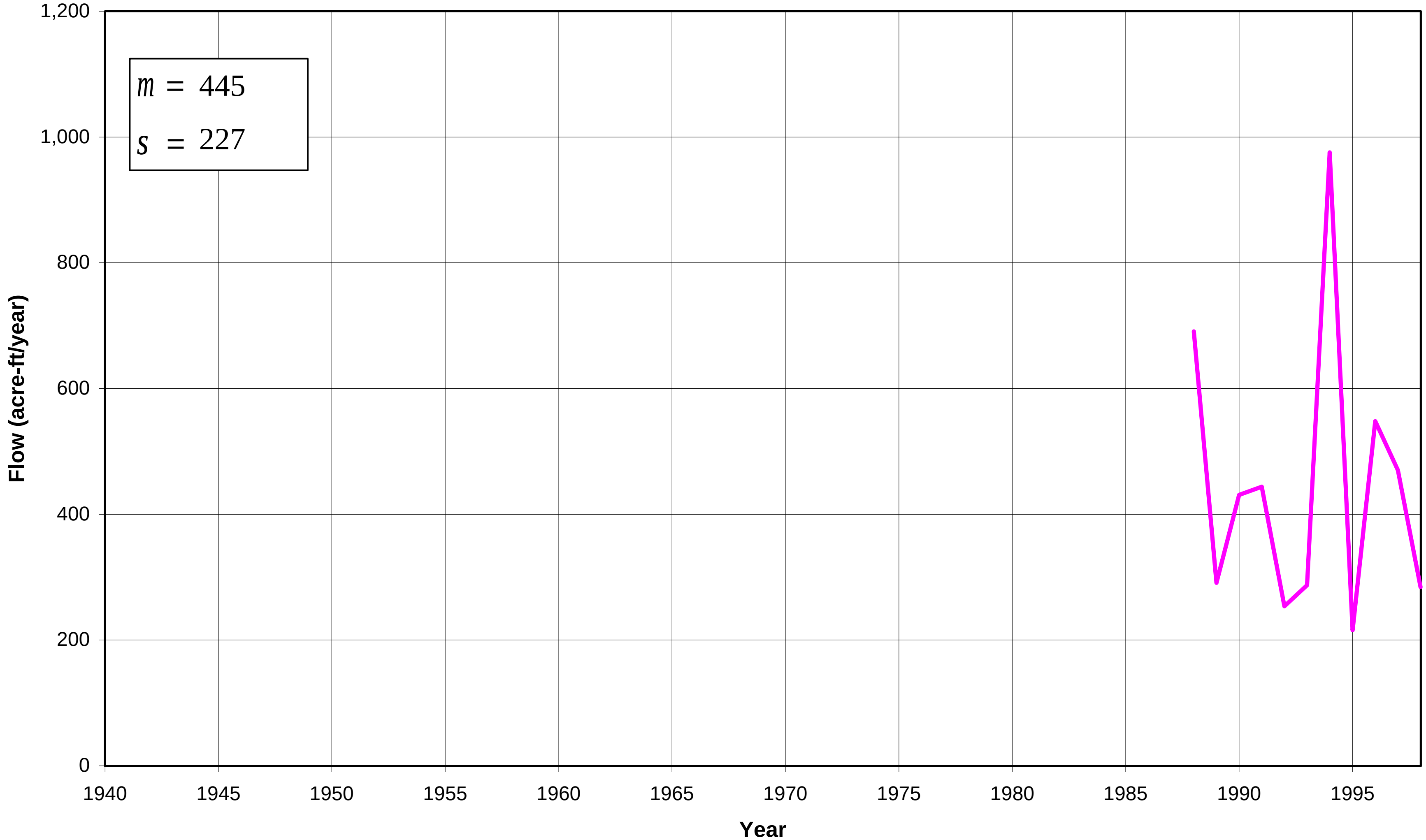
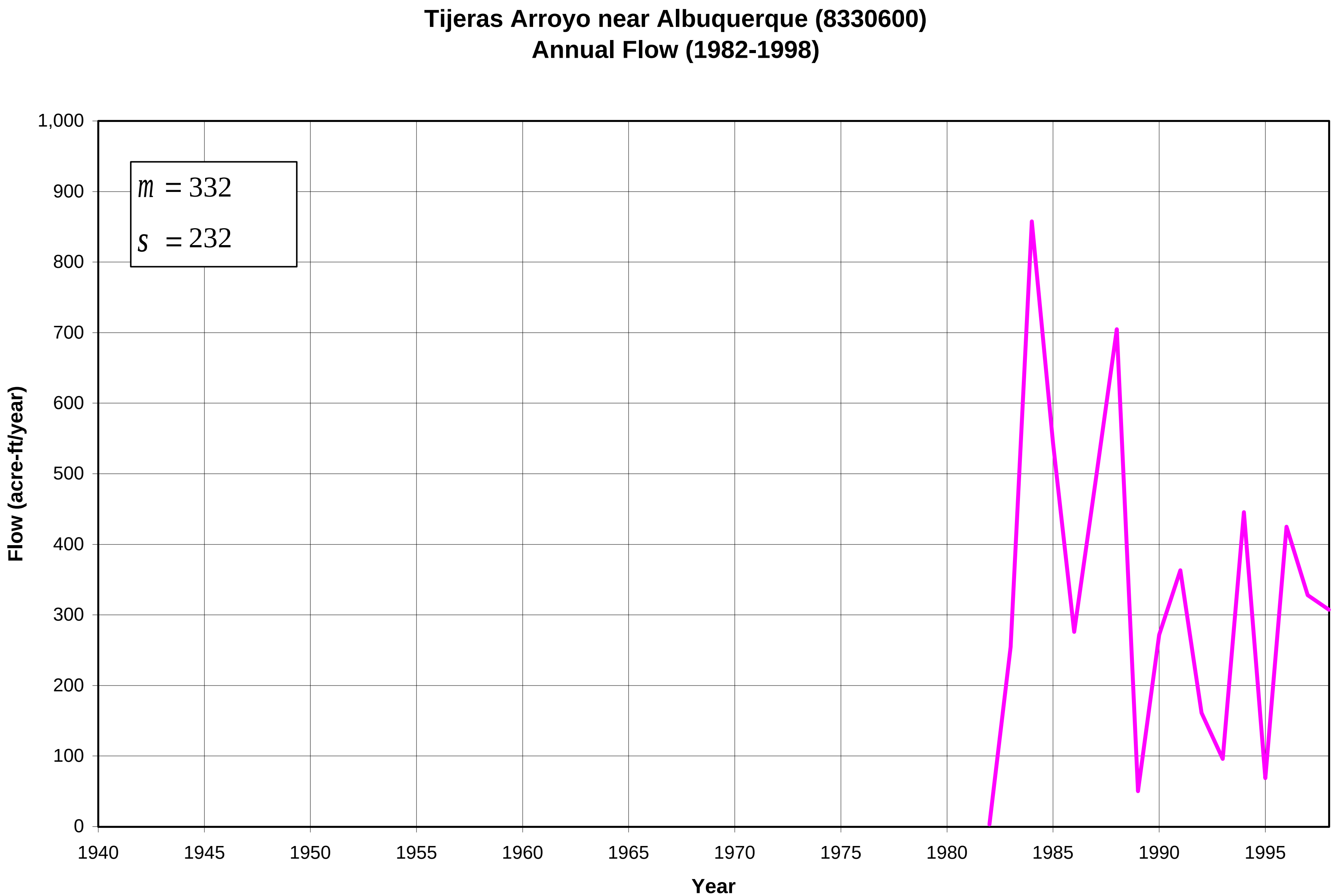


Figure B-2.6



10/3/00

Figure B-2.7

8330600_yearly

Tijeras Arroyo below South Diversion Inlet near Albuquerque (8330800)
Annual Flow (1976-1988)

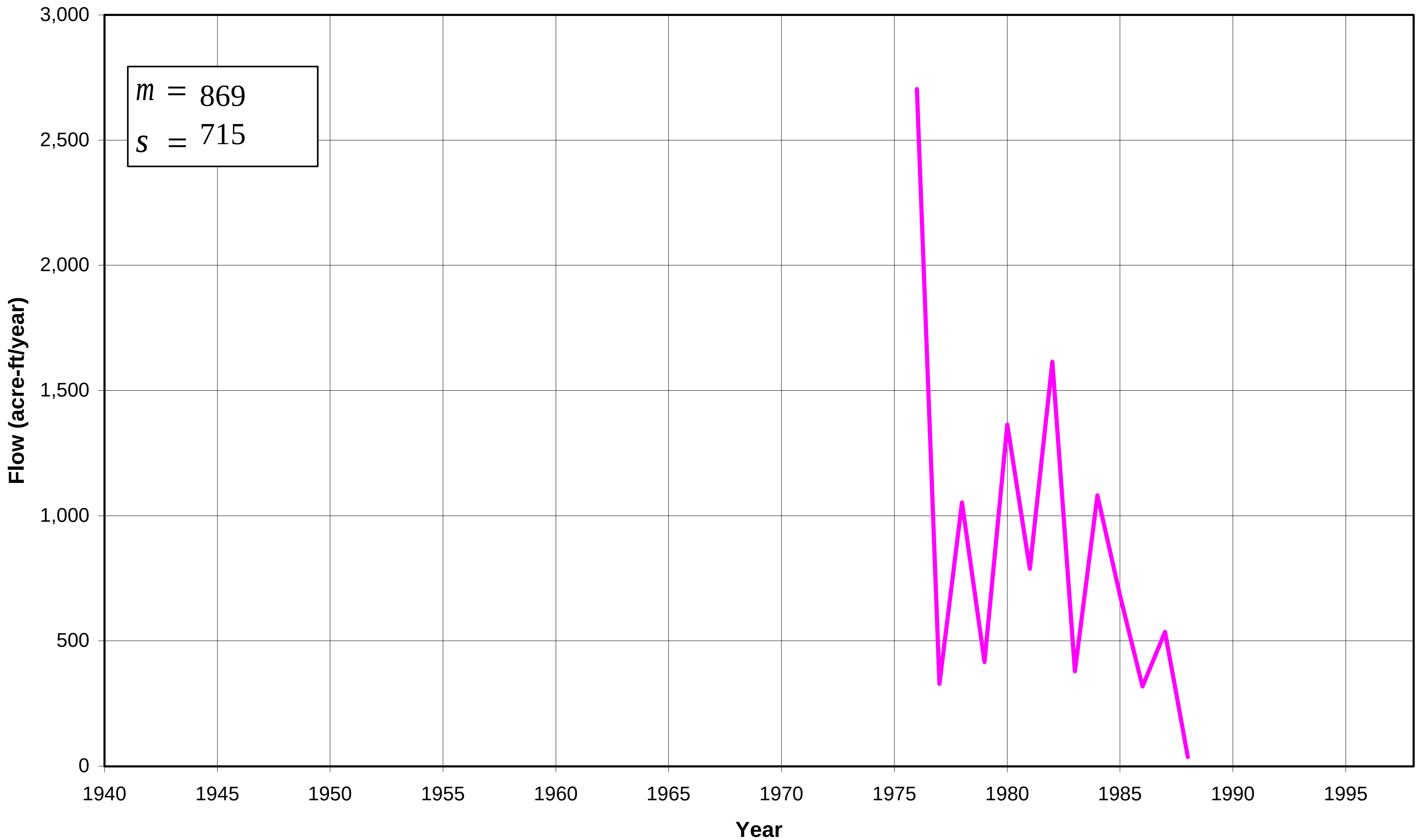


Figure B-2.8

Rio Puerco near Bernardo (8353000)
Annual Flow (1940-1998)

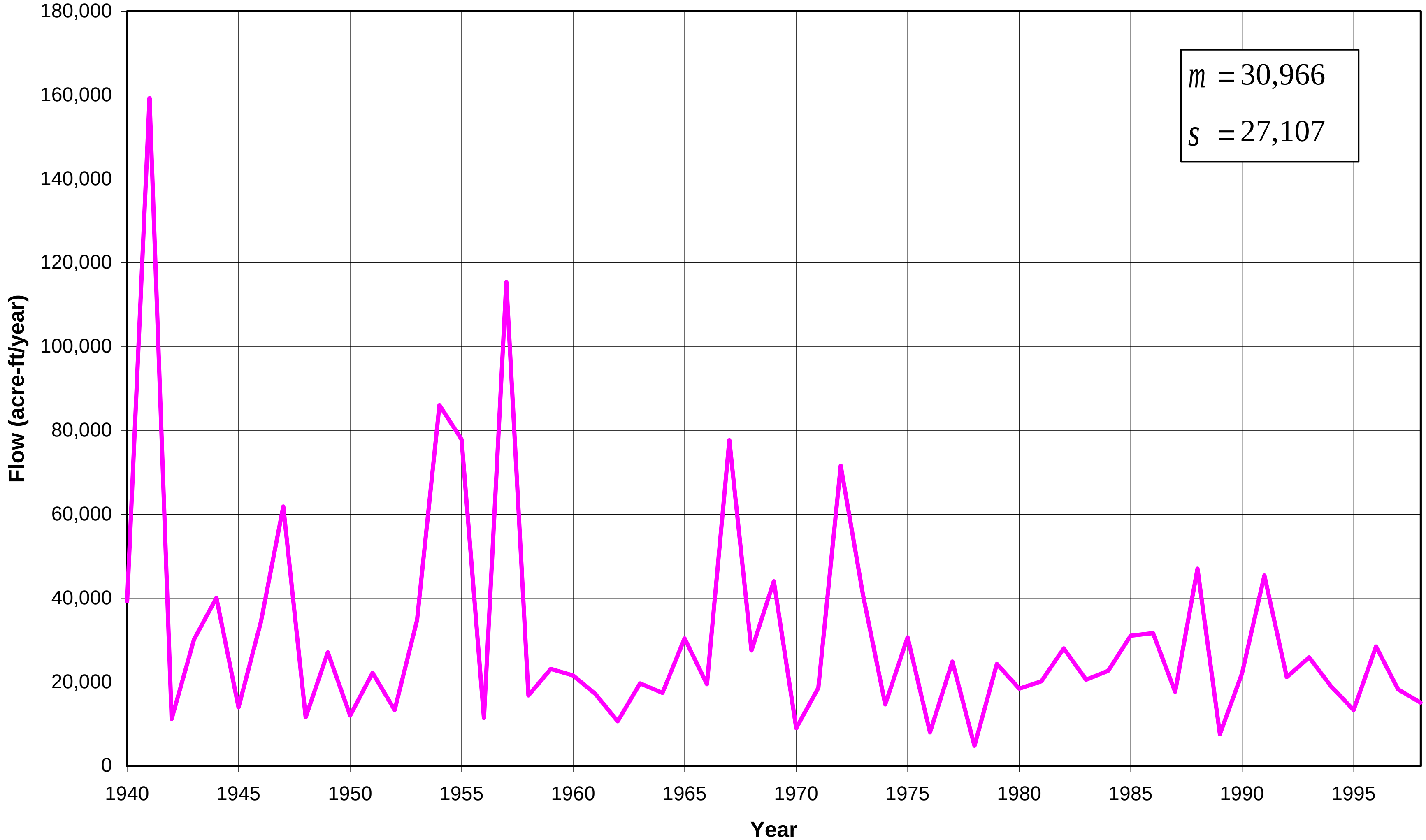
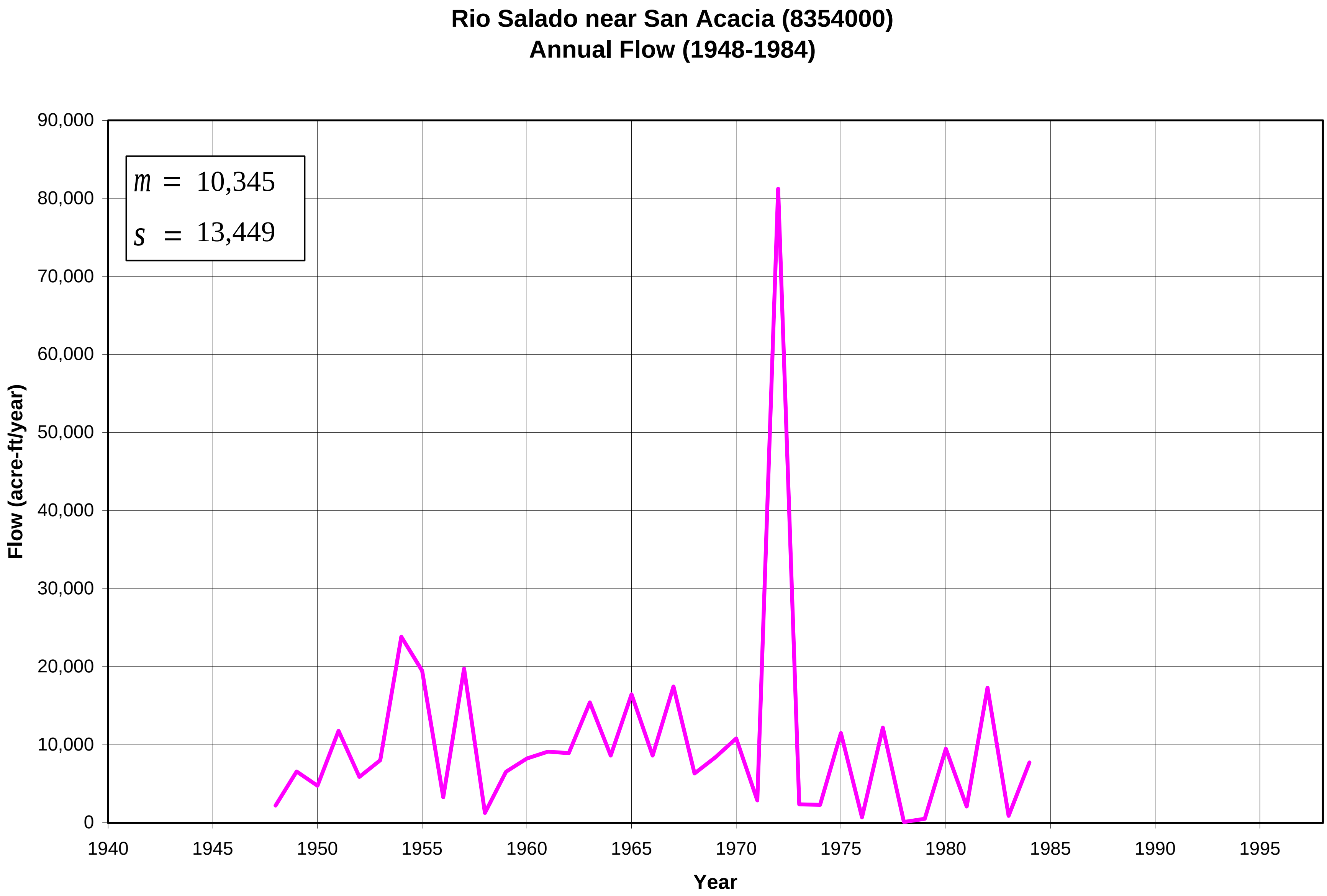


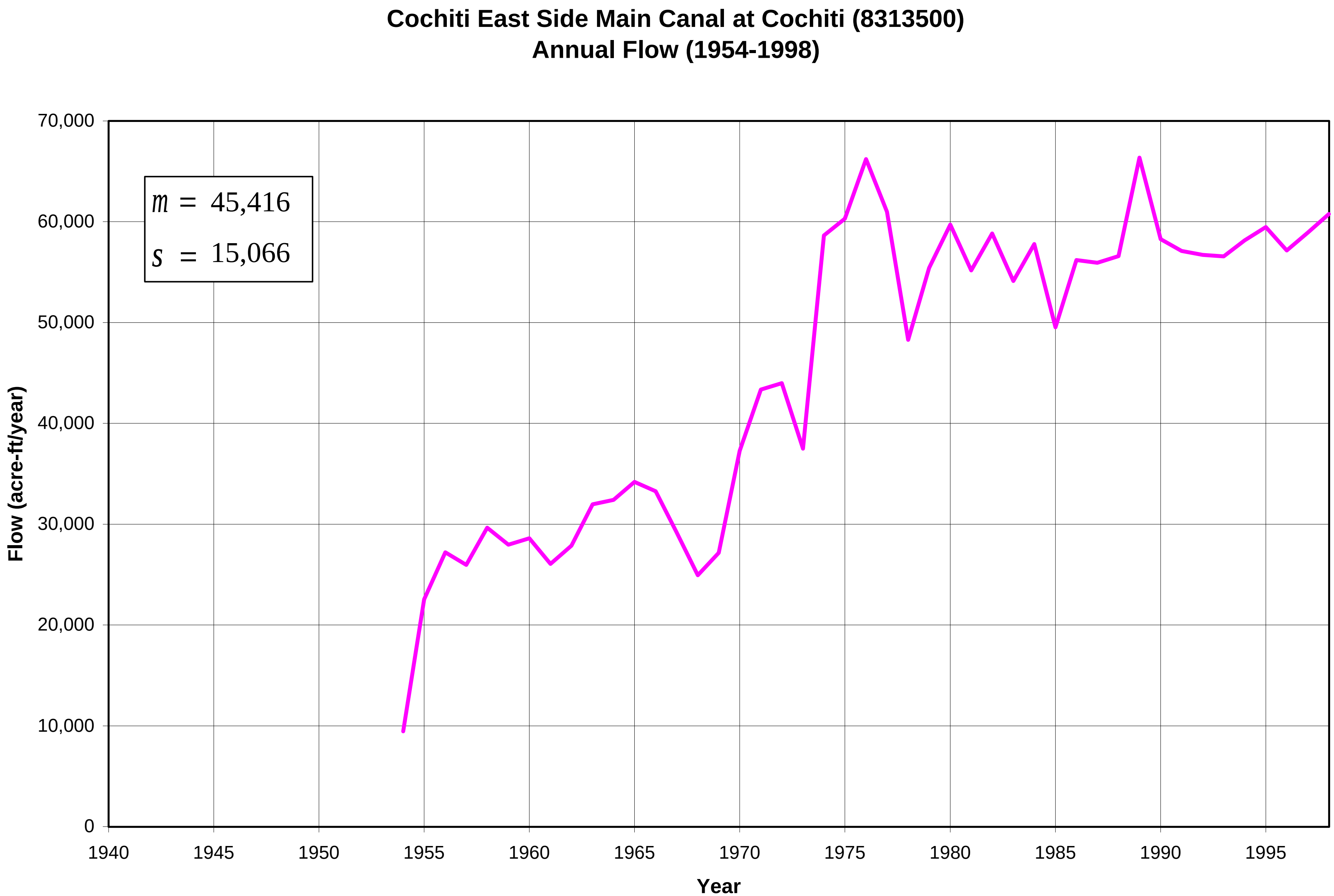
Figure B-2.9



10/3/00

Figure B-2.10

8354000_yearly



10/3/00

Figure B-3.1

8313500_yearly

Sili Main Canal (at head) at Cochiti (8314000)
Annual Flow (1954-1998)

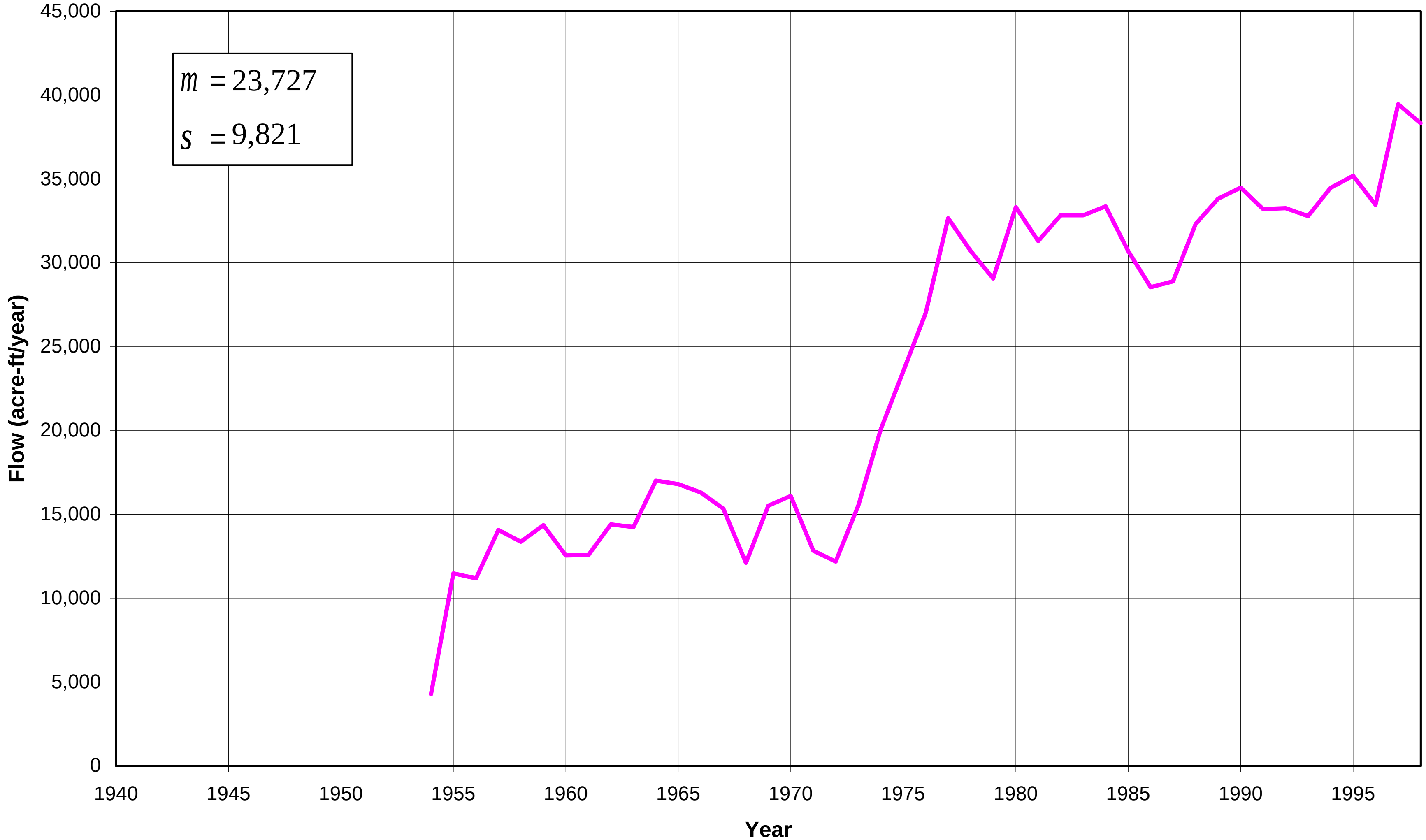
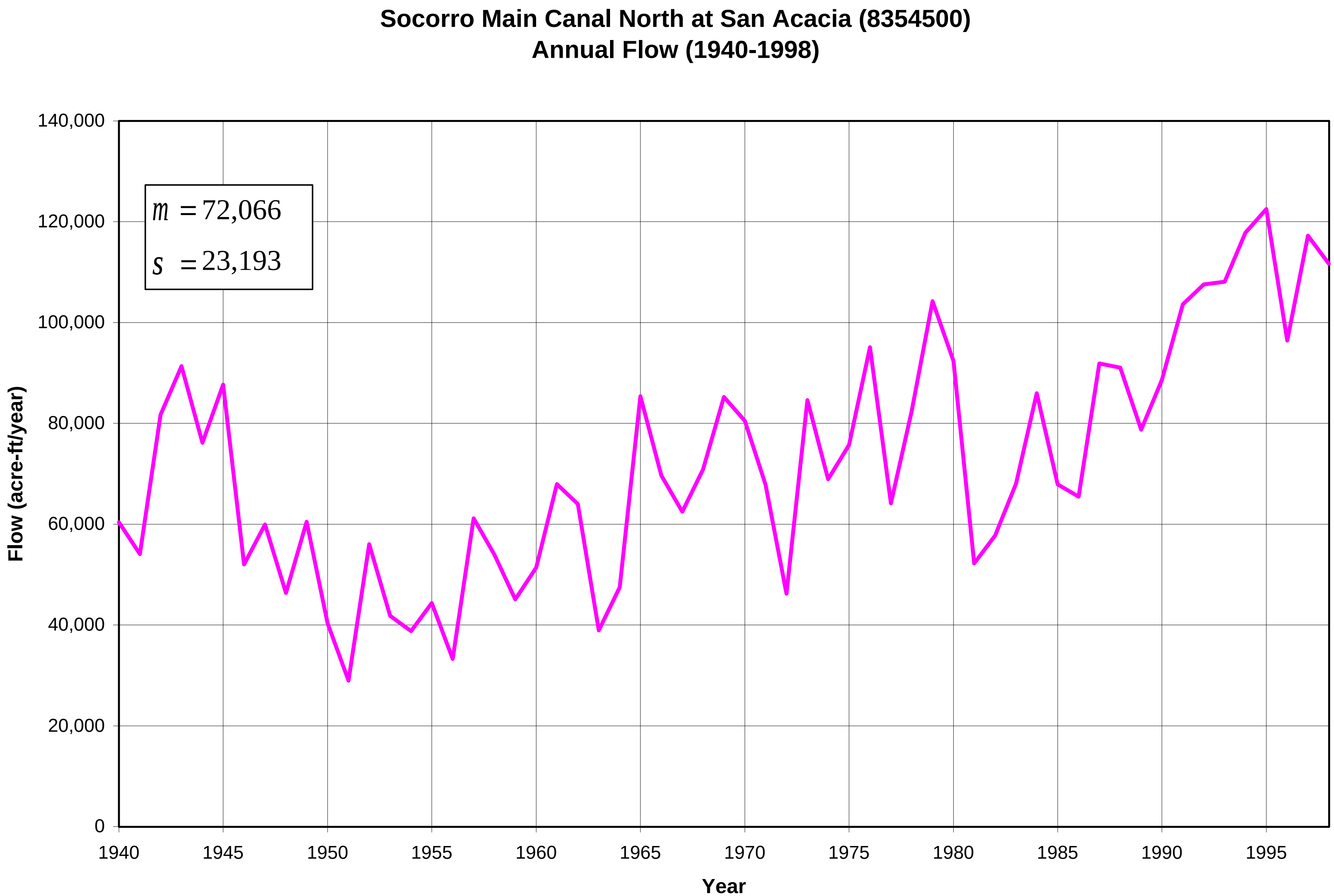


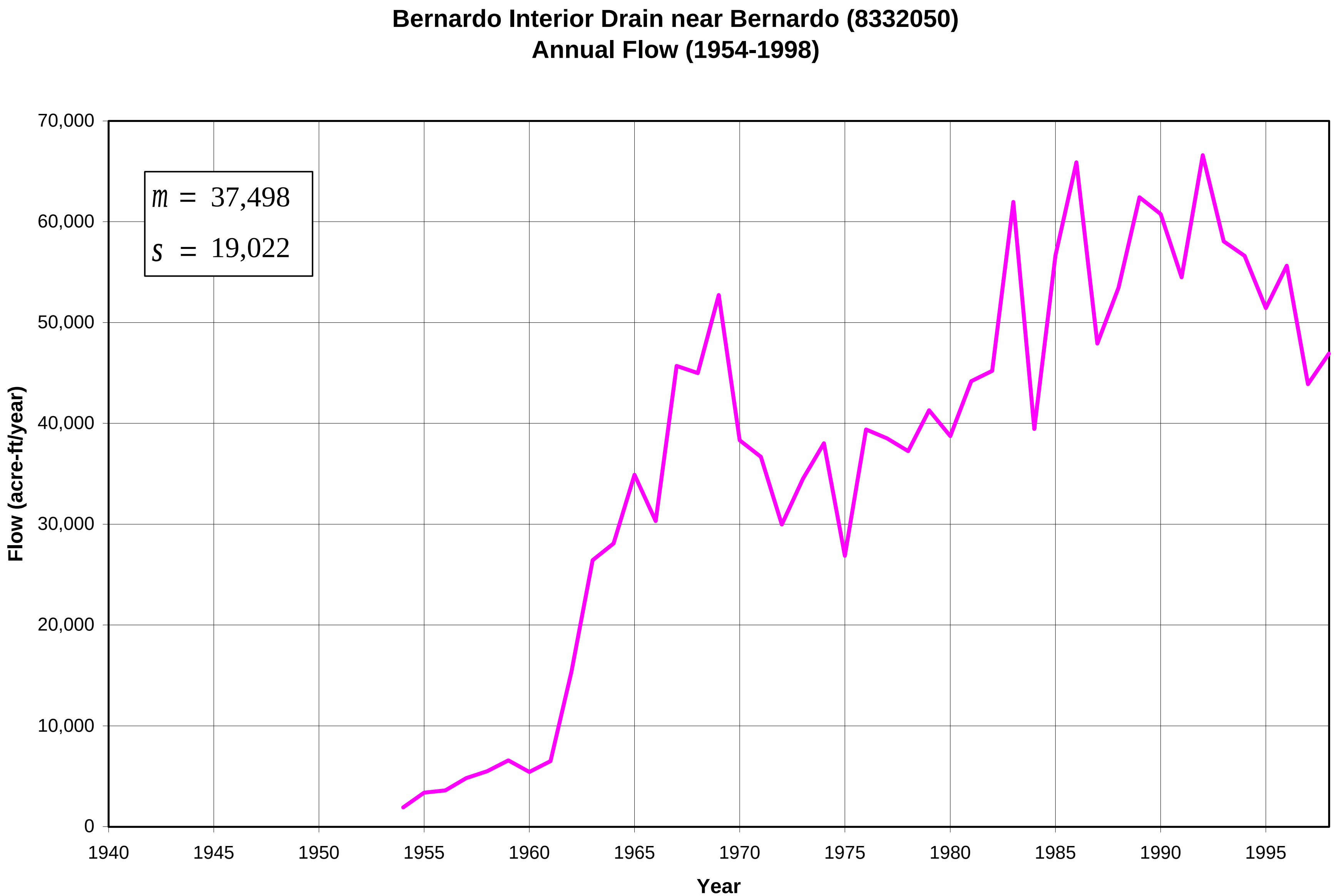
Figure B-3.2



10/3/00

Figure B-3.3

8354500_yearly



Bernardo Interior Drain near Bernardo (8332050)
Annual Flow (1954-1998)
m = 37,498
s = 19,022
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Flow (acre-ft/year)
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year

Figure B-4.1

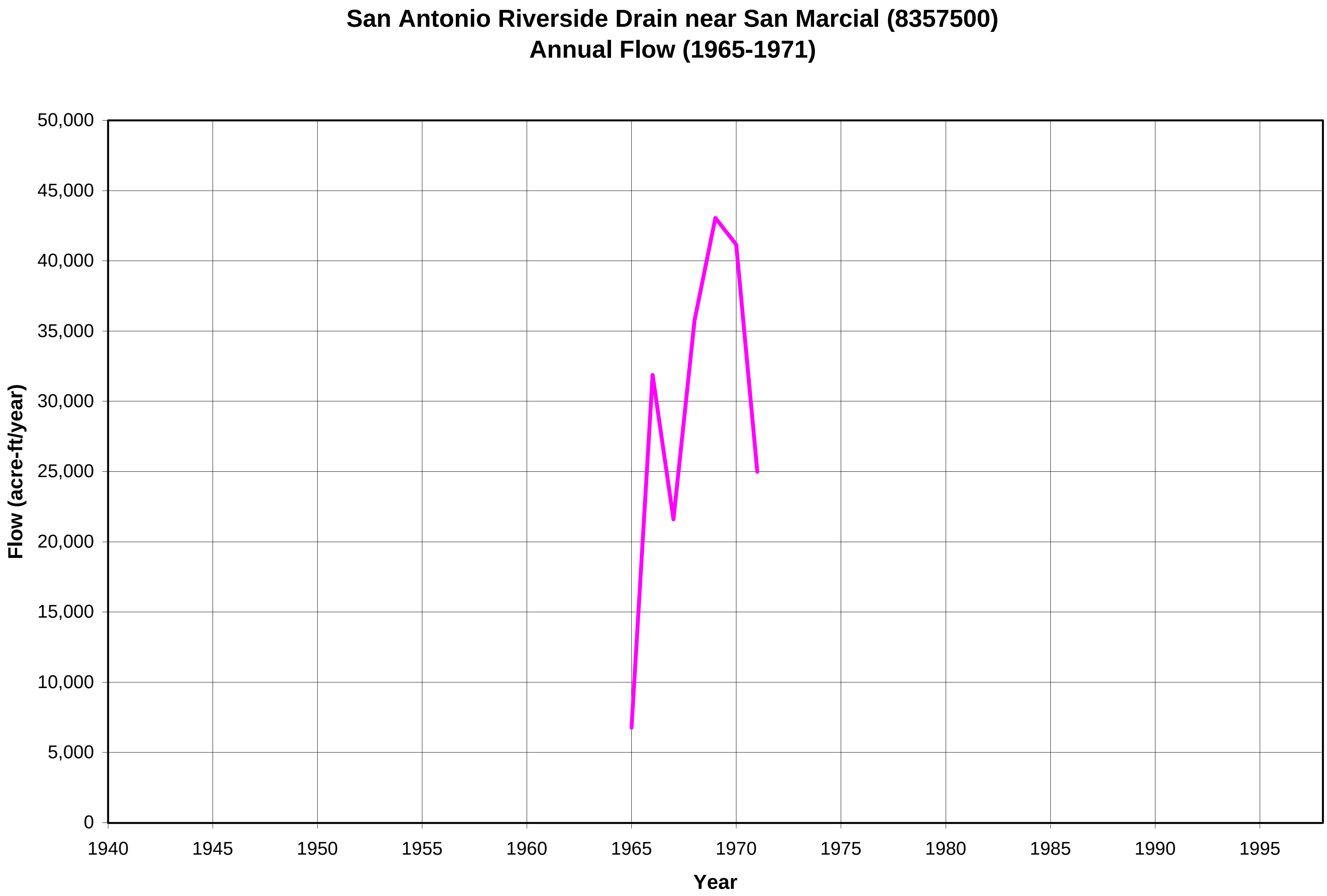
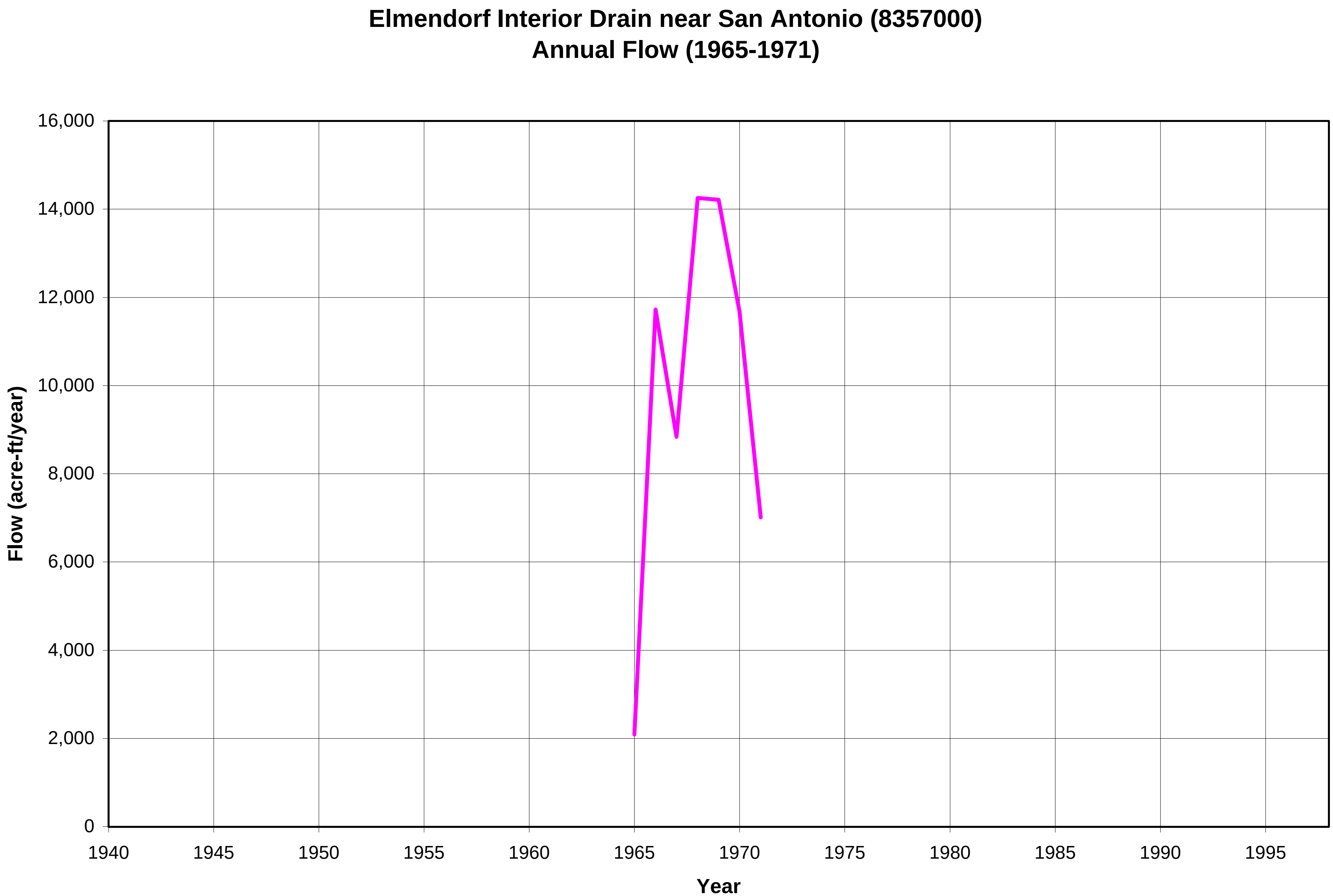
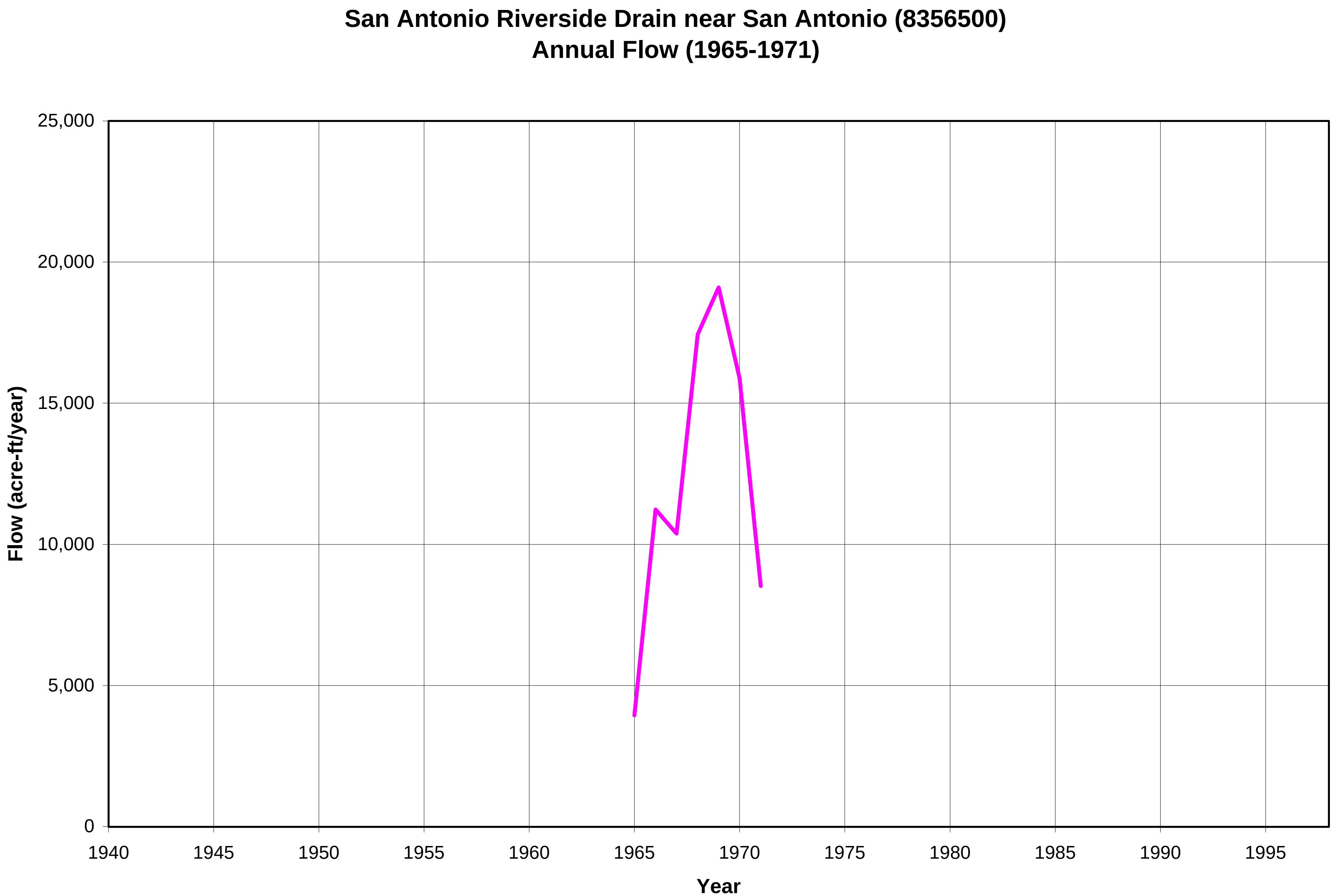

San Antonio Riverside Drain near San Marcial (8357500)
Annual Flow (1965-1971)
Flow (acre-ft/year)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year

Figure B-4.2



Elmendorf Interior Drain near San Antonio (8357000)
Annual Flow (1965-1971)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Flow (acre-ft/year)
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year

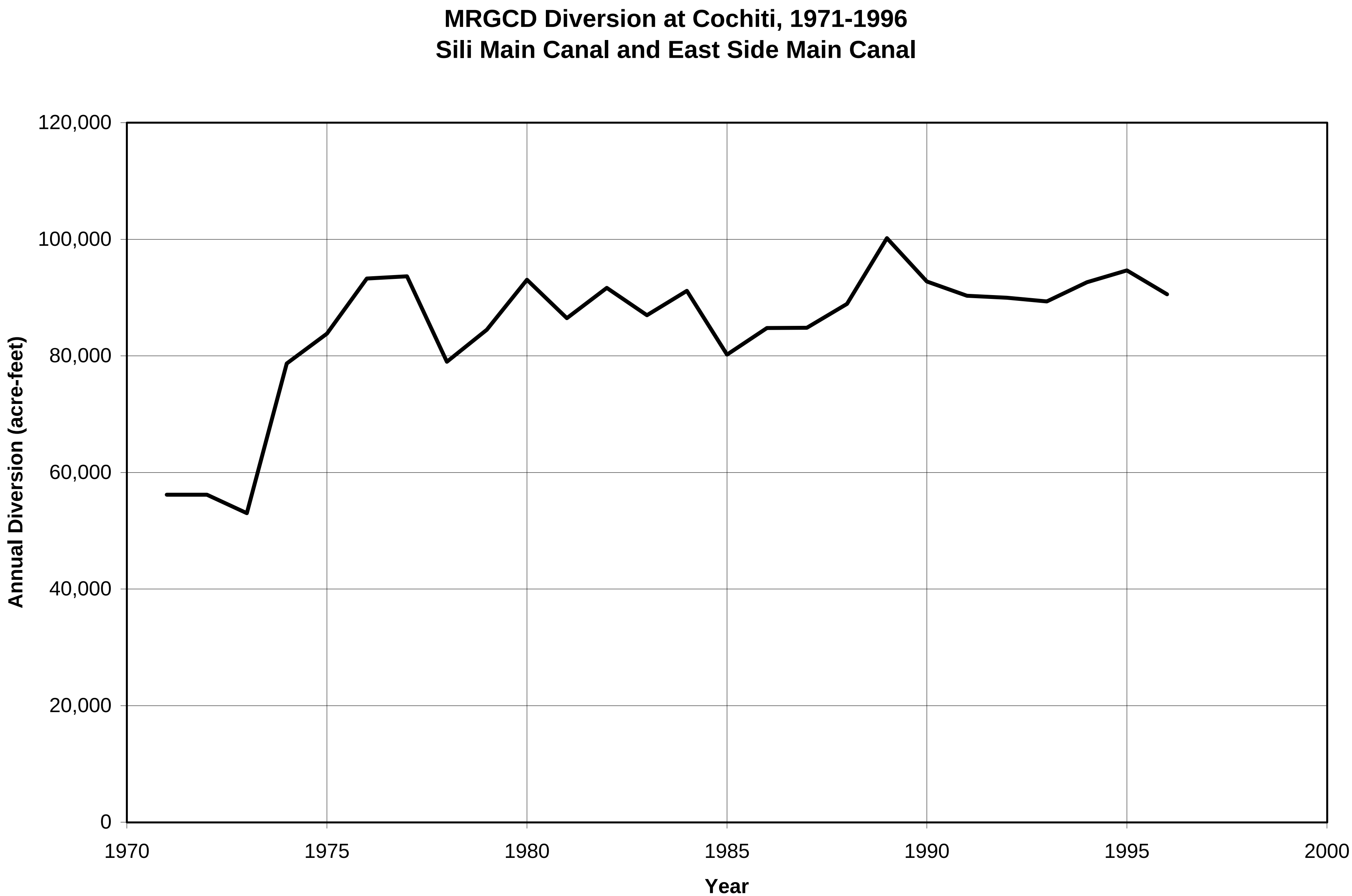
Figure B-4.3



10/3/00

Figure B-4.4

8356500_yearly



10/3/00

Figure B-5.1

cochiti_dam_diversion

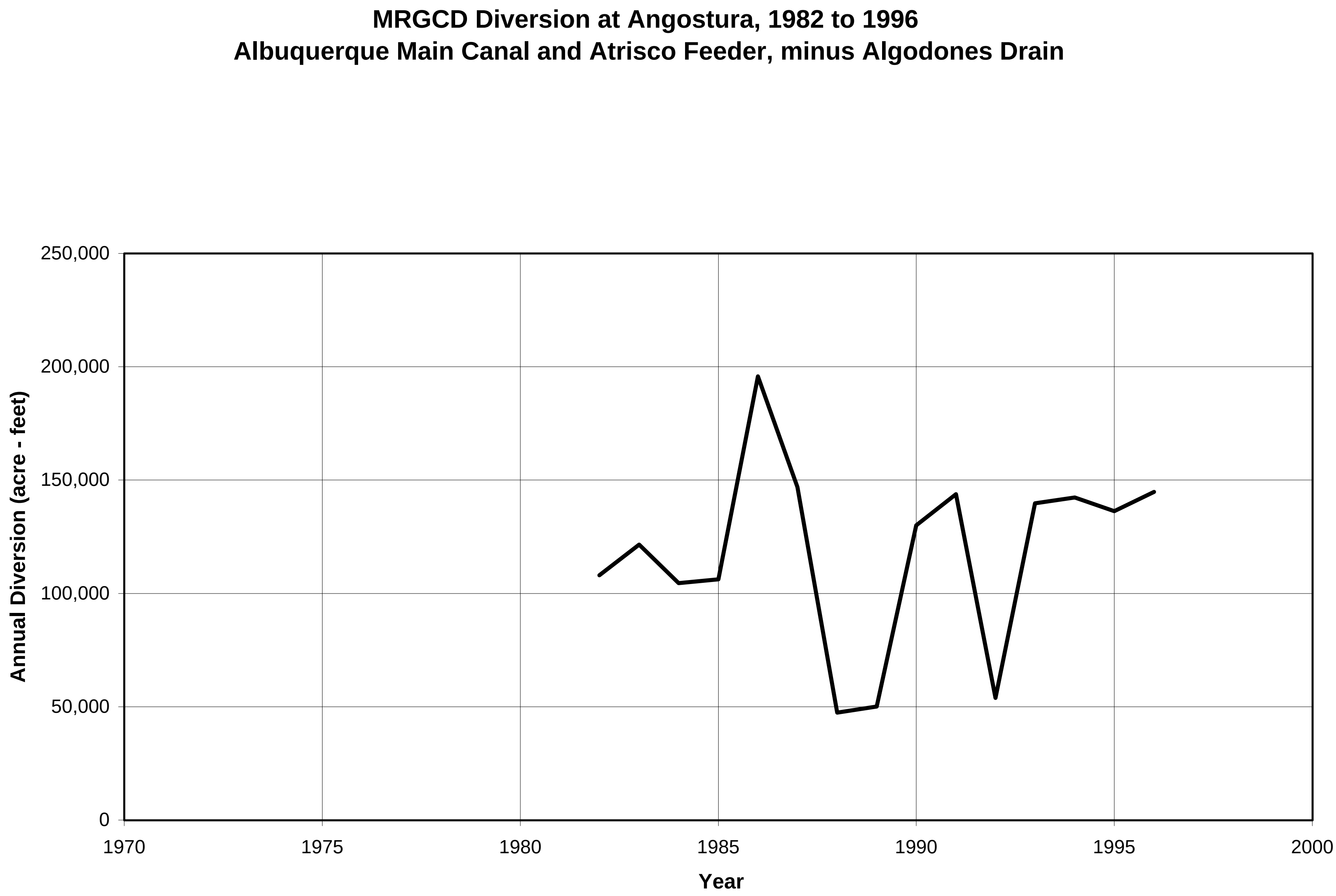
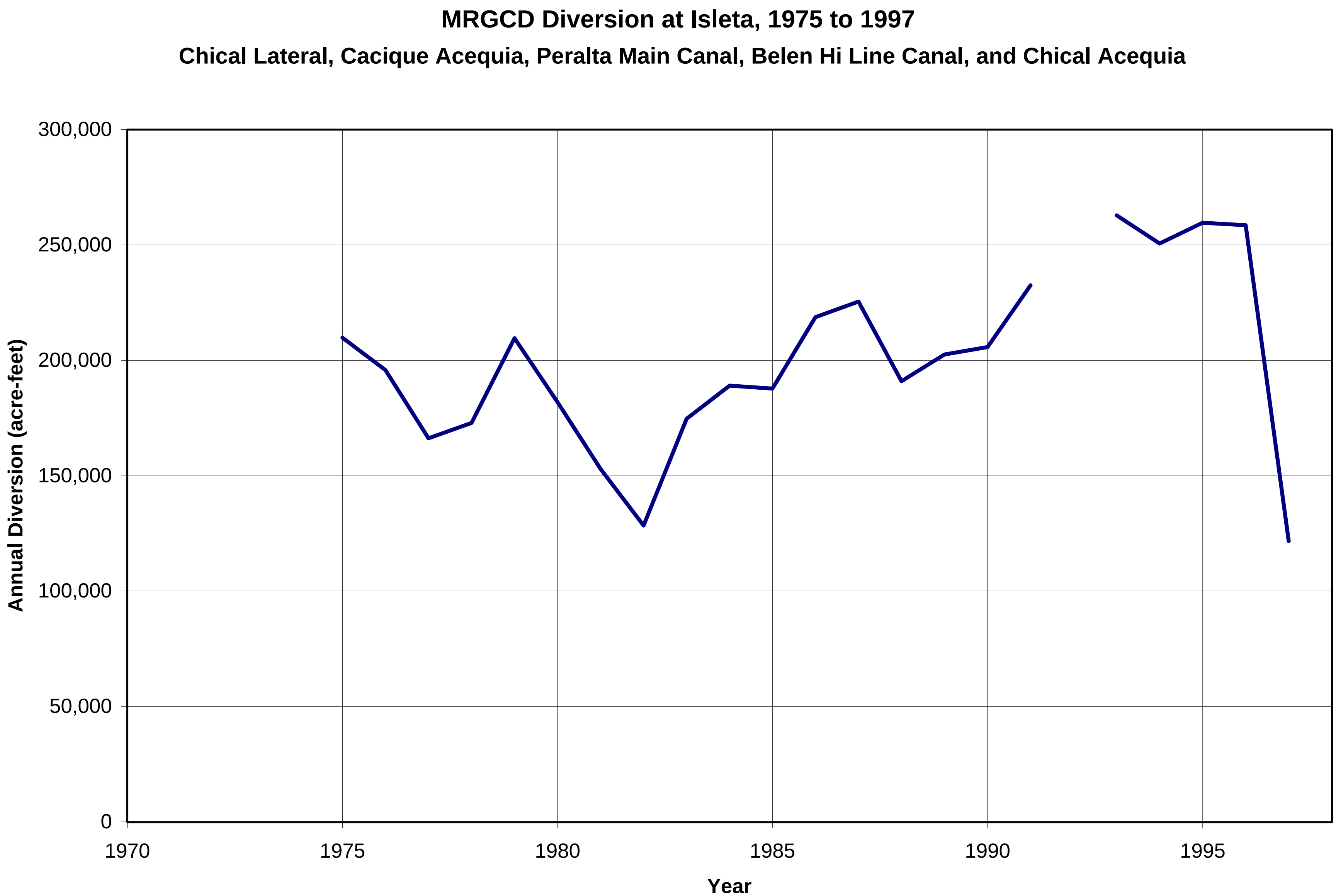

MRGCD Diversion at Angostura, 1982 to 1996
Albuquerque Main Canal and Atrisco Feeder, minus Algodones Drain
250,000
200,000
150,000
100,000
50,000
0
Annual Diversion (acre - feet)
1970
1975
1980
1985
1990
1995
2000
Year

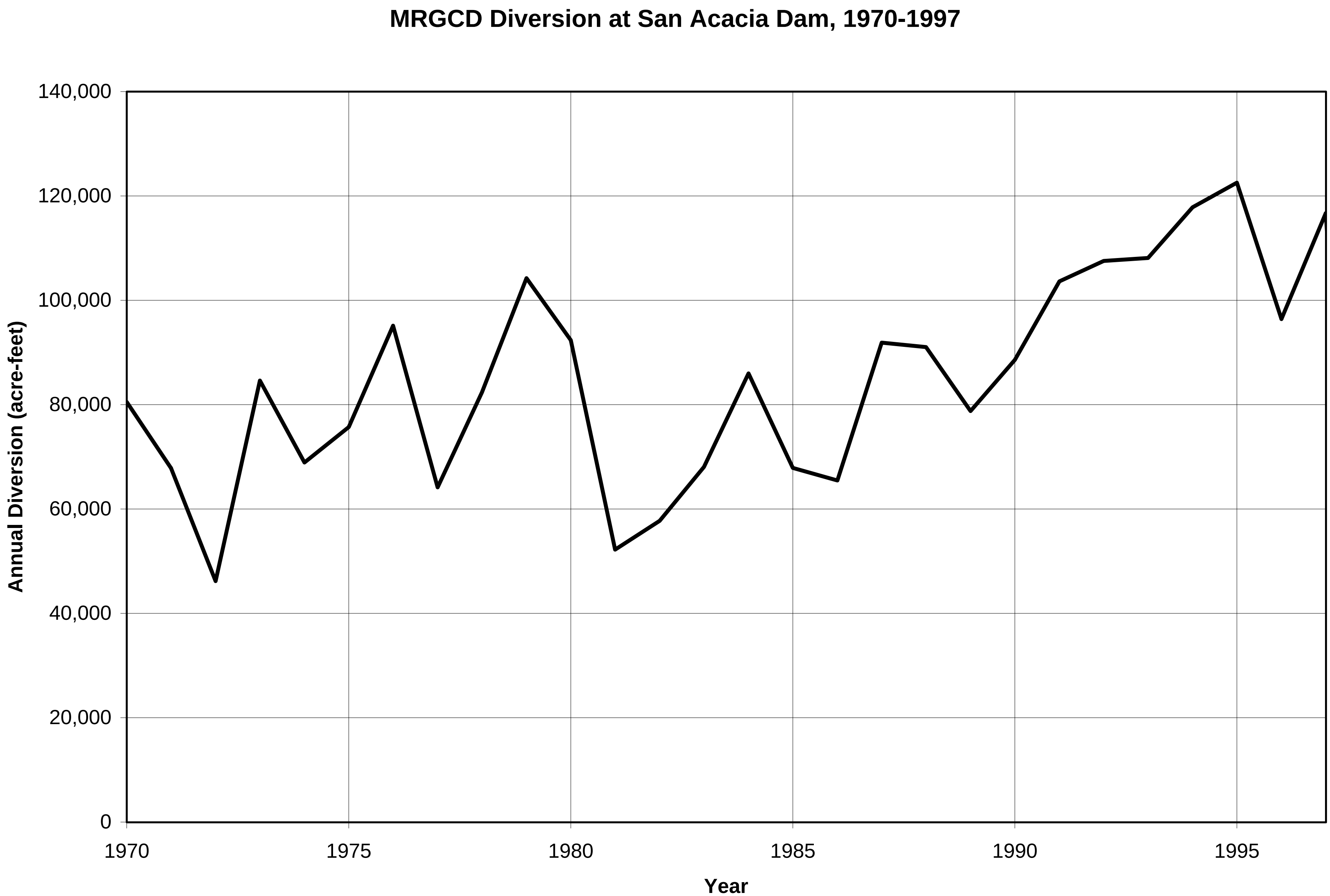
Figure B-5.2



10/3/00

Figure B-5.3

isleta_dam_diversion

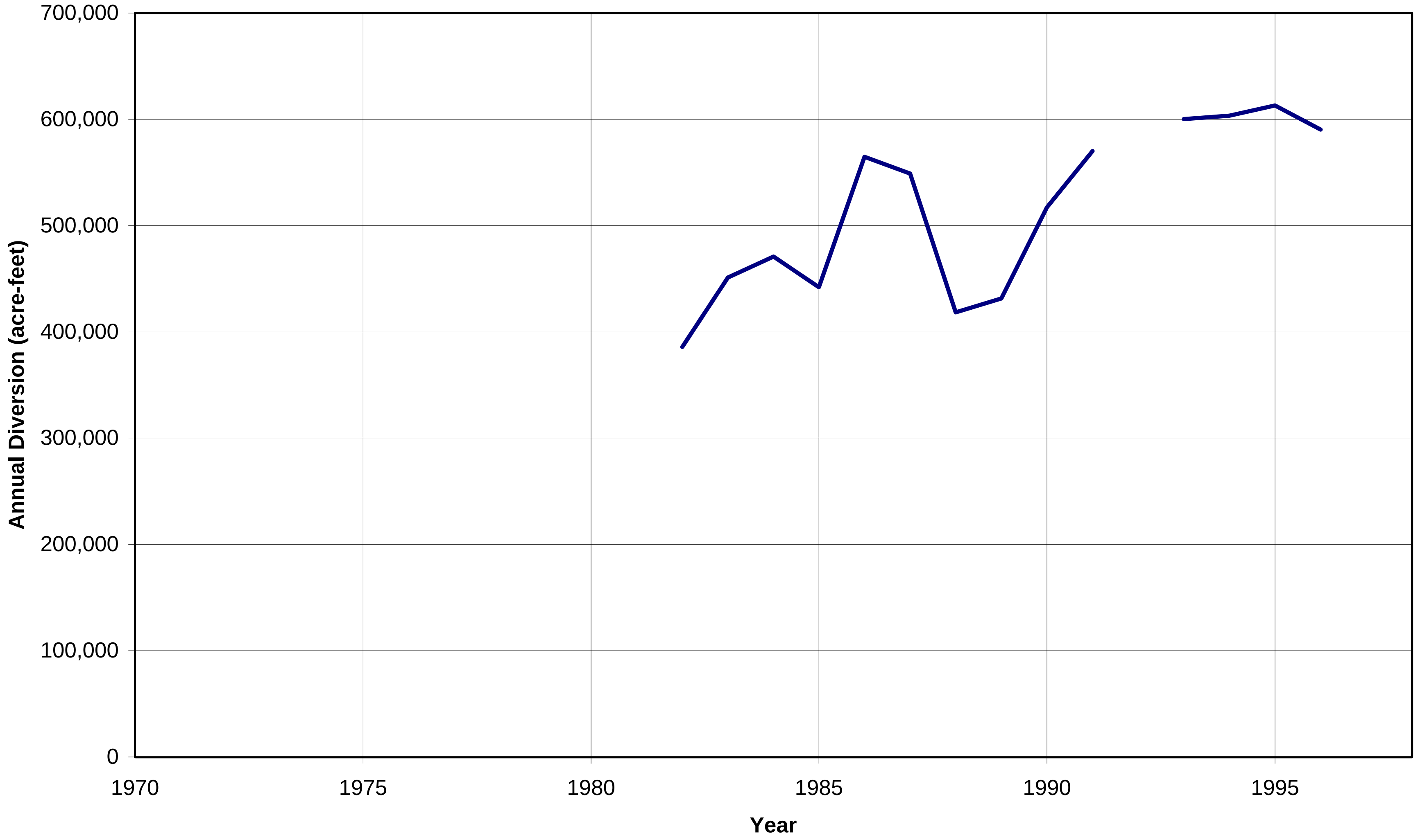


10/3/00

Figure B-5.4

sanacacia_dam_diversion

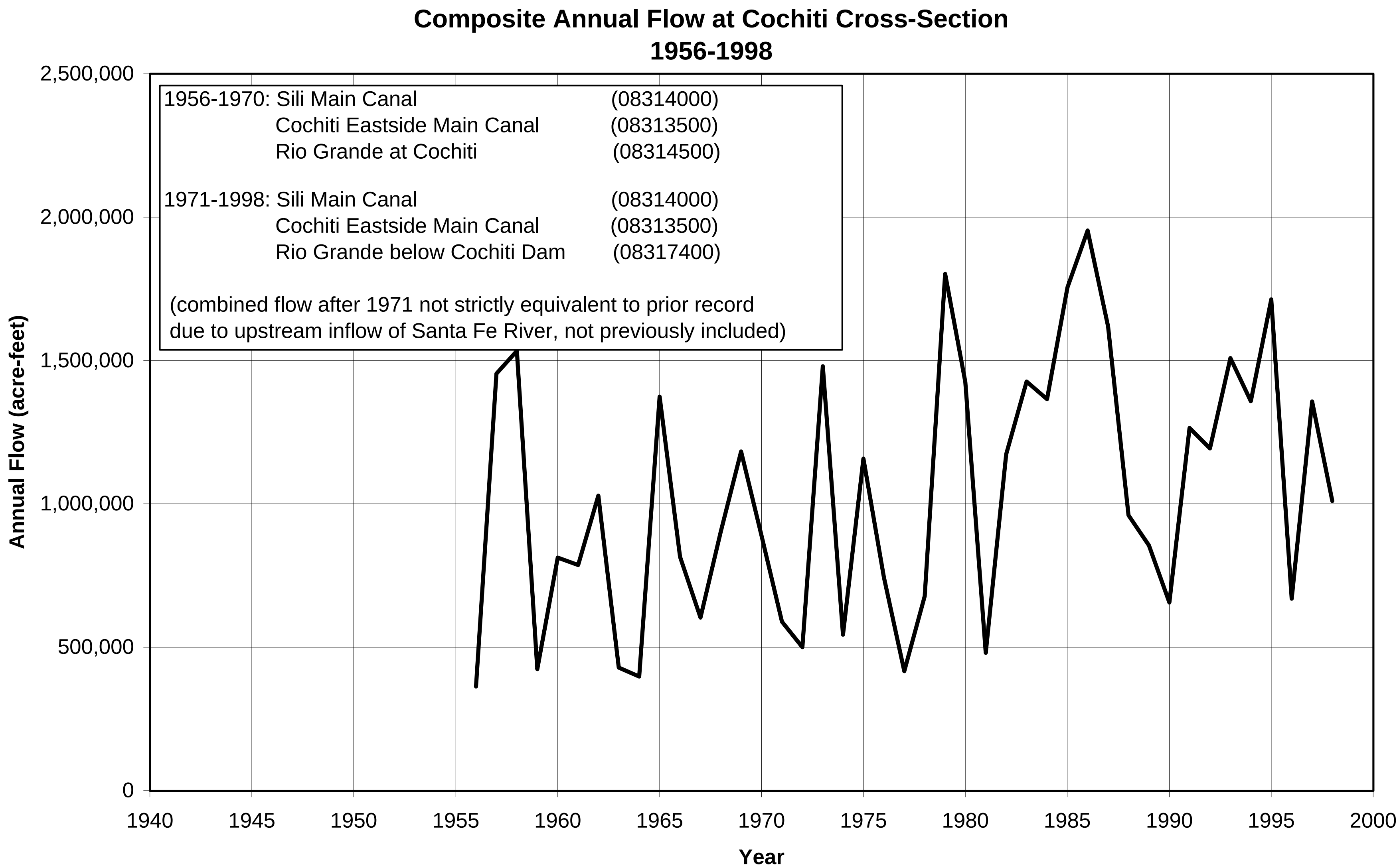
Total of MRGCD Recorded Canal Diversions, 1982 to 1996
Cochiti Dam, Angostura Dam, Isleta Dam, and San Acacia Dam



10/3/00

Figure B-5.5

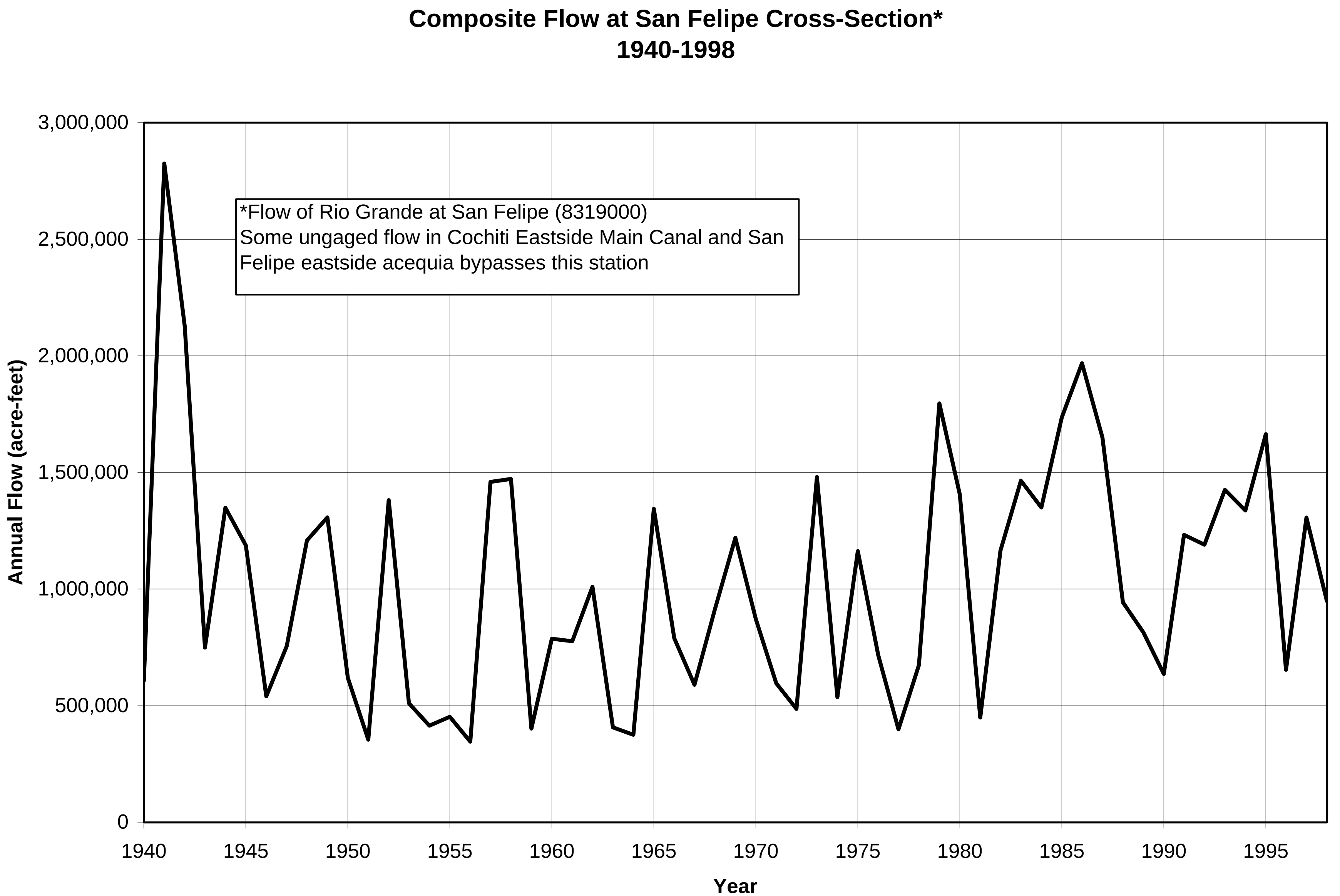
Total_MRGCD_diversions



10/3/00

Figure B-6.1

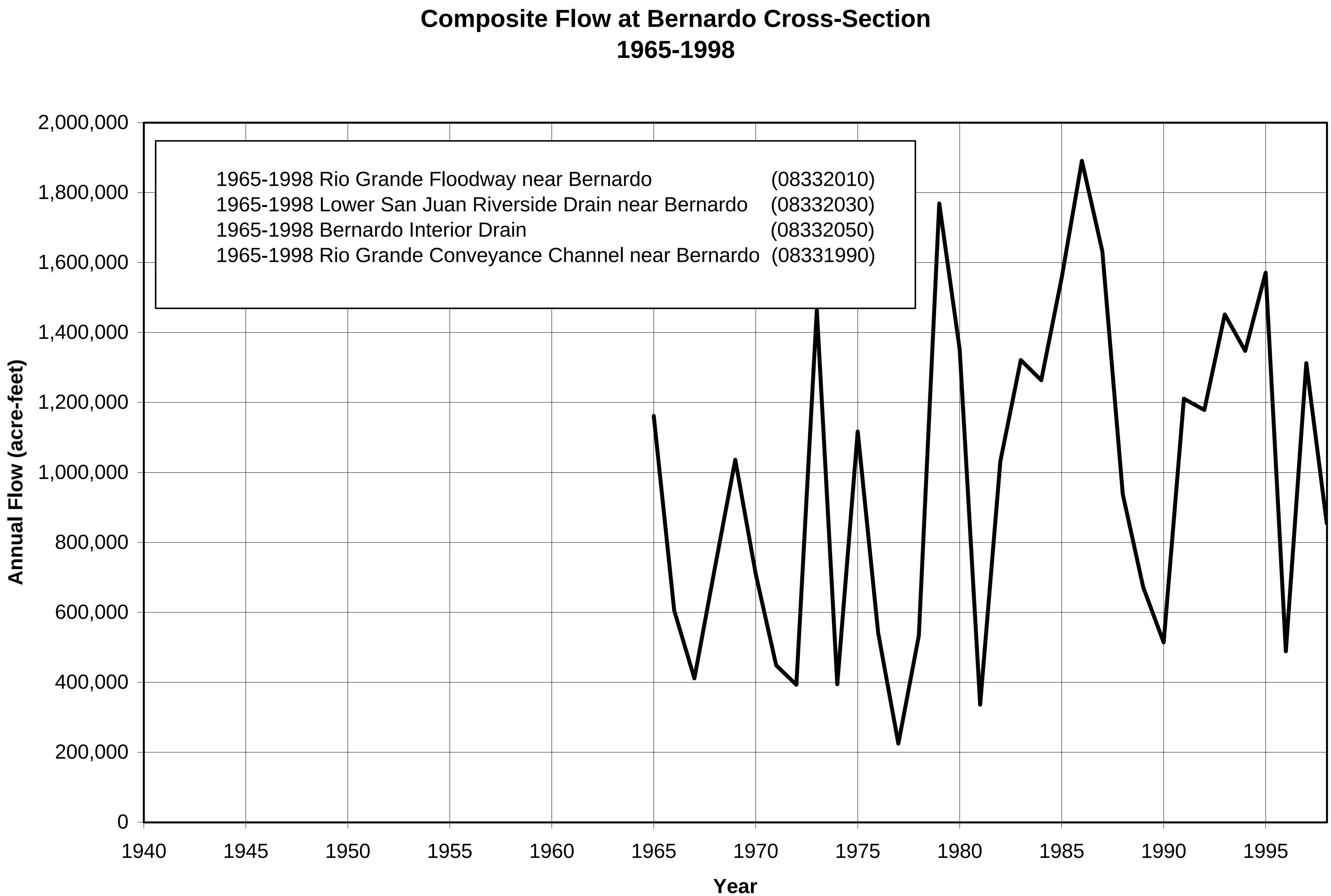
riogrande_cochiti_comp



10/3/00

Figure B-6.2

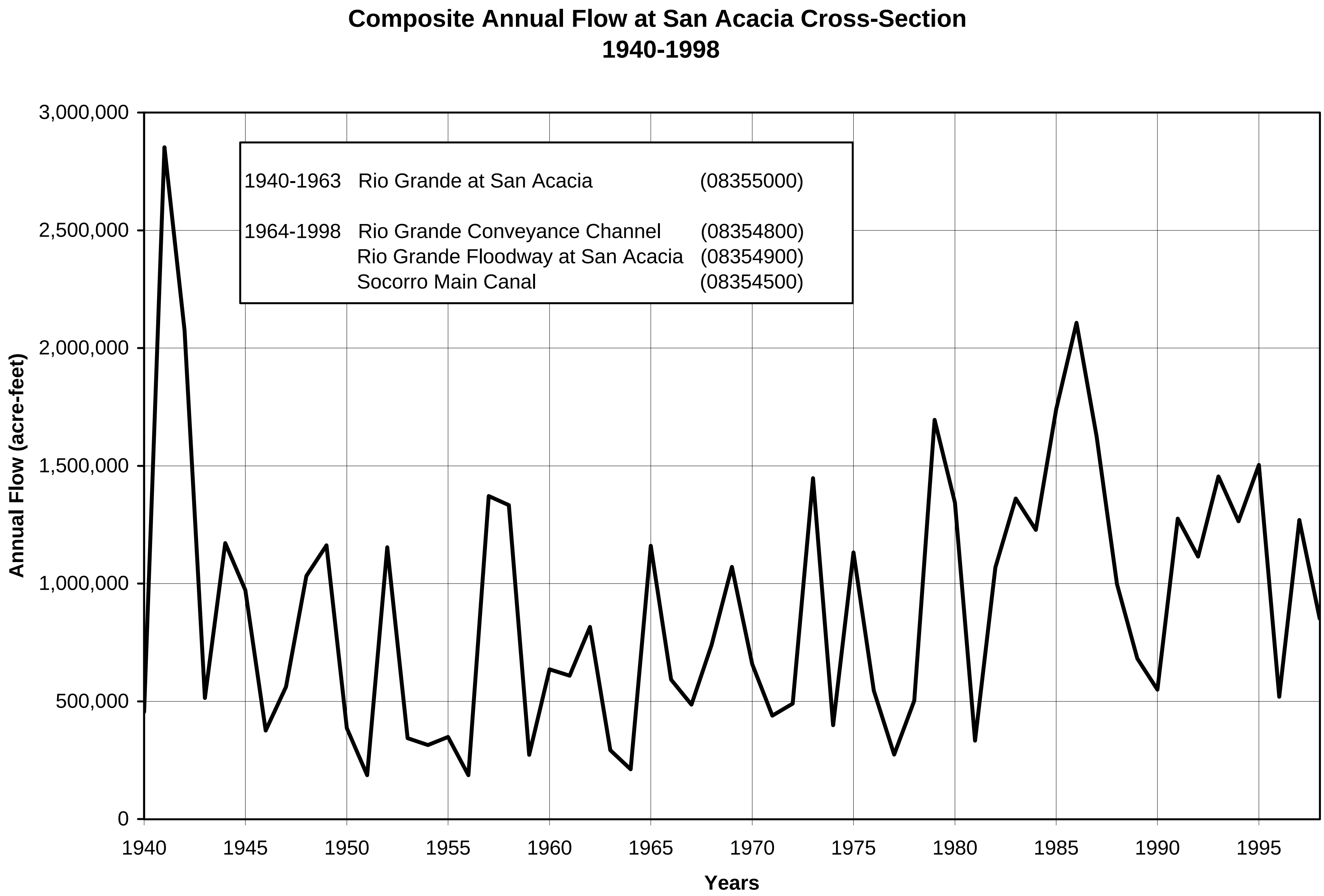
riogrande_sanfelipe_comp



10/3/00

Figure B-6.3

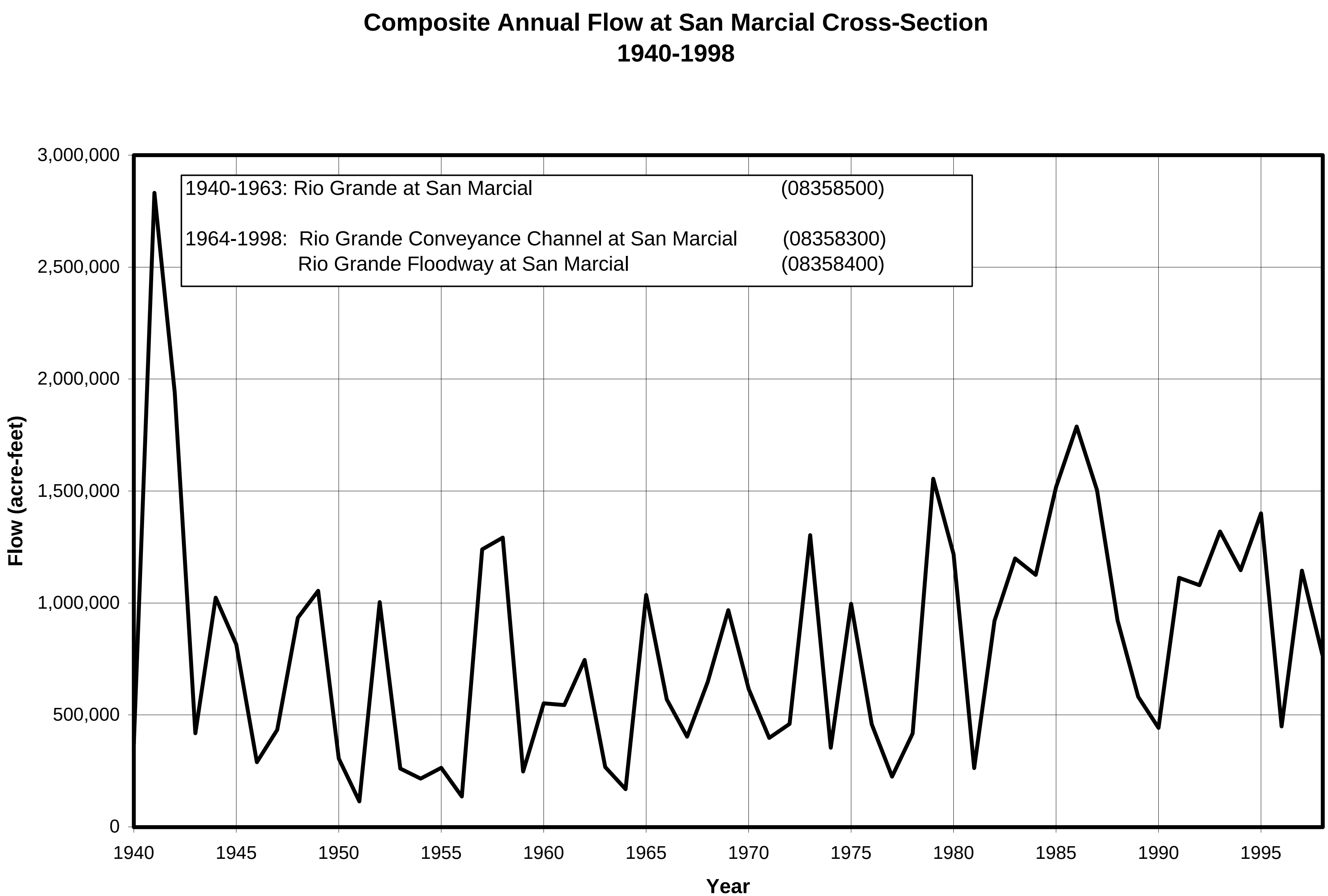
riogrande_bernardo_comp



10/3/00

Figure B-6.4

riogrande_sanacacia_comp



10/3/00

Figure B-6.5

riogrande_sanmarcial_comp

Wastewater Discharge at Rio Rancho, Bernalillo, Los Lunas, Belen and Socorro

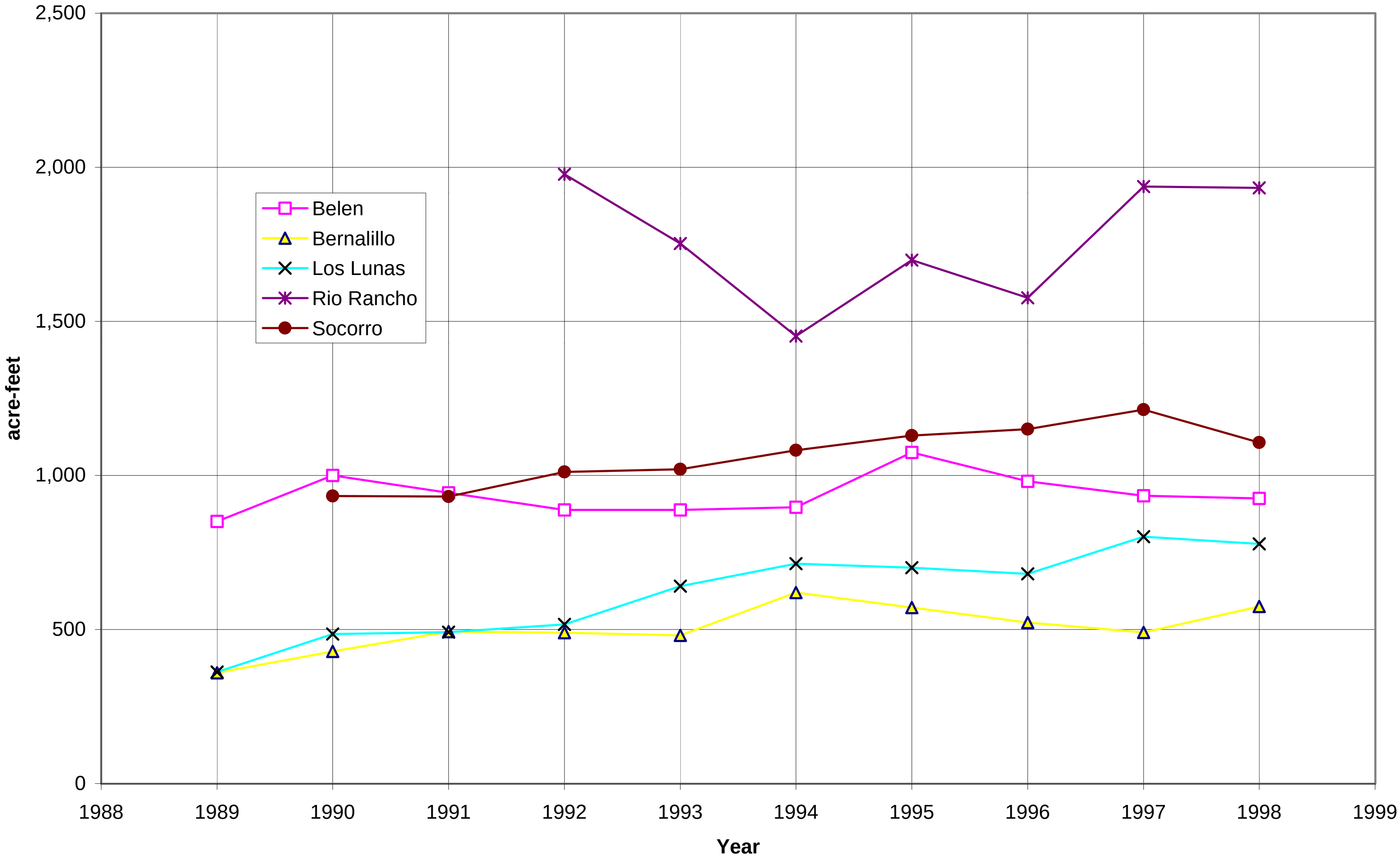


Figure B-7.1

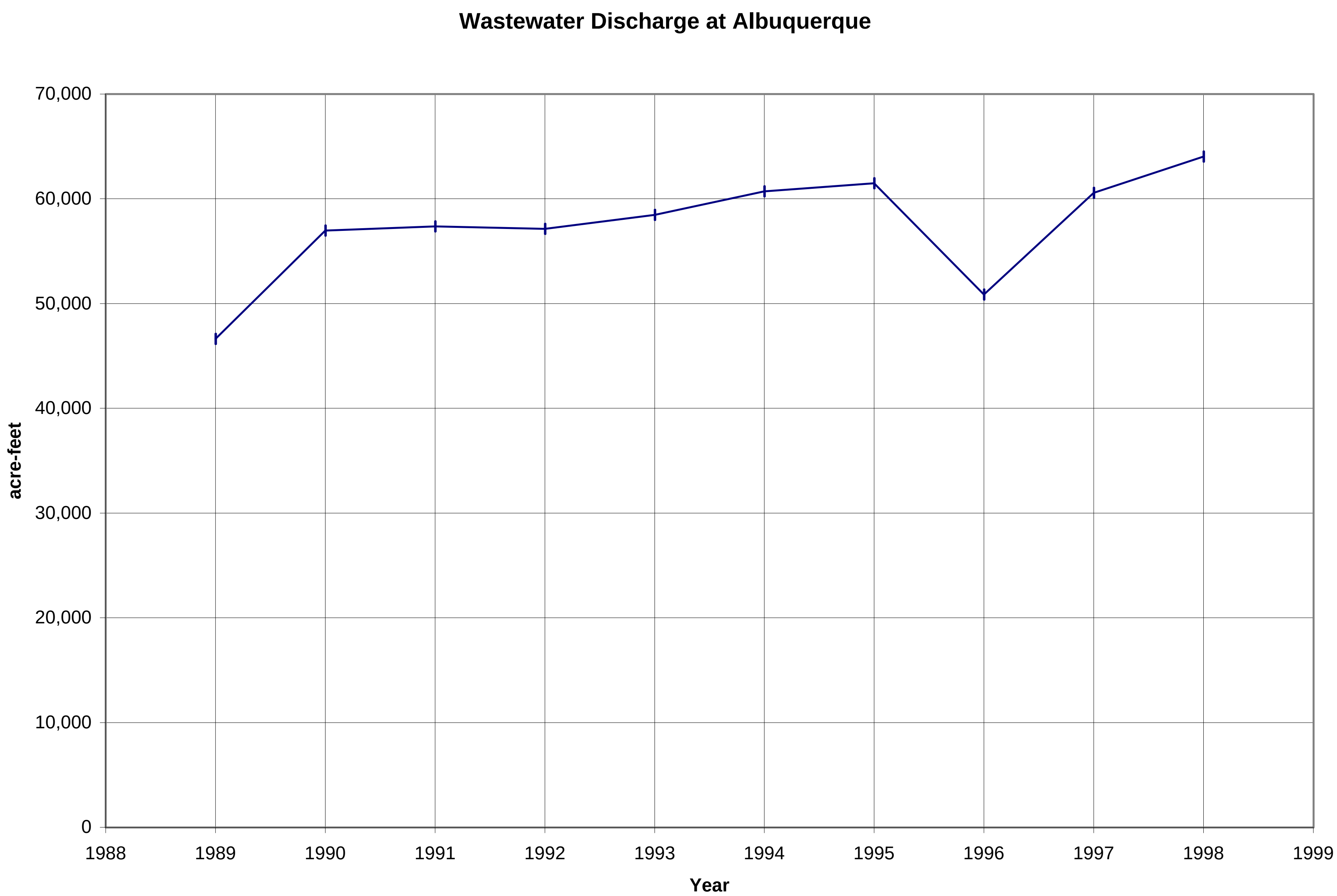
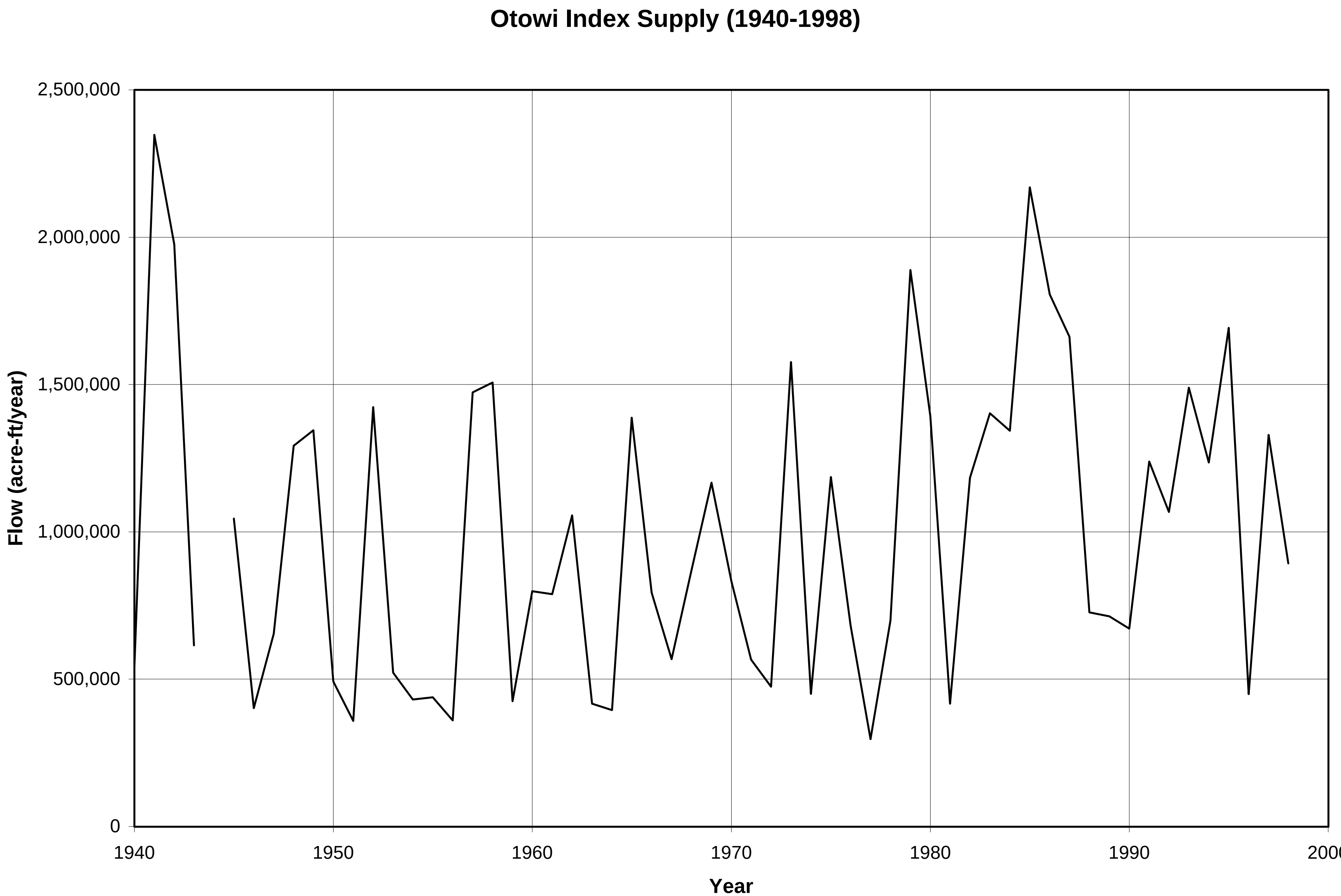
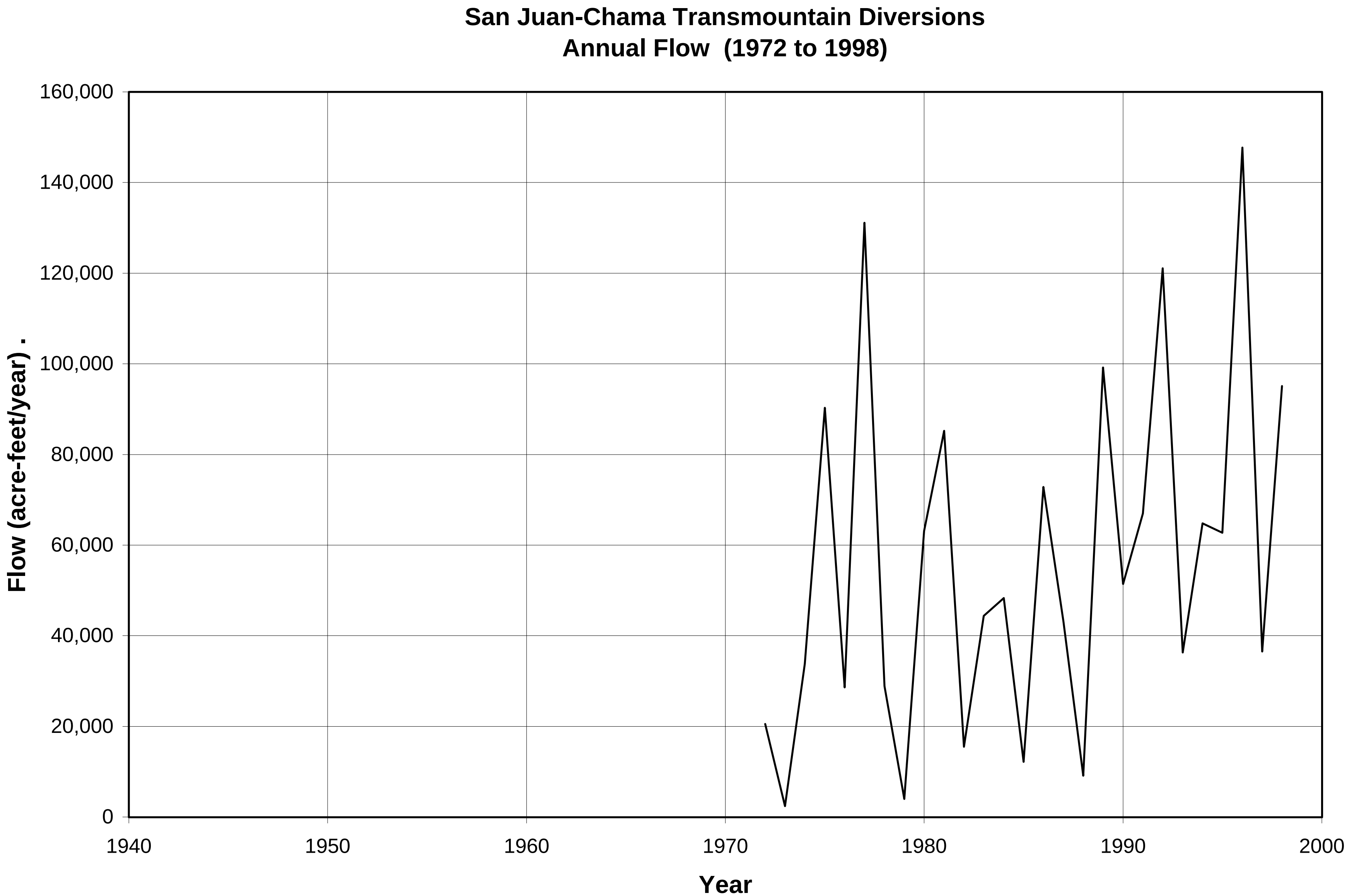

Wastewater Discharge at Albuquerque
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
acre-feet
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Year

Figure B-7.2



Otowi Index Supply (1940-1998)
Flow (acre-ft/year)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1940
1950
1960
1970
1980
1990
2000
Year

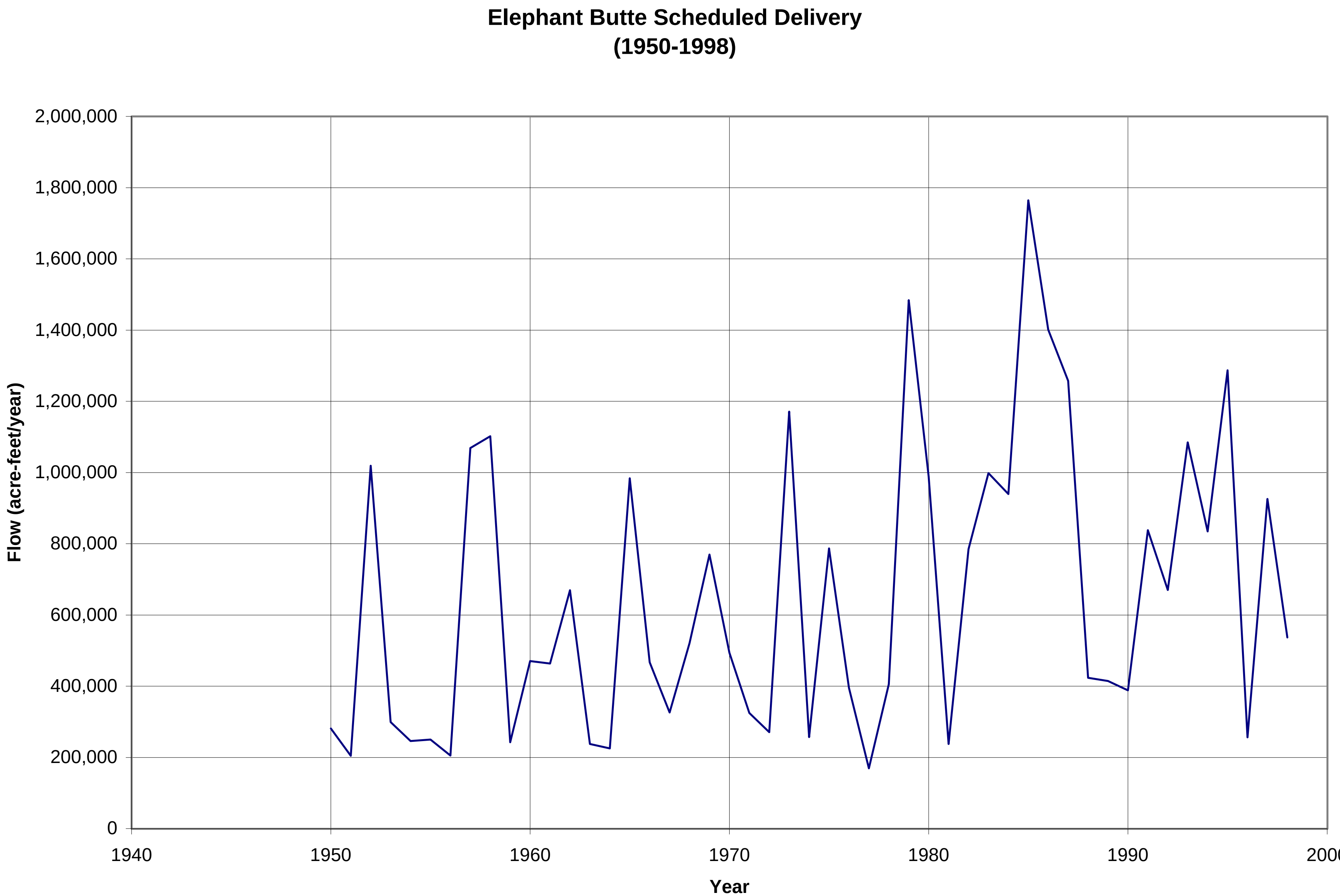
Figure B-8.1



10/3/00

Figure B-8.2

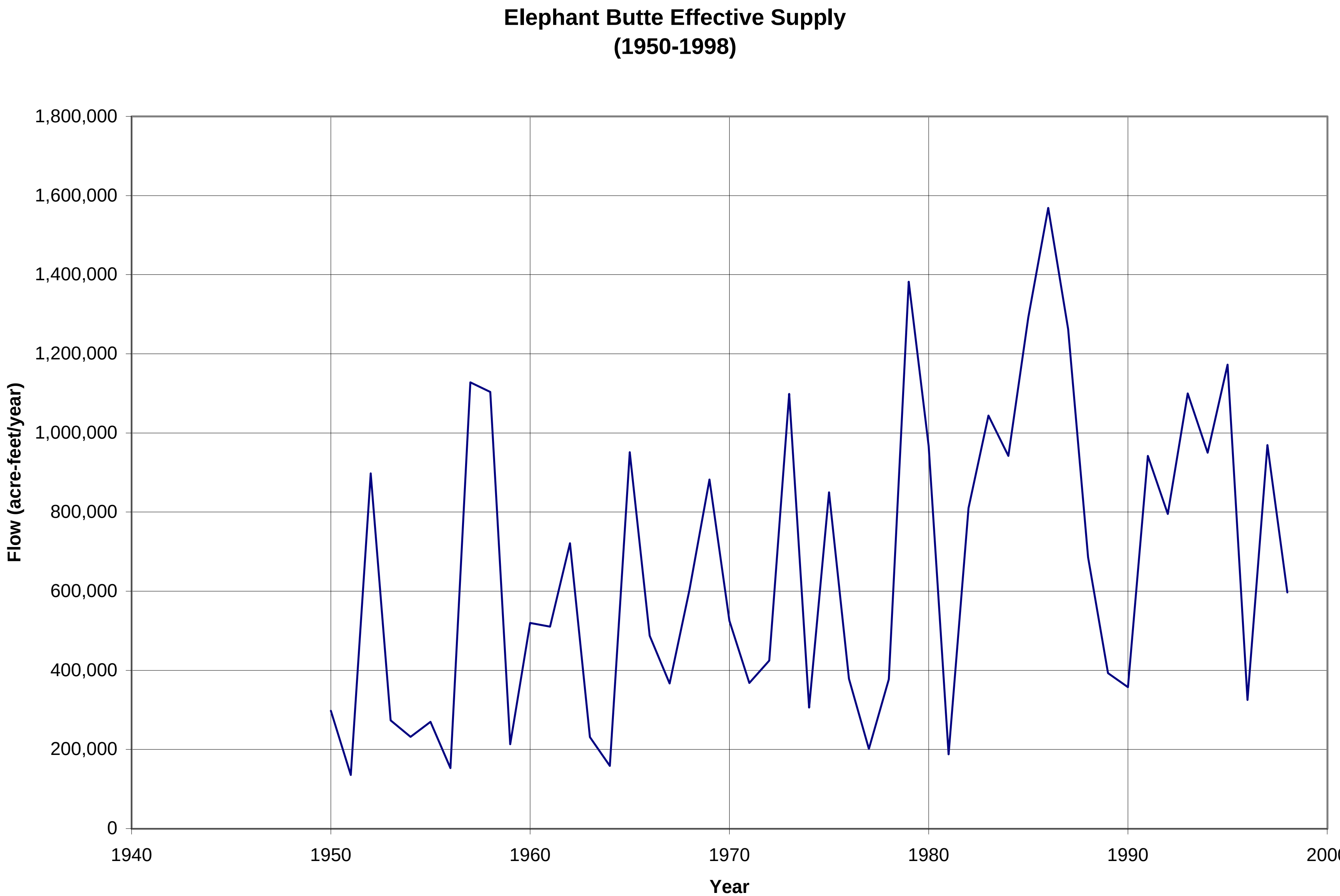
chama_annual



10/3/00

Figure B-8.3

EB_Sched_Delivery



10/3/00

Figure B-8.4

EB_Effective_Supply

Rio Grande Compact: NM Credit History
(computed as difference between sequential beginning-of-year balances)

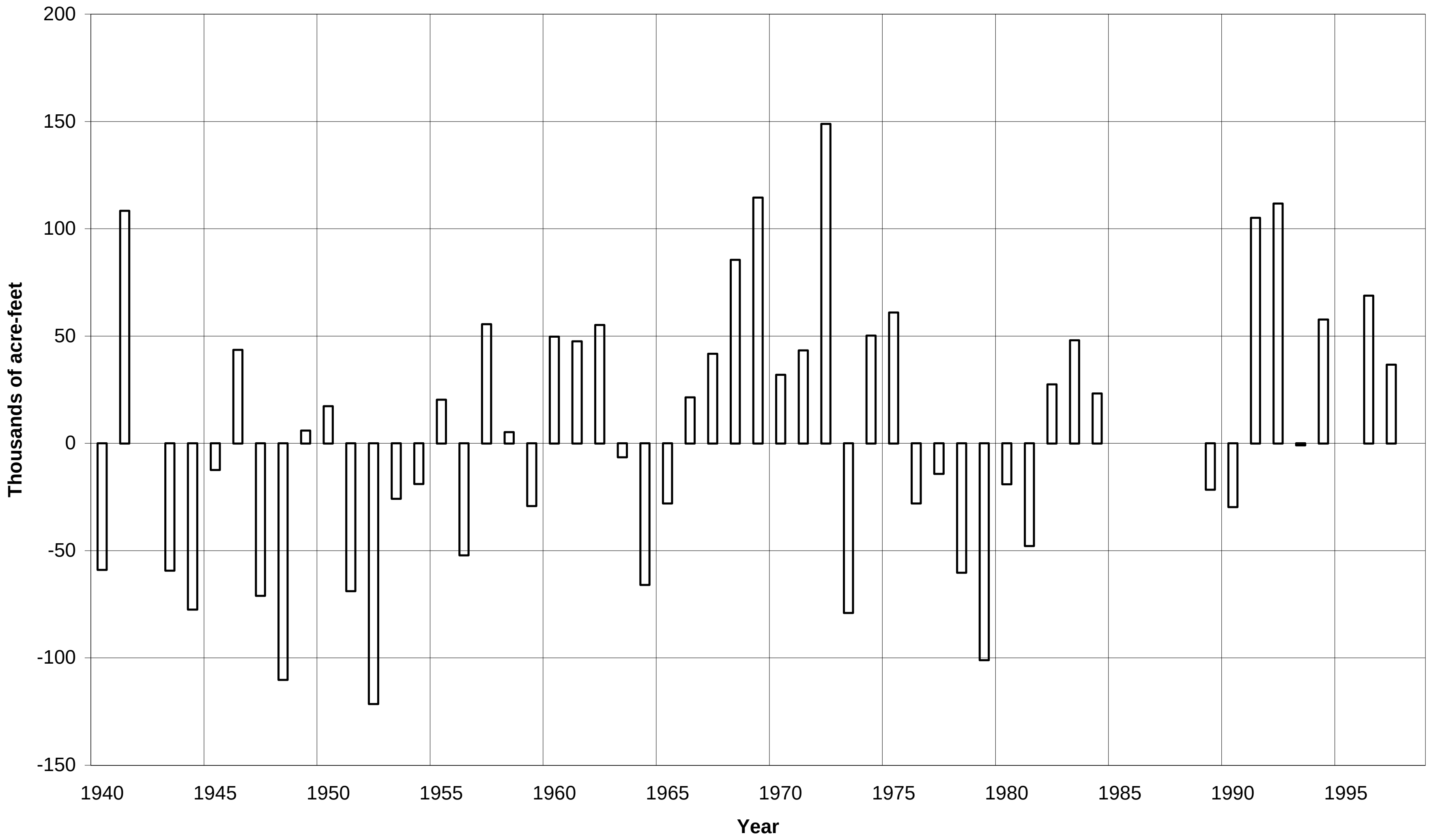


Figure B-8.5

APPENDIX C
Middle Rio Grande Water Supply Study
Summary of Consumptive Use Data

This appendix includes time-series graphs for consumptive use data compiled and evaluated as part of the Middle Rio Grande Water Supply Study. Metadata for source data sets is provided in Appendix A.

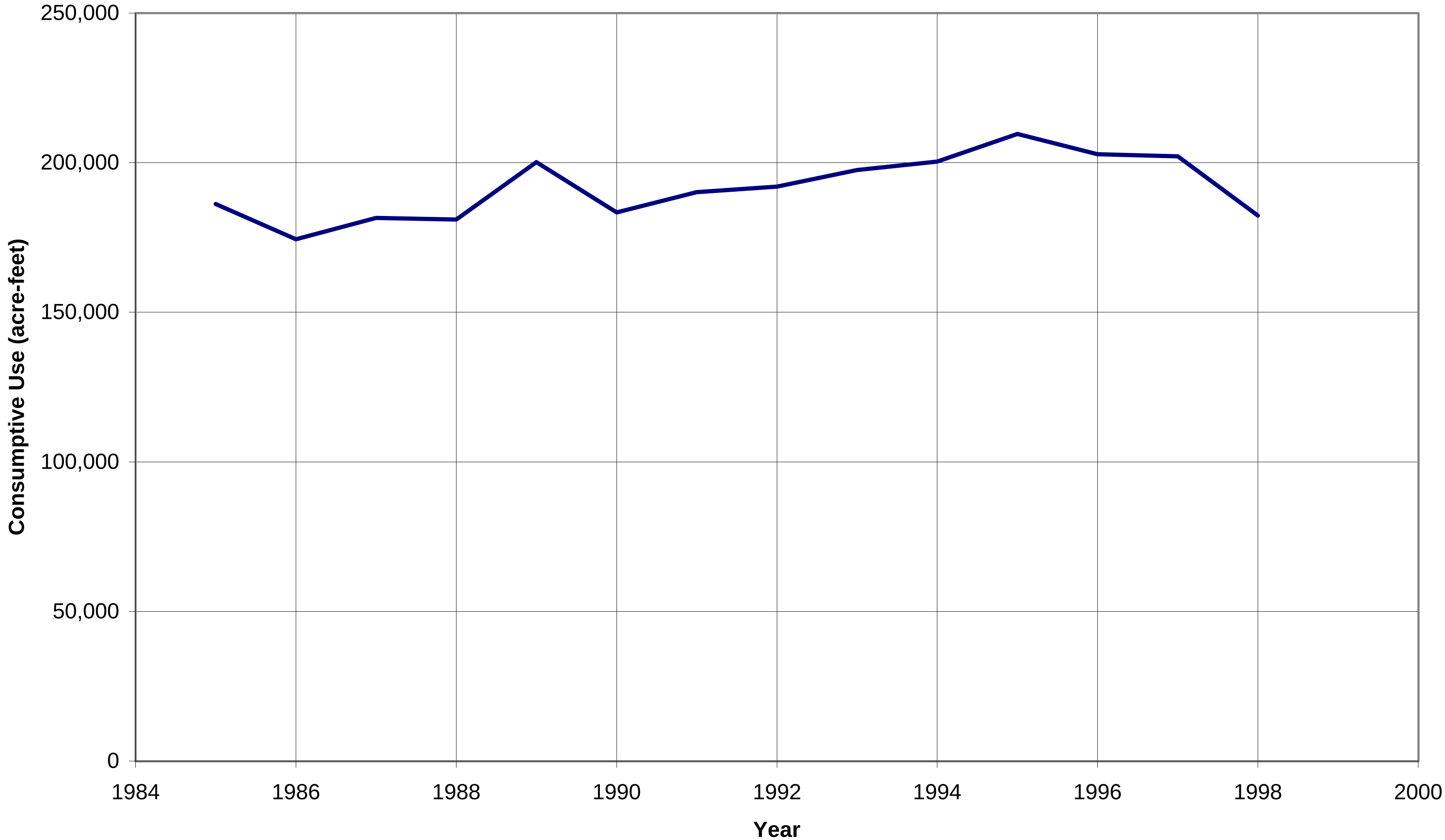
Agricultural Consumptive Use
Figure C-1.1 Annual Agricultural Consumptive Use, Cochiti to San Acacia
Figure C-1.2 Annual Agricultural Consumptive Use, San Acacia to San Marcial

Riparian Consumptive Use
Figure C-2.1 Annual Riparian Consumptive Use, Cochiti to San Acacia
Figure C-2.2 Annual Riparian Consumptive Use, San Acacia to San Marcial

Cochiti Lake Evaporation
Figure C-3.1 Cochiti Lake Annual Evaporation

Elephant Butte Reservoir Evaporation
Figure C-4.1 Elephant Butte Reservoir Annual Evaporation

Annual Agricultural Consumptive Use (1985-1998)
Total for URGWOM Reaches 1 through 5 (Cochiti to San Acacia)



6/16/2000

Figure C-1.1

ET_Toolbox_Summary.xls

Annual Agricultural Consumptive Use (1985-1998)
URGWOM Reach 6 (San Acacia to San Marcial)

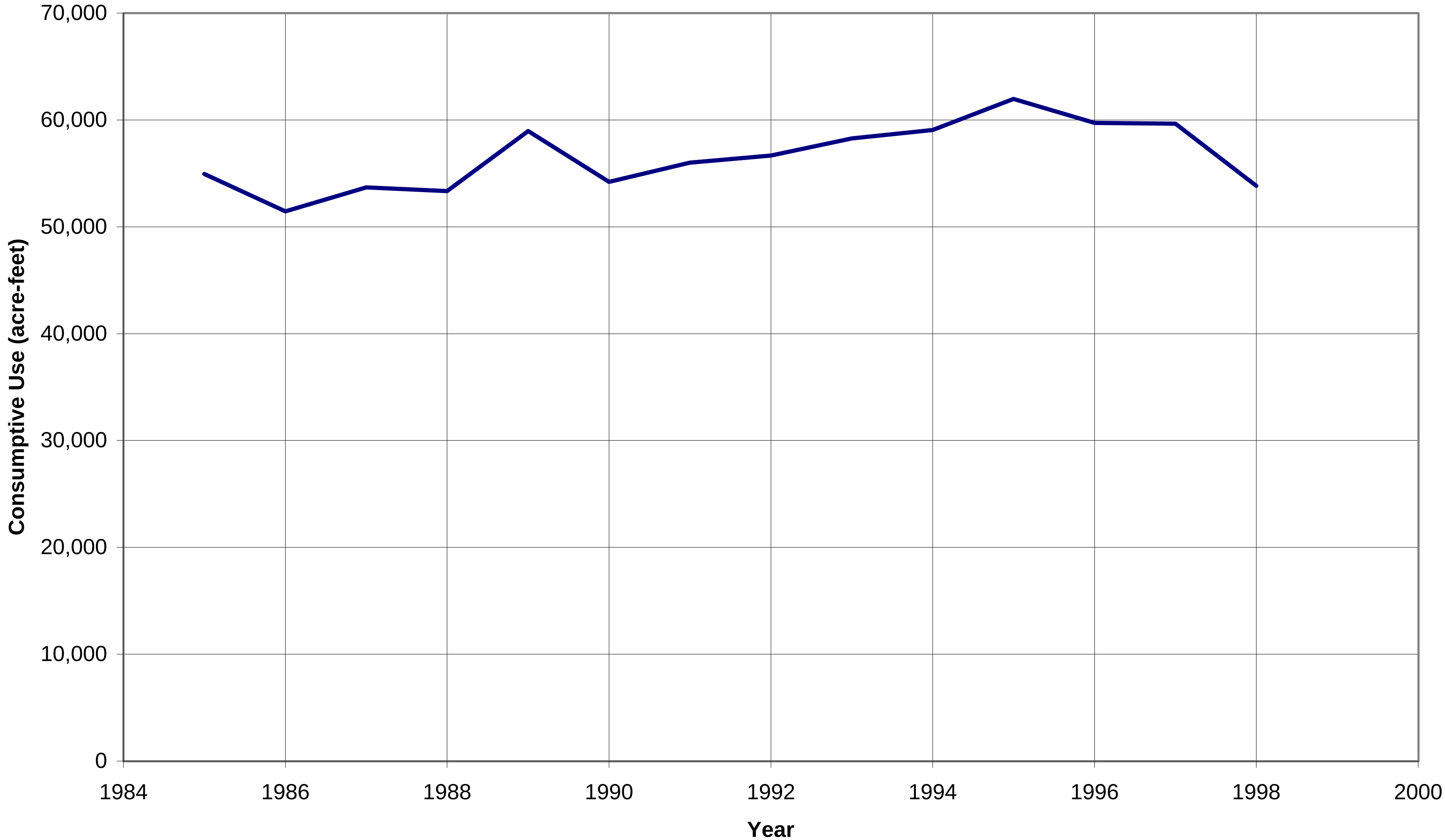
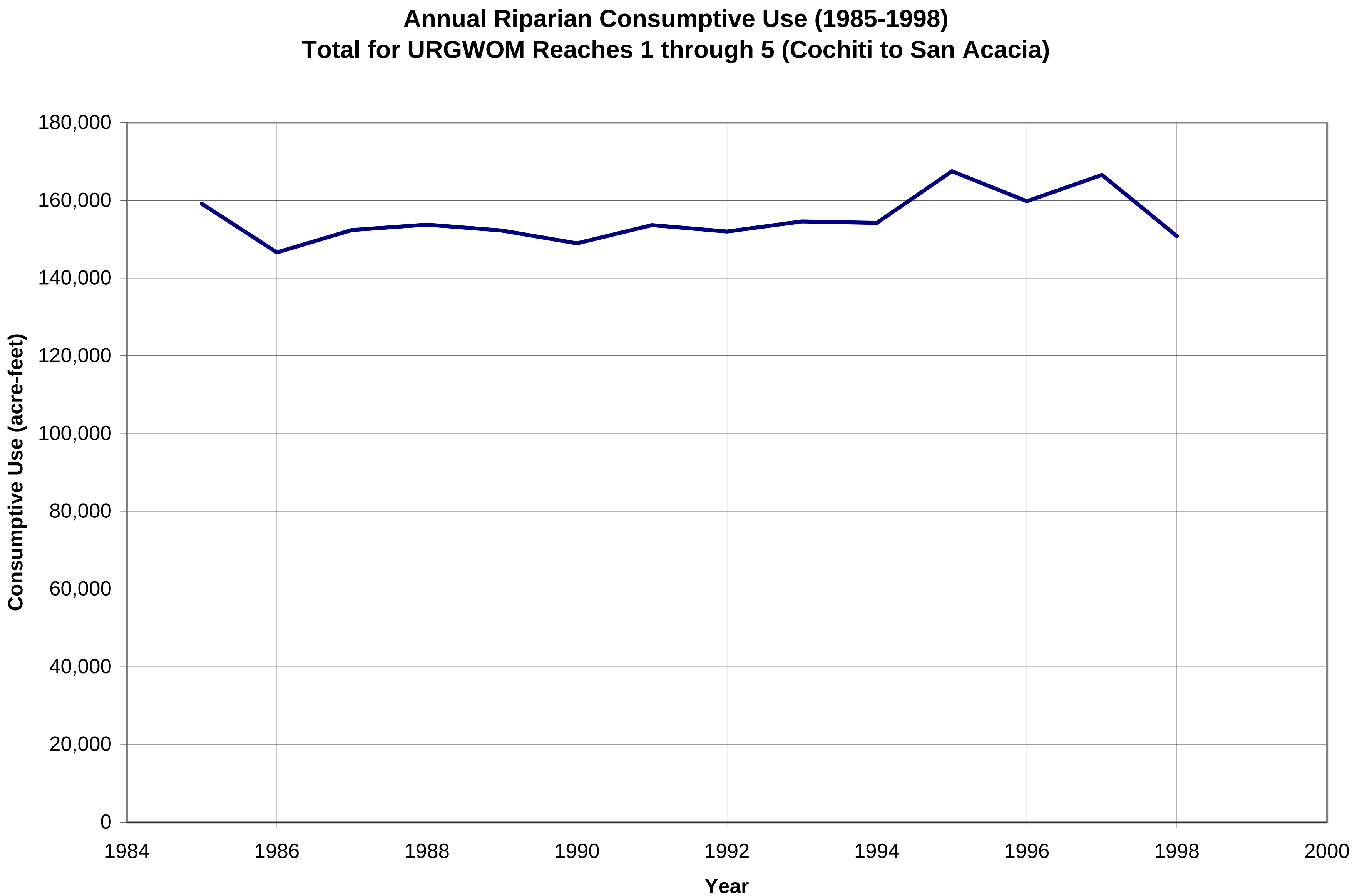


Figure C-1.2



06/16/2000

Figure C-2.1

ET_Toolbox_Summary.xls

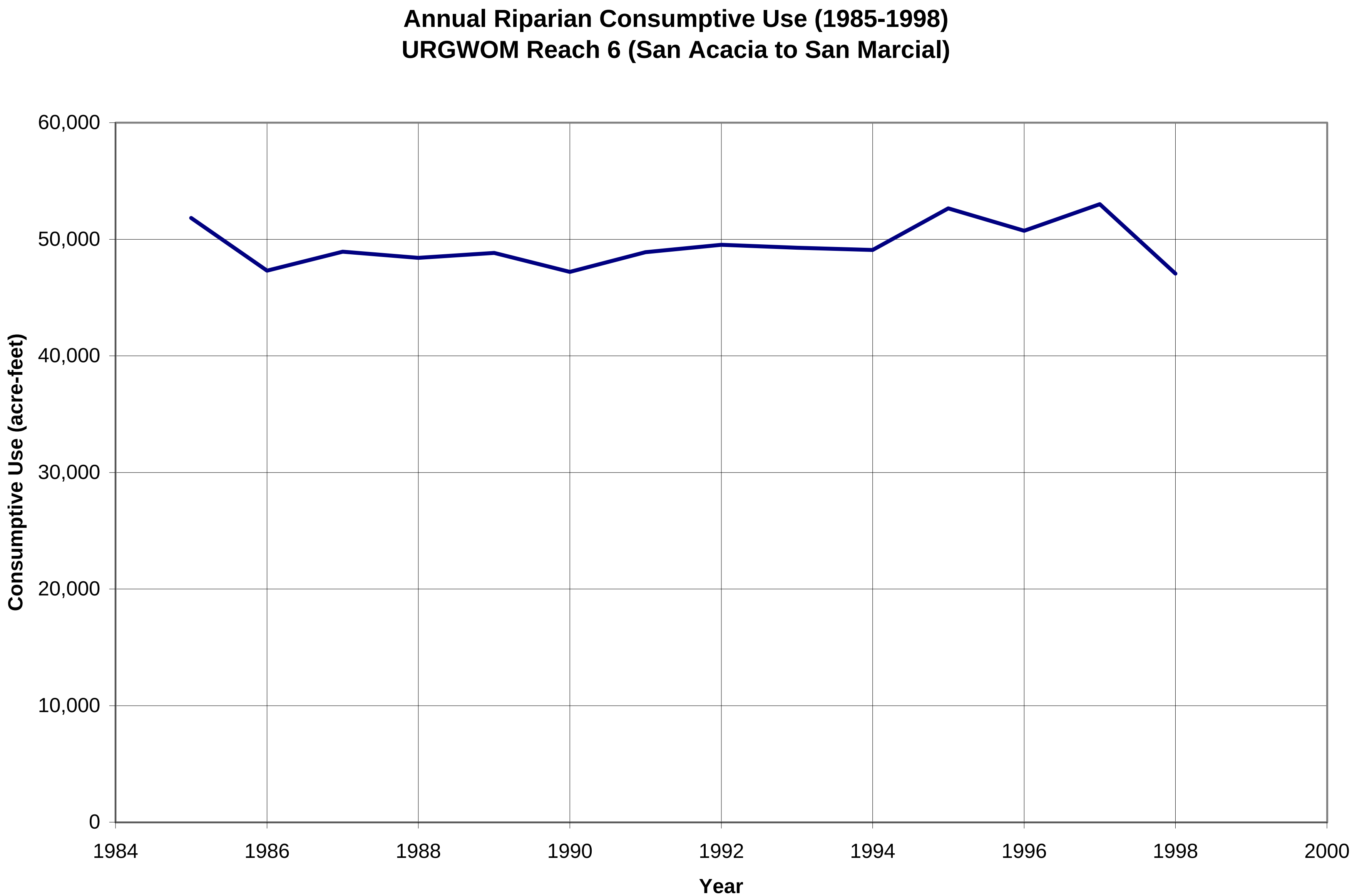
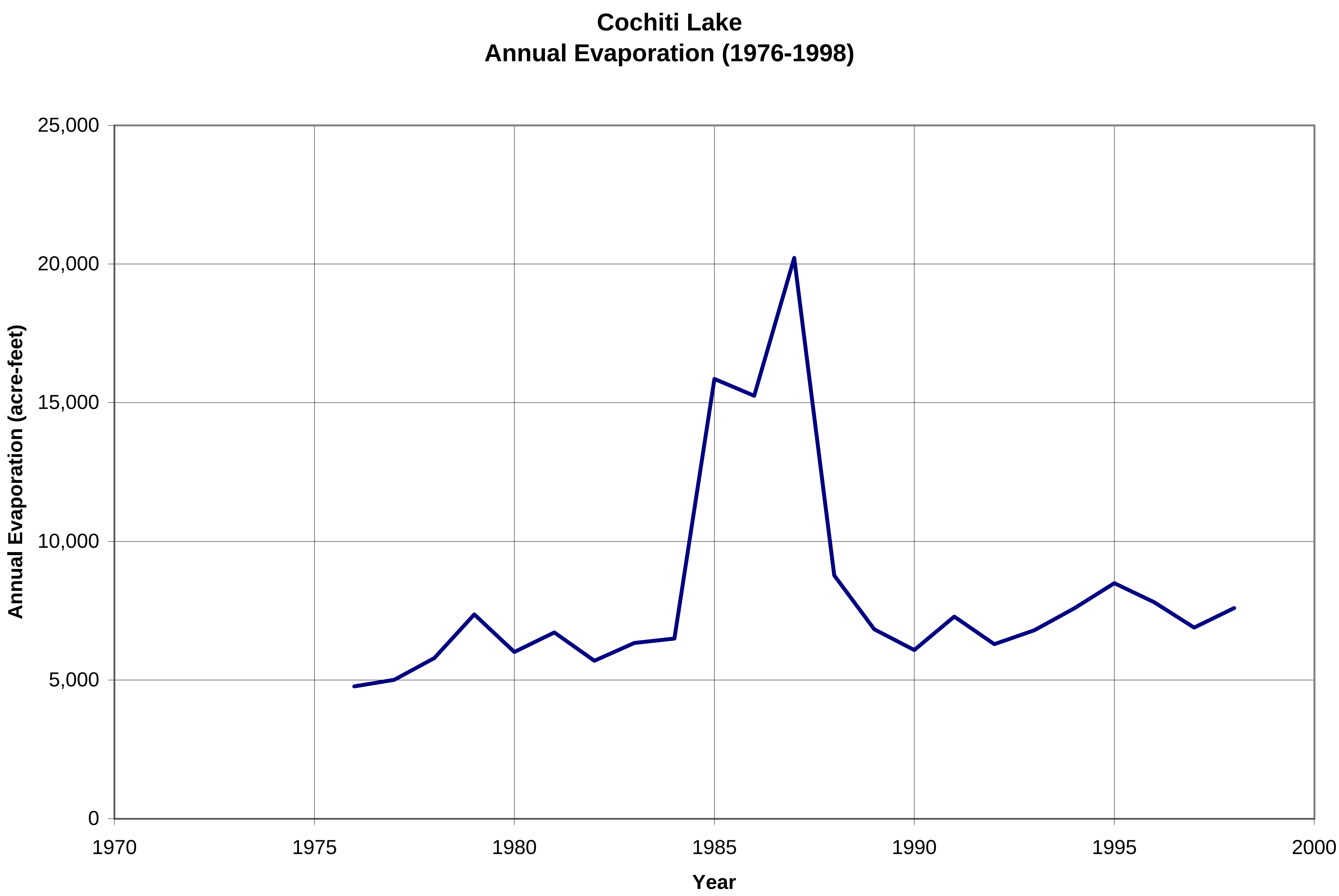

Annual Riparian Consumptive Use (1985-1998)
URGWOM Reach 6 (San Acacia to San Marcial)
Consumptive Use (acre-feet)
60,000
50,000
40,000
30,000
20,000
10,000
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year

Figure C-2.2



06/16/2000

Figure C-3.1

Cochiti_Evap.xls

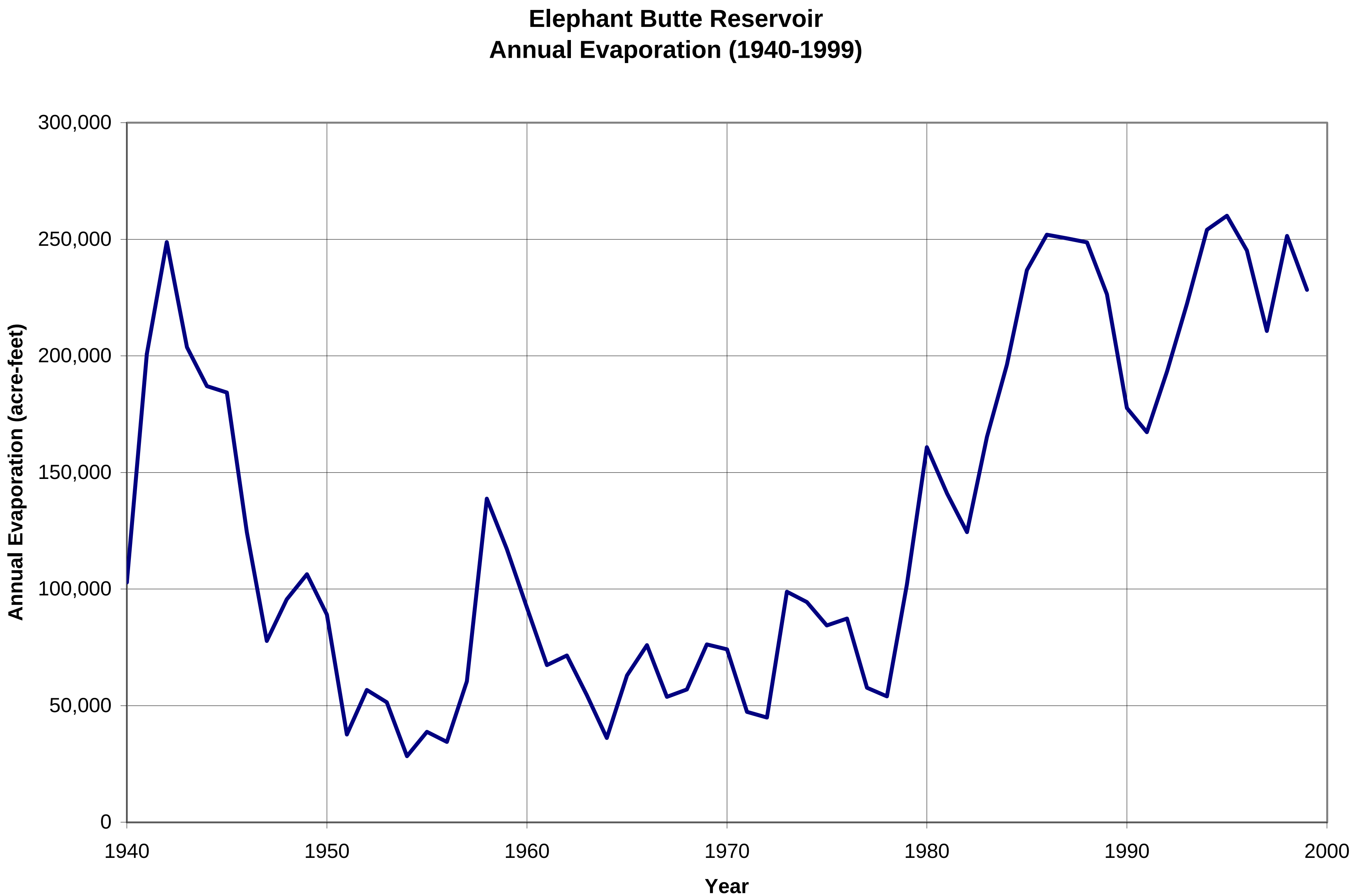

Elephant Butte Reservoir
Annual Evaporation (1940-1999)
Annual Evaporation (acre-feet)
300,000
250,000
200,000
150,000
100,000
50,000
0
1940
1950
1960
1970
1980
1990
2000
Year

Figure C-4.1

APPENDIX D
Middle Rio Grande Water Supply Study
Summary of Inflow-Outflow and Depletions Analysis

This appendix includes time-series graphs for cumulative reach outflow-inflow and depletions. These analyses are provided on an annual basis and by sub-annual periods. The selected sub-annual periods correspond to “winter”, November through February; “spring”, March through June; and “summer”, July through October. These analyses utilize time-series composite values at the Middle Rio Grande cross-sections at Cochiti, San Felipe, Bernardo, San Acacia, San Marcial, and the basin end-points at Otowi and below Elephant Butte.

Annual Double Mass Graphs for Basin and Reaches

Figure D-1.1 Cumulative Outflow vs. Inflow, Otowi to below Elephant Butte
Figure D-1.2 Cumulative Outflow vs. Inflow, Otowi to Cochiti
Figure D-1.3 Cumulative Outflow vs. Inflow, Cochiti to San Felipe
Figure D-1.4 Cumulative Outflow vs. Inflow, San Felipe to Bernardo
Figure D-1.5 Cumulative Outflow vs. Inflow, Bernardo to San Acacia
Figure D-1.6 Cumulative Outflow vs. Inflow, San Acacia to San Marcial
Figure D-1.7 Cumulative Outflow vs. Inflow, San Marcial to below Elephant Butte

Winter Double Mass Graphs for Basin and Reaches

Figure D-2.1 Cumulative Outflow vs. Inflow, Otowi to below Elephant Butte
Figure D-2.2 Cumulative Outflow vs. Inflow, Otowi to Cochiti
Figure D-2.3 Cumulative Outflow vs. Inflow, Cochiti to San Felipe
Figure D-2.4 Cumulative Outflow vs. Inflow, San Felipe to Bernardo
Figure D-2.5 Cumulative Outflow vs. Inflow, Bernardo to San Acacia
Figure D-2.6 Cumulative Outflow vs. Inflow, San Acacia to San Marcial
Figure D-2.7 Cumulative Outflow vs. Inflow, San Marcial to below Elephant Butte

Spring Double Mass Graphs for Basin and Reaches

Figure D-3.1 Cumulative Outflow vs. Inflow, Otowi to below Elephant Butte
Figure D-3.2 Cumulative Outflow vs. Inflow, Otowi to Cochiti
Figure D-3.3 Cumulative Outflow vs. Inflow, Cochiti to San Felipe
Figure D-3.4 Cumulative Outflow vs. Inflow, San Felipe to Bernardo
Figure D-3.5 Cumulative Outflow vs. Inflow, Bernardo to San Acacia
Figure D-3.6 Cumulative Outflow vs. Inflow, San Acacia to San Marcial
Figure D-3.7 Cumulative Outflow vs. Inflow, San Marcial to below Elephant Butte

Summer Double Mass Graphs for Basin and Reaches

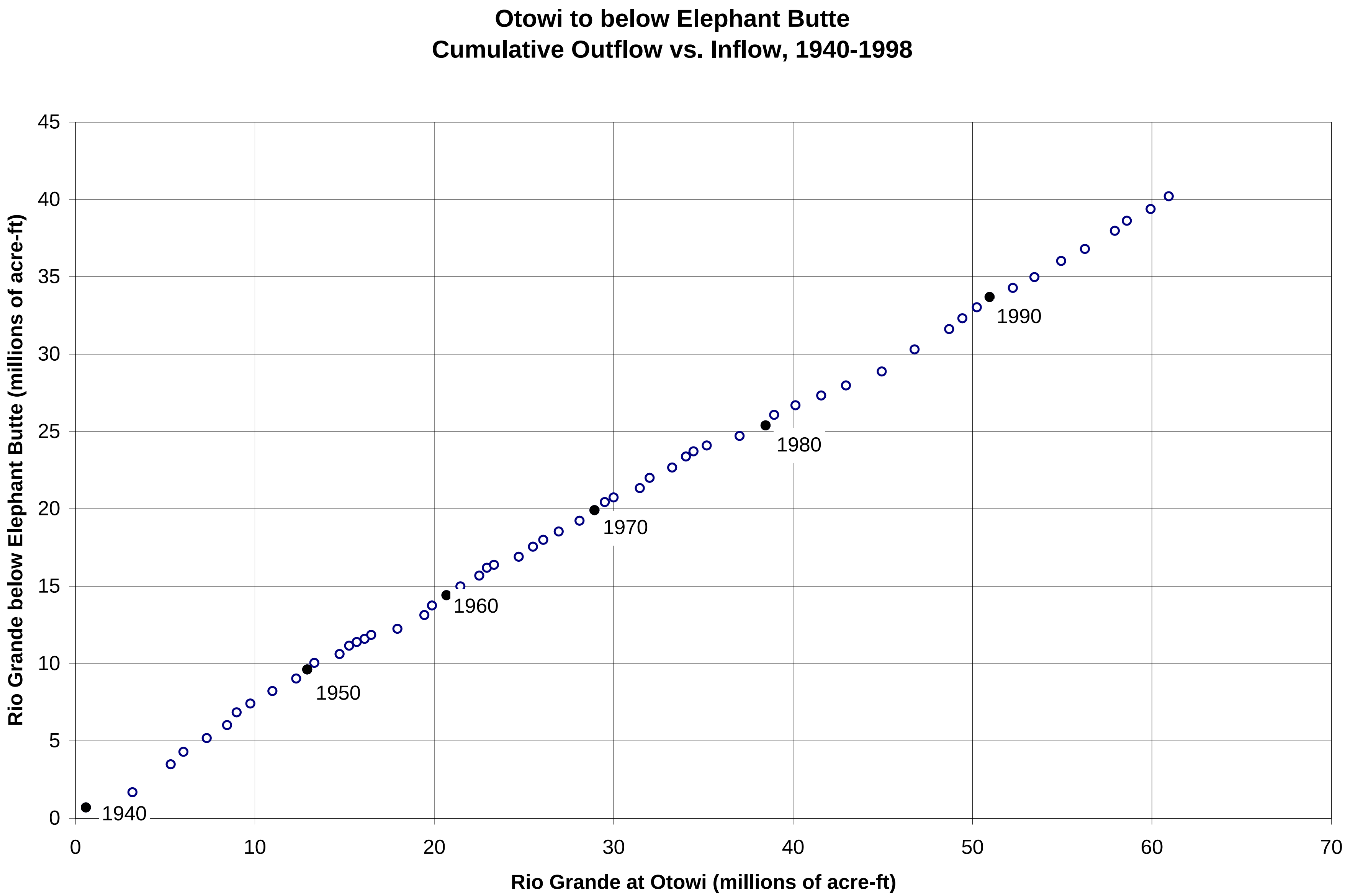
Figure D-4.1 Cumulative Outflow vs. Inflow, Otowi to below Elephant Butte
Figure D-4.2 Cumulative Outflow vs. Inflow, Otowi to Cochiti
Figure D-4.3 Cumulative Outflow vs. Inflow, Cochiti to San Felipe
Figure D-4.4 Cumulative Outflow vs. Inflow, San Felipe to Bernardo
Figure D-4.5 Cumulative Outflow vs. Inflow, Bernardo to San Acacia
Figure D-4.6 Cumulative Outflow vs. Inflow, San Acacia to San Marcial
Figure D-4.7 Cumulative Outflow vs. Inflow, San Marcial to below Elephant Butte

Annual Depletion Trends for Basin and Reaches
Figure D-5.1 Annual Depletions, Otowi to below Elephant Butte
Figure D-5.2 Annual Depletions, Otowi to Cochiti
Figure D-5.3 Annual Depletions, Cochiti to San Felipe
Figure D-5.4 Annual Depletions, San Felipe to Bernardo
Figure D-5.5 Annual Depletions, Bernardo to San Acacia
Figure D-5.6 Annual Depletions, San Acacia to San Marcial
Figure D-5.7 Annual Depletions, San Marcial to below Elephant Butte

Winter Depletion Trends for Basin and Reaches
Figure D-6.1 Winter Depletions, Otowi to below Elephant Butte
Figure D-6.2 Winter Depletions, Otowi to Cochiti
Figure D-6.3 Winter Depletions, Cochiti to San Felipe
Figure D-6.4 Winter Depletions, San Felipe to Bernardo
Figure D-6.5 Winter Depletions, Bernardo to San Acacia
Figure D-6.6 Winter Depletions, San Acacia to San Marcial
Figure D-6.7 Winter Depletions, San Marcial to below Elephant Butte

Spring Depletion Trends for Basin and Reaches
Figure D-7.1 Spring Depletions, Otowi to below Elephant Butte
Figure D-7.2 Spring Depletions, Otowi to Cochiti
Figure D-7.3 Spring Depletions, Cochiti to San Felipe
Figure D-7.4 Spring Depletions, San Felipe to Bernardo
Figure D-7.5 Spring Depletions, Bernardo to San Acacia
Figure D-7.6 Spring Depletions, San Acacia to San Marcial
Figure D-7.7 Spring Depletions, San Marcial to below Elephant Butte

Summer Depletion Trends for Basin and Reaches
Figure D-8.1 Summer Depletions, Otowi to below Elephant Butte
Figure D-8.2 Summer Depletions, Otowi to Cochiti
Figure D-8.3 Summer Depletions, Cochiti to San Felipe
Figure D-8.4 Summer Depletions, San Felipe to Bernardo
Figure D-8.5 Summer Depletions, Bernardo to San Acacia
Figure D-8.6 Summer Depletions, San Acacia to San Marcial
Figure D-8.7 Summer Depletions, San Marcial to below Elephant Butte



6/16/00

Figure D-1.1

Otowi_ElephantButte.xls

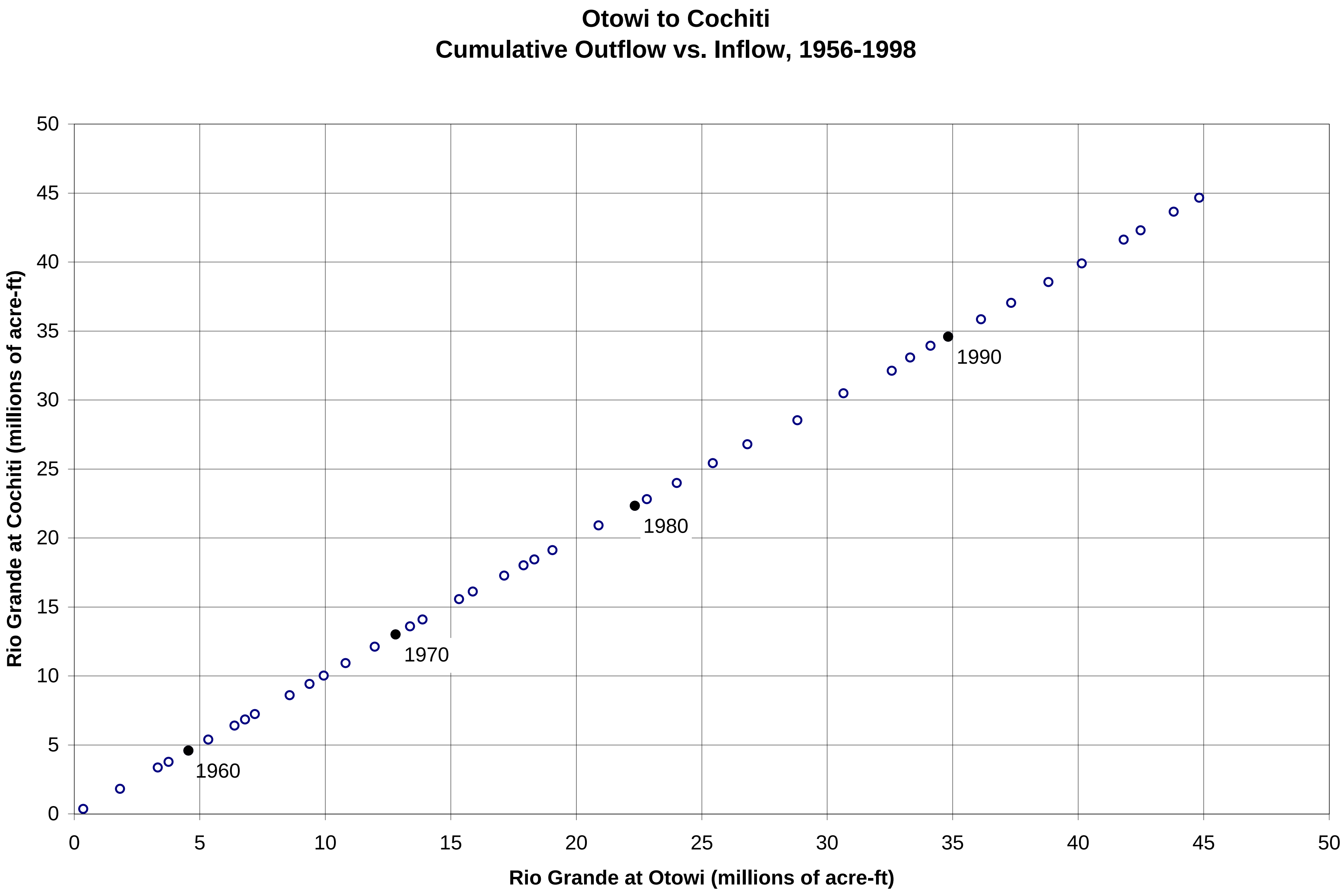

Otowi to Cochiti
Cumulative Outflow vs. Inflow, 1956-1998
Rio Grande at Cochiti (millions of acre-ft)
Rio Grande at Otowi (millions of acre-ft)
0
5
10
15
20
25
30
35
40
45
50
1960
1970
1980
1990

Figure D-1.2

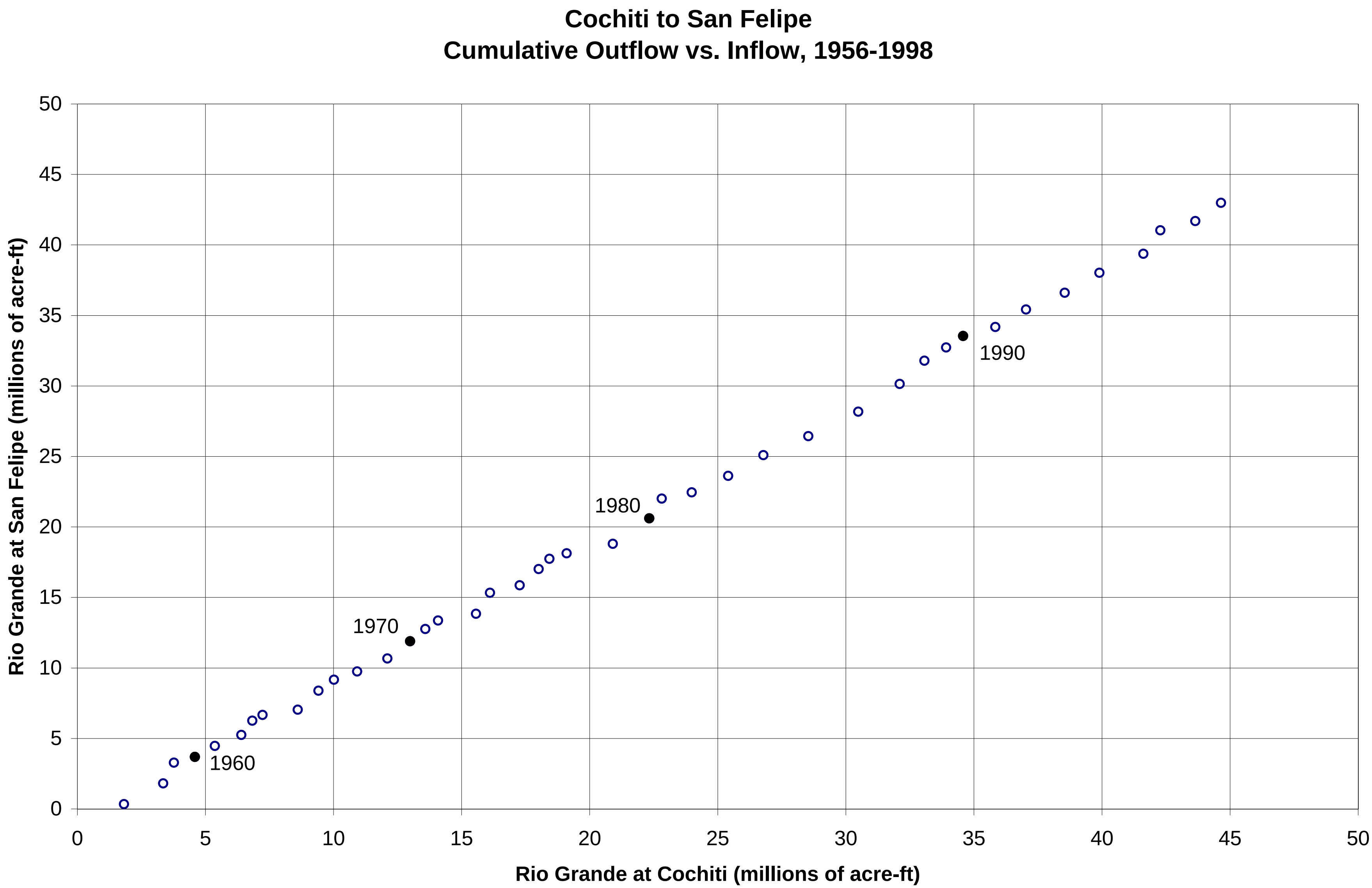

Cochiti to San Felipe
Cumulative Outflow vs. Inflow, 1956-1998
Rio Grande at San Felipe (millions of acre-ft)
Rio Grande at Cochiti (millions of acre-ft)
0
5
10
15
20
25
30
35
40
45
50
1960
1970
1980
1990

Figure D-1.3

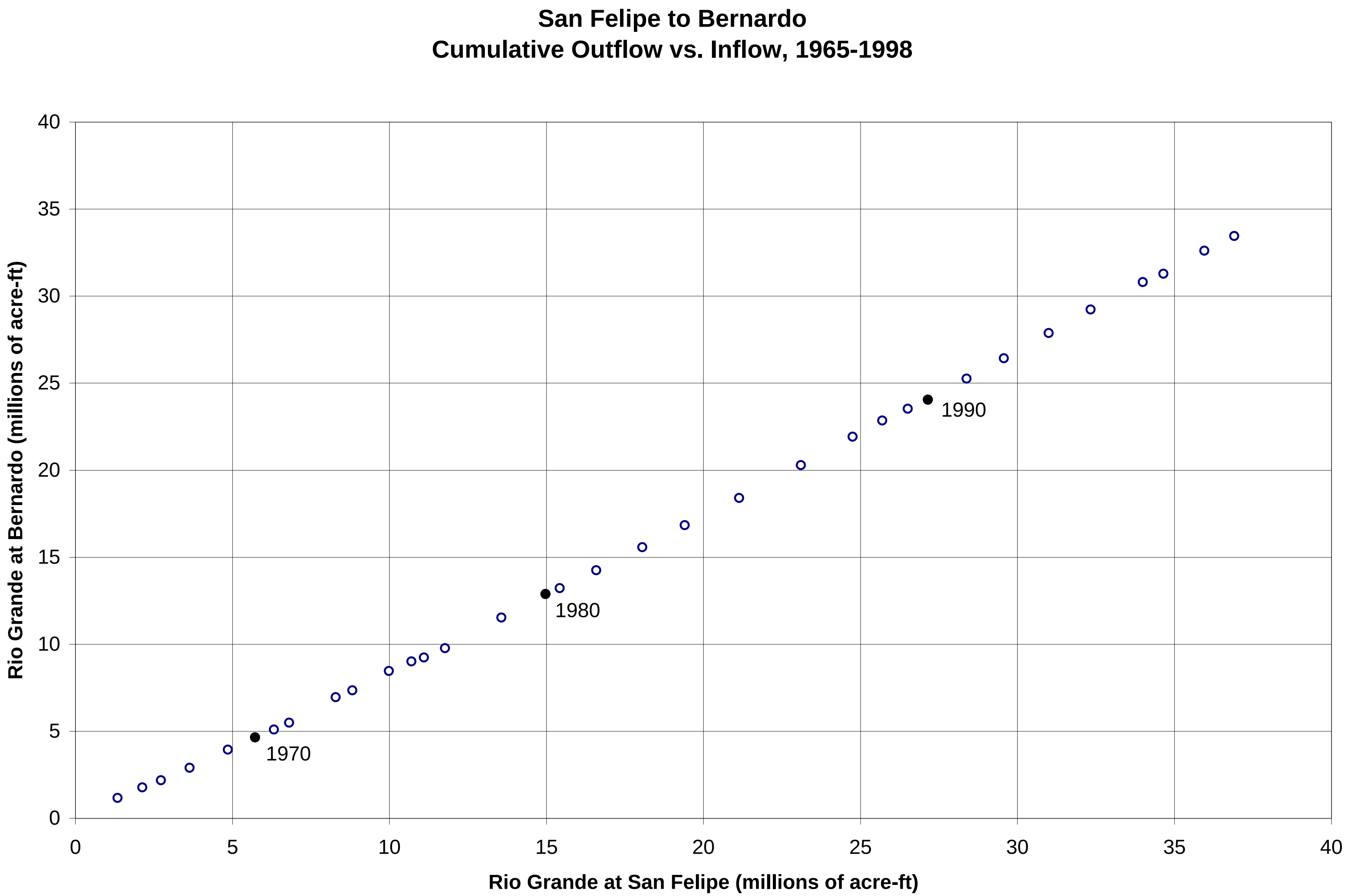
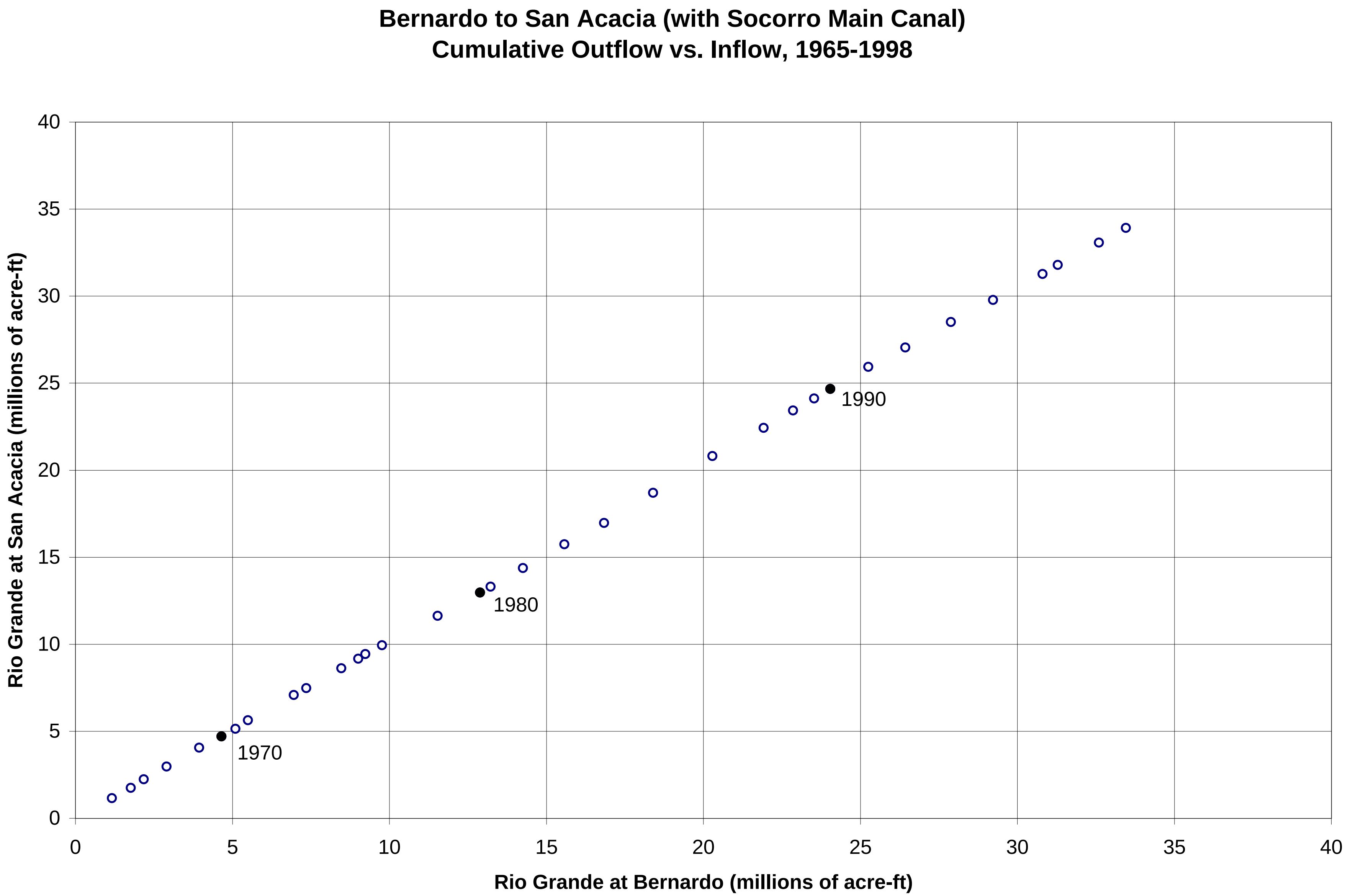

San Felipe to Bernardo
Cumulative Outflow vs. Inflow, 1965-1998
Rio Grande at Bernardo (millions of acre-ft)
Rio Grande at San Felipe (millions of acre-ft)
0
5
10
15
20
25
30
35
40
1970
1980
1990

Figure D-1.4

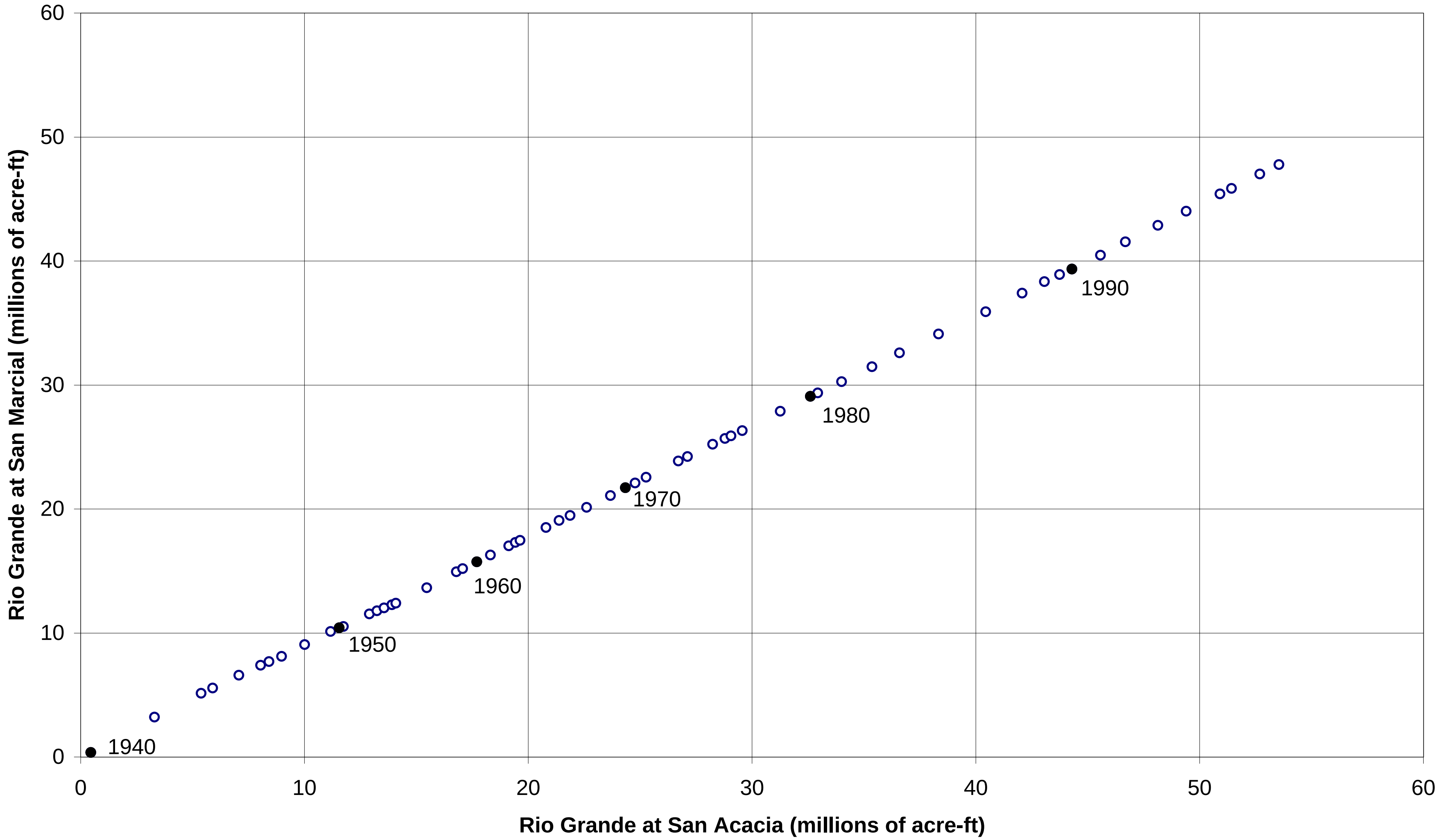


6/16/00

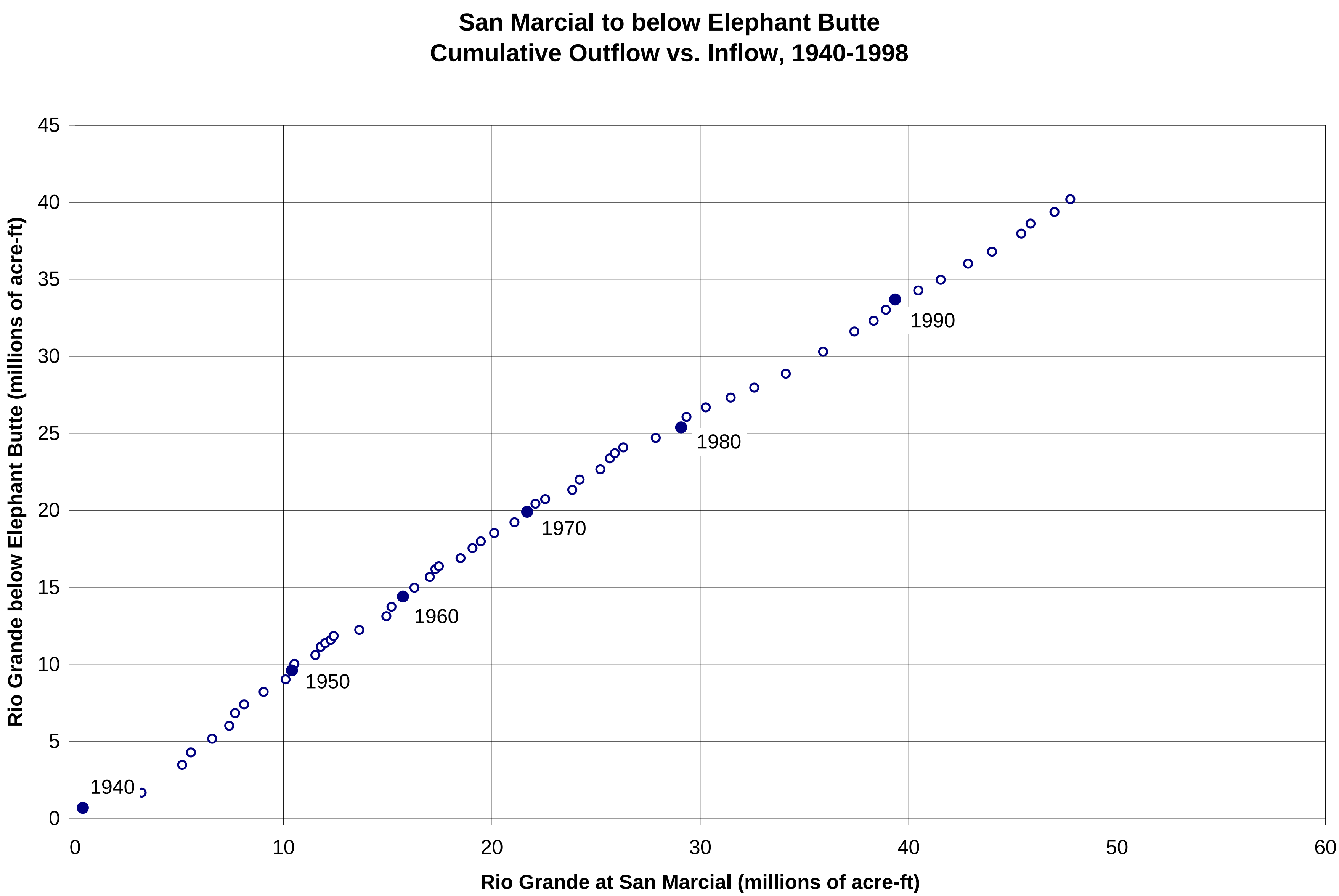
Figure D-1.5

Bernardo_SanAcacia.xls

San Acacia (with Socorro Main Canal) to San Marcial
Cumulative Outflow vs. Inflow, 1940-1998



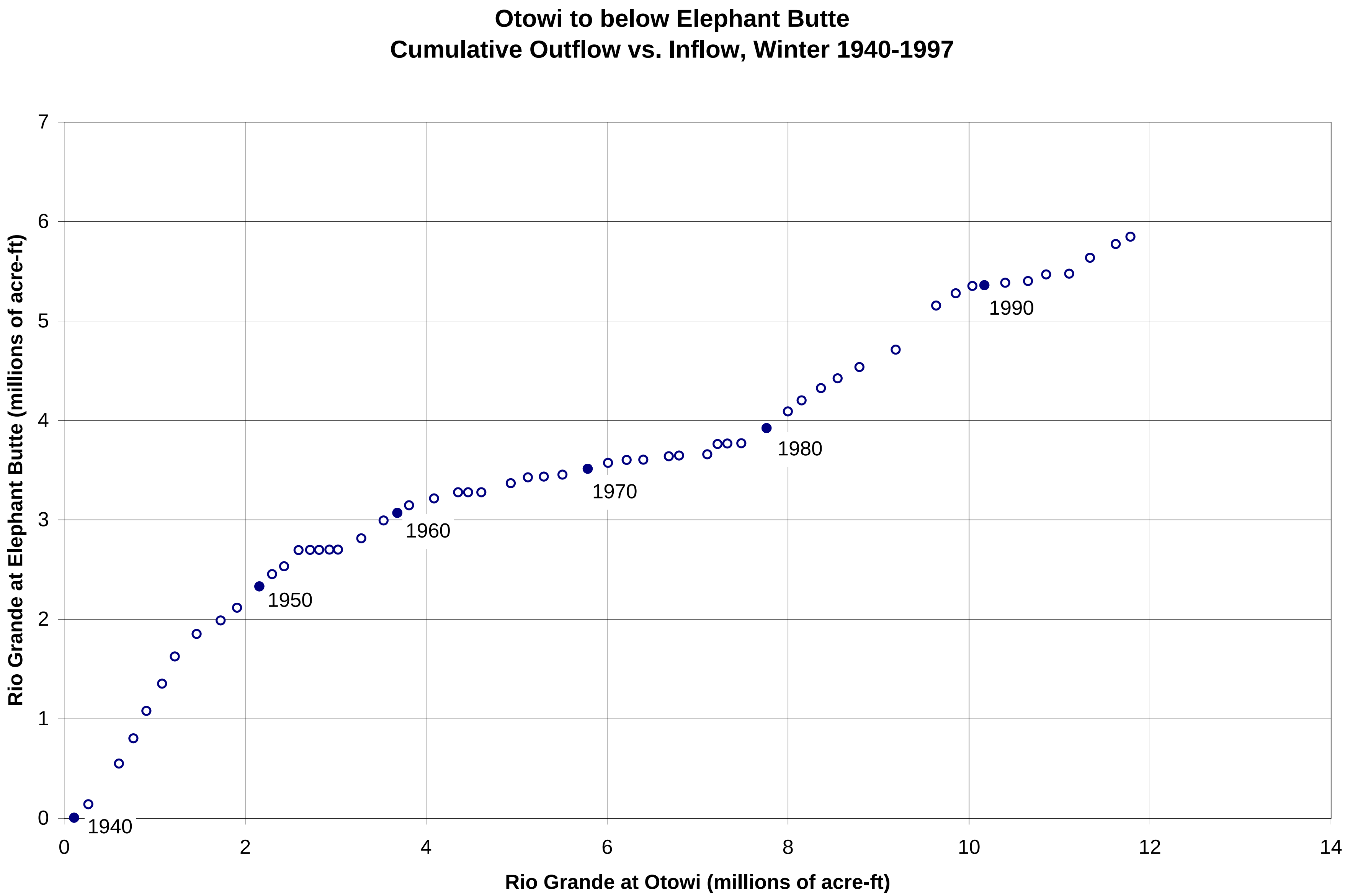
6/16/00 **Figure D-1.6** SanAcacia_SanMarcial.xls



6/16/00

Figure D-1.7

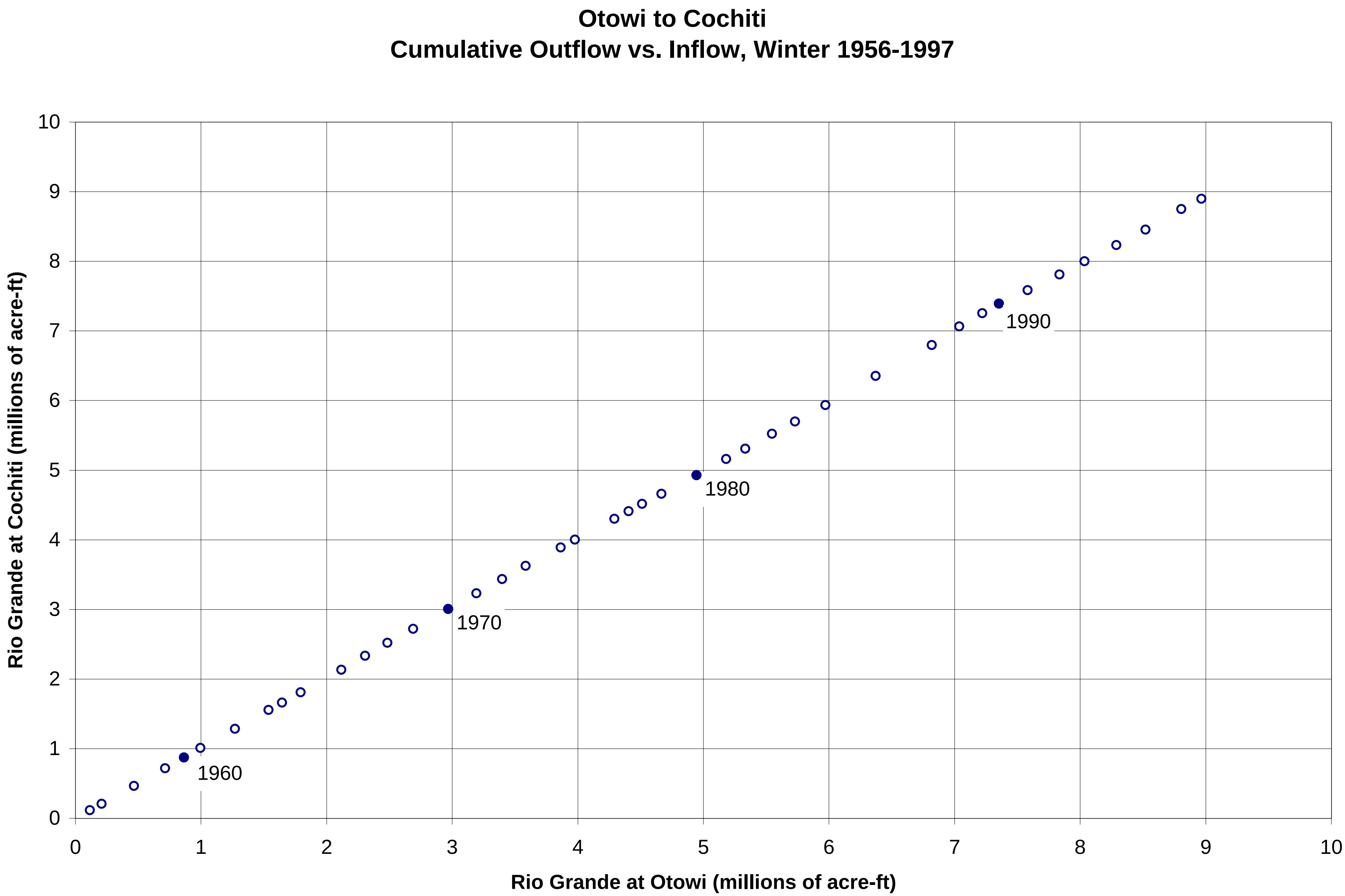
SanMarcial_ElephantButte.xls



6/16/00

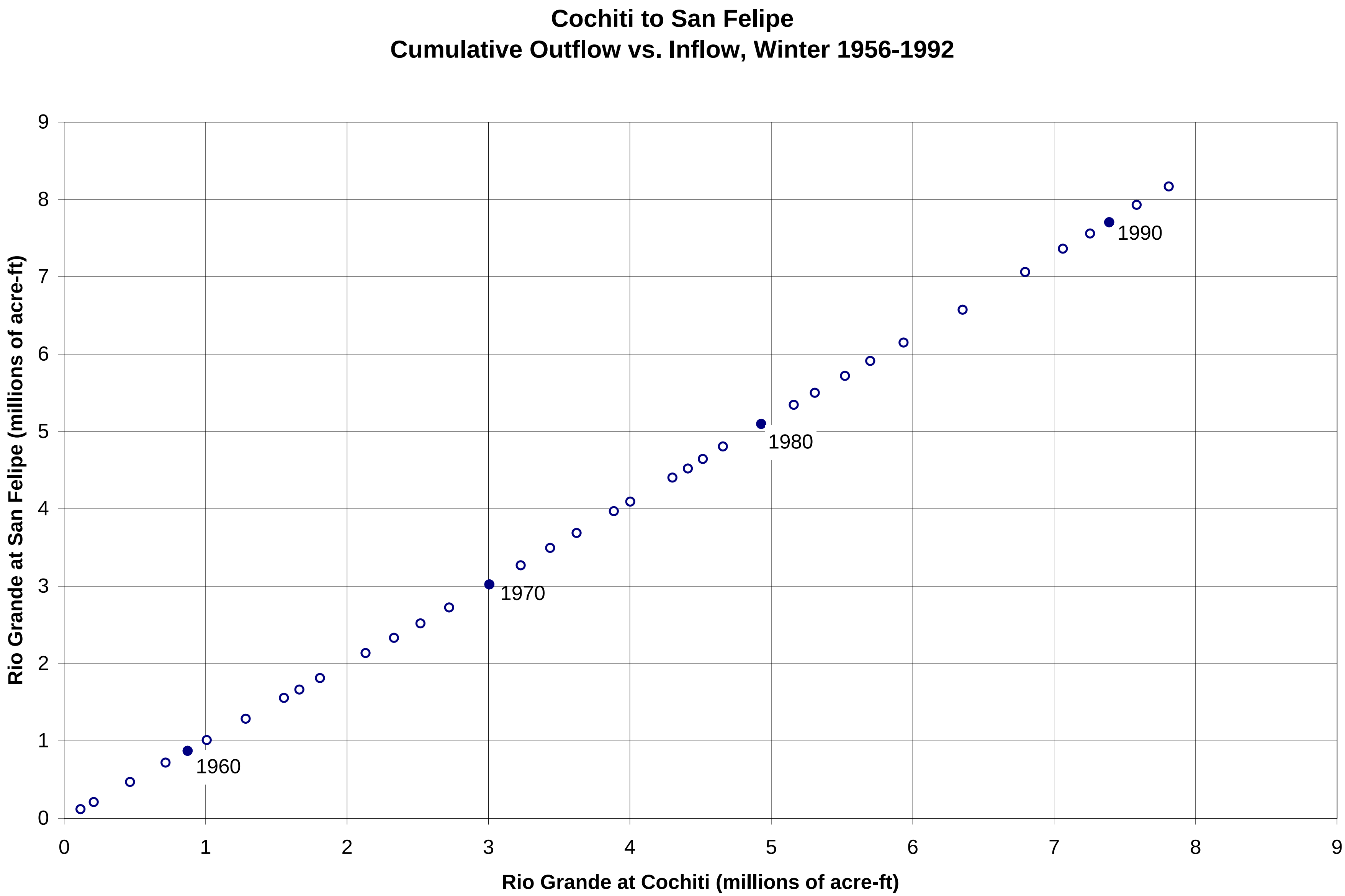
Figure D-2.1

Otowi_ElephantButte.xls



Otowi to Cochiti
Cumulative Outflow vs. Inflow, Winter 1956-1997
Rio Grande at Cochiti (millions of acre-ft)
Rio Grande at Otowi (millions of acre-ft)
0
1
2
3
4
5
6
7
8
9
10
1960
1970
1980
1990

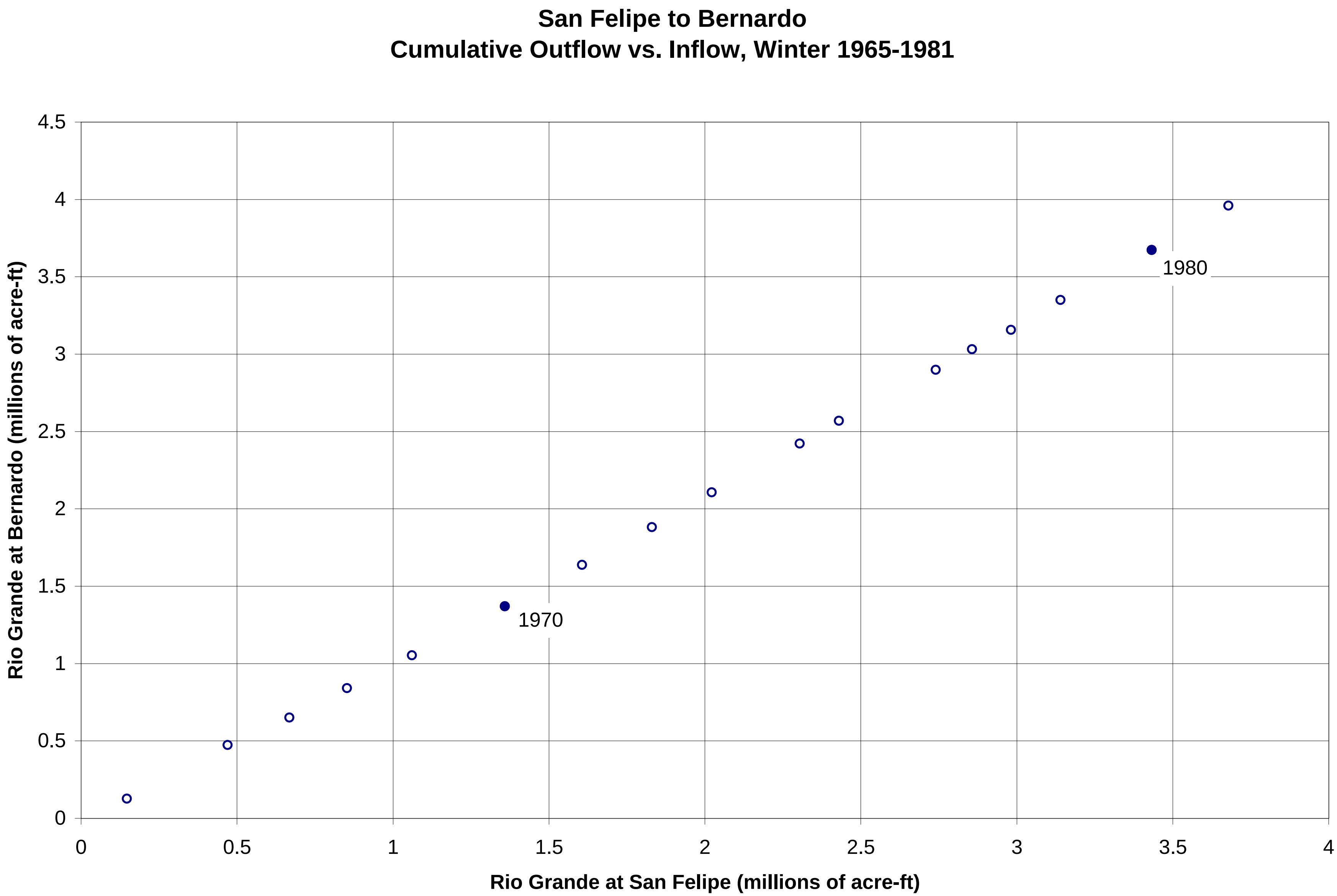
Figure D-2.2



6/16/00

Figure D-2.3

Cochiti_SanFelipe.xls



6/16/00

Figure D-2.4

SanFelipe_Bernardo.xls

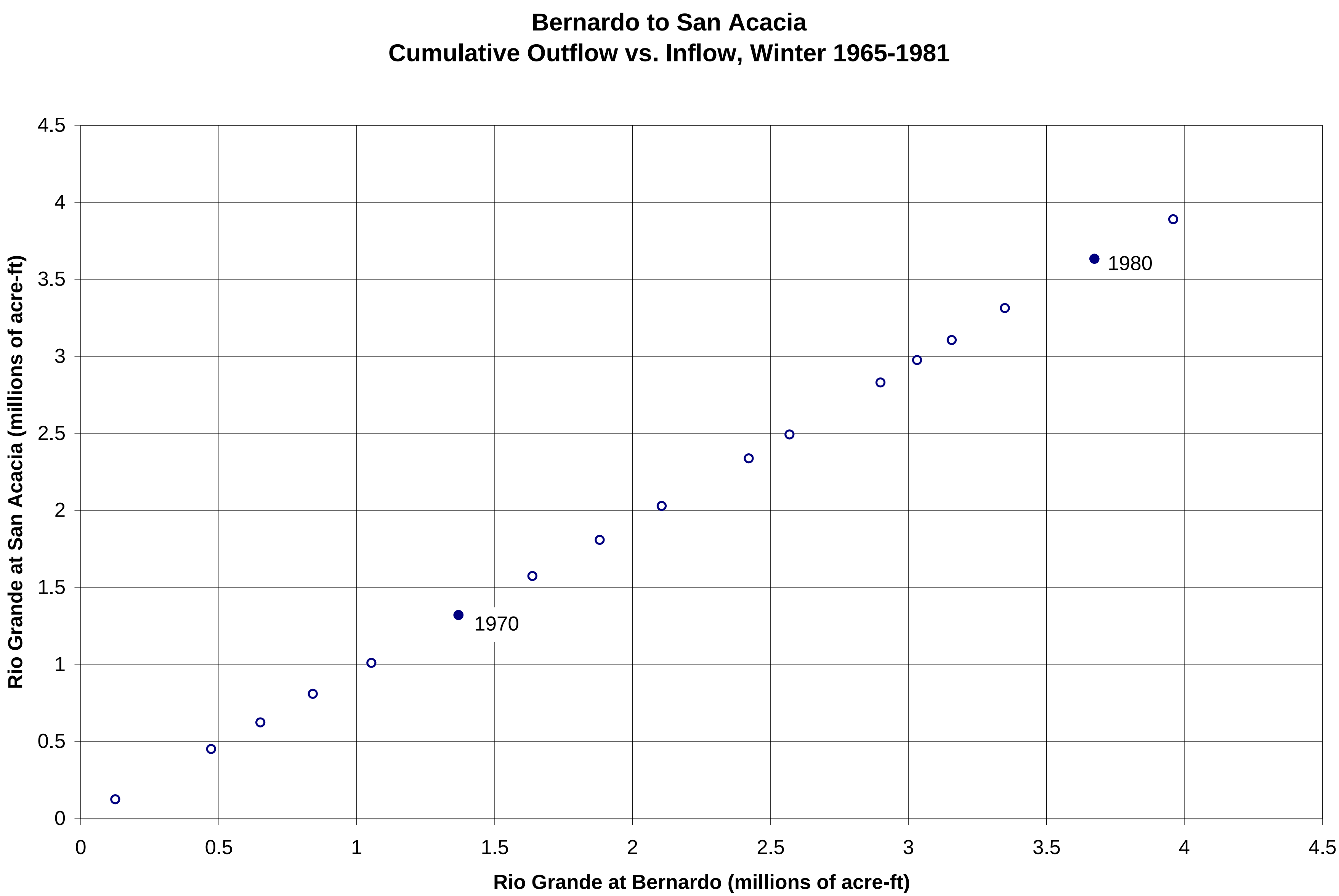

Bernardo to San Acacia
Cumulative Outflow vs. Inflow, Winter 1965-1981
Rio Grande at San Acacia (millions of acre-ft)
Rio Grande at Bernardo (millions of acre-ft)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
1970
1980

Figure D-2.5

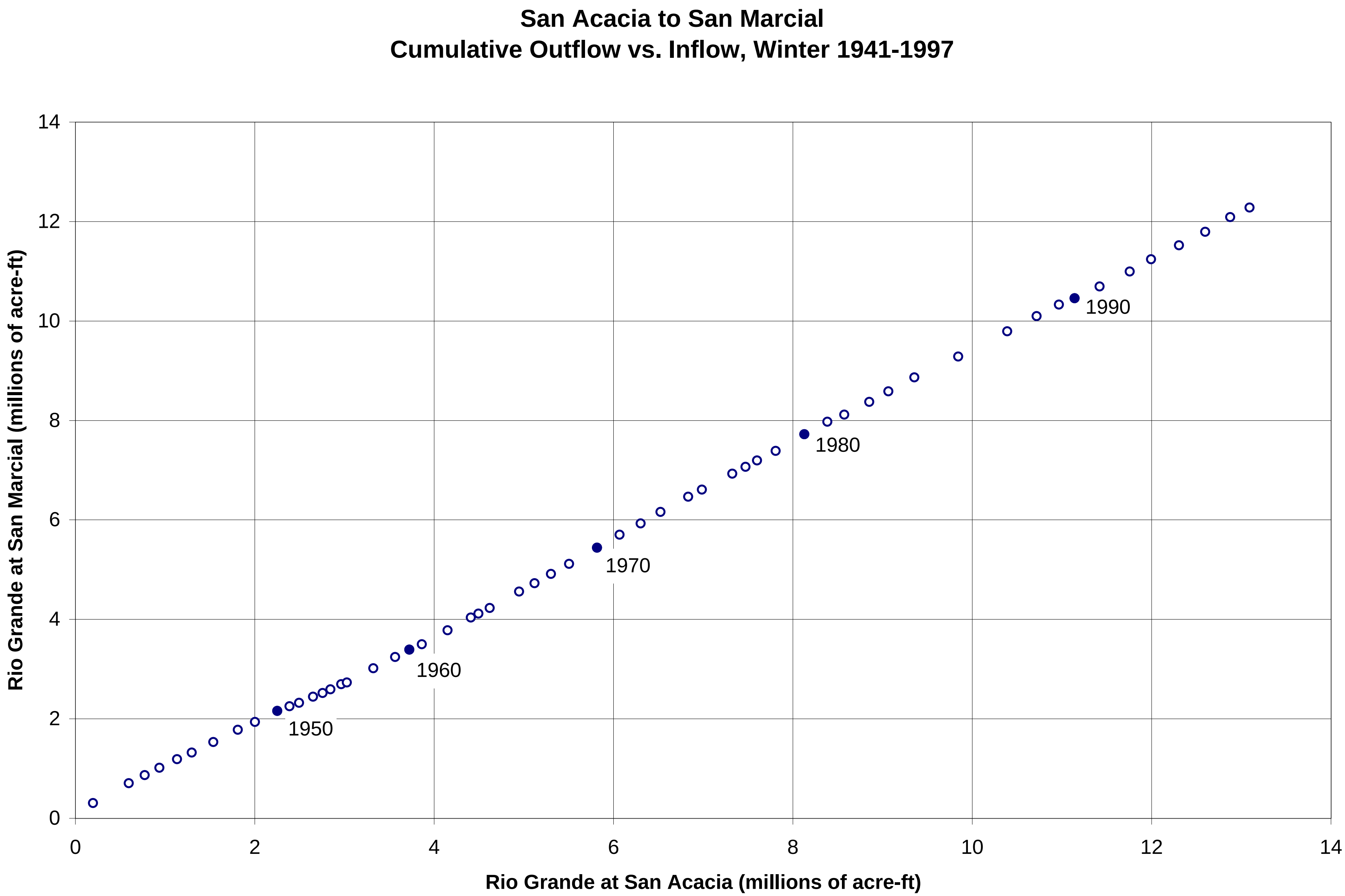

San Acacia to San Marcial
Cumulative Outflow vs. Inflow, Winter 1941-1997
Rio Grande at San Marcial (millions of acre-ft)
Rio Grande at San Acacia (millions of acre-ft)
0
2
4
6
8
10
12
14
1950
1960
1970
1980
1990

Figure D-2.6

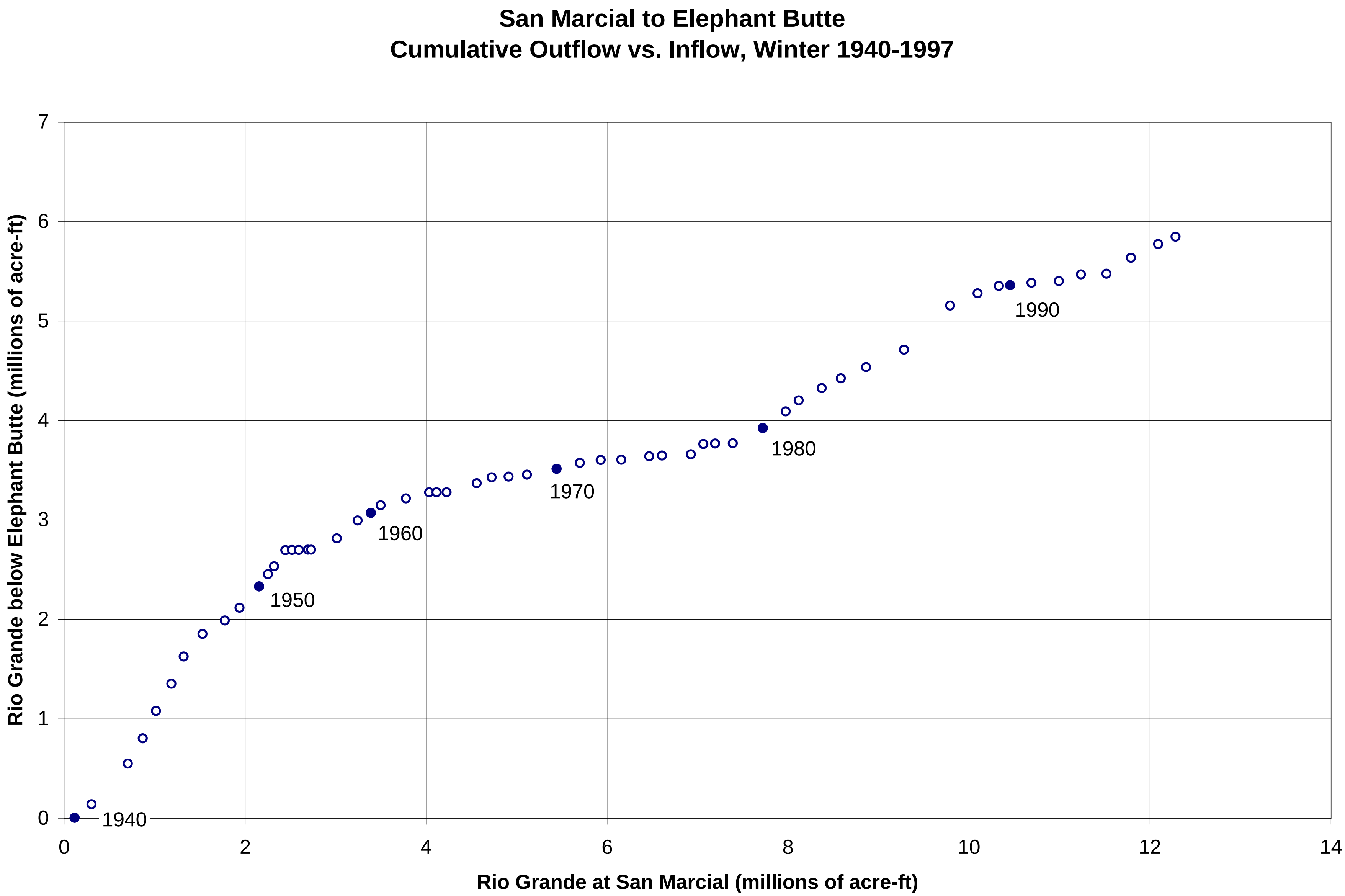
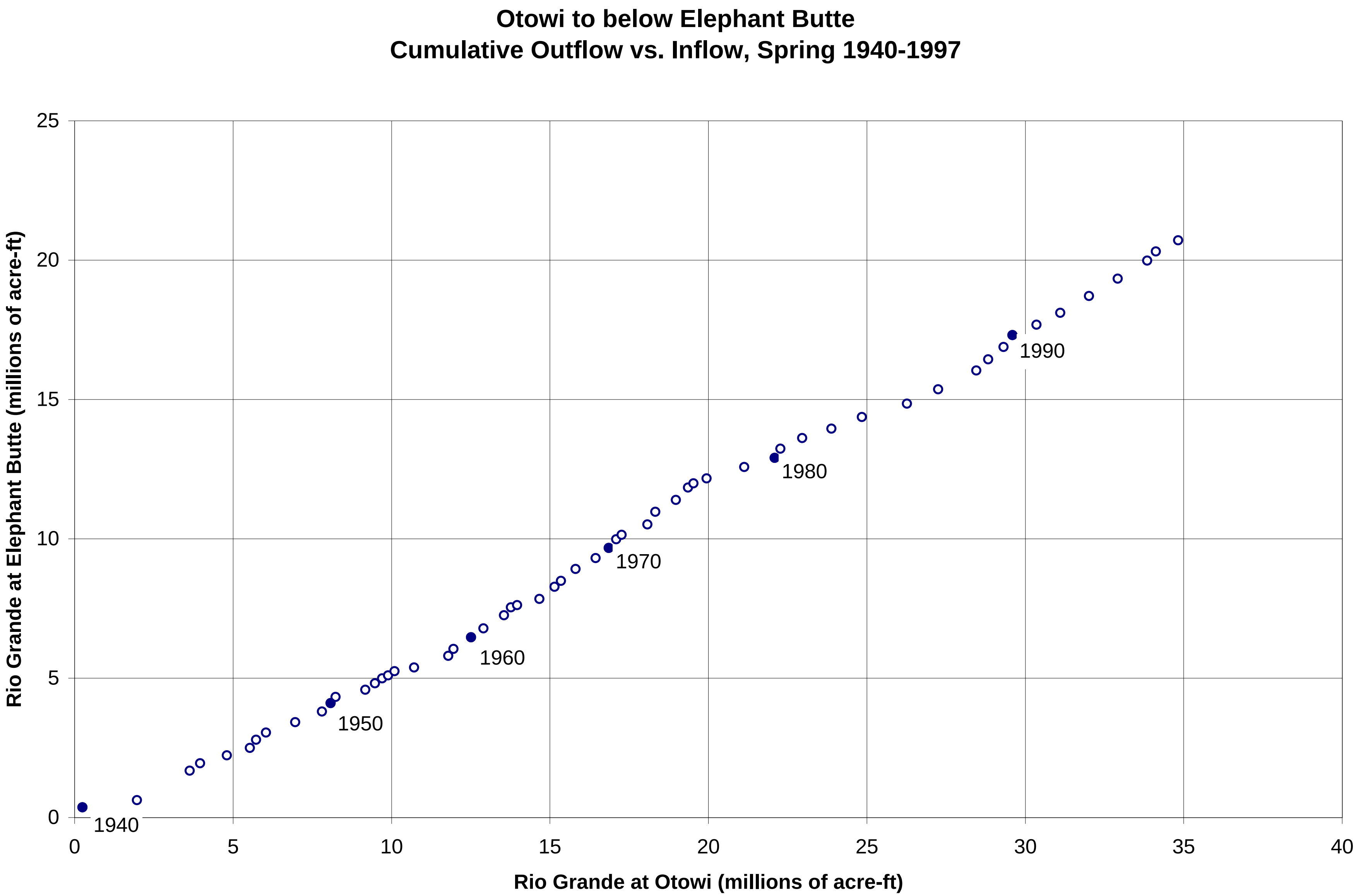

San Marcial to Elephant Butte
Cumulative Outflow vs. Inflow, Winter 1940-1997
Rio Grande below Elephant Butte (millions of acre-ft)
Rio Grande at San Marcial (millions of acre-ft)
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
1940
1950
1960
1970
1980
1990

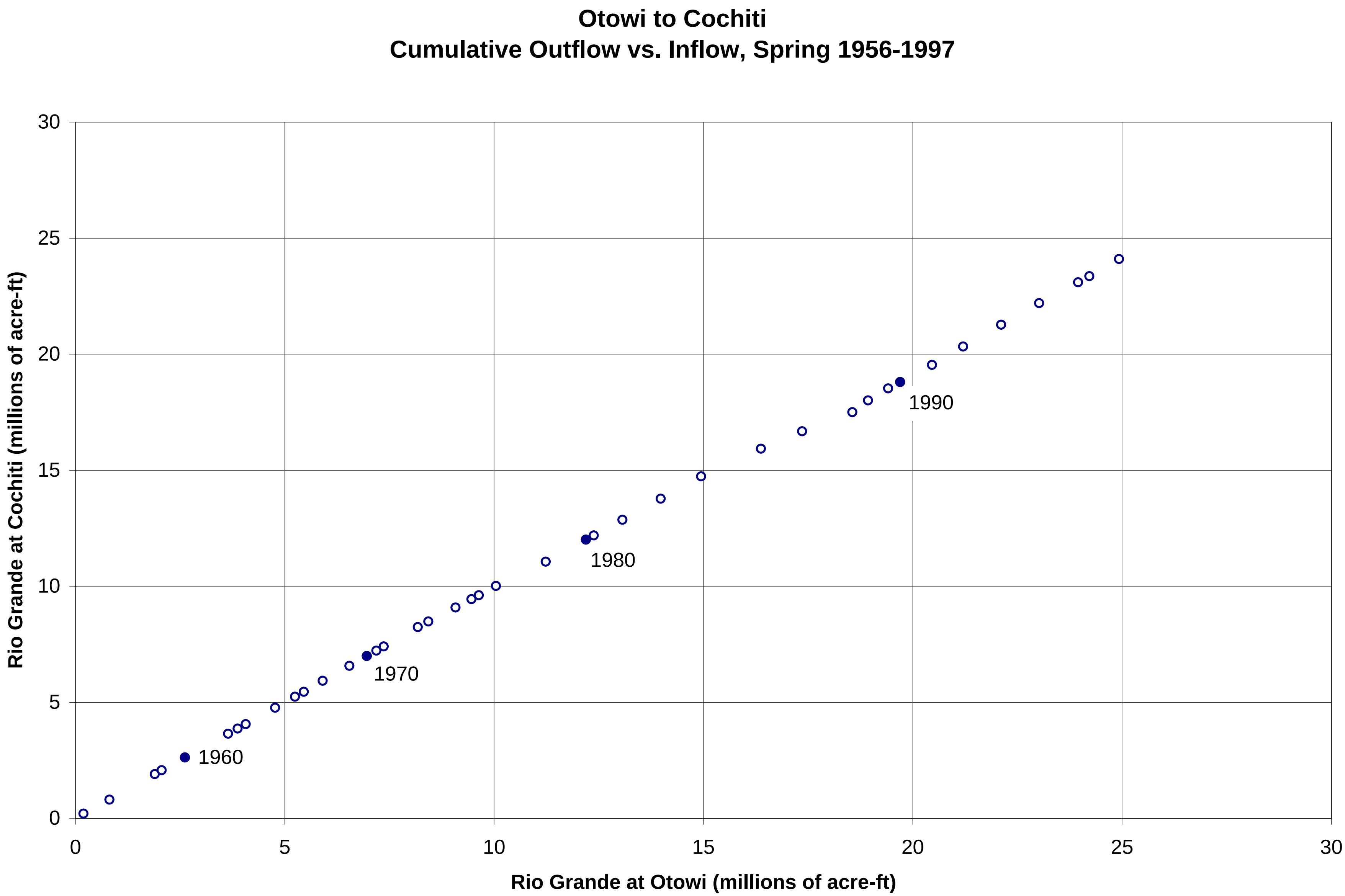
Figure D-2.7



6/16/00

Figure D-3.1

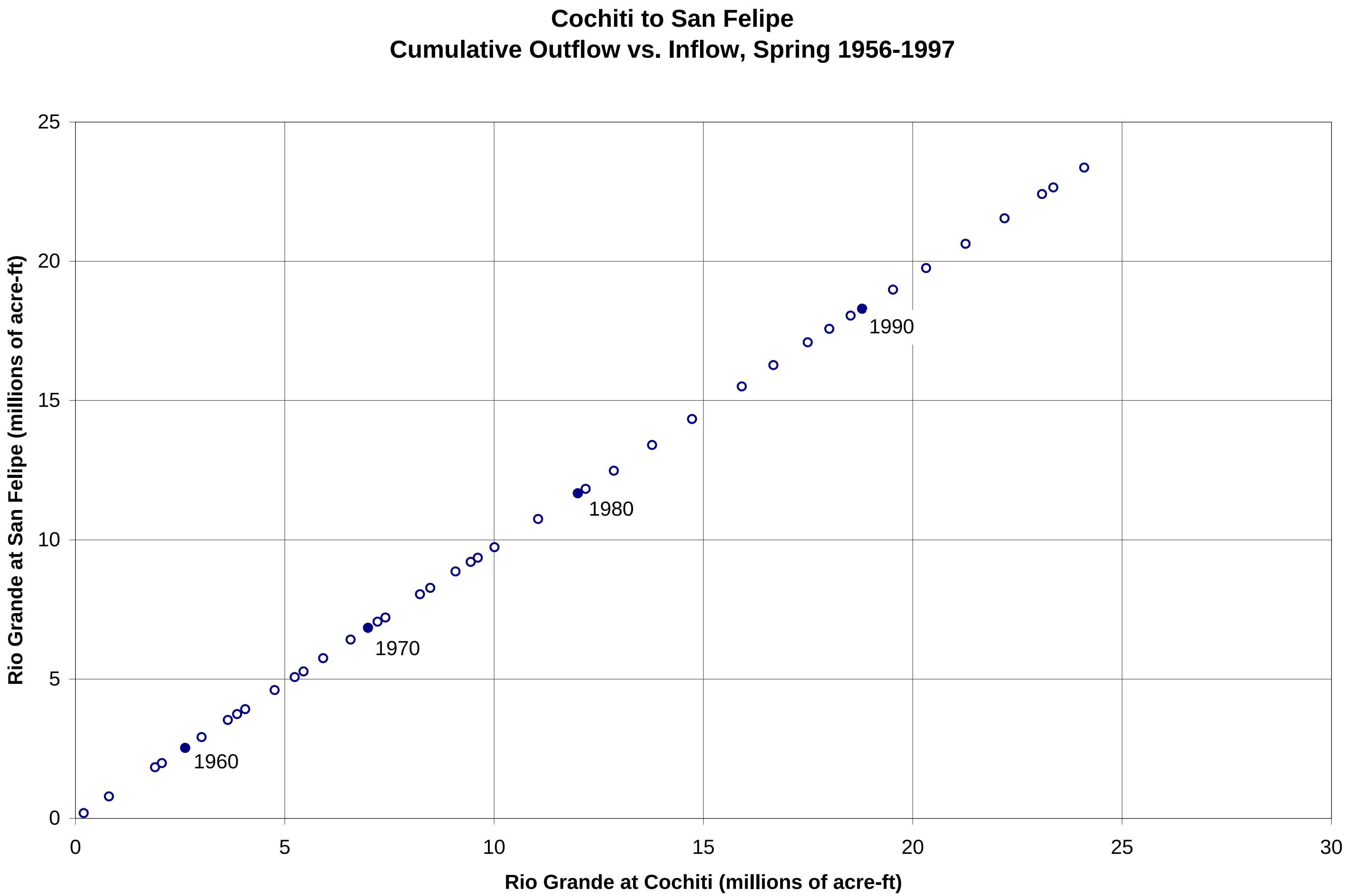
Otowi_ElephantButte.xls



6/16/00

Figure D-3.2

Otowi_Cochiti.xls



6/16/00

Figure D-3.3

Cochiti_SanFelipe.xls

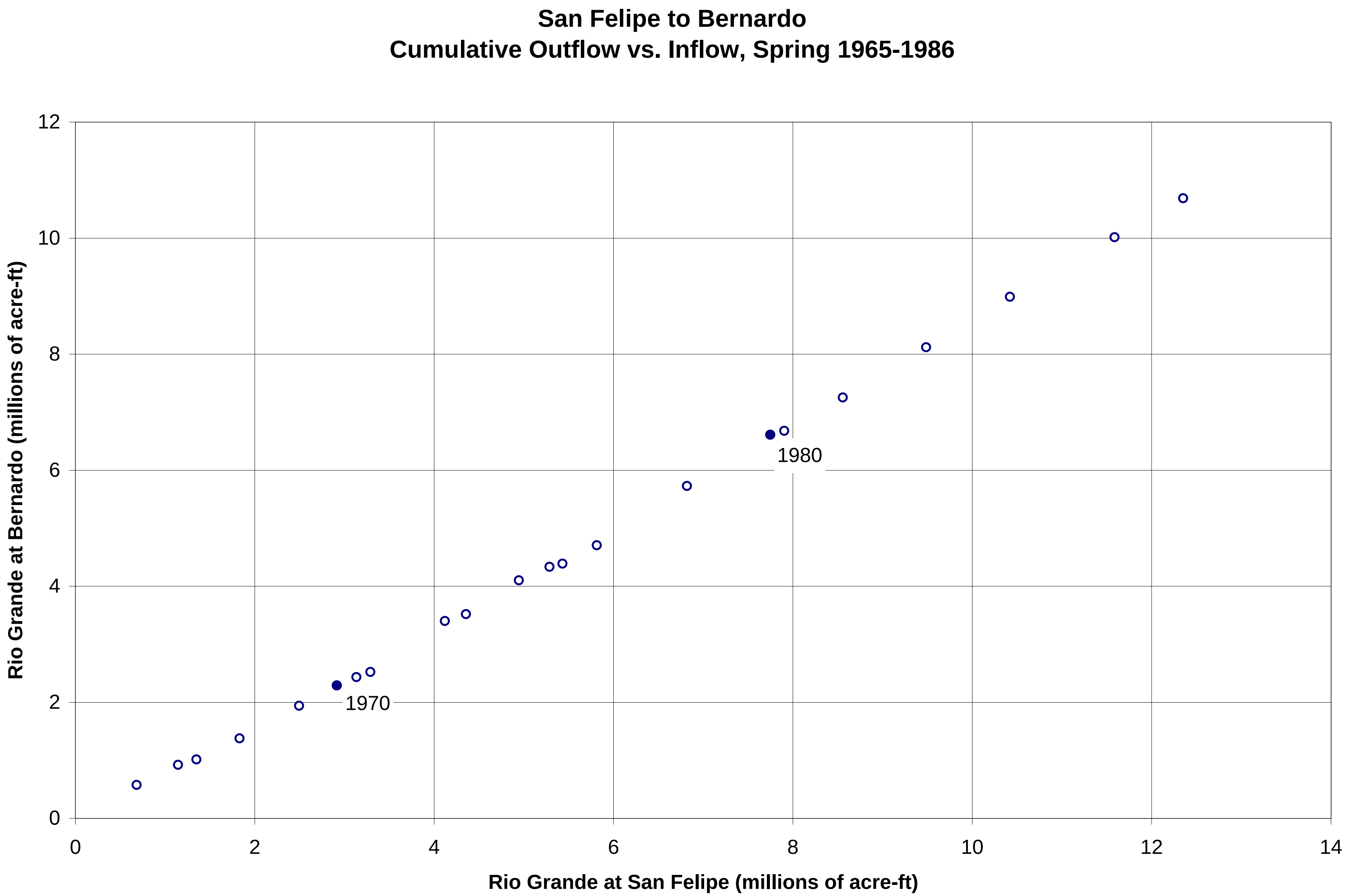

San Felipe to Bernardo
Cumulative Outflow vs. Inflow, Spring 1965-1986
Rio Grande at Bernardo (millions of acre-ft)
Rio Grande at San Felipe (millions of acre-ft)
0
2
4
6
8
10
12
14
1970
1980

Figure D-3.4

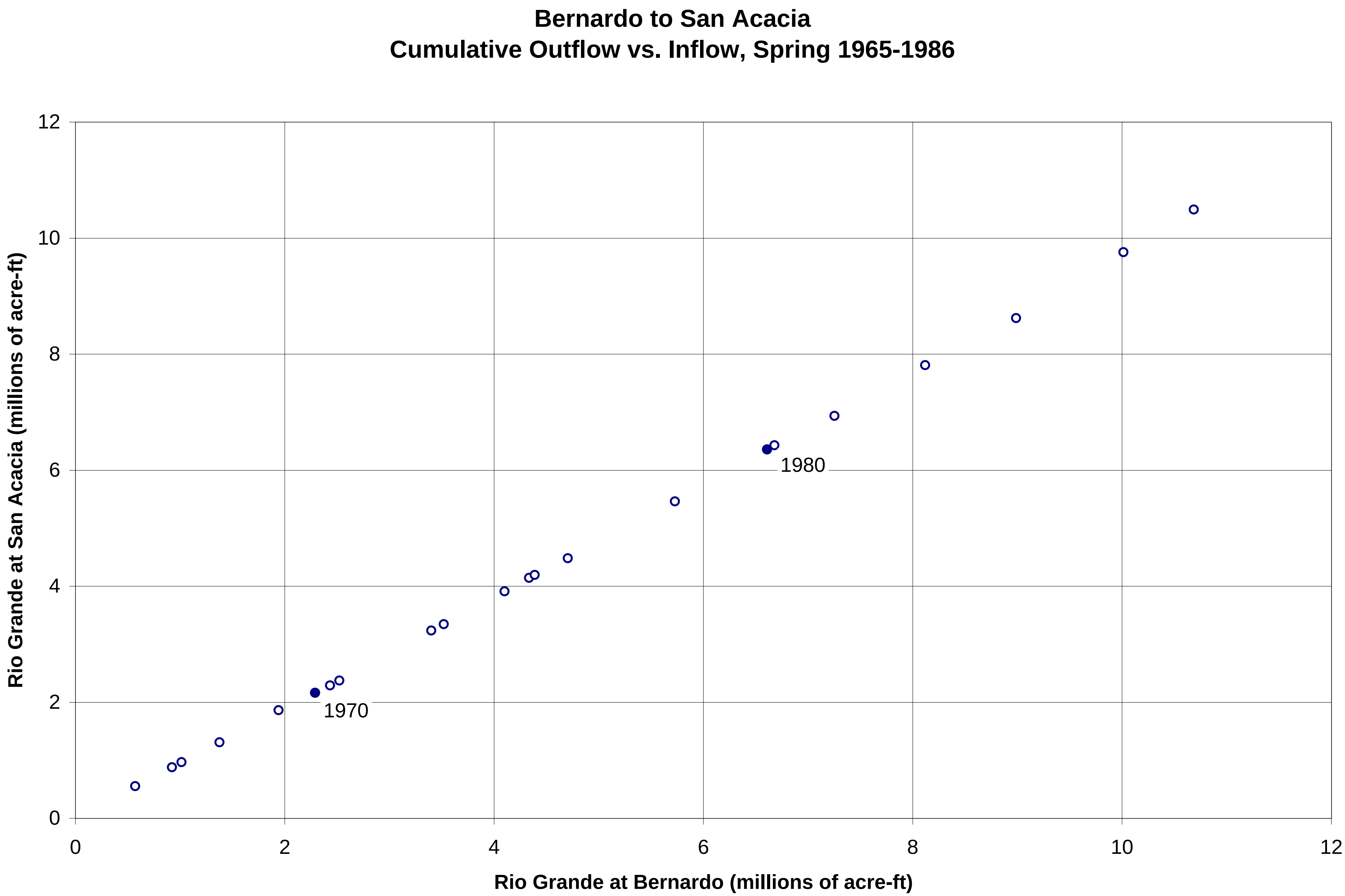
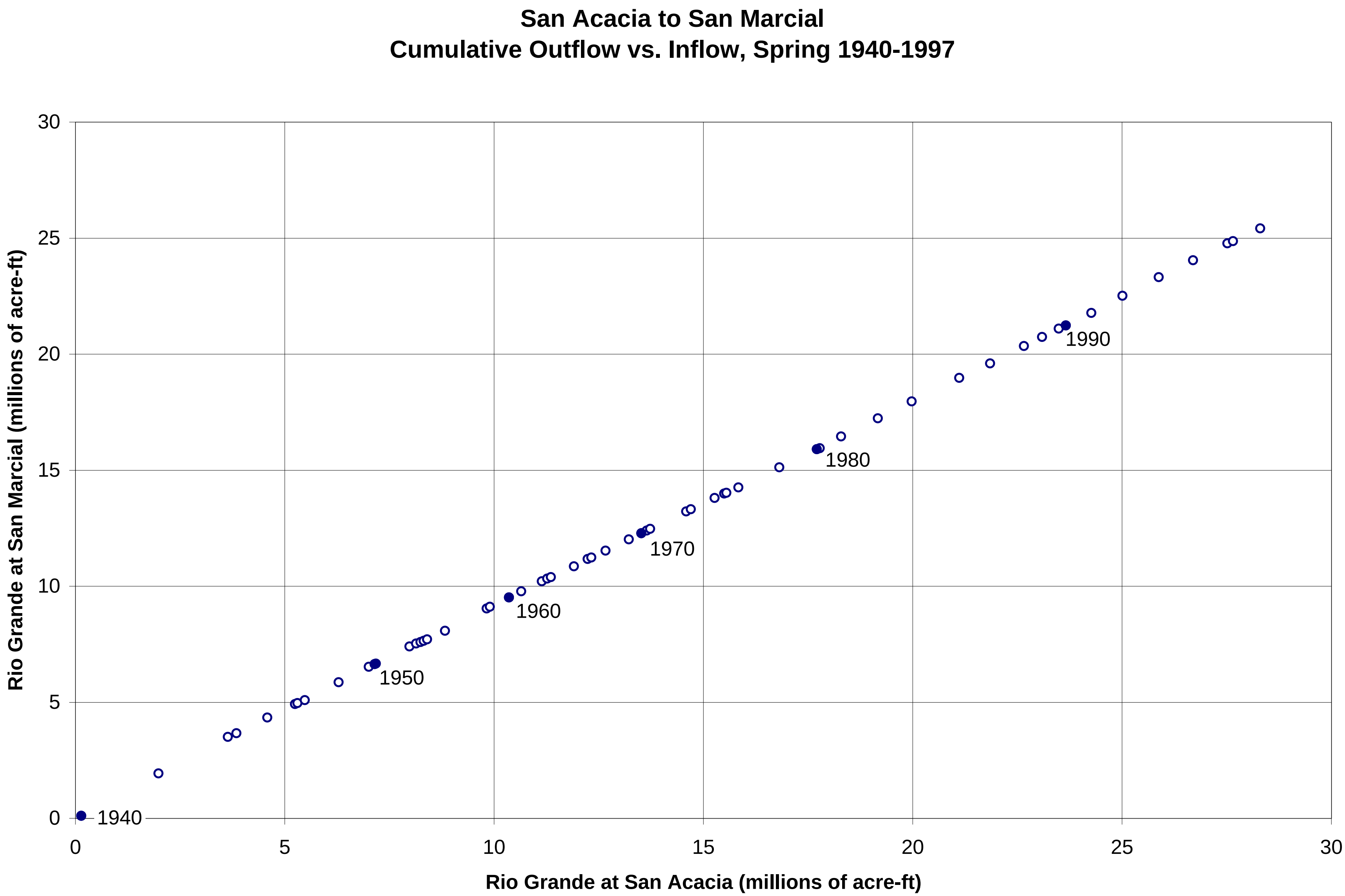

Bernardo to San Acacia
Cumulative Outflow vs. Inflow, Spring 1965-1986
Rio Grande at San Acacia (millions of acre-ft)
Rio Grande at Bernardo (millions of acre-ft)
0
2
4
6
8
10
12
1970
1980

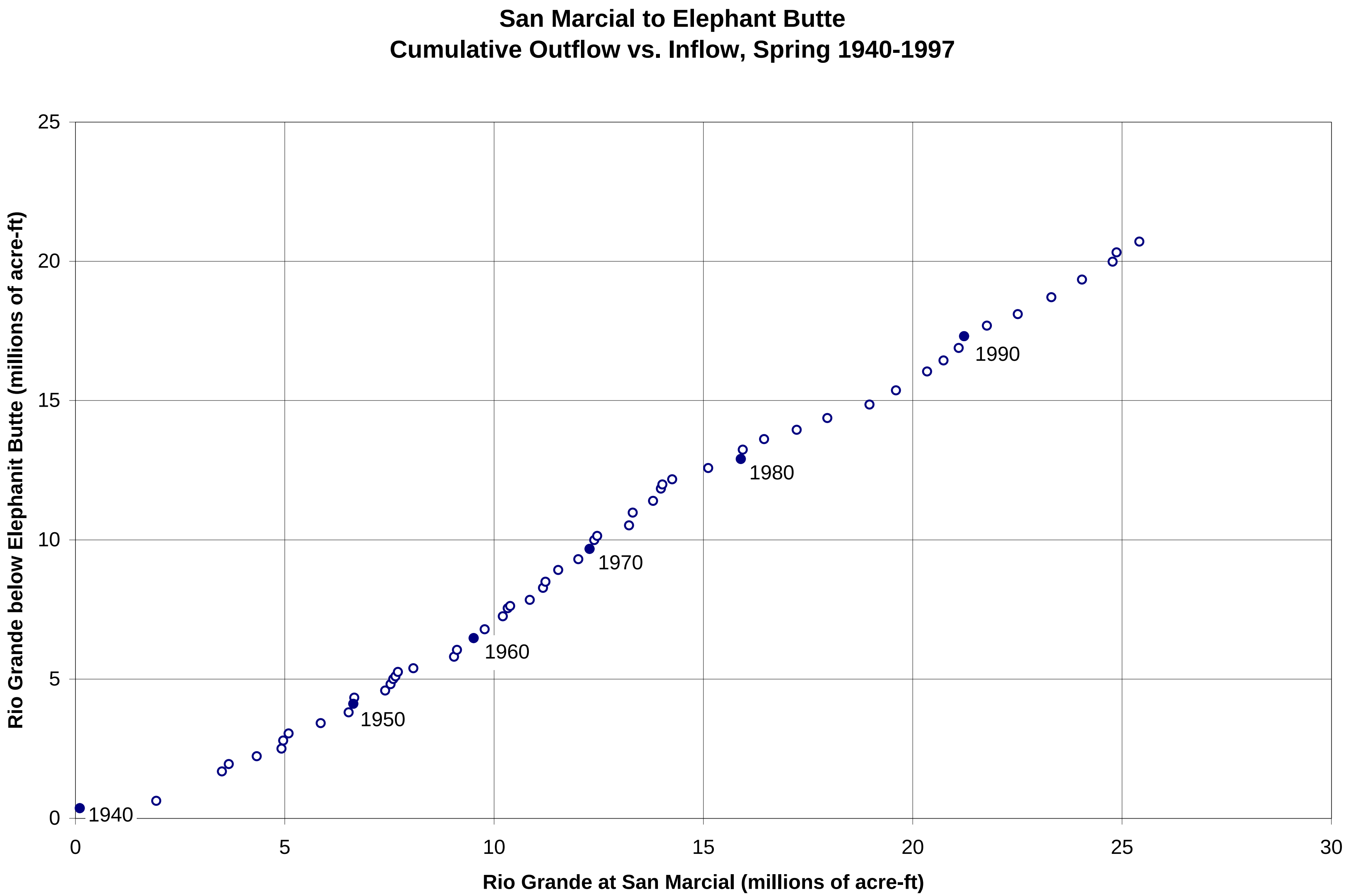
Figure D-3.5



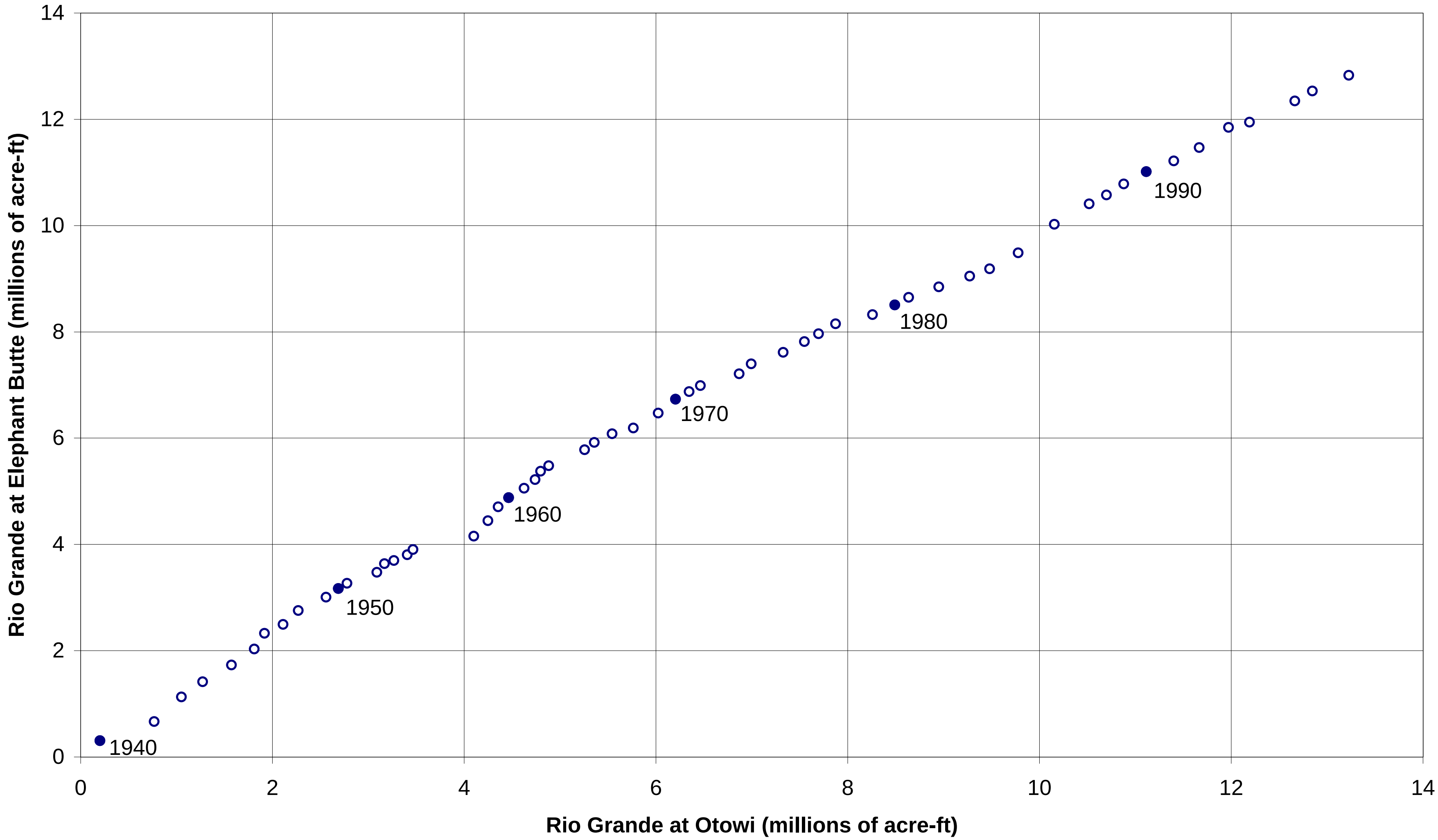
6/16/00

Figure D-3.6

SanAcacia_SanMarcial.xls


San Marcial to Elephant Butte
Cumulative Outflow vs. Inflow, Spring 1940-1997
Rio Grande below Elephanit Butte (millions of acre-ft)
Rio Grande at San Marcial (millions of acre-ft)
0
5
10
15
20
25
30
1940
1950
1960
1970
1980
1990

Otowi to below Elephant Butte
Cumulative Outflow vs. Inflow, Summer 1940-1997



6/16/00

Figure D-4.1

Otowi_ElephantButte.xls

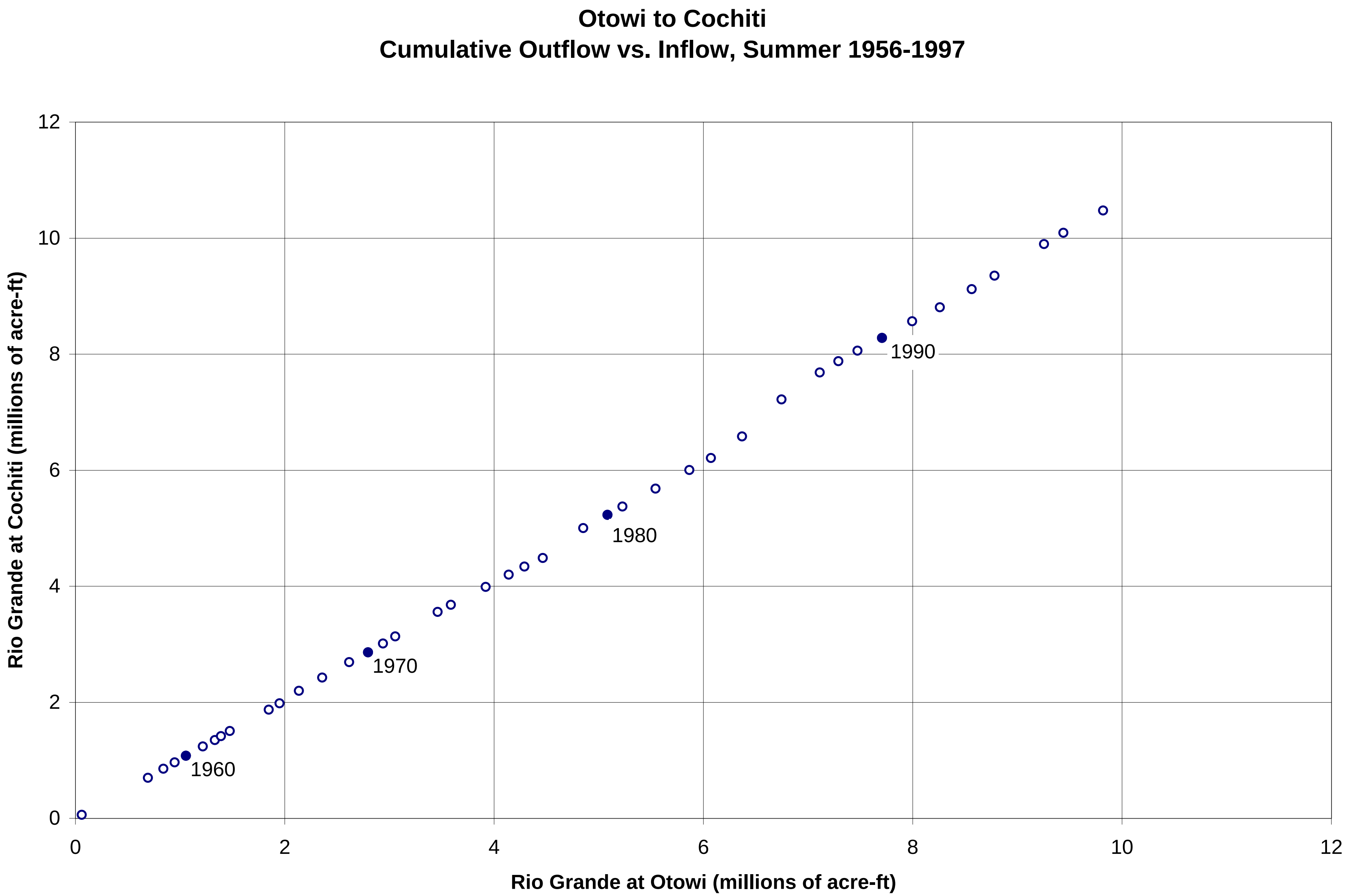

Otowi to Cochiti
Cumulative Outflow vs. Inflow, Summer 1956-1997
Rio Grande at Cochiti (millions of acre-ft)
Rio Grande at Otowi (millions of acre-ft)
0
2
4
6
8
10
12
1960
1970
1980
1990

Figure D-4.2

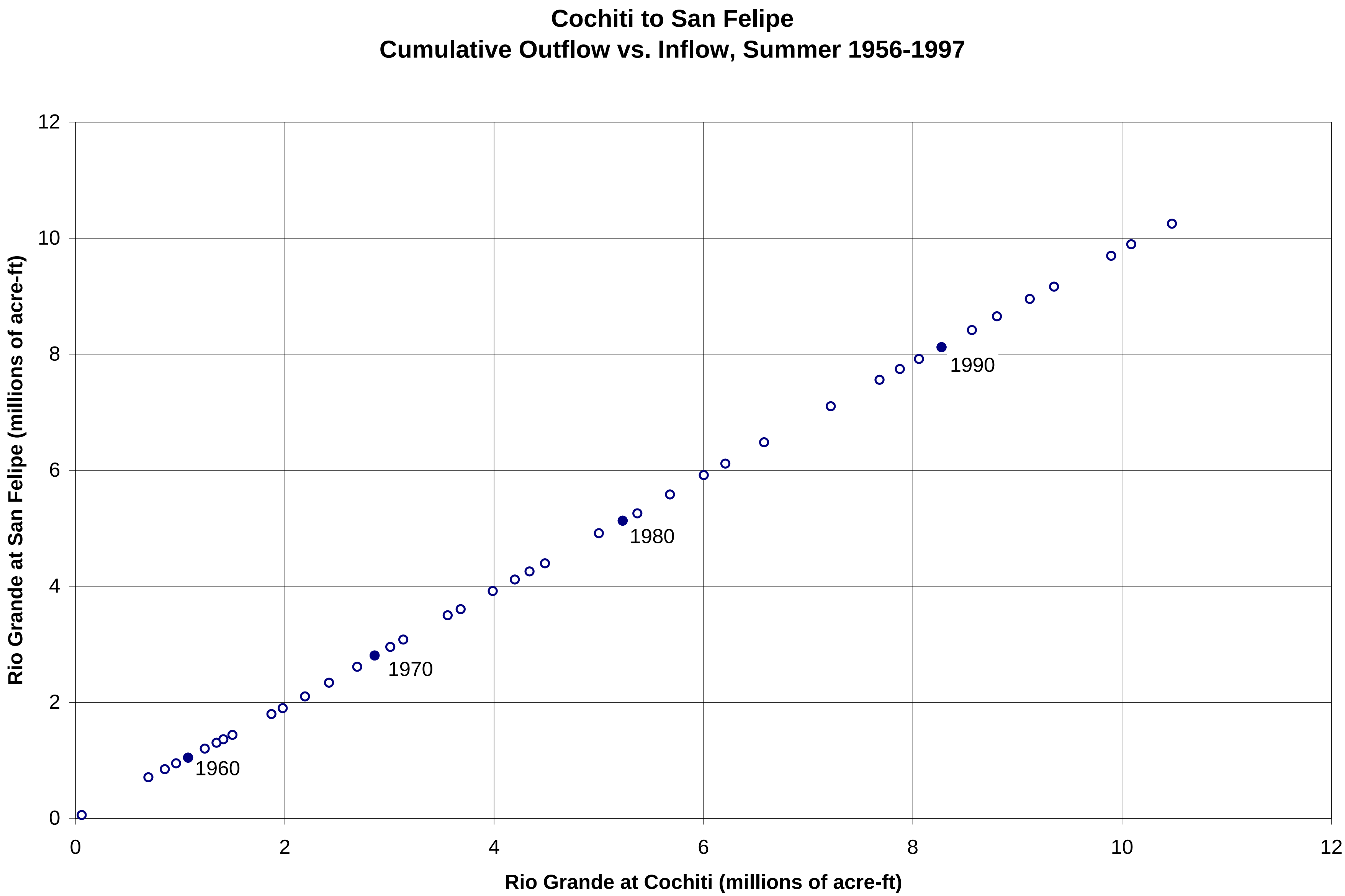
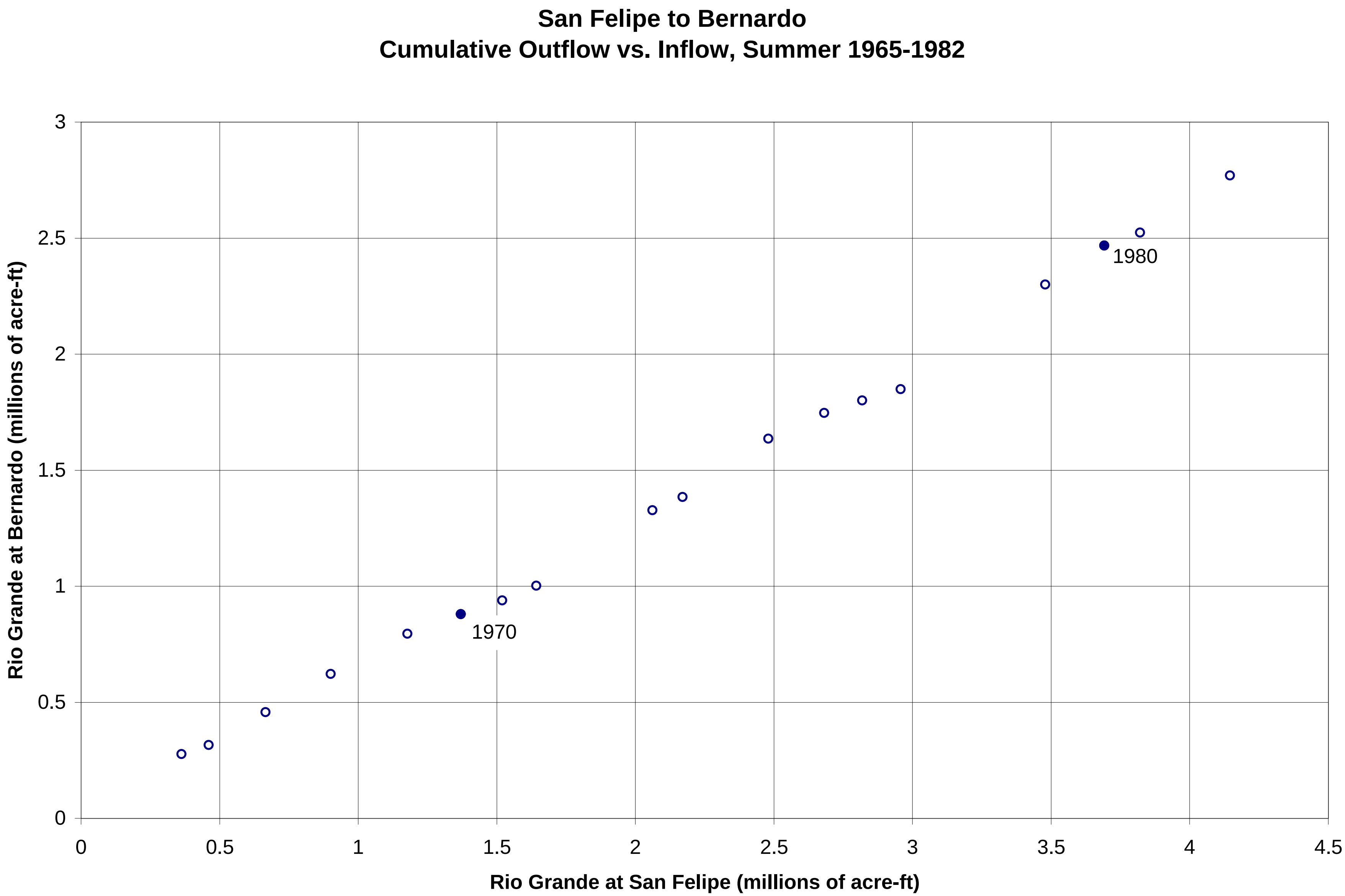

Cochiti to San Felipe
Cumulative Outflow vs. Inflow, Summer 1956-1997
Rio Grande at San Felipe (millions of acre-ft)
Rio Grande at Cochiti (millions of acre-ft)
0
2
4
6
8
10
12
1960
1970
1980
1990

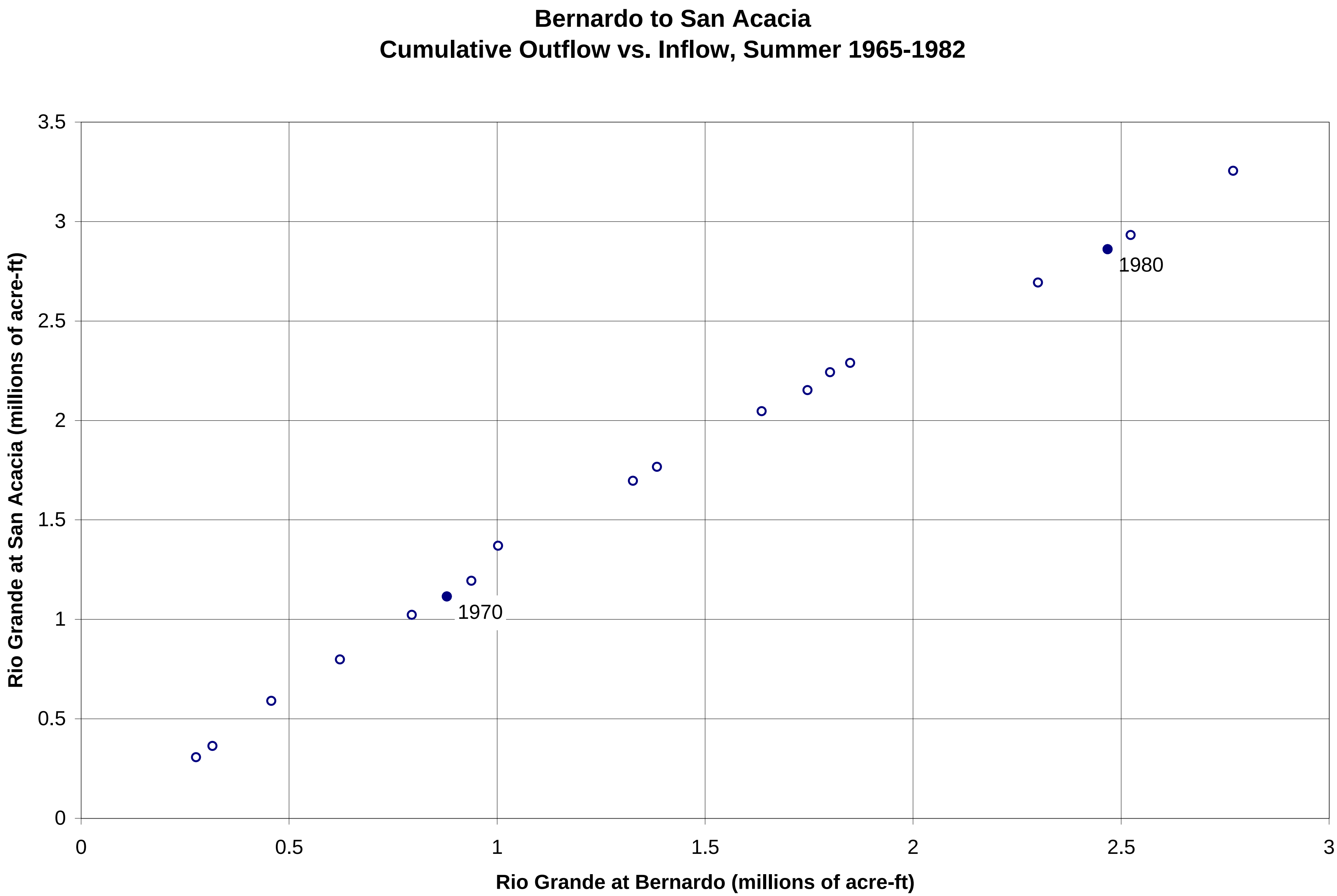
Figure D-4.3



6/16/00

Figure D-4.4

SanFelipe_Bernardo.xls



6/16/00

Figure D-4.5

Bernardo_SanAcacia.xls

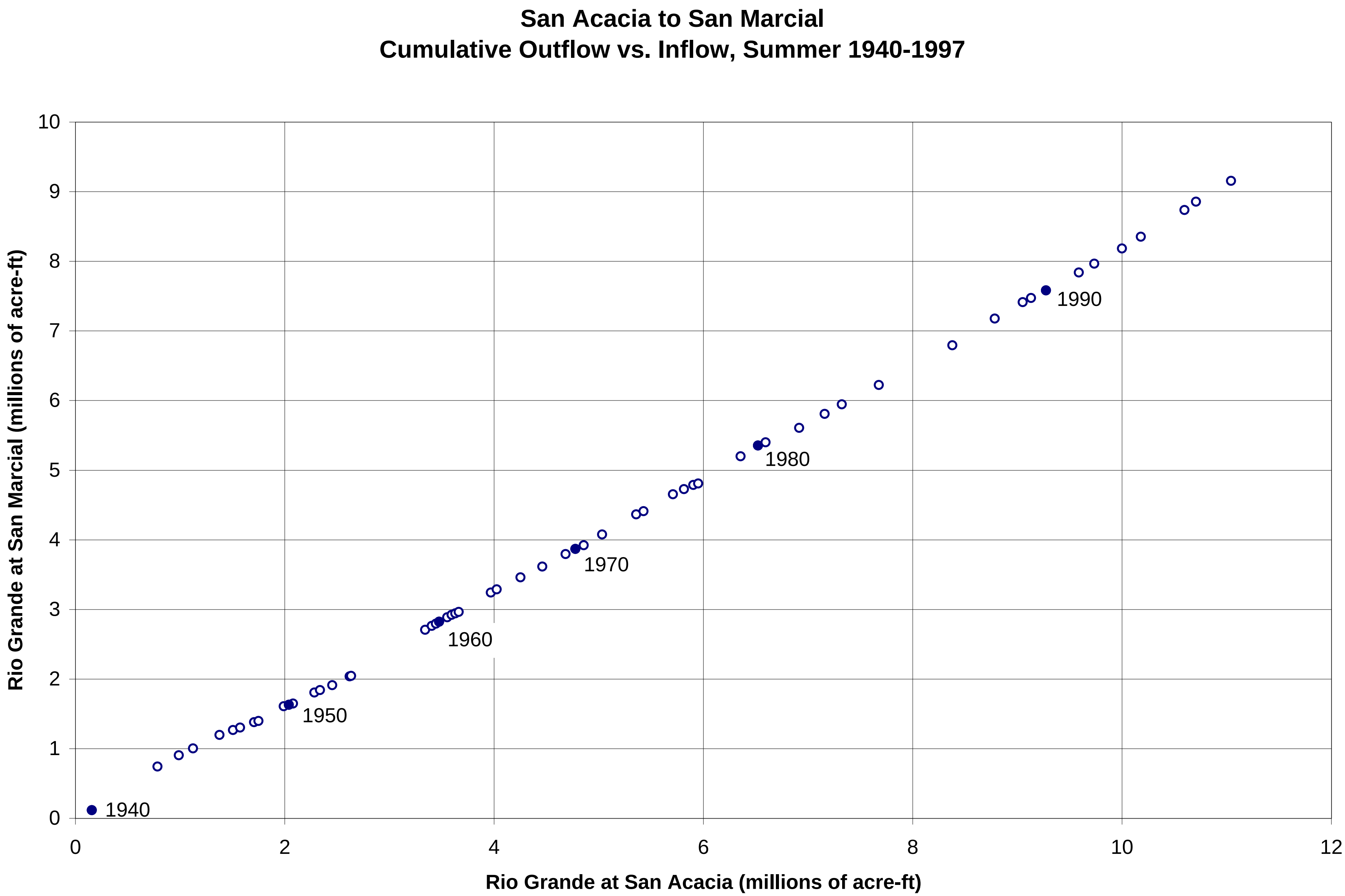
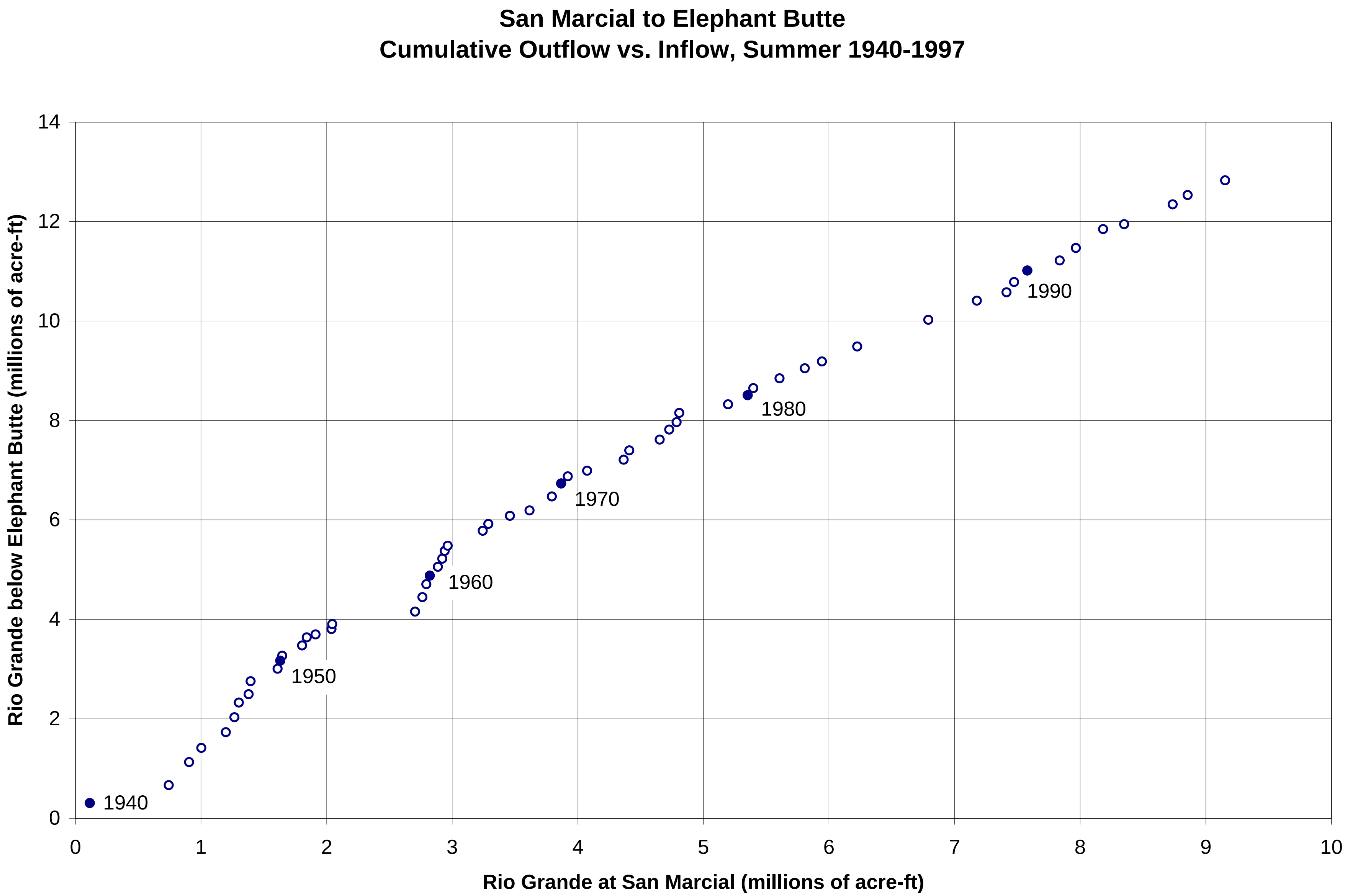

San Acacia to San Marcial
Cumulative Outflow vs. Inflow, Summer 1940-1997
Rio Grande at San Marcial (millions of acre-ft)
Rio Grande at San Acacia (millions of acre-ft)
0
1
2
3
4
5
6
7
8
9
10
12
1940
1950
1960
1970
1980
1990

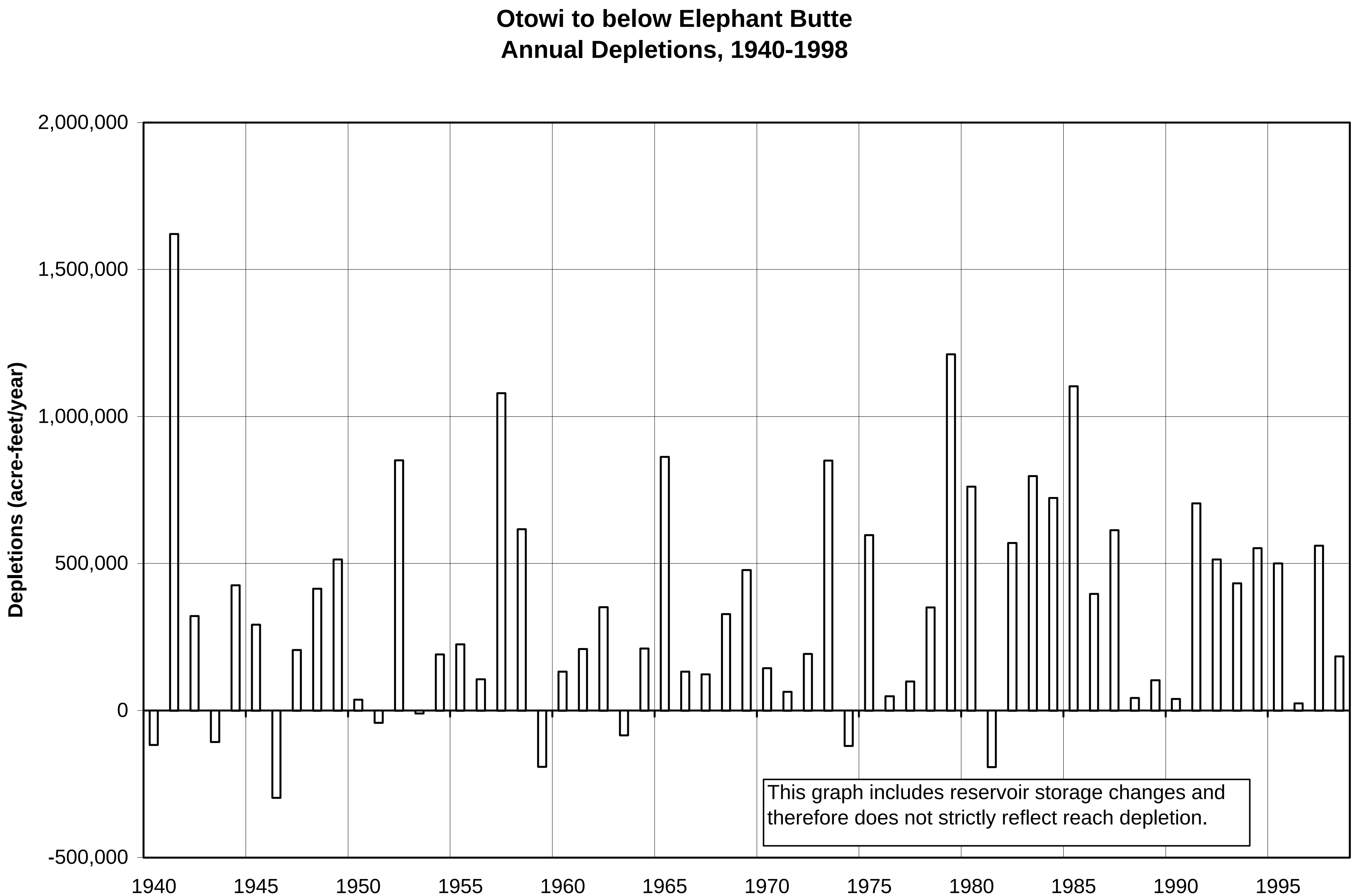
Figure D-4.6



6/16/00

Figure D-4.7

SanMarcial_ElephantButte.xls



Otowi to below Elephant Butte
Annual Depletions, 1940-1998
Depletions (acre-feet/year)
2,000,000
1,500,000
1,000,000
500,000
0
-500,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
This graph includes reservoir storage changes and therefore does not strictly reflect reach depletion.

Figure D-5.1

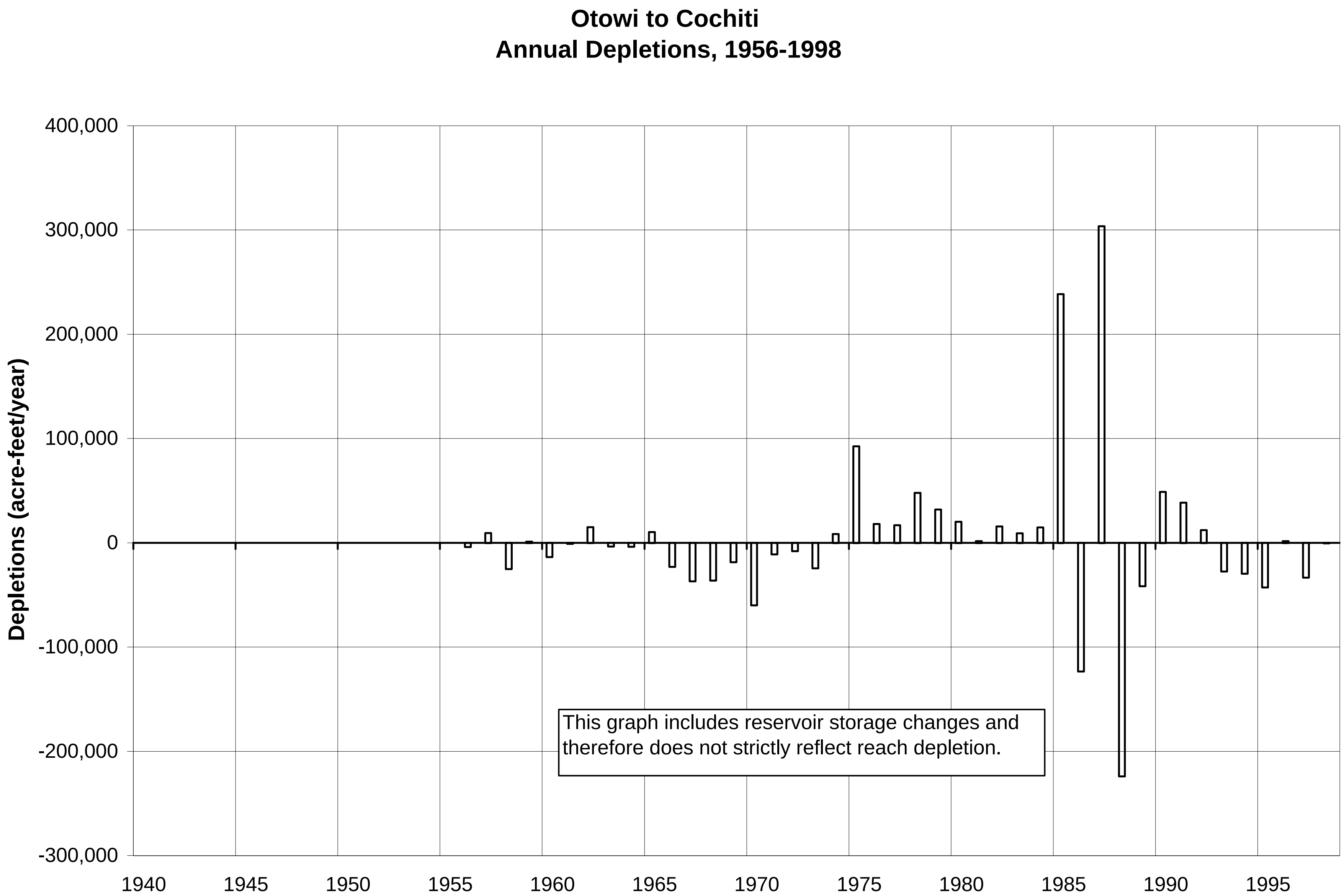
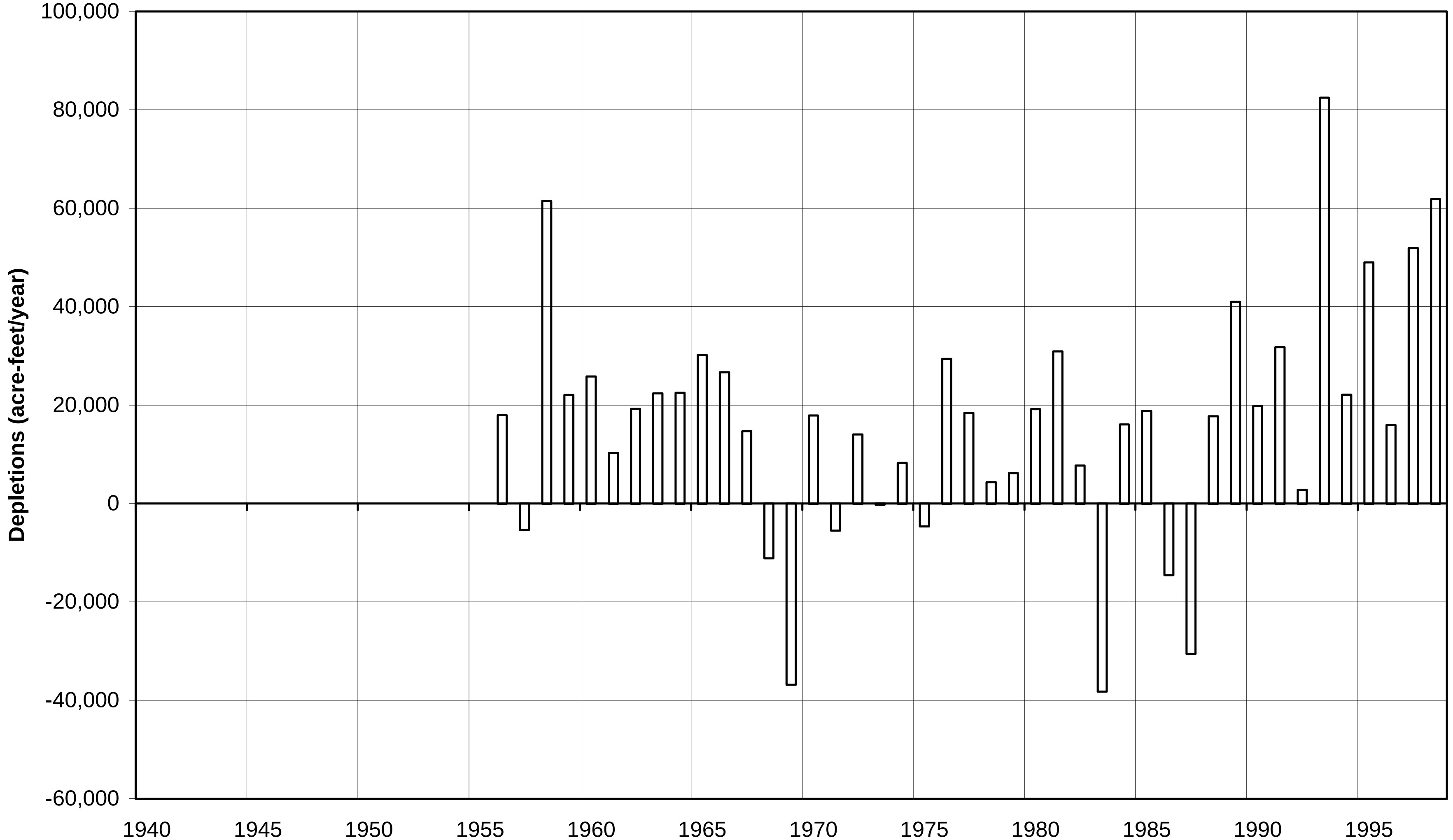

Otowi to Cochiti
Annual Depletions, 1956-1998
Depletions (acre-feet/year)
400,000
300,000
200,000
100,000
0
-100,000
-200,000
-300,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
This graph includes reservoir storage changes and therefore does not strictly reflect reach depletion.

Figure D-5.2

Cochiti to San Felipe
Annual Depletions, 1956-1998



6/16/00

Figure D-5.3

Cochiti_SanFelipe.xls

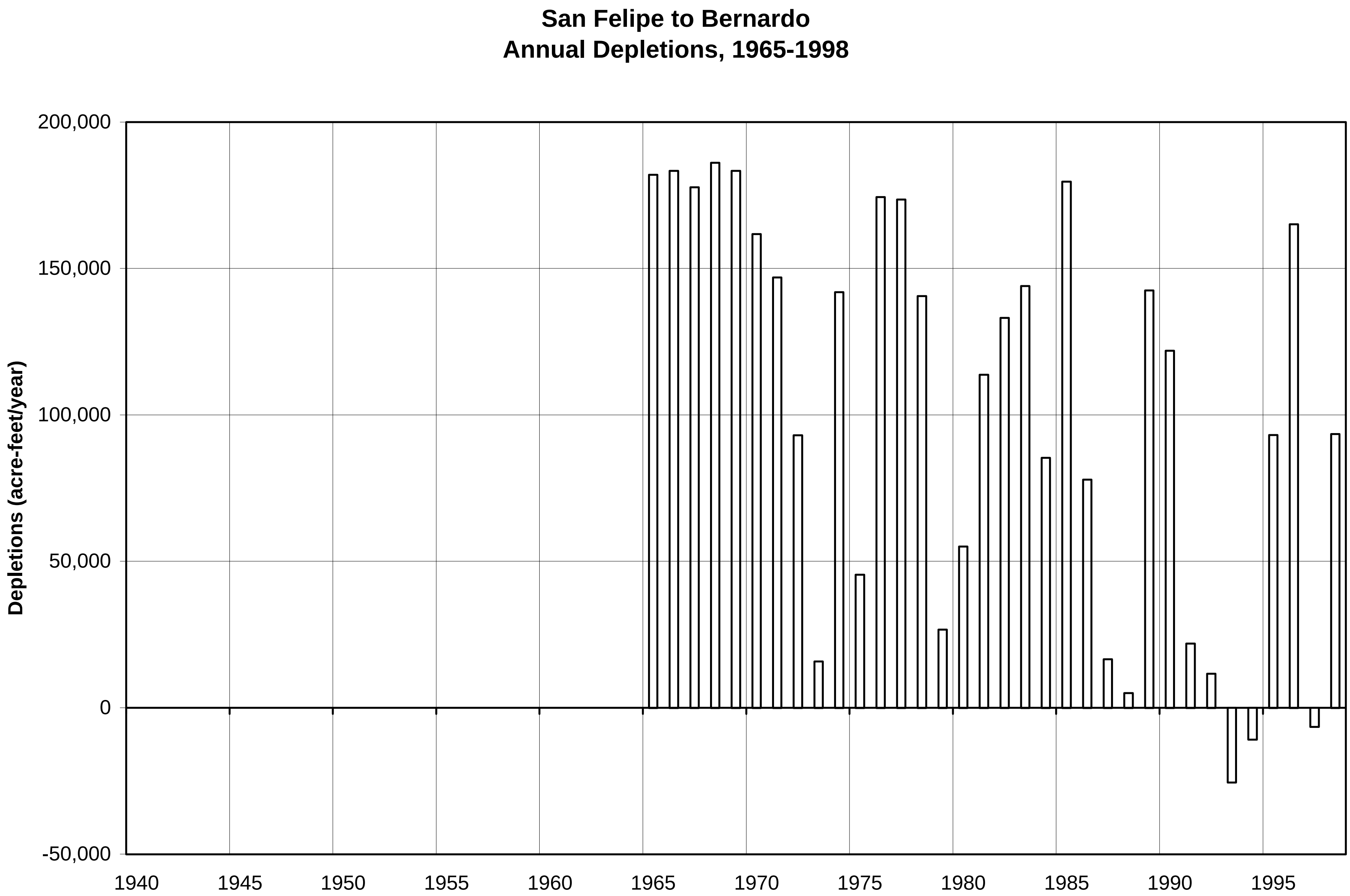

San Felipe to Bernardo
Annual Depletions, 1965-1998
Depletions (acre-feet/year)
200,000
150,000
100,000
50,000
0
-50,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

Figure D-5.4

Bernardo to San Acacia
Annual Depletions, 1965-1998

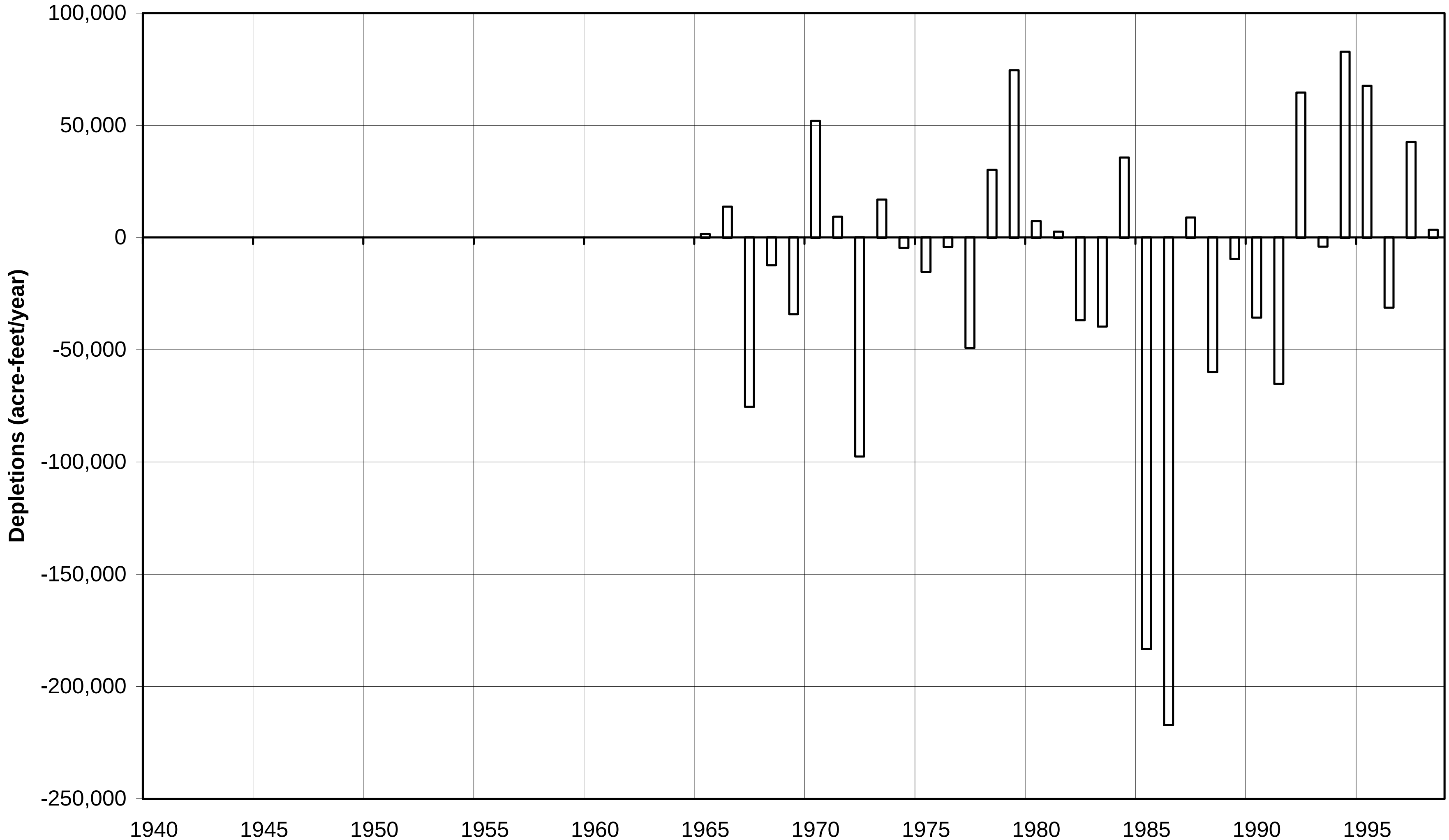


Figure D-5.5

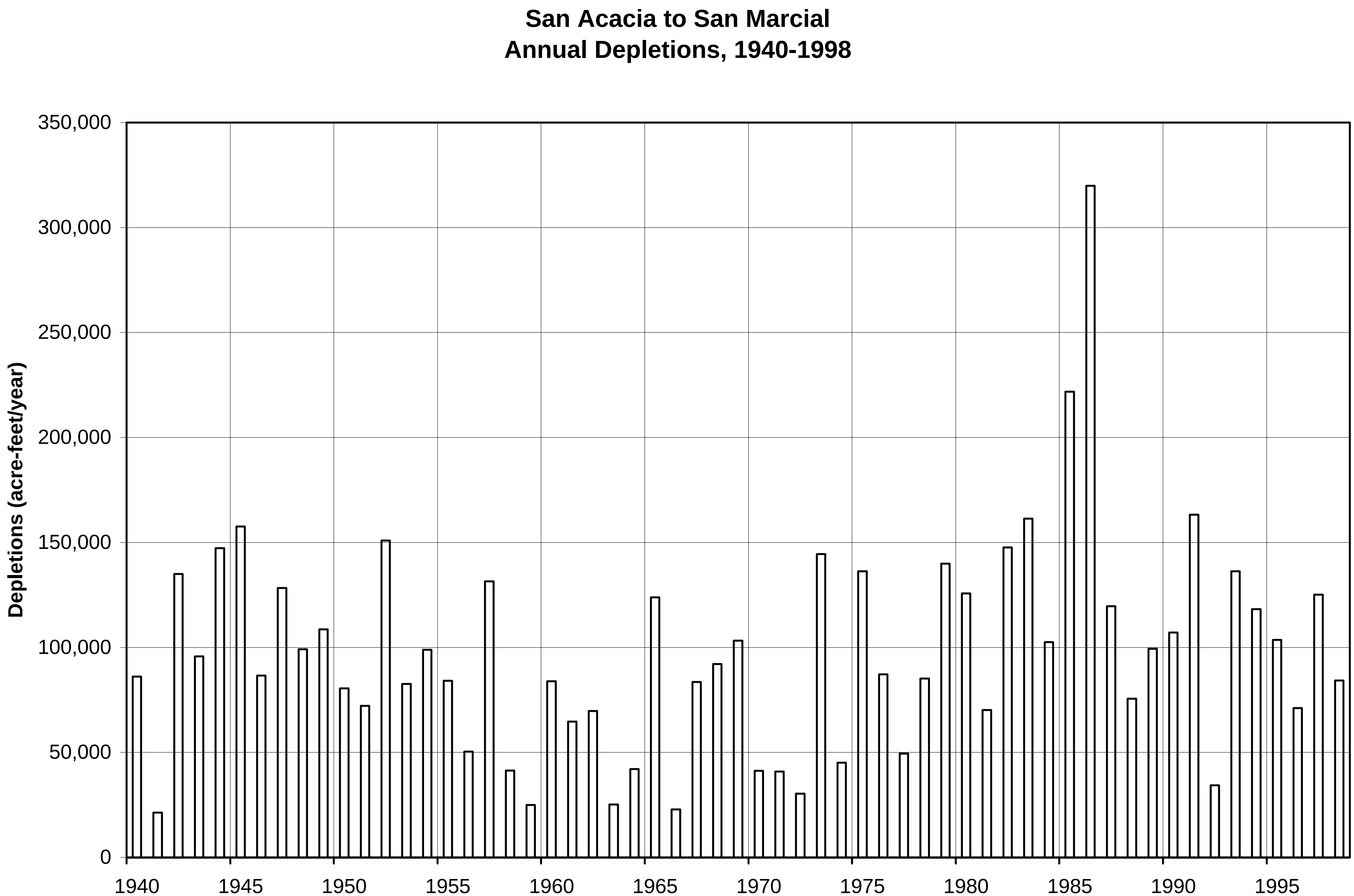
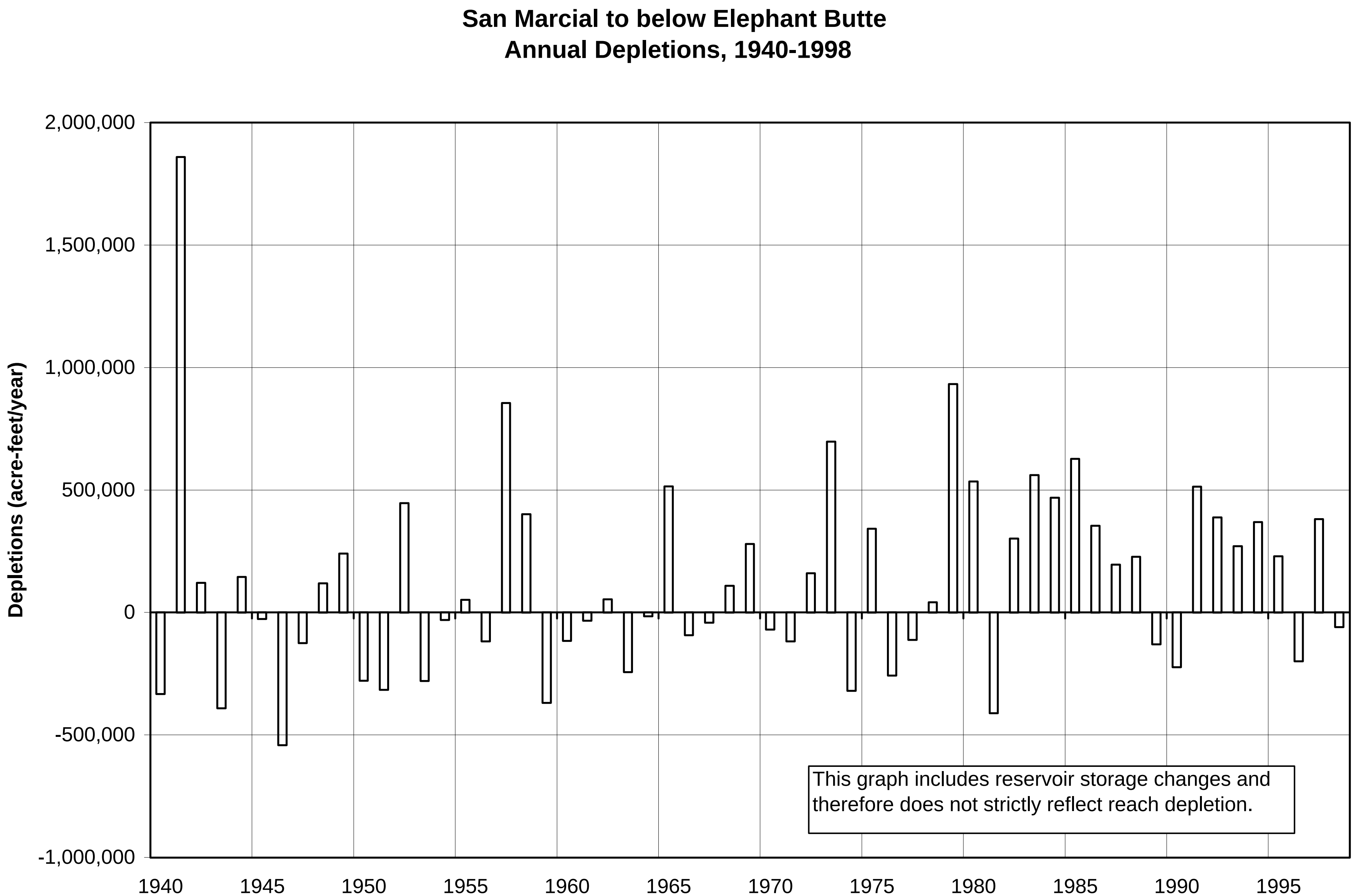

San Acacia to San Marcial
Annual Depletions, 1940-1998
Depletions (acre-feet/year)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

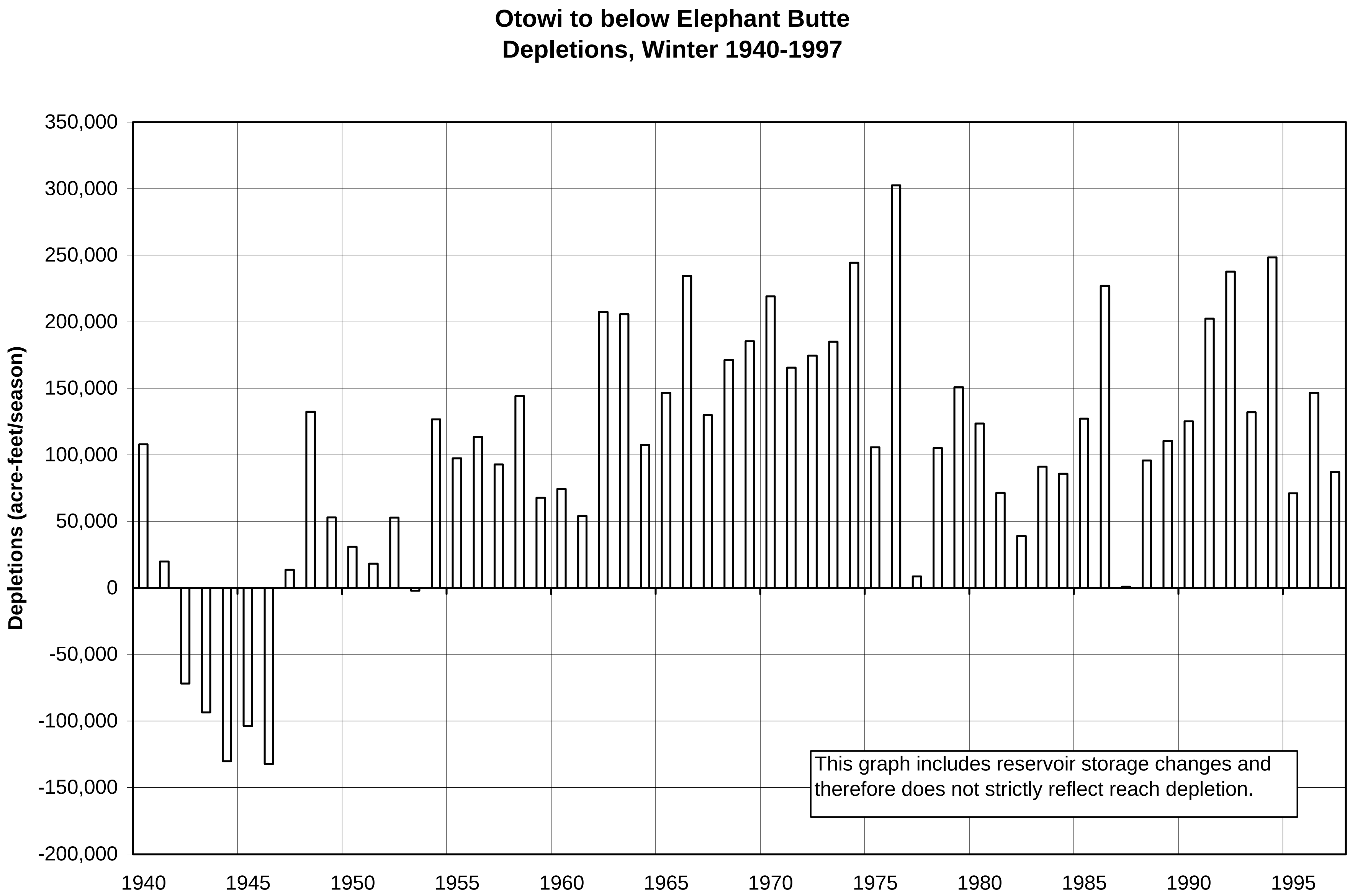
Figure D-5.6



6/16/00

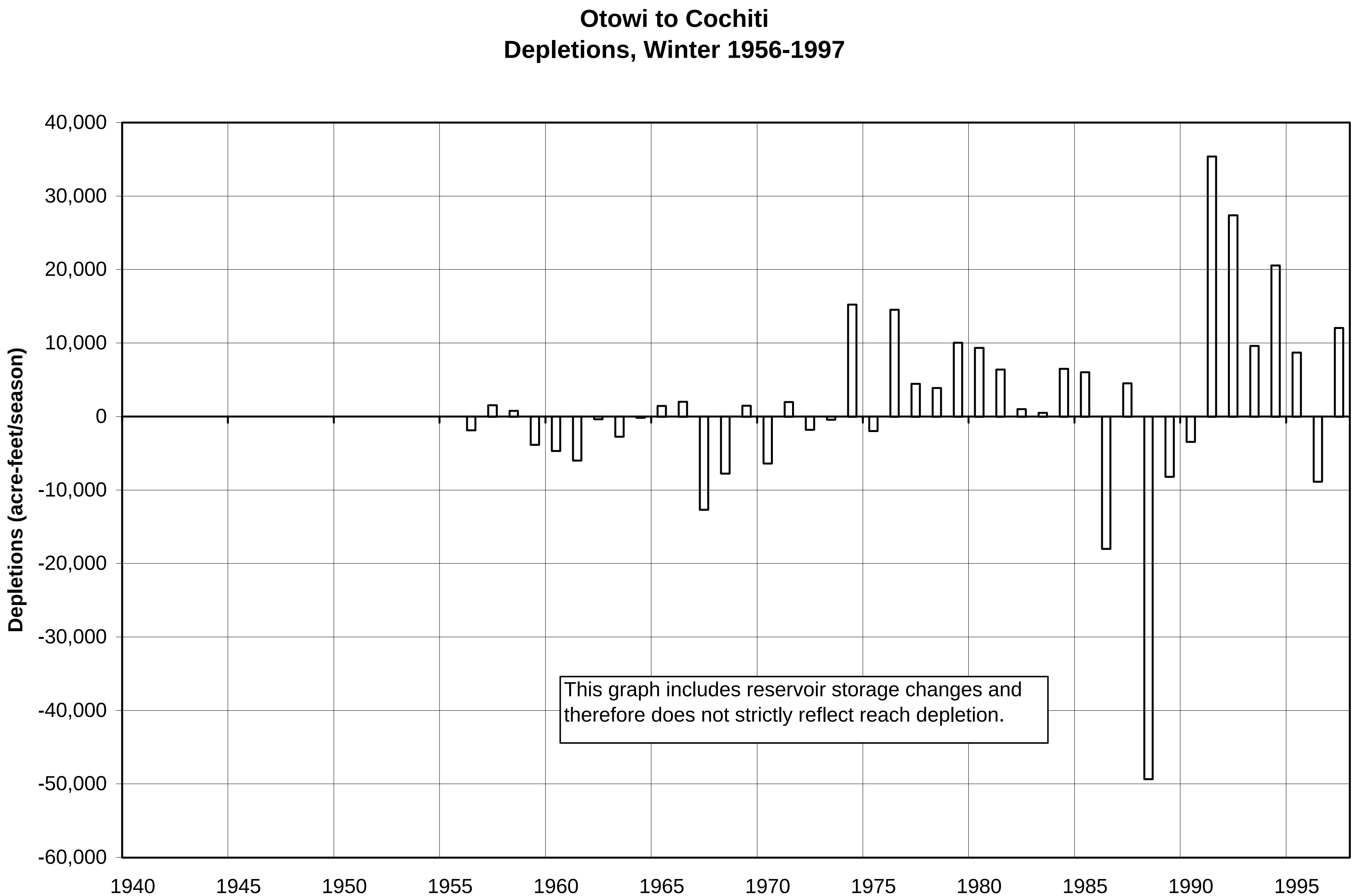
Figure D-5.7

SanMarcial_ElephantButte.xls



Otowi to below Elephant Butte
Depletions, Winter 1940-1997
Depletions (acre-feet/season)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
-50,000
-100,000
-150,000
-200,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
This graph includes reservoir storage changes and therefore does not strictly reflect reach depletion.

Figure D-6.1



6/16/00

Figure D-6.2

Otowi_Cochiti.xls

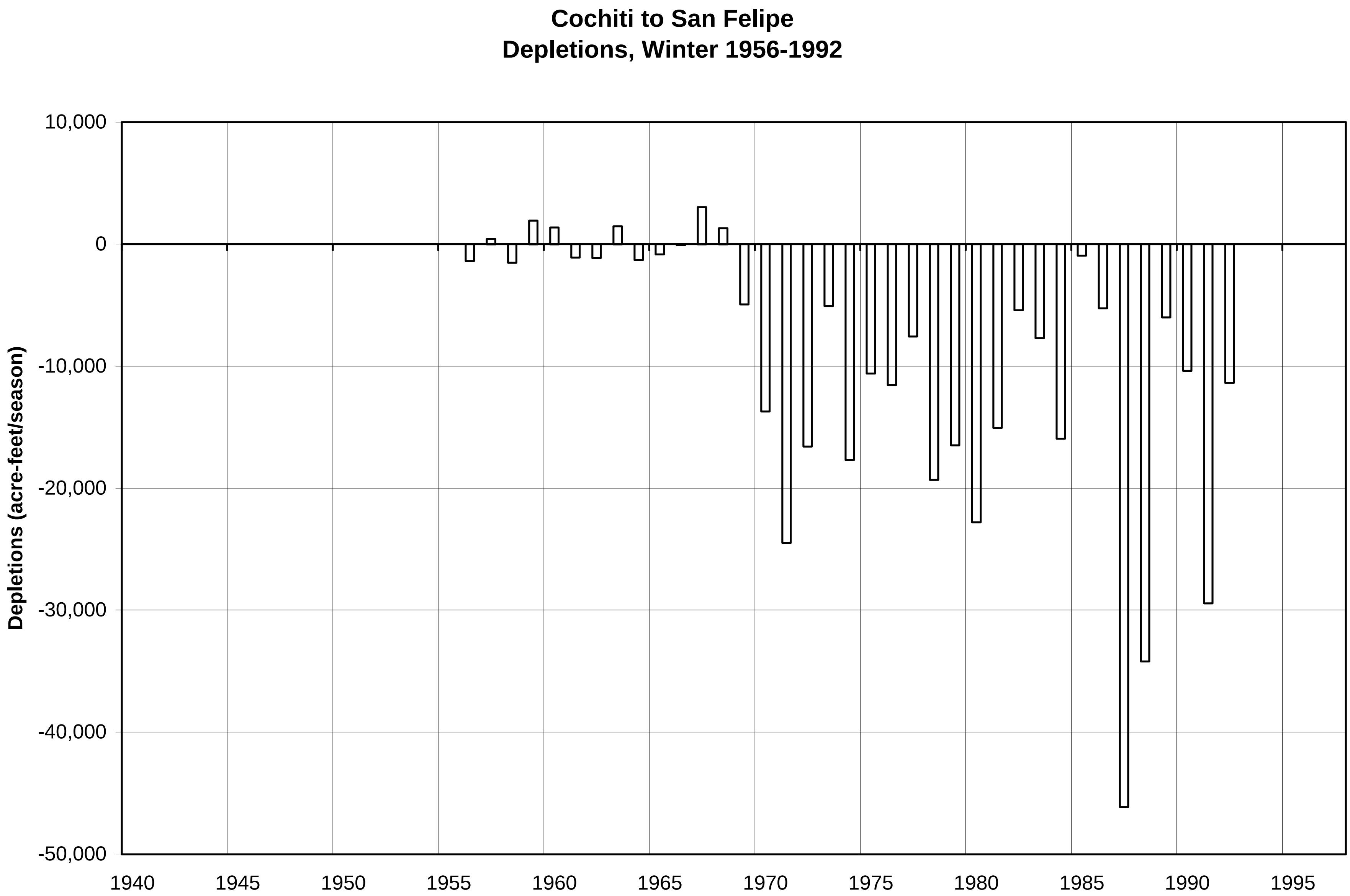
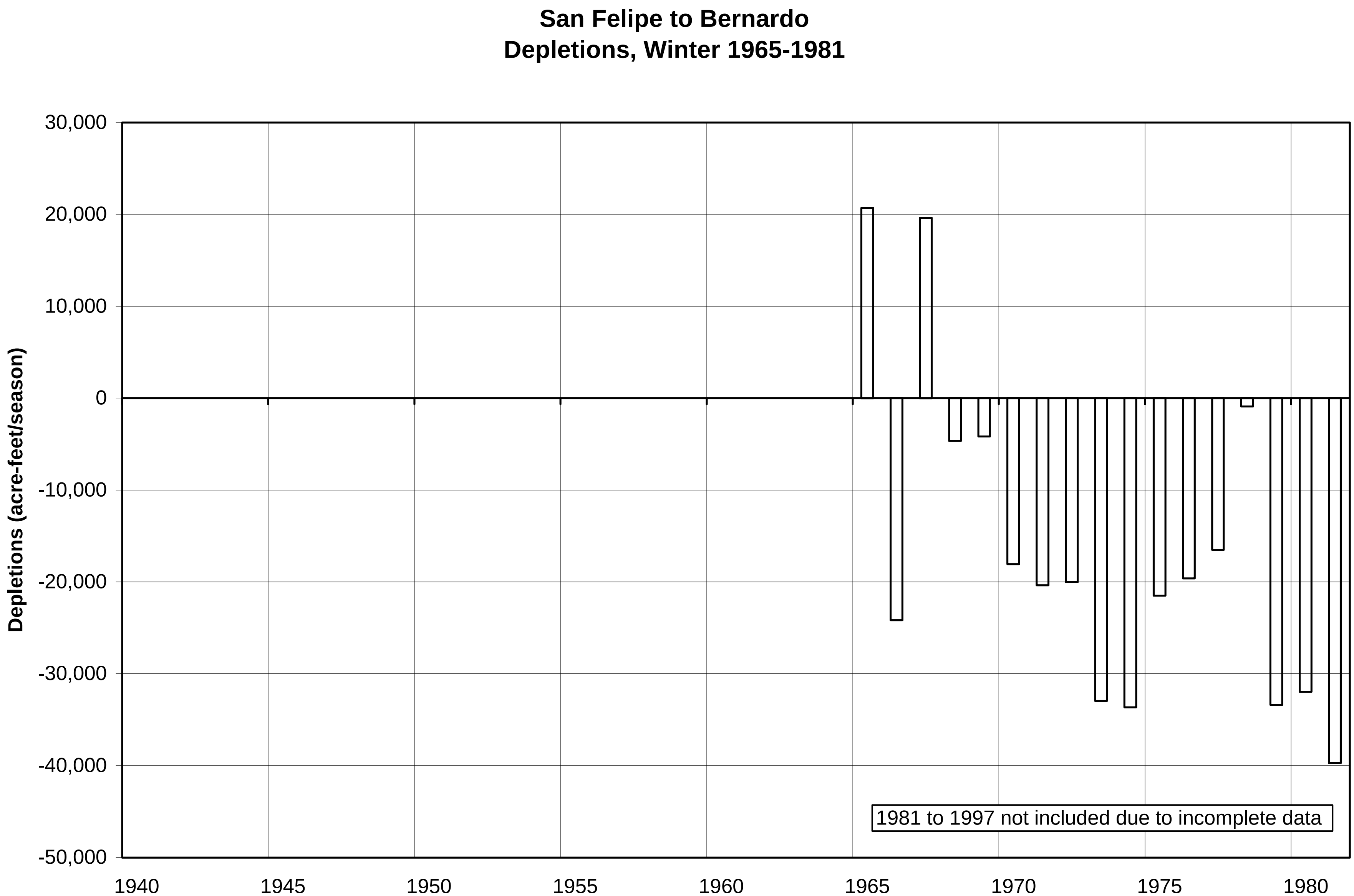

Cochiti to San Felipe
Depletions, Winter 1956-1992
Depletions (acre-feet/season)
10,000
0
-10,000
-20,000
-30,000
-40,000
-50,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

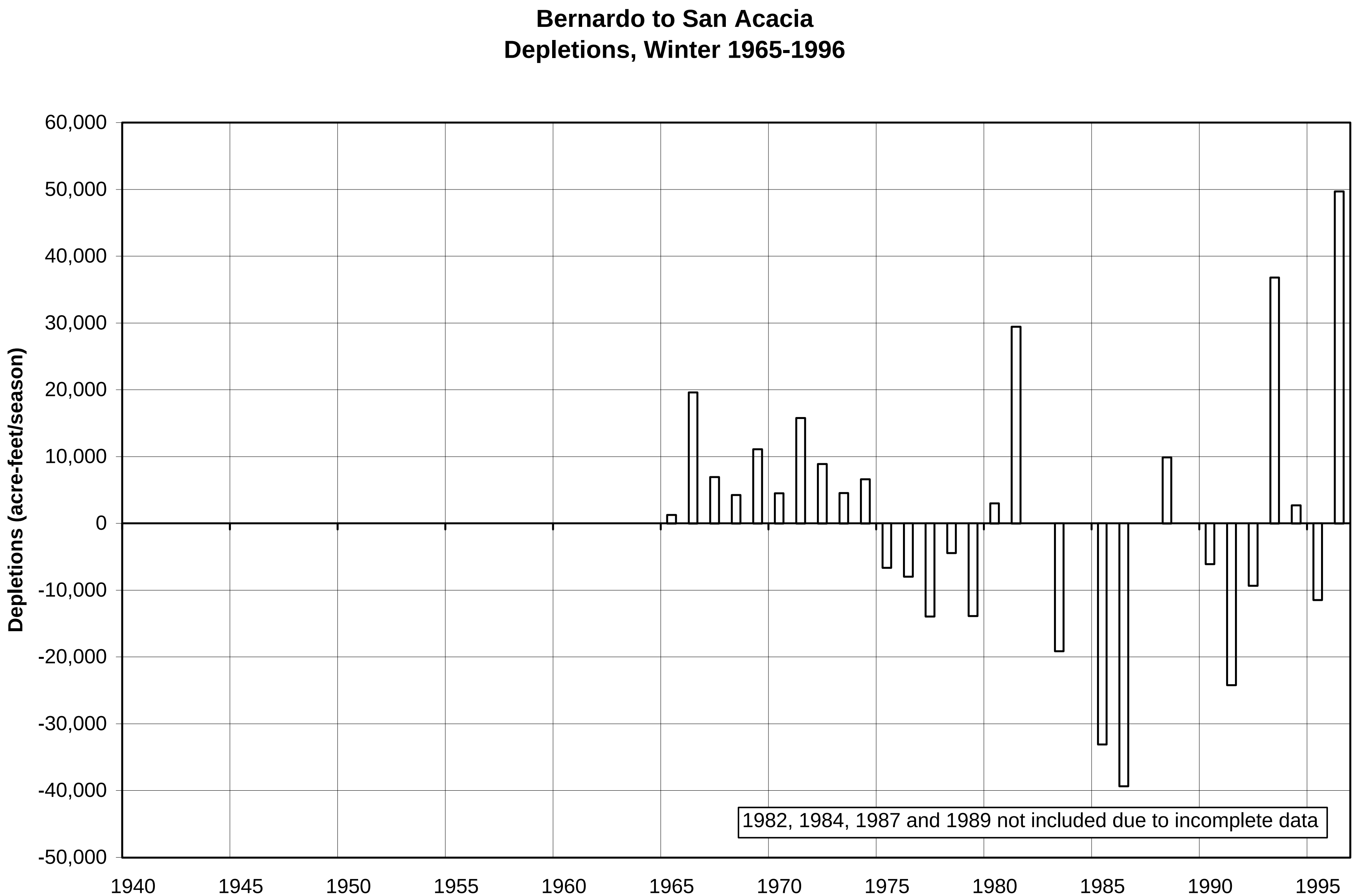
Figure D-6.3



6/16/00

Figure D-6.4

SanFelipe_Bernardo.xls



6/16/00

Figure D-6.5

Bernardo_SanAcacia.xls

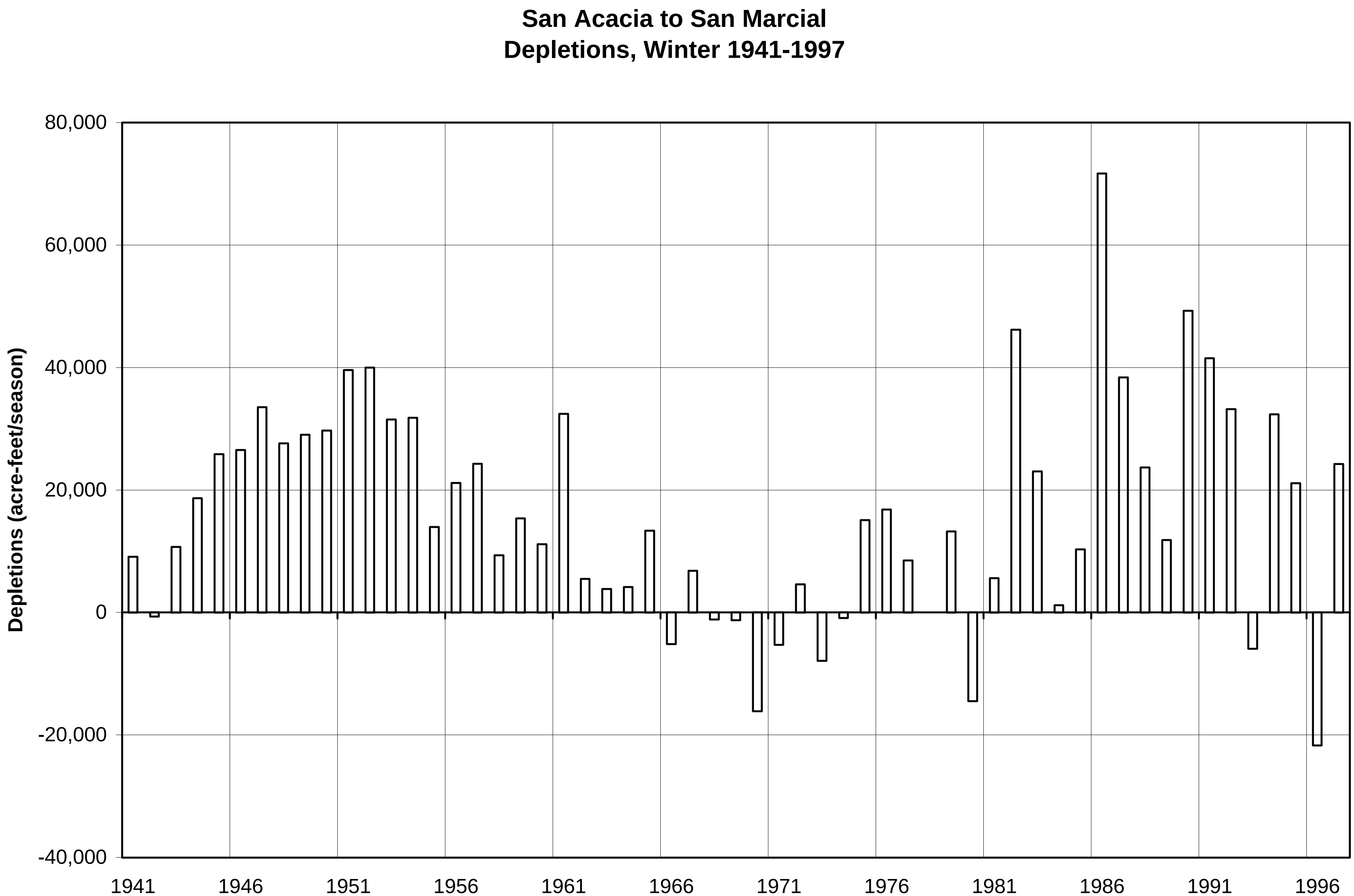

San Acacia to San Marcial
Depletions, Winter 1941-1997
Depletions (acre-feet/season)
80,000
60,000
40,000
20,000
0
-20,000
-40,000
1941
1946
1951
1956
1961
1966
1971
1976
1981
1986
1991
1996

Figure D-6.6

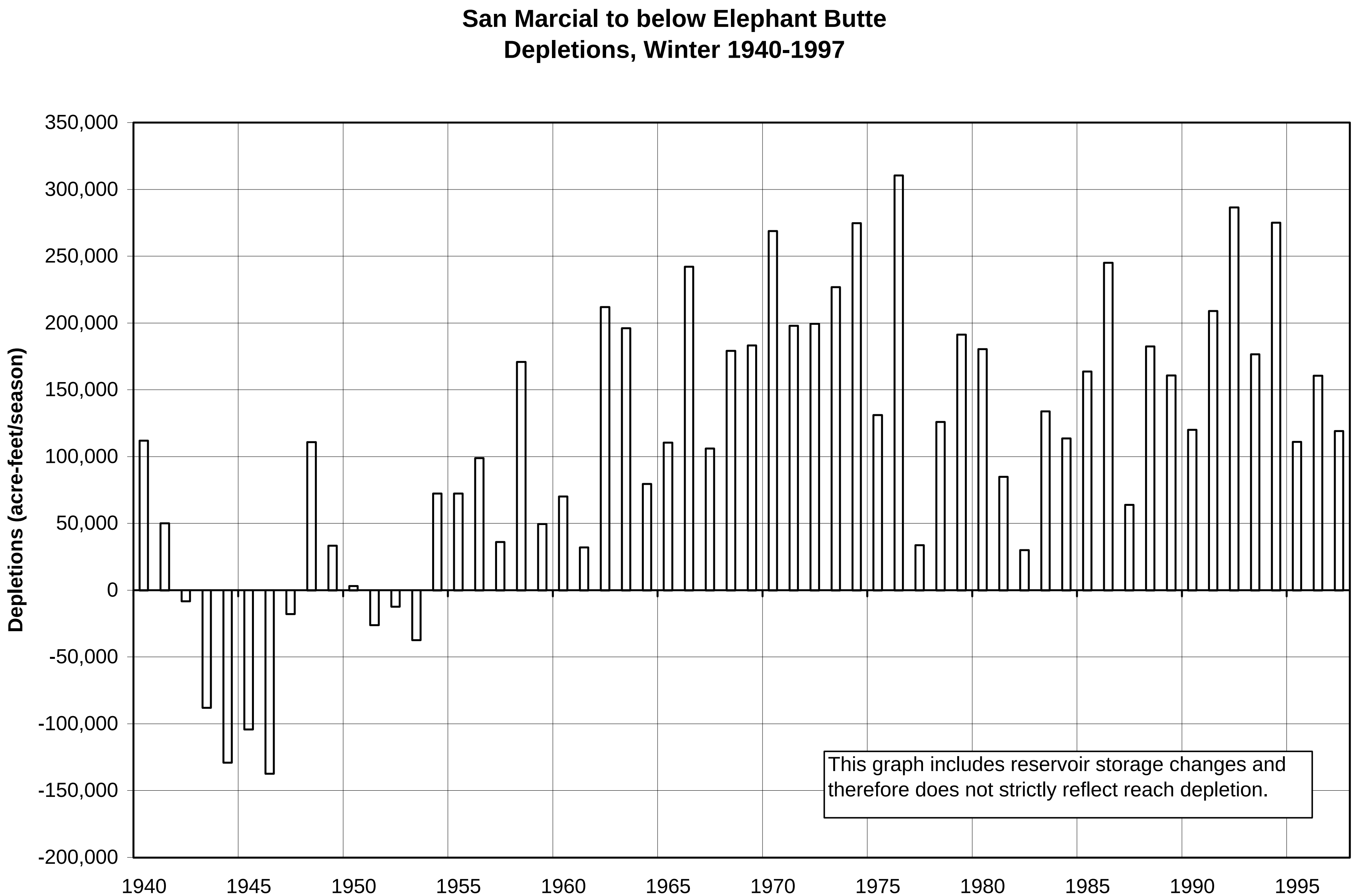
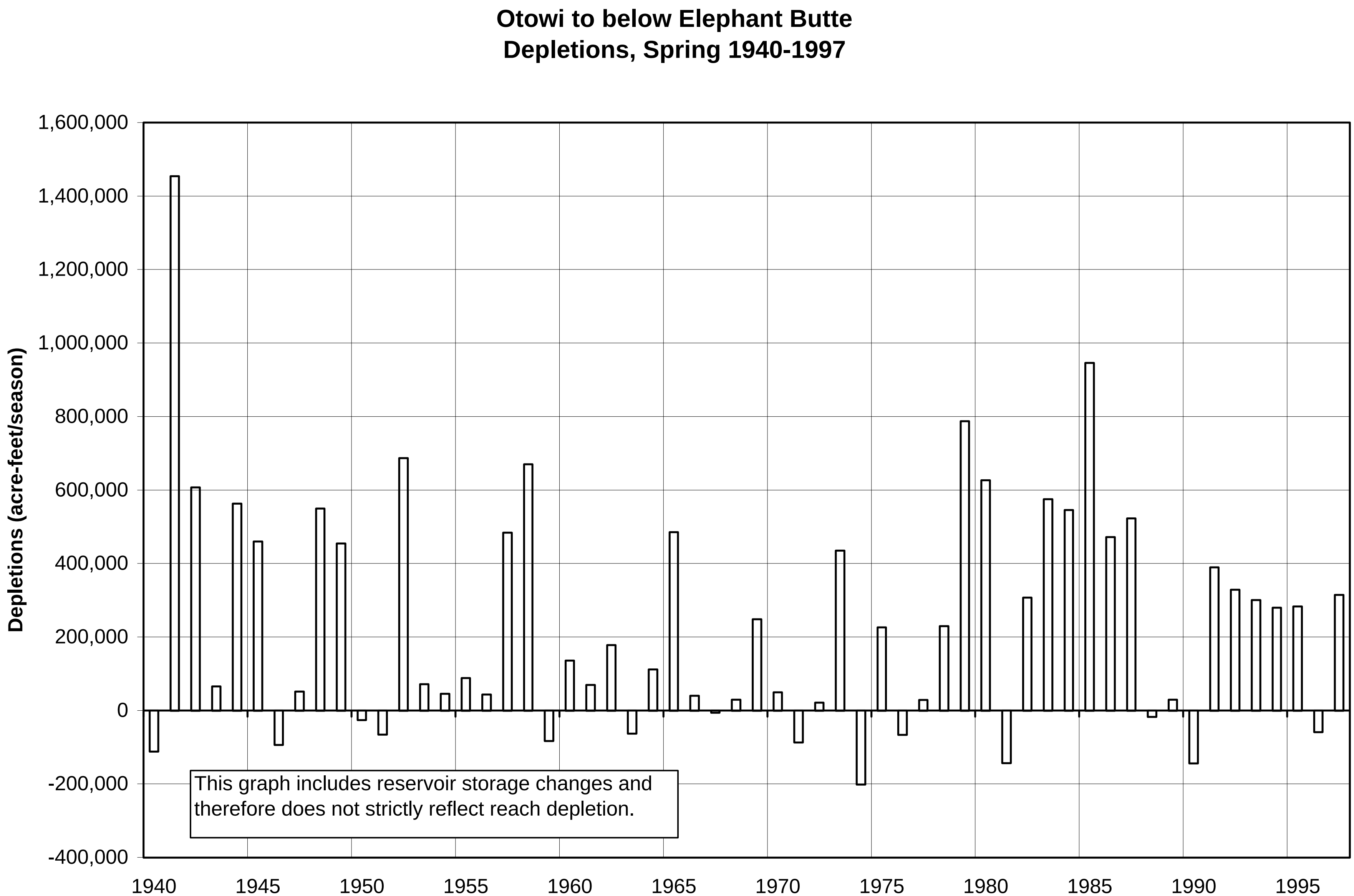

San Marcial to below Elephant Butte
Depletions, Winter 1940-1997
Depletions (acre-feet/season)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
-50,000
-100,000
-150,000
-200,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
This graph includes reservoir storage changes and therefore does not strictly reflect reach depletion.

Figure D-6.7



Otowi to below Elephant Butte
Depletions, Spring 1940-1997
Depletions (acre-feet/season)
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
-400,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
This graph includes reservoir storage changes and
therefore does not strictly reflect reach depletion.

Figure D-7.1

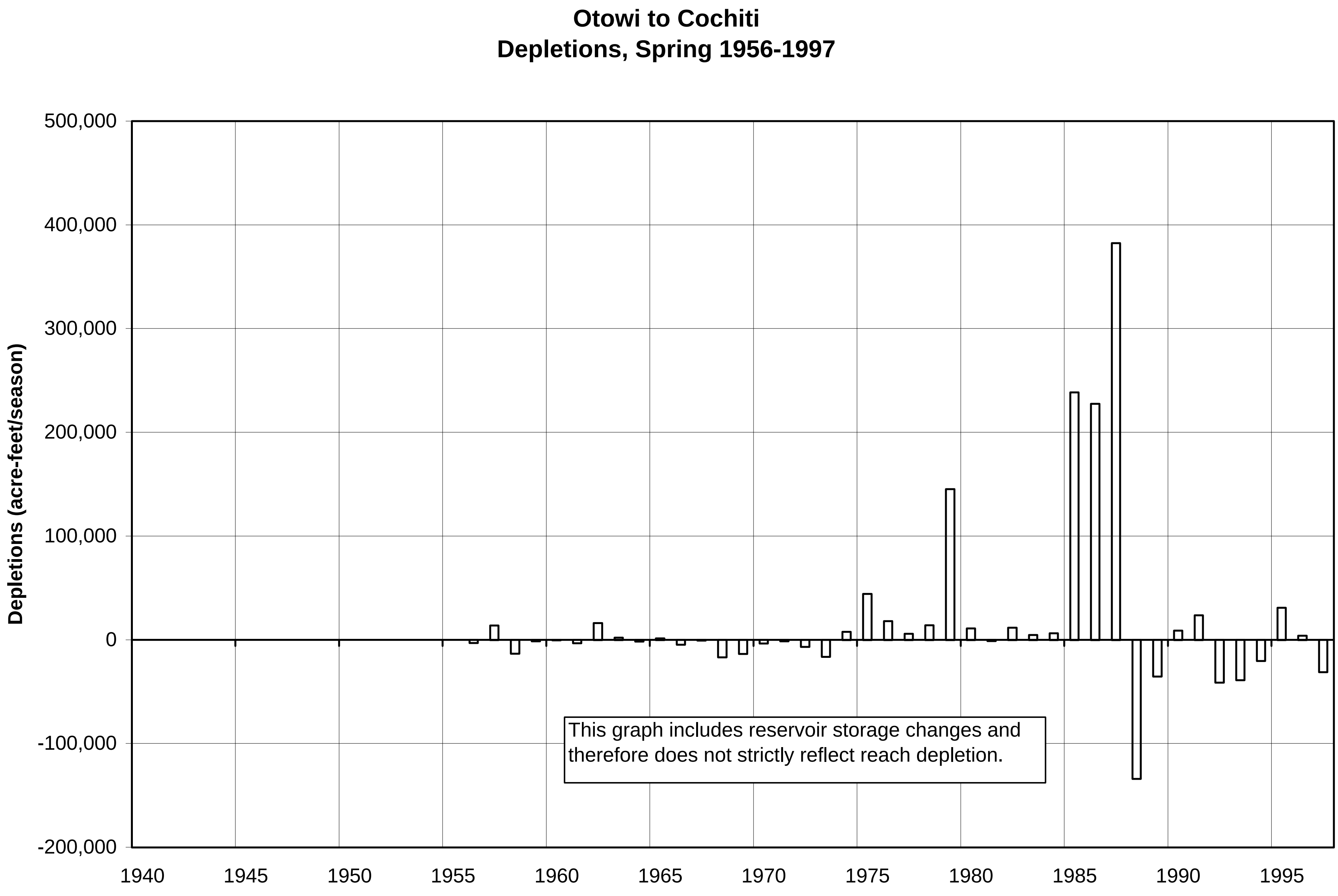

Otowi to Cochiti
Depletions, Spring 1956-1997
Depletions (acre-feet/season)
500,000
400,000
300,000
200,000
100,000
0
-100,000
-200,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
This graph includes reservoir storage changes and therefore does not strictly reflect reach depletion.

Figure D-7.2

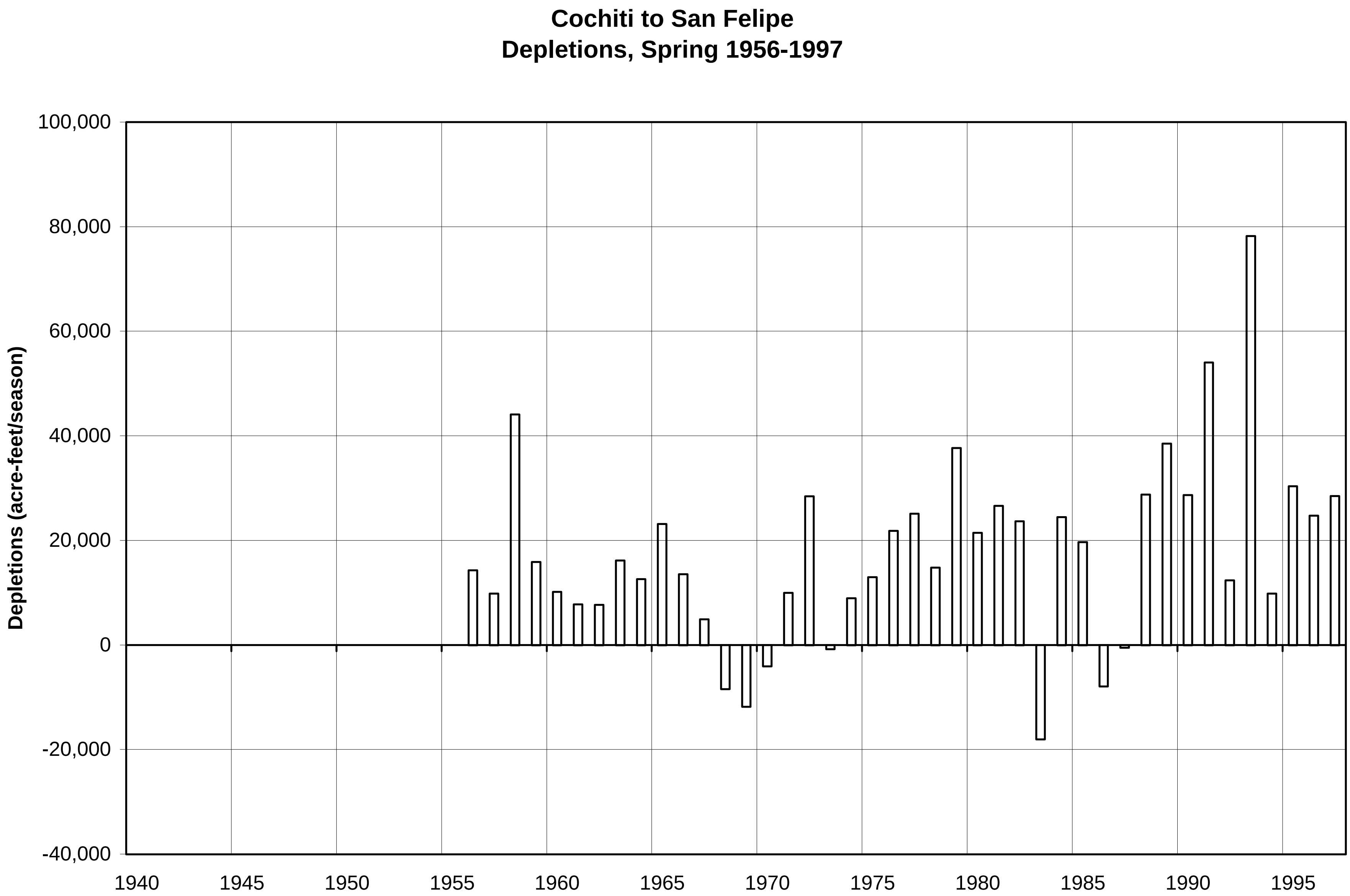
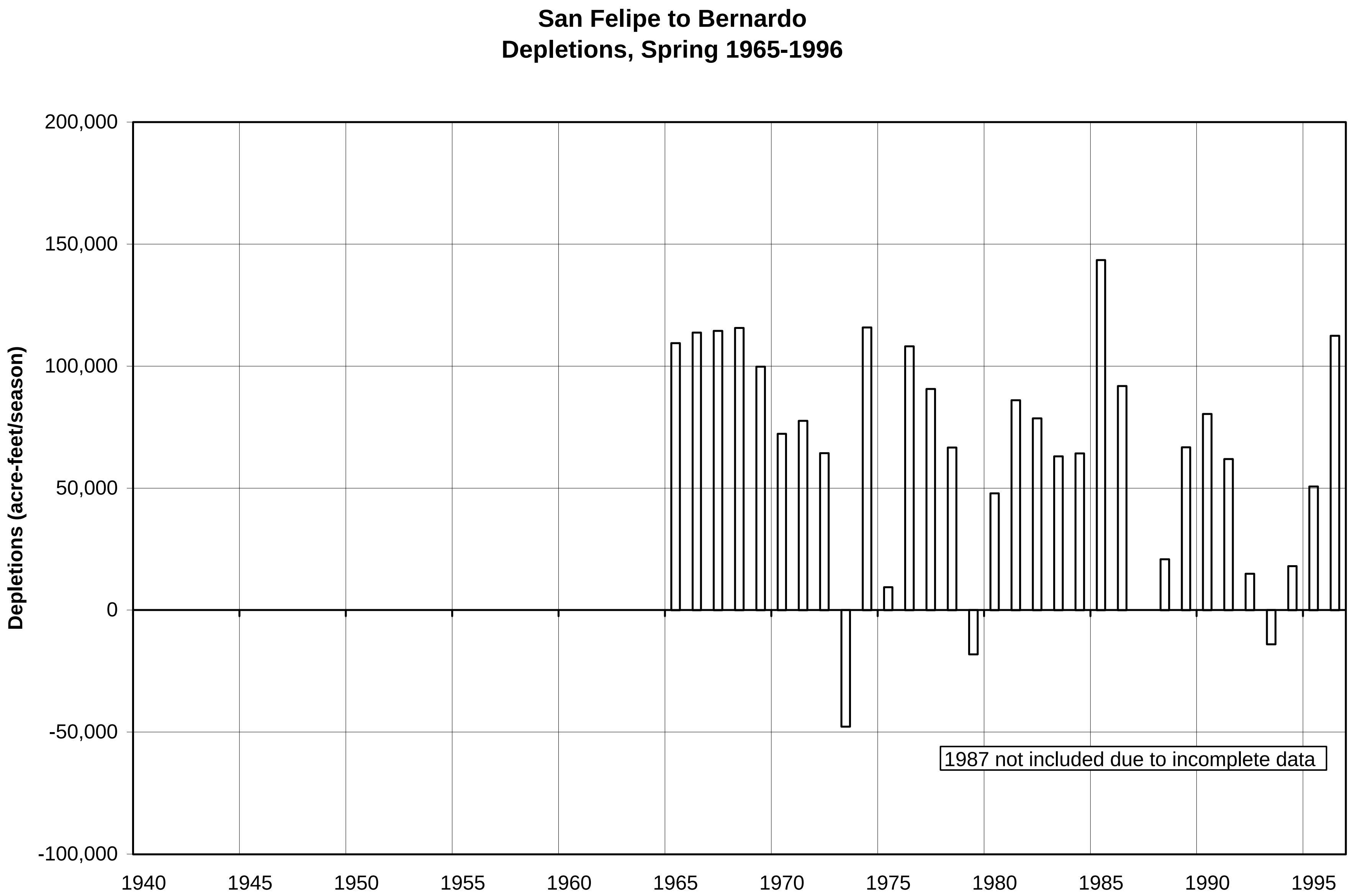

Cochiti to San Felipe
Depletions, Spring 1956-1997
Depletions (acre-feet/season)
100,000
80,000
60,000
40,000
20,000
0
-20,000
-40,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

Figure D-7.3



6/16/00

Figure D-7.4

SanFelipe_Bernardo.xls

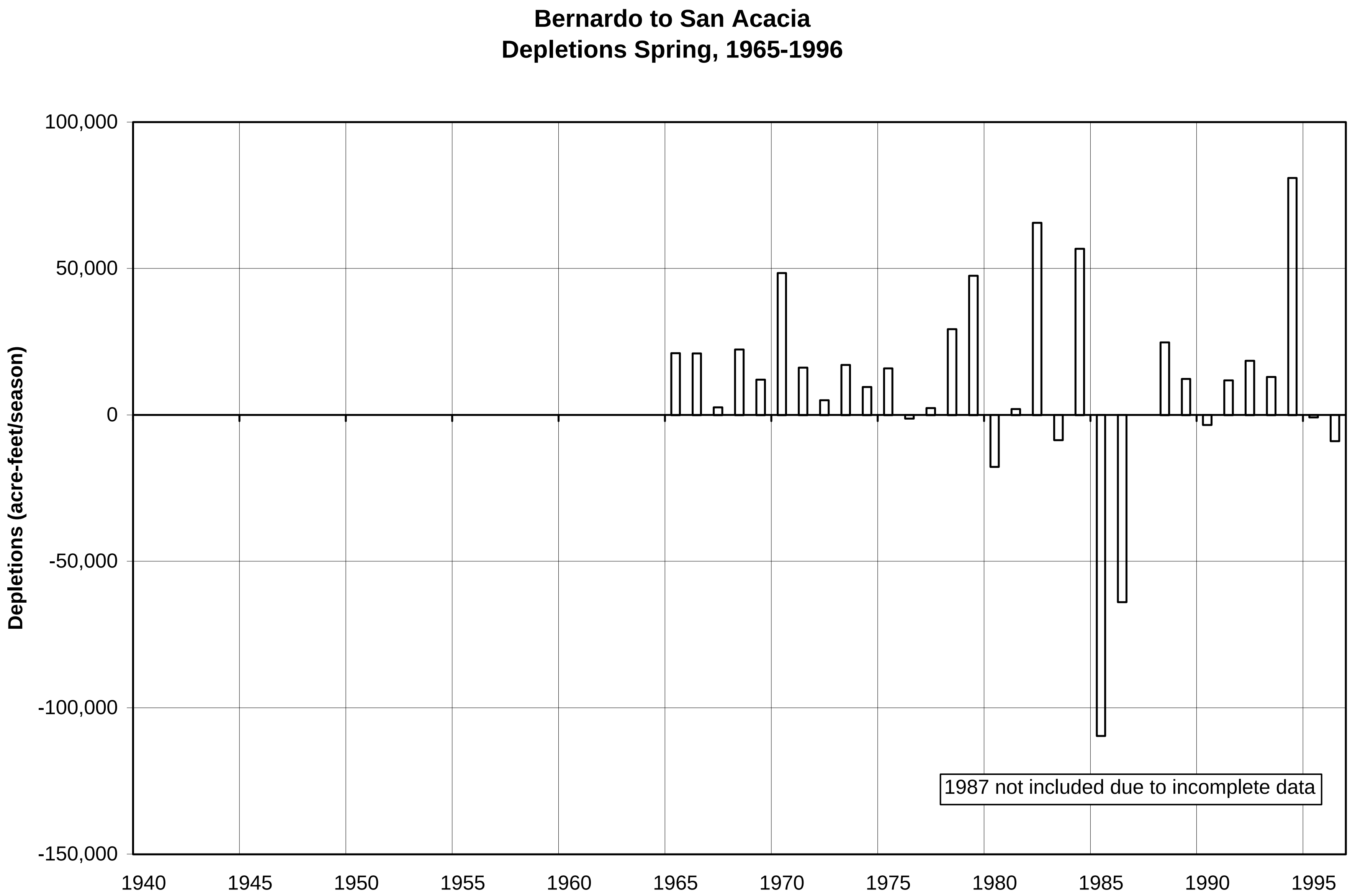
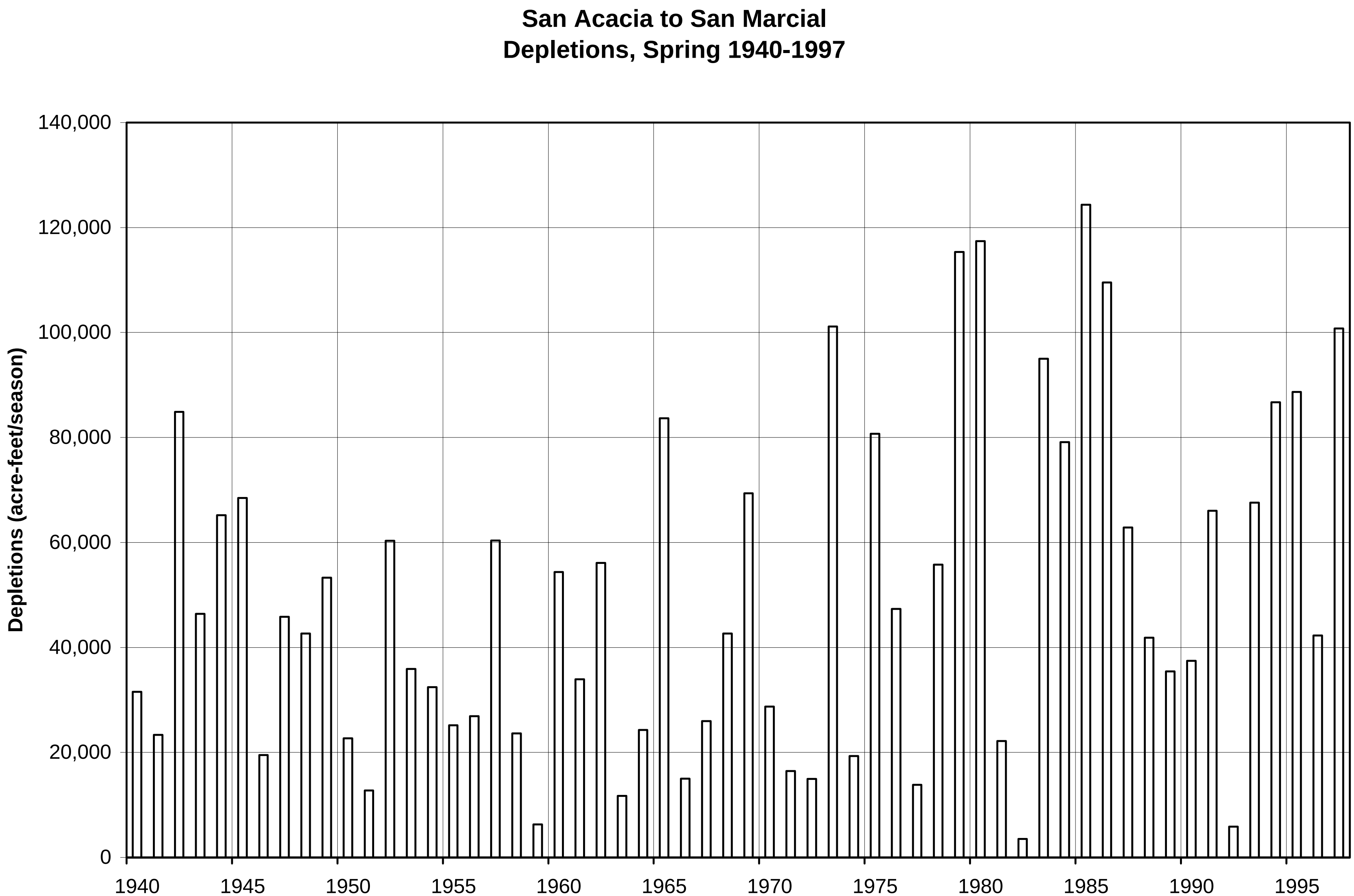

Bernardo to San Acacia
Depletions Spring, 1965-1996
Depletions (acre-feet/season)
100,000
50,000
0
-50,000
-100,000
-150,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
1987 not included due to incomplete data

Figure D-7.5



6/16/00

Figure D-7.6

SanAcacia_SanMarcial.xls

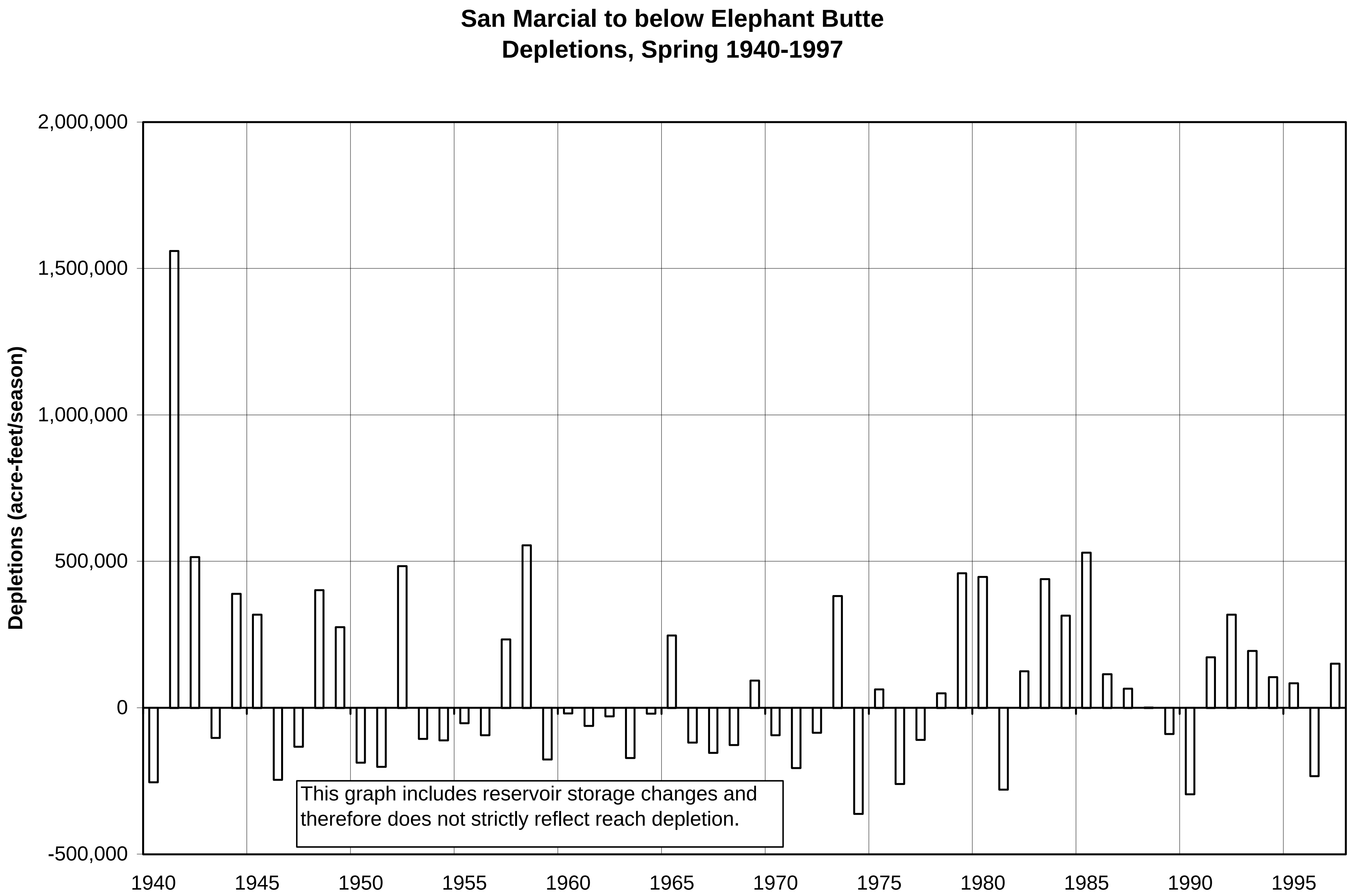
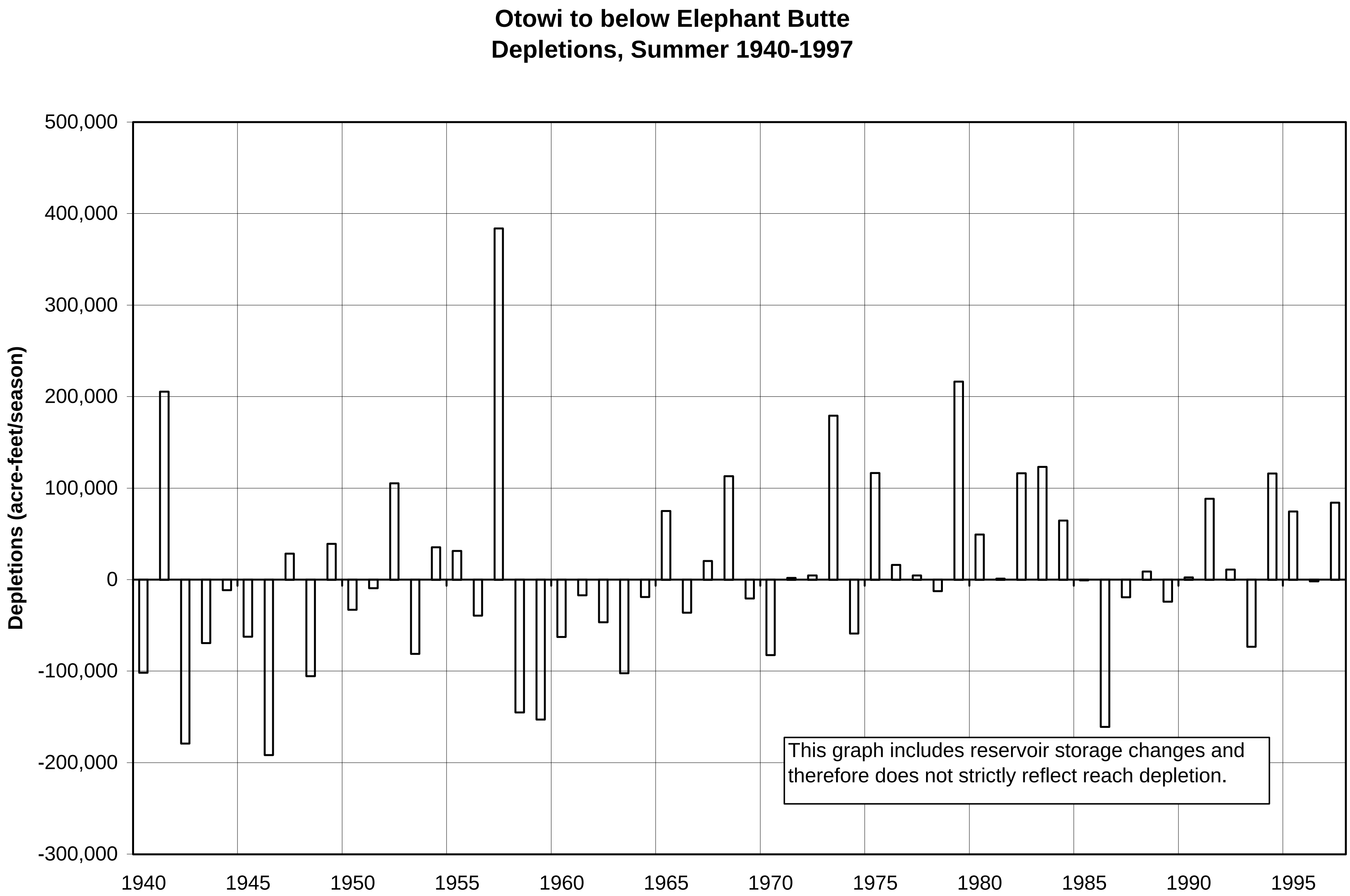

San Marcial to below Elephant Butte
Depletions, Spring 1940-1997
Depletions (acre-feet/season)
2,000,000
1,500,000
1,000,000
500,000
0
-500,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
This graph includes reservoir storage changes and therefore does not strictly reflect reach depletion.

Figure D-7.7



6/16/00

Figure D-8.1

Otowi_ElephantButte.xls

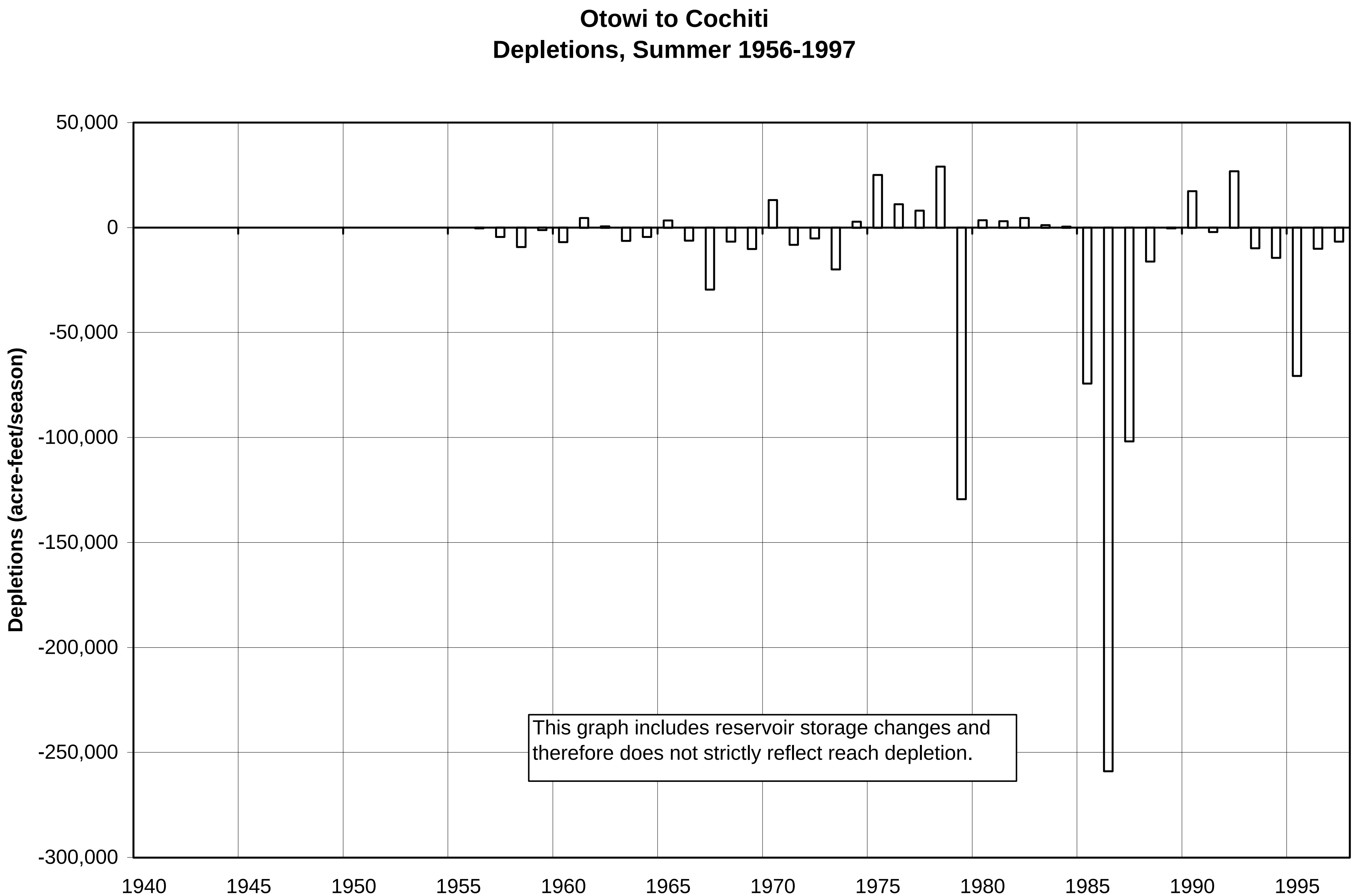

Otowi to Cochiti
Depletions, Summer 1956-1997
Depletions (acre-feet/season)
50,000
0
-50,000
-100,000
-150,000
-200,000
-250,000
-300,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
This graph includes reservoir storage changes and therefore does not strictly reflect reach depletion.

Figure D-8.2

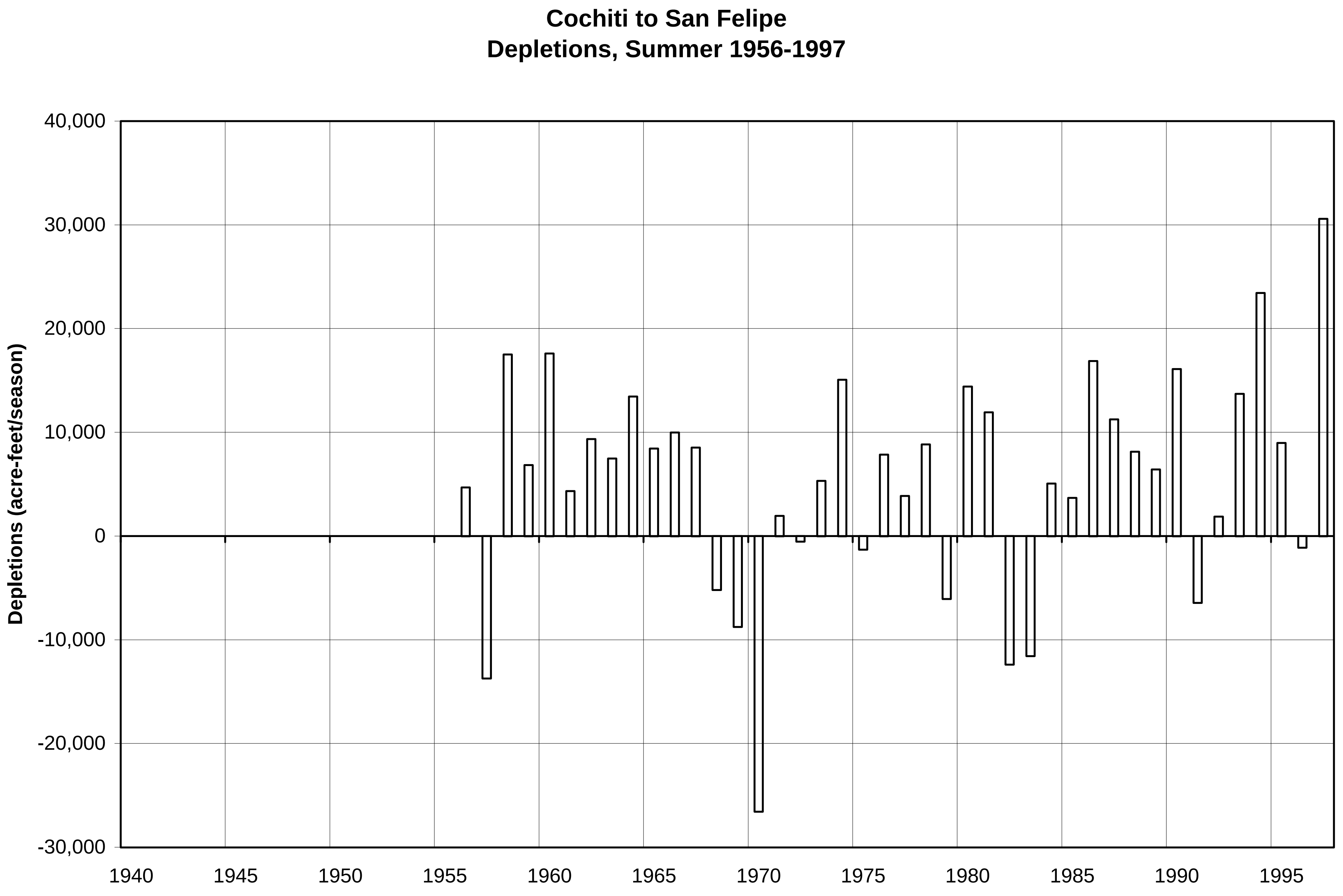

Cochiti to San Felipe
Depletions, Summer 1956-1997
Depletions (acre-feet/season)
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

Figure D-8.3

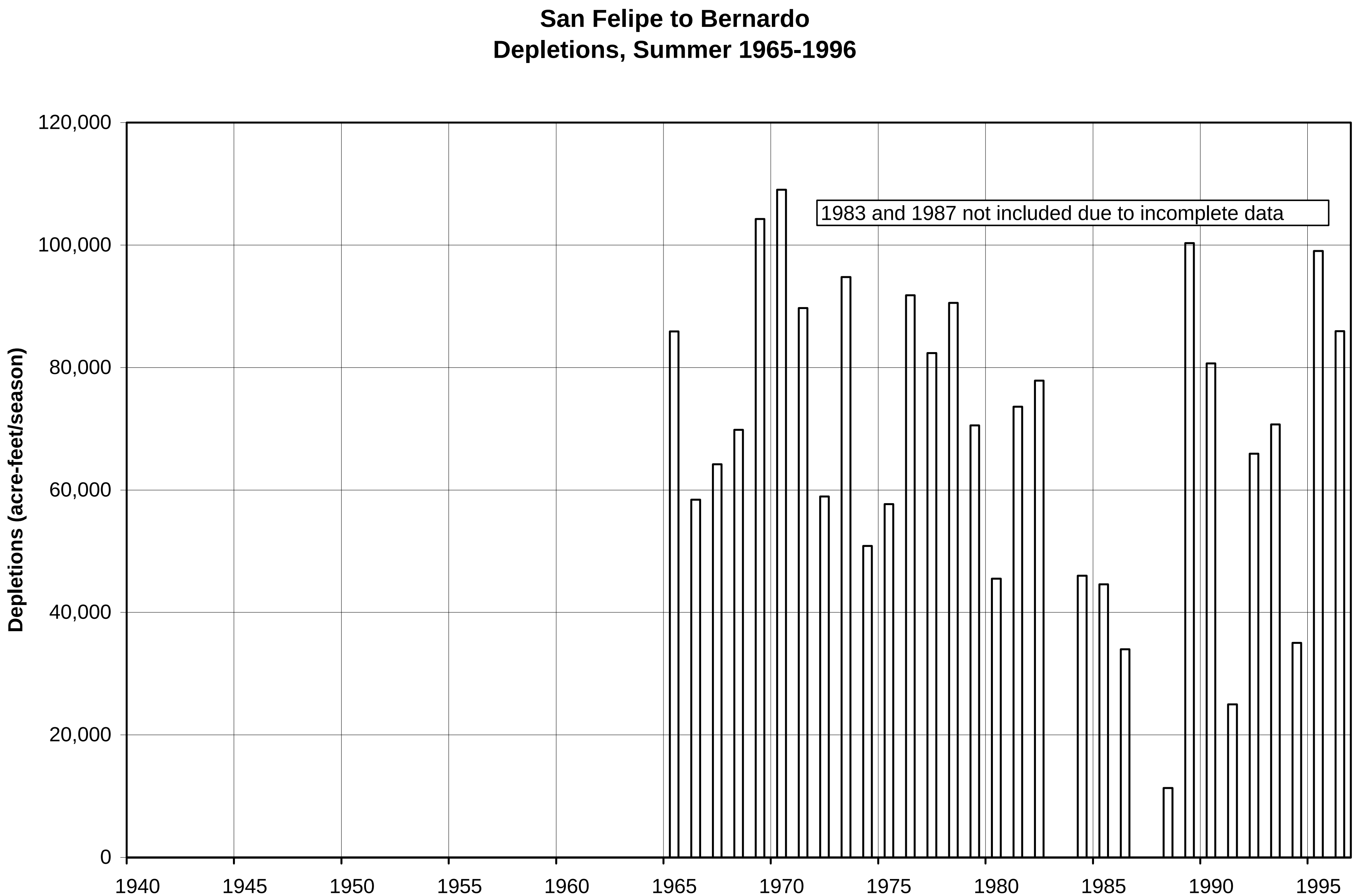
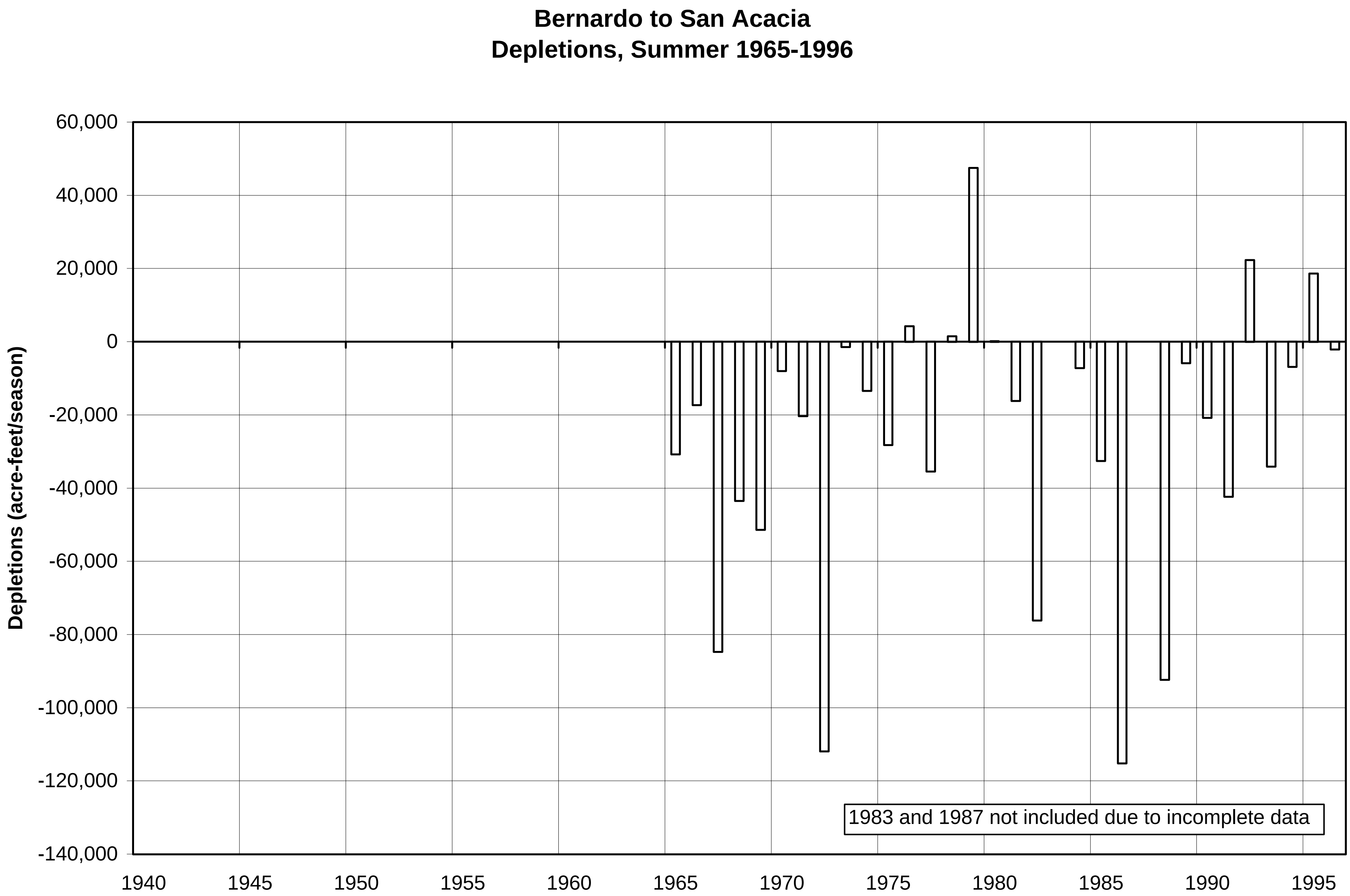

San Felipe to Bernardo
Depletions, Summer 1965-1996
Depletions (acre-feet/season)
120,000
100,000
80,000
60,000
40,000
20,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
1983 and 1987 not included due to incomplete data

Figure D-8.4



Bernardo to San Acacia
Depletions, Summer 1965-1996
Depletions (acre-feet/season)
60,000
40,000
20,000
0
-20,000
-40,000
-60,000
-80,000
-100,000
-120,000
-140,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
1983 and 1987 not included due to incomplete data

Figure D-8.5

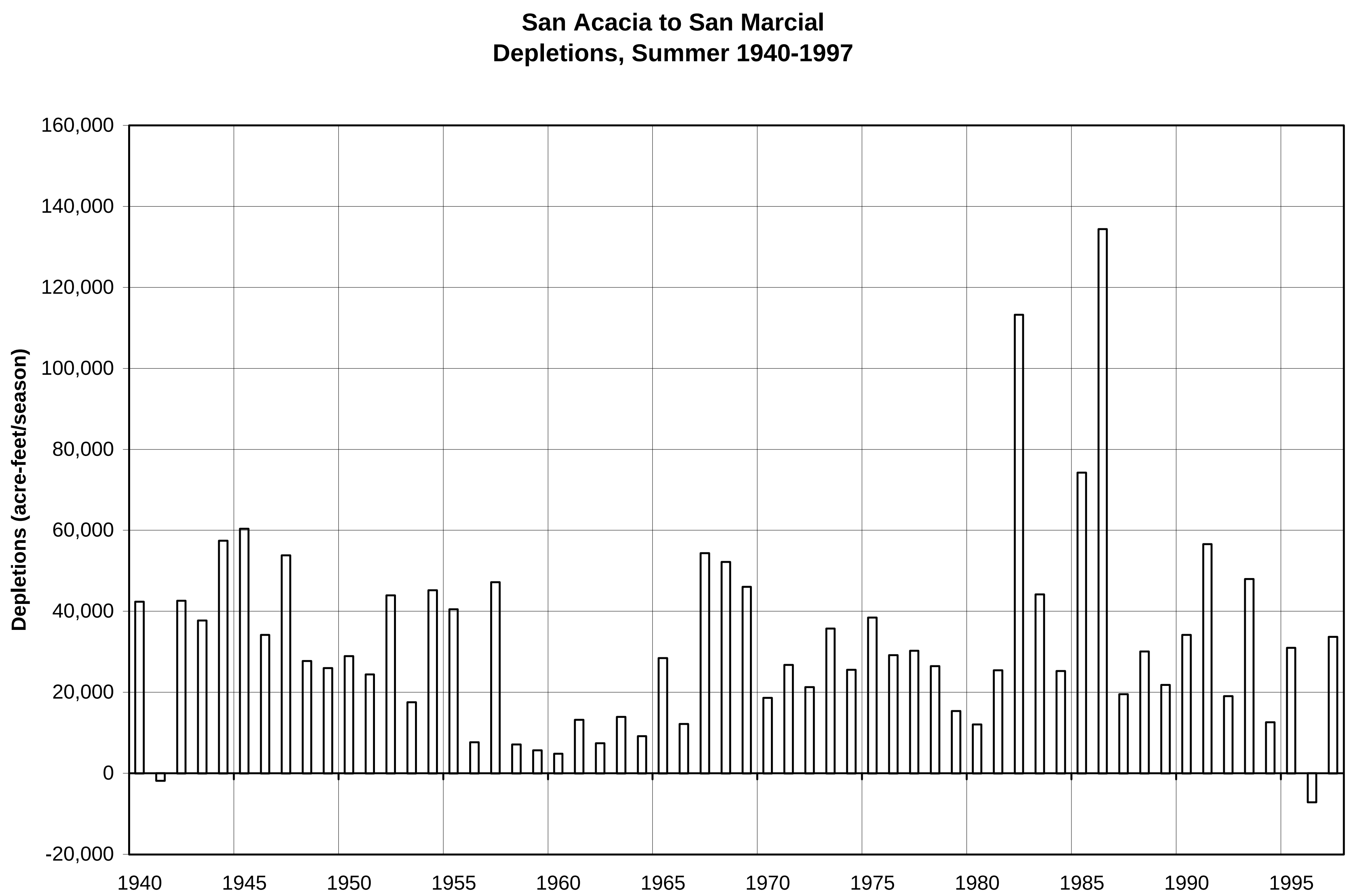
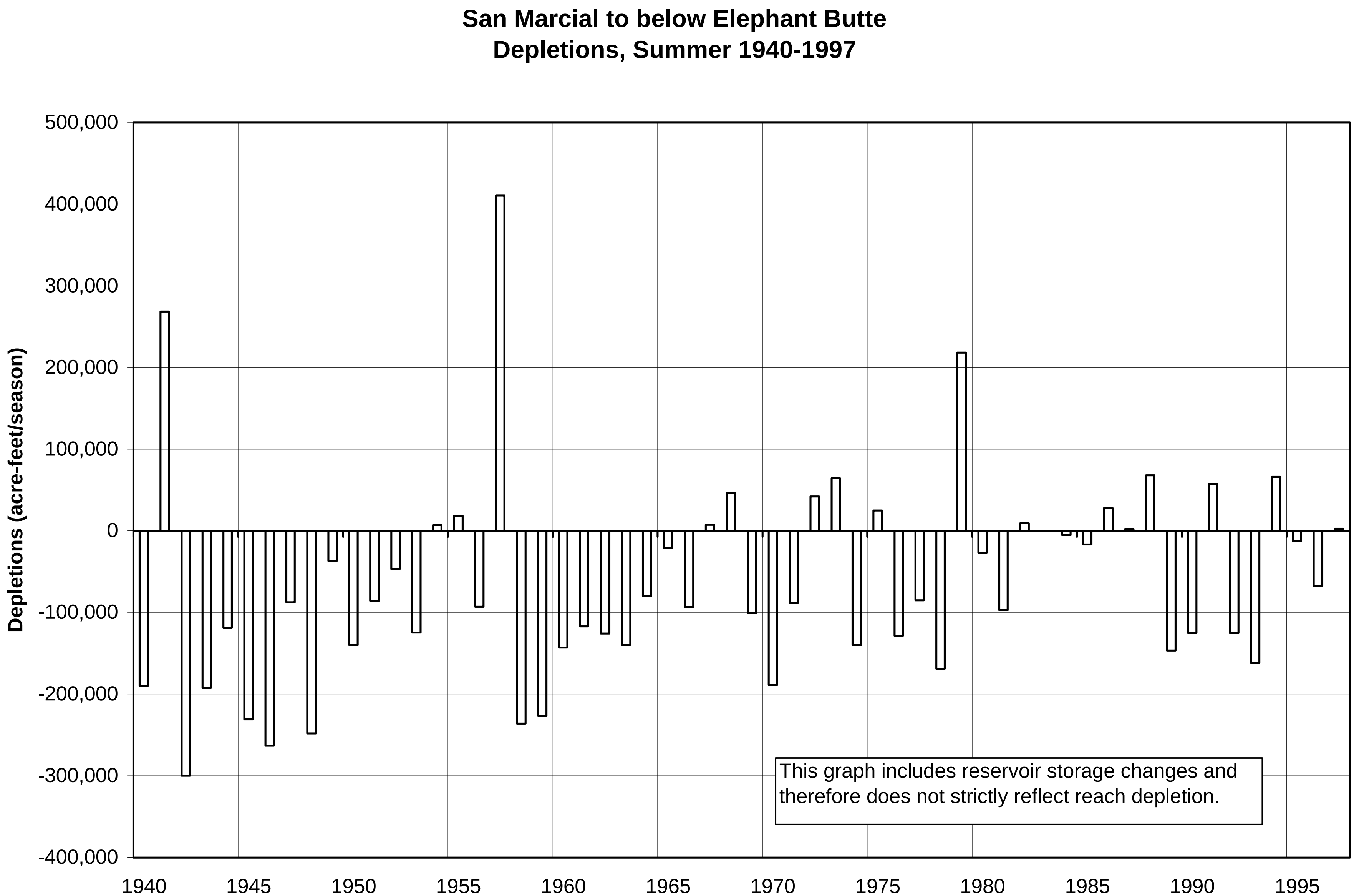

San Acacia to San Marcial
Depletions, Summer 1940-1997
Depletions (acre-feet/season)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
-20,000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

Figure D-8.6



6/16/00

Figure D-8.7

SanMarcial_ElephantButte.xls

APPENDIX E
Profiles of Previous Water Budget and Depletion Studies

Profiles of previous water budget and depletion studies are provided in this section. These profiles summarize the study objectives, spatial domain, physical domain, time frame, study approach and results. Because the studies differed in these aspects, the water budget results are often not strictly comparable. For example, a water budget based on one time period will not readily compare to one based on another time period. Water budgets constructed for different time periods differ due to the highly variable nature of water supply conditions and due to changes in the development of water conveyance, storage and drainage features. Other key differences relate to the study domain, i.e., whether they are surface water referenced, or include groundwater effects.

These profiles are intended to highlight aspects of the following studies:

1938, National Resources Committee, *Rio Grande Joint Investigation*

1991, Turney, *Rio Grande Depletion Analysis*

1993, Thorn et al, *Geohydrologic Framework and Hydrologic Conditions in the Albuquerque Basin, New Mexico*

1997, Gould, *Middle Rio Grande Basin Surface Water Budget for Calendar Years 1935, 1955, 1975, 1993*

1998, Kelton, *A Comparative History of Middle Rio Grande Water Supplies and Assessments*

1999, Action Committee of the Middle Rio Grande Water Assembly, *Middle Rio Grande Water Budget, Averages for 1972 - 1997*

Title:	The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico and Texas, 1936-37
Author:	National Resources Committee
Date:	February 1938
Citation:	National Resources Planning, Part VI
Study Objectives:	To provide a factual base on which a reasonable plan for the future development of the water resources of the Upper Rio Grande may be constructed; prepared at the request of the Rio Grande Compact commissioners for the states of Colorado, New Mexico and Texas.
Spatial Domain:	Rio Grande Basin above Fort Quitman, Texas
Time Frame:	1890 to 1937
Physical Domain:	Surface water and groundwater

Study Approach:
Basic data are reviewed for each of the regions:

- San Luis Section (Colorado),
- Middle Section (New Mexico, above Otowi; Middle Rio Grande Conservancy District; and MRGCD to San Marcial),
- Elephant Butte to Fort Quitman Section (San Marcial to Rincon, Rio Grande project, and Hudspeth County)

Basic data are presented including climatological , streamflow, drainage returns, groundwater, and quality of water. Sections are included on irrigation development, water uses and requirements, storage development, salvage opportunities, water utilization, water quality and water importation. Estimates of basin run-off, irrigated and native vegetation acreage, evaporation, groundwater conditions and consumptive use are provided for various sub-regions.

Study Conclusions:

Summarized below are a subset of the report conclusions, relating to the water budget of the Middle Rio Grande Section, from Otowi to Elephant Butte:

Table 2

- Irrigated acres, Otowi to San Marcial	60,000 acres (excluding tributaries)
- Native vegetation, ”	104,000 acres
- Open water surfaces, ”	25,000 acres

Table 4

Streamflow depletion in Middle Section	768,000 acre feet per year

Table 5

Diversion demand in Middle Valley

MRGCD	580,000 acre feet per year
MRGCD to San Marcial	80,000 acre-feet per year

Table 72

1936 canal diversions for MRGCD	619,989 acre feet
1936 irrigated acres in MRGCD	59,159 acres

Table 79

Estimate of Consumptive Use Requirements, acre-feet (summed):
(MRGCD, Bosque del Apache, and Bosque to San Marcial)

	Irrigation	Native Veg.	Open Water
Cochiti, Alb, Belen Divisions	139,345	245,400	80,934
Socorro, Bosque, and to San Marcial	20,663	129,400	55,688

Table 81

Estimate of Consumptive water requirement San Marcial to Elephant Butte Dam

Native Vegetation	22,071 acres	114,796 acre-feet
Open Water & Misc.	20,750 acres	110,873 acre-feet

Title Rio Grande Depletion Analysis

Author Patricia Turney

Date 9-19-91

Citation Presentation to New Mexico Section of American Water Resources Association, Conference on Rio Grande Basin Hydrology

Study Objective Summary of Compact and depletion trends in Middle Valley for conference presentation

Spatial Domain Otowi index gage to Elephant Butte Dam (and subdivision into 6 reaches)

Time Domain 1942-1990

Physical Domain Surface Supplies native and (non-native)

Study Approach Presentation of cumulative depletion vs. time for each of six river reaches. Identification of periods evidencing change in depletion, by reach, and discussion of natural or man-made events which may explain changes

Study Conclusions **(all units in af/y)**

Reach	Description	Period	Depletion	Comments
Otowi to San Felipe	Typically a losing reach, exceptions 1942-1946,1966-1970, 1983,1987-1989, depletions 1948-1966~26,000af/y	1948-1966 1967-1971 1972-1982 1983-1990	26,000 -30,000 30,000 variable	 High Precipitation Operational Changes (SJC)
San Felipe to Albuquerque	Losing	1942-1982 1983-1986	150,000 200,000	 Wet period
Albuquerque to Bernardo	Losing	1942-1986 1986-1989	85,000 33,000	Except 1972, above average rainfall Wet years, drain rehabilitation at Isleta
Bernardo to San Acacia		1944-1958 1959-1973 1985,1986 1986-1990	General trend of no gains or losses -21,000 -200-300,000 -21,000	 By 1959, significant rehabilitation completed
San Acacia to San Marcial	Losing	1944-1957 1957-1964 1965-1972 1973-1981 1982-1987	100,000 50,000 70,000 100,000 180,000	 Low flow conveyance channel, 1958 Wet years, 1985 forward, no Low Flow (LFCC); Also increase in diversions due to upstream water salvage (1965)

San Marcial to Elephant Butte Dam	Losing	1944-1981 1981-1990	60,000 not quantified	Reservoir evaporation 61,000 before 1980, since 1980, ~154,000
Otowi to Elephant Butte		1941-1979 1980-1987 1988	390,000 520,000 350,000	 Average Otowi flow 1.3 maf Average Otowi flow .7 maf

The low flow conveyance channel and water salvage were significant in reversing the compact debit trend. Climate is also a potential factor.

Title: Geohydrologic Framework and Hydrologic Conditions in the Albuquerque Basin, Central New Mexico

Author: Conde R. Thorn, Douglas P. McAda and John Michael Kernodle

Date: 1993

Citation: USGS Water-Resource Investigations Report 93-4149

Study Objectives: To characterize the conceptual geohydrologic framework and hydrologic conditions of the Albuquerque Basin; to characterize the surface water and groundwater budget.

Spatial Domain: Albuquerque Basin (Cochiti to San Acacia)

Time Frame: Water budget, average 1974 to 1992

Physical Domain: Combined surface water-groundwater domain, wet water

Study Approach: The following parameters were calculated: surface and groundwater inflows and outflows; groundwater change in storage; consumptive use, combined groundwater or surface water. The calculated average values for 1974 to 1992 are summarized below.

Surface Water		
Inflow	1,210,600 af/y	Cochiti composite plus tributaries
Outflow	1,040,000 af/y	San Acacia composite flow
Wastewater	59,300 af/y	
Groundwater		
Inflow	49,400 af/y	From adjacent basins
Outflow	15,000 af/y	To adjacent basins
Recharge	139,100 af/y	Mountain front and tributary
Withdrawal	136,700 af/y	From wells
Consumptive Use (excluding Jemez)		
Riparian and Open Water	146,500 af/y	Based on 3 af/y per riparian acre and 5 af/y per open water acre
Agriculture	120,900 af/y	Based on 2 af/y per acre
Change in Groundwater Storage	-31,000 af/y	Based on water level declines and estimated storage coefficient

Study Conclusions: The total annual average inflow was calculated as 1,458,400 acre-feet; outflow and consumptive loss was 1,459,100 acre-feet. The annual change in storage was estimated at 31,100 acre-feet. All water budget terms were independently estimated; the balance error, of 2 percent, was not unexpected.

Title: Middle Rio Grande Basin Surface Water Budget for Calendar Years 1935, 1955, 1975, and 1993

Author: Gould, J.

Date: August, 1995 (published 1997)

Citation: Middle Rio Grande Water Assessment Supporting Document Number 15

Study Objectives: Development of surface water budget for middle Rio Grande Basin from Cochiti to San Acacia, for each of seven sub-units.

Spatial Domain: Cochiti to San Acacia (seven sub-units)

Time Frame: Discrete evaluation for 4 years: 1935, 1955, 1975, 1993

Physical Domain: Surface water, native and non-native flows (does not include groundwater base inflow; changes to river or drain flow resulting from groundwater pumping not considered other than in broad structuring of canal-drain seepage estimates)

Study Approach:
For each of seven sub-units, and for each of 4 specific years, a water budget was developed, referenced to the stream system. Water budget terms were estimated as follows:

- Surface water inflow-generally based on gaged records for river and adjacent canals or other conveyance channels. Estimated for some components of some reaches.
- Seepage from canals, laterals, ditches-Seepage rates from ponding tests (Hansen, '94), soil conditions, groundwater conditions and channel length were used to develop seepage rates. Canal seepage for some years was used as inflow in the stream water budget, under the assumption that this water became return flow to the stream. Drain seepage was assumed as an outflow, assuming it was conveyed to groundwater. Handling of these terms varied from reach and for year, depending on assumed groundwater conditions.
- Vegetative Consumptive Use-Based on Kinkle (1995), which used consumptive use coefficients developed by King (1994) and Blaney-Criddle analysis.
- Open Water Evaporation-Based on USBR GIS database and pan evaporation data.

Study Conclusions:

- Discussion of general errors and uncertainty
- Notes that improvement in data collection would be useful in refining water budget

Title	A Comparative History of Middle Rio Grande Water Supplies and Assesments
Author	Andrew Kelton
Date	10-1-98
Citation	Alliance for Rio Grande Heritage
Study Objective	To reconcile USBR presentation conclusion (Hansen-Gould, 1998) that actual MRG depletions have exceeded Compact allowances, and to characterize MRG water budget including surface and groundwater, native and non-native supplies
Spatial Domain	Otowi Gage to Elephant Butte Dam
Time Domain	1935-1993, with general comments for earlier period and focus on '35, '33, '75, '93
Physical Domain	Surface and Groundwater supplies, Native and Non-Native Source
Study Approach	Compares and contrasts water budget components from Rio Grande Joint Investigation (1938), Hanson-Gould presentation (1998), Gould (1997), Summers (1997), Thorn (1993); discusses differences in assumptions and other possible factors affecting water budgets. Does not present new budget.

Study Conclusion

- Highlights uncertainty in estimating consumptive use by crops and riparian system
- Suggests that 1947 Engineer Advisors report and subsequent change in accounting procedure may change obligation beyond that envisioned by the Engineer Advisors, due to variety in summer thunderstorm inflow not indexed in base period (1925-1945)
- Criticizes Hansen-Gould budget for neglecting "groundwater subsidies" represented by return flow, S-J water, use of averages for tributary inflow and reservoir evaporation in years where these may have been greater than average, and, for neglecting groundwater inflow.
- Argues that too many investigations view "non-beneficial" CU as primary reason for non-compliance in debit years; and, that other possible causes have not adequately been explored.

Title	Middle Rio Grande Water Budget, Averages for 1972-1997
Author	Action Committee of the Middle Rio Grande Water Assembly
Date	October 1999
Citation	Middle Rio Grande Water Assembly, booklet for public information
Study Objective	To provide water budget information for a broad audience with interest in the region's water resources
Spatial Domain	Otowi Gage to Elephant Butte Dam
Time Domain	Average values, 1972 – 1997; and 1993
Physical Domain	Surface and Groundwater, Native and Non-Native Source
Study Approach	A committee including several professional hydrologists convened to derive a summary water budget for purposes of public information. Drawing from published studies and personal knowledge, estimates for water budget terms were derived. Specific procedures or references for individual estimates are not provided- the participating hydrologists have indicated (personal communications, 2000) that the intent of this exercise was to provide information at a general level. Water budgets were developed for each three domains: surface water, the shallow aquifer and the deep aquifer, including exchanges between these domains.
Study Conclusion	Results of the water budget analysis are illustrated in tabular and graphic formats, using averaged values. These presentations provide a general framework of the magnitude of various water budget elements. The author's note that many terms are highly variable, and that averages may not provide a clear assessment of conditions in individual years.

APPENDIX F
Probabilistic Analysis of Water Budget Terms

This appendix describes the process used to develop probability distribution functions for the water budget terms to which probabilistic analysis was applied, procedures for evaluating goodness of fit, and the analysis of correlation and dependencies. The general approach for characterizing the water budget terms is described in the main report, Section 3 and 5.

Probability Distribution Fitting for Use in Risk Analysis

Time series data for water budget terms were obtained as described in the Section 3 of the main report. These data indicate the magnitude of the water budget terms over a time interval. To summarize the range and distribution of these observations over the time interval of interest (e.g. 1950 to 1998) one can compute frequencies (or probabilities of occurrence) for various ranges of magnitudes and display this information as a probability histogram. Probability histograms were prepared for each water budget term considered to vary as a function of climate conditions (as opposed to land use or development conditions) as shown on report figures 5.1, 5.4-5.5, 5.7-5.9 and 5.12-5.15. In this process, the range of observed magnitudes was divided into a 'convenient' number of classes, typically ten. Each bar in a histogram represents the height corresponding to the probability density value in each class.

Using the grouping of observations indicated by probability histograms, continuous probability distribution (density) functions were selected and evaluated using goodness-of-fit statistical tests to obtain suitable distributions for modeling the water budget term in subsequent probabilistic evaluations. Mathematically, the integral of the probability distribution function is the probability over the class or interval of the continuous distribution. For example, if the continuous (random) variable X has a PDF of f then:

$$\text{Probability that } (a < X \leq b) = \int_a^b f(x)dx \qquad (1)$$

Many continuous distributions have been described in the literature. For this study, probability distributions were evaluated using the software *BestFit, Probability Distribution Fitting for Windows*, June 1997, distributed by Palisade Corporation. Using this software, distributions from a variety of available functions were readily evaluated and assessed with goodness-of-fit (GOF) tests.

Statistical Assessment of the Goodness-of-Fit (GOF) of the PDFs

Goodness-of-Fit Test Statistics

The Chi-Square (C-S), the Kolmogorov-Smirnov (K-S) and the Anderson-Darling (A-D) GOF tests were used to assess whether or not the sample of data was consistent with a chosen distribution function. These tests determine whether the distribution of empirical data is consistent with a fitted theoretical distribution function, at selected significance levels. The C-S test describes whether a particular distribution for a data set would be accepted or rejected, by comparison of the calculated C-S test statistic to the C-S critical value for the given significance level. While one of the most common tests of GOF, the C-S test has the disadvantage that the C-S test statistic is dependent on how the data is binned and also, that it requires sufficient sample size validate the C-S approximations. As implemented in the *Bestfit* software, this test utilizes a degree of freedom parameter equal to the number of classes minus one, ignoring the fact that the distribution parameters were estimated from the sample data. Therefore, conclusions regarding acceptance or rejection were also evaluated using conventional tables of critical values corresponding to a degree of freedom parameter equal to the number of classes, minus the number of distribution parameters, minus one. In addition to the C-S test, the K-S and A-D test statistics were considered in the evaluation of candidate distributions. The K-S test calculates the maximum vertical distance between an empirical and a fitted distribution function. The A-D test is a modification of the K-S test, giving more weight to the tails than the K-S test. If the computed GOF statistic is smaller than the critical value, the data do not show that the computed sample distribution is significantly different than the specified distribution.

Confidence Levels and Critical Values

The confidence level, also variously known as p-value, is a measurement of confidence or certainty. The significance level, also known as alpha (α), ((1 - p) * 100%), is a measure of the probability that the null hypothesis (that the fit is “good”) is rejected when it is true. *Bestfit* is used to identify the critical value (separating the rejection region from the acceptance region) at selected significance levels, and compares the test statistic (Chi-Square [C-S], Kolmogorov-Smirnov [K-S], or Anderson-Darling [A-D]) to the corresponding critical value. Generally, the smaller the fitting test statistic is, the better the probability distribution fit. Any probability distribution fit that has a value of the test statistic above the critical value is, generally rejected, while PDF fits with test statistic values below the critical value are accepted.

Final PDF Selection Considerations

A probability distribution fit is only as good as the historical data used in the fitting process. Since we would like to estimate an "unknown continuum" (the population in the form of a PDF) from a limited sample (the historical data), knowledge about the data becomes very important. Despite rigorous statistical testing during the probability distribution fitting, one cannot neglect the role the analyst must play in considering other important criteria such as 1) plausibility, 2) physical meaningfulness, 3) common sense, and/or 4) graphical considerations. In addition to the statistical testing, descriptive statistics are considered.

A table of GOF parameters used in evaluation of the selected probability distribution functions is provided as Table F-1. Figures F-1 to F-5 are the scatter plots of calculated empirical distributions versus selected fitted distributions for OTOWI index flow, Jemez River, Galisteo Creek, Rio Puerco, and Rio Salado, respectively. The selected distributions are described in Section 5.

Dependency Relationships

In certain cases, probability distribution functions may depend on each other. Values in a given distribution will be affected by what happens someplace else. Variables are either correlated or depend on each other in some fashion. The most common dependencies applied in the Middle Rio Grande (MRG) probabilistic water budget entail several different techniques to calculate dependency relationships.

Correlations in Sampling

The Pearson's correlation coefficient and the rank-order correlation coefficient are statistical procedures commonly used to measure the linear relationship between two phenomena. It allows specification of a relationship between the values sampled for different water budget elements, while still maintaining a degree of uncertainty for each. It also allows one to capture effects of sampled values that are affected by other calculations in the risk model. Mathematically, these are described as follows.

Pearson's Correlation (*r*):

For pairs of quantities (x_i,y_i), $i = 1,\ldots,n$, the Pearson product moment correlation coefficient (r) is defined as:

$$r = \frac{\dfrac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{n-1}}{\sqrt{\dfrac{\sum_i (x_i - \bar{x})^2}{n-1}}\sqrt{\dfrac{\sum_i (y_i - \bar{y})^2}{n-1}}}$$

where $\bar{x}$ is the mean of x_i's and $\bar{y}$ is the mean of y_i.

Based on this format, the estimated Pearson's r is between -1.0 and +1.0. The closer the absolute value of r is to 1.0 the stronger the relationship. A positive or negative sign refers to as a positive or negative correlation, respectively.

Rank-order correlation (r_s):

Rank-order correlation is a non-parametric measure of correlation between pairs of quantities (x_i,y_i). It is used for ranked data.

$$r_s = 1 - \frac{6\sum_i d_i^2}{n(n^2 - 1)}$$

where d_i is the difference between the ranks assigned to x_i and y_i, and n is the number of pairs of data.

In implementing the water budget model, a correlation matrix is specified that correlates values sampled in different distribution functions. Correlation coefficients were calculated based on the historical data records. Two water budget elements are treated as correlated pairs in the @Risk model for the Middle Rio Grande: 1) Otowi Index Supply vs. Jemez River Tributary Flow and 2) Rio Puerco Flow vs. Rio Salado Flow. The calculated Pearson's and rank-order correlations for Otowi Index Supply versus Jemez River are 0.861 and 0.881, respectively; and 0.574 and 0.669 for Rio Puerco versus Rio Salado, respectively. The calculated correlations suggest that Otowi Index Supply and Jemez River have strong association and Rio Puerco and Rio Salado show moderate to strong association. The values for both correlation coefficients are reasonably close in both cases. Slight deviations occurred where there was a tendency of outliers in one, or both, of the variables.

Dependent vs. Independent Variables

An independent variable is one that does not depend in any way on the values of any other variable in the model under consideration. The value of an uncertain independent variable is determined by drawing a sample from the appropriate probability distribution. This sample is drawn without regard to any other random sample drawn for any other variable in the model. A dependent variable is one that depends in some way on the values of other variables under consideration in the model. In one form, the value of an uncertain dependent variable can be calculated from an equation as a function of other uncertain model variables. Alternatively, the dependent variable may be drawn from a distribution based on the random number which is correlated with a random number used to draw a sample of an independent variable.

To maintain strict independence of a particular water budget item (e.g. Otowi Index Supply), an independent variable is defined that is totally unaffected by any other variable in the water budget. In contrast, a dependent variable (e.g. Jemez River flow) is determined in full or in part by one or more other variables. In this risk model, the Jemez River flow strongly follows the Otowi Index Supply and the Rio Salado flow moderately follows the Rio Puerco flow; therefore, we decided to declare the Otowi Index Supply and the flow of the Rio Puerco as independent variables and the Jemez River flow and the flow of the Rio Salado as the dependent variables, respectively.

Dependency Coefficients

Dependency coefficient values were assigned to specify dependent relationships between 'known' pairs of water budget elements. The dependency coefficient in the risk model is used in determining a random number, which will be used in sampling the dependent variable. Depending on the value of the dependency coefficient, the random number used will be more or less strongly correlated with the random number used to sample the independent variable. For example, negative dependency coefficient values cause a negative correlation between the paired samples. A dependency coefficient value of -1.0 causes the variables to have a fixed negative correlation during sampling (i.e. if a random number of 0.9 was used to sample the independent variable, 0.1 will be used to sample the dependent variable). Conversely, a dependency coefficient value of 1.0 causes the variables to have a fixed positive correlation during sampling (i.e. if a random number of 0.1 was used to sample the independent variable, 0.9 will be used to sample the dependent variable). A dependency coefficient value of 0.0 specifies that variables are mutually independent.

Practical Aspects

To detect anomalous structures in the data, relationships between two variables are graphically assessed. In addition, both Pearson and rank-order correlations of different water budget elements are calculated from their historical time series. The calculated correlation statistics are then adopted in the actual risk model to establish a dependency coefficient used in sampling the independent and dependent variables and to create a correlation matrix that allows one to correlate multiple distributions.

A graphical comparison of the Jemez River flow suggests a correlation to the Otowi Index Supply, Figure F-6. The calculated rank-order correlation of 0.881 is used to randomly sample and correlate the Jemez River input to the Otowi Index supply, using the mechanism of an independent-dependent variable pair in @Risk.

A graphical comparison of the Rio Puerco and Rio Salado similarly suggests some correlation, Figure F-7. The calculated rank-order correlation of 0.669 is used as a dependency measure in the probabilistic water budget model to have the two time series always correlated at the specified r and maintain a random sampling scheme at that approximate correlation level.

Table F-1. Probability Density Function (PDF) Fitting Statistics

Water Budget Term	PDF	Dependency	Chi-Square Test			Kolmogorov-Smirnov Test			Anderson-Darling Test		
			Statistics		Critical Value	Statistics		Critical Value	Statistics		Critical Value
OTOWI Index Flow	Beta	Independent	8.306	<	14.07 @ α = 0.05	0.550	<	1.358 @ α = 0.05	0.464	<	2.492 @ α = 0.05
Jemez River	Beta	Dependent	3.630	<	14.07 @ α = 0.05	0.444	<	1.358 @ α = 0.05	0.410	<	2.492 @ α = 0.05
Galisteo Creek	Gamma		13.515	<	14.07 @ α = 0.05	0.349	<	1.358 @ α = 0.05	0.153	<	2.492 @ α = 0.05
Rio Puerco	Pearson VI	Independent	18.946	>	12.59 @ α = 0.05	0.624	<	1.358 @ α = 0.05	0.474	<	2.492 @ α = 0.05
Rio Salado	Pearson VI	Dependent	19.086	>	12.59 @ α = 0.05	1.105	<	1.358 @ α = 0.05	1.209	<	2.492 @ α = 0.05

Notes:

1. The null hypothesis, that the sample data are reasonably represented by the candidate distribution, is rejected for a selected significance level (alpha), if the test statistic is greater than the critical value.
2. The critical value for the Chi-Square test reflects the degrees of freedom reduced by number of distribution parameters estimated from sample data.
3. Rejection or acceptance was based on consideration of all three test statistics.
4. The Kolmogorov-Smirnov test statistic and critical value is normalized with respect to sample size.

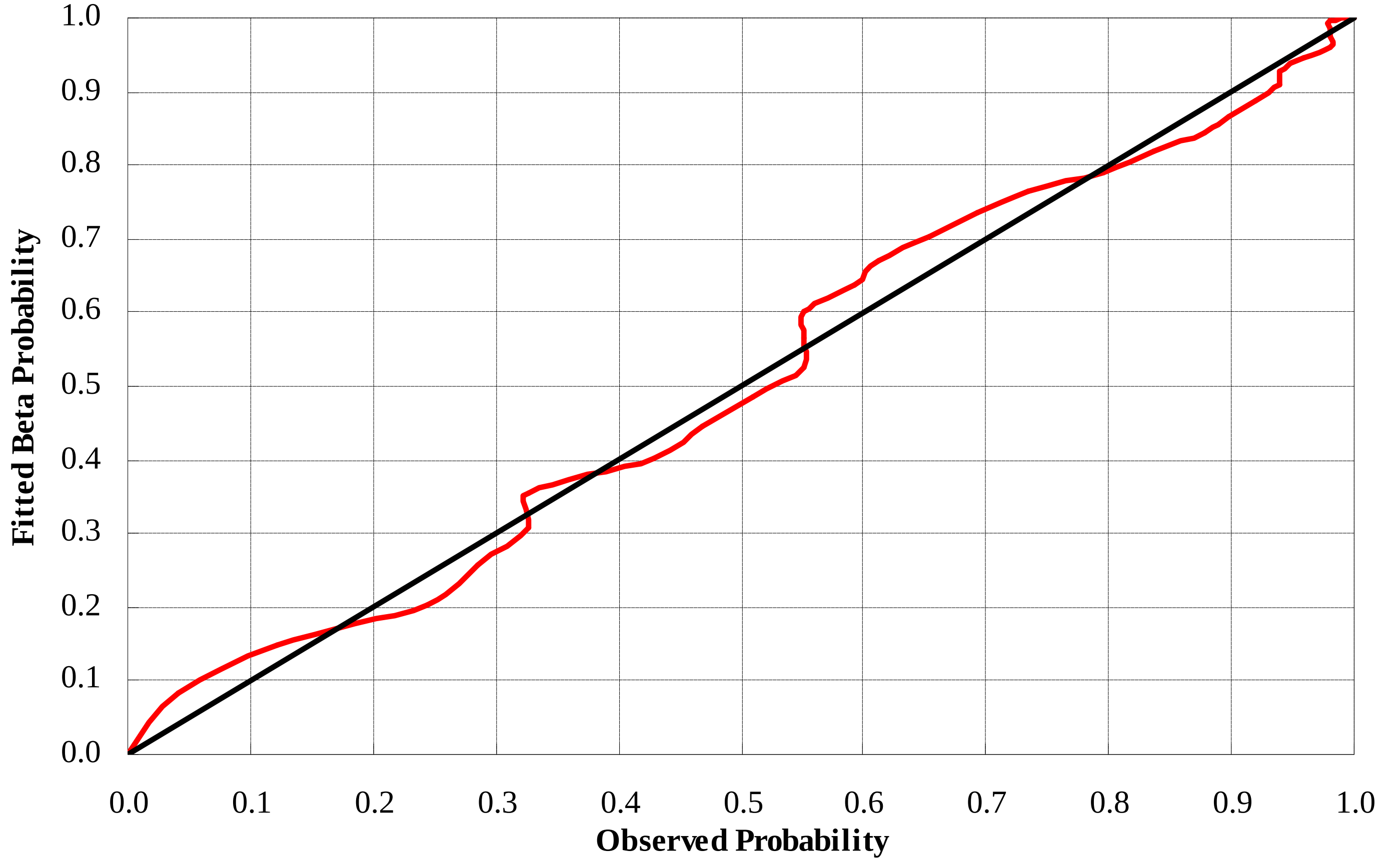


Figure F-1. Scatter plots of probability: observed versus fitted for OTOWI index flow.

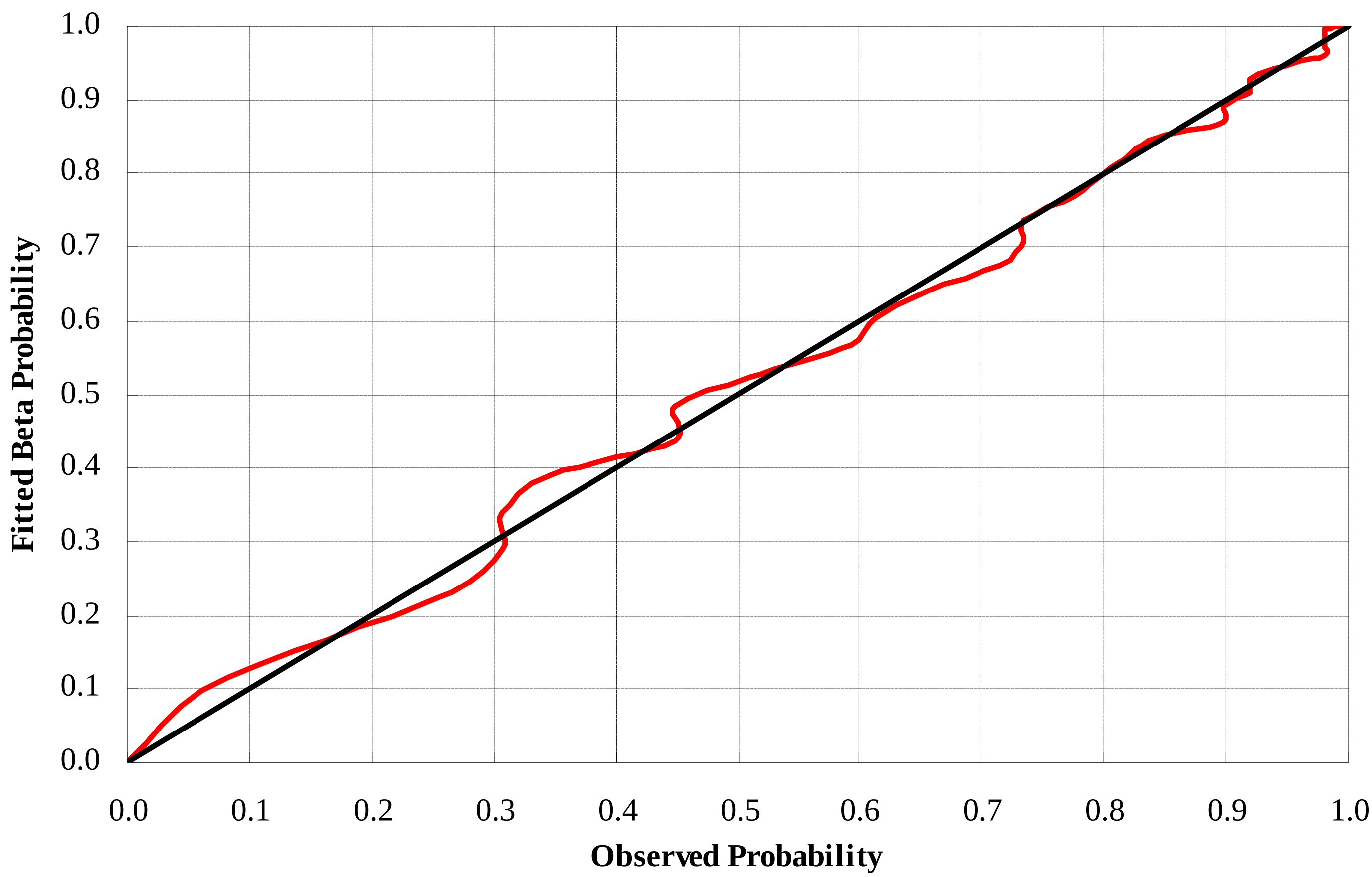


Figure F-2. Scatter plots of probability: observed versus fitted for Jemez River flow.

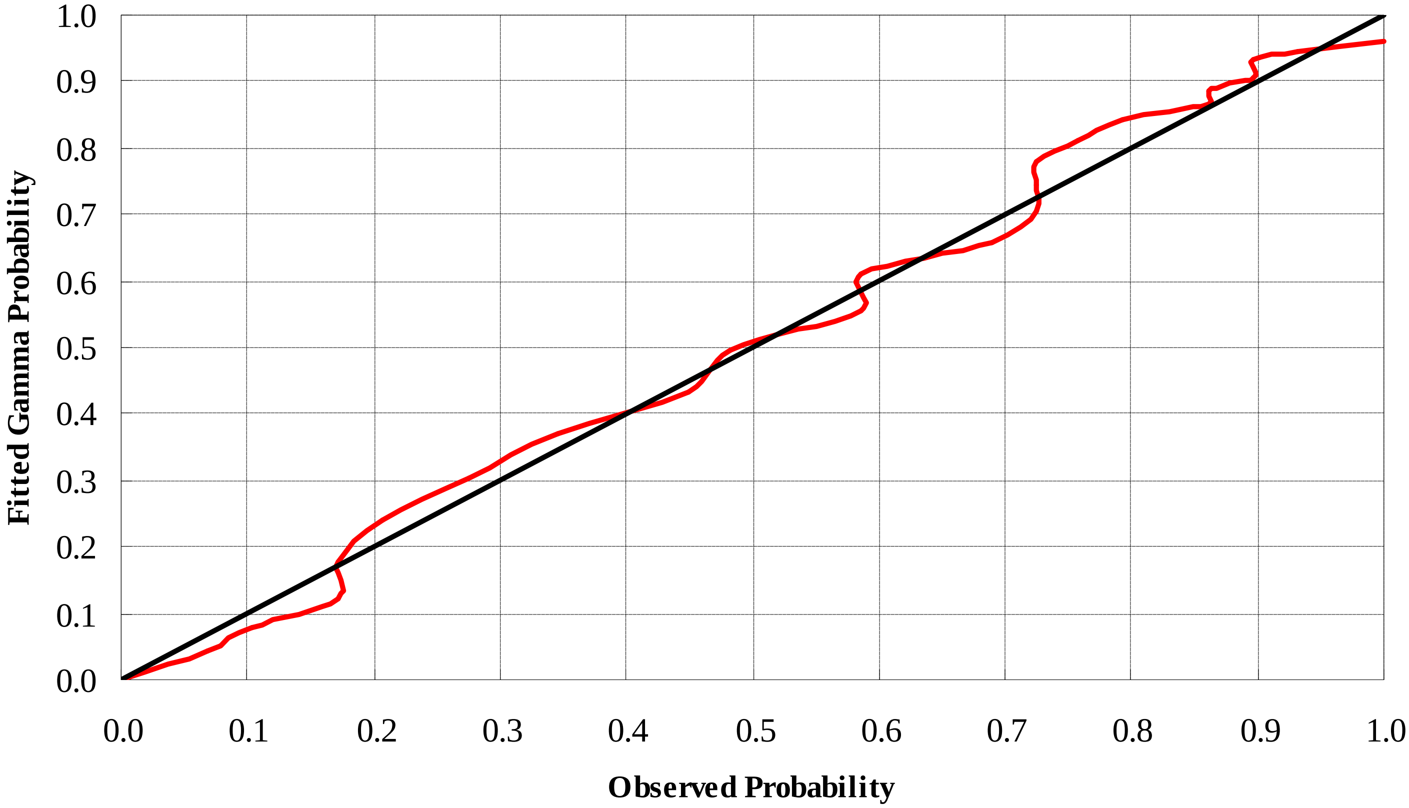


Figure F-3. Scatter plots of probability: observed versus fitted for Galisteo Creek flow.

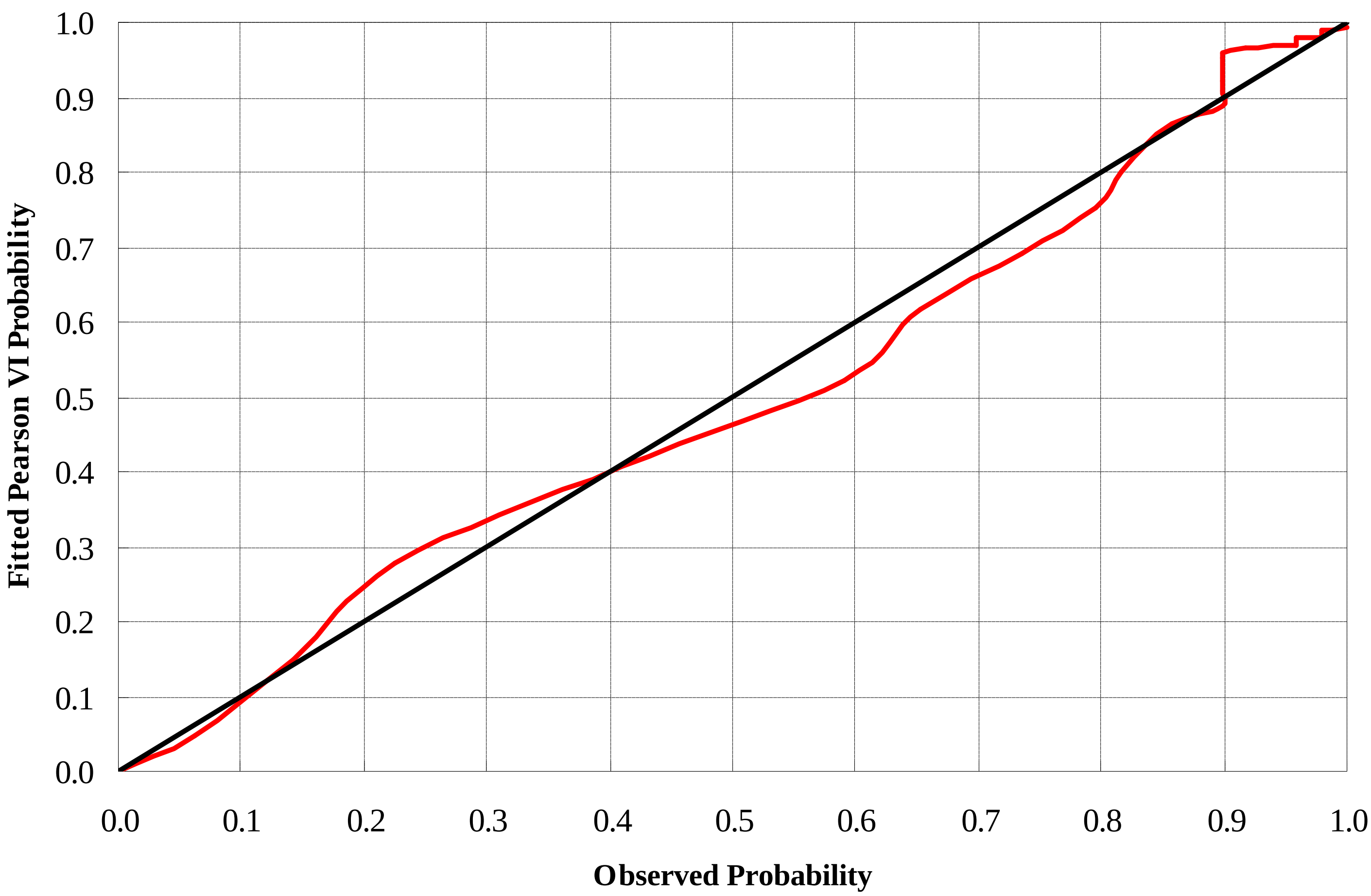


Figure F-4. Scatter plots of probability: observed versus fitted for Rio Puerco flow.

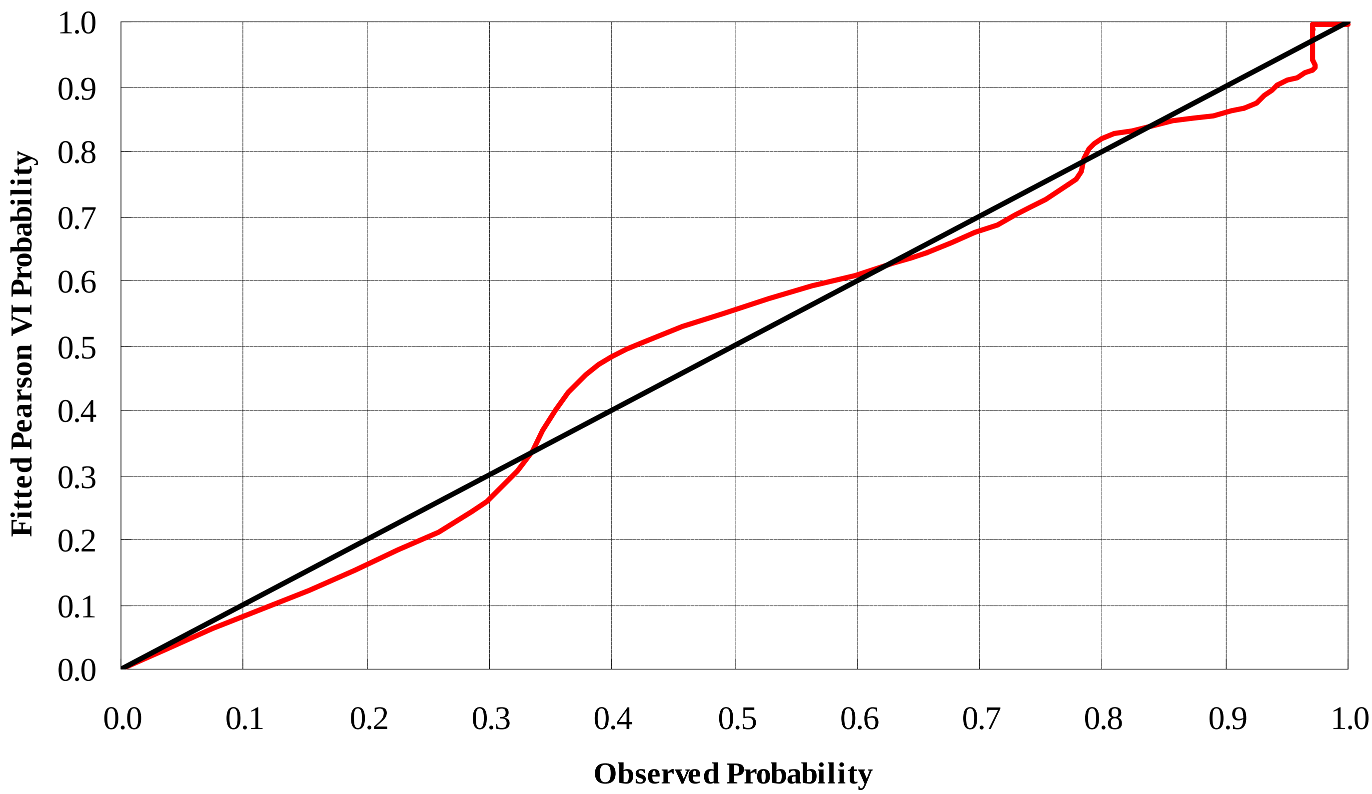
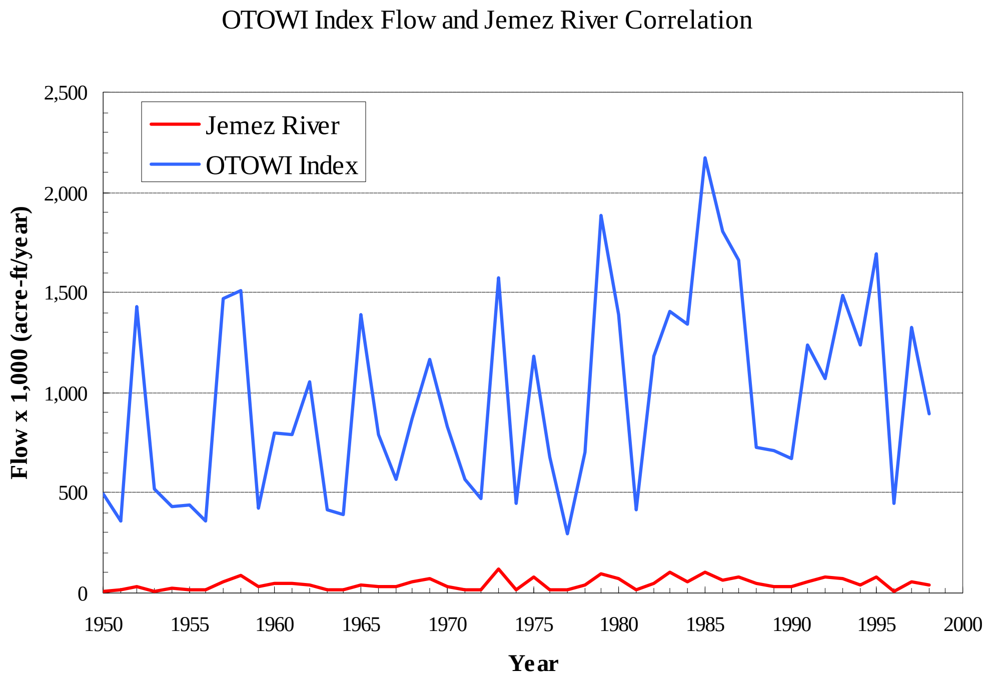


Figure F-5. Scatter plots of probability: observed versus fitted for Rio Salado flow.



Pearson's correlation : 0.861
Rank-Order correlation: 0.881

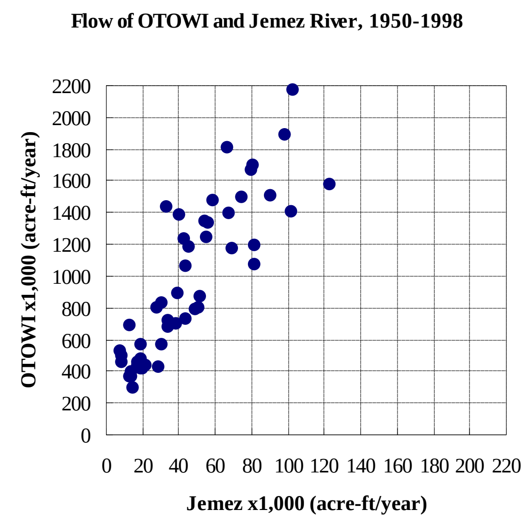
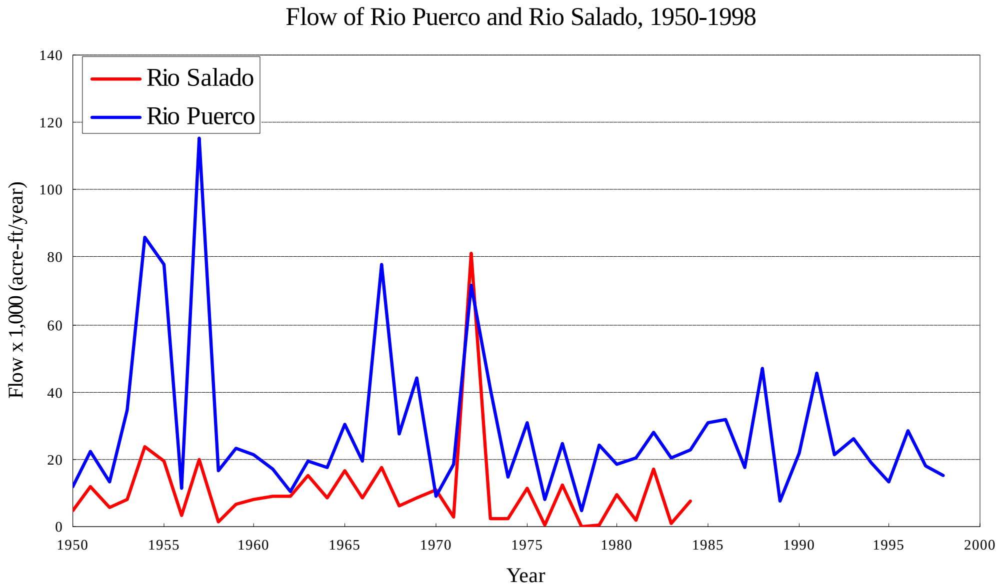


Figure F-6. Yearly time series, scatter plot, and correlation of the OTOWI Index flow and the Jemez River flow.

Pearson's correlation : 0.574
Rank-Order correlation: 0.669



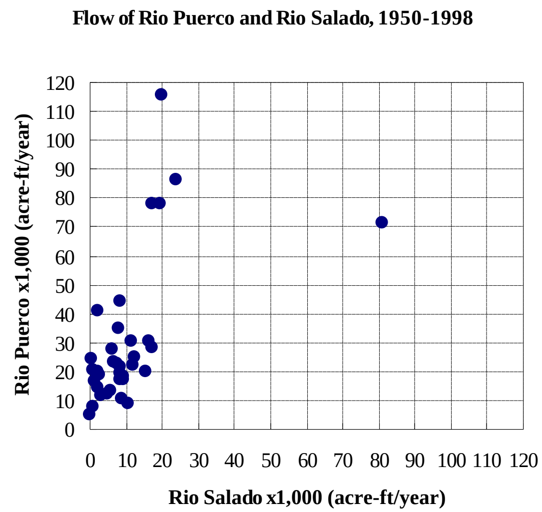


Figure F-7. Yearly time series, scatter plot, and correlation of the Rio Puerco flow and the Rio Salado flow.

APPENDIX G
Calculation of Groundwater Depletions and Base Groundwater Inflow

Model History, Development, and Structure

In this study, the New Mexico Office of State Engineer (NMOSE) model of the Albuquerque Basin was employed to integrate and represent groundwater processes and aquifer-stream interactions. This study used the existing flow model to characterize the groundwater depletions, depletions to the Rio Grande, and base groundwater inflow to the Rio Grande under both present and anticipated future groundwater pumping scenarios.

The groundwater model is a work product of long-term studies of the Middle Rio Grande Basin, undertaken by the USGS and cooperating agencies. The model was originally developed by the USGS as the Administrative Groundwater Model for the Middle Rio Grande Basin (Kernodle et al, 1995; Kernodle, 1998). The history and development of this model are described in Barroll, 1999.

The version of this model employed in this study has 6 layers and extends to a total depth of 1600 feet below ground surface. All layers simulate alluvial deposits of the Upper and Middle Santa Fe Group. The hydraulic conductivity of the Upper Santa Fe Group is simulated as 15 feet per day, and that in the Middle Santa Fe Group is simulated as 8.4 feet per day. The specific yield is 0.20, and the specific storage is 1.0×10^{-6} per foot. An anisotropy ratio (ratio of horizontal to vertical hydraulic conductivity) of 750 is employed. Most tributaries are simulated with specified fluxes to the groundwater system, however, the Jemez River and dammed reservoir are simulated with a head-dependent flux. Precipitation is incorporated through the modeled recharge terms, and groundwater basin inflow and outflow are incorporated through model boundary designations.

Model Simulations

The model was employed in this study to simulate hydrologic conditions under 4 pumping scenarios:

Case 1 - Present Condition, Year 2000: This scenario assumes the present development condition, in terms of groundwater pumping and other water uses, and evaluates impacts in the year 2000. Total groundwater withdrawal under this scenario is 156,800 acre-feet per year.

Case 2 - Present Condition, Year 2040: This scenario assumes continuation of the present development condition, in terms of groundwater pumping and other water uses, and evaluates the impacts as they would occur in the year 2040. As for Case 1, total groundwater withdrawal is 156,800 acre-feet per year.

Case 3 – Full Use of Existing Wells, Year 2040: This scenario assumes that the existing wells are all pumped at their full use of existing claimed water rights, as estimated by the

NMOSE, rather than their current rate, and evaluates the impacts in the year 2040. Total groundwater withdrawal is 217,600 acre-feet per year.

Case 4 - Alternative Development Condition, Year 2040: The two scenarios included within this case both assume an alternative development condition, reflecting an increase in groundwater pumping, and evaluate the groundwater impacts as they would occur in year 2040. Total groundwater withdrawal under both scenarios is 317,600 acre-feet per year, incorporating the "full-use" pumping (Case 3) of 217,600 acre-feet per year plus an additional 100,000 acre-feet per year as follows:

> Scenario a – Albuquerque Well Field: Increase in groundwater pumping consists of 100,000 acre-feet per year pumped from the Albuquerque well field.
>
> Scenario b – Eastern Well Field: Increase in groundwater pumping consists of 100,000 acre-feet per year pumped from a well field along the east side of the basin.

For the first two scenarios, modeling the effects over time of the present development condition, pumping was set in the model at the levels identified for 1999 in the NMOSE Albuquerque Basin model. These withdrawals of 156,800 acre-feet per year represent the sum total of estimated pumping presently occurring, and are distributed throughout the model according to actual well locations, depths, and pumping rates.

For the other two scenarios, hypothetical pumping distributions are assumed. In scenario 3, pumping from the existing wellfields is increased to the amount estimated by the NMOSE to represent "full use of existing claimed water rights", for a total withdrawal of 217,600 acre-feet per year from existing wellfields. For the two simulations performed under Case 4, an additional 100,000 acre-feet per year is assumed to be withdrawn, either from the Albuquerque Basin, or from a hypothetical well field along an extended region south of Albuquerque on the eastside of the basin. Thus, under Case 4, a total of 317,600 acre-feet per year is withdrawn from the aquifer.

To establish baseline conditions, a transient model simulation was also run to depict hydraulic conditions over time under non-pumping conditions, that is, if no extraction wells were operated since 1900. The locations of existing extraction wells within layer 4 are shown in figure G-1. Although additional wells are pumping in other layers, layer 4 includes the largest-producing wells, located primarily in the Albuquerque area. These wells are pumped at their designated rates in each of the four scenarios. Figure G-2 shows the locations of the wells added in scenario 4b, in which a series of wells along the eastern side of the basin is pumped at a total of 100,000 acre-feet per year.

Figures G-3 and G-4 depict the river depletions and groundwater storage depletions over time under the simulated pumping scenarios (existing conditions, full-use of existing water rights, and the two options for increase in pumping of 100,000 acre-feet per year over the full-use amount). These depletions have been calculated by subtraction of the model mass-balance terms in the 4 scenarios for net river exchange and groundwater storage from those terms in the non-pumping version of the model. This approach has allowed us to isolate the impacts of each pumping scenario on the river and the groundwater system. As can be seen on these graphs, under each of the four pumping scenarios, groundwater storage depletions decrease over time as groundwater pumping continues, and river depletions increase correspondingly. That is to say, as groundwater pumping continues, eventually the water produced in the wells is essentially all derived from the river. River depletions are the least under current conditions, but still increase over time even if pumping rates are not increased. Higher depletions are calculated for full use of existing water rights, and even higher depletions are calculated for increases in pumping of 100,000 acre-feet per year.

These model simulation results indicate that there is little difference in the timing or magnitude of depletions with the two alternative assumptions in Case 4 concerning wellfield placement. Figure G-3 shows that, after an initial period of time, the effects of the additional pumping in a new eastern well field are the same as the effects of this additional pumping in the Albuquerque well field. The expanded pumping in the Albuquerque area benefits from a short-term delay in impacts, probably due to present disconnected stream-aquifer conditions in this area. However, over time, the river depletions from pumping in the Albuquerque area are essentially the same as would occur if this pumping is dispersed further to the south. In both cases, the impact on the river increases from about 100,000 acre-feet per year in the first year, to about 220,000 acre-feet per year by Year 2040, and about 260,000 acre-feet per year by Year 2100.

The distributions of groundwater depletions are depicted in contour plots of drawdown and hydraulic head distributions across the basin under each of the four pumping scenarios, in Figures G-5 through G-14.

The assumption of the alternative increased pumping conditions is made for the purpose of demonstrating how the water supply model can be used to evaluate alternative development scenarios, and to illustrate the scale of long-term aquifer-stream interactions. These stream-aquifer interactions must be considered in any conjunctive use water supply evaluation that involves groundwater pumping. These results illustrate the surface water penalty incurred when obtaining long-term water supplies from groundwater in a stream-connected aquifer. Clearly, with limits on surface-water supply set by the Rio Grande Compact, these impacts would require offset by reducing water use from other sectors.

Use of Model for Determination of Base "Adjusted" Groundwater Inflow

Technical details describing the use of the NMOSE model of the Albuquerque Basin to determine base "adjusted" groundwater inflow are described in this section.

Base "Adjusted" Groundwater Inflow

Base "adjusted" groundwater inflow represents the net groundwater that would flow into or from the river, under conditions of the present river-conveyance infrastructure, without pumping of groundwater, without deep percolation of applied irrigation water, and without riparian evapotranspiration. While not strictly a physically based component, this component is important as a baseline term to the probabilistic water supply model (@Risk Model). The base "adjusted" groundwater inflow term is included in the probabilistic model as a term representing the combination of stream-aquifer exchanges occurring under steady-state conditions absent influences of pumping, irrigation and riparian use. The effect of pumping, irrigation and riparian use on the stream are calculated and tracked separately within the structure of the probabilistic water supply model. 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.

Simulations to Quantify Base "Adjusted" Groundwater Inflow

Two base runs are used to derive the base "adjusted" groundwater inflow. These runs are:

> Case 0: Use starting heads from non-pumping historical run (no pumping since 1900). Continue zero pumpage in period 2000-2100.
>
> Continuation Case: Use starting heads from historical pumpage run. Continue with 1999 pumping rates throughout the future, 2000-2100.

The results of these runs have been used in the @Risk simulation to quantify (as a fixed parameter) the ambient groundwater inflow to the river, and to determine the necessary adjustments to ambient groundwater inflow for consistency in handling of riparian evapotranspiration (to avoid double counting this term) and deep percolation from applied irrigation water. These results correspond to the reach included within the Albuquerque Basin model, approximately, from Cochiti to San Acacia.

a. Ambient groundwater inflow: This term is expressed in the MODFLOW water-balance output as river loss and is negative in sign. The value of –61,371 acre-feet per year represents the net stream gain under non-pumping conditions with the stream infrastructure as modeled for year 2000. For use in the @Risk model, as base *river inflow*, the sign of this number is reversed to obtain ambient groundwater inflow, then adjusted for evaporation, as described in (b) below, and adjusted for irrigation seepage, as described in (c) below.

b. Evaporation: The amount of riparian evaporation incorporated into the groundwater model for the pre-development case is 78,785 acre-feet per year. This amount of evaporation reduces the groundwater model-calculated ambient inflow to the stream. Because riparian evaporation is separately removed from the @Risk model as a stream outflow term (using the ET Toolbox estimates), the groundwater model calculated evaporation must be added back to the calculated ambient groundwater inflow term to develop the final ambient groundwater inflow term for the @Risk model. This is done to avoid double-subtracting riparian evaporation from the probabilistic water-budget model of the stream/near-stream zone. The evaporation varies slightly under various cases and is not constant in time. These variations, being relatively small in magnitude, are ignored.

c. Irrigation Seepage: The groundwater model includes irrigation seepage, in the amount of 1 acre-foot per irrigated acre, in the recharge package. Thus, river/aquifer exchanges computed by the model include return flow from applied irrigation water. Since the approach taken with the @Risk water budget analysis is to treat irrigation depletions as a net consumptive use, rather than explicitly handling diverted and returned waters, the inclusion of irrigation returns in groundwater-model-derived flow would overestimate the base groundwater inflow to the river. Therefore, the model assigned recharge from irrigation applications should be subtracted from the MODFLOW-derived base flow, in obtaining the adjusted baseflow for the @Risk model. Documentation for the model (WRI 94-4251) indicates that 1 acre-foot per acre is assumed under the present condition, for a total of 48,567 acres in the Albuquerque Basin. Therefore, for the full basin analysis, 48,567 acre-feet per year is subtracted from the computed baseflow. For sub-reach analyses, this acreage is prorated according to the URGWOM reaches, assuming 2,869 acre-feet per year in the Cochiti to San Felipe reach, 45,260 acre-feet per year in the San Felipe to Bernardo reach, and 438 acres in the Bernardo to San Acacia reach.

Summary:

The domain-adjusted groundwater base inflow is computed to reflect conditions of no pumping, no evapotranspiration and no irrigation recharge. This provides a base on which to superimpose the separately calculated effects of pumping, irrigation, and evapotranspiration in the @Risk model. This base is derived as follows:

+61,371	net stream-groundwater exchanges, as gain to river, under “no pumping condition”
+78,785	return of modeled evaporation to approximate base inflow under “no evaporation condition”
- 48,567	removal of irrigation recharge to reflect “no irrigation condition”
+91,589	acre-feet per year, adjusted base net stream inflow

References:

BARROLL, P, 1999 **Draft Documentation for the Administrative Groundwater Model for the Middle Rio Grande Basin,** New Mexico Office of the State Engineer.

KERNODLE, J.M., D.P. MCADA and C.R. THORN, 1995, **Simulation of ground-water flow in the Albuquerque basin, central New Mexico, 1901-1994, with projections to 2020,** United States Geological Survey Water-Resources Investigations Report 94-4251, and the City of Albuquerque Public woks Department.

KERNODLE, J.M. 1998, **Simulation of ground-water flow in the Albuquerque basin, Central New Mexico, 1901-1995, with projection to 2020**, U.S. Geological Survey Open-File Report 96-209.

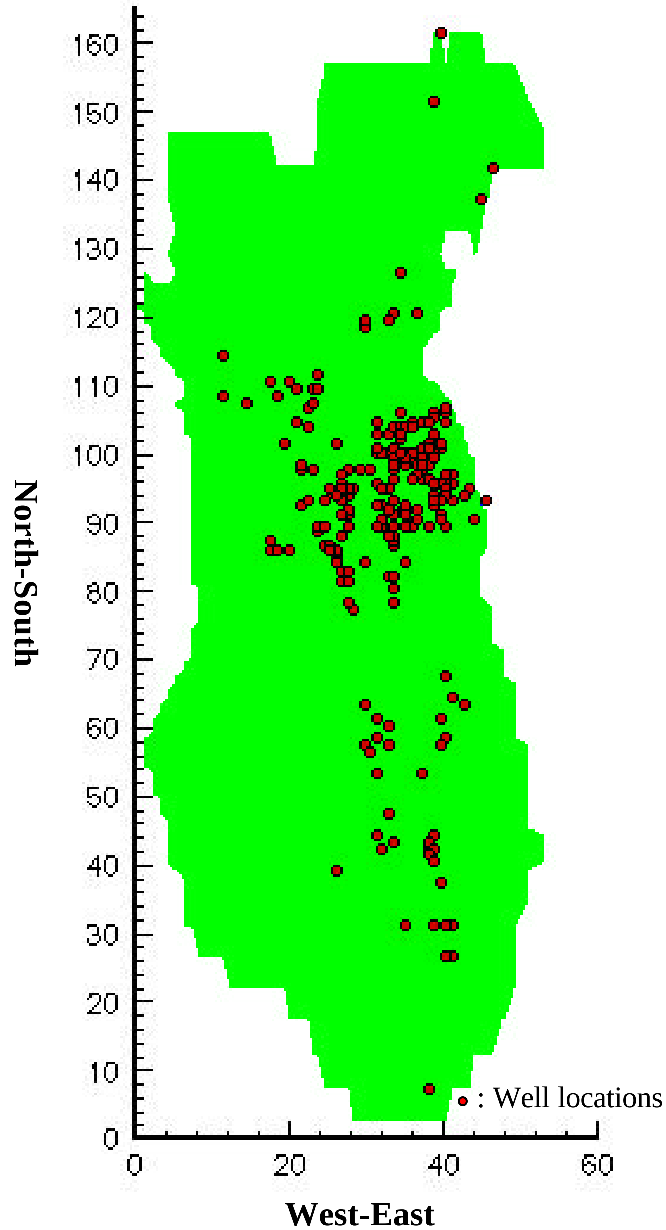


Figure G-1: Existing wells in model layer 4.

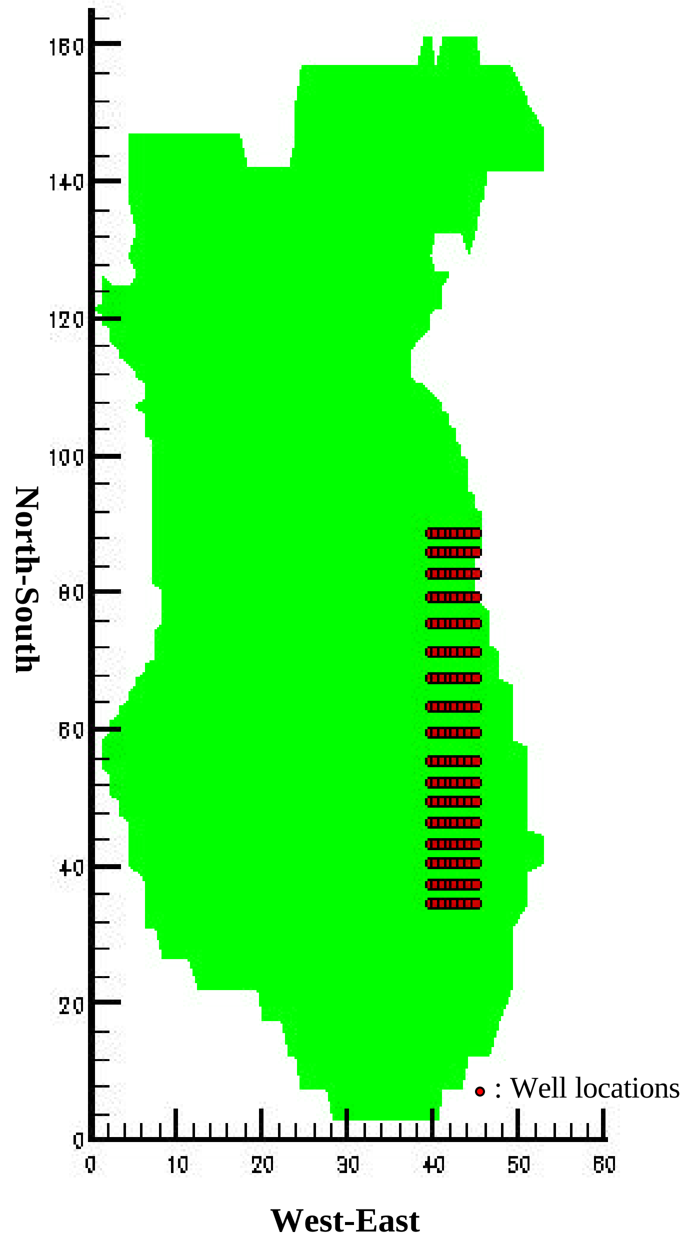


Figure G-2: Hypothetical eastside well field in numerical model.

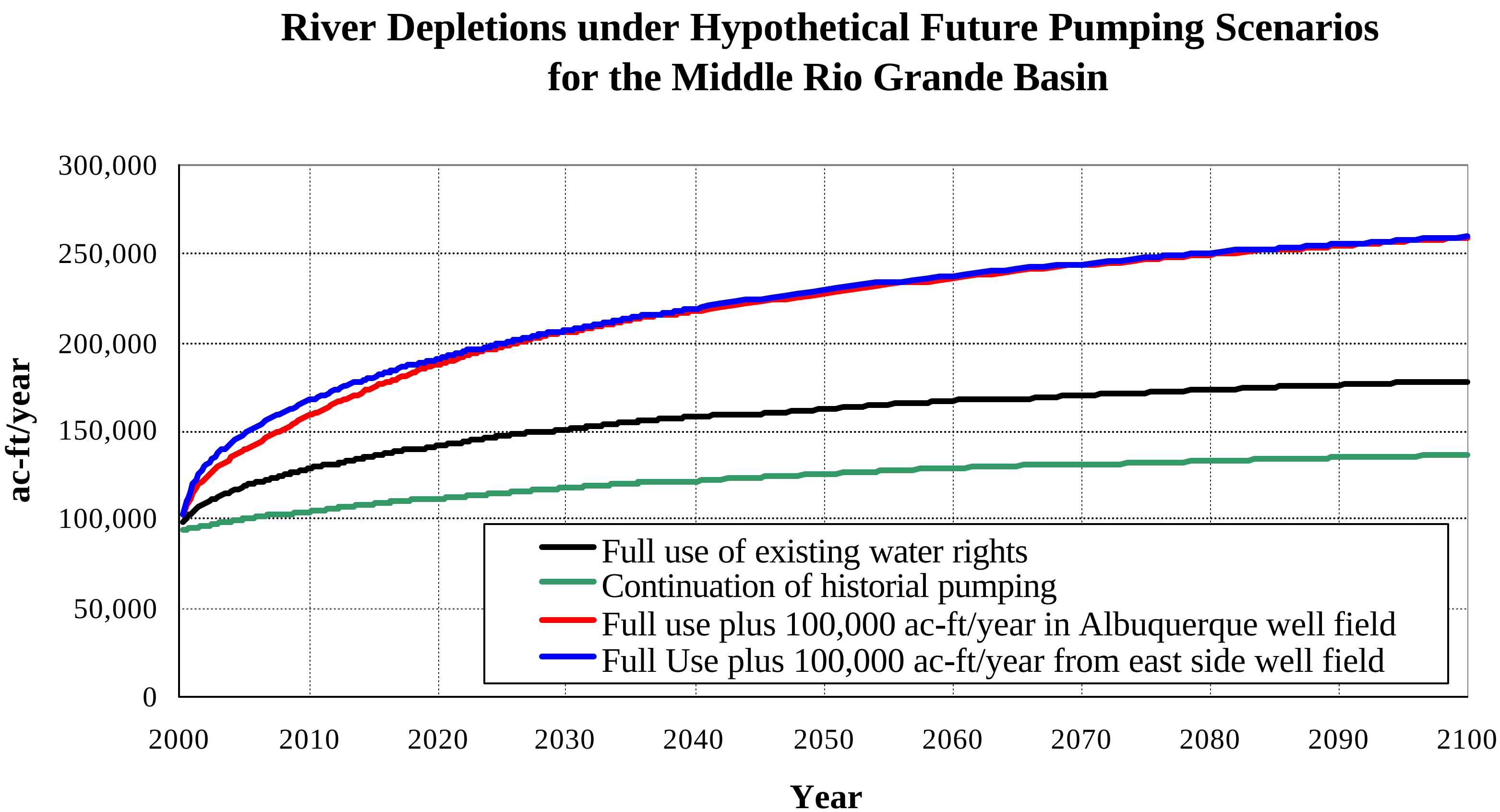

River Depletions under Hypothetical Future Pumping Scenarios
for the Middle Rio Grande Basin
300,000
250,000
200,000
150,000
100,000
50,000
0
ac-ft/year
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Full use of existing water rights
Continuation of historial pumping
Full use plus 100,000 ac-ft/year in Albuquerque well field
Full Use plus 100,000 ac-ft/year from east side well field

Figure G-3

Groundwater Storage Depletions under Hypothetical Future Pumping Scenarios for the Middle Rio Grande Basin

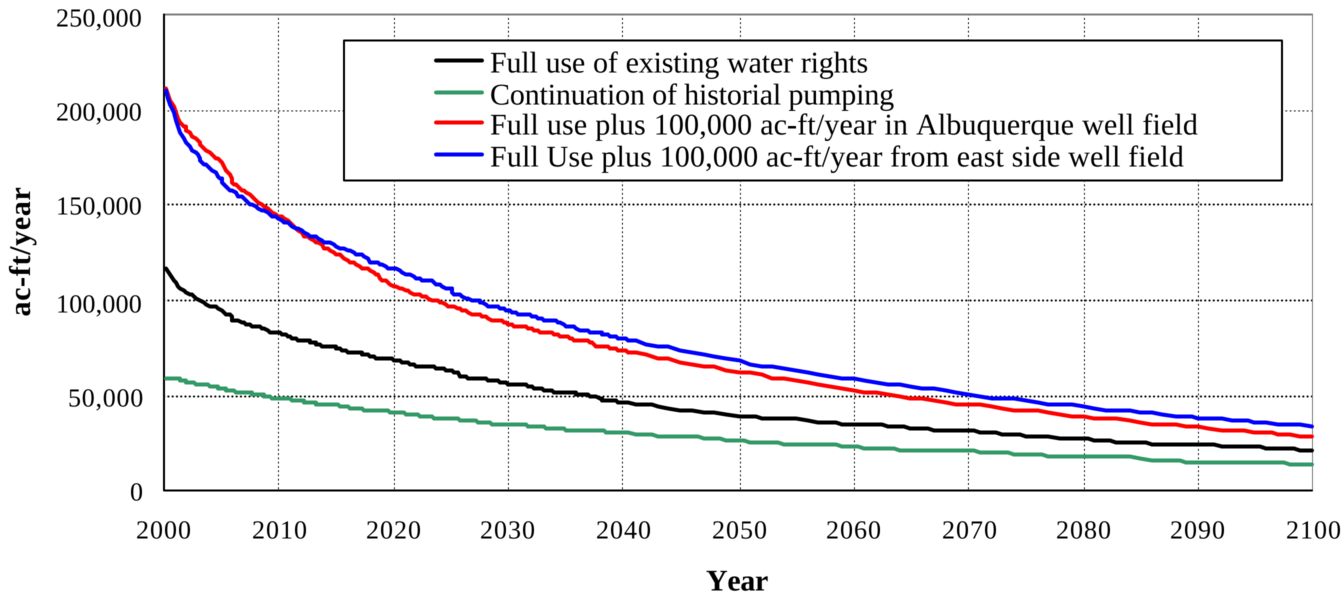


Figure G-4

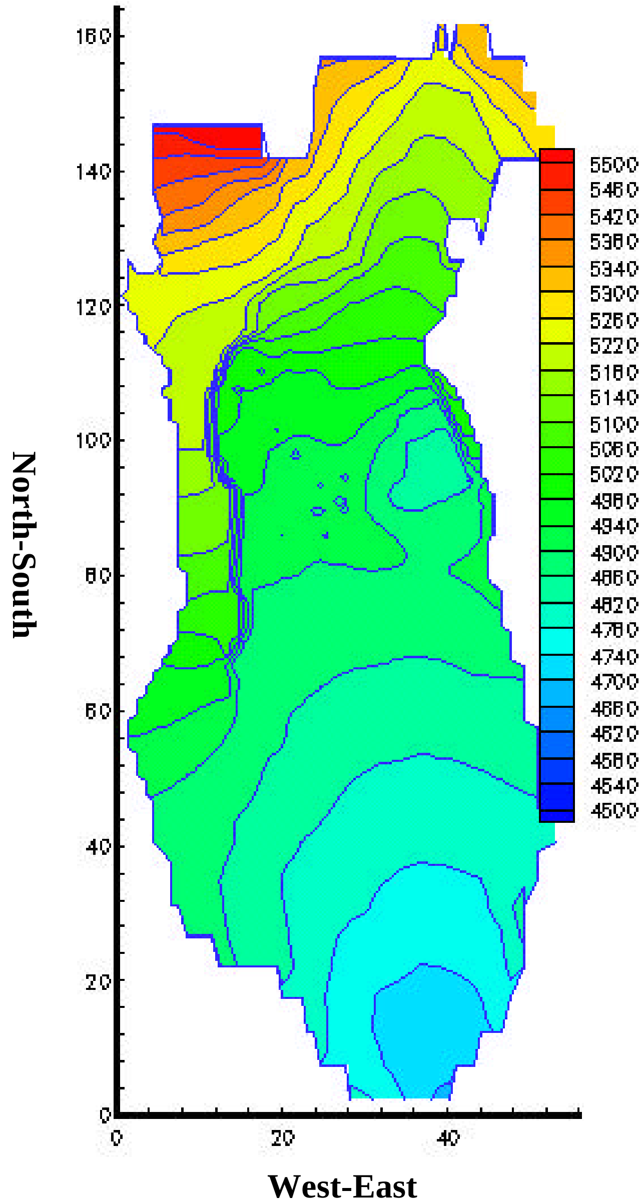


Figure G-5: Simulated year 2000 hydraulic heads in layer 4 based on existing well conditions.

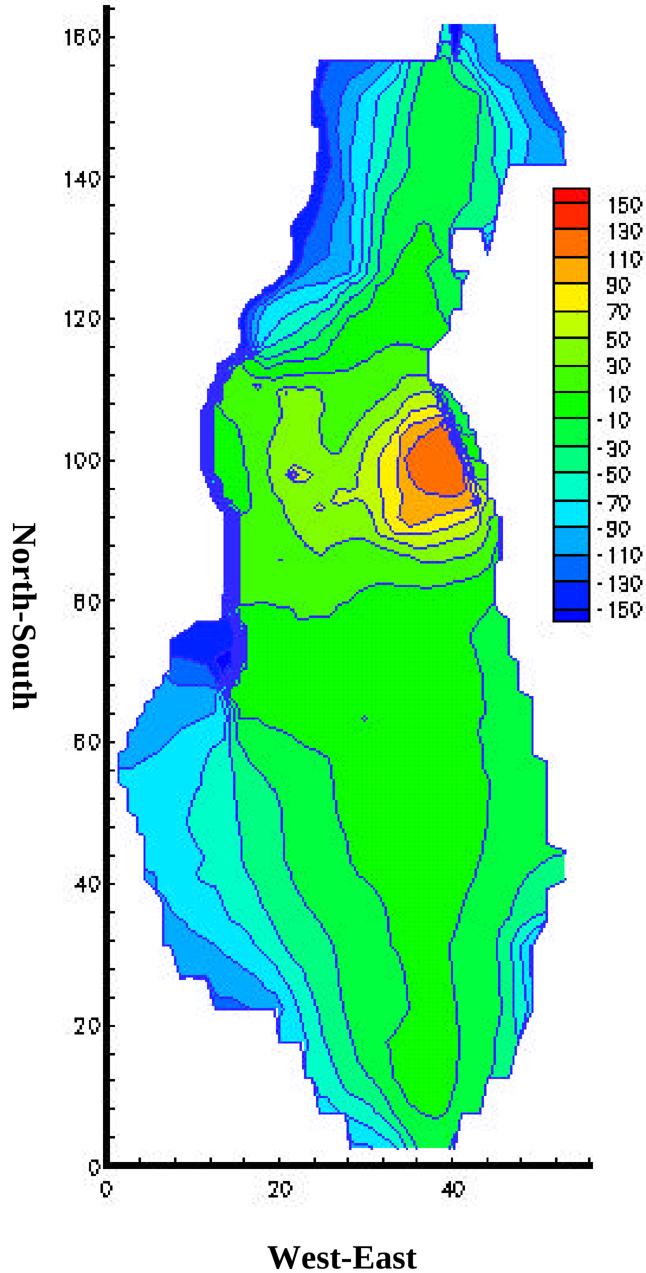


Figure G-6: Simulated year 2000 drawdown in layer 4 based on existing well conditions.

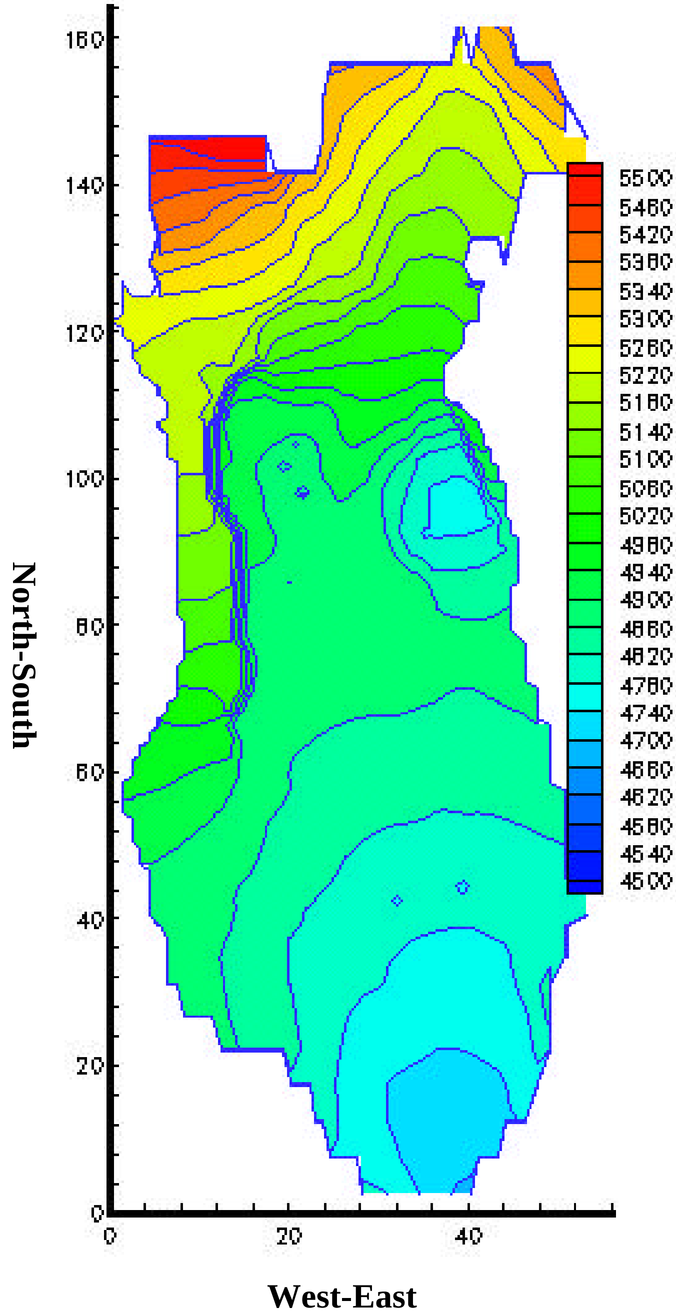


Figure G-7: Simulated year 2040 hydraulic heads in layer 4 based on existing well conditions.

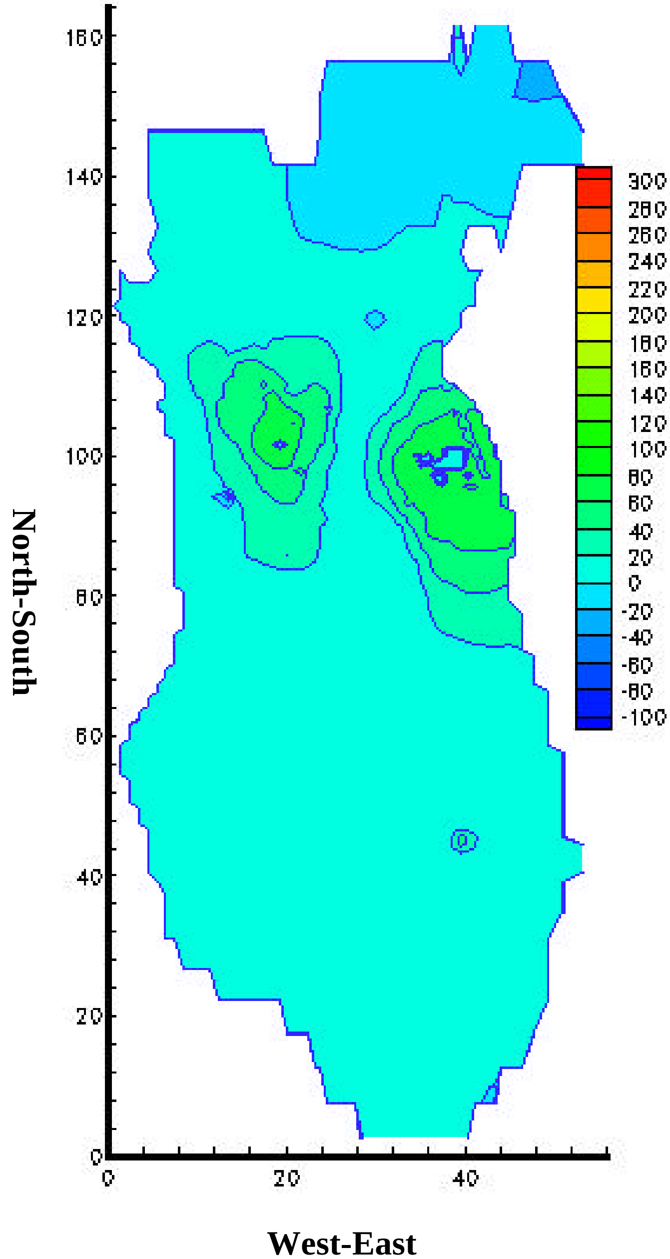


Figure G-8: Simulated year 2040 drawdown in layer 4
based on existing well conditions.

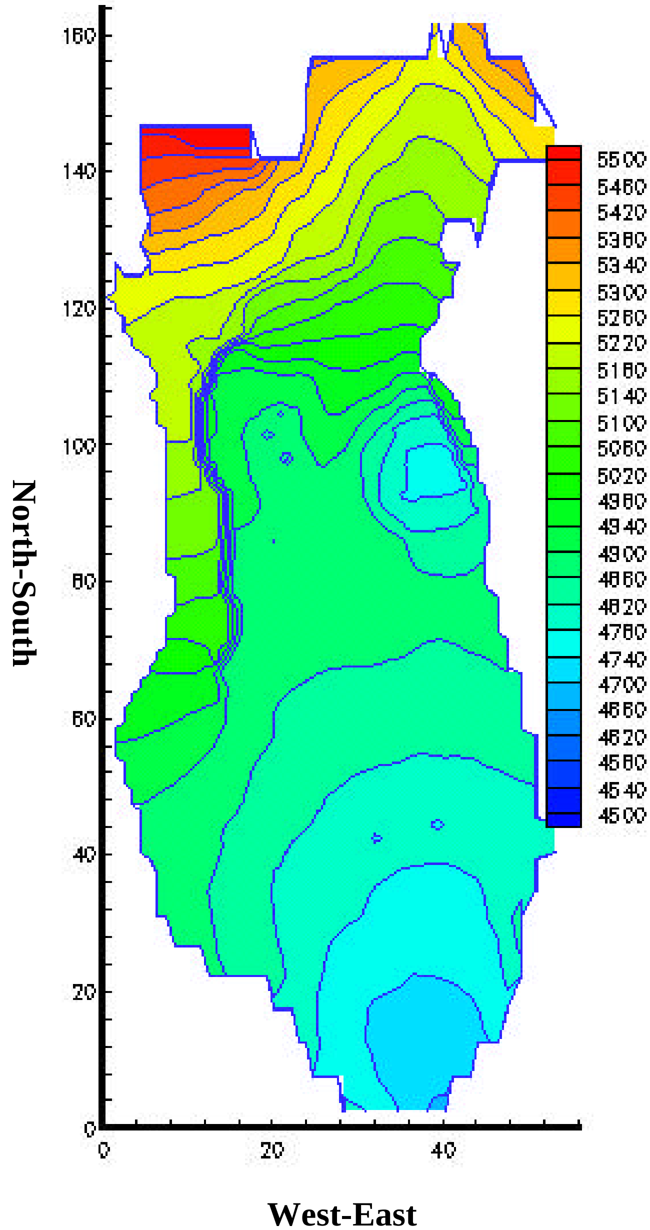


Figure G-9: Simulated year 2040 hydraulic heads in layer 4 based on full use of existing well conditions.

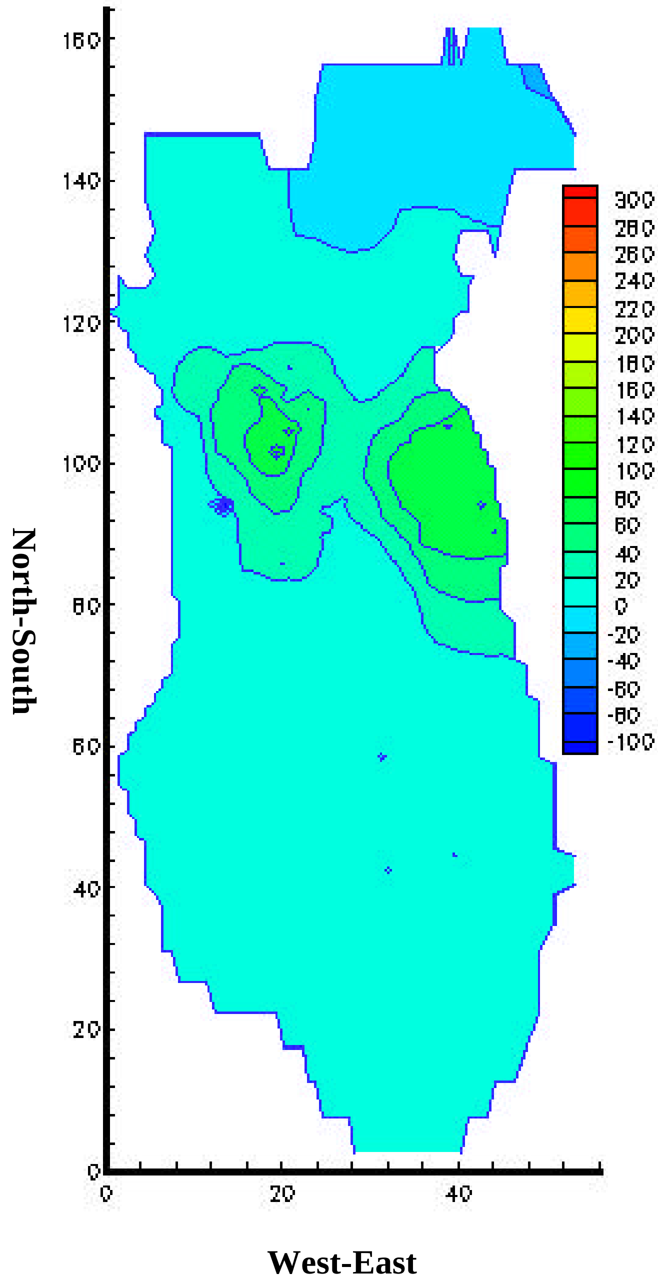


Figure G-10: Simulated year 2040 drawdown in layer 4 based on full use of existing well conditions.

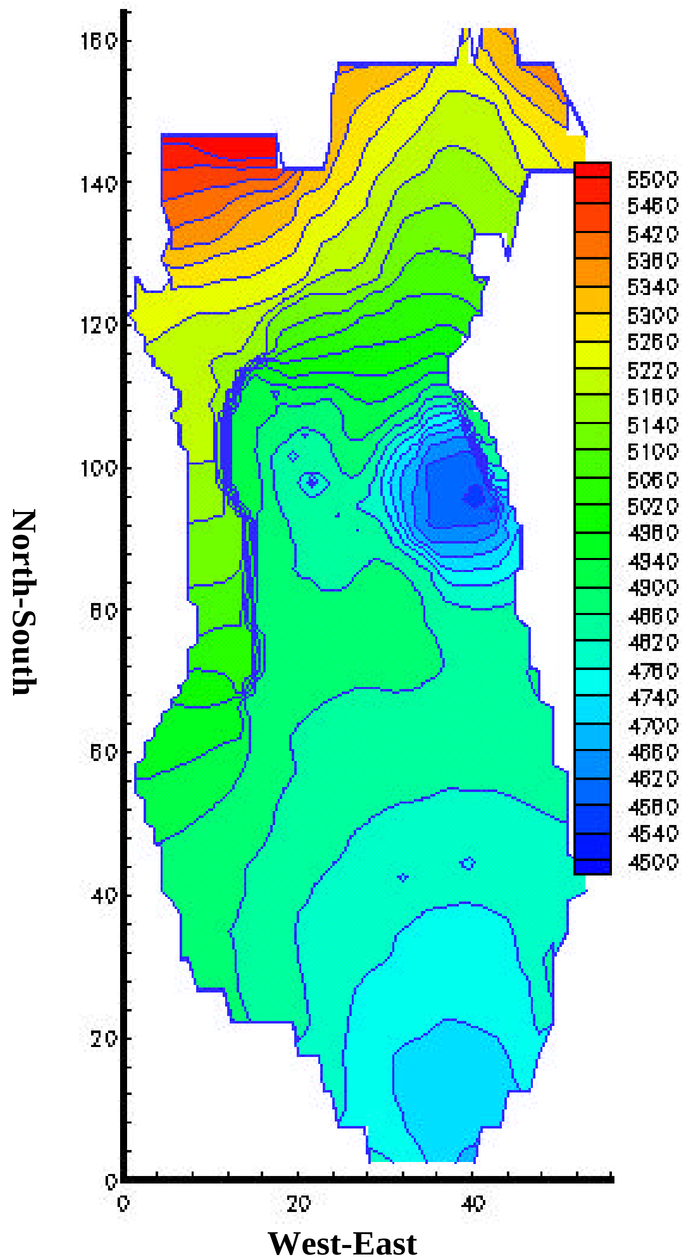


Figure G-11: Simulated year 2040 hydraulic heads in layer 4 based on full use plus 100,000 ac-ft/year in Albuquerque well field.

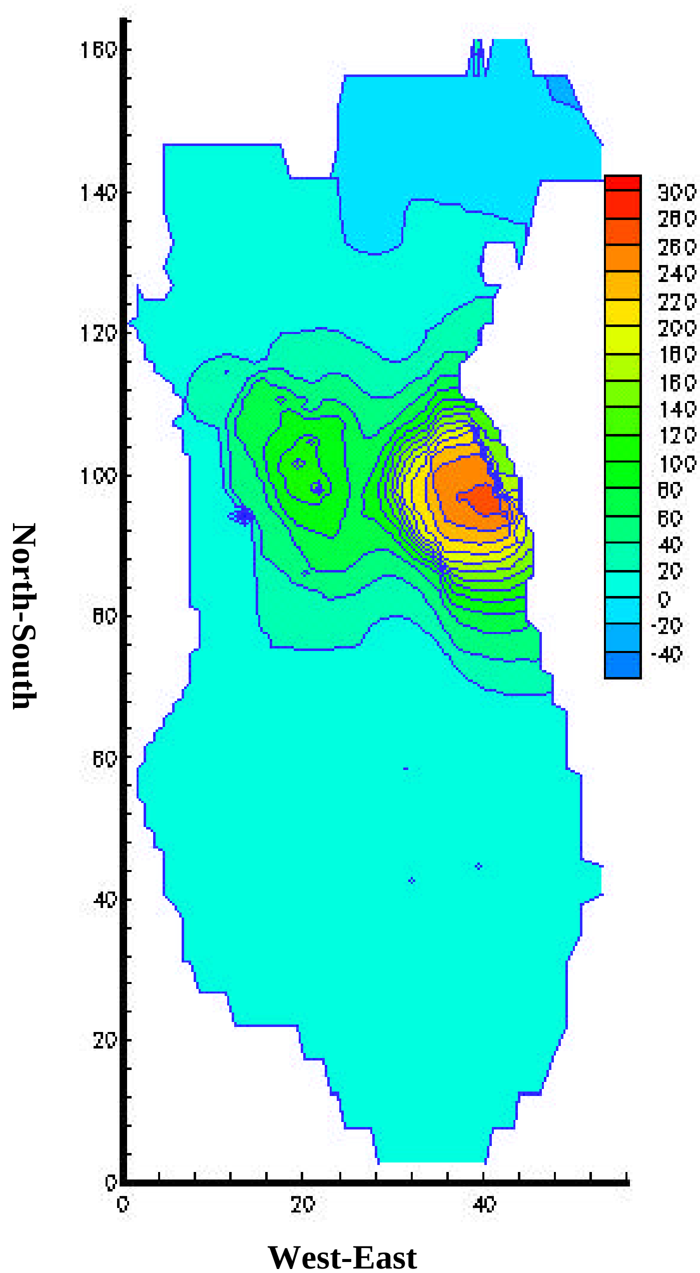


Figure G-12: Simulated year 2040 drawdown in layer 4 based on full use plus 100,000 ac-ft/year in Albuquerque well field.

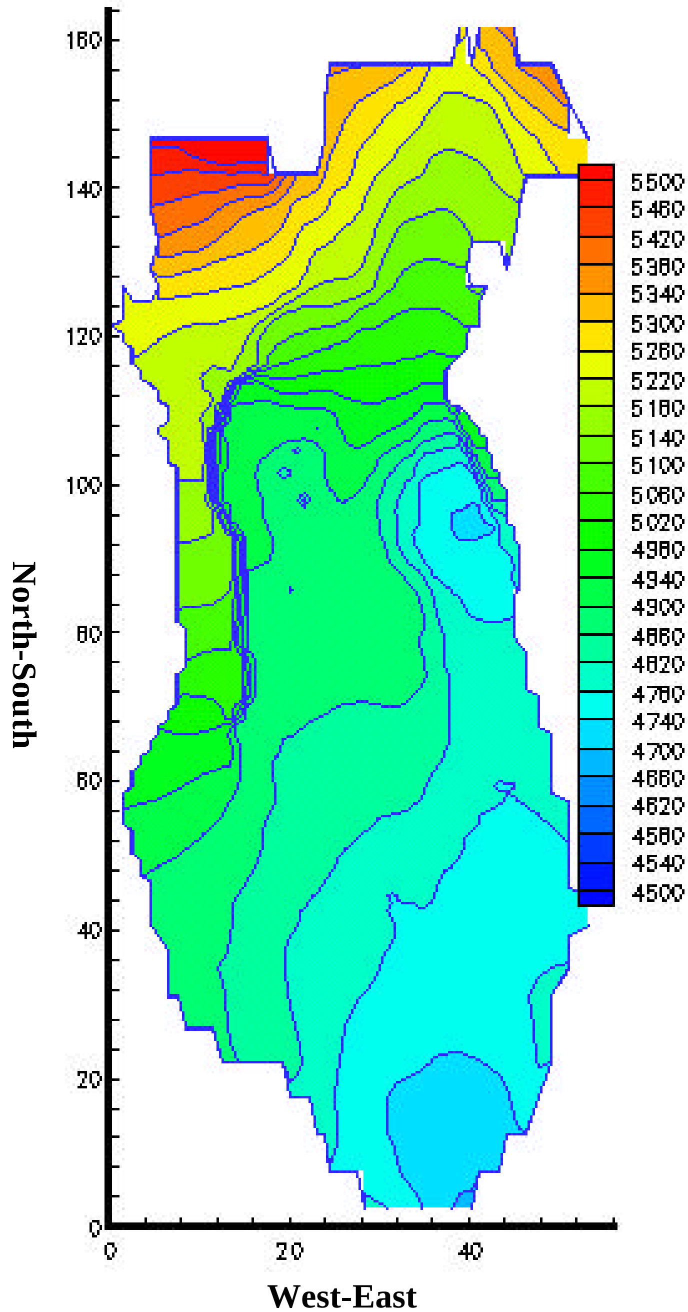


Figure G-13: Simulated year 2040 hydraulic heads in layer 4 based on full use plus 100,000 ac-ft/year in eastside well field.

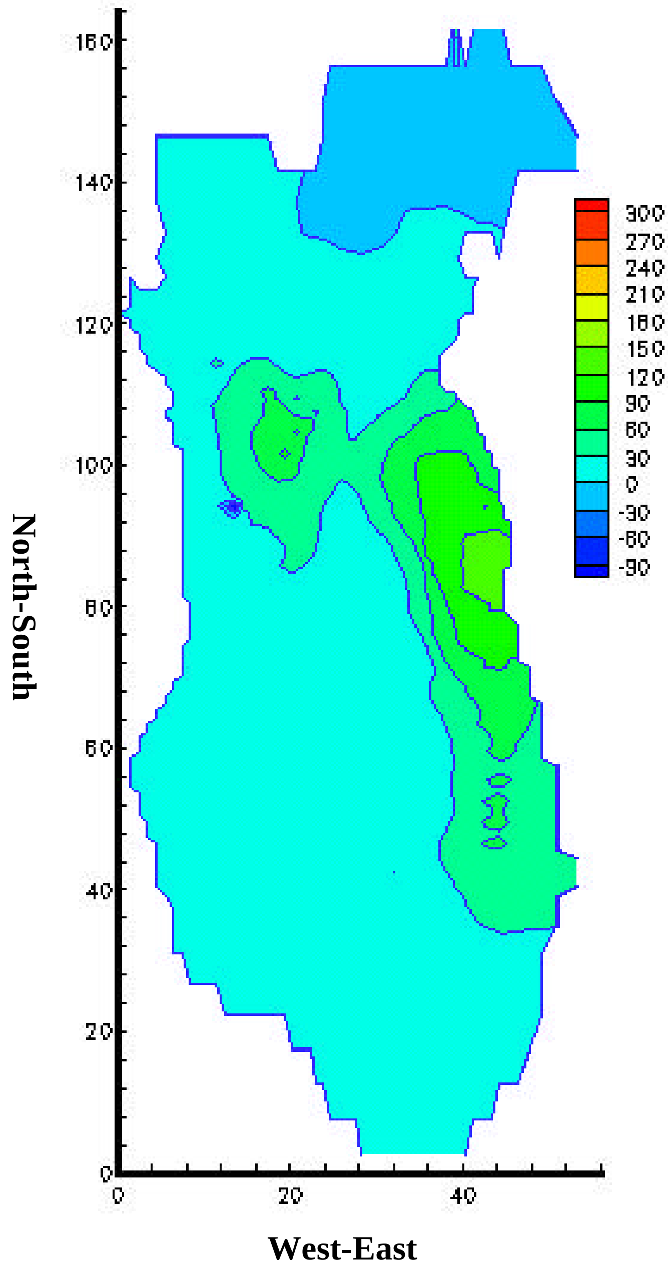


Figure G-14: Simulated year 2040 drawdown in layer 4 based on full use plus 100,000 ac-ft/year in eastside well field.

APPENDIX H
Use of Risk Analysis Model in Water Budget Evaluation

The water budget model developed for the Middle Rio Grande Basin uses a spreadsheet model that represents inflow and outflow terms of the water budget. Water budget terms were evaluated to characterize their variability, and relationships among variables (Appendix F). A risk analysis simulation is used to solve the spreadsheet water budget model for specific outcomes, incorporating the variability of individual water budget terms.

For this analysis, the commercial software, @*Risk*, (Risk Analysis and Simulation Add-In for Microsoft Excel, Version 4.0), is used to conduct the risk analysis simulations, evaluating a range of possibilities for specific water budget input terms. @Risk is distributed by the Palisade Corporation, 31 Decker Road, Newfield, NY, 14867 (http://www.palisade.com).

Water budget terms in the spreadsheet model are described with probability distributions, which specify the full range of possible values and some measure of the likelihood of occurrence for each possible value. To perform the simulation analysis, a Monte Carlo sampling technique was selected to sample from the input probability distributions. With this technique, the outcome of the water budget analysis is recalculated numerous times, each time using a different randomly selected set of values for the probability distributions for the water budget inflow/outflow terms. Through this simulation, all valid combinations of the input variables are sampled, to simulate all possible outcomes. In the simulation analysis for the Middle Rio Grande water budget, 10,000 iterations were specified. The results of the simulation consist of the set of all outcomes from each iteration. Summary descriptive statistics are then generated to describe the modeled outcomes, as well as distributions of selected outcomes. Histograms illustrating the probability distributions for selected outcomes are profiled in Section 5 of this report (Figures 5.18 to 5.24). Summary reports for each simulation analysis are provided in this section. Tables corresponding to these analyses are identified below:

H-1 Annual, Full Basin Simulation, Existing Uses, Year 2000
H-2 Annual, Full Basin Simulation, Existing Uses, Year 2040
H-3 Annual, Full Basin Simulation, Increased Uses, Year 2040
H-4 Annual, Otowi to San Felipe Simulation, Existing Uses, Year 2000
H-5 Annual, San Felipe to Bernardo Simulation, Existing Uses, Year 2000
H-6 Annual, Bernardo to San Acacia Simulation, Existing Uses, Year 2000
H-7 Annual, San Acacia to Elephant Butte Simulation, Existing Uses, Year 2000

Table H-1. Annual, Full Basin Simulation, Existing Uses, Year 2000

Name	Minimum	Mean	Maximum	x_1	p_1	x_2	p_2	x_2-x_1	p_2-p_1
OTOWI Index Supply	296,521.1	964,202.4	2,167,768.0	331,246.6	5%	1,869,913.0	95%	1,538,666.0	90%
San Juan - Chama	75,844.0	75,844.0	75,844.0	75,844.0	5%	75,844.0	95%	0.0	90%
Jemez River	7,748.2	45,868.8	122,723.8	9,430.2	5%	101,356.5	95%	91,926.3	90%
Galisteo Creek	929.5	4,262.9	9,500.6	1,501.6	5%	8,003.5	95%	6,501.9	90%
Rio Puerco	4,756.7	27,085.5	115,422.1	8,696.7	5%	62,494.8	95%	53,798.1	90%
Rio Salado	134.6	10,364.7	100,000.0	1,464.4	5%	32,044.8	95%	30,580.4	90%
Santa Fe River Above Cochiti	9,956.0	9,956.0	9,956.0	9,956.0	5%	9,956.0	95%	0.0	90%
AMAFCA Channels	3,072.1	10,458.5	17,843.9	3,809.4	5%	17,105.8	95%	13,296.3	90%
Total Gaged Tributaries	33,417.5	107,996.3	316,446.7	55,627.1	5%	176,272.2	95%	120,645.0	90%
Ungaged Tributaries, HUC 13020211	215.8	15,547.1	149,999.4	2,194.7	5%	48,067.3	95%	45,872.6	90%
Ungaged Tributaries, HUC 13020203	141.1	10,161.5	98,038.8	1,434.4	5%	31,416.5	95%	29,982.1	90%
Total Ungaged Tributaries	356.9	25,708.7	248,038.2	3,629.1	5%	79,483.8	95%	75,854.7	90%
Net Groundwater Inflow - Above San Acacia	91,589.0	91,589.0	91,589.0	91,589.0	5%	91,589.0	95%	0.0	90%
Net Groundwater Inflow - Below San Acacia	16,500.0	16,500.0	16,500.0	16,500.0	5%	16,500.0	95%	0.0	90%
Total Inflow	531,306.2	1,281,840.0	2,605,791.0	642,702.3	5%	2,188,409.0	95%	1,545,706.0	90%
Obligation	169,017.0	649,831.8	1,762,768.0	188,810.6	5%	1,464,913.0	95%	1,276,102.0	90%
Inflow - Obligation	359,831.4	632,008.6	958,118.4	442,324.8	5%	777,867.6	95%	335,542.8	90%
Cochiti Evaporation	4,806.8	7,829.0	20,178.5	5,515.1	5%	12,347.3	95%	6,832.2	90%
Elephant Butte Evaporation	28,265.9	123,119.1	260,083.0	36,362.3	5%	251,973.0	95%	215,610.7	90%
Depletions Due to GW Pumping (Albuquerque Basin)	94,360.0	94,360.0	94,360.0	94,360.0	5%	94,360.0	95%	0.0	90%
Wastewater Returns	-68,941.0	-68,941.0	-68,941.0	-68,941.0	5%	-68,941.0	95%	0.0	90%
Agricultural ET (Above San Acacia)	174,394.6	195,064.1	209,567.3	182,460.7	5%	204,557.7	95%	22,097.0	90%
Riparian ET (Above San Acacia)	146,612.9	156,051.5	167,496.5	150,770.4	5%	161,394.5	95%	10,624.1	90%
Agricultural ET (Below San Acacia)	51,443.8	56,689.3	61,852.3	53,175.3	5%	59,429.2	95%	6,253.9	90%
Riparian ET (San Acacia to San Marcial)	47,065.6	49,699.2	52,991.0	48,110.7	5%	51,320.9	95%	3,210.3	90%
Effective Precipitation (Cochiti to San Marcial)	-38,535.0	-38,535.0	-38,535.0	-38,535.0	5%	-38,535.0	95%	0.0	90%
Depletions Due to GW Pumping (City of Santa Fe)	2,400.0	2,400.0	2,400.0	2,400.0	5%	2,400.0	95%	0.0	90%
Depletions Due to GW Pumping (Below San Acacia)	2,507.0	2,507.0	2,507.0	2,507.0	5%	2,507.0	95%	0.0	90%
Riparian Consumptive Use (Below San Marcial)	38,238.0	38,238.0	38,238.0	38,238.0	5%	38,238.0	95%	0.0	90%
Net Depletions	502,878.7	618,481.2	777,117.8	531,028.9	5%	748,696.5	95%	217,667.6	90%
Credit/Debit	-375,526.6	13,527.4	421,647.3	-216,084.8	5%	203,142.0	95%	419,226.8	90%

Note: x_i and p_i are the probabilities and corresponding values.

Table H-2. Annual, Full Basin Simulation, Existing Uses, Year 2040

Name	Minimum	Mean	Maximum	x_1	p_1	x_2	p_2	x_2-x_1	p_2-p_1
OTOWI Index Supply	296,513.6	964,202.3	2,164,734.0	331,213.8	5%	1,870,135.0	95%	1,538,921.0	90%
San Juan - Chama	75,844.0	75,844.0	75,844.0	75,844.0	5%	75,844.0	95%	0.0	90%
Jemez River	7,748.5	45,868.6	122,591.7	9,427.3	5%	101,355.3	95%	91,928.0	90%
Galisteo Creek	928.8	4,262.9	9,502.8	1,502.2	5%	8,003.7	95%	6,501.6	90%
Rio Puerco	4,774.7	27,085.5	115,422.0	8,697.5	5%	62,492.7	95%	53,795.3	90%
Rio Salado	132.1	10,364.7	99,999.9	1,463.3	5%	32,042.1	95%	30,578.8	90%
Santa Fe River Above Cochiti	9,956.0	9,956.0	9,956.0	9,956.0	5%	9,956.0	95%	0.0	90%
AMAFCA Channels	3,073.4	10,458.5	17,844.0	3,809.2	5%	17,105.7	95%	13,296.5	90%
Total Gaged Tributaries	33,469.4	107,996.1	325,317.8	55,332.9	5%	178,298.9	95%	122,966.0	90%
Ungaged Tributaries, HUC 13020211	217.1	15,547.1	149,999.9	2,195.4	5%	48,067.9	95%	45,872.5	90%
Ungaged Tributaries, HUC 13020203	141.9	10,161.5	98,039.1	1,434.9	5%	31,416.9	95%	29,982.0	90%
Total Ungaged Tributaries	358.9	25,708.6	248,039.0	3,630.3	5%	79,484.8	95%	75,854.5	90%
Net Groundwater Inflow - Above San Acacia	91,589.0	91,589.0	91,589.0	91,589.0	5%	91,589.0	95%	0.0	90%
Net Groundwater Inflow - Below San Acacia	16,500.0	16,500.0	16,500.0	16,500.0	5%	16,500.0	95%	0.0	90%
Total Inflow	533,788.9	1,281,840.0	2,572,198.0	643,628.3	5%	2,197,198.0	95%	1,553,570.0	90%
Obligation	169,012.8	649,831.8	1,759,734.0	188,791.9	5%	1,465,135.0	95%	1,276,343.0	90%
Inflow - Obligation	358,479.6	632,008.3	1,025,224.0	442,330.8	5%	779,496.8	95%	337,166.0	90%
Cochiti Evaporation	4,786.5	7,829.0	20,195.9	5,515.6	5%	12,346.2	95%	6,830.6	90%
Elephant Butte Evaporation	28,260.8	123,119.3	260,091.6	36,367.0	5%	251,968.1	95%	215,601.1	90%
Depletions Due to GW Pumping (Albuquerque Basin)	122,158.0	122,158.0	122,158.0	122,158.0	5%	122,158.0	95%	0.0	90%
Wastewater Returns	-68,941.0	-68,941.0	-68,941.0	-68,941.0	5%	-68,941.0	95%	0.0	90%
Agricultural ET (Above San Acacia)	174,408.6	195,064.1	209,568.0	182,459.3	5%	204,557.7	95%	22,098.4	90%
Riparian ET (Above San Acacia)	146,618.5	156,051.5	167,491.5	150,771.2	5%	161,395.5	95%	10,624.3	90%
Agricultural ET (Below San Acacia)	51,447.1	56,689.2	61,544.7	53,175.5	5%	59,429.1	95%	6,253.6	90%
Riparian ET (San Acacia to San Marcial)	47,062.7	49,699.2	53,007.2	48,111.2	5%	51,321.2	95%	3,210.0	90%
Effective Precipitation (Cochiti to San Marical)	-38,535.0	-38,535.0	-38,535.0	-38,535.0	5%	-38,535.0	95%	0.0	90%
Riparian Consumptive Use (Below San Marcial)	38,238.0	38,238.0	38,238.0	38,238.0	5%	38,238.0	95%	0.0	90%
Depletions Due to GW Pumping (City of Santa Fe)	2,400.0	2,400.0	2,400.0	2,400.0	5%	2,400.0	95%	0.0	90%
Depletions Due to GW Pumping (Below San Acacia)	2,507.0	2,507.0	2,507.0	2,507.0	5%	2,507.0	95%	0.0	90%
Net Depletions	528,754.6	646,279.3	800,750.9	558,836.1	5%	775,896.4	95%	217,060.3	90%
Credit/Debit	-392,088.0	-14,271.1	398,399.5	-247,699.9	5%	175,332.7	95%	423,032.5	90%

Note: x_i and p_i are the probabilities and corresponding values.

Table H-3. Annual, Full Basin Simulation, Increased Uses, Year 2040

Name	Minimum	Mean	Maximum	x_1	p_1	x_2	p_2	x_2-x_1	p_2-p_1
OTOWI Index Supply	296,511.5	964,202.2	2,164,012.0	331,214.1	5%	1,870,017.0	95%	1,538,803.0	90%
San Juan - Chama	75,844.0	75,844.0	75,844.0	75,844.0	5%	75,844.0	95%	0.0	90%
Jemez River	7,748.5	45,868.8	122,796.5	9,430.2	5%	101,356.6	95%	91,926.3	90%
Galisteo Creek	928.8	4,262.9	9,504.6	1,502.0	5%	8,002.3	95%	6,500.2	90%
Rio Puerco	4,762.4	27,085.5	115,422.0	8,697.2	5%	62,493.3	95%	53,796.1	90%
Rio Salado	122.0	10,364.7	99,999.8	1,463.8	5%	32,042.0	95%	30,578.2	90%
Santa Fe River Above Cochiti	9,956.0	9,956.0	9,956.0	9,956.0	5%	9,956.0	95%	0.0	90%
AMAFCA Channels	3,072.6	10,458.5	17,844.9	3,810.0	5%	17,105.0	95%	13,295.0	90%
Total Gaged Tributaries	32,735.6	107,996.4	341,964.6	55,896.6	5%	176,867.6	95%	120,971.0	90%
Ungaged Tributaries, HUC 13020211	191.1	15,547.2	149,998.6	2,196.3	5%	48,067.9	95%	45,871.6	90%
Ungaged Tributaries, HUC 13020203	124.9	10,161.5	98,038.3	1,435.5	5%	31,416.9	95%	29,981.4	90%
Total Ungaged Tributaries	315.9	25,708.7	248,036.9	3,631.8	5%	79,484.8	95%	75,853.0	90%
Net Groundwater Inflow - Above San Acacia	91,589.0	91,589.0	91,589.0	91,589.0	5%	91,589.0	95%	0.0	90%
Net Groundwater Inflow - Below San Acacia	16,500.0	16,500.0	16,500.0	16,500.0	5%	16,500.0	95%	0.0	90%
Total Inflow	525,140.8	1,281,840.0	2,610,863.0	641,433.4	5%	2,185,596.0	95%	1,544,163.0	90%
Obligation	169,011.6	649,831.4	1,759,012.0	188,792.0	5%	1,465,017.0	95%	1,276,225.0	90%
Inflow - Obligation	353,312.7	632,008.8	989,688.5	441,773.0	5%	778,515.2	95%	336,742.2	90%
Cochiti Evaporation	4,807.9	7,829.0	20,173.0	5,515.2	5%	12,346.2	95%	6,831.1	90%
Elephant Butte Evaporation	28,265.1	123,119.1	260,088.8	36,367.1	5%	251,967.0	95%	215,599.9	90%
Depletions Due to GW Pumping (Albuquerque Basin)	218,076.0	218,076.0	218,076.0	218,076.0	5%	218,076.0	95%	0.0	90%
Wastewater Returns	-149,315.0	-149,315.0	-149,315.0	-149,315.0	5%	-149,315.0	95%	0.0	90%
Agricultural ET (Above San Acacia)	174,394.1	195,064.1	209,568.0	182,459.7	5%	204,557.7	95%	22,098.0	90%
Riparian ET (Above San Acacia)	146,630.5	156,051.5	167,491.4	150,770.0	5%	161,394.4	95%	10,624.4	90%
Agricultural ET (Below San Acacia)	51,444.6	56,689.2	61,830.5	53,175.3	5%	59,429.5	95%	6,254.2	90%
Riparian ET (San Acacia to San Marcial)	47,063.1	49,699.2	52,992.9	48,111.1	5%	51,320.9	95%	3,209.8	90%
Effective Precipitation (Cochiti to San Marcial)	-38,535.0	-38,535.0	-38,535.0	-38,535.0	5%	-38,535.0	95%	0.0	90%
Riparian Consumptive Use (Below San Marcial)	38,238.0	38,238.0	38,238.0	38,238.0	5%	38,238.0	95%	0.0	90%
Depletions Due to GW Pumping (City of Santa Fe)	2,400.0	2,400.0	2,400.0	2,400.0	5%	2,400.0	95%	0.0	90%
Depletions Due to GW Pumping (Below San Acacia)	2,507.0	2,507.0	2,507.0	2,507.0	5%	2,507.0	95%	0.0	90%
Net Depletions	536,320.3	661,823.2	816,042.9	574,588.1	5%	791,380.3	95%	216,792.2	90%
Credit/Debit	-431,490.5	-29,814.4	380,558.2	-262,638.1	5%	159,836.1	95%	422,474.2	90%

Note: x_i and p_i are the probabilities and corresponding values.

Table H-4. Annual, Otowi to San Felipe Simulation, Existing Uses, Year 2000

Name	Minimum	Mean	Maximum	x_1	p_1	x_2	p_2	x_2-x_1	p_2-p_1
Rio Grande Flow at OTOWI	296,507.8	964,207.5	2,157,349.0	331,161.0	5%	1,867,298.0	95%	1,536,137.0	90%
San Juan - Chama	75,844.0	75,844.0	75,844.0	75,844.0	5%	75,844.0	95%	0.0	90%
Galisteo Creek	932.8	4,262.7	9,469.9	1,495.4	5%	7,989.8	95%	6,494.4	90%
Santa Fe River Above Cochiti	9,956.0	9,956.0	9,956.0	9,956.0	5%	9,956.0	95%	0.0	90%
Net Groundwater Inflow	17,639.4	17,639.4	17,639.4	17,639.4	5%	17,639.4	95%	0.0	90%
Total Inflow	401,587.3	1,071,910.0	2,265,971.0	440,396.6	5%	1,976,852.0	95%	1,536,456.0	90%
Cochiti Evaporation	4,897.2	7,828.4	19,771.6	5,510.9	5%	12,316.2	95%	6,805.3	90%
Depletions Due to GW Pumping (Albuquerque Basin)	636.3	636.3	636.3	636.3	5%	636.3	95%	0.0	90%
Depletions Due to GW Pumping (City of Santa Fe)	2,400.0	2,400.0	2,400.0	2,400.0	5%	2,400.0	95%	0.0	90%
Effective Precipitation	-2,669.0	-2,669.0	-2,669.0	-2,669.0	5%	-2,669.0	95%	0.0	90%
Agricultural ET (URGWOM Reach 1)	10,220.6	10,220.6	10,220.6	10,220.6	5%	10,220.6	95%	0.0	90%
Riparian ET (URGWOM Reach 1)	20,528.6	20,528.6	20,528.6	20,528.6	5%	20,528.6	95%	0.0	90%
Net Depletions	36,013.7	38,944.9	50,888.1	36,627.4	5%	43,432.7	95%	6,805.3	90%
Difference - Rio Grande Flow at San Felipe	358,644.3	1,032,965.0	2,229,044.0	401,704.5	5%	1,938,762.0	95%	1,537,057.0	90%

Note: x_i and p_i are the probabilities and corresponding values.

Table H-5. Annual, San Felipe to Bernardo Simulation, Existing Uses, Year 2000

Name	Minimum	Mean	Maximum	x_1	p_1	x_2	p_2	x_2-x_1	p_2-p_1
Rio Grande at San Felipe (Output from Reach 1)	359,420.40	1,033,215.00	2,230,256.00	402,627.80	5%	1,938,506.00	95%	1,535,878.00	90%
Jemez River	7,747.85	45,868.78	122,693.60	9,427.34	5%	101,357.10	95%	91,929.73	90%
AMAFCA Channels	3,072.57	10,458.50	17,843.69	3,809.66	5%	17,105.40	95%	13,295.75	90%
Ungaged Tributaries, HUC 13020203	71.00	5,080.77	49,019.60	717.26	5%	15,708.24	95%	14,990.98	90%
Net Groundwater Inflow	63,655.71	63,655.71	63,655.71	63,655.71	5%	63,655.71	95%	0.00	90%
Total Inflow	442,783.00	1,158,279.00	2,410,219.00	526,284.50	5%	2,067,181.00	95%	1,540,897.00	90%
Wastewater Returns	-67,741.00	-67,741.00	-67,741.00	-67,741.00	5%	-67,741.00	95%	0.00	90%
Depletions Due to GW Pumping (Albuquerque Basin)	93,699.43	93,699.43	93,699.43	93,699.43	5%	93,699.43	95%	0.00	90%
Effective Precipitation	-23,897.00	-23,897.00	-23,897.00	-23,897.00	5%	-23,897.00	95%	0.00	90%
Agricultural ET (URGWOM Reach 2)	0.00	0.00	0.00	0.00	5%	0.00	95%	0.00	90%
Riparian ET (URGWOM Reach 2)	9,623.84	9,623.84	9,623.84	9,623.84	5%	9,623.84	95%	0.00	90%
Agricultural ET (URGWOM Reach 3)	27,468.04	27,468.04	27,468.04	27,468.04	5%	27,468.04	95%	0.00	90%
Riparian ET (URGWOM Reach 3)	33,812.30	33,812.30	33,812.30	33,812.30	5%	33,812.30	95%	0.00	90%
Agricultural ET (URGWOM Reach 4)	152,396.30	152,396.30	152,396.30	152,396.30	5%	152,396.30	95%	0.00	90%
Riparian ET (URGWOM Reach 4)	63,921.44	63,921.44	63,921.44	63,921.44	5%	63,921.44	95%	0.00	90%
Net Depletions	289,283.40	289,283.40	289,283.40	289,283.40	5%	289,283.40	95%	0.00	90%
Difference - Rio Grande Flow at San Bernardo	153,499.60	868,995.30	2,120,936.00	237,001.10	5%	1,777,898.00	95%	1,540,897.00	90%

Note: x_i and p_i are the probabilities and corresponding values.

Table H-6. Annual, Bernardo to San Acacia Simulation, Existing Uses, Year 2000

Name	Minimum	Mean	Maximum	x_1	p_1	x_2	p_2	x_2-x_1	p_2-p_1
Rio Grande at San Bernardo (Output from Reach 2)	155,692.50	869,082.30	2,060,133.00	231,086.30	5%	1,767,859.00	95%	1,536,773.00	90%
Rio Puerco	4,764.45	27,085.43	115,422.00	8,698.60	5%	62,494.58	95%	53,795.98	90%
Rio Salado	149.62	10,364.73	99,999.87	1,463.57	5%	32,042.00	95%	30,578.43	90%
Ungaged Tributaries, HUC 13020203	10.87	1,016.15	9,803.92	143.47	5%	3,141.04	95%	2,997.57	90%
Net Groundwater Inflow	10,082.74	10,082.74	10,082.74	10,082.74	5%	10,082.74	95%	0.00	90%
Total Inflow	181,313.10	917,631.30	2,180,619.00	280,413.10	5%	1,818,888.00	95%	1,538,475.00	90%
Depletions Due to GW Pumping (Albuquerque Basin)	26.46	26.46	26.46	26.46	5%	26.46	95%	0.00	90%
Effective Precipitation	-2,576.00	-2,576.00	-2,576.00	-2,576.00	5%	-2,576.00	95%	0.00	90%
Agricultural ET (URGWOM Reach 5)	1,490.92	1,490.92	1,490.92	1,490.92	5%	1,490.92	95%	0.00	90%
Riparian ET (URGWOM Reach 5)	27,191.49	27,191.49	27,191.49	27,191.49	5%	27,191.49	95%	0.00	90%
Net Depletions	26,132.87	26,132.87	26,132.87	26,132.87	5%	26,132.87	95%	0.00	90%
Difference - Rio Grande Flow at San Acacia	155,180.20	891,498.40	2,154,486.00	254,280.20	5%	1,792,755.00	95%	1,538,475.00	90%

Note: x_i and p_i are the probabilities and corresponding values.

Table H-7. Annual, San Acacia to Elephant Butte Simulation, Existing Uses, Year 2000

Name	Minimum	Mean	Maximum	x_1	p_1	x_2	p_2	x_2-x_1	p_2-p_1
Rio Grande at San Acacia (Output from Reach 3)	158,946.6	891,520.4	2,097,910.0	253,797.2	5%	1,797,151.0	95%	1,543,354.0	90%
Ungaged Tributaries, HUC 13020211	214.7	15,547.1	149,999.3	2,195.5	5%	48,058.5	95%	45,863.0	90%
Ungaged Tributaries, HUC 13020203	56.1	4,064.6	39,215.5	574.0	5%	12,564.3	95%	11,990.3	90%
Net Groundwater Inflow - Below San Acacia	16,500.0	16,500.0	16,500.0	16,500.0	5%	16,500.0	95%	0.0	90%
Total Inflow	178,697.9	927,632.1	2,174,343.0	285,357.5	5%	1,833,246.0	95%	1,547,889.0	90%
Depletions Due to GW Pumping (Below San Acacia)	2,507.0	2,507.0	2,507.0	2,507.0	5%	2,507.0	95%	0.0	90%
Elephant Butte Evaporation	28,266.9	123,118.9	260,093.9	36,352.5	5%	251,977.5	95%	215,625.0	90%
Socorro Wastewater	-1,200.0	-1,200.0	-1,200.0	-1,200.0	5%	-1,200.0	95%	0.0	90%
Effective Precipitation	-9,355.0	-9,355.0	-9,355.0	-9,355.0	5%	-9,355.0	95%	0.0	90%
Agricultural ET (URGWOM Reach 6)	56,520.2	56,520.2	56,520.2	56,520.2	5%	56,520.2	95%	0.0	90%
Riparian ET (URGWOM Reach 6)	49,451.6	49,451.6	49,451.6	49,451.6	5%	49,451.6	95%	0.0	90%
Riparian Consumptive Use (Below San Marcial)	15,372.0	15,372.0	15,372.0	15,372.0	5%	15,372.0	95%	0.0	90%
Net Depletions	126,190.7	221,042.7	358,017.7	134,276.3	5%	349,901.2	95%	215,624.9	90%
Difference - Rio Grande Flow at Elephant Butte Dam	-168,963.9	706,589.5	2,024,592.0	46,574.0	5%	1,620,355.0	95%	1,573,781.0	90%

Note: x_i and p_i are the probabilities and corresponding values.