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WATER SUPPLY STUDY
JEMEZ Y SANGRE WATER PLANNING REGION
NEW MEXICO

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EXECUTIVE SUMMARY

This water supply study constituted one of a series of steps that the Jemez y Sangre Water Planning Council is taking to provide for management of the water supplies in its planning region. Activities simultaneous to and subsequent to the water supply assessment will make it possible for the Council to produce a regional water management plan, which will be one of several water plans being prepared for regions in New Mexico. The regional water planning process is overseen by the New Mexico Interstate Stream Commission.

Water supply in the Jemez y Sangre Planning Region was examined through a systematic evaluation of regional surface-water, groundwater, and weather processes. The planning region, which is located in the Española geologic basin, was divided into ten sub-basins to facilitate a more detailed evaluation of water resources on a sub-basinal scale. Both surface-water and groundwater flow budgets under recent conditions were developed for the sub-basins, which were, in turn, useful in summarizing the hydrology of the region as a whole. Because of the considerable uncertainty in many of the components that make up the respective budgets, the determination of final inflow and outflow quantities required numerous iterations. The iterative process not only involved the balancing of flows computed for each medium (surface water and groundwater) and sub-basin, but also necessitated the coordination of flows between media and between sub-basins.

The final groundwater budget components were compared to state-administered water rights in a cursory manner to provide some measure of the capacity of the planning region's existing water supply to meet water claims. These comparisons were not comprehensive, partly because of the inherent differences that exist between state water rights and federal rights. The latter are generally in the form of Indian Pueblo water rights, which, though mostly unquantified, have priority over state-administered rights. Because Pueblo rights have not been fully quantified, it is difficult to ascertain the extent to which the planning's region water supply is capable of supporting water claims, or the total extent to which water rights are being used.

Because of the inherent uncertainty and variability in budget components for both surface water and groundwater supplies, quantitative ranges of values for the individual components were developed. These ranges were not intended to express specific uncertainty bounds. Rather they were developed to provide feasible estimates of minimum and maximum values that would be observed if budget components could be directly measured. The logic applied in the resulting uncertainty analyses helped to identify which components were supported by field measurements, and which were most poorly understood.

The quality of both surface water and groundwater in the sub-basins was also investigated so that planning efforts could take into account any facets of water chemistry that might prevent water development, such as contaminated sites. The investigation revealed that, in general, water quality in both surface water and regional groundwater is very good to excellent. Scattered cases do exist, however, where surface water quality is

adversely affected by some form of wastewater discharge, and some drinking water standards are exceeded in local groundwater, either as a result of natural effects of geologic media on groundwater chemistry or contamination from chemical spills, septic tank effluent, leaking underground storage tanks, or similar human-related phenomena.

In addition to the water budgets prepared for the sub-basins, a great deal of supporting data are provided in this report so that the reader can develop an understanding of the various type of information that were used in the budget development process. These data are presented in text, tabular form, and graphical form, both throughout the report text and in several appendices. Many of the quantitative analyses conducted for this study were performed in an ArcView geographic information system that was developed specifically for the planning region. The database and the interactive computer graphics features in the project-specific ArcView package are provided to the Council along with this report as another means of planning for future water needs.

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JEMEZ Y SANGRE WATER PLANNING REGION, NEW MEXICO
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LIST OF ABRREVIATIONS AND ACRONYMS

afy	acre-feet/year
amsl	above mean sea level
BIA	Bureau of Indian Affairs
cfs	cubic feet per second
CIR	consumptive irrigation requirement
Corps	U.S. Army Corps of Engineers
DBS&A	Daniel B. Stephens & Associates
DE&S	Duke Engineering & Services
DEM	Digital Elevation Model
DO	dissolved oxygen
EC	electrical conductance
EDAC	Earth Data Analysis Center
ENSO	El Nino Southern Oscillation
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
ft	foot/feet
ft^2/day	square feet per day
FWS	free water surface
GIS	geographic information system
gpd	gallons per day
ISC	Interstate Stream Commission
JySWP	Jemez y Sangre Water Planning
LANL	Los Alamos National Laboratory
lb/day	pound(s) per day
LUST	leaking underground storage tank
MCL	maximum contaminant level
mgd	million gallons per day
mg/L	milligrams per liter
mi^2	square mile(s)
NAWQA	National Water Quality Assessment
NCDC	National Climatic Data Center
NM	New Mexico
NMDWB	New Mexico Drinking Water Bureau
NMED	New Mexico Environment Department
NMED DP	NMED Discharge Plans
NM EID	New Mexico Environmental Improvement Divsision (now NMED)
NMWQCC	New Mexico Water Quality Control Commission
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NWIS	National Water Information System
OSE	Office of the State Engineer
PDSI	Palmer Drought Severity Index

LIST OF ABBREVIATIONS AND ACRONYMS, Concluded

PET	potential evapotranspiration
PVID	Pojoaque Valley Irrigation District
SWQB	Surface Water Quality Bureau
TDS	Total dissolved solids
TMDL	total maximum daily load
TSS	total suspended solids
URGWOM	Upper Rio Grande Water Operations Model
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WWTP	Waste Water Treatment Plant

1.0 INTRODUCTION

This report presents the results of a water supply study for the Jemez y Sangre Water Planning Region (study region) in the State of New Mexico. The study was conducted on behalf of the Jemez y Sangre Water Planning (JySWP) Council. The data and discussions presented herein represent the first phase in a series of activities that the Council is engaging in to provide long-term planning of water resources.

1.1 Study Purpose

The JySWP Council has begun a multi-phase program that will lead to informed management of the water resources within its study area. This effort is being made as one of several water plans that are being prepared for regions in New Mexico (NM). The regional water planning process is overseen by the NM Interstate Stream Commission (NM ISC) and the steps involved in the planning are described in a Regional Water Planning Handbook (NM ISC, 1994).

Under the various phases of the regional water planning process, the Council is seeking to address numerous concerns, ranging from the current supply of regional water resources to future water demands, and the pros and cons of various alternatives put forth to meet those demands. To address questions arising from such concerns, the water planners must make use of recent, technically sound data collected from the region. However, it is important that factors other than scientific data are also taken into account; legal issues and the general welfare of the public must also be included in the Council's considerations.

Before all technical, legal, and general welfare matters can be included in the Council's deliberations, the existing data must be examined to answer an initial question: What is the water supply available to the region? Thus this first phase of work was conducted to help develop an answer to this question. As with any well-conceived water planning initiative, the answer is to be found in scientifically defensible water budgets for each of the sub-basins comprising the study area. These water budgets not only present estimates of the long-term inflows and outflows of water from the region, but also provide some measure of the water stored within the region, and how that storage is potentially influenced by stresses on the existing hydrologic system.

To better plan for the foreseeable future, it is important for the Council to not only understand the quantities of water resources, but also the quality of those waters. Moreover, it is imperative that the Council is aware of how the numerous hydrologic and chemical processes occurring in the several basins comprising the region are related geographically. Effective planning cannot be made on the basis of numbers alone; the numbers must be associated with real features of the region. Accordingly, one of the major purposes of this study was to present geospatial aspects of the hydrologic and water quality information existing for the study region. From the outset of the study, it was intended that this would be accomplished using the geographic information system (GIS) software ArcView.

1.2 Study Region

The JySWP region, which encompasses approximately 1892 square miles (mi^2), is located in north-central NM. Figure 1-1 shows the study region boundary. The most dominant local hydrologic feature is the Rio Grande, which traverses the study region in a north-south direction. As Figure 1-1 indicates, the study region extends in a north-south direction from Embudo on the main stem Rio Grande to Cochiti Reservoir, and in an east-west direction from the crest of the Sangre de Cristo Mountains to the Jemez Mountains on the western end of the Pajarito Plateau near Los Alamos, NM.

Numerous tributaries to the Rio Grande occur within project boundaries. Most of these tributaries are associated with much smaller drainage areas than the cumulative drainage area for the Rio Grande within the study region. However, a relative large watercourse, the Rio Chama, is tributary to the Rio Grande along the northwest boundary of the planning region. Though the Rio Chama is not included in the planning region, it clearly plays a significant role in the water budget for the entire region.

The planning region lies mostly within a geologic structural basin known as the Española Basin (Kelley, 1977; 1978). The basin is an expansion of the better known Española Valley, which is centered on the city of Española near the confluence of the Rio Grande and Rio Chama. A small portion of the study region near its southern extent is formally considered to be part of the Albuquerque geologic basin (Kelley, 1977).

1.2.1 Sub-basins

Prior to this Phase 1 study, the region was divided into ten sub-basins. Their names, using the order in which they approximately occur moving from north to south, are: (1) Velarde, (2) Santa Cruz, (3) Santa Clara, (4) Los Alamos, (5) Pojoaque-Nambe, (6) Tesuque, (7) Caja del Rio, (8) Santa Fe River, (9) North Galisteo Creek, and (10) South Galisteo Creek. The location of each is presented in Figure 1-1. Inspection of the figure shows that, for the most part, the sub-basin boundaries are aligned with surface water flow divides; however, a few small portions of some of the borders conform to other boundaries, such as county lines. In some cases, the sub-basins encompass drainages that essentially empty into the Rio Grande via a single tributary to the mainstem river; in others, several creeks are tributary to a substantially long reach of the Rio Grande. Because the sub-basins are hydrologically interrelated, their geospatial relationships are of critical importance to understanding how they can best be managed in the future using a full, regional perspective.

1.2.2 Affected Counties and Communities

The JySWP region encompasses most of Santa Fe County, all of Los Alamos County, and a small part of the southern half of Rio Arriba County. In addition, two very small portions of Sandoval County are located within the region's borders. The first of these occurs near Cochiti Reservoir on the south end of the planning region, and the second encompasses a small section of the Santa Clara sub-basin near the region's northwest border. Cities in the study area include Santa Fe in Santa Fe County, Española in Rio

Arriba County, and Los Alamos in Los Alamos County. Smaller communities include towns and villages such as Pojoaque, Galisteo, Truchas, White Rock, and Golden. All or part of seven Pueblos occur within the water planning region: (1) Cochiti, (2) Nambe, (3) Pojoaque, (4) Santa Clara, (5) San Ildefonso, (6) San Juan, and (7) Tesuque.

1.3 Objectives

There were basically two final products to be provided under this study: (1) well-founded water budgets for the sub-basins comprising the study region, and (2) realistic appraisals of the water quality in the region. Several secondary objectives were also striven for in the process of developing these two products. These included the tabulation of, and various means of illustrating, hydrologic and water quality parameters descriptive of the region. Descriptions of current conditions in the planning area were to be derived using both available data and estimates of certain hydrologic variables using alternative techniques. In addition to presenting information about existing conditions in the region, Duke Engineering & Services (DE&S) also sought to identify any trends or cycles that might have bearing on the long-term water supply. An underlying objective of all activities was to develop and present study findings using procedures and formats that comply with Regional Water Planning Guidelines established by the NM ISC (1994).

1.4 Project Organization

The water supply study was divided into seven different tasks to coincide with specific requests made by the JySWP Council. Task 1 comprised an initial data compilation effort that involved the review of existing databases, the collection and perusal of reports on the study region, and communication with various government agencies and other entities familiar with the regional geology and hydrology. Task 2 consisted of summarizing and statistically analyzing historical weather data, which led to a brief characterization of the region's climate in terms of precipitation quantities, temperature values, evaporation, and drought frequency. The results of Task 2 had some bearing on the subsequent Task 3, which dealt with the quantification of surface water supplies, both within each of the study sub-basins and cumulatively for the region as a whole. Task 3 was oriented toward determining salient river, stream, and reservoir characteristics; preparing surface water budgets; and identifying processes that potentially influence the future management of surface-water sources.

Task 4 focused on the quality (water chemistry) of regional surface water supplies, and particular attention was paid to identifying potential pollution sources for rivers and streams. Task 5 comprised the groundwater equivalent to Task 3, wherein estimates of recharge, discharge, and subsurface storage were developed as input to sub-basin groundwater budgets. Characterization of regional geology and hydrogeologic units was instrumental to explaining the resulting groundwater basin budgets. The background inorganic chemistry of groundwater was assessed under Task 6, and local areas of either existing or potential groundwater contamination were identified. Under Task 7, DE&S has prepared both (1) a final report on the activities conducted per Tasks 1-6 and the results therefrom, and (2) several graphical and tabular summaries of the data examined in the study. The first of these products is the report presented here, and the second is

largely provided in the form of results from the ArcView package prepared for the JySWP Council's use. GIS-based study results, as prepared in ArcView, are discussed in more detail in Section 1.6.

It is important to note that the study approach applied to Task 3 (surface-water supply) and Task 5 (groundwater supply) was notably different from the approach used in Tasks 2, 4, and 6. Specifically, both water supply tasks were focused on the estimation of water budgets of each sub-basin, whereas the remaining tasks involving meteorology and water quality were more oriented toward describing the general, regional character of these issues. As a consequence, the reader will find that the chapters describing water supply (Chapters 3 and 5) include a number of basin-specific descriptions, and those used to describe meteorology and water quality (Chapters 2, 4, and 6) cover much larger areas. Features of specific sub-basins regarding weather and water chemistry are usually only highlighted when specific conditions occur within them that call for some distinction.

During the project, attempts were made to hold regular meetings between DE&S and members of a technical subcommittee representing the Council, as well as with the entire committee itself. These meetings were particularly advantageous for establishing a study orientation that was aligned with the specific needs of the Council, and for facilitating transfer of useful information from members of the committee to DE&S.

1.5 Data Sources

Hydrologic descriptions of the region and its sub-basins were developed through the compilation of many different types of information. Much of the data necessary for conducting Tasks 2 through 6 had either existed prior to the start of the study, or was provided to DE&S during Task 1. These information sources were made available by representatives of the JySWP Council. A great deal of data existed in the form of a Microsoft ACCESS database that has largely been developed by Los Alamos National Laboratory (LANL) and is easily accessible by ArcView. This source, which is referred to as the Tier 1 database, is documented in Berg et al. (2000). A substantial quantity of additional information existed in the form of Microsoft EXCEL spreadsheets; these are referred to as Tier 2 data. An important development stemming from the initial data compilation efforts was the selection of base maps for presenting ArcView results.

Not all of the information necessary for completing the project was readily available through sources provided by the Council. Consequently, DE&S sought out other information sources. Much of the data was derived from Internet sites maintained by government agencies with the authority to collect and disseminate relevant information to the public. Many of the Internet sites are referenced in this report in the event that readers might seek additional information from them. In addition, numerous reports and papers dealing with the region or parts of it were consulted. The publishers of these literature sources consisted mostly of government agencies, such as the U.S. Geological Survey (USGS), the U.S. Bureau of Reclamation (USBR), the U.S. Environmental Protection Agency (EPA), the New Mexico Environment Department (NMED), the U.S.

Bureau of Indian Affairs (BIA), the U.S. Army Corps of Engineers (Corps), and the U.S. Department of Agriculture (USDA).

Additional data collection efforts included visits to, correspondence with, or telephone calls to various government-related entities, including LANL, USBR, Santa Fe County, Rio Arriba County, and a representative of the Pueblos.

The types of information sources used for each of Tasks 2 through 6 are discussed near the beginning of each of the report chapters dealing with a specific task. Specific references are provided within the following report chapters that elaborate on the respective task's findings.

1.6 Data Analysis and Presentation

The information needed by the JySWP Council to conduct long-term planning constitutes both (1) data that are relatively well documented and readily accessible, and (2) quantified hydrologic parameters that are estimated using existing data. This report is intended to document the various data sources and techniques that have been employed to provide both types of information, and to present data analysis results in forms that are most useful for the Council. The reader will find that, in addition to providing a great deal of text regarding project activities and findings, the majority of the study results are presented in tabular and graphical formats. However, due to the fact that the total quantity of information gathered and summarized is so large, not all of the data are reported herein. Where possible, report appendices have been included so that many of the more detailed data sets can be accessed in a single document. Nonetheless, much of the relevant information is only accessible via the ArcView package that accompanies this report.

The ArcView package makes hydrologic data and parameters available through an interactive computer interface. Much of the information in the ArcView database is simply retrieved by displaying any of the numerous maps that have been prepared from it. But detailed quantification of parameters is more typically available via computer mouse operations with each map. Examples of information provided through this type of interaction include relevant properties of surface water stream gages found in the region, and graphs depicting the frequency of runoff quantities at each gaging station. Clearly, it is not possible to provide in this report all these types of information for each data site.

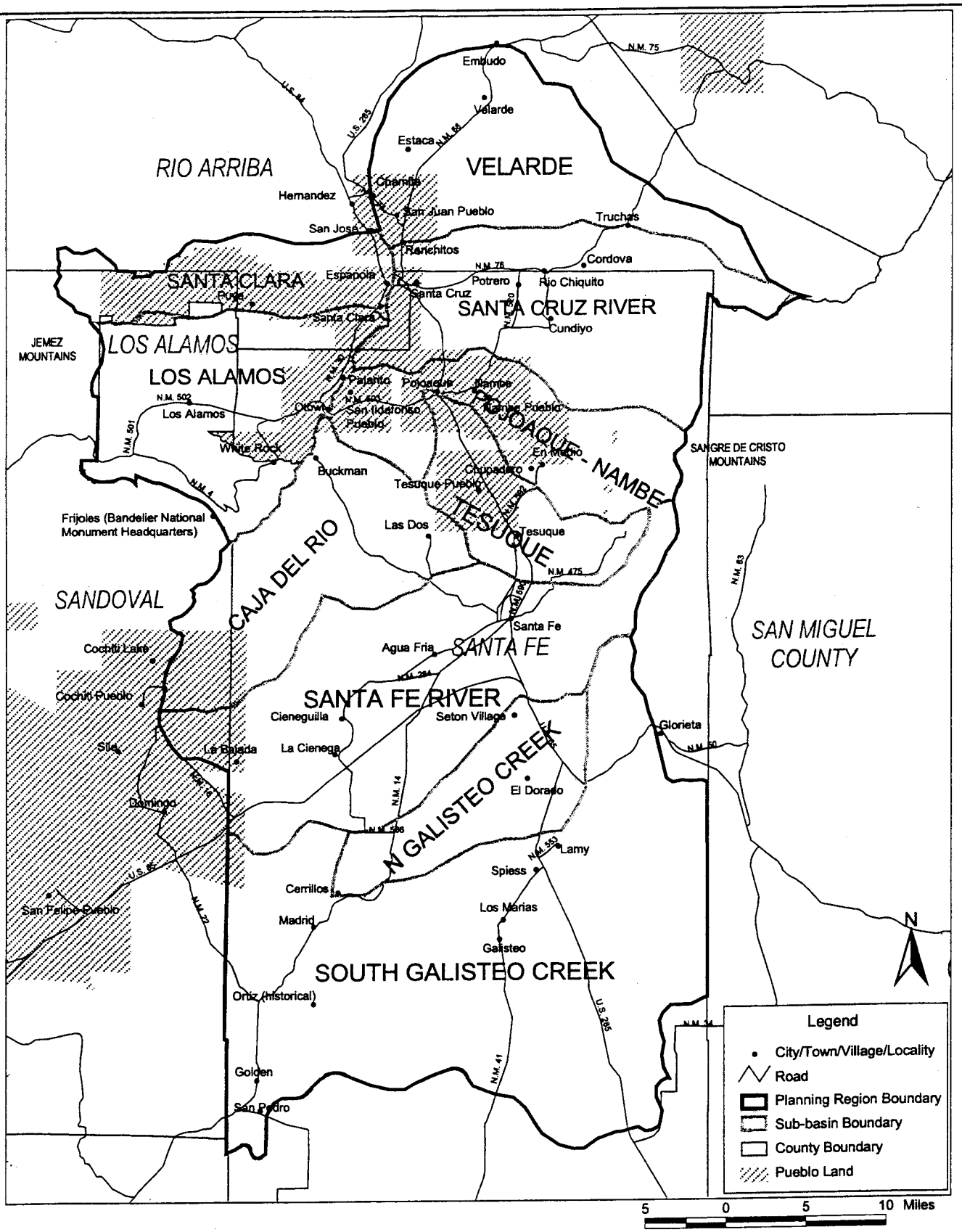

Figure 1-1 Jemez y Sangre Water Planning Region and Sub-basins

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2.0 WEATHER AND CLIMATE

The objective of Task 2 was to summarize historical weather data for the study area. Though not specifically part of the task's scope-of-work, the meteorology data collected were indirectly assessed for their utility in projecting runoff and groundwater recharge in the study sub-basins. As part of Task 2, DE&S identified temperature, precipitation, and snowpack-monitoring stations, statistically analyzed the data collected at them, and summarized the statistical results. Inspection of the multi-year records from all stations combined made it possible to arrive at a general description of the region's climate. Included in the assessment of climate was a brief summary of droughts in the study region. A synopsis of past climatic conditions on the basis of tree ring studies was also provided.

2.1 Sources of Weather and Climate Data

Most of the information used for this task consisted of data collected at fixed weather stations, whose records are maintained by the National Climatic Data Center (NCDC), a branch of the National Oceanic and Atmospheric Administration (NOAA). General descriptions and ancillary data regarding climate of the region were provided in a publication dealing with New Mexico as a whole (Tuan et al., 1969), annual precipitation maps prepared by the U.S. Soil Conservation Service (SCS, 1972) and Wasiolek (1995), and in a LANL report discussing climatology of the Pajarito Plateau (Bowen, 1990). Information regarding long-term variations in climate was drawn primarily from an in-progress manuscript by Allen (1999) that will be included in a book published by University of New Mexico Press.

2.2 Weather Stations

Eighteen NOAA weather stations exist either within or close to the planning region. Table 2-1 lists the station numbers, locations, elevations, and periods of record for each. The spatial distribution of the weather stations in and near the study region is illustrated in Figure 2-1. Precipitation, temperature and snow data for each site were collected from the NCDC digital database. Data from one of the stations, Los Alamos, was included in the Tier 1 database.

2.3 Precipitation

2.3.1 Annual Precipitation

A contour plot showing the distribution average annual precipitation in the study region, as shown in Figure 5-23, was prepared using precipitation maps previously prepared by the SCS (1972) and Wasiolek (1995). The figure illustrates that the spatial variation in average annual precipitation is large. Average annual precipitation in the mountain ranges on either side of the study area approaches values as large as 30 to 35 inches, whereas mean annual precipitation in the lowest elevations is about 8 inches.

Table 2-1. Weather Stations and Average Annual Precipitation Quantities.

Station Number	Name	Latitude	Longitude	Elevation (feet)	Years[1]	Mean Annual Precipitation (inches)	Mean Annual Snowfall (inches)	Mean Annual Snow Depth (inches)
290041	ABIQUIU DAM	36.2333	-106.4333	6400	1957-1996	9.95	8	0
290245	ALCALDE	36.1000	-106.0667	5680	1953-1996	9.89	10.3	0
290743	BANDELIER NATIONAL MONUMENT	35.7833	-106.2667	6060	1931-1976	15.50	30.2	0
290903	BERNALILLO 1 NNE	35.3167	-106.5500	5050	1938-1982	8.86	6.9	0
291982	COCHITI DAM	35.6333	-106.3167	5560	1975-1996	12.59	7.3	0
292100	CORRALES	35.2333	-106.6000	5010	1982-1999	10.77	8.9	0
292820	EL RITO	36.3333	-106.18333	6870	1931-1996	12.08	30.8	0
293031	ESPAÑOLA	36.0000	-106.0833	5640	1938-1996	9.98	10.2	0
294369	JEMEZ SPRINGS	35.7666	-106.6833	6260	1931-1996	17.44	30.8	0
295084	LOS ALAMOS	35.8667	-106.3167	7360	1931-1996	18.40	56	1
296676	PECOS RANGER STN	35.5833	-105.6833	6940	1931-1996	16.17	22.4	0
298011	SANDIA CREST	35.2167	-106.4500	10690	1953-1979	22.94	116.2	7
298015	SANDIA PARK	35.1667	-106.3667	7020	1939-1999	19.07	58.3	0
298072	SANTA FE	35.6833	-105.9000	7210	1868-1972	14.08	25.8	0
298078	SANTA FE CAA AIRPORT	35.6167	-106.0833	6350	1924-1958	9.77	17.7	0
298085	SANTA FE 2	35.6167	-105.9833	6720	1972-1996	14.27	17.3	0
298518	STANLEY 1 NNE	35.1667	-105.9667	6380	1954-1996	12.27	17.4	0
299113	TRUCHAS	36.0333	-105.8167	8040	1914-1962	14.53	43.9	0

[1] Years of record used to determine mean annual precipitation quantities.

The large spatial variation in annual precipitation is also indicated in Table 2-1, which lists mean annual precipitation quantities, including snowfall, for each weather station. For the most part, precipitation increases proportionally with increase in land surface elevation. In the northern portion of the study region, mean annual precipitation varies from 9.91 inches at Española (Station 293031), at an approximate elevation of 5600 feet (ft) above mean sea level (amsl), to as much as 35 inches in the surrounding mountains (greater than 10,000 ft amsl). Further south in the Española Basin, the Santa Fe station (Station 290072), at an elevation near 7000 ft amsl, averages about 13.84 inches of precipitation per year. The correspondence between elevation and average annual precipitation for the 18 stations used to represent the study region is illustrated in Figure 2-2.

2.3.1.1 Temporal Changes in Annual Precipitation

In addition to exhibiting large spatial variations in precipitation, annual precipitation at each station tends to change substantially over multi-year periods, and sometimes from year to year. Table 2-2, which provides a statistical summary of annual precipitation quantities at several of the stations, aptly demonstrates this temporal variability. In this listing, the records from two stations, Santa Fe and Santa Fe 2, have been combined because of their close proximity to each other. Here, annual precipitation ranges from 5.03 inches in 1917 to 21.75 inches in 1881.

Graphs comparing annual precipitation by year to long-term average annual precipitation at each of the NOAA stations are included in Appendix B. These temporal plots again reinforce a phenomenon that is common to New Mexico: Yearly precipitation at a location can fluctuate widely around a long-term mean value. As an example, in the Santa Fe area (Santa Fe and Santa Fe 2 stations), with a combined record extending from 1868 to 1996, annual precipitation appears to fluctuate over a range of about 50 percent above and below the long-term average.

To assess whether there was any periodicity in the temporal plots of annual precipitation, moving average analyses were conducted with annual data from several of the stations. The resulting graphs, also presented in Appendix B, clearly illustrate that periods of below-average precipitation occurred during the years 1950-1963 and 1975-1985. Moreover, multi-year spans of above-average precipitation occurred during the periods 1964-1974 and 1986-1998. These moving average plots are similar to those developed by Bowen (1990) for a separate weather station at Los Alamos maintained by LANL. It is interesting to note that, at all stations with records extending as far back as 1950, with the exception of Santa Fe, whose record began in 1868, the lowest annual precipitation was always observed in 1956.

These results, along with statistical analyses of deviation from the mean, strongly suggest that extended wet and dry periods tend to alternate with each other, and that each period is about 10 to 15 years in length. Such phenomena are of interest because, in addition to providing a different perspective on precipitation variability, they give the JySWP Council some sense of what may be expected in terms of extended dry periods.

Table 2-2. Statistical Summary of Annual Precipitation at Selected Weather Stations.

Station Number	Name	Years[1]	Annual Precipitation (inches)				
			Mean	Median	Standard Deviation	Maximum	Minimum
290041	ABIQUIU DAM	1957-1963	9.95	9.77	1.94	14.38	4.98
290245	ALCALDE	1953-1996	9.89	9.28	3.05	16.16	2.66
290743	BANDELIER NATIONAL MONUMENT	1931-1976	15.50	14.85	4.17	25.96	4.94
291982	COCHITI DAM	1975-1996	12.59	12.05	3.49	19.86	6.82
292820	EL RITO	1931-1996	12.08	12.04	2.84	21.90	4.95
293031	ESPAÑOLA	1938-1996	9.98	9.81	2.65	20.30	3.76
294369	JEMEZ SPRINGS	1931-1996	17.44	16.54	4.39	28.72	6.17
295084	LOS ALAMOS	1931-1996	18.40	18.34	4.46	30.34	6.80
296676	PECOS RANGER STN	1931-1996	16.17	16.46	3.67	25.34	9.23
298072 and 298085	SANTA FE AND SANTA FE 2	1868-1996	13.84	13.37	3.39	21.75	5.03
298085	SANTA FE 2	1972-1996	14.27	13.77	3.03	20.09	7.89
298518	STANLEY 1 NNE	1954-1996	12.27	12.17	3.65	21.28	4.65

[1] Years of record used to determine statistical descriptors of annual precipitation.

2.3.1.2 Frequency Analyses

Frequency analyses were performed with quantities of total annual precipitation at several of the stations with relatively long records. In cases where skewness of the yearly values was close to zero, a normal distribution was fit to the data. For records with pronounced skewness, an algorithm in Microsoft EXCEL was used that automatically provided a best fit to plotting position values for ranked quantities of annual precipitation. Using the resulting probability fits, the annual precipitation depths corresponding to 2, 50, and 90 percent exceedance probabilities were computed, as listed in Table 2-3. The three exceedance probabilities correspond to return periods of 50, 2, and 1.1 years, respectively. Graphical results from the frequency analyses are presented in Appendix C.

2.3.2 Monthly, Seasonal, and Daily Precipitation

Monthly variation in precipitation was investigated by calculating the average monthly precipitation over the thirty-year period 1961–1990. Graphs of the average monthly precipitation at several of the stations are included in Appendix D. Each shows a prominent peak in mean monthly precipitation, usually in August, apparently the result of moisture moving into the area from the Gulf of Mexico at this time of year (Tuan et al., 1969). A very large percentage of the precipitation occurring in the region between July and September is the result of convective thunderstorms (Allen, 1999). Furthermore, inspection of each of the selected stations indicates that the cumulative mean precipitation in the three summer months of June, July, and August contributes more than

forty percent of the total annual precipitation. It also indicates that winter is the driest season, with January and February usually being the driest months. Most of the snowfall occurring in the winter is the result of cyclonic storms associated with the polar jet stream. Cyclones entering the region from the northwest and west are also responsible for bringing rainfall during early spring months and late fall months. As further illustration of seasonal variability in precipitation, Figures 2-3 through 2-6 contain contour plots of the average cumulative precipitation during winter, spring, summer, and fall months, respectively.

Table 2-3. Frequency of Annual Precipitation at Weather Stations.

	Probability of Exceedance	0.02	0.5	0.9
	Return Period (yr)	50	2	1.1
Station Number	Station Name	Annual Precipitation (inches)		
290041	ABIQUIU DAM	14.38	9.78	7.97
290245	ALCALDE	16.16	9.34	5.95
290743	BANDELIER NATIONAL MONUMENT	25.96	14.86	10.67
291982	COCHITI DAM	19.86	12.00	7.02
292820	EL RITO	21.02	12.06	9.10
293031	ESPAÑOLA	20.30	9.81	7.03
294369	JEMEZ SPRINGS	28.12	16.61	12.95
295084	LOS ALAMOS	30.34	18.30	12.95
296676	PECOS RANGER STN	24.22	16.58	11.73
298518	STANLEY 1 NNE	21.28	12.17	7.47
298072 and 298085	SANTA FE AND SANTA FE 2	21.52	13.38	9.73

Temporal variations in daily precipitation were also examined. Appendix D contains graphs of average daily precipitation for several of the weather stations. In general, these plots look very similar to the graphs of mean monthly precipitation.

2.4 Temperature

In assessing temperature in the study region, DE&S examined calculated mean values of this variable at the weather stations, but focused more on temperature extremes. Table 2-4 lists the mean temperatures and the mean of annual maximum and minimum temperatures at each of the weather stations. Graphs of mean monthly maximum and minimum temperatures, along with standard deviations of monthly extreme temperatures, are presented in Appendix D. These plots show that the variation in monthly temperature extremes is smaller during summer months than it is during winter months. January is typically the coldest month of the year, and July the warmest. At the Santa Fe weather station (Station 298072) the average January maximum temperature is 42 °F and the average minimum temperature in January is 17 °F. At the same station, the average July

maximum temperature is 84 °F and the minimum temperature is 56 °F. In addition to plots of monthly maximum and minimum temperatures, Appendix D also contains graphs of average daily maximums and minimums.

Table 2-4. Mean Annual Temperature and Mean Values of Annual Extreme Temperatures.

Station Number	Station Name	Mean Annual Temperature (degrees Fahrenheit)	Mean of Annual Maximum Temperature (degrees Fahrenheit)	Mean of Annual Minimum Temperature (degrees Fahrenheit)
290041	ABIQUIU DAM	50.0	64.3	35.6
290245	ALCALDE	51.3	68.1	34.5
290743	BANDELIER NATIONAL MONUMENT	50.1	68.0	32.2
291982	COCHITI DAM	54.3	68.6	39.9
292820	EL RITO	48.5	63.2	33.8
293031	ESPAÑOLA	51.7	68.8	34.6
294369	JEMEZ SPRINGS	52.0	66.8	37.1
295084	LOS ALAMOS	47.9	59.8	36.0
296676	PECOS RANGER STN	48.9	65.0	32.7
298072	SANTA FE	49.0	62.9	35.1
298085	SANTA FE 2	50.5	64.1	36.9
298518	STANLEY 1 NNE	49.3	65.5	33.0

2.5 Evaporation

Evaporation rates in the study region were examined using three different sources of information. First, pan evaporation data from four weather stations were used to develop an estimate of the general magnitude free water surface (FWS) evaporation rates that typify the region. For the purposes of this study, the FWS evaporation rate was loosely defined as the rate of evaporation from an extensive free water surface, such as that associated with a lake. The second approach involved the extraction of FWS rates from a NOAA Technical Report (Farnsworth and Thompson, 1982) that discusses the distribution of evaporation rates over the entire state. The third focused on the development of representative potential evapotranspiration (PET) rates. These rates were estimated using a map of PET quantities prepared by Tuan et al. (1969).

Table 2-5 lists the characteristics of monthly (April to October) pan evaporation loss at four weather stations that are likely to reflect evaporation rates in the study region: (1) Abiquiu Dam, (2) Cochiti Dam, (3) Eagle Nest, and (3) Santa Fe. These data were derived from the New Mexico Climate Center at New Mexico State University in Las Cruces and can be accessed via the Internet at http://weather.nmsu.edu/Pan_Evaporation/.

Of the four stations, two, Cochiti Dam and Santa Fe, lie within the study region. Abiquiu Dam lies west-northwest of the planning region in the Rio Chama drainage, and Eagle Nest is located northeast of Jemez y Sangre in the Sangre de Cristo Mountains east of Taos, NM.

Table 2-5 suggests that the maximum pan evaporation rate in the study region occurs during the month of June. Converting the listed monthly values to FWS evaporation rates is accomplished using a pan evaporation modifier, such as a Pan Coefficient (Shuttleworth, 1993). NOAA Technical Report NWS 34 (Farnsworth and Thompson, 1982) suggests that the pan evaporation rates in Table 2-5 be multiplied by a Pan Coefficient of 0.74 to arrive at estimates of FWS evaporation. NOAA Technical Report NWS 33 (Farnsworth and Thompson, 1982) contains a map depicting average annual FWS evaporation over the entire state of NM. The evaporation rates extracted from that map for the planning region are shown in Figure 2-7.

A similar map of annual PET rates for the study region, shown in Figure 2-8, was derived using a statewide map of this parameter developed by Tuan et al. (1969).

2.6 Drought

2.6.1 Short-Term Climatic Cycles

2.6.1.1 El Niño - Southern Oscillation Cycle

Short-term changes between dry and wet periods in New Mexico can be partly explained by episodes of temperature change in the central tropical Pacific Ocean. The El Niño - Southern Oscillation (ENSO) cycle refers to large-scale seesaw changes in surface pressure between the tropical Eastern Pacific and the Western Pacific–Indian Ocean region (Rasmusson et al., 1993). A periodic effect of the change is El Niño, in which an anomalous warming of upper ocean occurs along the northern coast of Peru, typically shortly after Christmas; hence the Spanish name El Niño, or "the Christ Child." A common effect of El Niño is increased winter and spring precipitation in the Southwest, including in the study region (Allen, 1999). The counter to El Niño, which is referred to as La Niña, causes drought (Allen, 1999). When successive years of either phenomenon occur, it is possible to observe multi-year sequences of wetter-than-normal and drier-than-normal weather, such as those illustrated in the graphs of annual precipitation and moving average plots of annual precipitation in Appendix B.

Table 2-5. Pan Evaporation Data For Stations In and Near the Study Region

Station	Site Description	Statistic	Evaporation (inches)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abiquiu Dam	Record = 1964-1995	**Maximum**	---	---	4.8	9.4	13	14	13	10	9.1	7.3	3.6	---
	Latitude = N36:14:00	**Minimum**	---	---	4.8	5.9	7.5	8.8	8	7.6	5.7	3.1	2.2	---
	Longitude = W106:26:00	**Average**	---	---	---	7.4	9.8	11	11	8.9	7.2	5.3	2.9	---
	Elevation = 1944.6 m													
Cochiti Dam	Record = 1975-1995	**Maximum**	---	---	7.1	11	13	16	16	13	10	7.8	2.8	---
	Latitude = N35:38:00	**Minimum**	---	---	4.4	6.9	8.2	8.4	10	8.2	7.5	4.4	2.1	---
	Longitude = W106:19:00	**Average**	---	---	6.1	8.5	11	13	13	11	8.8	6.4	2.4	---
	Elevation = 1694.7 m													
Eagle Nest	Record = 1948-1995	**Maximum**	---	---	---	5	10	11	9.4	8.3	7.2	6	---	---
	Latitude = N36:33:00	**Minimum**	---	---	---	3.8	4.1	1	1.4	3.2	3	2.1	---	---
	Longitude = W105:16:00	**Average**	---	---	---	4.4	7	7.6	6.9	5.9	5.2	4.4	---	---
	Elevation = 2517.6 m													
Santa Fe	Record = 1951-1971	**Maximum**	---	---	3	7.7	10	15	11	12	9.7	6.4	2.7	---
	Latitude = N35:41:00	**Minimum**	---	---	3	6.5	6.7	8.6	8.1	6.2	5.2	2.7	1.9	---
	Longitude = W105:54:00	**Average**	---	---	---	7.3	8.5	11	9.9	8.3	7.2	5.1	2.2	---
	Elevation = 2196.0 m													

Note: m = meter(s)

2.6.1.2 Palmer Drought Severity Index

As additional indications of the cyclical nature of short-term wet and dry periods, plots of the annual Palmer Drought Severity Index (PDSI) calculated for two grid locations in north-central New Mexico are presented in Figures 2-9 and 2-10. PSDI values approaching –4 indicate severe drought conditions, whereas values approaching +4 represent very wet conditions (McMahon, 1993). Figures 2-9 and 2-10 indicate the grid number and its location in terms of latitude and longitude for which the PDSI has been prepared. The source of the index data is NOAA's Paleoclimatology Program, which can be accessed over the Internet at http://www.ngdc.noaa.gov/paleo.

2.6.2 Long-Term Drought Issues

2.6.2.1 Tree Rings and Other Evidence of Paleoclimates

Drought can also be examined from the perspective of longer records than those developed at twentieth-century weather stations. In particular, dendroclimatology, which involves the study of tree rings, can be used to discern general periods of drier-than-normal conditions extending back hundreds of years or more. Allen (1999), in summarizing a variety of tree ring studies by others, identified significant dry periods in the Jemez Mountains centered around 10 distinctive time spans between the mid-1100s A.D. and current times. One of the time spans, occurring in the late 1500s, is considered to be "very dry" relative to the other dry periods identified in the approximately 800 to 900 years included in the tree ring analyses. The tree ring analyses clearly identify the drought period of the 1950s as being significant over the same 800-900 year duration.

Allen (1999) also summarizes the work of others who have used geomorphic evidence to interpret past climate trends. A conclusion that can be drawn from his summary, and that may be relevant to water planning, is that relatively dry periods lasting as long as 100 to 300 years have occurred in the last two thousand years. In some cases, researchers attribute these extended dry spans to less frequent occurrences of El Niño events.

Stahle et al. (2000) used several tree ring studies to demonstrate that severe extended drought conditions occurred throughout the southwestern U.S. during most of the last half of the 16th Century. They evoke the work of Grissino-Mayer (1996) who, in the process of reconstructing precipitation quantities for the El Malpais area in western New Mexico, shows that the16th Century drought constituted the most extreme prolonged drought in the past 2000 years.

2.6.2.2 Global Climate Change

Water supply issues involving drought become all the more significant when considering the potential for very dry conditions to persist for up to hundreds of years as a result of global climate change. This observation holds particularly true if the some of the recent theories regarding global warming being the result of an increasing greenhouse effect are viable. Crowley (2000) has conducted studies indicating that recent global warming trends can be attributed to the increasing greenhouse effect, and that the observed increase in global temperature has already established itself above the level of natural

variability in the climate system of the last 1000 years. If global warming is indeed being brought about by anthropogenic phenomena, extended drought periods for periods of several tens of years and greater should be anticipated as a possible consequence.

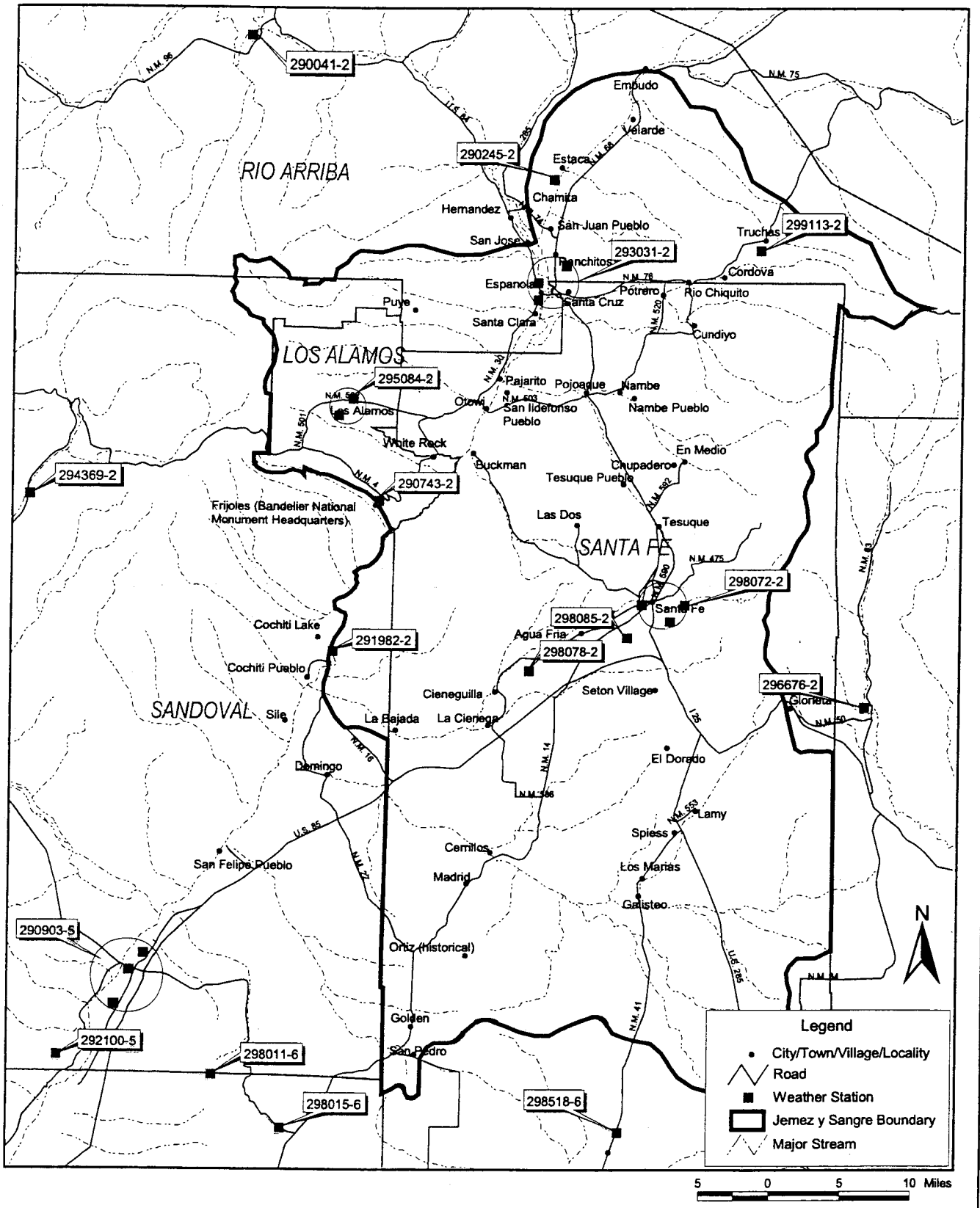

Figure 2-1 Weather Stations In and Near the Study Region

Duke Engineering & Services
A Duke Energy Company

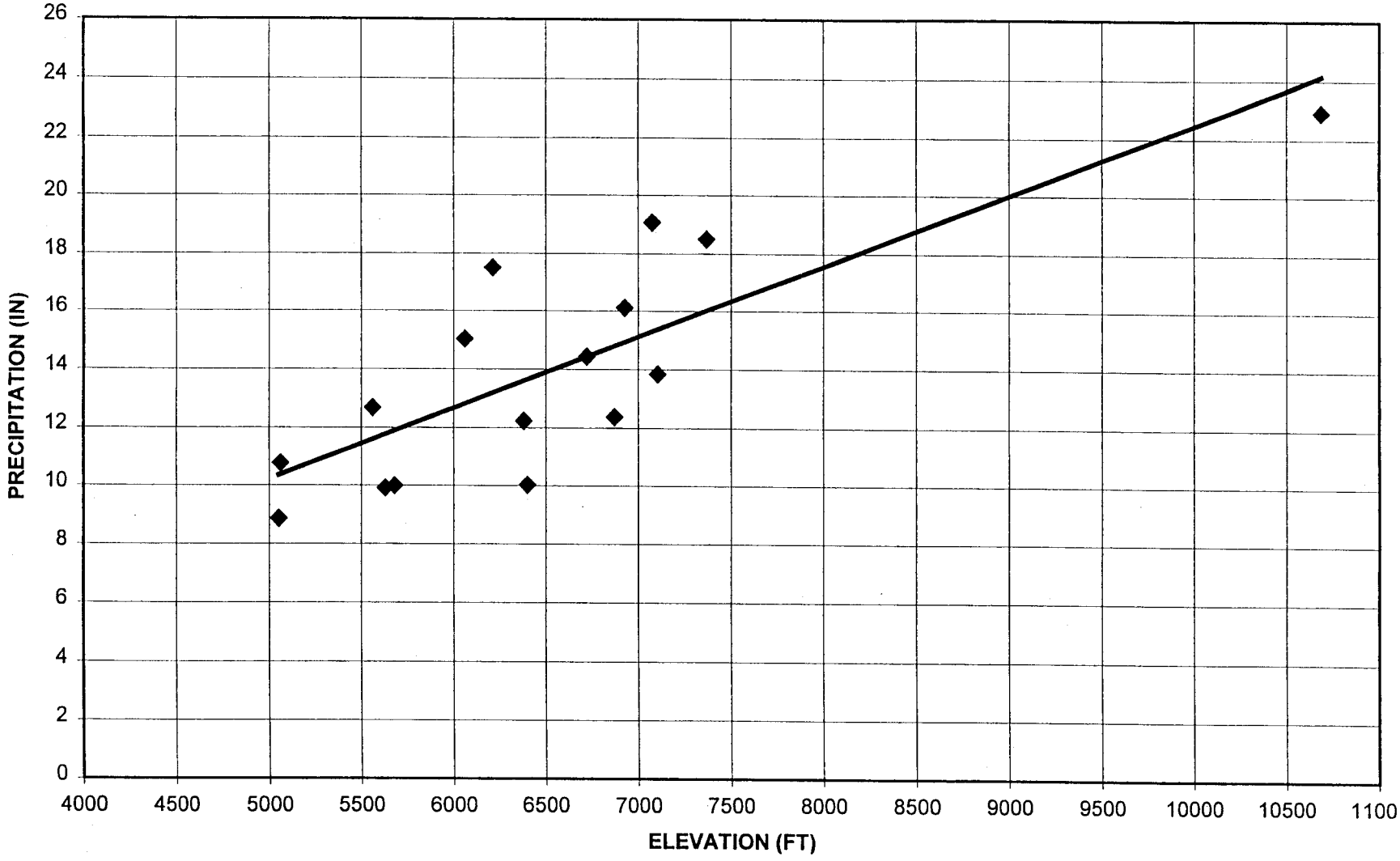

Figure 2-2. Average Annual Precipitation Versus Weather Station Elevation.

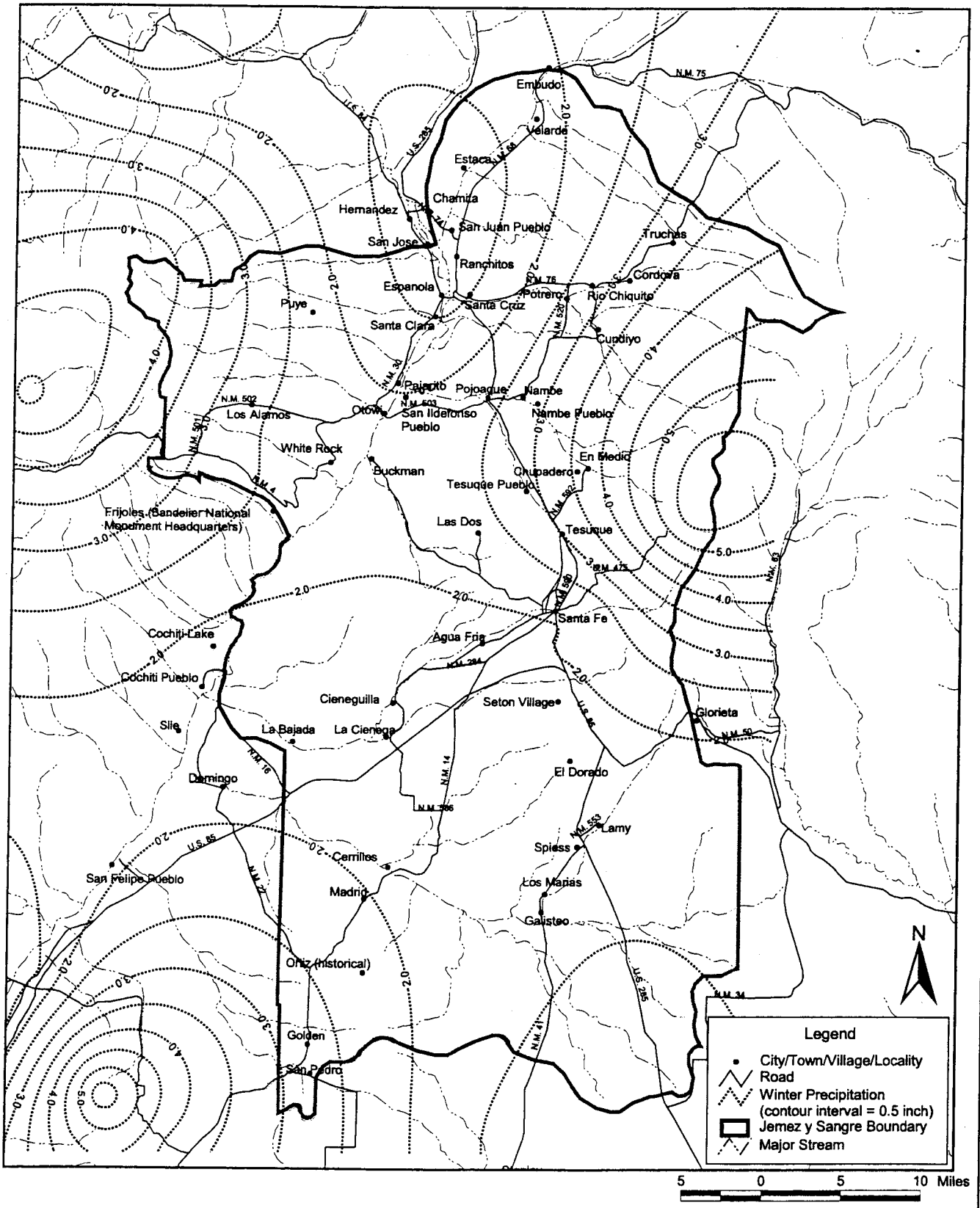

Figure 2-3 Average Cumulative Precipitation During Winter
(December - February)

Duke Engineering & Services
A Duke Energy Company

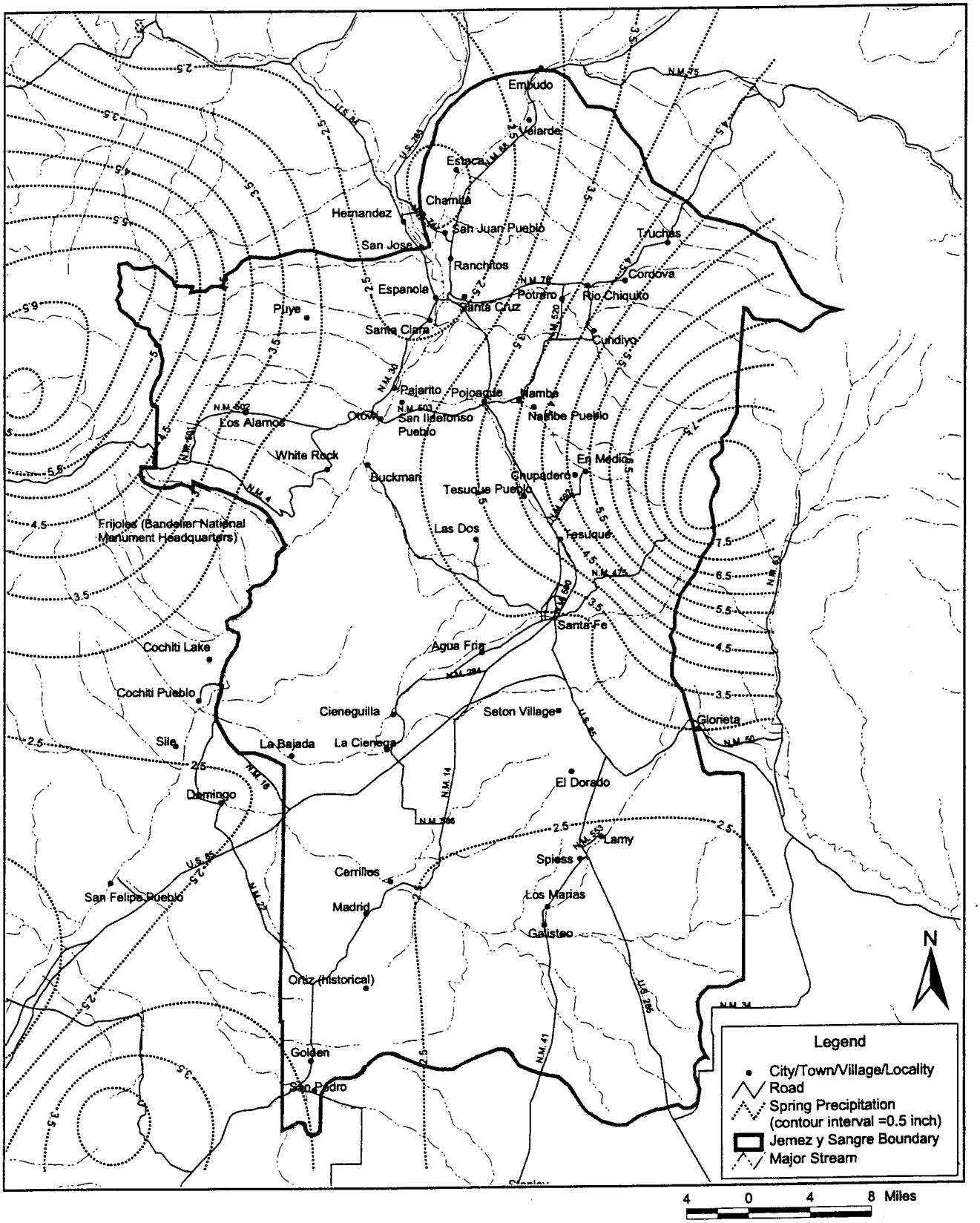

Figure 2-4 Average Cumulative Precipitation During Spring (March - May)

Duke Engineering & Services
A Duke Energy Company

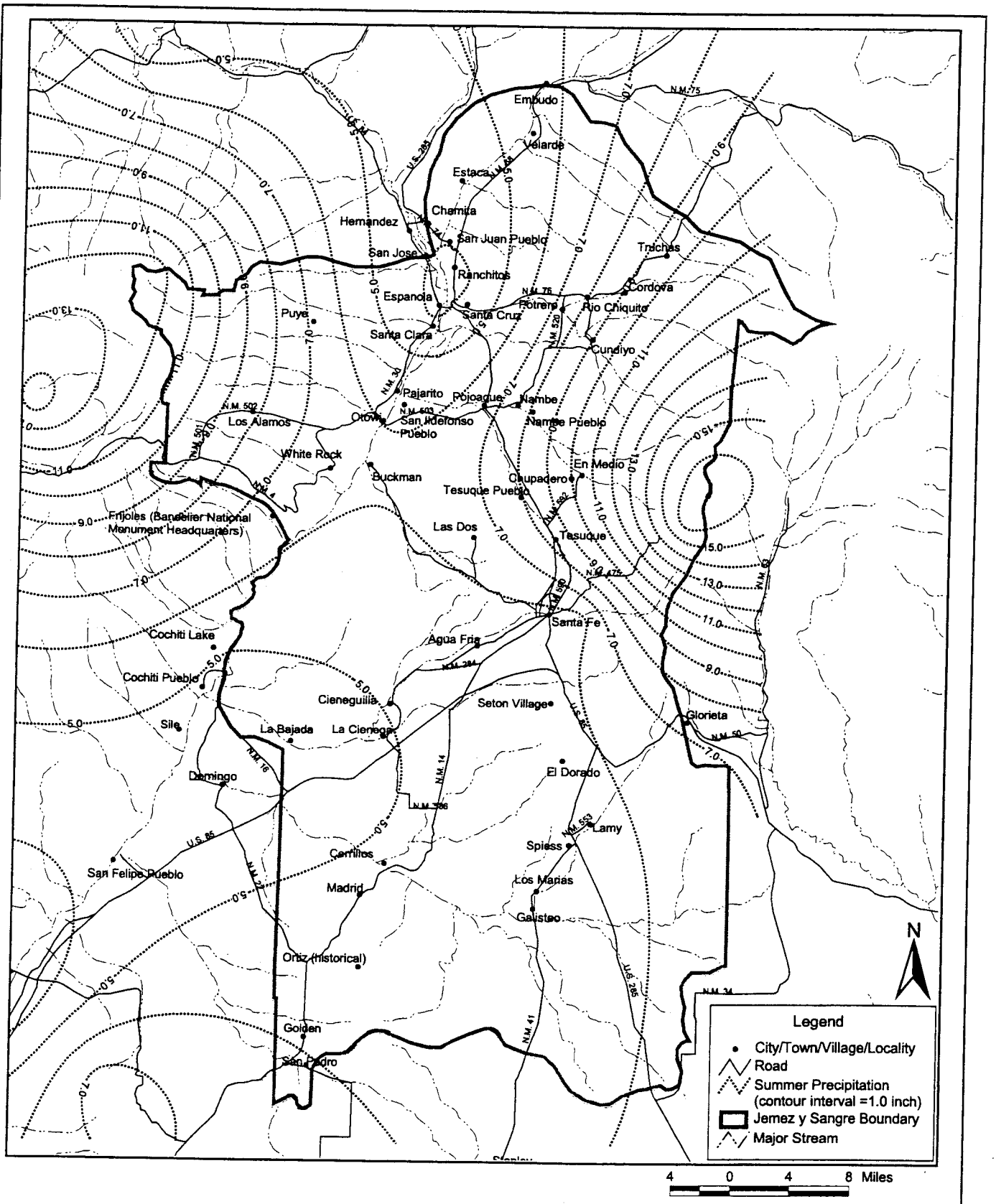

Figure 2-5 Average Cumulative Precipitation During Summer (June - August)

Duke Engineering & Services
A Duke Energy Company

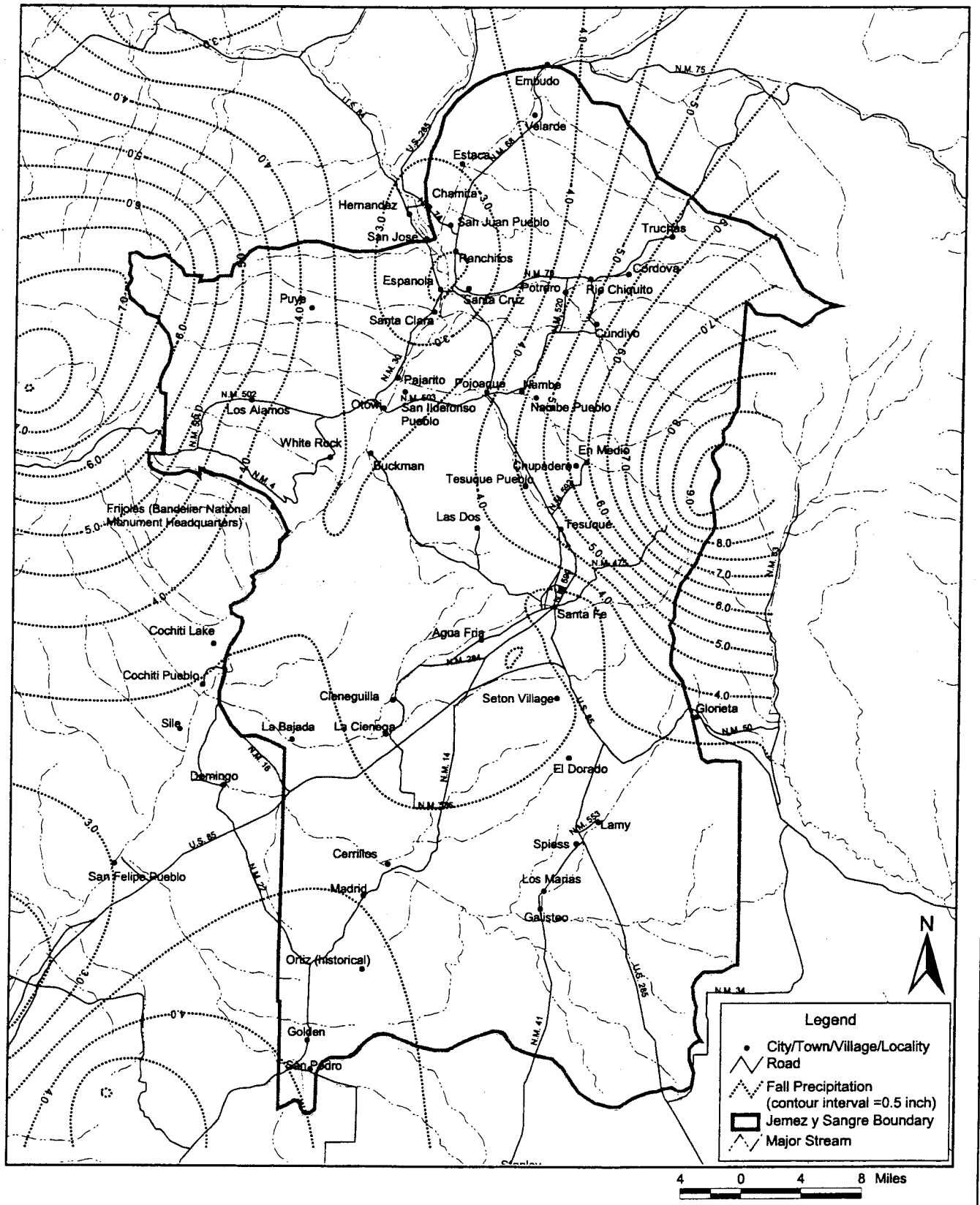

Figure 2-6 Average Cumulative Precipitation During Fall (September - November)

Duke Engineering & Services
A Duke Energy Company

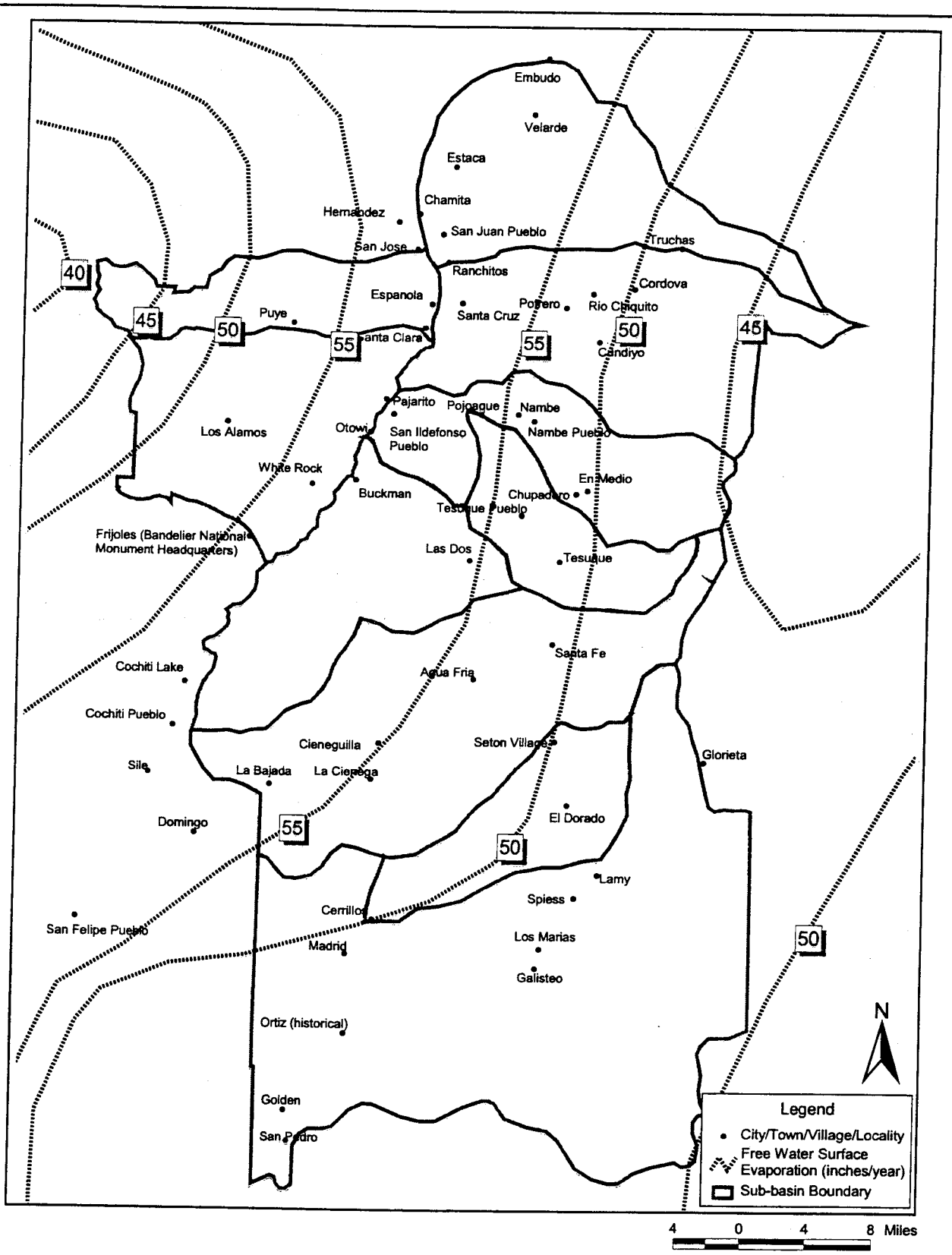

Figure 2-7 Average Free Water Surface Evaporation Rate (inches/year)

Duke Engineering & Services
A Duke Energy Company

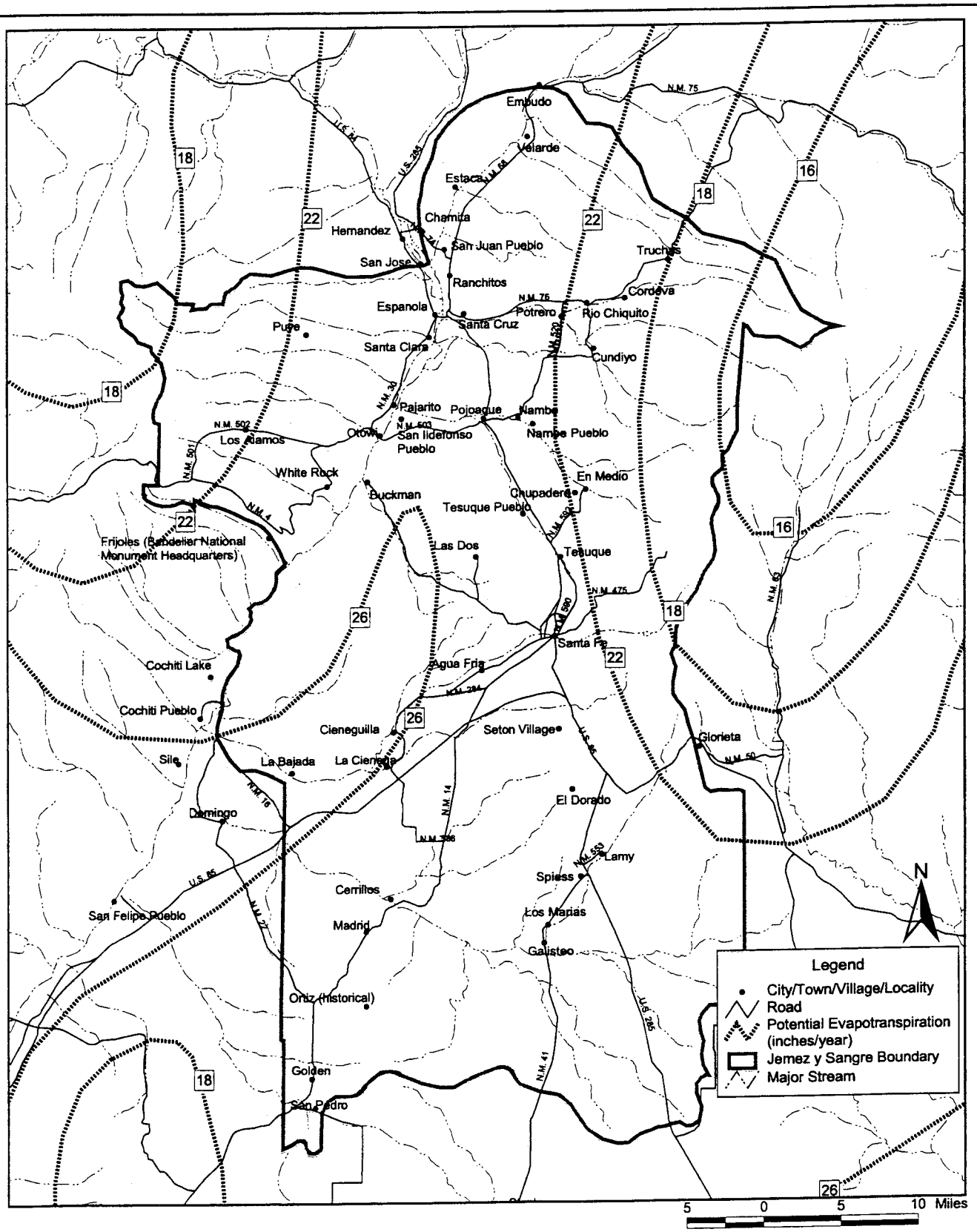

Figure 2-8 Average Potential Evapotranspiration Rate (inches/year)
(After Tuan et al., 1969)

Duke Engineering & Services
A Duke Energy Company

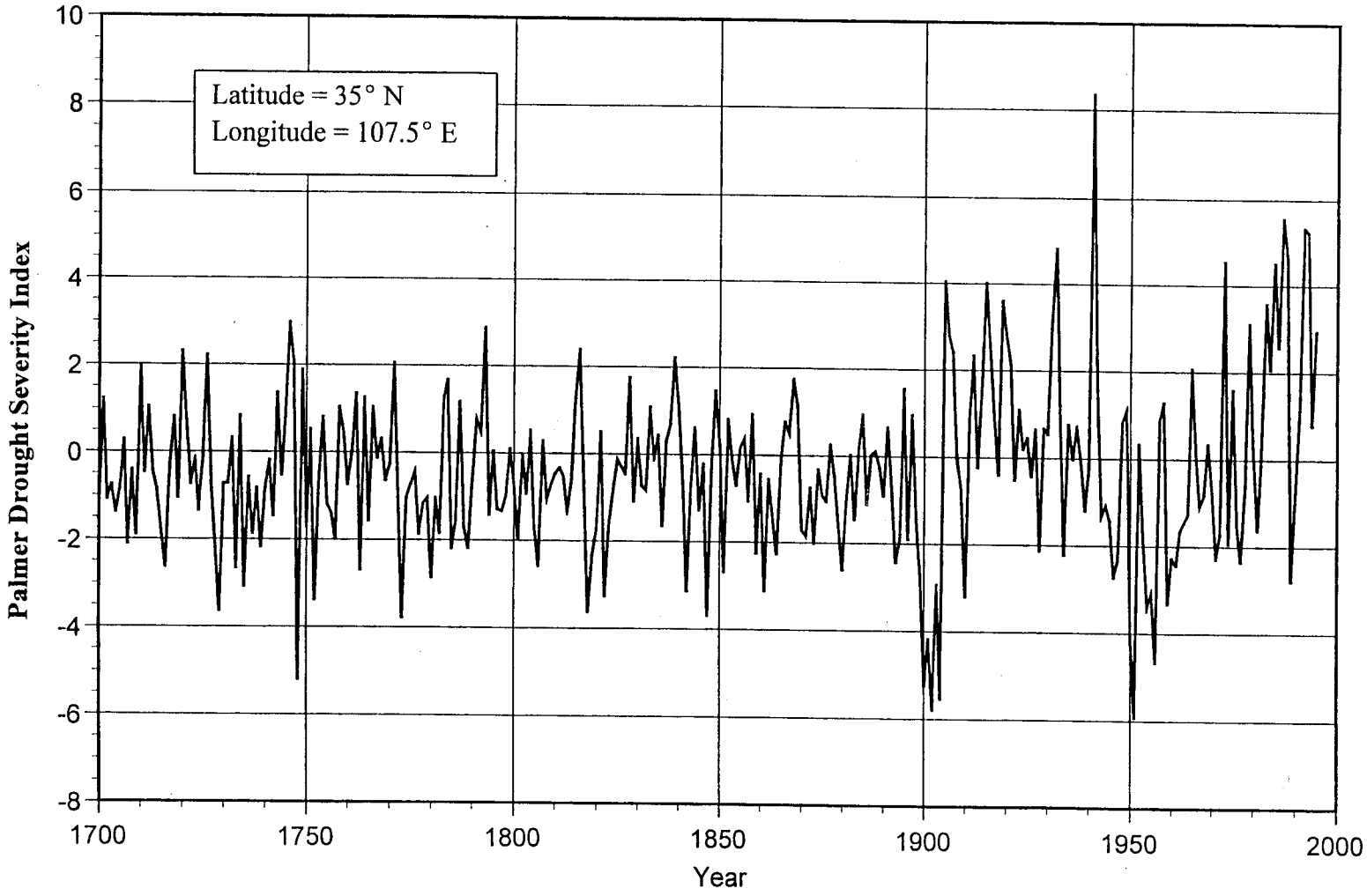

Figure 2-9. Annual Palmer Drought Severity Index at NOAA Paleoclimate Station 51 in North-central New Mexico

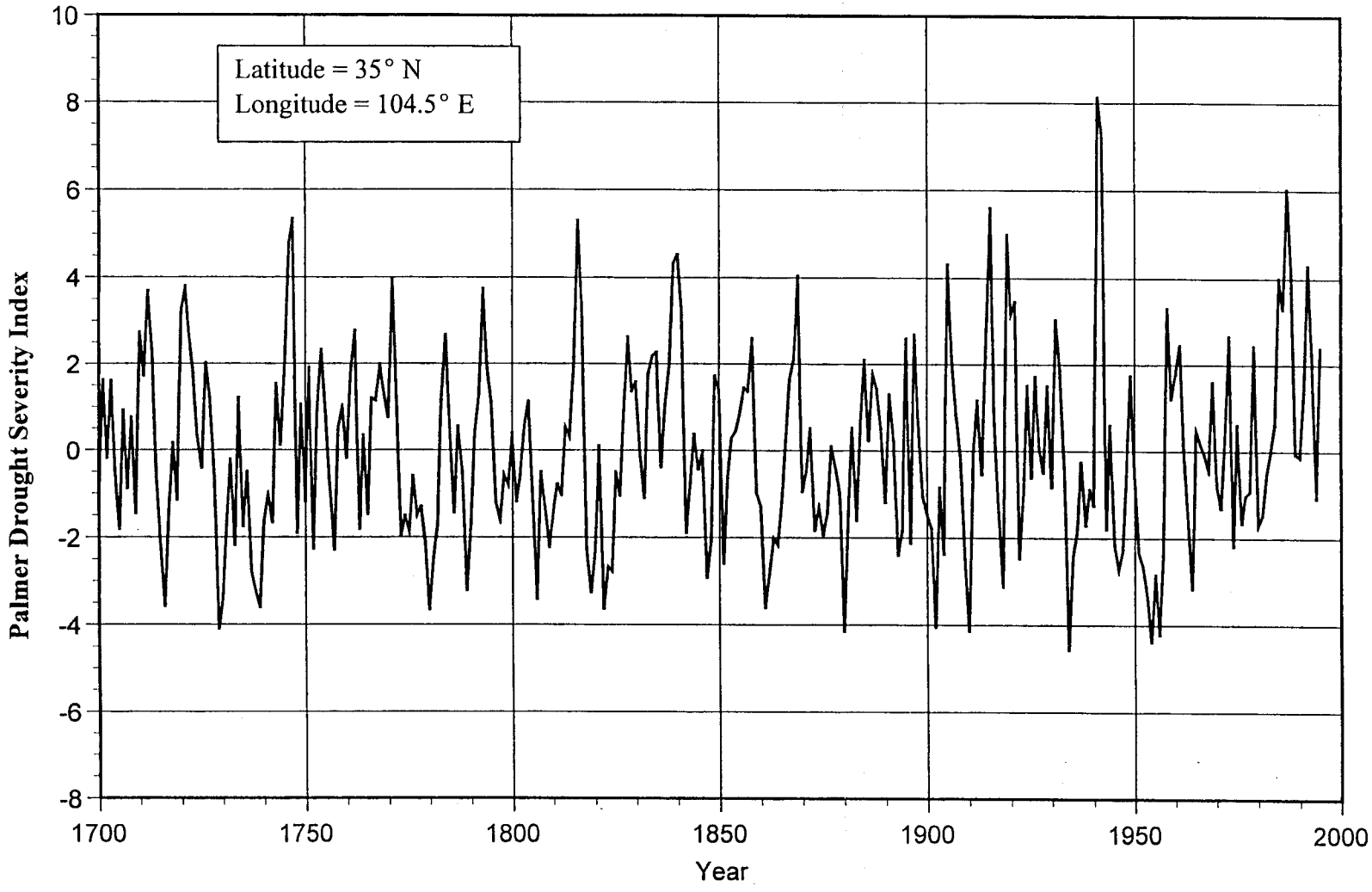

Figure 2-10. Annual Palmer Drought Severity Index at NOAA Paleoclimate Station 61 in North-central New Mexico.

3.0 SURFACE WATER SUPPLIES

The findings from Task 3, which comprised an assessment of surface water resources in the planning region, are presented in this chapter. The most important products stemming from this assessment are estimated surface water budgets for each sub-basin. A general assessment of surface-water inflows and outflows for the entire water planning region is provided as well to help the reader gain a general understanding of the quantities of water that flow through the region on an annual basis.

Several factors affecting streamflow had to be examined in developing the sub-basin budgets. For example, it was not only necessary to estimate annual runoff in the upper reaches of each sub-basin due to snowmelt and other sources, but it was also important to assess potential stream losses and accretions between headwater sections and basin outlets. Processes falling into this latter category include stream-aquifer exchange, irrigation diversions, and agricultural consumptive use. To provide some measure of how existing surface water resources comply with existing water demands, the resulting budgets were compared with estimated surface water rights in each of the sub-basins.

A wide variety of items related to surface water were examined as a part of this task. Before developing water budgets for each of the sub-basins, it was important to accurately delineate their boundaries, and to assess physical attributes of local and regional areas that may have a bearing on surface water processes. The topography of each sub-basin and stream mileage within it, as well as streamflow sources, were characterized. Pertinent land uses, such as irrigated areas, were also identified.

Numerous streamflow gaging stations within the study region provided valuable insight into the existing condition of surface water resources. Consequently, a large part of Task 3 was devoted to characterizing flow data collected at these sites. The information that was developed and ultimately reported on in this chapter included station location, years during which flow records were kept, graphs of historical flow, statistical summaries of the recorded flows, and frequency analyses of specific flow quantities.

Just as flow characteristics of watercourses are very important for assessing water supply, so too are surface water reservoir features because the ability of the reservoirs to store runoff can ultimately affect the region's ability to provide water for human uses. Thus a portion of this chapter is also given to descriptions of the physical attributes of reservoirs in the planning region and the manner in which they are operated.

An item of particular interest in this task was the identification of ungaged streams, and of methods that would be helpful in estimating their annual contributions to watercourses in the region. Several potential sources of information for this type of analysis were considered for use in developing water budgets. Ultimately, resource constraints led DE&S to rely upon some relatively simple techniques for estimating runoff in ungaged locales.

3.1 Sources of Surface Water Supply Information

A large quantity of surface water data for the planning region was included in the Tier 1 ACCESS databases provided by LANL. Streamflow data from gaging stations with more than ten years of daily records were downloaded from an Internet site maintained by the USGS. Topographic data and associated maps were assembled using the 15-minute, 30 meter grid, Digital Elevation Model (DEM) maps distributed by the Earth Data Analysis Center (EDAC). Statistical analyses of daily surface-water data were performed using the USGS program SWSTAT (Lumb et al., 1990). Information on reservoir characteristics and operations was collected from an Internet site maintained by the Corps. Surface water flows associated with springs were determined using a compilation of measured spring flows by White and Kues (1992). A water-balance technique developed by Suhr (1999) was examined to assess methods for developing water budgets in the vicinity of Tesuque Creek and Nambe Creek.

3.2 Drainage Basin Attributes

As discussed in Chapter 1, most of the Jemez y Sangre Water Planning Region lies within the Española geologic basin, and a small fraction of the region occurs in the northern-most portion of the Albuquerque Basin. As shown in Figure 1-1, the region has been divided into ten watersheds, or sub-basins: Velarde, Santa Cruz, Santa Clara, Los Alamos, Pojoaque-Nambe, Tesuque, Caja del Rio, Santa Fe River, North Galisteo Creek and South Galisteo Creek. Figure 3-1 shows the major watercourses and drainage patterns found in each of the sub-basins. Two of the watersheds, Santa Clara and Los Alamos, originate on the east slope of the Jemez Mountains and drain eastward to the Rio Grande, while the remaining eight drain the west slope of the Sangre de Cristo Range on the east side of the Rio Grande. As delineated for this study, the boundaries of each sub-basin are not everywhere coincident with actual drainage boundaries; in some locations the sub-basin borders are aligned with county boundaries. Excluding the locations that are omitted from study by such delineation, the total study area drainage encompasses 1892 square miles.

Watershed attributes examined in this chapter include such features as drainage area, mean land elevation, measures of land surface relief, main channel slope, mean annual precipitation and mean annual potential evapotranspiration (PET). The last two of these features were also discussed in Chapter 2 in reference to regional and local weather characteristics; they are injected here because of the potentially strong influence they have on surface runoff in each sub-basin. The values used for sub-basin mean annual precipitation should not be confused with mean annual precipitation quantities presented in Chapter 2 for weather stations. In this chapter, mean annual precipitation in a sub-basin represents the average yearly precipitation as weighted by sub-areas within the sub-basin and using the precipitation contour map in Figure 5-23. In contrast the mean annual precipitation quantities presented in Tables 2-1 and 2-2 are representative of specific weather stations in the sub-basin.

Previously mentioned 15-minute, 30-meter DEM maps by EDAC were used to calculate many of the watershed attributes. Figure 3-2 presents a composite DEM map for the entire planning region, which was built by combining the numerous 15-minute maps for the study area. Attributes derived from DEM information included mean watershed elevation, mean elevation of the main channel, and main channel slope. The mean channel elevation and slope were calculated using streambed elevations occurring at 10 percent and 85 percent of the channel length, as measured from the main channel's outlet location.

To enhance the general descriptions of each sub-basin, DE&S also took into account recent land use. Figure 3-3 depicts general land use in the study region using Landsat imagery.

Table 3-1 provides a brief summary of the sub-basins' physical attributes. The following sections describe each sub-basin's characteristics in more detail.

3.2.1 Velarde Sub-basin

The Velarde sub-basin, covering an area of 167 square miles (mi^2), mostly drains the Sangre de Cristo Range in the vicinity of the Truchas Peaks. However, a small portion of the sub-basin, located on the western side of the Rio Grande, drains slopes on the east side of Black Mesa. This latter part of the sub-basin does not play a major role in the local surface water supply. Thus most of the text regarding surface water drainage in the sub-basin refers to watersheds on the eastern side of the Rio Grande. As discussed later in the chapter, the surface water budget for this sub-area takes into account flows on the Rio Grande itself. This is accomplished using historical measured flows at a main stem gaging station located near the sub-basin's north border, Rio Grande at Embudo, the first such station in New Mexico, with flow records extending back to 1889.

The main streams draining the Sangre de Cristo mountain slope in the Velarde sub-basin are Rio de Truchas and Cañada de Las Entranas. Land elevation ranges from an altitude of 12,300 feet above mean sea level (amsl) at the sub-basin's highest point to about 5572 ft amsl at the Rio de Truchas outlet on the Rio Grande, thus encompassing some 6730 ft of elevation relief. The average elevation of the watershed is 6847 ft amsl. Arroyos that drain lower elevations include Arroyo del Pueblo, Arroyo Ocote, Cañada Ancha, Arroyo del Palacio, Arroyo de Los Chavez, Arroyo de Ranchitos and Arroyo de Los Borregos. The watershed receives about 12.2 inches of annual precipitation and exhibits a PET rate of about 22.2 in/yr. The slope of the main watershed channel (Rio de Truchas) is about 123 feet per mile (ft/mi).

Table 3-1. Summary of Sub-basin Physical Attributes

Sub-basin	Drainage Area	Minimum Elevation	Maximum Elevation	Elevation Relief	Mean Elevation	Main Channel Mean Elevation	Main Channel Slope	Average Annual Precipitation[1]	Average Potential Evapo-transpiration[2]
	(square miles)	(ft amsl)	(ft amsl)	(ft)	(ft amsl)	(ft amsl)	(feet/mile)	(inches)	(inches/year)
Velarde	167	5572	12306	6734	6847	6976	123	12.2	22.1
Santa Cruz	206	5494	12982	7488	7672	7108	147	16.3	19.1
Santa Clara	84	5523	11525	6002	7501	7316	176	18.3	21.2
Los Alamos	173	5359	10423	5064	7073	7047	230	17.8	18.6
Pojoaque-Nambe	123	5494	12621	7127	7489	7247	182	16.9	21.1
Tesuque	77	5753	11844	6091	7272	6335	91	15.3	21.8
Caja del Rio	158	5244	7399	2155	6395	6130	80	12.0	26.0
Santa Fe River	284	5257	12136	6879	6742	6332	62	12.4	24.0
North Galisteo Creek	93	5720	8229	2509	6661	6258	64	13.0	24.0
South Galisteo Creek	527	5405	10512	5107	6595	6086	38	14.0	24.0

Notes:
amsl = above mean sea level
ft = feet
[1] Average annual precipitation based on spatial weighting of precipitation contours shown in Figure 5-23 over entire sub-basin.
[2] Average potential evapotranspiration (PET) based on spatial weighting of PET contours shown in Figure 2-8 over entire sub-basin.

3.2.2 Santa Cruz Watershed

The Santa Cruz drainage area encompasses about 206 square miles and drains the western slope of the Sangre de Cristo Mountains. Headwaters of the major streams in this watershed are located near the Truchas Peaks and Pecos Baldy. The sub-basin's elevation varies from 12,980 ft amsl at the Sangre de Cristo crest to 5490 ft amsl at its outlet, thus creating 7488 ft of elevation relief, the largest vertical relief of all ten sub-basins. The main streams draining the mountain slopes are the Santa Cruz River and its tributaries, including the Rio Quemado, Rio Medio and Rio Frijoles. Other streams draining lower elevations include Arroyo Seco, Arroyo Madrid and Arroyo de la Mesilla. Average annual precipitation for this watershed is 16.3 inches and the PET rate is about 19 in/yr. The slope of the main channel (Santa Cruz River/Rio Quemado) is 147 ft/mi.

3.2.3 Santa Clara Watershed

The Santa Clara watershed originates on the eastern slope of the Jemez Mountains and adjoins the main stem Rio Grande a few miles south of Española. Covering an area of about 84 square miles, the watershed contains the eastward-flowing, perennial stream Santa Clara Creek and several ephemeral, tributary drainages. Maximum watershed elevation is 11,525 ft amsl near the headwaters of Santa Clara Creek, and the basin outlet elevation is 5523 ft amsl, thus providing about 6000 ft of elevation relief. Drainages in the sub-basin's lower elevations include Arroyo Plaza Larga, Arroyo del Gaucho and Arroyo de Guachupangue. The watershed receives an average of 18.2 inches of annual precipitation and is characterized by a PET rate of about 21.2 inches/year. The slope of the main channel (Santa Clara Creek) is approximately 176 ft/mi.

3.2.4 Los Alamos Sub-basin

Rather than comprising a single, main watershed with a distinct outlet, the Los Alamos sub-basin actually contains several creeks that flow southeastward to eastward and are directly tributary to the Rio Grande, which forms the sub-basin's eastern boundary. Streams falling into this category are all associated with canyons that incise the Pajarito Plateau. They include Guaje Canyon, Los Alamos Canyon, Pajarito Canyon, Water Canyon, Ancho Canyon, and the Canyon de los Frijoles. Several other smaller streams aligned with additional canyons are tributary to these major drainages. None of the drainages within the sub-basin stands out as a so-called main stream. When considering the full stream lengths within each watershed, all streams in the sub-basin, with the exception of the Rito de Los Frijoles along the sub-basin's south boundary, are considered ephemeral. It should be noted, however, that some of the ephemeral watersheds contain reaches that apparently contain surface water throughout the year (Allen, 1999). Flows observed in some of the canyon watercourses are attributed to effluent discharges, either from facilities at LANL or from sewage treatment. The relationship between surface water and groundwater appears to vary spatially, with stream water recharging shallow groundwater in some locales, including downstream of effluent outfalls, and shallow groundwater resurfacing at others.

The Rito de los Frijoles on the sub-basin's south boundary is of interest because its upper reaches are located within Los Alamos County and, by virtue of the manner in which the planning region's boundaries are delineated, are considered part of the Los Alamos sub-

basin. However, the lower reaches of this tributary to the Rio Grande lie within Sandoval County, and are thus not formally within the Los Alamos sub-basin. Nonetheless, some streamflow and water quality data that have been collected on the lower reaches of the Rito de los Frijoles help shed light on hydrologic processes occurring in the sub-basin. Information regarding this watercourse is mentioned later in this chapter regarding the surface water budget for the Los Alamos sub-basin, and in Chapter 4 regarding surface water quality.

The watersheds within the sub-basin encompass a total area of approximately 173 mi^2. The sub-basin extends from a high elevation of 10,423 ft amsl in the Jemez Mountains to about 5360 ft amsl at the Rio Grande where the southernmost tributary (Rito de los Frijoles) joins the main stem river; thus the total elevation relief is about 5060 ft. The sub-basin receives an average annual precipitation of about 17.7 inches and a representative PET rate is 18.8 in/yr. The average slope of the several streams draining the area is approximately 230 ft/mi.

3.2.5 Pojoaque-Nambe Watershed

The Pojoaque-Nambe watershed contains several perennial and ephemeral streams that combine to form the perennial Pojoaque Creek above Pojoaque Pueblo. The tributary creeks include Rio Nambe, Rio en Medio, and Rio Chupadero, all of which originate in a part of the Sangre de Cristo Range extending from Santa Fe Baldy to Lake Peak. The Rio Capulin is a major tributary of the Rio Nambe. Upstream of the Rio en Medio's confluences with the Rio Nambe and Rio Chupadero, respectively, the Rio en Medio is the only one of the three tributaries that is considered entirely perennial. The Rio Nambe upstream of Nambe Dam contains water during much of each year, as does the reach of the river located just below Nambe Falls Dam. An operation contract between the USBR, the Pojoaque Valley Irrigation District (PVID), and the Pueblos of Nambe, Pojoaque, and San Ildefonso requires that a minimum of 0.5 cubic feet per second (cfs) be released from Nambe Falls Dam at all times. Despite the contract, zero flows have been recorded at a streamflow gaging station located a short distance downstream of the dam (Ortiz et al., 1998). In this study, most of the Nambe River downstream of the Nambe Falls Dam is classified as ephemeral.

Pojoaque Creek generally flows westward, and eventually merges with the Rio Tesuque, a perennial stream draining an entirely separate sub-basin. Below its confluence with the Rio Tesuque, the creek is referred to as the Pojoaque River.

The total drainage area for Pojoaque-Nambe watershed is approximately 123 square miles. The range in elevation is from 12,620 ft amsl on the Sangre de Cristo crest to 5490 ft amsl at Pojoaque River's outlet at the Rio Grande on San Ildefonso Pueblo. Average annual precipitation on the Pojoaque-Nambe watershed is 16.9 inches, and the estimated PET rate is 21.1 in/yr. Assuming that the combination of Nambe Creek and Pojoaque Creek forms the main stream for the watershed, the average stream slope is 182 ft/mi.

3.2.6 Tesuque Watershed

The main stream in the Tesuque drainage area is the Rio Tesuque, which is formed by the confluence of Tesuque Creek and Little Tesuque Creek. The cumulative drainage area for this watershed is 77 square miles. Originating on the west slope of the Sangre de Cristo

Range south of Lake Peak, both creeks generally flow from east to west, whereas the Rio Tesuque trends mostly north-northwest before it joins Pojoaque Creek. The elevation range is from 11,850 ft amsl to about 5750 ft amsl at the confluence with Pojoaque Creek, thus creating total elevation relief of 6100 ft. This watershed receives an average annual precipitation of about 15.3 inches and the average PET rate is 21.8 in/yr. The average slope of the main stream channel, which consists of Tesuque Creek and the Rio Tesuque, is about 90 ft/mi.

3.2.7 Caja del Rio Sub-basin

The Caja del Rio sub-basin, like the Los Alamos sub-basin, does not actually contain a single main stream that defines its drainage area. Instead, several watercourses and arroyos originating within it are directly tributary to the Rio Grande, which forms the sub-basin's west boundary. Sandwiched between the combined Tesuque and Pojoaque-Nambe watersheds on the north and the Santa Fe River on the south, the Caja del Rio sub-basin has a combined drainage area of about 158 square miles. Land surface elevations in this sub-basin are, on the whole, considerably lower than elevations for the previously-mentioned watersheds to the north, and vary from 7400 ft amsl at the highest point to about 5250 ft amsl at the Rio Grande near the sub-basin's south boundary. Accordingly, the total estimated elevation relief of 2150 feet is significantly less than comparable reliefs mentioned previously. The largest stream is Cañada Ancha, which drains the northern portion of the sub-basin and flows from southeast to northwest. The slope of its channel is 80 ft/mi, which lies toward the low end of channel slopes computed for the sub-basins. Two additional drainages occurring in the northern half of the sub-basin are defined respectively by Thirtyone Draw and Arroyo Eighteen. Drainages in the southern half include Santa Cruz Arroyo, Arroyo Tetilla, and Arroyo Colorado, the latter two of which combine to form Cañada de Cochiti, which ultimately empties into Cochiti Lake. This watershed receives an average annual precipitation of 12 inches, which is the lowest observed annual precipitation value for all of the sub-basins, and reflective of its relatively low mean elevation. The relatively low elevation also results in an estimated average PET rate of 26 in/yr, which is the highest observed value for this parameter.

3.2.8 Santa Fe River Watershed

The Santa Fe River watershed, which drains the southern extent of the Sangre de Cristo Range and covers a total area of 284 square miles, is the most urbanized of the ten sub-basins in the planning region. Major tributaries to the river include Arroyo Hondo, Arroyo Calabasas, Cienega Creek, and Alamo Creek. The Santa Fe River flows mostly from east-northeast to west-southwest from about 7 miles above Santa Fe to the Santa Fe Airport, which is located approximately 10 miles west of the city center. From the airport to its confluence with Cienega Creek, the river tends to flow more in a southward direction, and then heads almost directly east toward Cochiti Pueblo.

The elevation above the river's headwaters near Lake Peak is 12,150 ft amsl. The natural outlet for the Santa Fe River is at the Rio Grande about 2 miles south of Cochiti Lake, but the river's discharges are diverted northward to the lake about 3 miles upstream of the natural outlet. The elevation at the lake outlet is approximately 5250 ft amsl, which results in a total elevation relief for the watershed of 6900 ft. The watershed's main channel slope of 62 ft/mi

is the third lowest of all computed channel slopes, a result of a very large portion of the basin lying in relatively flat, lower-lying terrain west of the City of Santa Fe. The average annual precipitation on the watershed of 12.4 inches is the third lowest of all the sub-basin values, which somewhat reflects the fact that a large part of its drainage area lies at relatively low elevations in comparison to most watersheds located north of it. It is noteworthy to point out that the computed mean annual precipitation of 12.4 inches is smaller than the mean annual precipitation values determined for the Santa Fe and Santa Fe 2 weather stations, (14.08 and 14.27 inches, respectively [Table 2-1]) because the former is based on spatially weighted values of the contours presented in Figure 5-23, whereas the latter values are computed means using the historical record at each station. The average PET rate, computed at 24 in/yr, lies toward the high end of the range of estimated PET values.

3.2.9 North Galisteo Creek Watershed

The North Galisteo Creek watershed lies immediately south of the Santa Fe River watershed. With a drainage area of 93 square miles, it is one of the smallest sub-basins in the region. Of the ten study sub-basins, the North Galisteo Creek watershed is distinguished by having the smallest elevation relief (2510 ft), with land elevations varying from 8230 to 5720 ft amsl. In contrast to its name, the watershed does not actually contain Galisteo Creek. Rather Galisteo Creek is the defining watercourse for the South Galisteo Creek watershed, and the drainages in North Galisteo Creek watershed eventually empty into Galisteo Creek. The main stream within it is the southwestward-trending Gallina Arroyo, which is formed by the merger of Cañada de las Minas and Cañada Ancha in the foothills near the southern extent of the Sangre de Cristo Range. San Marcus Arroyo joins Gallina Arroyo about two miles upstream of the watershed's outlet at Galisteo Creek. Using the previously described procedure for computing mean annual precipitation in a sub-basin (Section 3.2), the watershed is estimated to have an average annual precipitation of 13 inches. The average PET rate is estimated to be 24 in/yr. The slope of its main stream channel is approximately 64 ft/mi.

3.2.10 South Galisteo Creek Watershed

The South Galisteo Creek watershed comprises one of the sub-basins mentioned in Section 3.2 whose borders do not everywhere coincide with natural drainage boundaries. Part of the eastern boundary of the defined sub-basin is formed by the eastern boundary of Santa Fe County. All of the western boundary of the sub-basin coincides with the border between Santa Fe County and Sandoval County. Despite these non-natural border demarcations, the South Galisteo Creek watershed is the largest of the study sub-basins, encompassing an area of about 527 square miles. The Ortiz Mountains form part of the watershed's south boundary.

In upper portions of the watershed, Apache Canyon River and Galisteo Creek combine to drain about 32 square miles of the southern end of the Sangre de Cristo Mountains. For the initial 15 miles below the confluence of these two streams, Galisteo Creek flows toward the southwest. About one mile west of the town of Galisteo, the creek begins flowing toward the west-northwest and continues in this direction until it joins the Rio Grande about 5 miles west of the Santa Fe County/Sandoval County border. Tributaries to Galisteo Creek include

Cañada Estacada, Arroyo de la Jara, Gavisco Arroyo, Cunningham Creek, and Arroyo Charro.

The South Galisteo Creek watershed varies in elevation from 10,500 ft amsl in the Sangre de Cristo Mountains to about 5400 ft amsl upon reaching the western Santa Fe County line. It receives an annual average precipitation of 14 inches, and its average PET rate is approximately 24 in/yr.

3.3 Perennial and Ephemeral Streams

Perennial and ephemeral streams in the study region were identified using a combination of a USGS 1:500,000 surface-drainage map and daily streamflow records in cases where the latter were available. Figure 3-1 illustrates the watercourses where surface water flow is perennial. The two most dominant perennial waterways are the Rio Grande and the Rio Chama. Though too numerous to list all, some of the more prominent regional perennial streams that are either directly or indirectly tributary to the Rio Grande include the Santa Cruz River, Santa Clara Creek, Rio en Medio, Pojoaque Creek, Rio Tesuque, Pojoaque River, and the Santa Fe River.

3.4 Stream Gaging Stations

DE&S identified 61 USGS stream gaging stations that may have either (1) existed within the study region, or (2) monitored flows that are indicative of surface water processes occurring in the region. Stations falling into the latter category include several on the Rio Chama, a few located downstream of Cochiti Dam in Sandoval County, and two in the Estancia Basin which lies to the southwest of the South Galisteo Creek sub-basin. The Rio Chama stations are incorporated in the surface water analysis because processes on this river affect the transfer of San Juan-Chama water rights occurring in the planning region. Figure 3-4 shows the locations of the sites and Table 3-2 lists them, distinguishing each by its USGS identifier (station number), name, location, sub-basin, drainage collection area, datum elevation, and type and period of record. It should be noted that the stations lying outside of the study region are assigned to arbitrarily named regions that include the Rio Chama, Western Estancia, and Albuquerque basins.

Gaging of flows on some tributaries to the Rio Grande has been conducted by agencies other than the USGS. Specifically, streamflow monitoring has been conducted by LANL on watersheds in the Los Alamos sub-basin (Shaull et al., 1996a; 1996b; 1998; 1999; 2000) that are tributary to the Rio Grande, which is useful for helping to quantify some surface water processes in this Los Alamos area.

Graphs of annual flow and statistical analyses have been performed on the monitored streamflow from USGS gaging stations "within" the study region having 10 or more years of daily records; 26 of the original 61 stations fall into this category. The graphs of annual streamflow in comparison to long-term average discharges are presented in Appendix E. Quantitative descriptions of each station's record are discussed in the following sections. First statistical summaries are provided for annual, monthly, and daily flows. Subsequent analyses focus on the magnitude and probability of annual low flow, magnitude and probability of annual high flow, and duration of flow.

Table 3-2. Stream Gaging Stations In and Near the Study Region

Station	Station Name	Latitude	Longitude	County	Sub-basin	Drainage Area (square miles)	Datum (feet NGVD)	Record Type	Years of Record
8291000	Santa Cruz River Near Cundiyo, NM	35.9647	-105.9039	Santa Fe	Santa Cruz	86.00	6460	daily	1932 - 1999
8293700	Arroyo Seco Tributary Near Pojoaque, NM	35.9425	-106.0200	Santa Fe	Santa Cruz	0.72	5845	peak	
8294210	Rio Nambe Below Nambe Falls Dam Near Nambe NM	35.8461	-105.9047	Santa Fe	Pojoaque-Nambe	34.10		daily	1979 - 1983, 1984 -1997
8294300	Rio Nambe At Nambe Falls, Near Nambe NM	35.8461	-105.9081	Santa Fe	Pojoaque-Nambe	25.10	6513.7	daily	1963 - 1978
8295000	Rio Nambe Near Nambe , NM	35.8597	-105.9347	Santa Fe	Pojoaque-Nambe	38.20	6280	daily	1932 - 1951
8295200	Rio En Medio Near Santa Fe, NM	35.7917	-105.7939	Santa Fe	Pojoaque-Nambe	0.63	10600	daily	1963 - 1973
8301000	Pojoaque Cr A Pojo B Near Nambe NM	35.8958	-106.0167	Santa Fe	Pojoaque-Nambe		5830	daily	1936 - 1941
8302200	Nf Tesuque Cr Near Santa Fe, NM	35.7700	-105.8086	Santa Fe	Tesuque	1.60	9670	daily	1962 - 1970
8302300	Mf Tesuque Cr Near Santa Fe, NM	35.7675	-105.8069	Santa Fe	Tesuque	0.43	9770	daily	1961 - 1970
8302400	Sf Tesuque Cr Near Santa Fe, NM	35.7603	-105.8108	Santa Fe	Tesuque	0.47	9740	daily	1962 - 1970
8302500	Tesuque Cr Above Diversions Near Santa Fe, NM	35.7389	-105.9056	Santa Fe	Tesuque	11.70	7100	daily	1936 - 1951
8304100	L Tesuque Cr Near Santa Fe, NM	35.7467	-105.8275	Santa Fe	Tesuque	0.64	9020	daily	1962 - 1970
8304200	L Tesuque Cr Tr 4 Near Santa Fe N M	35.7353	-105.8331	Santa Fe	Tesuque	0.69	8600	daily	1964 - 1965, 1968 - 1970
8304300	L Tesuque Cr Tr 3 Near Santa Fe N M	35.7264	-105.8336	Santa Fe	Tesuque	0.65	8460	daily	1963 - 1965, 1968 - 1970
8304400	L Tesuque Cr Tr 2 Near Santa Fe, NM	35.7261	-105.8567	Santa Fe	Tesuque	0.45	7960	daily	1968 - 1970
8305000	Little Tesuque Cr N San Fe, NM	35.7250	-105.8875	Santa Fe	Tesuque	7.06	7520	daily	1936 - 1941
8308025	Rio Tesuque At Grant Boundary Near Tesuque, NM	35.7669	-105.9375	Santa Fe	Tesuque			no data	
8312600	Pojoaque River Near San Ildefonso Pueblo, NM	35.8975	-106.1067	Santa Fe	Pojoaque-Nambe	184.00	5560	peak	1972 - 1978
8313000	Rio Grande At Otowi Bridge, NM	35.8747	-106.1417	Santa Fe	Los Alamos, Pojoaque-Nambe	14300.00	5488.48	daily	1895 - 1905, 1909 - 1914, 1918 - 1999
8313042	Los Alamos Canyon Near Los Alamos, NM	35.8669	-106.2225	Santa Fe	Los Alamos	9.08	6380	daily	1991 - 1995

Station	Station Name	Latitude	Longitude	County	Sub-basin	Drainage Area (square miles)	Datum (feet NGVD)	Record Type	Years of Record
8313060	Pueblo Canyon Near Los Alamos, NM	35.8703	-106.2156	Santa Fe	Los Alamos	6.94	6330	daily	1992 - 1995
8313100	Cañada Ancha Tri Near Santa Fe, NM	35.7347	-106.1167	Santa Fe	Santa Fe	1.23	6450	peak	1943 - 1976
8313350	Rito de los Frijoles In Bandelier National Monument	35.7764	-106.26834	Sandoval	Albuquerque	18	6035	daily	1963-1969 1977-1982 1993-1996
8315480	Santa Fe R Abv McClure Res, Near Santa Fe, NM	35.6889	-105.8236	Santa Fe	Santa Fe			no data	
8316000	Santa Fe River Near Santa Fe, NM	35.6867	-105.8431	Santa Fe	Santa Fe	18.20	7718	daily	1930 - 1997
8316505	Santa Fe R. blw Nichols Res.,Santa Fe	35.4122	-105.5255	Santa Fe	Santa Fe			daily	1998 - 1999
8316530	Santa Fe R. Abv St. Francis, Santa Fe	35.4119	-105.5702	Santa Fe	Santa Fe			daily	1998 - 1999
8316535	Santa Fe R. at Ricardo Rd., Santa Fe	35.4044	-105.5827	Santa Fe	Santa Fe			daily	1998 - 1999
8316600	North Frijoles Arroyo Near Santa Fe, NM	35.7194	-105.9583	Santa Fe	Santa Fe	0.33	7160	peak	
8316650	Arr. De Los Fri., Locust Tree, Near Santa Fe, NM	35.7036	-105.9719	Santa Fe	Santa Fe	1.30	7030	peak	
8316700	Arroyo De Los Frijoles Near Santa Fe, NM	35.7014	-106.0083	Santa Fe	Santa Fe	2.92	6830	peak	
8317100	Arroyo Yuma Tributary. Near Cerrillos, NM	35.5328	-106.1458	Santa Fe	Santa Fe	0.47	6017	peak	
8317200	Santa Fe River Above Cochiti Lake, NM	35.5469	-106.2281	Santa Fe	Santa Fe	231.00	5505	daily	1970 - 1997
8317203	Santa Fe River Above La Bajada, NM	35.5506	-106.2367	Santa Fe	Santa Fe			daily	1996 - 1997
8317207	Santa Fe River Below La Bajada, NM	35.5572	-106.2475	Santa Fe	Santa Fe			daily	1996 - 1997
8317500	Galisteo Creek At Canoncito, NM	35.5506	-105.8222	Santa Fe	S. Galisteo Ck	11.30	6940	peak	
8317600	San Cristobal Arroyo Near Galisteo, NM	35.3819	-105.8514	Santa Fe	S. Galisteo Ck	116.00	6190	peak	
8317700	Tarhole Canyon Near Galisteo, NM	35.3653	-105.8444	Santa Fe	S. Galisteo Ck	2.15	6270	peak	
8317720	Cañada De La Cueva Near Galisteo, NM	35.4369	-106.0125	Santa Fe	S. Galisteo Ck	1.79	6120	peak	
8317800	Cañada De Las Minas Tributary Near Santa Fe, NM	35.6075	-105.9117	Santa Fe	N. Galisteo Ck	0.56	7195	peak	
8317850	Galisteo Creek Above Galisteo Reservoir, NM	35.4494	-106.1522	Santa Fe	S. Galisteo Ck	567.00	5595	daily	1970 - 1976
8317950	Galisteo Creek Below Galisteo Dam,	35.4656	-106.2158	Santa Fe	S. Galisteo Ck	597.00	5450	daily	1970 - 1997

Station	Station Name	Latitude	Longitude	County	Sub-basin	Drainage Area (square miles)	Datum (feet NGVD)	Record Type	Years of Record
	NM								
8488000	Estancia Valley Tributary At Cedar Grove, NM	35.1681	-106.1689	Santa Fe	Western Estancia	1.21	6760	peak	
8488100	Juan Tomas Canyon Near Edgewood, NM	35.0764	-106.2294	Santa Fe	Western Estancia	20.00	6670	peak	
8313300	Rito De L Frijoles Near Los Alamos NM	35.8153	-106.3597	Los Alamos	Los Alamos	8.9	7000	daily	1960 - 1963
8279500	Rio Grande At Embudo, NM	36.2056	-105.9636	Rio Arriba	Velarde	10400	5789.14	daily	1889 - 1894, 1894 - 1912, 1912 - 1997
8281100	Rio Grande Above San Juan Pueblo, NM	36.0569	-106.0817	Rio Arriba	Velarde	10550	5630	daily	1963 - 1986, 1986 - 1997
8281200	Wolf Creek Near Chama, NM	36.9556	-106.5361	Rio Arriba	Rio Chama	27.7	8310	peak	
8283500	Rio Chama At Park View, NM	36.7375	-106.5778	Rio Arriba	Rio Chama	405	7280	daily	1913 - 1915, 1930 - 1955
8284100	Rio Chama Near La Puente, NM	36.6625	-106.6325	Rio Arriba	Rio Chama	480	7083	daily	1955 - 1997
8285500	Rio Chama Below El Vado Dam, NM	36.5800	-106.7233	Rio Arriba	Rio Chama	877	6696.12	daily	1935 - 1997
8286500	Rio Chama Above Abiquiu Re, NM	36.3183	-106.5972	Rio Arriba	Rio Chama	1600	6275	daily	1961 - 1997
8287000	Rio Chama Below Abiquiu Dam, NM	36.2367	-106.4164	Rio Arriba	Rio Chama	2147	6040	daily	1961 - 1997
8287500	Rio Chama Near Abiquiu, NM	36.2167	-106.2500	Rio Arriba	Rio Chama	2284	5873.17	daily	1941 - 1967
8290000	Rio Chama Near Chamita, NM	36.0739	-106.1111	Rio Arriba	Rio Chama	3144	5653.61	daily	1912 - 1915, 1916 - 1919, 1921 - 1923, 1927 - 1928, 1929 - 1997
8291500	Santa Cruz R At Riverside NM	35.9875	-106.0681	Rio Arriba	Santa Cruz	188	5580	daily	1942 - 1951
8292000	Santa Clara Creek Near Española, NM	35.9778	-106.1722	Rio Arriba	Santa Clara	34.5	6120	daily	1936 - 1941, 1949 - 1950, 1984 - 1994
8313500	Cochiti East Side Main Canal At Cochiti, NM	35.6172	-106.3239	Sandoval	S. Galisteo Ck			daily	1954 - 1992, 1993 - 1993, 1994 - 1995, 1996 - 1996
8314000	Sili Main Canal (At Head) At Cochiti,	35.6194	-106.3244	Sandoval	Albuquerque			daily	1954 - 1992,

Station	Station Name	Latitude	Longitude	County	Sub-basin	Drainage Area (square miles)	Datum (feet NGVD)	Record Type	Years of Record
	NM								1993 - 1993, 1994 - 1995, 1996 - 1996
8314500	Rio Grande At Cochiti, New Mexico	35.6322	-106.3189	Sandoval	S. Galisteo Ck	14600	5224.7	daily	1926 - 1970
8317400	Rio Grande Below Cochiti Dam, NM	35.6178	-106.3239	Sandoval	S. Galisteo Ck	14900	5226.08	daily	1970 - 1997
8318000	Galisteo Cr At Domingo, NM	35.5119	-106.3169	Sandoval	S. Galisteo Ck	640	5255.5	daily	1941 - 1971
8318900	San Pedro Creek Near Golden, NM	35.2292	-106.3000	Sandoval	Albuquerque	45.2	6280	peak	1953 - 1995
8319000	Rio Grande At San Felipe, NM	35.4442	-106.4397	Sandoval	Albuquerque	16100	5115.73	daily	1930 - 1997

Note:
NVGD = National Geodetic Vertical Datum

3.4.1 Annual, Monthly, and Daily Flow Statistics

Statistical descriptors of annual, monthly and daily streamflows are presented in Tables 3-3, 3-4 and 3-5, respectively. As these tables indicate, the range in monitored flows at most of the stations is quite large. On the Rio Grande at Embudo (Station 08279500), monitored daily flow rates range from 165 cubic feet per second (cfs) to 13,900 cfs; the equivalent range for the station Rio Grande at Otowi (Station 08313000) is from 106 cfs to 22,200 cfs. As an indication of how such large ranges relate to mean annual discharges, the average annual flow of the Rio Grande at Embudo is 913 cfs and that at Otowi Bridge, augmented by tributary inputs from the Rio Chama, Santa Cruz River, Santa Clara Creek, Pojoaque River, and other feeder drainages, is 1500 cfs.

Similarly, streams that drain the Sangre de Cristo Mountains show large ranges in their flows. To illustrate how flows can vary substantially at and between stations, ranges in mean daily flow and mean annual flows for several gaging stations on tributaries are mentioned. On the Santa Cruz River (Station 08291000), mean daily flow varies from 1.1 to 623 cfs, and the average annual flow is 31.7 cfs. At the Rio Tesuque Above Diversions Near Santa Fe (Station 08302500), mean daily flow varies from 0.0 to 72 cfs, and the mean annual flow is 3.36 cfs. At Station 08295200 on Rio en Medio, daily flow varies from 0.2 to 9.5 cfs, and mean annual flow is 0.83 cfs. Mean daily flow on the Rio Nambe at Nambe Falls (Station 08294300), before construction of Nambe Falls Dam, ranged from 0.3 cfs and 132 cfs, and had a mean annual discharge of 10.34 cfs. Since the dam was completed, releases from Nambe Reservoir control mean daily flow at a new station (Station 08294210), which now varies from 0.0 to 112 cfs, and maintains a mean annual value of 15.83 cfs.

The Santa Fe River Near Santa Fe (Station 08316000) is of interest because its flows are controlled by releases from McClure Reservoir; here the mean daily flow varies from 0.1 cfs to 378 cfs, and average annual flow is 8.32 cfs. Farther downstream of this site, for several miles downstream of the City of Santa Fe, flow in the river is often non-existent, and usually only occurs during periods of high runoff. Effluent from the Santa Fe Waste Water Treatment Plant (WWTP), which is located about 12 miles downstream of downtown Santa Fe, helps to maintain flow in the river upstream of its outlet at Cochiti Lake. The mean daily flow of the Santa Fe River above Cochiti Dam (Station 08317200), located approximately 11 miles downstream of the WWTP, varies from 0.0 to 1000 cfs, and has a mean annual flow of 11.67 cfs. New gages installed in 1998 on the Santa Fe River will help define the water budget between Nichols Reservoir and the WWTP when these data become available.

Three of the gaging stations that have been used to monitor flows on Galisteo Creek are respectively located (1) above Galisteo Reservoir, (2) below Galisteo Dam, and (3) at Domingo. Galisteo Creek is not a perennial stream but shows high variability of daily streamflow. Its mean daily flow at Domingo varies from 0.0 to 4100 cfs and averages 10.19 cfs.

Table 3-3. Statistical Summary of Annual Flows at Gaging Stations[1]

Station Number	Station Name	Period of Record	Annual Flow (cubic feet per second)					Coefficient of Variation
			Minimum	Maximum	Mean	Median	Standard Deviation	
8279500	Rio Grande At Embudo	1912-1997	308.21	2076.60	913.86	850.53	438.83	0.48
8281100	Rio Grande Above San Juan Pueblo	1963-1986	292.35	1644.70	808.85	807.38	388.93	0.48
8283500	Rio Chama At Park View	1930-1955	127.76	645.30	328.31	295.73	164.73	0.50
8284100	Rio Chama Near La Puente	1955-1997	63.02	723.17	364.10	367.77	170.31	0.47
8285500	Rio Chama Below El Vado Dam	1935-1997	147.76	823.44	421.52	396.02	181.92	0.43
8286500	Rio Chama Above Abiquiu Reservoir	1961-1997	186.20	823.67	479.94	440.33	191.01	0.40
8287000	Rio Chama Below Abiquiu Dam	1961-1997	199.52	872.48	506.73	490.69	178.25	0.35
8287500	Rio Chama Near Abiquiu	1941-1967	178.92	1060.70	397.33	375.31	197.75	0.50
8290000	Rio Chama Near Chamita	1929-1997	159.72	1209.90	543.54	528.41	252.44	0.46
8291000	Santa Cruz River Near Cundiyo	1932-1997	8.93	75.17	31.70	27.81	16.70	0.53
8291500	Santa Cruz River At Riverside	1942-1951	1.81	19.66	9.69	8.32	7.65	0.79
8292000	Santa Clara Creek Near Española	1984-1994	2.91	6.24	4.05	3.80	1.08	0.27
8294210	Rio Nambe Below Nambe Falls Dam	1984-1997	7.01	25.75	15.83	15.97	5.31	0.34
8294300	Rio Nambe At Nambe Falls, Near Nambe	1963-1978	6.18	28.36	10.34	9.14	5.64	0.55
8295000	Rio Nambe Near Nambe	1932-1951	3.22	28.50	10.77	9.68	6.65	0.62
8295200	Rio En Medio Near Santa Fe	1963-1973	0.50	1.60	0.83	0.77	0.37	0.44
8302500	Tesuque Cr Above Diversions Near Santa Fe	1936-1951	0.74	8.14	3.36	2.92	2.24	0.67
8313000	Rio Grande At Otowi Bridge	1918-1997	520.53	3321.60	1500.34	1464.70	671.23	0.45
8314500	Rio Grande At Cochiti	1926-1970	454.96	3298.40	1301.79	1221.65	676.36	0.52
8316000	Santa Fe River Near Santa Fe	1913-1997	1.88	26.22	8.23	6.50	4.98	0.60
8317200	Santa Fe River Above Cochiti Lake	1970-1997	6.10	40.24	11.67	8.84	6.95	0.60
8317400	Rio Grande Below Cochiti Dam	1970-1997	452.13	2355.10	1444.66	1487.60	595.94	0.41
8317850	Galisteo Creek Above Galisteo Reservoir	1970-1976	3.49	12.47	8.15	9.02	3.19	0.39
8317950	Galisteo Creek Below Galisteo Dam	1970-1997	1.28	12.80	6.13	5.72	2.99	0.49
8318000	Galisteo Cr At Domingo	1941-1971	1.49	27.61	10.19	7.94	6.82	0.67
8319000	Rio Grande At San Felipe	1930-1997	502.65	3401.70	1418.86	1344.40	674.24	0.48

[1] For stations with 10 or more years of record.

Table 3-4. Statistical Summary of Monthly Flows at Gaging Stations[1]

Station Number	Station Name	Period of Record	Statistic	Flow (cubic feet per second)												
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Calendar Year
8279500	Rio Grande At Embudo	1912-1997	Average	515.5	585.0	735.7	1082.0	2312.3	2284.0	860.5	509.7	454.5	493.7	584.9	538.1	912.98
			Median	510.4	584.5	735.3	887.3	1888.4	1876.7	533.2	378.4	330.9	373.1	530.8	524.1	
			Max	799.4	887.7	1290.0	3773.3	7227.7	8601.7	3540.1	1742.3	2255.2	1888.4	1610.8	1052.2	
			Min	300.2	323.0	285.5	273.6	248.9	199.1	188.0	185.7	170.5	181.5	243.4	269.4	
			Std Dev	98.6	118.9	210.0	737.3	1816.8	1969.8	800.1	346.8	330.6	354.8	268.1	145.5	
8281100	Rio Grande Above San Juan Pueblo	1963-1986	Average	496.7	553.6	736.3	871.4	1670.5	1918.0	836.7	492.8	384.4	427.7	601.0	507.7	791.39
			Median	489.6	533.5	736.1	807.2	1399.7	1481.4	583.1	424.7	287.6	327.1	589.6	521.9	
			Max	783.8	868.8	1146.7	3266.3	5065.8	5951.3	2721.6	1151.1	1155.0	1056.3	1213.0	840.5	
			Min	335.2	368.4	438.6	232.9	217.0	142.5	131.6	157.5	152.1	181.4	257.1	277.8	
			Std Dev	106.7	120.8	190.9	648.1	1404.5	1750.1	729.8	281.5	235.8	237.0	270.4	150.7	
8283500	Rio Chama At Park View	1930-1955	Average	44.0	53.9	114.9	927.5	1676.2	698.6	130.8	61.5	55.2	68.3	51.9	43.6	327.21
			Median	40.2	49.1	89.0	799.0	1458.6	380.0	70.1	52.4	46.0	50.5	39.0	38.0	
			Max	99.7	142.9	245.9	2710.3	3814.2	2391.0	550.3	189.4	132.9	379.8	227.9	110.7	
			Min	18.5	26.1	42.2	231.1	285.9	47.7	6.7	9.5	4.3	5.2	19.0	18.0	
			Std Dev	18.3	23.1	58.5	585.1	959.6	628.6	139.4	45.4	39.2	72.9	44.1	22.3	
8284100	Rio Chama Near La Puente	1955-1997	Average	55.4	70.1	188.3	848.0	1859.4	790.2	136.4	98.9	80.9	92.0	84.3	59.9	363.65
			Median	52.5	63.3	154.9	760.5	1732.3	552.9	84.3	82.5	61.7	59.9	63.5	54.6	
			Max	103.2	173.6	523.3	1845.7	4194.5	3200.0	571.0	352.0	320.1	561.7	422.4	131.4	
			Min	15.8	25.8	49.9	244.3	122.7	19.1	9.2	9.0	8.0	9.8	24.8	25.9	
			Std Dev	20.5	30.8	117.4	411.9	1023.3	783.1	135.7	76.6	67.0	94.0	66.0	24.9	
8285500	Rio Chama Below El Vado Dam	1935-1997	Average	89.2	150.1	272.9	648.0	1327.5	827.2	446.7	424.1	287.2	158.4	231.0	199.8	421.84
			Median	55.7	75.9	202.1	492.9	1092.2	771.5	362.8	353.9	250.6	157.1	133.4	91.0	
			Max	434.7	1414.2	1279.7	1886.7	3915.6	2341.7	1688.3	1315.8	751.0	610.4	1269.9	1271.6	
			Min	0.5	2.0	1.8	4.0	15.7	143.4	61.0	17.5	11.7	8.0	2.6	0.9	

Station Number	Station Name	Period of Record	Statistic	Flow (cubic feet per second)												
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Calendar Year
			Std Dev	102.1	220.0	284.6	553.2	936.1	499.2	334.4	308.2	200.7	125.0	280.2	277.9	
8286500	Rio Chama Above Abiquiu Reservoir	1961-1997	Average	149.2	174.6	323.1	872.3	1651.6	852.8	368.4	371.9	266.5	174.8	246.3	287.2	478.24
			Median	113.1	132.2	286.6	829.5	1603.8	728.1	333.4	322.1	249.4	159.1	184.3	189.9	
			Max	431.0	494.6	1050.0	1984.6	3740.9	2618.7	1248.7	1310.5	724.3	625.3	913.4	1273.4	
			Min	29.1	29.9	44.1	106.0	259.1	144.0	63.2	86.1	32.6	28.4	36.1	38.4	
			Std Dev	106.1	136.9	233.8	584.7	960.1	596.1	240.8	250.1	154.4	120.8	215.4	300.2	
8287000	Rio Chama Below Abiquiu Dam	1961-1997	Average	170.0	221.9	384.7	860.4	1207.1	1005.7	556.2	425.9	343.7	241.7	371.2	325.8	509.52
			Median	102.2	116.8	322.8	932.4	1159.2	934.7	505.1	374.6	304.0	183.2	294.8	152.3	
			Max	859.8	1707.9	1668.4	1894.0	3163.0	2417.7	1487.9	1084.1	1199.0	1261.1	1181.3	1308.4	
			Min	35.7	36.2	52.4	111.3	241.5	139.5	69.9	98.4	33.6	29.8	45.8	40.6	
			Std Dev	187.0	362.4	332.3	525.9	613.1	651.3	383.1	247.4	250.1	231.3	298.9	344.5	
8287500	Rio Chama Near Abiquiu	1941-1967	Average	63.2	199.8	313.9	629.8	983.0	723.1	462.1	431.3	264.5	139.6	340.8	209.5	396.70
			Median	50.2	99.7	184.0	448.1	890.3	701.0	301.6	306.9	178.6	83.2	115.3	52.0	
			Max	205.8	1381.7	1382.1	2727.7	3164.8	2083.0	1697.0	1324.2	818.0	730.0	1265.1	1111.6	
			Min	11.9	28.2	23.2	12.9	149.7	119.8	61.8	48.4	4.1	7.5	15.0	9.4	
			Std Dev	53.8	291.8	366.9	613.3	738.9	480.2	440.1	323.8	248.5	156.0	394.6	322.1	
8290000	Rio Chama Near Chamita	1929-1997	Average	144.3	240.2	420.3	1098.3	1551.1	966.9	514.9	459.2	331.6	223.4	311.5	247.6	542.46
			Median	87.6	134.9	303.8	807.8	1422.0	832.4	396.4	381.9	289.1	173.4	184.3	114.4	
			Max	876.2	1676.8	1705.2	4129.3	6542.3	3152.7	1711.9	1372.8	1163.7	1273.0	1235.8	1291.0	
			Min	29.8	49.8	44.5	57.0	187.9	70.9	24.7	10.5	2.3	1.6	20.7	25.2	
			Std Dev	153.6	315.7	358.6	841.4	1170.2	667.6	383.5	305.3	242.8	217.4	315.9	308.6	
8291000	Santa Cruz River Near Cundiyo	1932-1997	Average	9.43	10.19	20.14	51.29	98.95	78.09	28.43	25.59	19.40	15.43	12.16	10.39	31.62
			Median	8.72	9.53	15.16	49.37	83.90	56.33	23.55	19.14	15.13	12.42	10.22	9.50	
			Max	19.48	23.93	51.13	205.40	329.39	293.50	115.19	108.74	78.63	61.32	43.40	25.16	
			Min	4.75	5.44	6.97	13.22	15.88	7.05	5.64	4.57	2.47	3.88	4.69	3.82	
			Std Dev	3.11	3.48	12.06	33.78	69.34	65.57	19.90	18.32	13.01	9.23	6.08	4.09	

Station Number	Station Name	Period of Record	Statistic	Flow (cubic feet per second)												
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Calendar Year
8291500	Santa Cruz R At Riverside	1942-1951	Average	5.87	4.73	4.79	33.07	60.02	27.69	9.34	5.19	2.63	2.86	2.41	3.96	13.55
			Median	5.02	4.20	3.42	1.39	21.44	5.74	1.71	1.52	1.87	2.84	1.30	4.42	
			Max	17.94	10.93	14.98	198.57	248.45	183.85	72.55	21.39	7.80	7.45	8.40	11.45	
			Min	0.32	0.14	0.00	0.03	0.29	0.00	0.19	0.00	0.00	0.00	0.00	0.13	
			Std Dev	4.72	3.05	4.66	63.87	80.53	56.37	22.26	7.38	2.79	2.83	2.75	3.64	
8292000	Santa Clara Creek Near Española	1984-1994	Average	2.98	3.64	3.82	5.48	7.40	3.53	3.34	3.57	3.61	3.03	3.56	3.47	3.95
			Median	3.09	3.62	4.19	4.32	5.21	3.49	3.11	3.17	3.44	2.98	3.51	3.67	
			Max	3.66	4.93	5.87	13.20	17.82	5.44	5.81	6.53	7.25	4.64	6.61	4.16	
			Min	1.77	2.71	1.69	0.78	2.98	1.58	2.08	1.74	1.98	1.68	0.70	1.87	
			Std Dev	0.57	0.69	1.57	3.82	5.08	1.05	1.24	1.35	1.53	1.05	1.46	0.70	
8294210	Rio Nambe Below Nambe Falls Dam	1984-1997	Average	2.68	3.67	7.37	19.21	43.34	47.54	22.23	15.64	12.90	7.77	5.21	2.88	15.87
			Median	2.58	4.36	6.61	17.85	38.57	49.05	23.43	14.95	9.17	6.24	3.57	1.99	
			Max	5.29	7.68	17.43	42.30	85.42	93.73	47.06	32.39	45.43	19.52	11.91	8.70	
			Min	0.52	0.50	0.52	8.39	17.31	8.76	5.42	2.86	1.47	2.83	1.10	0.53	
			Std Dev	1.66	2.14	5.24	9.07	22.30	23.35	10.11	8.07	10.94	4.84	3.54	2.60	
8294300	Rio Nambe At Nambe Falls, Near Nambe	1963-1978	Average	3.59	3.62	4.95	11.51	22.96	23.78	12.32	10.84	9.16	6.89	5.43	4.23	9.94
			Median	3.70	3.78	4.65	9.44	18.10	15.90	10.34	10.43	9.43	6.93	5.39	4.26	
			Max	5.14	6.16	10.82	38.53	85.74	109.53	41.42	19.10	15.18	9.29	8.17	7.62	
			Min	1.33	1.30	1.36	2.95	7.64	6.93	4.05	4.74	3.49	4.88	1.01	0.96	
			Std Dev	1.00	1.16	2.54	8.26	18.08	24.72	9.52	4.23	2.96	1.29	1.67	1.91	
8295000	Rio Nambe Near Nambe	1932-1951	Average	3.62	3.38	4.79	14.70	31.59	25.06	10.26	8.61	8.02	7.30	5.31	3.87	10.54
			Median	3.42	3.30	4.05	14.10	26.23	17.03	8.32	6.39	6.18	6.39	4.53	3.33	
			Max	7.33	5.34	8.11	54.63	105.55	95.67	45.10	21.26	22.84	26.55	19.50	10.06	
			Min	0.71	0.95	1.26	3.37	4.67	3.30	1.36	2.52	2.25	2.10	1.19	0.78	
			Std Dev	1.28	1.01	1.97	11.23	25.24	23.92	9.81	5.13	5.39	5.24	3.78	1.86	

Station Number	Station Name	Period of Record	Statistic	Flow (cubic feet per second)												
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Calendar Year
8295200	Rio En Medio Near Santa Fe	1963-1973	Average	0.33	0.29	0.33	0.58	1.59	1.98	1.12	1.18	0.83	0.66	0.53	0.40	0.82
			Median	0.34	0.30	0.30	0.56	1.47	1.08	0.89	1.02	0.86	0.66	0.51	0.38	
			Max	0.41	0.38	0.51	0.92	3.19	7.69	3.70	1.78	1.21	0.94	0.64	0.50	
			Min	0.25	0.22	0.22	0.29	0.56	0.42	0.34	0.39	0.44	0.48	0.43	0.31	
			Std Dev	0.05	0.05	0.09	0.23	0.88	2.23	1.01	0.42	0.22	0.13	0.09	0.06	
8302500	Tesuque Cr Above Diversions Near Santa Fe	1936-1951	Average	0.98	1.04	2.09	6.21	10.60	6.76	2.40	1.79	1.53	2.02	1.50	1.07	3.17
			Median	0.94	0.97	1.67	5.10	8.95	4.31	1.84	1.19	1.42	1.58	1.10	0.96	
			Max	2.02	1.98	4.32	26.42	37.03	27.03	7.68	3.67	4.43	10.31	6.60	2.65	
			Min	0.35	0.49	0.42	0.75	0.81	0.54	0.29	0.32	0.36	0.38	0.39	0.35	
			Std Dev	0.35	0.36	1.20	5.87	9.32	6.54	2.07	1.05	0.93	2.37	1.47	0.51	
8313000	Rio Grande At Otowi Bridge	1918-1997	Average	708.6	877.0	1212.3	2250.2	4125.6	3239.1	1353.9	952.5	793.3	720.3	920.3	825.6	1498.23
			Median	677.5	806.7	1085.7	1851.0	3733.9	2899.4	1038.2	877.7	704.1	603.3	778.1	708.1	
			Max	1757.4	2641.4	3126.8	7328.7	14585.5	10401.0	4548.1	3307.7	3000.3	2685.5	2420.7	1959.0	
			Min	401.9	453.3	472.5	366.1	433.1	274.1	211.9	235.7	191.0	167.6	281.0	355.0	
			Std Dev	215.5	378.7	523.3	1536.8	3026.3	2449.5	1010.1	528.8	497.3	455.4	465.1	358.8	
8314500	Rio Grande At Cochiti		Average	650.4	826.1	1011.1	1948.6	3666.6	2699.7	1065.9	863.2	656.0	575.0	876.0	764.3	1300.23
			Median	655.3	744.9	935.3	1460.6	2556.6	1893.5	744.9	746.7	507.8	384.2	638.3	633.7	
			Max	1031.8	2161.8	2194.1	7387.0	15332.6	10113.3	4276.5	3217.4	2894.8	2863.6	2797.7	1861.0	
			Min	393.6	449.4	378.0	267.1	486.7	147.8	71.1	81.3	116.3	75.9	253.9	357.3	
			Std Dev	124.3	291.0	492.9	1526.3	3156.7	2248.1	992.9	630.3	535.3	541.6	562.0	348.3	
8316000	Santa Fe River Near Santa Fe	1931-1997	Average	2.37	2.48	4.29	10.75	21.03	16.33	8.40	7.49	6.84	4.71	2.96	2.53	7.52
			Median	1.91	1.97	3.12	6.65	13.82	11.02	7.80	6.33	5.34	3.81	2.46	1.97	
			Max	6.87	9.75	24.40	57.67	92.87	55.97	21.29	33.36	28.84	22.58	13.49	7.19	
			Min	0.20	0.25	0.34	0.24	0.53	0.70	1.06	0.81	0.90	0.58	0.20	0.22	
			Std Dev	1.44	1.82	4.42	11.34	19.65	12.47	3.63	4.96	4.84	3.52	2.34	1.74	

Station Number	Station Name	Period of Record	Statistic	Flow (cubic feet per second)												
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Calendar Year
8317200	Santa Fe River Above Cochiti Lake	1970-1997	Average	10.24	10.29	10.74	21.32	19.11	15.75	9.03	8.10	7.93	7.83	9.35	10.46	11.68
			Median	9.59	9.50	9.25	7.43	6.64	8.76	7.27	7.51	6.70	7.35	9.17	9.55	
			Max	14.58	16.50	28.58	305.93	69.32	75.33	27.98	32.79	19.21	16.42	15.53	15.35	
			Min	6.51	7.18	3.20	3.64	2.29	1.19	2.29	2.14	3.09	3.98	5.53	7.76	
			Std Dev	2.18	2.17	5.50	57.54	20.60	17.69	6.58	6.12	4.14	2.77	2.40	2.53	
8317400	Rio Grande Below Cochiti Dam	1970-1997	Average	843.6	998.1	1280.5	2104.0	3270.2	3142.8	1742.1	879.3	696.0	545.3	891.4	928.0	1443.46
			Median	756.2	825.4	1202.8	2188.7	3494.5	3742.0	942.3	748.6	653.2	537.8	848.5	796.0	
			Max	2244.8	3639.3	2868.4	6320.3	6101.0	6204.7	5643.2	3683.2	1635.0	1192.4	1878.3	1787.4	
			Min	428.3	493.1	437.7	280.8	353.3	391.6	293.1	254.0	120.9	213.9	330.8	461.1	
			Std Dev	370.5	671.9	588.6	1372.9	1934.6	2048.3	1523.2	632.6	382.4	241.7	386.2	369.0	
8317850	Galisteo Creek Above Galisteo Reservoir	1970-1976	Average	2.22	2.36	2.60	6.02	2.74	4.55	35.12	18.73	13.75	6.95	2.17	2.34	8.30
			Median	2.31	1.78	1.80	1.11	0.71	1.33	44.28	12.39	8.14	6.23	1.72	2.34	
			Max	2.52	4.83	5.45	25.60	15.26	17.42	73.88	49.75	40.29	16.58	4.15	3.60	
			Min	1.78	1.35	1.01	0.91	0.31	0.20	3.85	3.98	1.66	0.86	1.12	1.36	
			Std Dev	0.31	1.36	1.86	9.82	5.52	6.87	25.76	16.31	14.12	6.68	1.14	0.90	
8317950	Galisteo Creek Below Galisteo Dam	1970-1997	Average	1.49	2.14	2.65	2.94	3.19	6.40	21.36	16.82	10.05	4.33	1.58	1.54	6.21
			Median	1.29	1.51	1.32	1.27	0.48	0.86	15.30	12.75	4.83	0.38	0.87	0.86	
			Max	6.25	11.61	19.84	23.83	31.73	33.83	109.94	55.73	52.37	28.89	7.70	6.55	
			Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	
			Std Dev	1.39	2.42	4.04	5.34	6.92	9.71	23.28	14.54	13.58	8.10	1.98	1.71	
8318000	Galisteo Cr At Domingo	1941-1971	Average	0.3	0.1	0.4	2.9	2.1	8.6	27.2	50.4	18.2	8.9	0.6	0.4	10.01
			Median	0.1	0.0	0.0	0.0	0.0	1.5	13.7	35.0	4.1	0.8	0.0	0.1	
			Max	2.4	1.1	7.9	65.8	25.9	64.7	90.6	231.9	143.4	146.0	7.8	2.7	
			Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	
			Std Dev	0.5	0.3	1.5	12.4	5.2	16.0	28.2	49.2	33.1	27.9	1.6	0.7	
8319000	Rio Grande At San Felipe	1930-1997	Average	752.7	928.1	1182.1	2044.8	3496.2	2970.3	1484.3	994.8	742.8	637.8	929.5	862.2	1418.79

Station Number	Station Name	Period of Record	Statistic	Flow (cubic feet per second)												
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Calendar Year
			Median	700.8	809.7	1071.8	1616.9	2775.5	2334.6	1005.8	831.0	691.8	578.9	771.9	757.1	
			Max	2163.2	3694.6	3053.6	7133.0	15086.5	10655.0	5979.0	3666.8	1780.8	3328.0	3018.7	1968.7	
			Min	399.6	484.3	439.1	335.7	365.8	212.0	96.6	129.6	141.1	123.0	279.4	350.7	
			Std Dev	277.9	504.8	556.6	1481.3	2747.1	2276.8	1365.6	634.0	396.9	439.5	518.7	385.2	

[1] For stations with 10 or more years of record.

Table 3-5. Statistical Summary of Daily Flows at Gaging Stations[1]

Station Number	Station Name	Period of Record	Daily Flow (cubic feet per second)				
			Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation
8279500	Rio Grande At Embudo	1912-1997	165.00	13900.00	912.92	1184.41	1.30
8281100	Rio Grande Above San Juan Pueblo	1963-1986	95.00	7850.00	796.60	924.84	1.16
8283500	Rio Chama At Park View	1930-1955	1.30	7030.00	328.12	694.66	2.12
8284100	Rio Chama Near La Puente	1955-1997	4.40	7720.00	363.86	733.79	2.02
8285500	Rio Chama Below El Vado Dam	1935-1997	0.00	6010.00	423.57	623.54	1.47
8286500	Rio Chama Above Abiquiu Reservoir	1961-1997	7.60	6480.00	478.50	687.04	1.44
8287000	Rio Chama Below Abiquiu Dam	1961-1997	8.80	2780.00	506.53	555.06	1.10
8287500	Rio Chama Near Abiquiu	1941-1967	1.00	5330.00	397.11	549.50	1.38
8290000	Rio Chama Near Chamita	1929-1997	0.00	8760.00	543.26	743.30	1.37
8291000	Santa Cruz River Near Cundiyo	1932-1997	1.10	623.00	31.69	45.12	1.42
8291500	Santa Cruz R At Riverside	1942-1951	0.00	594.00	14.03	48.04	3.42
8292000	Santa Clara Creek Near Española	1984-1994	0.00	29.00	4.01	2.78	0.69
8294210	Rio Nambe Below Nambe Falls Dam	1984-1997	0.00	112.00	16.10	19.79	1.23
8294300	Rio Nambe At Nambe Falls, Near Nambe	1963-1978	0.30	138.00	10.02	12.30	1.23
8295000	Rio Nambe Near Nambe	1932-1951	0.10	152.00	10.57	15.00	1.42
8295200	Rio En Medio Near Santa Fe	1963-1973	0.20	9.50	0.82	0.96	1.18
8302500	Tesuque Cr Above Diversions Near Santa Fe	1936-1951	0.00	72.00	3.23	5.22	1.62
8313000	Rio Grande At Otowi Bridge	1918-1997	106.00	22200.00	1499.61	1826.16	1.22
8314500	Rio Grande At Cochiti	1926-1970	1.00	22400.00	1300.16	1737.22	1.34
8316000	Santa Fe River Near Santa Fe	1913-1997	0.10	378.00	8.32	13.41	1.61
8317200	Santa Fe River Above Cochiti Lake	1970-1997	0.00	1000.00	11.51	30.23	2.63
8317400	Rio Grande Below Cochiti Dam	1970-1997	0.51	8290.00	1443.92	1478.49	1.02
8317850	Galisteo Creek Above Galisteo Reservoir	1970-1976	0.01	873.00	8.79	40.85	4.65
8317950	Galisteo Creek Below Galisteo Dam	1970-1997	0.00	1170.00	6.32	35.42	5.60
8318000	Galisteo Cr At Domingo	1941-1971	0.00	4100.00	9.93	87.86	8.85
8319000	Rio Grande At San Felipe	1930-1997	34.00	21300.00	1418.17	1658.55	1.17

[1] For stations with 10 or more years of record.

3.4.2 Low and High Flow Analysis

Extreme, low flows at the gaging stations were also analyzed by fitting a Log-Pearson Type III probability distribution (Stedinger et al., 1993) to each series of daily measurements. The resulting probability plots are included in Appendix F, wherein the smallest mean discharge for consecutive periods of 1, 7, 30, 90, and 183 days are shown. Table 3-6 lists the corresponding consecutive 30-day low-flow values for non-exceedance probabilities of 50, 20, 10, 5, 2, and 1 percent (corresponding to return periods of 2, 5, 10, 20, 50, and 100 years, respectively).

Consecutive 30-days high flows were also analyzed probabilistically using a Log-Pearson Type III approach. The results from this exercise are summarized in Table 3-7 and presented

in graphical form in Appendix F. Comparing the probabilistic low and high flow provides a measure of the high variability associated with the surface water supply.

3.4.3 Annual Flow Probabilities

The cumulative distribution of average annual flows at the gaging stations was also investigated. Table 3-8 lists the annual flows corresponding to several different exceedance probabilities.

3.5 Dams and Reservoirs

3.5.1 Physical Features

Major dams and associated reservoirs in the planning region have bearing on the water supply study because they represent locales with existing surface-water storage capacity that may, at least conceptually, be part of a prudent water-management plan. As is often the case, most reservoirs have been constructed with their intended purposes and operations well established before dam construction. Nonetheless, because processes occurring in the reservoirs, such as FWS evaporation, may affect regional hydrologic processes, a summary of their general properties is useful. Many of the data in this regard were collected from an Internet site maintained by the Corps that presents an inventory of the dams in the United States: http://crunch.tec.army.mil/nid/webpages/nid.html. To augment information provided by this site, reservoir storage data maintained by the USGS local office (Robert Gold, USGS information officer) were accessed.

Figure 3-5 shows the locations of major dams and reservoirs in the study region. Table 3-9 summarizes characteristics of the in-region dams and associated reservoirs, and also includes descriptions of dams and reservoirs that are either located a short distance outside the planning boundary or have some bearing on potential water supply of the region. Included in this latter category are surface-water storage entities that have influence on San Juan-Chama water diverted to the Rio Chama drainage. It is important to note that one of the dams mentioned in Table 3-9 and shown on Figure 3-5, Two Mile Dam, was breached in 1994 due to dam instability. The capacity of the Two Mile Reservoir was transferred to McClure Dam by raising the height of the latter.

Water elevations at four of the reservoirs listed in Table 3-9 are included in the yearly summaries of water resources data provided by the USGS for the State of New Mexico (e.g., Ortiz et al., 1998). The reservoirs and their respective USGS station numbers are Nambe Falls Reservoir (08294200), McClure Reservoir Near Santa Fe, NM (08315500), Nichols Reservoir Near Santa Fe, NM (08316500), and Cochiti Lake Near Cochiti Pueblo, NM (08317300).

As Table 3-9 indicates, with the exception of Cochiti Reservoir on the main stem Rio Grande, the largest storage reservoirs in the study region are Santa Cruz Lake on the Santa Cruz River; Nambe Falls Reservoir on the Rio Nambe; and McClure Reservoir on the Santa Fe River. To demonstrate how inflows and outflows from reservoirs in the region can vary considerably, and to identify any potential trends in long-term reservoir storage, the historical end-of-the month storage volumes in Nambe and McClure Reservoirs are presented in

Figures 3-6 and 3-7, respectively. Each of these graphs shows the respective storage dropping considerably during 1989 and 1996, but neither indicates a long-term trend in terms of either gain or loss in storage.

3.5.2 Reservoir Operations

The storage and release of surface water in some reservoirs on the Rio Grande is subject to water delivery rules established under the Rio Grande Compact. The Compact allocates surface waters on the Rio Grande between the states of Colorado, New Mexico, and Texas, per the Compact agreement that was reached between these states in 1938. Features of the Rio Grande Compact that have bearing on the surface water flows that pass through the Jemez y Sangre region are discussed further in Section 3.9.3.

The Compact requires an annual accounting for water stored in reservoirs upstream from Elephant Butte Reservoir, which is located in southern New Mexico. Storages and releases for three of the reservoirs listed in Table 3-9 – El Vado, McClure and Nichols - are specifically affected by two requirements established under the Compact. To understand relevant storage accounting methods, it is first necessary to understand how the Compact affects the operations of these reservoirs.

The Rio Grande Compact provides that when New Mexico is in a debit status to the state of Texas, reservoirs above Elephant Butte that were constructed after 1929 must retain water in storage equal to the amount of the debit, up to the physical limitations of storage capacity of these reservoirs. Under this provision, a reservoir manager is not required to add to the amount of water already contained in the reservoir. That is, the manager is free to let inflow to the reservoir continue downstream. However, if the reservoir's storage is increased, the rules of the Compact require the manager to retain the increase in storage up to the amount of the accrued debit.

The Compact also provides that when there is less than 400,000 acre-feet of "Usable Water in Project Storage," reservoirs in New Mexico constructed after 1929 are not allowed to increase the amount of water in storage. The expression "Usable Water in Project Storage" has a specific meaning with regard to the Compact, but is roughly equivalent to the volume of water in Elephant Butte Reservoir and another reservoir located farther downstream, Caballo Reservoir, that is available for downstream use.

The Compact does not specify how the requirement to retain water in storage is to be divided between El Vado, McClure, and Nichols Reservoirs. This decision is internal to New Mexico.

Table 3-6. Probability of 30-Day Low Flow at Gaging Stations

	Probability of Non-Exceedance	0.01	0.02	0.05	0.1	0.2	0.5
	Return Period (years)	100	50	20	10	5	2
Station Number	Station Name	30-Day Low Flow (cubic feet per second)					
8279500	Rio Grande At Embudo	163.47	173.27	190.02	207.35	232.02	293.92
8281100	Rio Grande Above San Juan Pueblo	110.55	119.55	135.41	152.39	177.55	245.27
8283500	Rio Chama At Park View	2.19	3.09	4.99	7.39	11.40	23.15
8284100	Rio Chama Near La Puente	5.18	6.72	9.71	13.19	18.64	33.49
8285500	Rio Chama Below El Vado Dam	0.28	0.54	1.34	2.83	6.55	26.64
8286500	Rio Chama Above Abiquiu Reservoir	15.29	18.31	23.96	30.38	40.43	69.40
8287000	Rio Chama Below Abiquiu Dam	25.91	27.30	30.06	33.41	39.05	58.00
8287500	Rio Chama Near Abiquiu	1.58	2.38	4.23	6.75	11.25	25.56
8290000	Rio Chama Near Chamita	0.53	1.16	3.33	7.55	17.55	58.15
8291000	Santa Cruz River Near Cundiyo	3.44	3.88	4.60	5.31	6.25	8.26
8291500	Santa Cruz R At Riverside	0.00	0.00	0.00	0.00	0.00	0.13
8292000	Santa Clara Creek Near Española	0.42	0.55	0.78	1.04	1.39	2.12
8294210	Rio Nambe Below Nambe Falls Dam	0.22	0.25	0.33	0.41	0.57	1.12
8294300	Rio Nambe At Nambe Falls, Near Nambe	0.45	0.61	0.95	1.33	1.88	3.13
8295000	Rio Nambe Near Nambe	0.50	0.69	1.06	1.47	2.04	3.15
8295200	Rio En Medio Near Santa Fe	0.17	0.18	0.20	0.21	0.23	0.27
8302500	Tesuque Cr Above Diversions Near Santa Fe	0.56	0.57	0.59	0.62	0.66	0.80
8313000	Rio Grande At Otowi Bridge	141.17	164.60	205.56	248.39	309.22	456.21
8314500	Rio Grande At Cochiti	34.20	48.38	78.15	114.94	174.61	337.12
8316000	Santa Fe River Near Santa Fe	0.17	0.22	0.33	0.46	0.66	1.23
8317200	Santa Fe River Above Cochiti Lake	0.69	0.85	1.13	1.45	1.90	3.02
8317400	Rio Grande Below Cochiti Dam	72.41	89.67	122.09	158.68	214.70	366.10
8317850	Galisteo Creek Above Galisteo Reservoir	0.10	0.11	0.14	0.16	0.20	0.32
8317950	Galisteo Creek Below Galisteo Dam	0.00	0.00	0.00	0.00	0.00	0.00
8318000	Galisteo Cr At Domingo	0.00	0.00	0.00	0.00	0.00	0.00
8319000	Rio Grande At San Felipe	74.88	96.00	136.15	181.46	249.77	423.49

Table 3-7. Probability of 30-Day High Flow at Gaging Stations

	Probability of Exceedance	0.5	0.2	0.1	0.04	0.02	0.01
	Return Period (years)	2	5	10	25	50	100
Station Number	Station Name	30-Day High Flow (cubic feet per second)					
8279500	Rio Grande At Embudo	2361	4685	6586	9343	11628	14090
8281100	Rio Grande Above San Juan Pueblo	1845	3581	5032	7200	9050	11099
8283500	Rio Chama At Park View	1808	2749	3406	4266	4925	5598
8284100	Rio Chama Near La Puente	1991	3068	3699	4393	4840	5234
8285500	Rio Chama Below El Vado Dam	1489	2287	2849	3587	4155	4737
8286500	Rio Chama Above Abiquiu Re	1710	2684	3317	4085	4631	5153
8287000	Rio Chama Below Abiquiu Dam	1506	1960	2172	2368	2476	2561
8287500	Rio Chama Near Abiquiu	1256	1779	2172	2726	3181	3675
8290000	Rio Chama Near Chamita	1680	2635	3338	4302	5070	5880
8291000	Santa Cruz River Near Cundiyo	94	174	234	316	380	446
8291500	Santa Cruz R Above Riverside	32	96	165	288	408	552
8292000	Santa Clara Creek Near Española	7.2	11.7	16.0	23.5	30.8	40.1
8294210	Rio Nambe Below Nambe Falls Dam	54.5	77.5	89.8	102.5	110.3	116.8
8294300	Rio Nambe At Nambe Falls, Near Nambe	21.8	37.5	53.9	84.5	117.2	161.1
8295000	Rio Nambe Near Nambe	29.5	55.7	76.6	106.3	130.6	156.6
8295200	Rio En Medio Near Santa Fe	1.8	3.5	5.1	8.0	11.0	14.7
8302500	Tesuque Cr Above Diversions Near Santa Fe	9.8	20.4	28.6	39.8	48.4	57.0
8313000	Rio Grande At Otowi Bridge	4062	7274	9708	13052	15702	18463
8314500	Rio Grande At Cochiti	3516	6508	8949	12538	15569	18899
8316000	Santa Fe River Near Santa Fe	23	44	62	89	113	140
8317200	Santa Fe River Above Cochiti Lake	23	52	86	155	236	352
8317400	Rio Grande Below Cochiti Dam	3666	5954	7387	9051	10178	11210
8317850	Galisteo Creek Above Galisteo Reservoir	42	70	88	111	127	143
8317950	Galisteo Creek Below Galisteo Dam	31	57	75	98	115	133
8318000	Galisteo Cr At Domingo	72	134	171	210	234	254
8319000	Rio Grande At San Felipe	3506	6240	8369	11379	13832	16454

Table 3-8. Probability of Exceedance for Average Annual Flow at Gaging Stations

Station Number	Station Name	Period of Record	99	98	90	80	70	60	50	40	30	20	10	5	1
	Percent of Time Flow Was Exceeded		Average Annual Flow (cubic feet per second)												
8279500	Rio Grande At Embudo	1912-1997	283.6	297.2	385.0	473.6	589.6	737.3	872.1	989.5	1109.4	1268.8	1493.8	1759.4	2245.0
8281100	Rio Grande Above San Juan Pueblo	1963-1986	276.1	282.3	331.3	408.7	527.5	670.0	785.0	897.0	1008.2	1140.0	1370.0	1612.5	1842.5
8283500	Rio Chama At Park View	1930-1955	113.3	116.7	143.3	175.0	207.0	242.0	283.3	350.0	418.8	497.5	591.3	685.0	785.0
8284100	Rio Chama Near La Puente	1955-1997	56.7	63.4	157.5	183.8	237.3	302.0	350.0	427.0	490.0	542.5	595.0	670.0	782.0
8285500	Rio Chama Below El Vado Dam	1935-1997	134.4	152.2	200.7	243.4	290.4	344.7	390.3	435.1	500.5	592.0	708.0	769.0	923.1
8286500	Rio Chama Above Abiquiu Reservoir	1961-1997	168.0	186.0	230.3	274.0	346.0	396.8	446.3	508.8	576.3	661.4	764.3	839.0	1047.8
8287000	Rio Chama Below Abiquiu Dam	1961-1997	167.5	185.0	258.3	318.0	391.3	473.6	521.4	569.1	621.1	698.9	776.7	846.3	1049.3
8287500	Rio Chama Near Abiquiu	1941-1967	153.3	156.5	182.5	221.0	266.5	318.0	372.0	429.2	490.0	555.0	650.0	780.0	1024.6
8290000	Rio Chama Near Chamita	1929-1997	158.5	167.0	228.0	304.7	387.4	461.7	518.3	575.0	647.1	744.3	916.3	1080.7	1332.0
8291000	Santa Cruz River Near Cundiyo	1932-1997	8.5	9.5	13.0	17.1	20.6	24.2	27.7	33.0	38.6	46.4	58.0	65.4	82.5
8291500	Santa Cruz R At Riverside	1942-1951	1.8	1.8	2.2	2.8	3.3	3.6	4.0	13.6	15.2	17.2	19.6	20.8	21.8
8292000	Santa Clara Creek Near Española	1984-1994	2.3	2.4	2.7	3.1	3.3	3.6	3.8	4.0	4.7	5.3	6.2	6.7	7.0
8294210	Rio Nambe Below Nambe Falls Dam	1984-1997	5.5	5.8	7.8	10.9	12.9	14.2	15.5	17.0	18.5	20.1	21.6	24.1	27.2
8294300	Rio Nambe At Nambe Falls, Near Nambe	1963-1978	5.4	5.4	5.8	6.3	6.8	7.8	9.3	10.1	10.8	11.6	14.4	31.0	36.6
8295000	Rio Nambe Near Nambe	1932-1951	3.2	3.3	3.9	5.7	6.7	8.4	9.8	10.8	11.8	13.9	23.2	29.0	36.2
8295200	Rio En Medio Near Santa Fe	1963-1973	0.0	0.0	0.1	0.3	0.4	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.7
8302500	Tesuque Cr Above Diversions Near Santa Fe	1936-1951	0.1	0.3	1.4	1.8	2.1	2.4	2.7	3.1	3.6	4.5	7.9	8.6	9.2
8313000	Rio Grande At Otowi Bridge	1918-1997	479.8	499.5	652.2	831.1	1039.4	1286.7	1497.8	1669.6	1841.3	2108.0	2424.0	2828.0	3510.0
8314500	Rio Grande At Cochiti	1926-1970	398.4	446.8	545.0	670.0	819.7	1032.3	1228.6	1416.7	1600.0	1783.3	2140.0	2470.0	3124.0
8316000	Santa Fe River Near Santa Fe	1913-1997	2.2	2.4	3.4	4.3	4.9	5.7	6.8	8.1	9.7	11.7	16.8	20.2	25.6
8317200	Santa Fe River Above Cochiti Lake	1970-1997	5.4	5.5	6.1	6.9	7.7	8.4	9.2	12.1	13.9	15.7	19.5	21.5	46.8
8317400	Rio Grande Below Cochiti Dam	1970-1997	379.7	409.4	678.0	786.0	962.3	1220.0	1493.8	1662.5	1831.3	2037.1	2268.6	2384.3	2476.9
8317850	Galisteo Creek Above Galisteo Reservoir	1970-1976	3.2	3.2	3.6	5.7	6.7	7.5	8.2	8.9	9.8	11.5	13.6	14.8	15.8
8317950	Galisteo Creek Below Galisteo Dam	1970-1997	1.1	1.2	2.6	3.4	3.8	5.2	5.9	6.6	7.5	8.7	10.5	11.7	14.9
8318000	Galisteo Cr At Domingo	1941-1971	1.4	1.5	2.7	3.6	5.1	7.4	8.6	12.3	14.2	16.3	20.7	23.7	27.1
8319000	Rio Grande At San Felipe	1930-1997	476.8	493.5	625.6	774.4	957.9	1149.1	1331.8	1516.7	1702.8	1888.9	2278.0	2479.0	3965.0

Table 3-9. Major Dams and Reservoirs In and Near the Study Region

Corps ID	Dam Name	Latitude	Longitude	Section	County	River	Owner Type	Use	Year Completed	Maximum Discharge (CFS)	Maximum Storage (AF)	Normal Storage (AF)	Surface Area (Acre)	Drainage Area (Square Mile)
NM00179	KINSELL RESERVOIR DAM	35.1383	-105.8883	T11N R10E S32	Santa Fe	ARMIJO DRAW-TR	P	I	1911	0		574		0
NM00241	NICHOLS DAM	35.7133	-105.8797	T17N R10E S21	Santa Fe	SANTA FE RIVER	U	S	1943	19690	943	685	39	22
NM00242	MCCLURE DAM	35.6950	-105.8333	T17N R10E S24	Santa Fe	SANTA FE RIVER	U	S	1926	16100	3770	2700	77	17
NM00251	SANTA CRUZ DAM	35.9833	-105.9167	T20N R10E S27	Santa Fe	SANTA CRUZ RIVER	P	IR	1929	22000	3700		115	99
NM00561	SANTA CRUZ WATERSHED SITE 6	35.9767	-105.9850	T20N R9E S9	Santa Fe	SANTA CRUZ RIVER-TR	P	DD	1984	7134	1730	0	76	3
NM00547	LAS CAMPANAS DAM 18E	35.7167	-106.0583	T17N R8E S11	Santa Fe	OFF CHANNEL RESERVOIR	P	R	1992	840	58	31	4.9	0.92
NM00559	LAS CAMPANAS EFFLUENT STORAGE POND	35.7042	-106.0833	T17N R8E S15	Santa Fe		P	R		2	30		3	
NM00357	TWO MILE DAM	35.6883	-105.8933	T17N R10E S10	Santa Fe	SANTA FE RIVER-OS	U	S	1894	18200	605	387	23	27
NM00412	NAMBE FALLS	35.8458	-105.9092		Santa Fe	RIO NAMBE RIVER	F	IFR	1976	22500	2883	2023	74	35
NM00002	GALISTEO DAM	35.4617	-106.2083	T14N, R7E, S9	Santa Fe	GALISTEO CREEK	F	CO	1970	90000	152600	89800	1	596
NM00264	SANTA CRUZ SITE 6	35.9767	-105.9850		Santa Fe	ALAMO ARROYO TR-SANTA CRUZ	L	CO	1984	7134	1352	628	0	3.1391
NM00173	WP JOHNSON EROSION CTRL	35.8850	-107.1567	T19N R3W S9	Sandoval	JARIADO ARROYO	P	C	1945	616		124	34.7	17.89
NM00404	COCHITI	35.6250	-106.3333	T16N, R6W, S16	Sandoval	RIO GRANDE & SANTA FE	F	CROI	1975	136360	722000	50130	1200	14635
NM00127	EL VADO RESERVOIR DAM	36.5933	-106.7333	T28N R2E S33	Rio Arriba	RIO CHAMA	P	IR	1935	33500		219580		873
NM00262	SANTA CRUZ	36.0100	-105.9800	T21N R9E S34	Rio Arriba	MARTINEZ	P	C	1962	4898.6	322	0	29	2

Corps ID	Dam Name	Latitude	Longitude	Section	County	River	Owner Type	Use	Year Completed	Maximum Discharge (CFS)	Maximum Storage (AF)	Normal Storage (AF)	Surface Area (Acre)	Drainage Area (Square Mile)
	SITE 4 DAM					ARROYO								
NM00260	SANTA CRUZ SITE 1 DAM	36.0083	-105.9167	T21N R10E S31	Rio Arriba	CAÑADA ANCHA	P	C	1962	7298	963	0	43	8
NM00238	SANTA CRUZ SITE 3A DAM	36.0200	-105.9533	T21N R9E S26	Rio Arriba	SANTA CRUZ RIVER - TRIBUTARY	P	C	1972	6270	1610	0	60	2.2
NM00234	SEBASTIAN MARTIN SITE 6 DAM	36.1000	-106.0500	T22N R8E S26	Rio Arriba	ESTACA ARROYO	P	C	1973	0	1022	0	45	2
NM00261	SANTA CRUZ SITE 2G DAM	36.0133	-105.9367	T21N R9E S36	Rio Arriba	ARROYO DE LOS ENCINOS	P	C	1985	4730	1096	0	52.5	2
NM00263	SANTA CRUZ SITE 5 DAM	36.0033	-105.9867	T21N R9E S33	Rio Arriba	MORADA ARROYO	P	C	1962	3442	192	0	13	1
NM00237	SANTA CRUZ SITE 3 DAM	36.0183	-105.9550	T21N R9E S26	Rio Arriba	CAÑADA DE LOS RAMONES	P	C	1972	170	470	0	30	0.37
NM00233	SEBASTIAN MARTIN SITE 5 DAM	36.1067	-106.0650	T22N R8E S26	Rio Arriba	ARROYO DE LOPEZ	P	C	BLANK	1469	460	0	24	1
NM00441	SEBASTIAN MARTIN SITE 4 DAM	36.1033	-106.0700	T21N R8E S34	Rio Arriba	ARROYO DE BORREGOS	P	C	1977	2713	691	0	36	1
NM00122	HERON	36.6661	-106.7100		Rio Arriba	WILLOW CREEK	F	SI	1971	660	429646	401317	6148	193
NM00123	HERON DIKE	36.6717	-106.7200		Rio Arriba	WILLOW CREEK TR	F	SI	1971		429646	401317	6148	193
NM10008	EL VADO	36.5933	-106.7467		Rio Arriba	RIO CHAMA	F	ISR	1935	17800	209330	186250	3360	492
NM00001	ABIQUIU DAM	36.2400	-106.4300	T23N, R5E, S8	Rio Arriba	RIO CHAMA	F	CISO	1963	25000	1369000	170000	3900	2146
NM00438	SEBASTIAN MARTIN-BLACK MESA SITE 1	36.0817	-106.0817	T21N,R8E,S8	Rio Arriba	TRIB TO RIO GRANDE	L	CO	1978	1927	280	110	0	0.5594
NM00439	SEBASTIAN MARTIN-BLACK MESA SITE 2	36.0900	-106.0783		Rio Arriba	ARROYO DEL GUIQUE TR-RIO GRAND	L	CO	1977	636	152	48	0	0.2094
NM00440	SEBASTIAN MARTIN-BLACK MESA SITE 3	36.0967	-106.0733		Rio Arriba	SAN RAFAEL TR-RIO GRANDE	L	CO	1977	1190	151	76	0	0.3094

Corps ID	Dam Name	Latitude	Longitude	Section	County	River	Owner Type	Use	Year Completed	Maximum Discharge (CFS)	Maximum Storage (AF)	Normal Storage (AF)	Surface Area (Acre)	Drainage Area (Square Mile)
NM00518	SEBASTIAN MARTIN-BLACK MESA SITE 18	36.1383	-106.0683		Rio Arriba	TRIB. TO RIO GRANDE	L	C	1985	1666	235	67	0	0.95
NM83401	LOS ALAMOS	35.8417	-106.3731		Los Alamos	LOS ALAMOS CR	F	S	1943	600	49	41	3	5
NM00299	DOE LOS ALAMOS CANYON DAM	35.8417	-106.3731		Los Alamos	LOS ALAMOS CR	F	S	1938	600	49	41	3	5

Codes for Owner Type
F = Federal
S = State
L = Local Government
U = Public Utility
P = Private

Notes
AF = acre-feet
cfs = cubic feet per second

Codes for Use
C = Flood control/storm water management
H = Hydroelectric
I = Irrigation
N = Navigation
S = Water supply
R = Recreation
P = Fire protection, stock, or small farm pond
F = Fish and wildlife pond
D = Debris control
T = Tailings
O =Other

3.6 Ungaged Watersheds

Not every sub-basin in the study region has had flow monitored on its tributaries to the Rio Grande. A sub-basin that falls strictly into this category is Velarde. For all intents and purposes, however, the Caja del Rio and North Galisteo Creek sub-basins are ungaged, since only peak flows have been monitored on one watercourse in each sub-basin for limited periods of time. As shown in Table 3-2, Cañada Ancha Near Santa Fe (Station 08313100) in the Caja del Rio sub-basin was monitored for peak flows during the period 1943-1976. Similarly, Cañada de las Minas Near Santa Fe (Station 08317800) in the North Galisteo Creek watershed has had its peak flows monitored for an unspecified period. With such observations in mind, it is worthwhile to point out that the previously described technique for locating perennial streams identified all watercourses in each of these three sub-basins as ephemeral. Nonetheless it was important for this investigation to estimate the annual tributary inflow in ungaged areas so that water budgets could be developed for all sub-basins. One of the anticipated benefits from such an exercise was the identification of tributaries and stream reaches that would benefit from continuous monitoring.

Three separate techniques for estimating annual streamflow in ungaged areas were considered. All of the methods involved mathematical relationships that relate annual or monthly watershed yields to various factors that can potentially affect the yield. Two of the approaches were specifically based on equations describing mean flow in terms of drainage basin physiographic characteristics (Bolton, 1991; Tasker et al., 1986). The third technique by Reiland (1975) made use of a simple runoff-versus-elevation relationship based on the principles that average annual precipitation typically increases with elevation whereas temperature and PET decrease. Accordingly, streamflow is generated where precipitation exceeds evapotranspiration, resulting in greater streamflow per unit area as elevation increases. Reiland (1975), in specifically applying his methodology to the Pojoaque River watershed, developed average streamflow values per unit land area for elevation intervals that occurred within the watershed.

Because of its simplicity and project time constraints, DE&S elected to use the Reiland (1975) method to estimate the mean annual long-term streamflow from ungaged watersheds. The reader should note that this technique is frequently referred to as the elevation-area-yield approach in the following text. The unit area streamflow values used for selected elevation intervals are shown in Table 3-10. The topographic information required in using Reiland's method are derived from the 15-minute DEM maps, a composite of which is shown in Figure 3-2 for the entire study region.

Table 3-10. Unit Area Annual Streamflow Using the Method of Reiland

Elevation Interval (feet)	Annual Flow Per Unit Area (ac-ft/yr/mi^2)
5500-6000	8
6000-6500	10
6500-7000	12
7000-7500	15
7500-8000	21
8000-8500	33
8500-9000	53
9000-9500	100
9500-10,000	220
10,000-10500	400
10,500-11,000	750
11,000-11,500	1150
11,500-12,000	1600

ac-ft/yr/mi^2 = acre-feet per year per square mile.

3.7 Surface Water Budgets

Using the data and techniques described above, average annual water budgets were developed for each of the sub-basins. The budgets were based on the premise that the summed components of surface water inflow are equal to the cumulative outflow. Inflow processes included (1) watershed inflow; (2) discharge of groundwater to surface water (groundwater discharge); and (3) return flow, such as from irrigation. The surface water outflow processes comprised (1) diversions from watercourses; (2) stream loss to groundwater; (3) FWS evaporation and ET, collectively referred to as evapotranspiration; and (4) surface water outflow from the sub-basin. Some of these components have undergone change during the last century, such as those involving stream-aquifer interaction, and could still be changing. Accordingly, DE&S attempted to formulate the budgets using relatively recent hydrologic conditions, especially conditions observed during the period 1990-1999. Further explanations of what each water budget component represents and how it was developed are presented below.

3.7.1 Budget Components

3.7.1.1 Surface Water Inflow

Watershed inflow is the amount of water that annually enters the watershed as surface runoff. The exact method used to evaluate this component varies depending on the sub-basin for which it is being determined. In the Santa Cruz, Pojoaque-Nambe, Tesuque, and Santa Fe River sub-basins, surface-water inflow refers to the amount of runoff occurring at the

mountain-front, which, in this study, is defined as the lowest elevation at which crystalline rocks outcrop. (The concept of "mountain-front" is discussed further in Chapter 5). In the Velarde watershed, surface-water inflow is defined as the combined flow entering the sub-basin from the Rio Grande and mountain-front runoff. In the Santa Clara and Los Alamos areas, inflow represents the runoff generated near the eastern-most extent of lava flows on the Pajarito Plateau. Surface-water inflows to the Caja del Rio and North Galisteo Creek sub-basins were estimated for the entire surface area of each. In the South Galisteo Creek sub-basin, surface-water inflow was assumed to equal the runoff generated above an elevation of 6500 ft amsl. It should be noted that the choice of physical location at which to apply the Reiland (1975) method was arbitrary for the Santa Clara, Los Alamos, Caja del Rio, North Galisteo Creek, and South Galisteo Creek sub-basins. In contrast, the selection of the mountain-front as the location at which surface water inflow was calculated in the remaining basins draining the western side of the Sangre de Cristo Mountains was somewhat substantiated by the fact the Reiland (1975) method was developed using gaged flow data from this part of the study region.

Wherever possible, stream gage data were used to estimate surface-water inflow. Except for a few sub-basins, however, streamflow gaging stations did not coincide with the locations identified above as where inflow is determined. Thus most of the inflow estimates were developed using the elevation-area-yield approach (Reiland, 1975) described in Section 3.6. Typically, the inflow estimate was compared with streamflow data for stations located either up- or downstream from the point of estimation to develop a sense of its validity.

3.7.1.2 Stream-Aquifer Exchange

The two budget components reflective of exchange between surface-water and groundwater sources, namely groundwater discharge to surface water and stream losses to adjoining aquifers, were examined from two perspectives. Initially, DE&S examined the potential for computing stream-aquifer exchange using hydraulic heads in adjacent groundwater and surface water media. However, the data available for conducting such analyses was found to be quite approximate, which meant that any computed stream losses or gains using this approach would be very uncertain.

Consequently, DE&S began looking at stream-aquifer exchange from the alternative perspective, in which stream losses or gains were considered the most uncertain components of each surface water budget. This essentially meant that net stream gains or losses would be estimated as the balance remaining from comparison of other, more certain budget components. This in turn meant that such an estimated quantity represented a net gain or loss, and that specific losses or gains on actual stream reaches would not be quantified. For a few of the sub-basins, the process of elimination approach to estimating net stream-aquifer exchange could be somewhat altered if (1) selected stream-gage data could be used to reasonably estimate either gains or losses along specific watercourse reaches,
(2) groundwater discharge to surface water could be reasonably estimated using measured spring flows, or (3) estimates of stream-aquifer exchange quantities were available from separate sources.

3.7.1.3 Evapotranspiration

Total evapotranspiration in a sub-basin represents combined FWS evaporation and evapotranspiration (ET) from riparian areas where the water table is assumed to be, on average, quite shallow (3-10 feet below ground surface). The FWS evaporation outflows from streams, canals and reservoirs were developed by multiplying the surface areas of perennial water bodies by an average evaporation rate of 45 inches/year (in/yr). Comparison of this value with the free water evaporation rates shown in Figure 2-7 indicates that 45 in/yr is low compared to values estimated by others. To some extent, the choice of 45 in/yr was based on iterative approaches applied during the development of sub-basin water budgets.

Estimates of ET losses from riparian corridors were developed by multiplying riparian surface areas by representative PET rates taken from Table 3-1. Landsat imagery provided by Santa Fe County for land use in 1992, as shown in Figure 3-3, was used to delineate the riparian areas. Table 3-11 summarizes, by sub-basin, estimated free water surface (FWS) areas associated with perennial watercourses and reservoirs, estimated riparian areas, applied FWS evaporation and PET rates, and the resulting estimates of total ET.

3.7.1.4 Diversions, Depletions and Return Flows

Diversions represent the gross amount of water removed from waterways that is intended for human use. With the exception of the Santa Fe sub-basin, where some natural runoff is directed toward human consumption, irrigation of cropland comprises the predominant land use for which surface water is diverted. Irrigation diversions were estimated by multiplying an irrigated acreage value by an irrigation application rate that varied with each sub-basin. A definition of the irrigation application rate is presented in Section 3.7.2.

Depletions represent the amount of diverted water that is actually consumed. Most depletions in the study region result from crop ET losses, such as from a farm or field; FWS evaporation on streams and irrigation delivery canals; and ET losses to near-canal phreatophytes (Wilson and Lucero, 1997). It is uncommon, however, for all diverted water to be depleted; instead, much of the water is often returned to its natural flow system. Included in the category of "return flows" are (1) irrigation applications that initially seep into the ground but eventually return to a natural watercourse via groundwater discharge or drain flow and (2) delivery canal losses to groundwater that also eventually return to a natural watercourse via drain flow or groundwater discharge to surface water.

Table 3-11. Estimated Sub-basin Evapotranspiration Associated With Surface Water.

	Free Water Surface			Riparian Areas			
Sub-basin	Estimated FWS Area[1]	FWS Evapo-ration Rate	FWS Evapo-ration Volume	Estimated Riparian Area[2]	Average PET Rate	Riparian ET Volume	Total ET Volume[3]
	acres	in/yr	afy	acres	in/yr	afy	afy
Velarde (including the Rio Grande)	195 (Rio Grande surface)	45	731	1000	22.1	1842	2580
Santa Cruz	132	45	495	2000	19.1	3183	3680
Santa Clara	None	45	0	310	21.2	550	550
Los Alamos	106	45	398	1027	18.6	1592	1990
Pojoaque-Nambe	120	45	450	1365	21.1	2400	2850
Tesuque	80	45	300	540	21.8	980	1280
Caja del Rio	None	45	0	92	26.0	200	200
Santa Fe River	80	45	300	440	24.0	880	1180
North Galisteo Creek	None	45	0	65	24.0	130	130
South Galisteo Creek	125	45	469	1050	24.0	2100	2570

[1]FWS area estimated using 1992 Landsat image.
[2]Riparian area estimated using 1992 Landsat image.
[3]Total ET volume = FWS evaporation volume + riparian ET volume
in/yr = inches per year
afy = acre-feet per year

3.7.2 Estimation of Diversions, Depletions, and Return Flows

Several sources were considered for estimating irrigated acreage in the various sub-basins. These included (1) the planning office of Rio Arriba County; (2) Wilson and Lucero (1997); (3) 1992 Landsat imagery, a composite of which is shown in Figure 3-3; and (4) hydrographic surveys for various parts of the region. A listing of the irrigated acreages determined by each source is given in Table 3-12. As this table indicates, large discrepancies exist between the several estimates of irrigated acreage. Such discrepancies warrant some discussion of the various methods that have been used to arrive at the listed estimates.

In nearly all cases but one (subtotal irrigated acreage in the Santa Cruz sub-basin), the acreage estimated using 1992 Landsat imagery is smaller than comparable estimates based on ground surveys. If it is assumed that the areas based on the 1992 Landsat information are in error, and that the Landsat imagery was interpreted correctly, there are two possible causes of the error:

(1) Signature dilution – This phenomenon results when ground parcels are too small to occupy a whole pixel, a problem that might be corrected by ground-truthing the Landsat interpretation with field data or using a smaller pixel size.

(2) The ground truth for discriminating between irrigation and riparian land use may have been developed for an area other than the Jemez y Sangre region, and the other area may not provide appropriate discriminants for the planning region.

The possibility also exists that the estimated irrigated areas based on ground surveys might constitute what some investigators perceive as "overestimates." For example, some estimates might take into account land that has been "historically irrigated" rather than land that is currently irrigated. Similarly, a ground survey may classify as irrigated property land that is "potentially irrigable," in which the soils and slopes in question are adjacent to historically irrigated areas. Whether some estimates of irrigated acreage in Table 3-12 are more realistic than others is subject to debate. What is clear is that specific irrigated area quantities had to be selected so that surface water budgets could be developed.

The methods of Wilson and Lucero (1997) were applied to apportion surface water diversions among depletions and return flows. The reader should be aware that their methods make use of several terms and expressions that have very specific meanings, such as consumptive irrigation requirement (CIR); on-farm irrigation efficiency (Ef); off-farm conveyance efficiency (Ec); incidental, above-farm depletions; incidental, on-farm depletions; and incidental, below-farm depletions. A glossary describing the meaning of these and several other expressions applied by Wilson and Lucero (1997) is provided in Appendix G. The values assigned to many of them, along with total irrigated acreages that were adopted for each sub-basin, and computed diversions, depletions, and return flows, are listed in Table 3-13.

The diversion quantities given in Table 3-13 are representative of an irrigation application rate, which was defined as consumptive irrigation requirement (CIR) divided by the product of the on-farm irrigation efficiency and off-farm conveyance efficiency. Most of the CIR values used were taken from Wilson and Lucero (1997). CIR values for the Pojoaque-Nambe and Tesuque sub-basins were taken from a court order issued under the Aamodt water rights adjudication case (U.S. District Court, 1994). Total depletions were calculated by multiplying the appropriate CIR by the irrigated acreage, and in turn augmenting the resulting product by a fraction reflective of cumulative incidental losses. Return flows, which were assumed to go back to the natural drainage system, were determined by subtracting total depletions from irrigation diversions. In addition to surface-water computations, Table 3-13 lists analogous groundwater budget values associated with irrigation.

Surface water diversions for human consumption in the Santa Fe River sub-basin were estimated using historical records provided by a technical subcommittee to the JySWP Council. The average of annual Santa Fe River diversions for urban use between 1990 and 1999 was used to develop the budget for this sub-basin.

Another potential source of information that was considered for estimating sub-basin diversions and return flows was the Upper Rio Grande Water Operation Model (URGWOM) (U.S. Army Corps of Engineers, 2000). Because this model simulates flows on the Rio Grande and Rio Chama within the planning region, it was initially believed to be a viable

source of data regarding river channel seepage (i.e., losses and or gains), tributary inflow, river-surface evaporation, river diversions, agricultural depletions, and agricultural return flows. During the first few weeks of the project, DE&S personnel visited with Corps personnel to see if such budget components had been developed for the portion of the model lying within the JySWP region. Unfortunately, it was learned that the above-mentioned components for the Española Basin have only been developed in a very rough sense, with all of the components that affect river flow over a given reach being identified by a single term known as "local inflow." Consequently, DE&S could use the computed local inflows only to provide a rough check on composite budget values developed for each sub-basin that adjoins either the Rio Grande or the Rio Chama.

As URGWOM undergoes continued improvements in coming years, some of the more specific budget components developed for the model should provide additional information for use in several of the sub-basins. URGWOM is being developed jointly by personnel from the USBR, the Corps, and the USGS. The Jemez y Sangre Council could acquire information useful for its planning by maintaining contact with the model developers.

Table 3-14 summarizes the resulting computed inflows and outflows for each sub-basin. The following sections provide further discussion on the individual budgets.

Table 3-12. Irrigated Acreage Estimates for the Planning Region

Sub-basin	Information Source			
	Rio Arriba County Planning Office (irrigated acres)	1992-Landsat Image (irrigated acres)[1]	Wilson and Lucero (1997) (irrigated acres)	Hydrographic Survey (irrigated acres)
Velarde				
Velarde Area	1815	3176	2870	NA
Rio de Truchas Area	3258	334	2925	2064.3[1]
Subtotal	*5073*	*3510*	*5795*	*2064.3*
Santa Cruz				4780[2]
Rio Arriba County	1326	1010	4155	
Santa Fe County		910	5735	
Subtotal	*1326*	*1920*	*9888*	*4780*
Santa Clara	699	545	NA	NA
Los Alamos		0	0	0
Pojoaque-Nambe		957	2375	3538[3]
Tesuque		170	(included in Pojoaque-Nambe estimate)	(included in Pojoaque-Nambe estimate)
Caja del Rio		0	0	0
Santa Fe River		306	965	485[4]
North Galisteo Creek		0	0	0
South Galisteo Creek		88	0	0

[1] Hydrographic survey conducted during 1970.
[2] Hydrographic survey conducted during 1970.
[3] Hydrographic survey conducted during 1966.
[4] Hydrographic survey conducted during 1976.
NA = not available.

Table 3-13. Estimated Irrigation Diversions, Depletions, and Return Flows

Sub-basin	Irrigated Land[1] (acres)		Consumptive Irrigation Requirement, CIR[2] (ft/yr)		On-Farm Irrigation Efficiency[2] (dimensionless)		Off-farm Conveyance Efficiency[2] (dimensionless)		Total Diversion[3] (ac-ft/yr)		Incidental Depletion Fraction[2] (dimensionless)		Total Depletion[4] (ac-ft/yr)		Return Flow[5] (ac-ft/yr)	
	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water
Velarde																
Velarde and Vicinity	2835	35	1.807	1.122	0.5	0.85	0.7	0	14637	46	0.168	0	5983	39	8653	7
Rio deTruchas	2925	0	1.126	0	0.4	0	0.7	0	11763	0	0.113	0	3666	0	8097	0
Subtotal	*5760*	*35*							*26400*				*9649*		*16750*	
Santa Cruz																
Rio Arriba County	4155	0	0.894	0	0.55	0	0.7	0	9648	0	0.179	0	4379	0	5269	0
Santa Fe County	5735	0	0.675	0	0.55	0	0.7	0	10055	0	0.179	0	4564	0	5491	0
Subtotal	*9890*								*19703*				*8943*		*10760*	
Santa Clara	699[6]	0	0.894	0	0.55	0	0.7	0	1623	0	0.179	0	737	0	886	0
Pojoaque-Nambe	1900[7]	120	1.84[8]	1.678	0.55	0.55	0.7529	0.7529	8442	366	0.14	0.11	3985	224	4457	143
Tesuque	475[9]	0	1.84[8]	1.678	0.55	0.55	0.7529	0.7529	2111	0	0.14	0.11	996	0	1115	0
Caja del Rio	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Santa Fe River																
Drip Irrigation	0	20	0	0.938	0	0.85	0	0	0	22	0	0	0	19	0	3
Flood Irrigation	815	130	1.14	1.14	0.5	0.5	0.7	0.7	2655	296	0.179	0.15	1095	170	1559	126
Subtotal	*815*								*2655*	*318*			*1095*	*189*	*1559*	*129*
North Galisteo Cr.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
South Galisteo Cr.	88[10]	0	1.14	0	0.5	0	0.7	0	287	0	0.179	0	118	0	168	0

[1] Unless noted otherwise, irrigated acreage is taken from Wilson and Lucero (1997).
[2] Unless noted otherwise, values taken from Wilson and Lucero (1997).
[3] Total diversion = (irrigated acreage x CIR)/[(on-farm irrigation efficiency) x (off-farm irrigation efficiency)]
[4] Total depletion = (irrigated acreage x CIR) x (1 + incidental depletion fraction).

[5] Return flow = total diversion – total depletion.
[6] Irrigated acreage in the Santa Clara sub-basin taken from estimate by the Rio Arriba County Planning Office.
[7] Irrigated acreage in the Pojoaque-Nambe sub-basin assumed equal to 80% of Wilson and Lucero (1997) estimate for combined area of Pojoaque-Nambe and Tesuque Sub-basins.
[8] Consumptive irrigation requirement in the Pojoaque-Nambe sub-basin based on an Order of the Court in the Aamodt adjudication case. (U.S. District Court, 1994).
[9] Irrigated acreage in the Tesuque sub-basin assumed equal to 20% of Wilson and Lucero (1997) estimate for combined area of Pojoaque-Nambe and Tesuque Sub-basins.
[10] Irrigated acreage in the South Galisteo Creek sub-basin estimated using 1992 Landsat image.

Table 3-14. Surface Water Budgets by Sub-basin.

Sub-basin	Inflow (acre-feet/year)				Outflow (acre-feet/year)				
	Surface Inflow[1]	Groundwater Discharge[2]	Return Flow (IRRIG + M&I)[4]	Total Inflow[6]	Diversions (IRRIG + M&I)[3]	Stream Loss[5]	Evapotran-spiration[8]	Surface Outflow	Total Outflow[7]
Velarde (including the Rio Grande)	593,580[9]	5800[10]	16,750	616,130	26,400	1800	2570	585,360[11]	616,130
Santa Cruz	26,280[12]	0[13]	10,760	37,040	19,700	5190	3680	8470[14]	37,040
Santa Clara	5570	0[15]	890	6460	1620	510	550	3780[16]	6460
Los Alamos	2790	0[17]	0	2790	0	400	1990	400[18]	2790
Pojoaque-Nambe	10,540[19]	4000[20]	4455	18,995	8440	5000[21]	2850	2705[22]	18,995
Tesuque	3500	1815[23]	1115	6430	2110	2500[24]	1280	540[25]	6430
Caja del Rio	1350	0[26]	0	1350	0	1150	200	0	1350
Santa Fe River	7850[27]	2170[28]	8060[29]	18,080	7290[30]	8500[31]	1180	1110[32]	18,080
North Galisteo Creek	900	0[33]	0	900	0	770	130	0	900
South Galisteo Creek	6240	890	170	7300	290	0[34]	2570	4440	7300

[1] Unless noted otherwise, surface water inflow is estimated using the Reiland (1975) method.
[2] Unless noted otherwise, groundwater discharge to surface water represents a net surface water gain determined through comparison of all other budget components.
[3] Unless noted otherwise, diversions are equal to total irrigation diversions presented in Table 3-13.
[4] Unless noted otherwise, return flows are equal to irrigation return flows presented in Table 3-13.
[5] Unless noted otherwise, stream loss represents a net surface water loss determined through comparison of all other budget components.
[6] Total inflow = surface inflow + groundwater discharge + return flow.
[7] Total outflow = diversions + stream loss + evapotranspiration + surface outflow.
[8] Total evapotranspiration volumes taken from Table 3-11.
[9] Velarde surface inflow estimated using a combination of measured flows on the Rio Grande at Embudo (591,160 afy) and the Reiland (1975) method for watersheds draining the Sangre de Cristo Range (2420 afy).
[10] Based on information in Spiegel and Baldwin (1963), Hearne (1985), McAda and Wasiolek (1988), and Frenzel (1995), groundwater discharge in the Velarde sub-basin assumes an average loss to the Rio Grande between Embudo and San Juan Pueblo (16 miles) of 0.5 cfs/mi.
[11] Surface outflow from Velarde sub-basin based on reported average annual flow rate of 808 cfs at Rio Grande above San Juan Pueblo.
[12] Surface water inflow in the Santa Cruz sub-basin estimated based on gage data at the Santa Cruz River Near Cundiyo (22,950 afy) and surface water yields from the Rio Quemado using the Reiland (1975) method (3330 afy).
[13] Zero groundwater discharge in the Santa Cruz watershed corresponds with an estimated net stream loss rate as determined from comparison of all other water budget components.
[14] Surface water outflow from the Santa Cruz watershed based on (1) stream gage data for the Santa Cruz River Near Riverside (7015 afy) and (2) estimated annual yields from Arroyo Seco and Arroyo Madrid (1445 afy) using the method of Reiland (1975).
[15] Zero groundwater discharge in the Santa Clara watershed corresponds with an estimated net stream loss rate as determined from comparison of all other water budget components.
[16] Surface water outflow from the Santa Clara watershed based on a combination of average flows measured at gaging station Santa Clara Creek Near Española and estimated yields from other sub-basin tributaries using the method of Reiland (1975).
[17] Groundwater discharge to surface water estimated at zero based on LANL groundwater modeling (Elizabeth Keating, personal communication)

[18] Surface water outflow from Los Alamos sub-basin estimated as approximately half of measured flows during 1995-1999 water years on streams near the downstream boundary of LANL (Shaull et al., 1996a; 1996 b; 1998; 1999, 2000).
[19] Surface water inflow to the Pojoaque-Nambe sub-basin based on an estimated 10,000 afy from mountain-front sources and 540 afy inflow from the Tesuque sub-basin.
[20] Inflow from groundwater discharge in the Pojoaque-Nambe sub-basin estimated using data provided in Frenzel (1995).
[21] Outflow to stream loss in the Pojoaque-Nambe sub-basin estimated using data provided in Frenzel (1995).
[22] Surface water outflow from the Pojoaque-Nambe sub-basin computed through comparison of all other water budget components.
[23] Inflow due to groundwater discharge in the Tesuque sub-basin estimated using data provided in Frenzel (1995).
[24] Outflow due to stream loss in the Tesuque sub-basin estimated using data from Frenzel (1995).
[25] Surface water outflow from the Tesuque sub-basin computed through comparison of all other budget components.
[26] Zero groundwater discharge in the Caja del Rio sub-basin corresponds with an estimated net stream loss rate as determined from comparison of all other water budget components.
[27] Surface water inflow to Santa Fe River sub-basin represents combination of inflows calculated by Wasiolek (1995) for the river upstream of City of Santa Fe and estimated inflows from Arroyo Hondo using the Reiland (1975) method.
[28] Groundwater discharge to Santa Fe River occurs near La Cienega, based on information provided in CDM (1998).
[29] Return flow in the Santa Fe River Sub-basin estimated as a combination of return flows from irrigation using the method of Wilson and Lucero (1997) and average of measured Santa Fe Waste Water Treatment Plant discharge (6500 afy) during the years 1993-1997.
[30] Diversions in the Santa Fe River sub-basin represents a combination of agricultural diversions listed in Table 3-13 and the average surface water diversion for municipal purposes (4637 afy) during the years 1990-1999.
[31] Stream loss estimate in the Santa Fe River sub-basin based partly on data provided in CDM (1998) and partly on the basis of balancing total inflows with outflows. Of the 8500 afy total, 3770 afy is assumed to occur upstream of La Cienega, and 4730 afy is assumed to occur downstream of La Cienega, where it eventually surfaces in Cochiti Springs.
[32] Surface water outflow from the Santa Fe River sub-basin estimated through comparison of all other water budget components.
[33] Zero groundwater discharge in the North Galisteo Creek sub-basin corresponds with an estimated net stream loss rate as determined from comparison of all other water budget components.
[34] Zero stream loss in the South Galisteo Creek sub-basin corresponds with an estimated net groundwater discharge as determined from comparison of all other water budget components.
[35] Surface water outflow from the South Galisteo Creek sub-basin computed using the average flow at gaging station South Galisteo Creek Below Galisteo Reservoir.

3.7.3 Velarde Watershed

Inflow

Surface water inflow to the Velarde sub-basin consists primarily of Rio Grande flow at Embudo (measured at Station 08279500) and runoff from the Sangre de Cristo Mountains east of the river. Any runoff from the western side of the river in the vicinity of Black Mesa is considered so minor as to be imperceptible within the total sub-basin budget. The average of discharges at the Embudo gage during the years 1963 to 1986 (816 cfs) were used to compute part of the area's surface water inflow of 593,580 afy, while tributary inflow (2420 afy) was derived using the Reiland (1975) method.

Groundwater discharge to surface water along the Rio Grande has generally been estimated at about 0.5 to 1.0 cfs per river mile (Spiegel and Baldwin, 1963; Hearne, 1985; McAda and Wasiolek, 1988; Frenzel, 1995). On the river reach between Embudo and San Juan Pueblo (16 miles), the Rio Grande was assumed to gain in flow from groundwater discharge at a rate of 0.5 cfs/mi, which resulted in a total annual river gain of 5800 afy. Return flow in this sub-basin, estimated at 16,750 afy, was determined using irrigated acreages and the methods of Wilson and Lucero (1997), as previously summarized in Table 3-13.

Outflow

Irrigated acreage in the Velarde sub-basin is concentrated on either side of the Rio Grande and along reaches of the Rio de Truchas. Irrigated acreages in the area in 1995 as reported by Wilson and Lucero (1997) were used to estimate irrigation diversions. FWS evaporation losses from the Rio Grande channel were estimated assuming a river distance of 16 miles from Embudo to where the river intersects the sub-basin's south boundary, an average river width of 100 feet, and a FWS evaporation rate of 45 in/yr, which results in about 730 afy of outflow. ET losses near the Rio Grande and Rio de Truchas were computed using an estimated riparian acreage of 1000 acres, as measured from the 1992 Landsat map (Figure 3-3), and an ET rate of 22.1 in/yr.

The remaining budget component, loss of surface water to groundwater, was computed at 1800 afy by comparing all aforementioned components, and thus represents a net value. This outflow component was assumed to occur at higher elevations within the sub-basin, to the east of the Rio Grande.

Limitations of Velarde Sub-basin Budget Estimates

Estimation of the surface water budget for the Velarde sub-basin is somewhat complicated by the fact that it encompasses a part of the Rio Grande Valley that is relatively wide, and in which a considerable quantity of the land lying adjacent to the river is irrigated and traversed by irrigation canals. In addition, the Rio Chama enters the sub-basin along its western side close the sub-basin's southern extent. As discussed in

the foregoing paragraphs, the effect of the Rio Grande on the sub-basin's total water budget has been taken into account. However, because data from the gage Rio Grande Above San Juan Pueblo, which lies upstream of the river's confluence with the Rio Chama, has been used herein to estimate sub-basin outflow, the effects of the Rio Chama have been purposefully avoided. In taking the approach described above, certain items that potentially affect flows in the sub-basin are obviously not included in the budget estimates. One of these comprises the flows occurring in various irrigation canals that run parallel to the Rio Grande, and another exists in the form of irrigation canals carrying water diverted from the Rio Chama that enter the sub-basin and provide water that can potentially be returned in part to the Rio Grande. When examining the budget for the Velarde sub-basin, the reader should take into account that these items are not specifically assessed.

Another result of developing the Velarde sub-basin budget based on a combination of surface water processes occurring in and near the Rio Grande and (b) processes occurring in watersheds tributary to the Rio Grande is that the former are characteristically much larger than the latter, making it difficult to develop a more refined water surface water budget for the tributary portion of the sub-basin. In many ways, this problem is expected as all of the tributary watersheds in this area are classified as ephemeral, and no gaging stations are located in them. Yet, if the estimated surface water inflow to tributaries of 2420 afy is feasible, and a large portion of the estimated surface water diversion for the Rio de Truchas area (11,763 afy, Table 3-13) is actually attributed to diversions from tributaries, surface water flow in the tributaries has the potential to be significant.

An approximations of the total inflow to the tributary portion of the sub-basin can be computed as the sum of estimated surface water inflow and irrigation return flow, which results in 10,515 afy. Total surface outflow from the tributary area is calculated as the sum of irrigation diversions, loss of surface water to evapotranspiration, and a net loss of surface water to groundwater (stream loss), resulting in 16,135 afy. The difference in total inflow and outflow for the tributary portion of the watershed, as determined with two computations mentioned above, is unavoidable because of the method originally applied to develop the sub-basin's surface water budget. Nevertheless, both the computed tributary inflow and outflow are large enough to suggest that quantities of surface water flow associated with this part of the Velarde sub-basin are quite large. These observations indicate that more detailed studies of the water budget for the eastern side of the Rio Grande within this sub-basin are warranted.

3.7.4 Santa Cruz Watershed

Inflow

Surface water inflow to the upper part of the Santa Cruz watershed was partly estimated using data from the gaging station Santa Cruz River Near Cundiyo (Station 8291000), where the average measured annual flow translates into an inflow of 22,950 afy. The surface discharges at this location represent combined flow from Rio Medio and Rio Frijoles. To estimate the remaining mountain-front surface runoff from Rio Quemado as it joins the Santa Cruz River near Chimayo, the elevation-area-yield approach by Reiland

(1975) was applied, which produced an inflow of 3330 afy. The resulting total estimated flow entering the watershed near the mountain front was 26,280 afy.

Return flow in the Santa Cruz Sub-basin was estimated using irrigated acreages and the methods of Wilson and Lucero (1997), as documented in Table 3-13. The water budget in Table 3-14 shows no net groundwater discharge to surface water. This occurs because a net stream loss is computed for this sub-basin, as discussed in the following discussion concerning outflow. Thus the reader should understand that some surface water gains due to groundwater discharge in this sub-basin may be possible though they are not specifically included in the water budget.

Outflow

Computed irrigated acreages provided by Wilson and Lucero (1997) were used to estimate irrigation diversions of 19,700 afy. A combined FWS evaporation and ET outflow of 3680 afy was also estimated; this latter component was based on (1) an estimated 2000 acres of riparian area (from the 1992 Landsat image) subject to an ET rate of 19.1 in/yr and (2) an estimated 132 acres of combined stream channel and reservoir surface area (from the 1992 Landsat image) subject to a FWS evaporation rate of 45 in/yr. Surface water outflow from the watershed, estimated at 8460 afy, was based on (1) stream gage data from the Santa Cruz River Near Riverside (Station 08291500) combined with (2) estimated yields, using the Reiland (1975) method, from Arroyo Seco and Arroyo Madrid. The annual flows computed for these two locations were 7015 and 1445 afy, respectively.

Upon combining all of the above-mentioned budget components, a residual of 5190 afy of outflow was computed, which was assumed to represent a total net stream loss to groundwater.

Limitations of Santa Cruz Sub-basin Budget Estimates

The estimated surface water budget for the Santa Cruz sub-basin suggests that both surface water inflow from the mountain front and surface water diversions from Rio Grande tributaries are larger in this area than in any other sub-basin. With such large quantities of surface water moving through the watershed, the development of relatively reliable estimates of stream loss to groundwater and groundwater discharge to surface water would be desirable. However, the approach applied in this study only produces a net stream loss to groundwater, thus failing to differentiate between both types of stream-aquifer exchange. On the basis of a regional groundwater flow model of pre-development conditions developed by Hearne (1985), it appears that both stream losses to groundwater and groundwater discharges to surface water occur in the Santa Cruz watershed. Assessments of other, similar watersheds located to the south (Pojoaque-Nambe, Tesuque, Santa Fe River) would also seem to indicate that both types of stream-aquifer exchange occur in the Santa Cruz sub-basin. However, because Hearne's estimates of these budget components are for pre-development conditions, they are unlikely to be applicable to conditions as they exist today. And because the more recent

groundwater flow models developed by McAda and Wasioek (1988) and Frenzel (1995) do not directly address stream-aquifer exchange along the Santa Cruz River, assessments of relatively current conditions in the watershed do not exist.

As in the case of the Velarde sub-basin, a sizeable portion of the Santa Cruz sub-basin lies within the Rio Grande flood plain, where irrigation canals associated with diversions from the river may play a role in the sub-basin's water budget. Flows in such irrigation canals should be studied in detail to ascertain the role they play in local surface water hydrology.

3.7.5 Santa Clara Watershed

Inflow

Mountain-front inflow to the Santa Clara watershed, which represents runoff from the eastern slope of the Jemez Mountains, was calculated at 5570 afy using the elevation-area-yield approach (Reiland, 1975). On the basis of data provided by the Rio Arriba County Planning Office, 699 acres of the Santa Clara watershed were assumed to be irrigated. The methods of Wilson and Lucero (1997) were applied to this acreage to determine various surface water flow components, one of which was a sub-basin return flow of 890 afy.

The water budget for the Santa Clara watershed in Table 3-14 shows no net groundwater discharge to surface water. This occurs because a net stream loss is computed for this sub-basin, as discussed in the following discussion concerning outflow. Thus the reader should understand that some surface water gains due to groundwater discharge in this sub-basin may be possible though they are not specifically included in the water budget.

Outflow

Diversions in this watershed were computed using the estimated 699 acres of irrigated land and the methods of Wilson and Lucero (1997), as previously summarized in Table 3-13. Evapotranspiration losses were computed at 550 afy using an estimated riparian area of 310 acres (based on the 1992 Landsat image) and an average ET rate of 21.2 in/yr. Flows out of the watershed to the Rio Grande were estimated at 3780 afy by combining flow measurements from the gaging station at Santa Clara Creek Near Española with yields of other ephemeral tributaries within the watershed as estimated by the elevation-area-yield approach (Reiland, 1975).

An estimated net stream loss to groundwater of 510 afy resulted from a comparison of all derived inflows and other estimated outflows.

Limitations of the Santa Clara Sub-basin Budget Estimates

The surface water hydrology of the lower part of the Santa Clara sub-basin is similar to that observed in the Velarde and Santa Cruz sub-basins in that irrigation diversions from the Rio Grande may affect surface water flows locally. Further investigation of the

canals carrying Rio Grande water would help to ascertain the roles that they have, if any, local surface water processes.

3.7.6 Los Alamos Sub-basin

Inflow

Surface water inflow at the mountain-front in the Los Alamos Sub-basin was estimated at 2790 afy using the elevation-area-yield approach. This estimate appeared to be somewhat high when compared to other monitored flows on stream gaging stations both within the basin and close to the sub-basin's south boundary on the perennial Rito de los Frijoles. Despite the discontinuous record of measured flows at the Rito de los Frijoles at Bandelier National Monument (Station 08313350), Healy (1997) states that the average annual discharge at this locale for water years 1983 to 1995 was approximately 1600 afy. Flows from all LANL-operated gaging stations toward the western end of the sub-basin (Shaull et al., 1996a; 1996b; 1998, 1999; 2000) averaged about 260 afy during water years 1996-1999. Combining this latter average flow with the 1600 afy reported for the Rito de los Frijoles results in a total of 1860 afy, which is shy of the above-mentioned estimate of inflow based on Reiland's method by about 1000 afy. However, it should be noted that the Reiland method was applied to an area that extended to the easternmost extent of the lava flows that comprise the Pajarito Plateau, which is well east of the gaging locations mentioned above.

Investigations of the surface water system and the regional groundwater flow system in the Los Alamos sub-basin have demonstrated that the two act largely independent of each other. This conclusion is largely based on observations of interactions between surface water flowing in the base of the canyons with shallow groundwater systems occurring within relatively thin layers of alluvium that lie on the canyon bottoms. In the canyons, surface water tends to seep into the thin alluvium in some locales, and then discharge from the shallow groundwater back to the surface at others. Yet the regional groundwater system is located well below the levels at which this local groundwater-surface water interaction occurs, making it very unlikely for regional groundwater resources to discharge to the canyon streams. For this reason, a zero groundwater discharge was adopted for the surface water budget of the Los Alamos sub-basin. It should be noted, however, that, though groundwater discharge to surface water from the regional groundwater system to the canyons is improbable, the potential does exist for a relatively small amount of stream loss from surface water in the canyons to recharge the deeper groundwater system.

Outflow

The total ET volume computed for this sub-basin of 1990 afy was based on an estimated 106 acres of FWS area subject to an evaporation rate of 45 in/yr and 1027 acres of riparian area subject to an ET rate of 18.6 in/yr. The surface water outflow of 400 afy was estimated at about half of the average annual flow measured during water years 1996-1999 at several LANL-operated gaging stations (Shaull et al., 1996a; 1996b; 1998;

1999; 2000) located just upstream of the Laboratory's eastern boundary. The remainder of the total basin yield (400 afy) was assumed to recharge the area's groundwater system.

3.7.7 Pojoaque-Nambe Watershed

Inflow

Several information sources were consulted in developing estimates of surface-water inflow to the Pojoaque-Nambe sub-basin. Reiland (1975) estimated that about 12,820 afy enters the Pojoaque River drainage via combined runoff in the Rio Nambe, Rio en Medio, Rio Chupadero, and Tesuque Creek. Wasiolek (1995) estimated the combined surface runoff at the mountain-front from the Rio Nambe and Rio en Medio to be 11,020 afy. In the process of examining and attempting to balance all other surface water budget components, DE&S felt that the latter estimate was probably a little high and adopted a surface water inflow of 10,000 afy for the portion of the Pojoaque-Nambe sub-basin that excludes the Tesuque Creek watershed. This estimate is close in value to the combined mean annual inflow of 9795 afy estimated for the Rio Nambe, Rio en Medio, and the Rio Chupadero in a Finding of Fact from the Aamodt water rights case (U.S. District Court, 1997). As discussed in Section 3.7.8, about 540 afy of surface water outflow is calculated for the Tesuque sub-basin. Thus total estimated surface water inflow was assumed to equal the sum of the latter flow and the non-Tesuque runoff, amounting to 10,540 afy.

The estimated groundwater discharge in this basin of 4,000 afy was developed using data regarding stream-aquifer exchange provided in the modeling investigation by Frenzel (1995). Return flow from irrigation was calculated using the methods of Wilson and Lucero (1997).

Outflow

A variety of estimates exist for irrigated acreage and associated surface water diversion in the Pojoaque-Nambe sub-basin. Consequently, estimates of annual irrigation diversions in the sub-basin, from sources such as Wilson and Lucero (1997) and the PVID also vary. The discrepancies in these various data reports and estimates suggest that irrigation diversions in the watershed may comprise one of the most uncertain components of the surface water budget. DE&S chose to base its computation of diversions and depletions in this sub-basin using the Wilson and Lucero (1997) estimates of irrigated acreage for this area. However, the surface water consumptive irrigation requirement (CIR) of 1.84 acre-feet per acre per year was taken from a court order issued in the Aamodt water rights case (U.S. District Court, 1994).

Total ET in the Pojoaque-Nambe sub-basin was estimated at 2850 afy, assuming 120 acres of FWS area was subject to an evaporation rate of 45 in/yr, and a riparian area of 1365 acres was subject to and ET rate of 21.1 in/yr. An estimated 5000 afy surface water loss to groundwater was drawn from model data provided in Frenzel (1995).

The estimated outflow at the sub-basin's outlet of 2170 afy was determined as a result of comparing all previously estimated budget components. Two other estimates of the mean annual surface outflow from the sub-basin can be mentioned for for comparison with this value. First, Hearne (1985) mentioned that the average flow measured at a gaging station near the mouth of Pojoaque River for the period 1973-1977 was about 6000 afy, but felt that that the average long-term flow at this location was probably closer to a third of this quantity. Findings of Fact from the Aamodt water rights case (U.S. District Court, 1997) state that the average outflow from this area in the Pojoaque River is 2650 afy.

Limitations of Pojoaque-Nambe Sub-basin Budget

Taking into consideration surface flows stemming only from watersheds tributary to the Rio Grande, the estimated surface water inflow to the Pojoaque-Nambe Basin of 10,540 afy is the second largest value estimated for this component in all of the sub-basins. This observation, combined with the fact that various estimated acreages for the sub-basin differ substantially, and that estimated stream losses and groundwater discharges to surface water are relatively large, infers that the budget components shown in Table 3-14 could differ considerably from actual values. The Pojoaque-Nambe sub-basin appears to be a sub-basin that would benefit greatly from more detailed monitoring of irrigation diversions, depletions, and return flows, and from an explicit assessment of stream-aquifer exchange processes along Pojoaque Creek and the Pojoaque River.

3.7.8 Tesuque Sub-basin

Inflow

Combined flows in Little Tesuque Creek and Tesuque Creek essentially represent mountain-front surface inflow to the Tesuque watershed. In this study, a total of 3500 afy was estimated for this component using the elevation-area-yield approach. This value is of the same general magnitude as a comparable estimate provided by Wasiolek (1995) (3870 afy), and an estimate by Reiland (1975) of about 2042 afy for average discharge at the gaging station Tesuque Creek Above Diversions (Station 08302500).

Comparisons of Rio Tesuque streambed elevations with estimated nearby groundwater levels indicate that the upper reach of the Rio Tesuque loses water to groundwater and gains in flow due to groundwater discharge along its lower reach. A groundwater discharge of 1400 afy year was estimated for the Tesuque Sub-basin using information provided in Frenzel (1985). The estimated return flow in this sub-basin of 1115 afy was developed using the methods of Wilson and Lucero (1997).

Outflow

The estimated irrigation diversion of 2110 afy was based on the assumption that 20 percent of the total irrigated acreage reported by Wilson and Lucero (1997) for the combined Pojoaque and Tesuque watersheds was within the Tesuque sub-basin. Total ET in the Tesuque sub-basin was calculated at 1280 afy assuming 80 acres of FWS area subject to an evaporation rate of 45 in/yr and a riparian area of 540 acres subject to an ET

rate of 21.8 in/yr. The estimated stream loss of 2500 afy was based on data provided in Frenzel (1985). The sub-basin's outflow to the Pojoaque-Nambe watershed was estimated to be 540 afy as a result of comparing all other budget components.

3.7.9 Caja del Rio Sub-basin

Inflow

Because all watercourses in the Caja del Rio sub-basin are ephemeral and currently ungaged, surface inflow to the watershed (1350 afy) was estimated using the elevation-area-yield approach (Reiland, 1975). Historically, spring flows have been measured on the east side of the Rio Grande in this sub-basin (White and Kues, 1992), but these have apparently declined substantially in response to groundwater pumping at the Buckman Well Field. Consequently, the 1350 afy of estimated inflow based on the Reiland method was not augmented by past spring flow measurements.

Outflow

Total ET in this sub-basin was estimated at 200 afy based on an estimated riparian area of 92 acres subject to an ET rate of 26 in/yr. Comparison of this latter estimate with the computed surface water inflow resulted in an estimated groundwater recharge from stream loss of 1150 afy.

3.7.10 Santa Fe River Watershed

Inflow

Rather than using the elevation-area-yield approach, attempts were made to arrive at a reasonable estimate of surface inflow to the Santa Fe River watershed by using, to the extent possible, surface-water flow records. However, calculation of natural inflows at the mountain front in this sub-basin could not be directly determined using gaging station data alone. This is because the flows at the USGS gage with a long-term record of daily discharges in the watershed are controlled by releases from McClure Reservoir, which is located about 0.4 miles upstream. Thus natural inflow had to be estimated by adjusting the station's streamflow records in a manner that accounted for reservoir storage (as measured at USGS Station 08315500) and evaporation. The 7850 afy of inflow shown in Table 3-14 reflects this adjusted flow as calculated by Wasiolek (1995), plus additional flow from Arroyo Hondo as estimated with the Reiland (1975) method.

Most literature discussing stream-aquifer exchange processes on the Santa Fe River (e.g., McAda and Wasiolek, 1988; Frenzel, 1995; Lee Wilson and Associates, 1997; CDM, 1998; Thomas et al., 2000) indicate that this watercourse loses a significant amount of its flow to groundwater. The losses appear to occur within and near the City of Santa Fe, downstream of the Santa Fe Waste Water Treatment Plant (which discharges its effluent to the river), and within and downstream of the La Bajada area.. However, some of the above-mentioned studies do indicate that some discharge of groundwater to surface water has historically occurred and may still occur near LaCienega, upstream of the stream flow gaging station at La Bajada. It is not clear whether all of this discharge occurs directly on

the Santa Fe River or on the river tributaries La Cienega Creek and Alamo Creek, as is suggested in data used by Frenzel (1995). CDM (1998) used a value for groundwater discharge to the Santa Fe River in the La Cienega area of 3 cfs (approximately 2170 afy), but qualified this number by pointing out that the net stream gain along this reach of the river (1) is gradually declining with decreases in groundwater levels, and (2) during recent studies, has not been observed. A groundwater discharge value of 2170 afy was adopted for this study.

Estimated return flow in this sub-basin represents the combination of average waste water treatment plant discharge to the Santa Fe River during the years 1993-1997 (6500 afy), and estimated irrigation return flow (1560 afy) using the methods of Wilson and Lucero (1997).

Outflow

Water is diverted from the Santa Fe River for both irrigation and municipal uses, the total of which is estimated at 7290 afy. The irrigation diversion is computed at 2665 afy using the methods of Wilson and Lucero (1997). The estimated municipal diversion is about 4625 afy, which is the average diversion for the period 1990 to 1999 as recorded in city records.

The total ET volume of 1180 afy estimated for the Santa Fe River sub-basin is based on an estimated 80 acres of FWS area subject to 45 in/yr evaporation and 440 acres of riparian land subject to an ET rate of 24 in/yr. The estimated stream loss of 8500 afy for this sub-basin is derived partly from the findings of several studies, including Frenzel (1995), Lee Wilson and Associates (1997), CDM (1998), Thomas and Constantz (1999), and Thomas et al. (2000), and partly from the need to balance total sub-basin inflows with outflows. The CDM (1998) study suggests that average cumulative stream loss from surface water to groundwater on the Santa Fe River may amount to 12,000 afy or more.

As previously mentioned, a very large portion of the stream losses to groundwater appear to occur downstream of the La Bajada area, along a reach of the Santa Fe River between Cochiti Lake and the gaging station Santa Fe River Above Cochiti Lake (Lee Wilson and Associates, 1997; CDM, 1998; Thomas and Constantz, 1999). The length of this reach is about 5 miles. Stream losses are also observed downstream of Nichols Dam above and within the City of Santa Fe, and along several miles of river between the Santa Fe Waste Water Treatment Plant and La Cienega. In this study, data from the CDM (1998) study was adopted to develop a stream loss from the Santa Fe River above La Cienega of 3770 afy. Though somewhat lower than indicated in the CDM study, total stream losses to groundwater below the La Bajada area were assumed to equal 4730 afy. It was assumed in this study that all of this latter loss ends up as discharge to Cochiti Springs, which are located south of Cochiti Dam and west of the Santa Fe River channel that goes to Cochiti Lake.

The surface water outflow of 1110 afy is calculated as the residual from combining all other budget components. This latter value, which reflects an average flow of about 1.5 cfs, appears to jibe with the CDM (1998) investigation, during which it was observed that flows in the river often do not make it to Cochiti Lake, and more than likely travel the full distance to the lake only during periods of high runoff.

3.7.11 North Galisteo Creek Sub-basin

Surface water inflow in the North Galisteo Creek Sub-basin was calculated at 900 afy using the elevation-area-yield approach (Reiland, 1975). Evapotranspiration from an estimated riparian area of 65 acres near stream channels that are typically dry was estimated at 130 afy. The remaining budget balance (770 afy) was assumed to recharge the groundwater system.

It should be noted that little to no recorded data exist regarding surface water processes and quantities on the North Galisteo Creek watershed. Consequently, all of the water budget components estimated for this basin are considered very uncertain. Because the budget for this sub-basin is largely dependent on estimated surface water runoff using the Reiland (1975) method, it is evident that both this flow component and the resulting estimate for groundwater recharge are conjectural. The decision to apply the Reiland method to the entire area of this watershed (see Section 3.7.1 was arbitrary. If the estimated 900 afy of mean annual runoff were to occur on a steady, continuous basis, the discharge in surface watercourses would equal 1.24 cfs. Unfortunately no stream gage data exist for this watershed to either justify or contradict this estimated flow. Only peak flows have been monitored for an unspecified period at the stream gage Cañada de las Minas Near Santa Fe (Station 08317800), which is located toward the upstream end of the North Galisteo Creek watershed.

3.7.12 South Galisteo Creek Sub-basin

Inflow

About 6240 afy of surface-water inflow was calculated for this sub-basin using the elevation-area-yield approach of Reiland (1975). For comparison, records from the gaging station Galisteo Creek above Galisteo Reservoir during the years 1970-1976 showed an average flow of 5900 afy. Irrigation return flow (170 afy) was computed using the methods of Wilson and Lucero (1997). Groundwater discharge (900 afy) was estimated by balancing all other budget components.

Outflow

Irrigation diversions of 290 afy were estimated for this sub-basin using the methods of Wilson and Lucero (1997). Water losses to ET were calculated at 2570 afy, assuming 1050 acres of riparian vegetation experiencing an ET rate of 26 in/yr and 125 acres of FWS area undergoing an evaporation rate of 45 in/yr. Surface outflow from the watershed (4440 afy) was based on the average measured flow at Galisteo Creek Below Galisteo Reservoir during the period 1970-1997.

3.7.13 Monthly Breakdown of Surface Water Flows

The water budgets presented in Table 3-14 provide some measure of the quantity of surface water that may available over the full course of an average year, but do not provide any indication as to how the annual surface water volumes involved might be distributed throughout the year. Obviously, the development of monthly values for each of the water budget components would be useful for planning water uses that tend to be seasonal, such as surface water diversions for irrigation in several of the sub-basins or municipal use in the Santa Fe area. Though the development of such budgets is beyond the scope of this study, estimates of the seasonal distribution of streamflows on the watercourses in the sub-basins can be derived by examining the average percentages of annual flow that has been observed each month at several gaging stations in the planning region. Table 3-15 summarizes such average percentages for gaging stations found in five of the sub-basins. As this table indicates the largest flows generally occur during the months of April through June, and the smallest flows are typically observed from November through February.

Table 3-15. Mean Monthly Percentages of Annual Flow at Several Gaging Stations.

Sub-basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Gaging Stations Used
Velarde	5.1	5.1	7.4	9.4	19.7	20.2	8.5	5.0	4.0	4.6	5.8	5.2	100	Average of gaging stations 8279500 (Rio Grande at Embudo) and 8281100 (Rio Grande above San Juan Pueblo)
Santa Cruz	2.5	2.5	5.4	13.3	26.5	20.2	7.6	6.9	5.0	4.1	3.2	2.8	100	Santa Cruz River Near Cundiyo (station 8291000)
Santa Clara	6.4	7.1	8.2	11.4	15.9	7.3	7.2	7.7	7.5	6.5	7.4	7.5	100	Santa Clara Creek Near Española (station 8292000)
Pojoaque-Nambe	2.9	2.5	3.9	11.4	25.4	19.5	8.2	6.9	6.2	5.9	4.1	3.1	100	Rio Nambe Near Nambe (station 8295000)
Tesuque	2.6	2.5	5.6	16.1	28.4	17.5	6.4	4.8	4.0	5.4	3.9	2.9	100	Tesuque Creek Above Diversions Near Santa Fe (station 8302500)
Average	3.9	3.9	6.1	12.3	23.2	17.0	7.6	6.2	5.4	5.3	4.9	4.3		

3.8 Surface Water Uncertainty Analysis

The uncertainty and variability of the surface water budget in each sub-basin was analyzed by developing a plausible range of values for each of the components listed in Table 3-14. This analysis was not considered a rigid uncertainty analysis such as those based on probabilistic methods, but rather a preliminary assessment of the degree to which budget values could conceivably vary. For that reason, the ranges presented herein cannot be considered direct quantifications of the uncertainty in the best estimates of mean annual values of inflow and outflow that comprise Table 3-14. Rather, the computed ranges represent more the values of flow that might be possible in any given

year. In that sense, the minimum and maximum values presented more correctly signify the variability in component values over time. It was a secondary objective of this cursory analysis to identify the budget components that are most supported by existing data, and those for which supporting data is scarce to nonexistent.

Table 3-16 presents the values ultimately selected to represent the range for each budget component in each sub-basin. The minimum and maximum estimated values of each component are separated by a hyphen.

Several methods were repeated many times to arrive at the predicted ranges for budget components. Because they were applied repeatedly, they are mentioned briefly in the next several sections, and are subsequently referred to in following text regarding each sub-basin's budget uncertainty.

3.8.1 Ranges for Surface Inflows Estimated with the Reiland Method

Because so many surface water inflows were estimated using the method of Reiland (1975), an attempt was made to find feasible ranges of values that encompassed them. This range was expressed in terms of percentages of the Reiland estimate. To arrive at such percentages, the streamflow records at seven gaging stations in the region were analyzed. The stations were selected because they were perceived as being only moderately affected by human uses of water. The seven stations were: (1) Rio Chama Near La Puente, (2) Santa Cruz River Near Cundiyo, (3) Santa Clara Creek Near Española, (4) Rio En Medio Near Santa Fe, (5) Rito de los Frijoles in Bandelier National Monument, (6) Santa Fe River Near Santa Fe, and (7) Galisteo Creek Above Galisteo Reservoir.

At each of the seven stations, the percentages of the mean annual flow attributed to the minimum and maximum annual flow, respectively, was computed. The computed minimum annual flow percentages of the mean were then averaged, as were the maximum annual flow percentages of the mean. These latter averages, 42% and 205%, respectively, were in turn applied to Reiland-based estimates of inflow to develop corresponding estimates of minimum and maximum annual flow.

3.8.2 Ranges for FWS Evaporation and Riparian ET

To estimate minimum and maximum FWS evaporation quantities, the FWS acreages listed in Table 3-11 for each sub-basin were multiplied by 40 and 55 in/yr, respectively, which were the minimum FWS evaporation rates shown in Figure 2-7. Similarly, the estimated riparian acreages listed in Figure 2-8 were multiplied by 16 and 26 inches, respectively, which correspond to the smallest and largest PET rates shown in Figure 2-8.

3.8.3 Ranges for Irrigation Diversions and Return Flows

A simple approach was employed to determine minimum and maximum flows for budget components that are reflective of irrigation. Specifically, the same irrigation application rates and efficiencies used in developing Table 3-13 were applied to the minimum and maximum irrigated acreages listed in Table 3-12. Because in some cases the largest

acreage in Table 3-12 for a given sub-basin had been used in preparing Table 3-13, this approach sometimes resulted in a maximum irrigation diversion (and associated return flow) that was identical to the original estimate.

3.8.4 Ranges for Stream Losses and Groundwater Discharges

Six of the stream loss quantities and one of the groundwater discharges listed in Table 3-14 are estimated as residual quantities after comparing all remaining inflow and outflow components. The fact that so many of these quantities are reflective of stream-aquifer exchange raises the likelihood that stream losses and gains are some of the most uncertain budget items. Because no process-based method exists for estimating feasible ranges of stream losses and gains, their minimum and maximum values were arbitrarily assigned at 75% and 125% of the best estimate value provided in Table 3-14. These same percentages were also applied to estimates of stream loss and gain in Table 3-14 that were derived using separate literature sources, again because of a lack of process-based methods with which such losses could be calculated.

3.8.5 Velarde Sub-basin Flow Ranges

Minimum surface inflow to the Velarde sub-basin was computed using a combination of the minimum annual flow at the gaging station Rio Grande at Embudo and 42% of the annual inflow from the Sangre de Cristo Range as estimated using the Reiland (1975) method. Maximum surface inflow was computed using a combination of the maximum annual flow at the Embudo gaging station and 205% of the tributary inflow determined using the Reiland method. Minimum groundwater discharge was computed using an estimated loss from groundwater to the Rio Grande of 0.25 cfs/mi; maximum groundwater discharge was based on a per mile loss of 0.75 cfs. Minimum and maximum return flows were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated acreages, respectively, listed in Table 3-12.

Minimum and maximum diversions in the Velarde sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated areas, respectively, listed in Table 3-12. Minimum and maximum stream losses were estimated at 75% and 125%, respectively, of the estimated stream loss given in Table 3-14. The range for total ET was estimated by applying the techniques discussed in Section 3.8.2 to the estimated FWS and riparian areas listed in Table 3-11. Minimum and maximum surface outflows in the sub-basin were based on the minimum and maximum annual flows, respectively, measured at the gaging station Rio Grande Above San Juan Pueblo.

In general, the estimated flows in the Velarde sub-basin associated with the Rio Grande are much better understood and quantified than are those occurring in the part of the sub-basin that is tributary to the Rio Grande. Flows on the Rio Grande at Embudo and above San Juan Pueblo have been monitored for tens of years. The estimated range of groundwater discharges to the Rio Grande is based on the work of several other researchers (Spiegel and Baldwin, 1963; Hearne, 1985; McAda and Wasiolek, 1988; and Frenzel, 1995). In contrast, the relatively large range of estimated diversions and return flows does reflect the wide variation in irrigated areas estimated for this sub-basin. Of all

outflow components, stream loss is likely to be the most uncertain because it is calculated as a budget residual rather than determined through field studies.

3.8.6 Santa Cruz Sub-basin Flow Ranges

Minimum surface inflow to the Santa Cruz sub-basin was computed using a combination of the minimum annual flow at the gaging station Santa Cruz River at Cundiyo and 42% of the estimated annual inflow from the Rio Quemado as estimated using the Reiland (1975) method. Maximum surface inflow was computed using a combination of the maximum annual flow at the Cundiyo gaging station and 205% of the Rio Quemado inflow determined using the Reiland method. Minimum and maximum return flows in this sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated areas, respectively, listed for it in Table 3-12.

Minimum and maximum diversions in the Santa Cruz sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated acreages, respectively, listed in Table 3-12. Minimum and maximum stream losses were estimated at 75% and 125%, respectively, of the estimated stream loss given in Table 3-14. The range for total ET was estimated by applying the techniques discussed in Section 3.8.2 to the estimated FWS and riparian areas listed in Table 3-11. Minimum surface outflow in the sub-basin was based on a combination of the minimum annual flow measured at the gaging station Santa Cruz River Near Riverside and 42% of the estimated inflow from Arroyo Seco and Arroyo Madrid. Maximum surface outflow was computed by combining the maximum measured annual flow at the Riverside station with 205% of the estimated inflow from the tributary arroyos.

Irrigation diversions and return flows in the Santa Cruz sub-basin are considered very uncertain because of the large range in irrigated acreages reported for this area. Likewise, stream loss is again considered very uncertain due to the fact that it is calculated as a residual after comparing all other water budget components. In contrast, surface water inflows and surface water outflows can be estimated relatively well because a large component of each is based on stream gage data. Estimates of total ET are also considered fairly reliable because an approximate riparian area can be derived from the 1992 Landsat image, and ET rates can be drawn from well established data sources.

Table 3-16. Estimated Ranges of Surface Water Budget Components by Sub-basin.

Sub-basin	Inflow (acre-feet/year)				Outflow (acre-feet/year)				
	Surface Inflow	Groundwater Discharge[1]	Return Flow	Total Inflow[2]	Diversions	Stream Loss[4]	Evapotran-spiration	Surface Outflow	Total Outflow[3]
Velarde (including the Rio Grande)	224,150-1,508,370	2900-8690	6460-18710	233,510–1,535,780	10,710-29,500	1350-2250	2140-3050	211,650-1,190,730	225,850–1,225,530
Santa Cruz	7860–61,250	0	2150–10,760	10,010-72,010	3940-19,700	3890-6490	3400-4880	1920-17,200	13,150 – 48,270
Santa Clara	2340-11,420	0	690-890	3030-12,310	1265-1620	380-635	450-650	2460-6260	4555-9165
Los Alamos	1170-5720	0	0	1170-5720	0	300-500	1725-2710	200-710	2225-3920
Pojoaque-Nambe	4430-21,610	3000-5000	2245-6640	9675-33,250	4250-12,555	3500-6250	2350-3360	625-8025	10,275-30,190
Tesuque	1470-7175	1100-1750	400-1660	2970-10,585	755-3145	1875-3125	1090-1560	400-680	4120-8510
Caja del Rio	570-2770	0	0	570-2770	0	860-1440	140-200	0	1000-1640
Santa Fe River	3300-16,090	1630-2710	5460-9970	10,390-28,770	4470-8920	6375-10,625	930-1320	750-4970	12,525-25,835
North Galisteo Creek	380-1850	0	0	380-1850	0	580-960	100-140	0	680-1100
South Galisteo Creek	2620-12,800	665-1110	0-170	3285-14,080	0-290	0	1990-2850	930-9270	2920-12,410

[1]Minimum groundwater discharge = 0.75 x groundwater discharge in Table 3-14; maximum groundwater discharge = 1.25 x groundwater discharge in Table 3-14.
[2]Total inflow = surface inflow + groundwater discharge + return flow.
[3]Total outflow = diversions + stream loss + evapotranspiration + surface outflow.
[4]Minimum stream loss = 0.75 x stream loss in Table 3-14; maximum stream loss = 1.25 stream loss in Table 3-14.

3.8.7 Santa Clara Sub-basin Flow Ranges

Minimum surface inflow to the Santa Clara watershed was computed as 42% of the estimated inflow presented in Table 3-14, and maximum surface inflow was computed as 205% of the previously estimated inflow. Minimum and maximum return flows in this sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated acreages, respectively, listed for the sub-basin in Table 3-12.

Minimum and maximum diversions in the Santa Clara sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated areas, respectively, listed in Table 3-12. Minimum and maximum stream losses were estimated at 75% and 125%, respectively, of the estimated stream loss given in Table 3-14. The range for total ET was estimated by applying the techniques discussed in Section 3.8.2 to the estimated riparian area listed in Table 3-11. Minimum surface outflow from the Santa Clara sub-basin was computed using a combination of the minimum annual flow at the gaging station Santa Clara Creek Near Española and 42% of the estimated annual inflow from other tributaries to the Rio Grande in this area. Maximum surface inflow was computed using a combination of the maximum annual flow at the Santa Clara Creek gaging station and 205% of the estimated tributary inflow using the Reiland method.

Despite the fact that the irrigated acreages estimated for this sub-basin do not exhibit a wide range, it in unclear as to whether the computed ranges for irrigation diversions and return flows are accurate. This observation is made because the listed acreages may not take into account all of the land that is irrigated on the Santa Clara Pueblo.

Again stream loss is considered very uncertain due to the fact that it is calculated as a residual after comparing all other water budget components. Surface water outflow is considered one of the more certain budget components because a large portion of it is based on stream gage data. The estimate of total ET is also likely to be one of the more certain budget components because the riparian area for the sub-basin can be approximated using the 1992 Landsat image, and the ET rate applied to the area can be derived from well-established data sources.

3.8.8 Los Alamos Sub-basin Flow Ranges

Minimum and maximum surface inflows to the Los Alamos sub-basin were computed as 42% and 205%, respectively, of the estimated inflow for this area as presented in Table 3-14. Minimum and maximum groundwater discharges were computed as 75% and 125% of the estimated value given for this component in Table 3-14.

The range of stream losses in the Los Alamos sub-basin was estimated by multiplying the budget estimate for stream loss by 75% and 125%. The range for total ET was estimated by applying the techniques discussed in Section 3.8.2 to the estimated FWS and riparian areas listed in Table 3-11.

Streamflow measurements summarized by Shaull et al. (1996a; 1996b; 1998; 1999; 2000) were used to determine minimum and maximum surface outflows from the sub-basin. The minimum, mean, and maximum of cumulative annual flows at stations located along the eastern boundary of LANL were computed using data from water years 1996-1999. To estimate minimum surface outflow from the sub-basin, the percentage of the mean flow at these stations associated with the measured minimum annual flow was multiplied by the 400 afy year average outflow in Table 3-14. In a similar fashion, the percentage of the mean measured flow associated with the maximum measured annual flow along the Laboratory's eastern boundary was used to estimate a maximum sub-basin surface water outflow.

As with the previously analyzed sub-basins, stream loss in the Los Alamos sub-basin is considered very uncertain because it is calculated as a residual after comparing all other water budget components. Similarly, both surface water inflow and surface water outflow for the sub-basin must be considered very uncertain - the former because it is based solely on the Reiland (1975) method, and the latter because it stems from an analysis of just four years of streamflow data. Moreover, because the origins of surface flows, whether from local groundwater discharge to the surface, effluent discharges, or runoff generated at higher elevations, are poorly understood and/or quantified, all surface water budget components involving either stream discharge or groundwater/surface water exchange should be viewed with scrutiny. Of all the budget components developed for the Los Alamos sub-basin, the estimate of total ET is probably the most certain.

3.8.9 Pojoaque-Nambe Sub-basin Flow Ranges

Minimum surface inflow to the Pojoaque-Nambe sub-basin was computed as 42% of the estimated inflow presented in Table 3-14, and maximum surface inflow was computed as 205% of the previously estimated inflow. Minimum and maximum return flows in this sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated acreages, respectively, listed for the area in Table 3-12. To compute minimum and maximum groundwater discharges, the estimated value for this component in the surface water budget was multiplied by 0.75 and 1.25, respectively.

Minimum and maximum diversions in the Pojoaque-Nambe sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum estimated irrigated areas, respectively, for this watershed. The maximum irrigated acreage was estimated at 80% of the total irrigated area for the combined Pojoaque-Nambe and Tesuque sub-basins reported in a 1966 hydrographic survey of this area. Minimum and maximum stream losses were estimated at 75% and 125%, respectively, of the estimated stream loss given in Table 3-14. The range for total ET was estimated by applying the techniques discussed in Section 3.8.2 to the estimated FWS and riparian areas applicable to this sub-basin. The minimum surface water outflow was computed by multiplying the estimated value for this component in Table 3-14 by the percentage of mean flow attributed to the minimum annual flow at the gaging station Pojoaque River Near San Ildefonso Pueblo (Station 08312600) during the years 1973-1977; the

analogous percentage of mean flow at this station attributed to the measured maximum discharge was used to compute the maximum sub-basin outflow via surface water.

Of all derived budget components for this sub-basin, the most certain are probably the estimates for total evapotranspiration, surface water inflow, and surface water outflow. As with all sub-basins, the first of these can be computed from actual estimates of FWS area and riparian area taken from maps and/or Landsat images and average evaporation and ET rates have been relatively well quantified. The second of these components, surface water inflow, is thought to be relatively certain because it jibes well with related estimates of inflow by Reiland (1975), Wasiolek (1995), and a Finding of Fact in the Aamodt water rights adjudication case (U.S. District Court, 1997). The estimated surface water outflow corresponds fairly well with estimates of this component derived previously by Hearne (1985) and the previously mentioned Finding of Fact in the Aaamodt water rights adjudication case (U.S. District Court, 1997) (see Section 3.7.7).

All remaining budget components in the Pojoaque-Nambe sub-basin are likely to be very uncertain. Specifically, irrigation diversions and return flows are difficult to pinpoint because of the wide range in irrigated area reported for this sub-basin. This observation is complicated by the fact that irrigated acreage in the Tesuque sub-basin is included in two of the estimates of irrigated area in Table 3-11. For reasons enumerated previously, both components reflective of stream-aquifer exchange, groundwater discharge and stream loss, are inherently very uncertain.

3.8.10 Tesuque Sub-basin Flow Ranges

Minimum and maximum surface inflows to the Tesuque sub-basin were computed as 42% and 205%, respectively, of the estimated inflow for this area as presented in Table 3-14. Minimum and maximum return flows in the sub-basin were computed by applying the methods of Wilson and Lucero (1997) to estimated minimum and maximum irrigated acreages, respectively, for this area. These respective areas comprised 170 acres (the area estimated from the 1992 Landsat image) and 798 acres, the latter of which amounted to 20% of the total acreage estimated for combined Pojoaque-Nambe and Tesuque sub-basins measured in a 1966 hydrographic survey. The range for groundwater discharges in the Tesuque sub-basin was computed by multiplying the budget estimate for this component by 0.75 and 1.25, respectively.

Minimum and maximum diversions in the Tesuque sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the estimated minimum and maximum irrigated areas estimated for the watershed, as discussed in the previous paragraph. Minimum and maximum stream losses were estimated at 75% and 125%, respectively, of the estimated stream loss given in Table 3-14. The range for total ET was computed by applying the techniques discussed in Section 3.8.2 to the estimated FWS and riparian areas applicable to this sub-basin. Minimum and maximum surface water outflows were estimated at 75% and 125%, respectively, of the 540 afy estimated for this component in the surface water budget.

As with all previously analyzed sub-basins, groundwater discharge and estimated stream loss are likely to be two of the most uncertain budget components in the Tesuque sub-basin. The estimated surface outflow is also considered very uncertain because it is calculated as a budget residual. Budget components associated with irrigation (diversions and return flows) are likely to be quite uncertain given the relatively large range of estimated irrigated areas for the sub-basin. Estimated evapotranspiration is considered one of the more certain budget components. In addition, the estimate of average surface water inflow is relatively certain given that its value in the surface water budget (3500 afy) compares favorably with the mean flow measured at the gaging station Tesuque Creek Above Diversions.

3.8.11 Caja del Rio Sub-basin Flow Ranges

Minimum and maximum surface water inflows to the Caja del Rio sub-basin were estimated using the methodology discussed in Section 3.8.4. The range for total ET was estimated by applying the techniques discussed in Section 3.8.1 to the estimated riparian area for this sub-basin. Minimum and maximum stream losses were computed as 75% and 125%, respectively, of the budget estimate for this component.

Because little to no data exist to support the estimated budget values for the Caja del Rio sub-basin, all of the estimated components for the area should be considered very uncertain.

3.8.12 Santa Fe River Sub-basin Flow Ranges

Minimum surface inflow to the Santa Fe River watershed was computed as 42% of the estimated inflow presented in Table 3-14, and maximum surface inflow was computed as 205% of the previously estimated inflow. Minimum and maximum return flows in this sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated areas, respectively, listed for the sub-basin in Table 3-12.

Minimum and maximum diversions in the Santa Fe River sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated acreages, respectively, listed in Table 3-12. Minimum and maximum stream losses were estimated at 75% and 125%, respectively, of the estimated stream loss given in Table 3-14. The range for total ET was estimated by applying the techniques discussed in Section 3.8.2 to the sub-basin's estimated riparian area. Minimum surface water outflow was estimated by applying the percentage of mean flow associated with the minimum annual flow at the gaging station Santa Fe River Above Cochiti Lake to the estimated surface outflow provided in Table 3-14; an analogous percentage of mean flow associated with the maximum measured annual flow at this station was used to estimate maximum surface water outflow.

The best understood budget component in the Santa Fe River sub-basin is surface water inflow, as it is has been estimated using measured river flows above the City of Santa Fe (Wasiolek, 1995). The most uncertain component is stream loss. Despite the fact that

studies of stream-aquifer exchange along the river (e.g., Frenzel, 1995; Lee Wilson and Associates, 1997; CDM, 1998; Thomas et al., 2000) indicate that infiltration losses from the Santa Fe River are substantial, it is still difficult to accurately quantify them.

Though surface water outflow from the sub-basin is calculated as a budget residual, the value provided for this component in Table 3-14 is believed to be a defensible estimate of the average annual surface flow of the Santa Fe River into Cochiti Lake. Stream losses along the lower portion of the river below the gaging station Santa Fe River Above Cochiti Lake (e.g. CDM, 1998; Thomas et al., 2000) help to explain why the estimated surface outflow is considerably lower than the mean annual discharge measured at the Above Cochiti station. CDM (1998) reported that infiltration losses along the lowest reaches of the river often prevent river water from reaching Cochiti Lake. Thus, the surface outflow value presented in Table 3-14 and the range of values presented in Table 3-16 are believed to mostly represent lake inflows during times of high runoff.

3.8.13 North Galisteo Creek Sub-basin Flow Ranges

Minimum and maximum surface water inflows to the North Galisteo Creek sub-basin were estimated using the methodology discussed in Section 3.8.1. The range for total ET was estimated by applying the techniques discussed in Section 3.8.2 to the estimated riparian area listed in Table 3-11. Minimum and maximum stream losses were computed as 75% and 125%, respectively, of the budget estimate for this component.

Because little to no data exist to support the estimated budget values for the North Galisteo Creek sub-basin, all of its estimated components are considered very uncertain.

3.8.14 South Galisteo Creek Sub-basin Flow Ranges

Minimum and maximum surface water inflows to the South Galisteo Creek sub-basin were estimated using the methodology discussed in Section 3.8.1. Minimum and maximum return flows in this sub-basin were computed by applying the methods of Wilson and Lucero (1997) to the minimum and maximum irrigated acreages, respectively, listed for the sub-basin in Table 3-12. Minimum and maximum groundwater discharges were computed as 75% and 125%, respectively, of the budget estimate for this component.

The range for total ET was estimated by applying the techniques discussed in Section 3.8.2 to the estimated FWS and riparian areas for the sub-basin. Minimum and maximum surface water outflows corresponded to the minimum and maximum annual runoff volumes that have been recorded at the gaging station South Galisteo Creek Below Galisteo Dam (Station 08317950).

Because it is based on actual measurements, surface water outflow is likely the most reliable budget component derived for the South Galisteo Creek sub-basin. The estimate of total ET from surface water is also considered defensible because it is based on relatively well documented estimates of FWS evaporation and PET rates for the region as

well as estimates of FWS and riparian areas from Landsat images. For reasons discussed previously, groundwater discharge is probably the most uncertain budget component.

3.9 Surface Water Flow Summary for the Study Region

3.9.1 Major Rivers, Tributaries, and Rio Grande Losses and Gains

Understanding of the overall surface water flow system for the study region can be enhanced by summarizing the flow processes that occur. This section presents such a summary through Table 3-17, which lists the processes, lumps several of them together, and provides quantitative estimates of some of the flows involved. The table examines the regional system from the perspective of moving downstream along the Rio Grande from where it enters the region at Embudo to where it passes south of the planning region below Cochiti Lake. At selected points along the Rio Grande, data regarding measured annual flows at river gaging stations are presented along with lists of sub-basin and other Rio Grande inflows, and possible Rio Grande outflows, that influence the surface flows occurring between the gaging stations. Total surface inflows to relevant combinations of sub-basin surface inflows and total sub-basin outflows are also presented. Flow estimates that are quantified are given in units of acre-feet per year (afy).

Several items in Table 3-17 are worthy of explanation. First, the Los Alamos sub-basin is arbitrarily assumed to be tributary to the Rio Grande only between the Near Otowi Bridge and Cochiti Lake locations despite the fact that it contributes surface flow to the river both above and below the Near Otowi Bridge gage. The effects of this assumption are, however, assumed to be minor as the estimated surface outflow from the sub-basin (400 afy, Table 3-14) is relatively small. Second, two estimates are provided for mean annual flow of the river at the Embudo gage. The first of these, 591,600 afy, stems from the measured flow at the station during the years 1963-1986, which is the period of record for the Above San Juan Pueblo gage and the period upon which some components of the Velarde sub-basin budget was based. The second flow, 661,700 afy, is based on a measured mean annual flow at Embudo during the more extended period of record, 1912-1997, which was used to develop the discharge statistics for this gage in Table 3-3. This second quantity is presented so that the reader can develop a better feel for the total increase in river flow that occurs between Embudo and the Near Otowi gaging stations, the latter of which has a period of record extending from 1918 to the current year.

A third feature of Table 3-17 worth noting is the fact that no estimate of the surface outflow from the Velarde sub-basin has been made for this study. Though such a flow might be close to zero, a more accurate estimate of the surface water outflow from this sub-basin is desirable. Data regarding this flow component would be useful not only for estimating the potential contribution of Velarde sub-basin tributaries to the Rio Grande, but also for developing more reliable estimates of the surface water flows that typically occur in the watersheds of this sub-basin that drain the Sangre de Cristo Mountains.

Several general conclusions can be drawn from the flow estimates presented in the summary provided by Table 3-17. Some of the more obvious ones are reflected in the

flows presented for locations on the Rio Grande. The annual average flow entering the planning region on its north boundary via the Rio Grande is close in magnitude to 600,000 afy, and is likely larger than this quantity over the long term. The average increase in river flow between the Embudo and Near Otowi Bridge gages appears to be greater than 400,000 afy. Most of this increase in flow is attributed to inflow from the Rio Chama with much lesser river flow accretions being contributed by surface outflows from the sub-basins included in this study and groundwater discharge to the Rio Grande. The mean annual flow of the Rio Grande Near Otowi Bridge is close to 1.1 million afy. This same quantity is probably close to the average amount of water that flows into Cochiti Lake since river gains and losses on the reach between Otowi and Cochiti Lake (tributary inflow from Los Alamos, Caja del Rio, and Santa Fe River sub-basins and Rito de los Frijoles; groundwater discharge to the river; river losses at Buckman Well Field; and surface evaporation) are expected to be minor in comparison to total flow in the river.

Another general conclusion that can be drawn from Table 3-17 is that, of the total amount of surface water inflow that is assumed to enter the upper portions of the sub-basins, a relatively minor percentage (less than 25%) appears to leave the sub-basins via surface flow. This observation means that, for all sub-basins combined, surface water outflows due to diversions, stream losses, and evapotranspiration exceed surface inflows attributed to the combination of return flows and groundwater discharge to streams.

3.9.2 San Juan-Chama Project

The San Juan-Chama Project, authorized as a participating project of the Colorado River Storage Project, provides an average annual diversion of about 110,000 acre-feet of water from the upper tributaries of the San Juan River for use in the Rio Grande Basin within New Mexico. Some of this additional water is used for municipal, domestic, industrial, and agricultural purposes within the Jemez y Sangre Planning Region. The quantities of water involved include: (1) City and County of Santa Fe, 5605 acre-feet; (2) City of Los Alamos, 1200 acre-feet; (3) City of Española, 1000 acre-feet; and (4) Pojoaque Valley Irrigation District, 1030 acre-feet. In addition, an annual allocation of San Juan-Chama water is available to the Corps for its operation of Cochiti Reservoir, under the intent of the Corps to compensate for evaporation losses and maintain a minimum surface area of 1200 acres for the reservoir. The various entities that utilize San Juan-Chama water contract for their respective supplies with the USBR.

Mention of annual flow of the Rio Chama in the previous section is relevant not only because it is the largest tributary to the Rio Grande but also because the river itself and reservoirs on it play a role in delivering San-Juan Chama water. Upon being diverted from the San Juan Basin, project water is fed into the Rio Chama tributary Willow Creek, which in turn drains into Heron Reservoir. Releases from Heron Reservoir are in turn passed through El Vado Reservoir, which is located on the Rio Chama. The average annual flow of the Rio Chama Near Chamita (Station 08290000) before initiation of the San Juan-Chama project (1930-1972) was about 353,320 afy. From 1973 through 1997, after the project started, the average annual flow at this station was about 463,360 afy.

Nambe Falls Dam, on the Nambe River, was constructed as part of the San Juan-Chama Project. Nambe Reservoir provides supplemental irrigation water for the Pojoaque Valley Irrigation District and the Pueblos of San Ildefonso, Nambe, and Pojoaque.

3.9.3 Relationship of the Rio Grande Compact to the Regional Surface Water System

The Rio Grande Compact divides the water of the Rio Grande between Colorado, New Mexico and Texas. The Compact specifies how much water Colorado must deliver to New Mexico at a gaging station known as the Rio Grande Near Lobatos, Colorado, and how much water New Mexico must deliver to Texas at Elephant Butte Reservoir, located in southern New Mexico. The amount to be delivered to Elephant Butte is determined primarily by the annual flow of the Rio Grande at Otowi Bridge (Station 08313000). This flow is adjusted using methods specified in the Compact to produce the Otowi Index Supply (Otowi index). In the Compact, the Otowi index is linked to another flow index referred to as the Elephant Butte Effective Index Supply. The link establishes the quantity of water that must be delivered to Texas (i.e., Elephant Butte Reservoir) in terms of a percentage of the Otowi flow. This percentage varies from a low of 57% when the flow at Otowi is less than 400,000 afy to as much as 86.5% when the Otowi flow reaches 3,000,000 afy.

If the amount of water delivered to Elephant Butte during a calendar year is less than the amount required by the Compact, New Mexico has a debit to Texas for that year. If the amount delivered exceeds the requirement, New Mexico has a credit. An annual debit or credit is calculated for each year and is added to any existing debit or credit, with the accruing debit or credit being carried forward to the next year. Accounting of debits and credits is usually accomplished in late February or early March of each year when the Rio Grande Compact Commission meets. If the accounting results in an accrued debit, reservoir management in New Mexico is generally affected for the entire succeeding year.

The Compact establishes an explicit rule that governs the amount of accrued debit that can be allowed. Unfortunately, this rule was violated continually during the dry period between 1948 and 1968.

As discussed in Section 3.5, storage of water in Nichols and McClure Reservoirs in the Santa Fe River sub-basin is controlled in part by the Rio Grande Compact. Storage in the two reservoirs is subject to Article VII of the Compact, which bars the storage of water in reservoirs constructed after 1929 "whenever there is less than 400,000 acre-feet of usable water in project storage." "Project storage" in this case refers roughly to the amount of water in Elephant Butte Reservoir and Caballo Reservoir (located on the Rio Grande south of Elephant Butte Reservoir) that is available for downstream use. Exempt from Article VII is 1061 acre-feet stored in McClure Reservoir, because it and Two Mile Reservoir were constructed prior to 1929.

Table 3-17. Summary of Measured, Estimated, and Inferred Surface Water Flow Components for the Planning Region.

Rio Grande Location	Mean Annual Flow at Rio Grande Location (afy)	Sub-basins Tributary to the Rio Grande Above River Location	Estimated Total Tributary Inflow to Sub-basins[1] (afy)	Estimated Net Gain or Loss Between Total Sub-basin Inflow and Total Outflow[2] (afy)	Estimated Total Surface Outflow[3] (afy)	Other Tributary Inflows to the Rio Grande Above River Location[4]	Possible Outflows From the Rio Grande Above River Location[5]
Embudo Gaging Station	591,160[6], 661,600[7]	NA	NA	NA	NA	NA	NA
Gaging Station Above San Juan Pueblo	585,360[8]	Velarde	2420[9]	NE	NE	Groundwater Discharge (estimated at 5800 afy[10]), Possible Return Flow from Irrigation[11]	Irrigation Diversions[10], River Loss Due to Local Groundwater Withdrawal[12], River Surface Evaporation (estimated at 730 afy[13])
Gaging Station Near Otowi Bridge	1,086,200[14]	Santa Cruz, Santa Clara, Pojoaque-Nambe, Tesuque	45,890	-30,395	15,495	Rio Chama (estimated at 393,500 afy[15]), Groundwater Discharge[16]	River Loss Due to Local Groundwater Withdrawal[17], River Surface Evaporation[18]
Cochiti Lake	NA	Los Alamos[19], Caja del Rio, Santa Fe River	11,990	-10,480	1510	Rito de los Frijoles (estimated at 1600 afy[20]), Groundwater Discharge[16]	Stream Loss Due to Buckman Well Field[21], River Surface Evaporation[18]
Downstream of Cochiti Lake	NA	North Galisteo Creek, South Galisteo Creek	7140	-2700	4440	NA	NA
Totals for Sub-basin Flows			66,890	-41,080	23,390		

Notes:
NA = not applicable.
NE = not estimated.
afy = acre-feet per year
cfs = cubic feet per second
[1] Unless noted otherwise, total tributary inflow determined by summing relevant sub-basin surface inflows in Table 3-14.
[2] Total net gain or loss in relevant sub-basins determined by accounting for all flow components in Table 3-14 that do not comprise either surface inflow or net total surface outflow. Net loss is listed as a negative number.
[3] Estimated total surface outflow = estimated total tributary inflow + estimated total net gain (positive number) or loss (negative number).
[4] Estimated tributary inflows consist of inflows to the Rio Grande that are not explicitly accounted for in total sub-basin outflows.

[5] Possible outflows from the Rio Grande consist of outflows that are not explicitly accounted for in estimated sub-basin totals.
[6] Mean annual flow at Embudo of 591,160 afy based on average measured flow of 816 cfs at gaging station during 1963-1986.
[7] Mean annual flow at Embudo of 661,600 afy based on average measured flow of 913.86 cfs at gaging station during 1912-1997.
[8] Mean annual flow at gaging station Above San Juan Pueblo of 585,360 afy based on average measured flow at station of 808 cfs during 1983-1986.
[9] Estimated tributary inflow to the Velarde sub-basin computed using the method of Reiland (1975).
[10] Groundwater discharge to Rio Grande based on assumed discharge rate of 0.5 cfs/mile for a 16-mile stretch of river.
[11] Possible irrigation diversions from the Rio Grande in the Velarde sub-basin were not explicitly accounted for in the sub-basin's surface water budget.
[12] Possible river losses due to groundwater withdrawals are likely to be minor to non-existent assuming the estimated groundwater diversion of 46 afy for the Velarde portion of this sub-basin of 46 afy accurately reflects actual pumping.
[13] Estimated surface water evaporation from the Rio Grande in the Velarde sub-basin (Table 3-11).
[14] Mean annual flow at gaging station Near Otowi Bridge of 1,086,200 afy based on average measured discharge at station of about 1500 cfs during 1918-1997.
[15] Estimated tributary inflow to the Rio Grande from the Rio Chama based on measured mean annual flow at Rio Chama Near Chamita of 543.26 cfs during 1929-1997.
[16] Groundwater discharge to the Rio Grande between the Above San Juan Pueblo and Near Otowi Bridge gaging stations not explicitly accounted for in the estimated sub-basin budgets. Per-unit-length estimates groundwater discharge to the Rio Grande between Embudo and Cochit Lake range from about 0.2 cfs/mile to 1.3 cfs/mile.
[17] Possible river loss due to local groundwater withdrawals may occur due to municipal and/or irrigation pumping near Española and irrigation and/or community water supply pumping on Santa Clara and San Ildefonso Pueblo lands.
[18] Rio Grande evaporation losses were not computed for river reaches below southern limit of Velarde sub-basin.
[19] Los Alamos sub-basin is actually tributary to the Rio Grande both above and below the Near Otowi Bridge gage; the assumption in this table that it contributes surface inflow and groundwater discharge to the Rio Grande only below the Otowi gage is arbitrary.
[20] Estimated tributary inflow to the Rio Grande of 1600 afy from the Rito de Los Frijoles is based on information provided in Healy (1997).
[21] Stream loss due to Buckman Well Field is less than actual annual pumping from the field.

In the event that New Mexico is in debit status under the Compact and debit water is stored in Nichols or McClure Reservoirs, the debit water is subject to call by the State of Texas. To date, no water has ever been released from either reservoir as a result of this type of priority call. In the past, the City of Santa Fe has obtained permission from the Office of the State Engineer (OSE) to satisfy such calls by releasing some of its San-Juan Chama water from storage in the Rio Grande system in lieu of releasing water from either Nichols or McClure Reservoirs. The substitution of San Juan-Chama water for Santa Fe reservoirs in such instances makes practical sense because releases from either of the City's two reservoirs is unlikely to reach the Rio Grande due to significant infiltration losses within and downstream of the City (see Section 3.7.10)

3.10 Surface Water Rights

Comparison of estimated surface water uses in the planning region with pertinent surface water rights was not possible because the available water rights database lacked the comprehensive information necessary for such a comparison. The types of surface water rights that are applicable to the planning region include those associated with irrigation, municipal use in Santa Fe, and livestock water. An important distinction exists between the water rights that are administered by the State of New Mexico and water rights that fall under the purview of the Federal government. The latter types of rights constitute what are typically referred to as Pueblo water rights. Though Pueblo rights have priority over state-administered rights and are unending (Chestnut, 2000), they remain largely unquantified within the planning region. However, some court-ordered rights have been established for the Pojoaque-Nambe sub-basin. More of the Pueblo water rights may ultimately be quantified under an ongoing adjudication (e.g., U.S. District Court, 1997) that applies to the Pojoaque-Nambe and Tesuque sub-basins (Chestnut, 2000).

Though the available surface water rights database does not facilitate a full comparison of water rights with surface water uses, the use of municipal surface water rights by the City of Santa Fe can be assessed. The total surface water right claimed by the City for municipal purposes is 5040 afy, a value that is based on the 1976 hydrographic survey for this area. It should be noted that a portion of this right is actually associated with a City of Santa Fe well known as the St Michael's well; a maximum permitted pumping rate of 1000 gallons per minute applies to this well under the license that defines this portion of the surface water right. The City's average annual diversion from the river and St Michael's well for the period 1990-1999 was 4637 afy (personal communication, Amy Lewis, Sangre de Cristo Water).

It should be noted that water rights in the Santa Fe River sub-basin have not been decided per a completed adjudication. An ongoing adjudication pertaining to the sub-basin (New Mexico vs. Anita et al.) may ultimately lead to a final determination of some quantified water rights for the area (Chestnut, 2000).

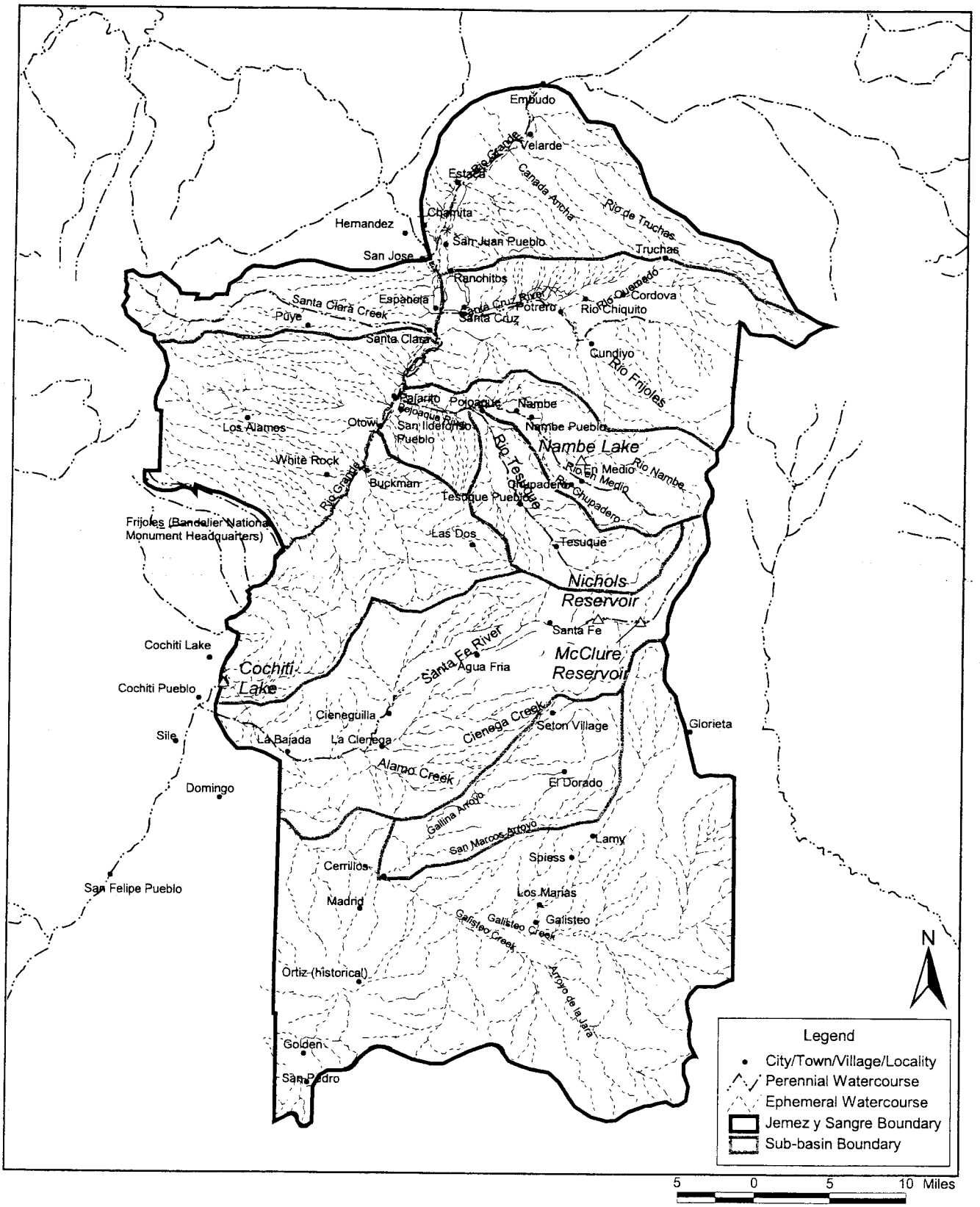

Figure 3-1 Perennial and Ephemeral Watercourses

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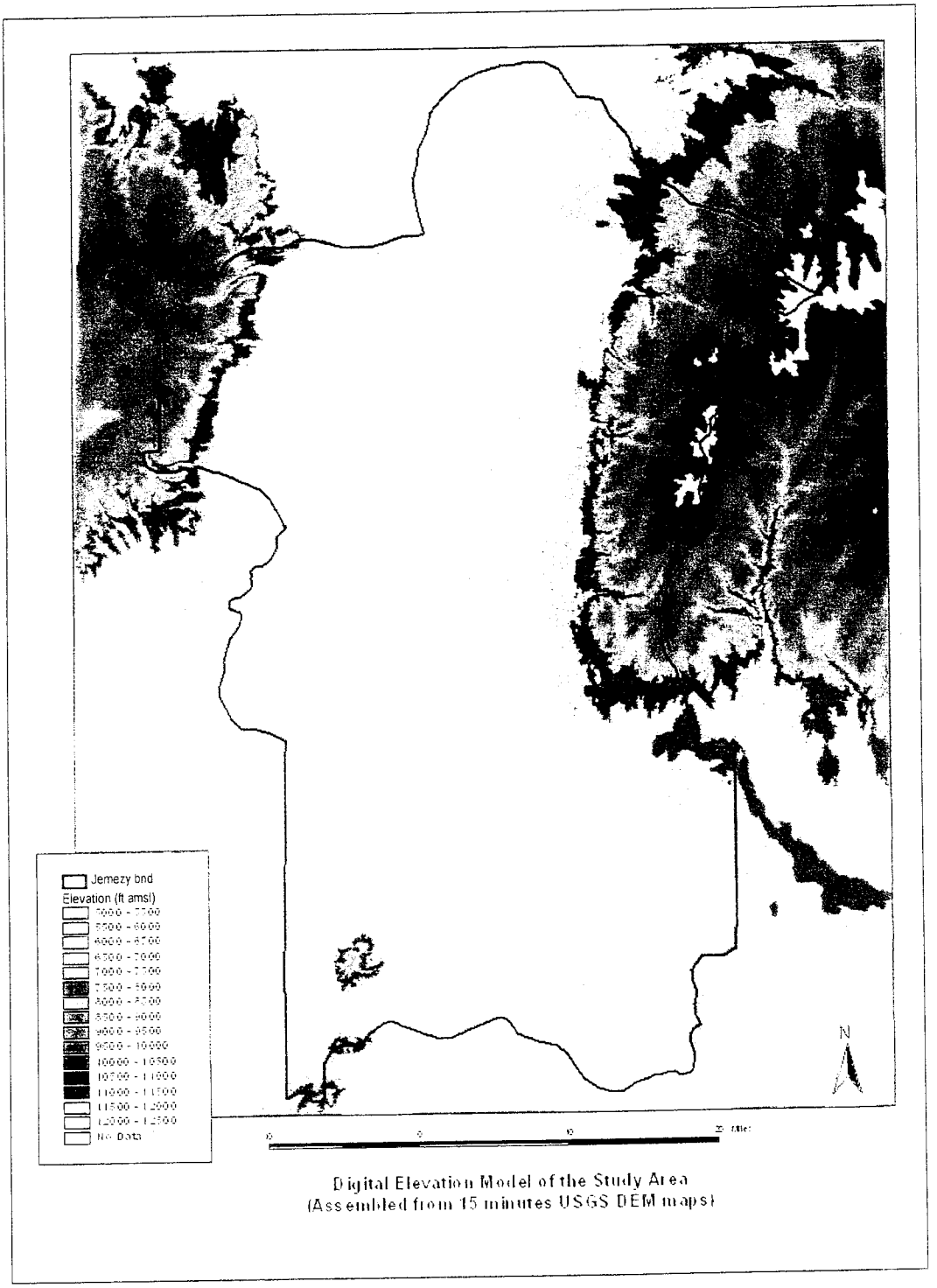

Figure 3-2 Digital Elevation Model of the Study Region
(Assembled from 15 Minute USGS DEM Maps)

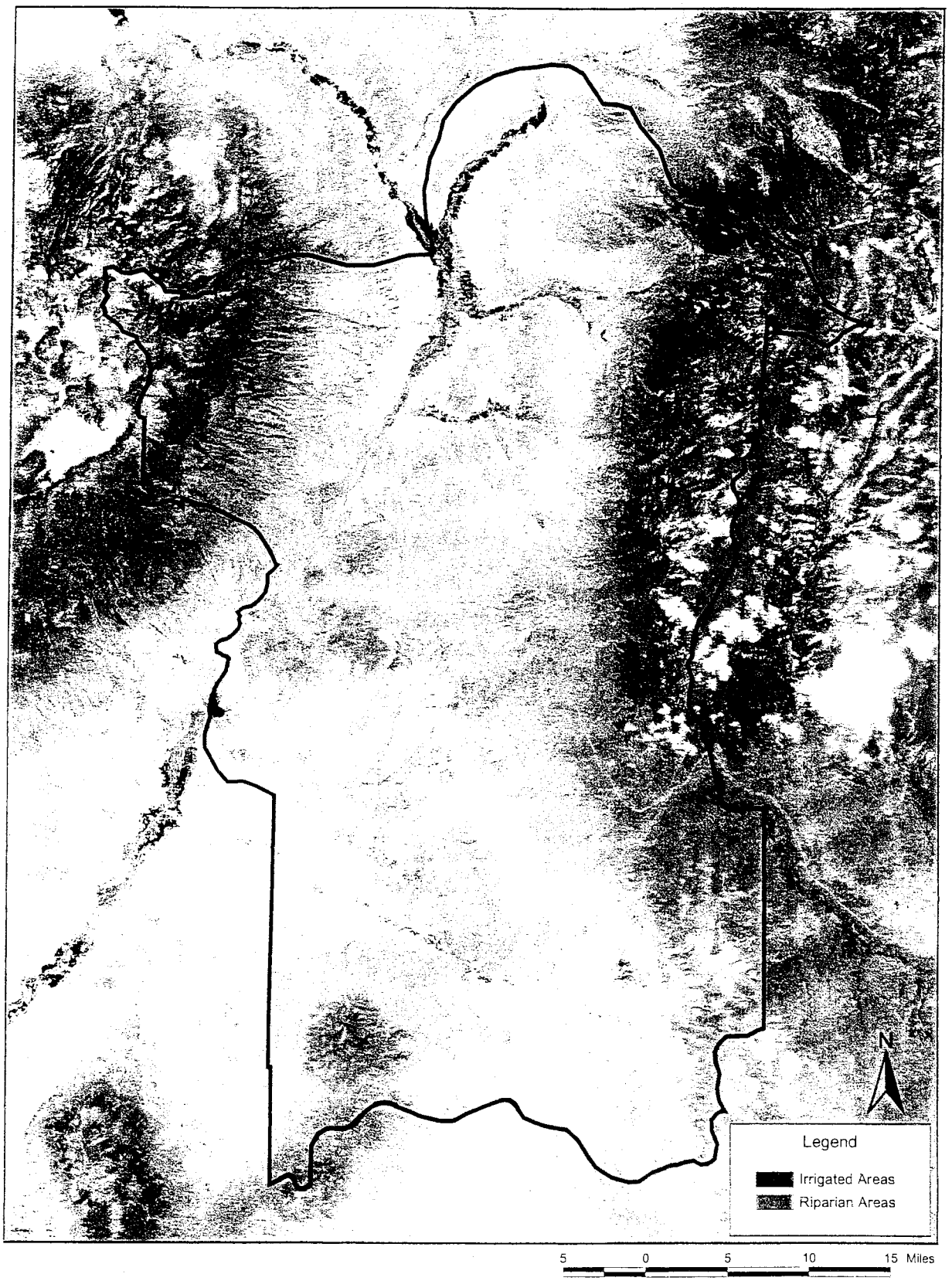

Figure 3-3 1992 Landuse/Landcover Map
(Source: Santa Fe County)

Duke Engineering & Services

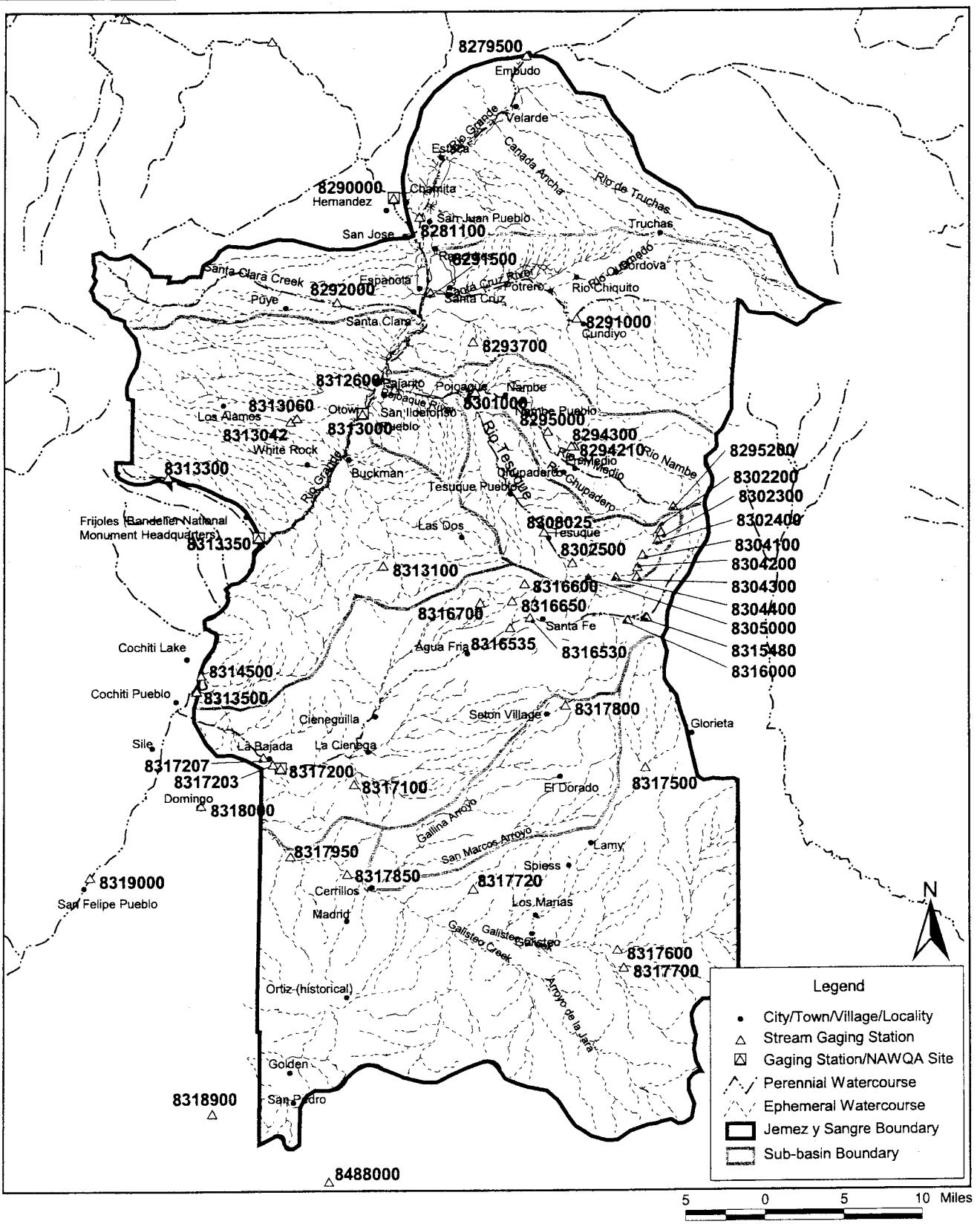

Figure 3-4 USGS Stream Gaging Stations and National Water Quality Assessment (NAWQA) Sites

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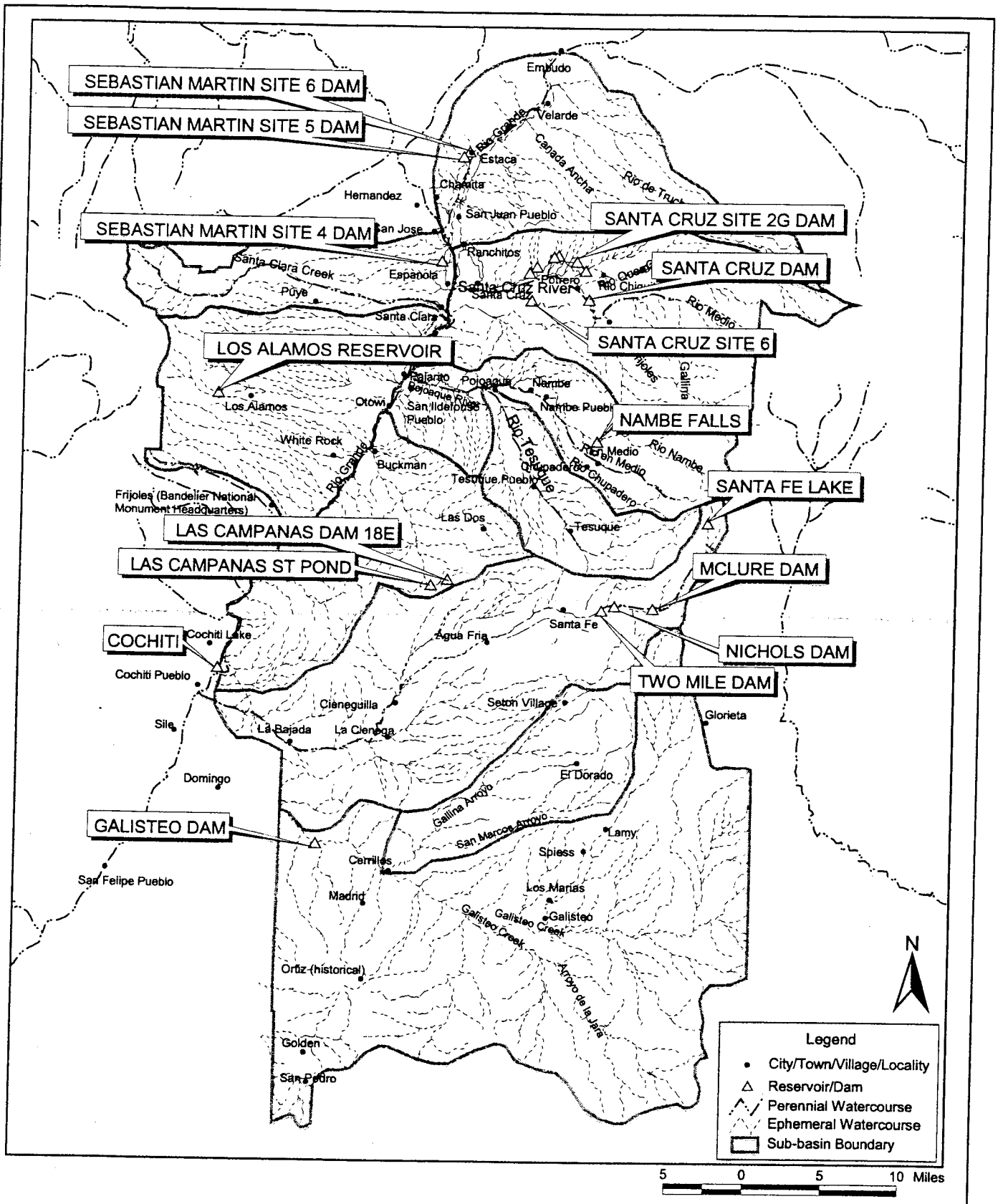

Figure 3-5 Reservoir and Dam Locations

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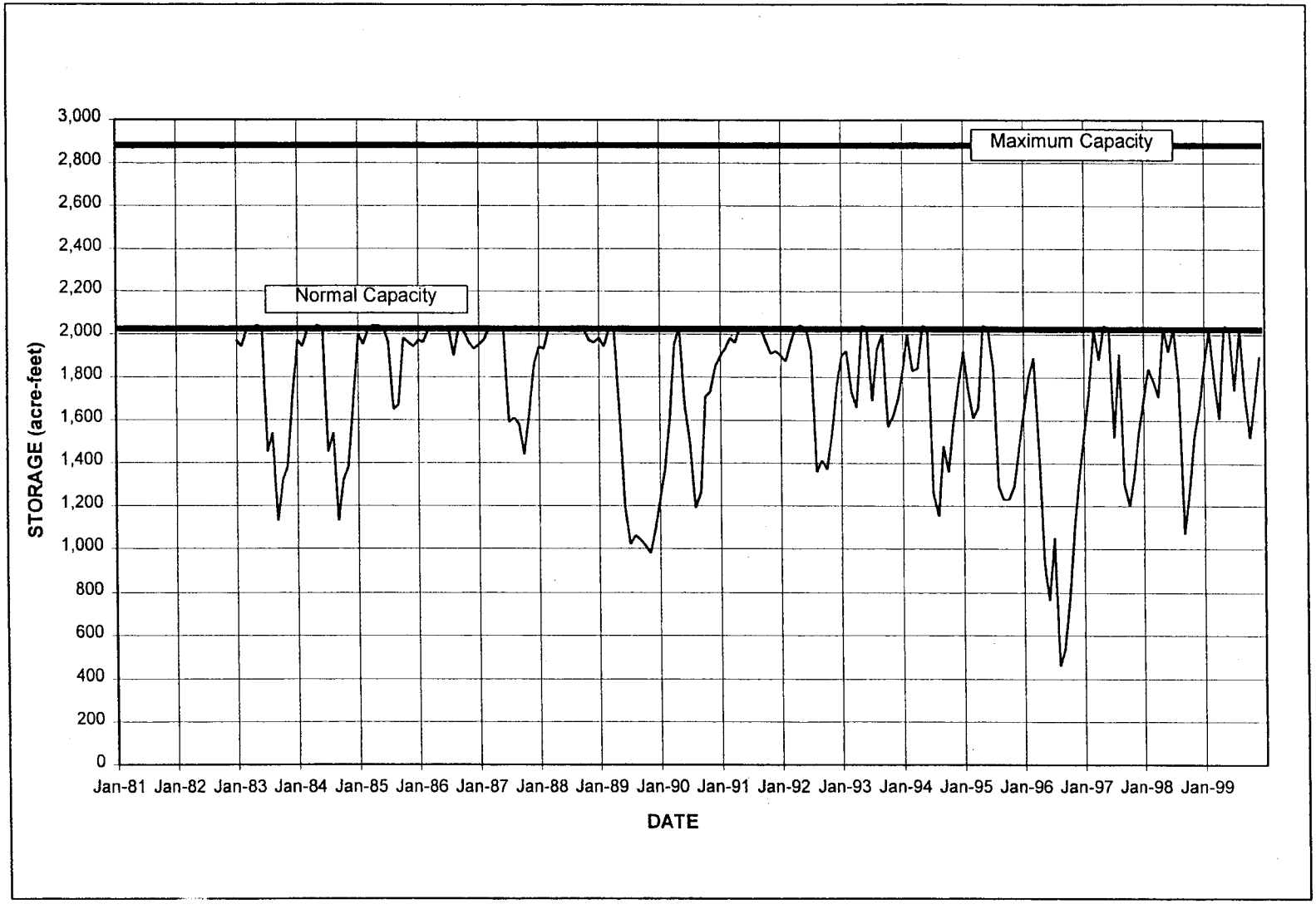

Figure 3-6. End-of-the-Month Storage in Nambe Reservoir

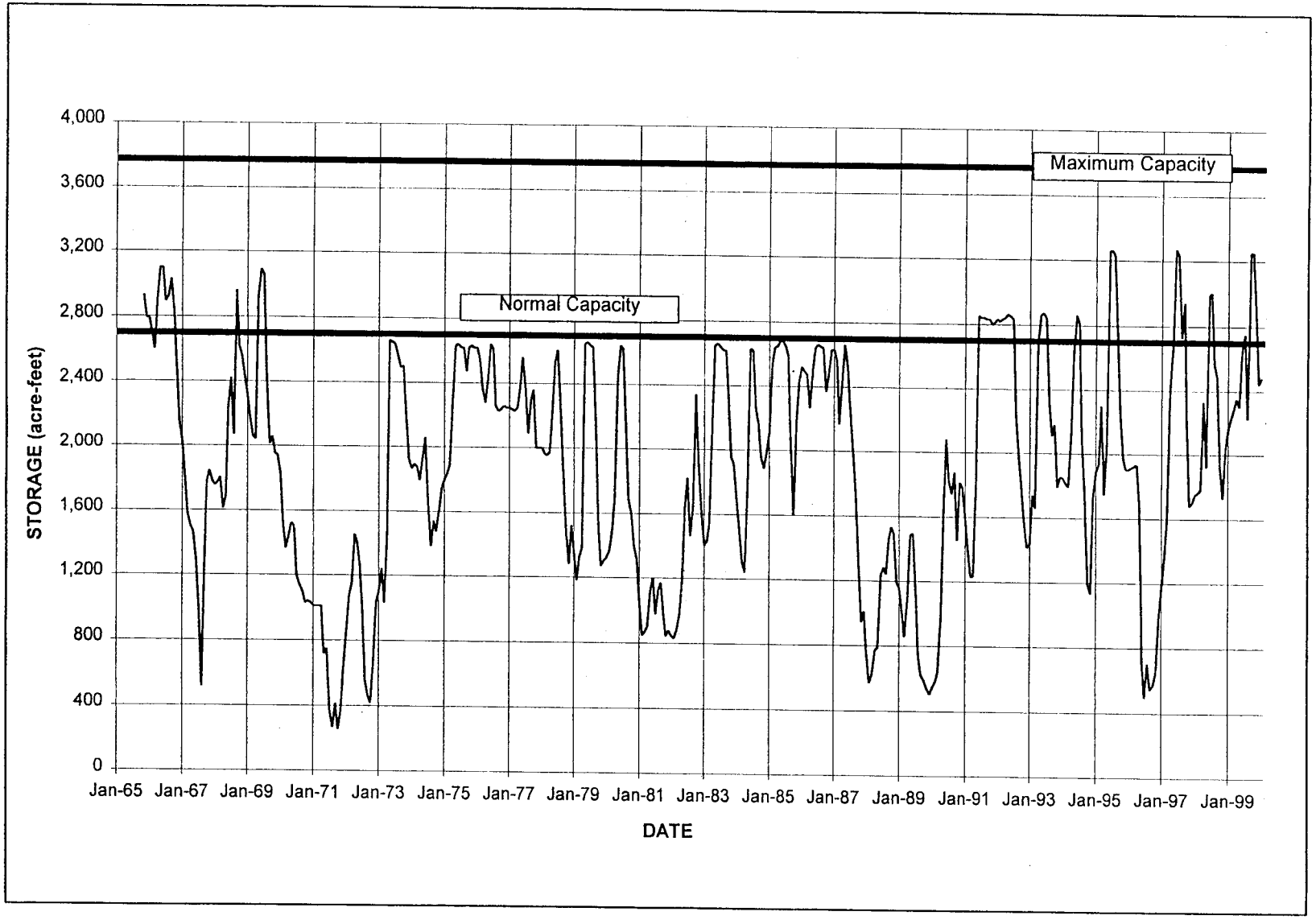

Figure 3-7. End-of-the-Month Storage in McClure Reservoir.

4.0 SURFACE WATER QUALITY

This chapter describes the quality of surface water supplies in the Jemez y Sangre study region. In general the quality of surface water in the region is very good to excellent. Instances where exceptions to this general rule are observed are limited to isolated locations and events where either naturally occurring or anthropogenic exceedances of water quality standards occur.

The first part of this chapter is devoted to a summary of the inorganic constituents dissolved in several of the rivers and streams located in the study region. This information is presented mostly in the context of whether pertinent drinking water standards are met. However, inorganic water chemistry is also examined from a more broad perspective so that ancillary water quality issues, such as the effects of nutrients on aquatic ecosystems, can be taken into account. It may be advantageous to the Council to consider such issues when assessing the potential of using specific watercourses to meet regional water demands.

Potential problems with inorganic constituents in surface water, or lack thereof, are assessed through short descriptons of water quality in selected areas and at specific sites. Four of the specific sites have been selected because they were the focus of a very detailed study of water quality in the Rio Grande Valley in NM that was recently performed by the USGS. Other specific sites constitute local stream reaches where water concentrations have been elevated in comparison to background levels. The potential sources of the elevated concentrations, whether natural or man-made, are mentioned.

To further elucidate potential problems with water quality in the study region, including instances involving contamination by organic chemicals, information is presented on point sources of surface water pollution. Specifically, a list of sites permitted under the National Pollutant Discharge Elimination System (NPDES) is presented. One of NPDES sites, the WWTP for the City of Santa Fe, is discussed further in the context of Total Maximum Daily Load (TMDL) specifications that have been established for the Santa Fe River. Other stream segments that have been the subject of TMDL studies are also summarized. The chapter concludes with a short discussion on non-point sources of surface water degradation.

4.1 Sources of Surface Water Quality Information

Sources of information on water quality within the study region mostly comprised five different types: (1) USGS data provided in its National Water Quality Assessment (NAWQA) study of the Rio Grande Valley; (2) STORET data from the EPA; (3) NMED data describing point and non-point sources of pollution; (4) NMED literature describing TMDL studies of the Santa Fe River and other streams; and (5) reports by other government agencies and consultants on water resources and water quality. Included in the last information category were a report by Blake et al. (1995) that discussed both surface-water and groundwater chemistry in and near the Los Alamos sub-basin and several annual environmental surveillance reports for LANL.

4.2 General Inorganic Water Chemistry

4.2.1 State and Federal Standards for Drinking Water

The identification of potentially problematic inorganic constituents focused on 19 measures of inorganic water quality: pH, TDS, dissolved aluminum, arsenic, barium, chloride, cyanide, fluoride, iron, lead, manganese, nickel, nitrate as nitrogen (NO_3 as N), silver, strontium, sulfate, tritium, and uranium. These measures were selected primarily because the NMED and/or the EPA have established either water standards or water quality guidelines for them. In the case of the NMED, the criteria consist of drinking water standards published by the New Mexico Water Quality Control Commission (NMWQCC, 2000a). EPA's standards comprise maximum contaminant levels (MCL), secondary drinking water regulations (SDWR), and action levels (AL) (EPA, 2000). Table 4-1 lists the relevant criteria for all 19 measures.

Another reason for selecting some of these constituents as water quality indicators is that, when elevated, they have the capacity to reflect various types of contamination sources. TDS and chloride are indicative of dissolved solids in general being high, possibly from wastewater discharge or irrigation return flow. Elevated manganese and sulfate levels may result from the use of agricultural fertilizers (Blake et al., 1995). Aluminum, arsenic, barium, cyanide, iron, nickel, and silver may indicate runoff affected by mining wastes. Uranium may also indicate mine-derived contamination, or possibly spills of radioactive waste. Nitrate as nitrogen is an indicator of nutrient contamination, possibly from leaching of soils at irrigated fields, leaching of livestock waste, fertilizer use, wastewater discharges, or urbanization.

4.2.2 Additional Water Quality Criteria

Other inorganic constituents in surface water are mentioned in this chapter because, though no explicit water quality standards or guidelines may exist for them, they could have bearing on the potential use of a water source. Examples of such constituents include dissolved calcium and magnesium, which together are the principal contributors to water hardness. Though hardness is not regulated as a water quality parameter, it is an indicator of other problems that may occur in water delivery systems, such as scaling in pipes and hot water heaters. Hardness is traditionally reported in terms of an equivalent concentration of calcium carbonate ($CaCO_3$). In practical water analysis, the hardness is computed by multiplying the sum of milliequivalents per liter of calcium and magnesium by 50 (Hem, 1989). The resulting equivalent concentration of calcium carbonate, expressed in units of milligrams per liter (mg/L) of $CaCO_3$, is categorized as follows with respect to hardness:

0-60 mg/L of $CaCO_3$.....Soft
61-120 mg/L of $CaCO_3$.....Moderately Hard
121-180 mg/L of $CaCO_3$.....Hard
More than 180 mg/L of $CaCO_3$.....Very Hard

Table 4-1. New Mexico Drinking Water Standards for Surface Water and EPA Drinking Water Standards.

Constituent	New Mexico Surface Water Standard	EPA Drinking Water Standard
pH	6-9	6.5-8.5[2]
Total Dissolved Solids (TDS)	-	500 mg/L[1]
Aluminum (Al)	-	0.05 mg/L[2]
Arsenic (As)	0.05 mg/L	0.05 mg/L[1], 0.005 mg/L[4]
Barium (Ba)	2.0 mg/L	2 mg/L[1]
Chloride (Cl)	-	250[2]
Cyanide (CN)	0.2 mg/L	0.2 mg/L[1]
Fluoride (Fl)	-	2[2]
Iron (Fe)	1.0 mg/L	0.3 mg/L[2]
Lead (Pb)	0.05 mg/L	0.015 mg/L[3]
Manganese (Mn)	-	0.05[2]
Nickel (Ni)	0.1 mg/L	-
Nitrate as Nitrogen (NO3 as N)	-	10 mg/L[1]
Selenium (Se)	0.05 mg/L	0.05 mg/L[1]
Silver (Ag)	-	0.1[2]
Strontium (Sr)	8 pCi/L	
Sulfate (SO_4)	-	250 mg/L[2]
Tritium (H_3)	20,000 pCi/L	
Uranium (U)	5 mg/L	0.02 mg/L[4]

Notes:
mg/L = milligram(s) per liter
pCi/L = picocurie(s) per liter
[1] EPA Maximum Contaminant Level (MCL) – the highest level of a contaminant that is allowed in drinking water. MCLs are enforceable.
[2] EPA Secondary Drinking Water Regulation (SDWR) – a non-enforceable health goal which is set at a level at which no known or anticipated adverse effect on the health of persons occur and which allows an adequate margin of safety.
[3] EPA Action Level (AL) – the concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow. For lead it is the level which, if exceeded in over 10% of the homes tested, triggers treatment.
[4] Proposed MCL.

An additional indicator of inorganic water chemistry used in this chapter is degree of water oxygenation, which is also referred to as a dissolved oxygen (DO) percentage. DO percentage reflects the general health of a watercourse with regard to supporting aquatic organisms, such as those found in vital fisheries; the larger the DO percent, the more likely

that a healthy fishery can be supported. The equilibrium concentration of DO in water in contact with air is a function of temperature and pressure, and to a lesser degree, the concentration of other solutes (Hem, 1989). Thus, the DO percentages presented herein reflect the fraction of possible DO concentrations in units of mg/L that are observed for the stream conditions under which water samples have been collected. DO percentages approaching a value of 100 are ideal for maintaining higher forms of aquatic life. Insufficient DO in surface water can cause the anaerobic decomposition of any organic materials present. This degradation can lead to the formation of noxious gases such as hydrogen sulfide or the development of carbon dioxide and methane in river sediments, which in turn bubble to the river surface (EPA, 1976).

Nutrients in the form of ammonia and total phosphorous are also used as indicators of surface water quality in this chapter. As measured by the USGS, total dissolved ammonia includes the ammonium ion (NH_4^+) and un-ionized ammonia (NH_3). The latter, though usually a minor component at pHs commonly observed in streams and groundwater, can be very toxic to fish at high levels (USGS, 1999). The EPA has established criteria for un-ionized ammonia in surface water because of its toxicity to fish; these criteria translate into equivalent total dissolved ammonia concentrations that vary from 0.07 to 2.1 mg/L for pHs of 6.5 – 9 and water temperatures of 0 – 30 °Centigrade (EPA, 1986).

When occurring at elevated concentrations in surface water, dissolved phosphorous can lead to nuisance plant growth (USGS, 1999). Phosporous is also a major contributor to stream and lake eutrophication. A measure of phosphorous content referred to in this chapther is total phosphorous, which is reported in units of milligrams per liter as phosphorous (mg/L as P). The EPA has not established a national criterion for total phosphorous in streams. However, it has established a national goal of 0.1 mg/L as P for this water quality measure in streams and other waterways not discharging directly into impoundments or lakes (EPA, 1986).

Elevated levels of either ammonia or phosphorous are often indicative of deleterious effects on watercourses brought about by wastewater discharges from either commercial or public entities such as sewage treatment plants.

4.2.3 Overall Quality of Surface Water

Examination of all of the information soures used to characterize inorganic water chemsistry indicates that the general quality of surface waters in the Jemez y Sangre planning region is very good to excellent. Total dissolved solids (TDS) levels in surface waters typically fall below a value of 250 milligrams per liter (mg/L); such TDS concentrations are substantially below the standards listed in Table 4-1, and well below the 1000 to 3000 mg/L range that the ISC uses to classify "slightly saline" waters (ISC, 1994). In addition to meeting TDS standards, surface waters in the study region typically comply with the other standards and guidelines listed in Table 4-1. Scattered cases where inorganic ions dissolved in surface water do present a potential problem occur mostly in locales that are affected by some form of wastewater discharge.

The most abundant cation in regional surface waters is calcium, with sodium, magnesium, and iron occurring in lesser quantities. The predominant anions are bicarbonate and sulfate. Over most of the study region, the surface water is characterized as a calcium-bicarbonate type, although calcium-magnesium-bicarbonate and sodium-bicarbonate types are occasionally observed (Blake et al., 1995). Most surface waters in the study region are classified as moderately hard to hard because of the concentrations of calcium and magnesium in them.

Nutrients dissolved in surface waters of the region occur mostly as a result of agricultural land uses, though they can also be the result of urbanization and wastewater discharges. Contributions to dissolved nutrients on the main stem Rio Grande are made by agricultural sources from as far north as the San Luis Valley in southern Colorado and the Rio Chama above El Vado Reservoir. Noticeable nutrient sources in and from tributaries include irrigated areas near Española, one of the more urbanized locales in the study region, and along the lower Santa Fe River downstream of the City of Santa Fe. Surface water in the Pojoaque Valley also occasionally contains elevated levels of nutrients.

The following sections describe the inorganic chemistry of surface water in specific parts of the study area. In attempting to identify sites with elevated concentrations, the focus has been placed on surface watercourses comprising the natural drainage system, rather than wastewater ponds or effluent pipes.

4.3 Water Quality at NAWQA Sites

The NAWQA study of the Rio Grande Valley (Healy, 1997) was conducted during the years 1993-1995. At most of the sites included in the study, monthly samples were gathered between April 1993 and September 1995, although the actual sampling schedule varied somewhat. The water chemistry variables that were examined included dissolved solids, major inorganic constituents, and nutrients.

Three of the sites included in the NAWQA study of the Rio Grande Basin fall within the boundaries of the JySWP region. A fourth, located on the Rio Chama near the community of Chamita, is situated approximately 2 miles upstream of the Rio Chama's confluence with the Rio Grande. The locations of the NAWQA sites are shown in Figure 3-4. Pertinent data regarding each of the four sites associated with the Jemez y Sangre study area are summarized in the following sections.

4.3.1 Rio Chama Near Chamita

This site is located on the downstream side of U.S. Highway 285, approximately 0.5 miles west of Chamita, NM, and is associated with USGS station 0829000. Water quality information was gathered monthly for this location as part of the NAWQA study during the years 1993-1995. The water at the site is characterized as a well oxygenated, calcium-bicarbonate type. The NAWQA results showed a median pH value of 8.2 and median dissolved oxygen (DO) percent of 101. The mean TDS value was 186 mg/L, and the

maximum measured TDS level was 242 mg/L. Measured hardness at this site ranged from 88 to 150 mg/L as $CaCO_3$, which places the water here in the moderately hard to hard category. A Stiff diagram of the major anions and cations at the site based on the mean of measured concentrations during the study is shown in Figure 4-1a.

Nutrient levels were also measured at the Rio Chama Near Chamita location. Nitrite plus nitrate, reported in units of mg/L as nitrogen (mg/L as N), had a median value of <0.05. Total ammonia showed a median value of 0.02 mg/L as N, indicating that nutrients in the river are at relatively low levels. The median concentration of total phosphorous was 0.06 mg/L as P.

Iron and manganese are two additional inorganic constituents that were monitored during the NAWQA study. At the Rio Chama Near Chamita site during the study, iron had a mean, median, and maximum concentration of 0.033, 0.023, and 0.14 mg/L, respectively. The mean, median, and maximum concentrations of manganese were 0.008, 0.006, and 0.045 mg/L (Healy, 1997).

4.3.2 Rio Grande at Otowi Bridge, Near San Ildefonso, NM

This site, located on the Rio Grande main stem approximately 1.8 miles southwest of San Ildefonso, is associated with USGS gaging station 0831300 reported on in Chapter 3. The west bank of the river at the Otowi Bridge is included in the Los Alamos sub-basin, whereas the right bank falls within the Caja del Rio sub-basin, approximately 2 miles south of where the Pojoaque-Nambe sub-basin joins the Rio Grande. The mainstem Otowi location is important from a water quality perspective because it represents a composite of all of the surface water contributions from north of the study area and the smaller tributaries located in the northern half of the study area. As such, the Otowi gage reflects the major ion and nutrient chemistry of irrigated areas in (1) the San Luis Valley of southern Colorado, (2) the Taos, NM region, (3) the Rio Grande Valley between Española and Embudo, (4) the Rio Chama Valley, and (4) the Santa Cruz, Nambe, and Pojoaque Valleys.

Like the Rio Chama Near Chamita, water at the Otowi gage is characterized as a well-oxygenated, calcium-bicarbonate type. During the 1993-1995 sampling period, the median pH at this location was 8.1 and the median DO percent of saturation was 95. The mean and maximum observed TDS levels were 186 and 221 mg/L, respectively. Hardness ranged from 95 to 140 mg/L as $CaCO_3$, again indicating moderately hard to hard water. A Stiff diagram based on the mean concentrations of dissolved inorganic ions at the site is presented in Figure 4-1b.

Nutrient levels tend to be slightly higher at the Otowi site than at the Rio Chama Near Chamita location. This is partially due to the tendency of both flows and nutrient concentrations to be higher on the main stem Rio Grande above Española than they are on the Rio Chama (Healy, 1997). During the NAWQA study, the Otowi median concentrations of nitrite plus nitrate and total ammonia were 0.06 and 0.02 mg/L as N, respectively. The median concentration of total phosphorous was 0.07 mg/L as P.

Mean, median, and maximum concentrations of iron at the Otowi site during the NAWQA study were 0.033, 0.019, and 0.140 mg/L, respectively. Mean, median, and maximum concentrations of manganese were 0.008, 0.006, and 0.015 mg/L, respectively.

4.3.3 Rito de los Frijoles in Bandelier National Monument, NM

This site is located south of the City of Los Alamos on the western side of the Rio Grande in Bandelier National Monument, about 800 feet downstream from the monument headquarters. USGS station 08313350 is located near the NAWQA site. The stream's course actually coincides with part of the western boundary of the water planning region and the southern boundary of the Los Alamos sub-basin. The Rito de los Frijoles is a relatively small tributary to the Rio Grande, draining a mostly-forested catchments of about 18 square miles at the monitoring site. Tertiary volcanic tuff constitutes the major rock type in the drainage area. It is considered a perennial stream (see Figure 3-1), but Allen (1999) reports that some of its reaches have been known to go dry in some years.

Surface water at this location is generally a well-oxygenated, sodium-calcium-magnesium-bicarbonate type. Median pH during the NAWQA study was 7.8, and the median DO percent of saturation was 98. The mean and maximum TDS concentrations were 112 and 126 mg/L, respectively. Measured values of hardness on the Rito de Frijoles were relatively low, ranging from 28 to 35 mg/L as $CaCO_3$. Figure 4-1c contains a Stiff diagram based on the mean concentrations of inorganic constituents monitored at the site during the NAWQA study.

The most notable feature of dissolved ion chemistry on the Rito de los Frijoles is the relatively high silica concentrations that are observed throughout the year. During the NAWQA study period, silica concentrations ranged from 39 to 64 mg/L, and the median silica level was 57 mg/L. These observed concentrations are outside the range of what is normally expected in surface waters, which is 1 to 30 mg/L (Hem, 1989). The large silica concentrations are likely the result of weathering of volcanic tuff in the drainage basin, and are also probably somewhat representative of other watersheds originating west of the main stem Rio Grande in the Los Alamos area.

Nutrient levels on the Rito de los Frijoles are very low. During the NAWQA study, median levels of nitrite plus nitrate and total ammonia were <0.05 and <0.015 mg/L as N, respectively. The median level of total phosphorous was 0.04 mg/L as P.

Mean, median, and maximum concentrations of iron at this site were 0.190, 0.120, and 0.840 mg/L, respectively. Though these results might suggest that surface water draining the Jemez Mountains and the Pajarito Plateau near the south boundary of the Los Alamos sub-basin tend to have higher iron concentrations than occur in the Rio Grande below, a possible explanation for the higher iron levels was the presence of particulates and/or colloids in samples collected at this site (Healy, 1997). Reported mean, median, and maximum levels of manganese were 0.009, 0.009, and 0.021 mg/L, respectively.

4.3.4 Santa Fe River Above Cochiti Lake, NM

This NAWQA site on the Santa Fe River is representative of a tributary watershed that has undergone substantial urbanization. Originating in the Sangre de Cristo Range, the river flows through Santa Fe, New Mexico, and drains to an area behind Cochiti Dam. The water quality monitoring at this location took place near USGS streamflow-gaging station 08317200, which is 0.8 miles southeast of La Bajada and 5 miles upstream of Cochiti Dam. The site may at times be inundated by Cochiti Lake, although this did not occur during the NAWQA sampling period.

The water chemistry at the Santa Fe River monitoring site is strongly influenced by effluent discharged from the Santa Fe WWTP, located about 11 miles upstream. During most of each year, a large percentage of the runoff at the NAQWA site is WWTP effluent. Thus nutrient levels at the Santa Fe River NAWQA site are expected to larger than observed at the other NAWQA sites in the study region. Other potential influences on water quality include a number of abandoned mines, including an abandoned uranium mine approximately 1.5 miles upstream of the site.

During the NAWQA study, this site exhibited two general types of water. During most of each year, it was characterized as a well-oxygenated, sodium-bicarbonate type. However, it became a calcium-bicarbonate to calcium-sodium-bicarbonate type during high flow periods, with calcium replacing sodium as the dominant cation. The difference was attributed to the percentage of effluent occurring in streamflow. During high flows, most of the runoff from above Santa Fe comprised the majority of streamflow, whereas WWTP effluent comprised most of the streamflow at other times. Though not specifically representative of either two general water chemistry types, a composite Stiff diagram, based on mean concentrations of major ions monitored during NAWQA, is presented in Figure 4-1d.

TDS levels at this site between 1993 and 1995 ranged from 117 to 459 mg/L, and the mean TDS level was 343 mg/L. Median pH was 8.5 and the median DO percent of saturation was 102. Water hardness at this site ranged from 60 to 170 mg/L as $CaCO_3$, and most measurements of this water chemistry descriptor indicated moderately hard to hard water. Nitrite plus nitrate levels varied between 0.12 and 5.0 mg/L as N, and the median measure of this nutrient indicator was 1.4 mg/L as N. The range for total ammonia was <.015 to 0.84 mg/L as N, but the median level for this measure was only 0.06 mg/L as N. The median total phosphorous concentration was 0.9 mg/L as P, and the maximum level was 3.3 mg/L. Both of these latter values exceed the national goal of 0.1mg/L as P established by the EPA (1986)

Mean, median, and maximum concentrations of iron at this site during the NAWQA study were 0.055, 0.028, and 0.430 mg/L, respectively. The mean, median, and maximum levels of manganese were 0.011, 0.008, and 0.022 mg/L, respectively.

4.4 Los Alamos Surface Water Quality

Much of the information available regarding surface water quality in the Los Alamos sub-basin has been collected as part of routine environmental monitoring programs at LANL dating back to the late 1940s. The results of that monitoring have been documented in annual environmental surveillance reports that were published as early as the 1970s. Four of the most recent surveillance reports (LANL, 1996; 1997; 1998; 1999) are used in this study to describe general water quality conditions in the sub-basin during recent years. The monitoring discussed applies not only to the National Laboratory property but also to adjacent areas, such as San Ildefonso Pueblo, that are routinely included in the analyses.

Most concerns regarding surface water quality in the Los Alamos sub-basin arise from the discharge of various forms of effluent in the several east-west trending canyons that incise the Pajarito Plateau. Some of the discharged effluent is associated with NPDES-permitted outfalls on LANL property. Publicly owned treatment works also release effluent to the canyons. However, because none of the streams within the sub-basin is considered perennial, most of the surface water containing any elevated levels of constituents due to mixing with effluent ends up recharging shallow, perched groundwater systems in the alluvium found in the canyon bottoms. Occasionally, runoff from storms is substantial enough to carry surface water beyond the eastern property boundary of LANL and into the Rio Grande.

During the years that LANL has been monitoring surface water chemistry, exceedances of water quality standards have occasionally been observed. However, these exceedances typically occur just below permitted outfall locations. Recent examples of these local surface water quality problems include nitrate concentrations greater than the 10 mg/L as N standard for this constituent in Pueblo Canyon, a phenomenon attributed to the release of treated sanitary effluent from Los Alamos Bayou Sewage Treatment Plant. Nitrate standards are also exceeded in Miranda Canyon due to the release of liquid waste at a NPDES outfall associated with the Radioactive Liquid Waste Treatment Facility at TA-50 (LANL, 1999). It should be emphasized that contaminants at elevated levels associated with effluent discharges on LANL property rarely find their way east of the property boundary via surface water flow. Radionuclide contamination in the form of tritium, strontium, and plutonium has also been observed in canyon surface watercourses. In addition to wastewater discharges, atmospheric fallout is a potential source for these latter dissolved constituents.

4.5 Upper Santa Fe River Water Quality

Approximately 40 percent of the drinking water provided through the City of Santa Fe's water distribution system comes from runoff in the upper parts of the Santa Fe River watershed. This runoff is stored in McClure and Nichols Reservoirs located east and upslope from the City. The surface water is treated at a treatment plant located near the east city boundary. The surface water provided via this river source has the highest quality of all water brought into the Santa Fe distribution system (City of Santa Fe Public Utilities Department, 1999).

4.6 STORET Sites

The potential existence of sites with elevated, or anomalous, surface water chemistry was partly explored using EPA's STORET database (EPA, 2000). This database was provided for DE&S by representatives of the JySWP Council.

A shortcoming of using STORET data to assess elevated concentration occurrences was that the database did not provide explanations for high constituent levels; thus other sources of information had to be examined to provide such explanations, and often no explanation could be found. The following text comprises short summaries of each of the identified sites.

4.6.1 Streams Draining the Sangre de Cristo Mountains

Elevated levels of iron, manganese and other inorganic constituents are occasionally observed in streams that drain the western side of the Sangre de Cristo Range. Though the exact causes of such anomalous concentrations are not clear, it is known that most, if not all inorganic solutes found in the upper reaches of these surface waters result from the natural weathering of granitic and quartzitic rocks found on the west slope of the range. A USGS study conducted in the summer of 1958 demonstrated that all of the inorganic solutes discussed in this section occurred naturally in stream runoff from this area (Miller, 1960). However, the dissolved levels of the inorganic constituents were all relatively low in comparison to the drinking water standards shown in Table 4-1. The relatively low concentrations are partially explained by the fact that the surface waters analyzed under this study were sampled in late June and early July, when stream discharges in the mountains are typically close to their largest values due to snowmelt runoff, and substantial dilution of dissolved species occurs.

STORET data from the years 1968-1971 indicate that manganese concentrations on the Rio de Truchas in the Velarde sub-basin were as high as 0.5 to 0.65 mg/L. The sources of the elevated concentrations of this constituent are not known.

Measured concentrations of iron on the Rio Medio within the Santa Cruz watershed ranged as high as 1 to 4 mg/L during the late 1980s. Manganese concentrations at this site ranged from 0.25 to 0.62 mg/L. Reasons for these elevated concentrations are unknown.

STORET data from samples collected in the late 1980s at a site called Rio en Medio Below Ski Basin in the Pojoaque-Nambe sub-basin indicated iron levels of 1.9 to 33.0 mg/L. Measured manganese levels during the same period were as high as 0.86 mg/L. A single sample collected in 1988 at a site known as Rio en Medio at Easy Street Lift contained dissolved iron at a level of 35.0 mg/L, and manganese at a concentration of 1.79 mg/L. Elevated levels of iron, ranging from 1.1 to 2.5 mg/L, were also observed in 1990, at a site known as Rio en Medio at the Forest Service Boundary. The cause of these anomalous levels of iron and manganese is unknown.

STORET data exist for samples collected in the late 1980s and early 1990s at various locations on the Rio Chupadero within the Pojoaque-Nambe sub-basin. Elevated levels of

iron, ranging from 0.7 to 2.5 mg/L were often observed during this period at all monitored locations on the river. Causes of the elevated iron levels are unknown.

The STORET data for Tesuque Creek and Little Tesuque Creek in the Tesuque sub-basin indicate that, at various times during the 1980s and 1990s, elevated levels of iron have been observed at monitoring stations scattered along each. In addition, a single sample from Tesuque Creek has shown elevated lead concentrations, and several samples taken from Little Tesuque Creek have shown anomalous levels of aluminum.

In 1994, at a site called Tesuque Creek at the End of County Road 72A, iron was measured at a level of 2.7 mg/L. In 1998, on this same creek at a site described as being above Hyde Park, lead was measured at a level of 0.27 mg/L. At a site referred to as Little Tesuque Creek above Evergreen Lodge, dissolved iron has been measured at elevated levels ranging from 1.1 mg/L in 1987 to 3.0 mg/L in 1994. In contrast to these measured iron levels in the creek, Miller (1960) reported a maximum iron concentration of 0.057 mg/L during the summer of 1958.

At sundry locations on Little Tesuque Creek, during the years 1992-1994, dissolved aluminum occurred at concentrations ranging from 1 to 2.2 mg/L. Though the explicit causes of elevated levels of iron and aluminum on Little Tesuque Creek are not clear, the land development along State Highway 475 leading to the Santa Fe Ski Basin, in addition to runoff from the highway itself, might be related to these observations. The largest dissolved concentration of aluminum reported by Miller (1960) was 0.02 mg/L for the Rio Tesuque, and 0.049 mg/L for all of the streams he sampled.

4.6.2 Rio Grande Downstream From Española

The STORET database showed that measured concentrations of aluminum on the Rio Grande below the City of Española, at a location just upstream of the Española WWTP, were as high as 2.4 mg/L during the mid-1990s. During the same period of time, monitored iron concentrations at this location reached levels of 1.5 mg/L and higher. Comparable aluminum and iron concentrations above the City of Española, near the San Juan Pueblo, were about 0.7 and 0.6 mg/L, respectively, in the mid-1990s. The apparent increase in concentrations of these two constituents with distance downstream could be attributable to any of a number of causes, ranging from influx of lesser quality water from the Rio Chama to unidentified waste-water discharges, irrigation return flow, and urban runoff. The first of these, Rio Chama inflows, would not seem likely in the case of iron, given the relatively low reported levels of this constituent on the Rio Chama Near Chamita during the NAWQA study (Healy, 1997).

STORET data from the early to mid 1990s for the Rio Grande below the Española WWTP outfall showed aluminum concentrations reaching levels as high as 1.8 to 1.9 mg/L. Over the same time span at this location, iron concentrations generally fell in the range of 0.4 to 1.0 mg/L, but sometimes reached levels as high as 1.3 mg/L. A single water sample from the river below the outfall collected in 1992 contained manganese at a level of 7.2 mg/L, though manganese concentrations here normally ranged between 0.05 and 0.09 mg/L.

4.6.3 Santa Fe River Below Santa Fe Waste-Water Treatment Plant

Both STORET data and the previously discussed NAWQA study of the Santa Fe River indicate that the water quality along several miles of river lying between the Santa Fe WWTP and Cochiti Lake is degraded somewhat due to the fact that most of the flow here is derived from effluent. Many of the STORET data for sites along this reach of river include analyses of radionuclides and pesticides. Radionuclide concentrations are of interest presumably because of former mining activity in this area, as mentioned in Section 4.3.4.

Despite the potential contributors to elevated levels of anions and cations along the Santa Fe River below the WWTP, most STORET analyses show electrical conductance (EC) values that are indicative of TDS levels below 500 mg/L. Moreover, with the exception of a single measure of 6.2 mg/L for iron at a site known as the Santa Fe River at Tetilla Peak, the STORET data do not show water standards for major ion such as sulfate, iron, and manganese being exceeded. This same observation also holds true for trace metals like arsenic, barium, selenium, and silver. Occasionally, total uranium has been observed along this reach at levels approaching 0.015 mg/L.

4.7 TMDL Status of Streams

A total Maximum Daily Load (TMDL) is simply described as a watershed or basin-wide budget for pollutant influx to a watercourse. A TMDL can also be established for a portion or a segment of a watershed. The NMWQCC is responsible for setting TMDLs in NM. In practice, the bulk of the work that goes into determining whether a TMDL is warranted is performed by the Surface Water Quality Control Bureau (SWQB) of the NMED. The SWQB performs assessments of watersheds or stream reaches within the state and then makes recommendations to the NMWQCC as to whether a TMDL should be set for a specific stream or river.

The SWQB must take into account both point and non-point sources of pollution when considering the determination of a TMDL. Once all the sources have been taken into account, the pollutants are then allowed to be allocated or budgeted among the sources in a manner that describes the limit (TMDL) that can be discharged into the river without causing exceedance of a stream standard set by the NMWQCC. By federal regulation, the TMDL cannot be based on pollutant sources alone, but must also include a margin of safety.

As a result of the TMDL process, the amount that a point or non-point source can contribute to a river is determined in terms of a daily loading quantity. Typically, such a loading is calculated in units of pounds per day (lb/day) of a specific pollutant.

4.7.1 Existing TMDL Studies

A variety of stream reaches within the study region have been and may continue to be the subject of TMDL assessments since the TMDL program was initiated in NM. Table 4-2 lists the stream reaches within the study region that are still being assessed, and provides a brief summary of the pollutants being examined for each and the current TMDL status. The

information provided in Table 4-2 is insufficient for assessing what effect proposed TMDL limits, should they be imposed, would have on instream flows. An entirely separate study would be necessary to estimate such effects.

4.7.2 TMDLs for the Santa Fe River

As Table 4-2 indicates, the Santa Fe River is the only watercourse in the study region for which the NMWQCC has set TMDL-based limits. Specifically, for the reach of the river lying between the Santa Fe WWTP and Cochiti Reservoir, loading limits have been established for chlorine and stream bottom deposits. Other water quality measures that have been assessed on this reach, but have not been assigned TMDL-based limits, include DO and pH. Though nitrate levels below the WWTP were observed to be as high as 5.0 mg/L during the NAWQA study (See Section 4.3.1.4), no TMDL-based limits have been established for nitrate.

Because non-point sources are not applicable to determining TMDL-based loading limits on the Santa Fe River, the limits for chlorine and stream bottom deposits have been established on the basis of a single point source, specifically, effluent from the Santa Fe WWTP. The standard that has been set for concentrations of total residual chlorine in the effluent is 0.011 mg/L. This is based on a design effluent flow of 8.5 million gallons per day (mgd) and an allowable target loading rate on the river of 0.78 pounds of chlorine per day (lb/day). The actual effluent flow rate at the WWTP now averages approximately 5.9 mgd.

The TMDL study of the Santa Fe River has identified a distinct link between chlorine in the river and effluent from the Santa Fe WWTP. A study by Camp Dresser and McKee (CDM, 1995) provided evidence that virtually all total residual chlorine in the river was coming from the WWTP and that levels of this dissolved constituent decrease downstream of the WWTP. It is expected that the WWTP will be required to meet the chlorine load limits established by the TMDL process. Per NPDES guidelines, the time frame for achieving compliance with such a limit is three years. However, the Santa Fe WWTP has already replaced its chlorination system with an ultraviolet disinfection system. Thus, the potential exists for meeting TMDL-based limits for chlorine very soon, if not immediately.

The setting of TMDL-based limits for stream bottom deposits on the Santa Fe River involves a more complex process than that involved with total residual chlorine. Part of this complexity stems from the manner in which the standard for stream bottom deposits is stated; it does not readily facilitate the determination of load limits in typical units of mass per time, whether in the form of point or non-point sources. The general standard for stream bottom deposits (NMWQCC, 2000a) partly reads as follows: "The stream shall be free of water contaminants from other than natural causes that will settle and adversely inhibit the growth of normal flora and fauna or significantly alter the physical or chemical properties of the bottom." To implement such a standard, the SWQB established an allowable quantity of fine-grained sediment that can be carried in stream discharge. However, because it is difficult to perform traditional load calculations for percent fines, the SWQB chose to create a load criterion for total suspended solids (TSS) in stream discharge.

Though the Santa Fe WWTP is not the only source for suspended solids on the Santa Fe River, it is the only known point source. Currently, the plant is permitted to have effluent discharge containing 30 mg/L TSS. The geometric mean of TSS measurements in WWTP effluent from data collected between July 1998 and June 1999 was 1.0 mg/L. From January 1995 to December 1995, the geometric mean load was 6.3 mg/L. For TMDL purposes, the waste load allocation for TSS in WWTP effluent is based on its current permitted TSS concentration of 30 mg/L and the plant's design flow of 8.5 mgd. Thus, on the basis of TSS information collected during the 1990s, it appears that the WWTP is meeting its allocation criteria.

4.8 Point Sources of Pollution

Potential point sources of surface water pollution in the study region were identified in a Tier 2 dataset that consisted of NPDES sites. A list of NPDES sites within the study region is presented in Table 4-3. It should be noted that NPDES permit NM 0028355 is a single permit that covers several different outfalls on LANL property that discharge both industrial effluent and domestic sewage.

4.9 Non-point Sources of Pollution

The NMED has expressed concern that non-point sources of pollution in New Mexico may constitute one of the more serious water quality problems facing the state (NMWQCC, 2000b). Being diffuse in origin, non-point pollution is the result of rain or snowmelt carrying pollutants from the land into streams, lake, and rivers. The principal contaminants contributed from this type of pollutant source are nutrients, sediments, toxic substances, organic matter, salts, metals, and petroleum and its byproducts. The NMED estimates that about 92 percent of known river water quality impairment in the state is due to non-point sources (NMWQCC, 2000b). Accordingly, given the occurrence of significant agriculture activity and urbanization within the Jemez y Sangre planning region, it can be assumed that some surface water quality degradation in the study area is attributed to this type of source.

Table 4-2. TMDL Status of Streams in the Jemez y Sangre Study Region.

WATER BODY NAME (Basin, segment) EVALUATED OR MONITORED (E/M), SUPPORT STATUS WBS NUMBER	TOTAL SIZE AFFECTED (MILES)	PROBABLE SOURCES(s) OF POLLUTANT	TMDL SCHEDULE (DATE TMDL DUE)	NO. OF NPDES PERMITS ON THE REACH	USES NOT FULLY SUPPORTED	SPECIFIC POLLUTANT(s)	ACUTE PUBLIC HEALTH CONCERN (YES/NO)
Pojoaque River from mouth on Rio Grande to Nambe Dam (Rio Grande, 2111), E Partially Supported (URG1-10200)	14.4	Rangeland, Removal of Riparian Vegetation, Streambank Modification/Destabilization	December 31, 2017	2 Pojoaque Terraces Mobile Home Park (NM0028436) Pojoaque Valley Schools-Jacona Site (NM0029882)	MCWF, WWF	Stream bottom deposits	NO
Tesuque Creek from the confluence with Little Tesuque Creek to the confluence of North and South Forks of Tesuque Creek (Rio Grande, 2118), M Not supported (URG0-10230)	6.7	Removal of Riparian Vegetation, Streambank Modification/Destabilization	December 31, 2017	0	HQCWF	Turbidity	NO
Little Tesuque Creek from Big Tesuque Creek to headwaters (Rio Grande, 2118), M Not supported (URG1 – 10230)	8.1	Recreation	December 31, 2017	0	HQCWF	Turbidity	NO
Little Tesuque Creek from Big Tesuque Creek to headwaters (Rio Grande, 2118), M Not Supported (URG1 – 10230)	8.1	Natural, Unknown	December 31, 2017	0	HQCWF	Metals	NO
Rio Frijoles from confluence with Rio Medio to Pecos Wilderness boundary (Rio Grande, 2112), E Partially Supported (URG1 – 10240)	2.5	Unknown	December 31, 2017	0	HQCWF	Unknown	NO
Rio Chupadero from USFS boundary to headwaters (Rio Grande, 2118), M Not Supported (URG1 – 10240)	4.1	Road Maintenance/runoff, Recreation , Unknown	December 31, 2017	0	HQCWF	Turbidity	NO
Rio Chupadero from USFS boundary to headwaters (Rio Grande, 2118), M Not Supported (URG1 – 10240)	4.1	Road maintenance/runoff, Recreation, Unknown	December 31, 2017	0	HQCWF	Turbidity	NO
Rito Canon de Frijoles from mouth on the Rio Grande headwaters (Rio Grande, 2118), M Partially Supported (MRG1 – 20100)	2.8	Land Disposal	December 31, 2017	0	HQCWF	Pesticides (DDT)	NO

WATER BODY NAME (Basin, segment) EVALUATED OR MONITORED (E/M), SUPPORT STATUS WBS NUMBER	TOTAL SIZE AFFECTED (MILES)	PROBABLE SOURCES(s) OF POLLUTANT	TMDL SCHEDULE (DATE TMDL DUE)	NO. OF NPDES PERMITS ON THE REACH	USES NOT FULLY SUPPORTED	SPECIFIC POLLUTANT(s)	ACUTE PUBLIC HEALTH CONCERN (YES/NO)
Santa Fe River from the Cochiti Pueblo to the Santa Fe WWTP (Rio Grande, 2110), M Not Supported (URG1 – 10300)	12.7	Municipal point sources	December 31, 1999	1 Santa Fe WWTP (NM0022292)	MCWF, WWF, LW	Dissolved Oxygen	NO
Santa Fe River from the Cochiti Pueblo to the Santa Fe WWTP(Rio Grange, 2110), M Not Supported (URG1 – 10300)	12.7	Municipal point sources, Rangeland, Resource extraction	TMDL WRITTEN AND WQCC APPROVED	1 Santa Fe WWTP (NM0022292)	MCWF, WWF, LW	Chlorine	NO
Santa Fe River from the Cochiti Pueblo to the Santa Fe WWTP (Rio Grande, 2110) M (URG1 – 10300)	12.7	Municipal point sources, Rangeland, Resource extraction	TMDL WRITTEN AND WQCC APPROVED	1 Santa Fe WWTP (NM0022292)	MCWF, WWF, LW	Stream bottom deposits	NO
Santa Fe River from the Cochiti Pueblo to the Santa Fe WWTP (Rio Grande, 2110), M Not Supported (URG1 – 10300)	12.7	Municipal point sources, Rangeland, Resource extraction	December 31, 1999	Santa Fe WWTP (NM0022292)	MCWF, WWF, LW	pH	NO
Cienega Creek from the mouth on the Santa Fe to Cienega Village (Rio Grande, 2110), M Partially Supported (URG1 – 10310)	4.1	Rangeland, Land Disposal , Unknown	December 31, 2017	2 Valle Vista Sewer Company (NM0028614) Arroyo Hondo (Geohydrology Association) (NM0029823)	MCWF, WWF, IRR	Fecal Coliform	NO
Cienega Creek from the mouth on the Santa Fe to Cienega Village (Rio Grande, 2110), M Partially Supported (URG1 – 10310)	4.1	Rangeland, Land Disposal	December 31, 20017	2 Valle Vista Sewer Company (NM0028614) Arroyo Hondo (Geohydrology Association) (NM0029823)	MCWF, WWF IRR	Chlorine	NO
Galisteo Creek, perennial portions (Rio Grande, unclassified), E Partially Supported	5.5	Rangeland, Hydromodification, Removal of Riparian Vegetation, Streambank Modification/Destabilization	December 31, 2017	0	WWF	Stream bottom deposits	NO

CODES FOR USES NOT FULLY SUPPORTED:

HQCWF = HIGH QUALITY COLDWATER FISHERY
MCWF = MARGINAL COLDWATER FISHERY
WWF = WARMWATER FISHERY
LW = LIVESTOCK WATERING

Table 4-3. NPDES-Permitted Sites in the Study Region

NPDES No.	NPDES Site	County	Latitude	Longitude
NM0020141	Los Alamos Co.-Bayo Canyon	Los Alamos	35.8833	-106.1667
NM0020133	Los Alamos Co.-White Rock	Los Alamos	35.8	-106.1667
NM0028991	Los Alamos Co.-Westgate Estates	Los Alamos	35.8334	-106.3845
NM0029351	Española, City of	Rio Arriba	35.9986	-106.0773
NM0022292	Santa Fe, City of	Santa Fe	35.6250	-106.0083
NM0029637	Los Alamos County Natatorium	Los Alamos	35.8869	-106.3169
NM0028088	Glorieta Baptist	Santa Fe	35.5833	-105.7583
NM0028711	LAC Minerals (Pegasus Gold)	Santa Fe	35.4167	-106.1667
NM0028436	Pojoaque Terraces Mobile Home Park	Santa Fe	35.8897	-106.0228
NM0000191	City of Santa Fe, Sangre de Cristo Water Co.	Santa Fe	35.6867	-105.8917
NM0028614	Valle Vista Sewer Co.	Santa Fe	35.5820	-106.0547
NM0029823	Arroyo Hondo (Underground Storage Tank remediation site)	Santa Fe	35.6275	-105.9244
NM0028355	LANL	Los Alamos	35.8744	-106.3178
NM0029645	Pueblo of Pojoaque	Santa Fe		
NM0029921	NM EID - Española Aquifer Remediation (pending)	Rio Arriba		
NM0029882	Pojoaque Valley Schools (pending)	Santa Fe		

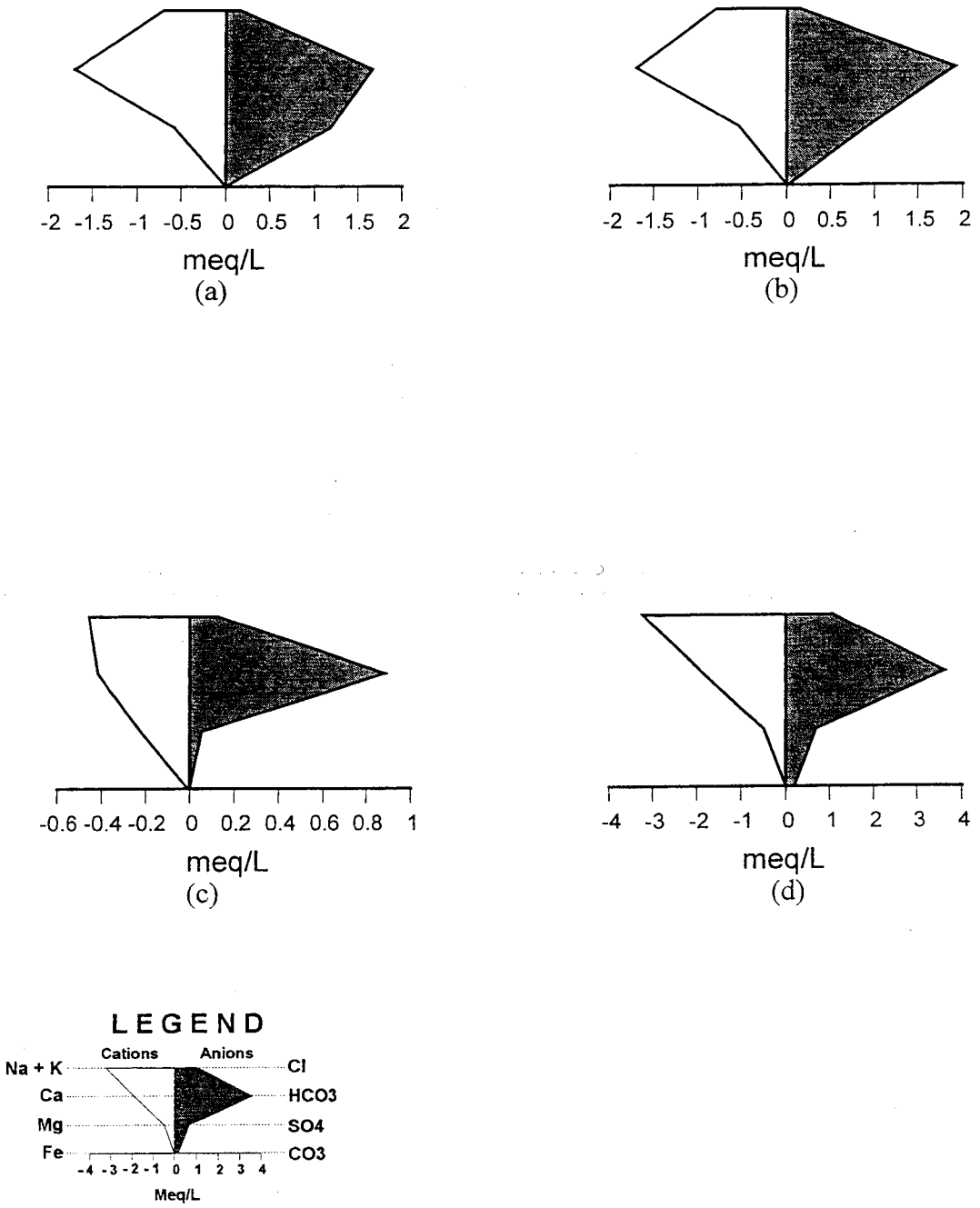

Figure 4-1. Stiff Diagrams for USGS NAWQA Sites:
(a) Rio Chama at Chamita, (b) Rio Grande at Otowi Bridge, (c) Rito de los Frijoles Near Bandelier National Monument, and (d) Santa Fe River above Cochiti Lake.

5.0 GROUNDWATER SUPPLIES

This chapter summarizes the activities and findings from Task 5, describing the various factors used to quantify groundwater supplies in the Jemez y Sangre study region. The general characteristics of hydrogeologic units in the Española Basin, both in the form of water-bearing aquifers and relatively impermeable units, are summarized. Using both relevant descriptions of the basin's geology and previously described information regarding weather and surface water processes, conceptual models are developed of the groundwater recharge and discharge processes in each of the sub-basins, as well as for the entire study region. Moreover, the conceptual inflow and outflow processes are combined with information about regional subsurface water levels to assess the groundwater storage in each sub-basin, and to identify any trends, such as gradual declines in the storage.

The groundwater resource evaluation draws upon many diverse forms of data. Particular attention is paid to the locations and characteristics of the numerous wells found in the region's hydrogeologic units. The types of wells included in the discussion range from monitoring wells maintained by the USGS to irrigation and municipal supply wells. Groundwater level hydrographs from many of the wells are presented as are pumping records from wells for which discharges have been recorded.

Two general types of products are of paramount importance to the groundwater supply evaluation. The first consists of maps, mostly in ArcView form, that help to portray (1) the spatial distribution of aquifers, groundwater levels, and associated hydraulic gradients, and (2) the distribution of groundwater withdrawals. The second product comprises estimated groundwater flow budgets for the sub-basins. This latter type of analysis is crucial to understanding the long-term supply of groundwater. The budget information in this chapter is compared with tabulated groundwater rights that apply to each sub-basin.

5.1 Sources of Groundwater Supply Information

A great deal of the data that were used to delineate groundwater supplies exists within the Tier 1 database. Such information as piezometric heads, water-table levels, pumping rates for many of the community supply wells, and groundwater rights had been tabulated in Tier 1 form for this project. To develop an understanding of both regional and local geology, DE&S largely relied upon reports from the USGS, the New Mexico Bureau of Mines and Mineral Resources, and LANL. Information regarding the major aquifer systems in the study region, as well as other less-transmissive hydrogeologic units, was provided in government agency and consulting reports addressing groundwater flow conditions throughout the region. To develop conceptual models of groundwater flow and storage, DE&S used all of the aforementioned information sources, and also consulted several groundwater modeling studies that were historically performed or are now being conducted for the region. Both the groundwater modeling reports and the general hydrogeology reports helped in the development of groundwater budgets for each sub-basin.

5.2 Regional Geology and Hydrogeologic Units

The study region lies within the Española structural geologic basin (Kelley, 1977). The basin is centered on the confluence of the Rio Grande with its principal tributary, the Rio Chama, near the City of Española. The basin encompasses the Española Valley, which is generally considered to comprise the lower-lying areas within the structural basin. The Sangre de Cristo Mountains form the eastern boundary of the basin, and the Jemez Mountains the western boundary.

Figure 5-1 illustrates the surface geology of the planning region, as presented in Green and Jones (1997). The eastern part of the planning region is covered by Precambrian rocks of the Sangre de Cristo Mountains, which are inferred to exist under the entire study area. The Precambrian rocks have relatively low permeability and storage capacity. However, they can transmit water though fractures to overlying younger sediments. Paleozoic rocks are also found intermittently along the the west flank of the Sangre de Cristo Mountains. Most of the sediments lying within the basin comprise the geologic unit known broadly as the Santa Fe Group. It consists primarily of three geologic units: (1) the Tesuque Formation, (2) the Puye Formation, and (3) the Ancha Formation.

Permian and Mesozoic rocks outcrop south of the Santa Fe River watershed within the North Galisteo Creek and South Galisteo Creek sub-basins. Lower and middle Tertiary units, consisting of the Galisteo Formation and extrusive and intrusive rocks, are exposed in the southern part of the study area. These rocks, together with the Permian and Mesozic rocks, have generally low permeability and compose a bedrock floor that controls the accumulation and movement of groundwater in overlying sediments (Spiegel and Baldwin, 1963). The Galisteo Formation consists of sandstone, mudstone, and conglomerate (Kelley, 1978).

The Tertiary Tesuque Formation of the Santa Fe Group consists of reddish-brown and pinkish-tan silty sand and gravel derived largely from the Sangre de Cristo Mountains (Spiegel and Baldwin, 1963). With a thickness of more than 9000 feet near the Rio Grande (Kelley, 1978), it is the principal groundwater-bearing unit in the planning region. Because it is the primary groundwater-bearing unit in the region, it is sometimes referred to in this chapter as the Tesuque Formation aquifer. The beds of the Tesuque Formation in the eastern part of the region dip to the west and northwest an average of 5 to 10 degrees (Kelley, 1952; Hearne, 1985). This formation consists of interbedded layers of gravel, sand, silt, and clay with some intercalated volcanic ash beds. For this study, the southern extent of the Tesuque Formation (Figure 5-2) was delineated by the intersection of mapped shallow groundwater levels with the base of the Santa Fe Group as developed by LANL. Because of stratification within the Tesuque Formation and the dipping of its sedimentary beds, the aquifer is considered anisotropic, with the major hydraulic conductivity direction occurring along the bedding plane.

The Puye Formation of the Santa Fe Group is present on the western side of the Rio Grande (Griggs, 1964; Purtymun and Johanson, 1974) and is covered by Bandelier Tuff in the Jemez

Mountains area. It consists of poorly sorted boulders, cobbles, and coarse sands (Spell et al., 1990). The thickness of the Puye formation varies from 60 feet near Otowi to more than 700 feet in Santa Clara Canyon (McAda and Wasiolek, 1988). The Puye Formation is generally underlain by the Tesuque Formation. Groundwater is found in the Puye Formation.

The Ancha Formation of the Santa Fe Group is found in an area north of South Galisteo Creek, particularly within the North Galisteo Creek and Santa Fe River sub-basins. The Ancha is more permeable than the Tesuque formation and is as thick as 300 feet in some areas. In most locales, the Ancha formation is above the water table; however, water can accumulate in it where it is underlain by a low permeability unit. Sediments in the form of pediment gravels that occur in the eastern parts of the Velarde and Santa Clara sub-basins are very similar to the Ancha Formation.

Shallow alluvial deposits that are younger than the Santa Fe Group exist in the planning area beneath and adjacent to the Rio Grande and its main tributaries. These deposits are of larger average grain size and better sorted than the sediments comprising the Tesuque Formation. Widths of the shallow alluvial bodies vary from about two miles along the Rio Grande to less than a few hundred feet along the tributaries (Figure 5-2). Thicknesses of these deposits are at least 55 feet along the Rio Grande (Galusha and Blick, 1971) and less than 100 feet along the tributaries (Hearne, 1985).

Appendix H presents generalized east-west trending cross sections that help to illustrate the sequence of sediments occurring in the Española Basin and their location with respect to basement rocks and volcanic materials in the region. These cross-sections also help to illustrate the general locations of north-sound trending fault systems.

5.3 Aquifer Characteristics

It is important for planning purposes to develop representative estimates for hydraulic properties of the main aquifer systems occurring in the study region. Such properties can be used to estimate the amount of groundwater in storage, its availability, and the rate at which it flows. The Santa Fe Group, consisting of the Tesuque, Ancha and Puye Formations, forms the principal aquifer system in all sub-basins, except in the South Galisteo Creek sub-basin where the Galisteo Formation comprises the main hydrogeologic unit. Summaries of the hydraulic characteristics of groundwater-bearing units in the Española Basin were developed using hydrogeology reports for areas within the planning region (e.g., Spiegel and Baldwin, 1963; Hearne, 1985; McAda and Wasiolek, 1988; DBS&A, 1994a; Frenzel, 1995; U.S. District Court, 1997). General aquifer characteristics resulting from this work that can be used to quantify groundwater storage and flows include storage coefficient, porosity, aquifer-saturated thickness, hydraulic conductivity, and transmissivity. Transmissivity is defined as the product of hydraulic conductivity and the aquifer saturated thickness.

Daniel B. Stephens and Associates (DBS&A) (1994a) provided a summary of pumping test results for 150 wells in Santa Fe County. The summary, which is included with this study in Appendix I, includes well location, aquifer unit, well depth, screen thickness, estimated

transmissivity, hydraulic conductivity, specific capacity, storage coefficient, and data sources for different aquifer units.

5.3.1 Transmissivity

Analysis of the aquifer test data indicated that estimates of the transmissivity of the Santa Fe Group aquifer system vary from 0.05 square feet per day (ft^2/day) to 10,960 ft^2/day. Hearne (1985) estimated that the hydraulic conductivity of the Tesuque Formation aquifer system varies from 0.5 to 2 feet/day with a most likely value of 1 feet/day. The estimated range of hydraulic conductivities translates into transmissivities of 500 ft^2/day to 2000 ft^2/day for the top 1000 feet of the aquifer system. McAda and Wasiolek (1988) estimated the transmissivity to vary from 160 ft^2/day to 2400 ft^2/day for the upper 800 feet of the Santa Fe Group with an average of 880 ft^2/day. For deeper portions of the Santa Fe Group, transmissivity estimates varied from 36 ft^2/day to 670 ft^2/day (McAda and Wasiolek, 1988). Frenzel (1995) reported that the estimated hydraulic conductivity of the Santa Fe Group in the Los Alamos Well Field varies from 0.4 feet/day (well LA-3) to 24 feet/day (well PM-3).

As listed in Appendix I, estimates of transmissivity for the Ancha Formation range from 300 ft^2/day to 2100 ft^2/day. On the basis of information presented in Appendix I, hydraulic conductivity estimates for this formation range from 3 feet/day to 21 feet/day. Thus the Ancha formation is typically more permeable than the Tesuque Formation.

Aquifer test data from the southern part of the planning region are too sparse to derive a hydraulic conductivity range for the Galisteo Formation. Spiegel and Baldwin (1963) reported that the permeability of the Galisteo Formation is very low, which limits the availability of groundwater contained within it.

5.3.2 Storage Coefficient and Specific Yield

Analyses of some of the aquifer tests conducted in wells pumping from the Santa Fe Group have produced estimates of both elastic storage coefficient, under confined, artesian conditions, and specific yield, under water-table conditions. Reported storage coefficient values vary from 0.002 to 8.5×10^{-5}, and specific yields range from 0.01 to 0.17 (Appendix I). Hearne (1985) reported specific storage values for the Santa Fe Group that ranged from 1×10^{-6} per foot to 1×10^{-5} per foot of aquifer thickness, and are typically on the order of 2×10^{-6} (i.e., a storage coefficient of 0.002 for 1,000 feet of aquifer thickness). He also reported that the average specific yield of the Tesuque Formation varies from 0.1 to 0.2, with a most likely value of 0.15. McAda and Wasiolek (1988) adopted a specific storage of 1×10^{-6} per foot and a specific yield of 0.15 for the Tesuque Formation.

Little information exists regarding the storage coefficient and specific yield of the Ancha and Galisteo Formations. A storage coefficient value of 0.05 is given for one of the aquifer tests listed for the Ancha Formation in Appendix I.

5.4 Municipal Wells

Groundwater withdrawals are used for municipal water supply in the City of Santa Fe (Buckman and City of Santa Fe well fields), Los Alamos (Los Alamos, Guaje, Pajarito Mesa, and Otowi Well fields), the City of Española, and smaller communities such as El Dorado, south of Santa Fe (Figure 5-3). Table 5-1 lists the reported annual pumpages from these well fields.

The Los Alamos Well Field began production in 1947, withdrawing 451 afy. This well field went out of service during 1993 (Figure 5-4). The Guaje Well Field began production in 1950, and the Pajarito Mesa Well Field started operating in 1965. The Otowi Well Field was added to the municipal supply system during 1993. Total pumping from all well fields in Los Alamos has varied from 451 afy during 1947 to 5193 afy in 1976. The average total groundwater withdrawal for the period between 1947 and 1997 was 3782 afy, and the average total pumpage for the period 1990-1997 was 4418 afy.

Due to the variability of and limited quantity of surface water supplies, the City of Santa Fe depends on both surface water and groundwater for its municipal water supply. The Santa Fe River and its storage reservoirs are the sources for the surface water supply. The surface water diversion from the Santa Fe River was about 2819 afy during 1950 and averaged about 3736 afy from 1950 through 1999. The City diverts groundwater from Buckman Well Field and the city's well field centered on the western end of Santa Fe. The City began diverting water during 1950 from its local well field; the St. Michael's well was added to the supply system in 1961, and the Buckman Well Field was added in 1972. Figure 5-5 illustrates the annual withdrawal from each well field. The average groundwater withdrawal from both well fields by the City of Santa Fe during the period 1950-1999 was 3352 afy, and the average rate of pumping from 1990 through 1999 was 7177 afy.

The City of Española Well Field began diverting groundwater in 1967. Annual pumping was increased from 335 afy during 1967 to 1336 afy in 1995. The average groundwater withdrawal rate for the period 1990-1997 was 1170 afy. Pumping from the El Dorado Well Field started in 1972 at a rate of 12 afy and increased to about 500 afy in 1999 (Shomaker and Associates, personal communication). Total annual groundwater withdrawals from the major well fields in the planning region are presented in Table 5-1 and illustrated in Figure 5-6.

5.5 Monitoring Wells and Groundwater Level Maps

Water level data from monitoring wells maintained by the USGS and LANL, and other water level data presented in consulting reports, were used to investigate the temporal and spatial variations of groundwater levels in the study region. For areas with little to no monitoring well data, the monitoring well database was supplemented using information regarding the elevations of springs or streambed elevations on perennial watercourses. This latter type of information was mainly utilized to estimate subsurface water levels close to the Rio Grande outside the study region, and along the lower reaches of Galisteo Creek and Santa Clara

Creek. Appendix J lists data regarding monitoring wells in Santa Fe, Rio Arriba, and Los Alamos Counties that were used in developing the groundwater level maps.

The spatial distribution and the temporal variation of groundwater levels were investigated by developing two regional groundwater level contour maps, each corresponding to a distinct time period. The first map, shown in Figure 5-7, represents groundwater levels before 1975. It was developed using the first reported water levels at all observation wells before 1975. The map shown in Figure 5-8 was developed primarily using the last water level reading from all wells for which data was collected between 1990 and 2000. To develop this map for areas that are located far from monitoring wells and unlikely to be impacted by stresses on the groundwater system, the more recent monitoring well data were supplemented with earlier well observations. In general, both maps are similar to previously developed water table maps by Spiegel and Baldwin (1963), Mourant (1980), and DBS&A (1994a).

Figures 5-7 and 5-8 provide useful illustrations of hydraulic heads generally measured in the upper 500 to 1000 feet of saturated aquifer material and corresponding general directions of flow in a horizontal direction. However, they do little to indicate piezometric levels that exist in deeper sediments within the region or the vertical hydraulic gradients that may occur within specific locales. To develop a realistic impression of hydraulic head variations with depth, more refined maps showing groundwater levels within specific sub-basins and distinct depth ranges within the saturated zone would have to be developed. Review of groundwater budget calculations that make use of the levels presented in either Figure 5-7 or 5-8, as presented in subsequent report sections, should take into account the limitations of these two maps to distinguish difference in groundwater levels between various depths.

5.5.1 General Directions of Groundwater Flow

The water levels shown in Figures 5-7 and 5-8 indicate that groundwater generally flows from east to west in the Velarde, Santa Cruz, Pojoaque-Nambe, Tesuque, Caja del Rio, and Santa Fe River sub-basins. Though not indicated in Figures 5-7 and 5-8, the general westward decline of groundwater levels within the Santa Fe Group appears to occasionally become relatively steep across suspected fault zones. One such zone reported on by Shomaker and Associates (1996) is located just to the northwest of the City of Santa Fe, along an approximately north-south trending line extending from about a 1000 feet west of Agua Fria on its south end to the vicnity of Las Dos on its north end. Drops in hydraulic head of about 300 feet are observed between wells east of this fault zone and wells located west of it. The assumed cause of decreased permeability in the vicinity of the fault zone that causes the apparent head drop is either fault gouge or mineral precipitation (Shomaker and Associates, 1996).

Table 5-1. Average Annual Production of Major Well Fields.

Year	Santa Fe (afy)	Buckman (afy)	Los Alamos (afy)	Española (afy)	Eldorado (afy)	Total (afy)
1947	0		451			451
1948	0		810			810
1949	0		930			930
1950	121		1688			1809
1951	2010		2366			4376
1952	699		2449			3148
1953	594		2504			3098
1954	1618		2314			3932
1955	1649		2397			4046
1956	2594		2891			5485
1957	993		2228			3221
1958	0		2354			2354
1959	1255		2673			3928
1960	550		3262			3812
1961	488		3588			4076
1962	601		3603			4204
1963	734		3661			4395
1964	3154		3962			7116
1965	199		3428			3627
1966	185		3655			3840
1967	3257		4048	335		7640
1968	1213		4297	374		5884
1969	1338		4100	339		5777
1970	4315		4229	328		8872
1971	4055		4760	225		9040
1972	3739	849	4628	393	15	9625
1973	962	2325	4803	522	11	8623
1974	2202	3288	4984	664	11	11149
1975	450	2372	4711	621	13	8167
1976	1801	2700	5193	758	14	10465
1977	2009	3100	4517	510	23	10160
1978	810	1609	4413	627	26	7485
1979	1196	511	4318	657	53	6735
1980	1565	507	4803	733	46	7654
1981	2607	2486	4616	760	41	10510
1982	2192	1274	4640	630	57	8793
1983	2772	16	4484	547	82	7901
1984	2868	312	4800	881	74	8935
1985	2227	1130	4864	914	590	9726
1986	2095	1548	4591	667	118	9020
1987	2800	1442	4889	603	150	9884

Year	Santa Fe (afy)	Buckman (afy)	Los Alamos (afy)	Española (afy)	Eldorado (afy)	Total (afy)
1988	2909	2470	4478	1149	148	11154
1989	3192	4551	5180	727	181	13831
1990	2984	3824	5039	1153	197	13198
1991	2427	3186	4444	1045	230	11332
1992	2248	4752	4689	897	349	12935
1993	2027	5610	4484	1275	395	13791
1994	2054	4982	4379	1264	466	13145
1995	2026	5891	4161	1337	503	13918
1996	2578	5656	4195	1302	406	14138
1997	1241	4716	3950	1094	460	11461
1998	2271	5216	-	-	519	-
1999	2802	5279	-	-	502	-

Notes:
afy = acre-feet per year

In the Los Alamos and Santa Clara sub-basins, most groundwater flows from west to east to the Rio Grande where it eventually discharges to the surface. In the North Galisteo Creek sub-basin, groundwater flows southwest toward Galisteo Creek. Groundwater flow in the upper elevations of the South Galisteo Creek sub-basin is toward the south. At lower elevations, groundwater flows in several different directions but mostly toward Galisteo Creek. Groundwater levels in the planning region vary from a high elevation of about 7600 feet amsl in the Sangre de Cristo Mountains to about 5300 feet amsl near the Rio Grande at Cochiti Lake.

5.5.2 Temporal Changes in Groundwater Levels

Because the groundwater level maps in Figures 5-7 and 5-8 are more regionally based, rather than focused on a few specific sub-basins, it is difficult through visual inspection alone to delineate locations where either decreases or increases in groundwater levels have occurred between pre-1976 and post-1990 conditions. However, a more computational comparison between the two maps using ArcView showed that discernible drops in groundwater levels have occurred during the past 15 to 20 years in the vicinities of the Buckman, Los Alamos, and City of Santa Fe well fields. The observed decreases in water level in these areas generally ranged from 20 to 100 feet. No specific decreases in groundwater levels were observed elsewhere within the region,

Potential temporal changes in groundwater levels were also investigated using hydrographs for specific monitoring wells. Figure 5-9 shows the locations of wells that were used for this purpose, and resulting graphs of groundwater levels with time are presented in Figures 5-10 through 5-20. Piezometric levels from monitoring wells in the Santa Cruz (Figure 5-10), Santa Clara (Figure 5-11), Pojoaque-Nambe (Figure 5-13), and Tesuque (Figure 5-14) sub-basins all suggested that groundwater levels in these areas have remained relatively constant during the past 20 to 30 years. It should be noted that the observation of no water level decline in the Tesuque sub-basin differs from observations in the study by DBS&A (1994a)

that revealed groundwater level declines in some parts of this sub-basin that ranged from 0.1 to 1.4 feet per year (ft/yr).

As Figure 5-12 indicates, the water level in Well TW-1 in the Los Alamos sub-basin dropped about 50 feet between the late 1980s and late 1990s. Other wells in this region, particularly TW-2 and TW-3, experienced a decline of less than 20 feet during this same period, and also revealed an upward hydraulic gradient between deeper and shallower sediments in the regional aquifer system.

Two USGS piezometer nests monitor hydraulic heads at the Buckman Well Field in the Caja del Rio sub-basin. The nest known as SF-3 monitors piezometric levels within the upper 300 feet of sediment below ground surface (Figure 5-15). The shallowest monitoring levels (SF-3B [169 ft deep] and SF-3C [60 ft deep]) are potentially shallow enough to be indicative of water-table levels. Both of these piezometers have shown a decline of less than 20 feet in hydraulic head since each was first installed in the late 1980s. A third monitoring level in the nest, SF-3A, located at a depth of 294 feet, has shown a drop in hydraulic head of about 140 feet since the installation of this piezometer. SF-3A, in addition to being much closer to the pumping depth zone (near the 900-foot depth), is probably deep enough such that the hydraulic head changes it records are more reflective of confined aquifer conditions than unconfined, water-table conditions.

The SF-2 piezometer nest monitors piezometric levels below the 300-foot depth (Figure 5-16). SF-2C (324 feet deep) has shown a piezometric level decline of about 140 feet since its installation in the late 1980s, which is similar to the decline observed in piezometer SF-3A. Piezometer SF-2B, located 864 feet below ground surface, has shown more than 400 feet of water level decline during the period 1987-1999. In 1987, hydraulic head in the deepest piezometer (SF-2A, 1863 feet deep) was greater than ground surface elevation, but dropped 125 feet below ground surface by August 1988. The water level in this piezometer dropped another 30 feet between August 1988 and September 1999. During 1987, there was virtually no difference in heads measured in piezometers SF-2B and SF-2C, but the hydraulic head in them was about 200 feet lower than the piezometric level measured in SF-2A. This suggested that, at levels below the main pumping zone, groundwater flow was upward and was occurring at a rate that was much larger than any downward flow that might be occurring above the main pumping zone. In the late 1980s, pumping from Buckman Well Field was increased from 2470 afy to 4550 afy. This increase in pumping rate apparently created a measurable downward gradient between the shallow zone (SF-2C) and the pumping zone, the latter of which was represented by piezometer SF-2B. Figure 5-16 shows that the current downward gradient between these two piezometers is about 0.45 feet/feet, and the upward gradient between SF-2A and SF-2B is also about 0.45 feet/feet.

Monitoring well 17N.09E.27.441 in the Santa Fe River sub-basin showed a water level drop of about 150 feet between 1950 and 1999 (Figure 5-17), which equates approximately to a rate of decline of about 3 feet/year. The piezometer nest SF-1, which monitors groundwater levels in Santa Fe River sub-basin near the City of Santa Fe Well Field, has recorded drops in

hydraulic head (Figure 5-18) between 1987 and the current year. Piezometer SF-1C, at a depth of 780 feet below ground surface, which is within the pumping zone elevations in the well field, showed a water level decline of nearly 75 feet for the period 1987-1989. This piezometer tends to reflect pumping in the St. Michael's well. Pumping from the St. Michael's Well decreased after 1989, which allowed SF-1C to recover as much as 45 feet during the next several years. Between 1997 and 1999, the water level in this piezometer fluctuated greatly in response to varied pumping. A deeper piezometer in the SF-1 nest (SF-1A ,1952 feet deep) has tended to show a much more gradual decline in hydraulic head, dropping about 10 feet between 1987 and 2000.

Near the community of La Cienega in the Santa Fe River sub-basin, groundwater levels in Wells 16N.08E.17.2111 and 16N.08E.33.4343 have tended to remain stable since 1960 (Figure 5-17). Water levels in the North and South Galisteo Creek sub-basins (Figures 5-19 and 5-20) have also tended to remain constant since the 1970s.

5.6 Recharge and Discharge

5.6.1 Recharge

In general, recharge to the Santa Fe Group aquifer system is provided by precipitation over and runoff from the Sangre de Cristo and Jemez Mountains (Figure 5-21). Different recharge mechanisms occur within the planning region. Many watercourses draining the Sangre de Cristo Mountains are perennial and recharge the aquifer through stream losses. In addition several tributary watercourses that are considered ephemeral help to recharge the regional groundwater system. Other forms of recharge include sub-surface flow across mountain fronts (mountain-front recharge) and direct areal recharge from precipitation.

5.6.1.1 Recharge from Stream Losses

McAda and Wasiolek (1988) estimated that total recharge to the Santa Fe Group from streams draining the Sangre de Cristo Mountains in the Pojoaque-Nambe, Tesuque, and Santa Fe River sub-basins was 18 cfs (13,000 afy) under natural, pre-development conditions. Hearne (1985) arrived at similar estimates of net recharge to the Tesuque Formation under pre-development conditions from stream losses along the western side of the Sangre de Cristo Mountains. The estimates of recharge from stream loss developed in this study are presented in Chapter 3. As previously discussed, this form of recharge, along with groundwater discharge to surface water, is considered to be one of the most uncertain water budget components.

5.6.1.2 Mountain-Front Recharge

Mountain-front recharge consists of sub-surface flow across the interface between basin sediments and the igneous rocks that are found on the eastern and western margins of the Española Basin. Because mountain-front recharge cannot be measured directly, it, like groundwater/surface water exchange, is considered one of the most uncertain water budget components. Though various methods can be employed to estimate this form of recharge, it is often approximated as the remainder of precipitation minus evaporation and runoff. McAda

and Wasiolek (1988) estimated mountain-front recharge on the eastern side of the Jemez Mountains to be 18.6 cfs (13470 afy), and 20 cfs (14,500 afy) for much of the western side of the Sangre de Cristo Mountains. Wasiolek (1995) developed groundwater budgets for several mountainous sub-areas on the western slope of the Sangre de Cristo Mountains that resulted in an estimated total mountain-front recharge for this part of the study region of about 20 cfs (14,500 afy).

DE&S used mass balance techniques involving annual volumes of precipitation, evaporation, and surface runoff from the mountains to develop separate estimates of mountain-front recharge for each of the sub-basins in this study. To produce the estimates, the mountain front along the eastern side of the planning region was delineated as the contact line between the crystalline rocks of the Sangre de Cristo Range and sediments of the Santa Fe Group. The mountain front along the western side of the planning region was delineated as the contact line between the volcanic rocks of the Jemez Mountains and the sediments of the Santa Fe Group (Figure 5-22).

Average precipitation on the mountains was estimated using the precipitation map developed by Wasiolek (1995) (Figure 5-23), and the potential evapotranspiration map prepared by Tuan et al. (1969) (presented in Figure 2-8) was used to estimate the PET for each sub-basin. Representative values of both precipitation and PET volumes were developed for the mountainous area in each sub-basin via weighting of areas between contours of these variables.

The surface runoff volume associated with mountainous areas in each sub-basin was estimated using either by the area-elevation-yield approach of Reiland (1975) or using gaging station data. Table 5-2 lists the resulting estimated mountain-front recharge for each of the sub-basins and comparable estimates by Wasiolek (1995). A total of about 27.5 cfs (19,940 afy) is estimated to recharge the regional aquifer system via mountain-front sources in the Sangre de Cristo Mountains. The estimated subsurface inflow from the mountain front along the Jemez Mountains is about 10.5 cfs (7,600 afy).

Initial inspection of Table 5-2 seems to indicate that the estimated mountain-front recharge in the Santa Cruz sub-basin (3080 acre-feet) is inordinately small given the relatively large area encompassed by the mountain-front extent in this sub-basin (Figure 5-22). The apparent reason for this relatively low value is that the estimated mountain runoff from this area is quite large, as is indicated by the large estimated surface water inflow to the sub-basin presented in Table 3-14.

Table 5-2. Estimated Mountain-Front Recharge[1] by Sub-basin.

Sub-basin	Current Study Estimate (acre-feet/year)	Wasiolek (1995) Estimate (acre-feet/year)
Velarde	2100	NA
Santa Clara	3760	NA
Santa Cruz	3080	NA
Los Alamos	3820	NA
Pojoaque-Nambe	4500	7230
Tesuque	2460	3320
Caja del Rio	0	NA
Santa Fe River	5050	4170
North Galisteo Creek	0	NA
South Galisteo Creek	3200	NA

Notes:
NA = not applicable
[1]Mountain-front recharge = sub-basin average precipitation volume - volume of surface runoff – evapotranspiration volume.
Precipitation volumes were calculated using Figure 5-23.
Evapotranspiration volumes were calculated using Figure 2-8.

5.6.1.3 Areal Recharge

Natural recharge from precipitation is poorly understood, but is generally believed to be quite small. Hearne (1985), in his evaluation of regional groundwater supplies, did not consider recharge from precipitation. Lee Wilson (1978) suggested that a recharge rate of 0.28 inches per year (in/yr) for the Santa Fe Group is a conservatively large estimate. McAda and Wasiolek (1988) adopted a recharge distribution that varied from 0.5 in/yr on the Ancha Formation within and south of the Santa Fe River sub-basin to 0.2 in/yr for the Tesuque Formation and 0.05 in/yr at Tetilla Peak. Anderholm (1994) concluded on the basis of chloride profiles in regional soils that the rate of areal recharge is quite minor, and, if it is present, occurs mostly on the beds of sandy arroyos. It was assumed in this study that the rate of areal recharge was zero.

5.6.2 Discharge

Groundwater in the planning region discharges naturally to the Rio Grande and several of its tributaries. Other natural processes for groundwater loss include evapotranspiration from a shallow water table and discharges to springs. Groundwater pumping for agricultural, municipal and industrial purposes is also a form of groundwater discharge.

5.6.2.1 Groundwater Discharge to Surface Water

Spiegel and Baldwin (1963) estimated groundwater discharge to the Rio Grande over the reach between Otowi Bridge and Cochiti Lake to be 0.96 cfs per river mile. Griggs (1964) estimated groundwater discharge for the same reach to be 1.1-1.3 cfs per river mile. Hearne (1985) suggested that groundwater discharge to the Rio Grande throughout the Española Basin averages about 0.5 cfs per river mile or less, but is certainly no more than 1 cfs per river mile. Frenzel (1995) concluded that the total discharge to the Rio Grande on the reach between Otowi Bridge and Cochiti Lake varied from 10 to 30 cfs, which translated into a per unit length groundwater discharge of 0.4 to 1.3 cfs per river mile.

Separate estimates of groundwater discharge to the Rio Grande were also developed for each of the sub-basins in this study that border the river. The methods used to compute these groundwater outflows initially made use of the groundwater levels adjacent to the river as shown in Figure 5-8. Preliminary estimates of the discharge were computed using Darcy's Law (Fetter, 1980), a hydraulic gradient as reflected in Figure 5-8, a hydraulic conductivity of 0.5 feet per day (ft/day), and a saturated thickness of 1000 feet. These calculations were performed using a 1000- by 1000-meter grid created in ArcView. Because the groundwater level contours shown in Figure 5-8 do not reflect any information regarding vertical gradients, which are relatively strong beneath the Rio Grande, some adjustments were made to the preliminarily calculated discharges to arrive at final estimates. The final estimated discharges to the Rio Grande are included in Table 5-3.

5.6.2.2 Groundwater Discharge Across Sub-basin Boundaries

The groundwater level maps shown in Figures 5-7 and 5-8 indicate that considerably large groundwater flows have historically occurred and continue to take place between basins. To develop estimates of those flows, the same methods discussed above regarding discharge to the Rio Grande were applied. That is, initial estimates of interbasin flow were developed using Darcy's Law and the parameters discussed in Section 5.6.2.1. These initial values were then adjusted to account for other influences on the transfer of water such as possible vertical gradients and deeper aquifer thicknesses in some locales. Table 5-3 presents all of the resulting estimates of interbasin groundwater discharge.

5.6.2.3 Discharge to Springs

Groundwater discharge to springs, as it was occurring mostly in the late 1970s, has been inventoried by the USGS. (White and Kues, 1992). Unfortunately, more current measurements of spring discharge are relatively limited, but some evidence exists to suggest that many of the spring flows reported by White and Kues (1992) have been severely reduced

or have totally ceased. Such evidence indicates that, on the whole, groundwater levels in the region have been gradually dropping during the past twenty years.

5.6.2.4 Discharge to Evapotranspiration

Groundwater discharge to evapotranspiration was estimated for areas with a depth to groundwater of 20 feet or less. This estimate was not intended to overlap with other estimates of water loss to the atmosphere such as losses due to evapotranspiration by irrigated crops and ET losses by riparian vegetation. Consequently, the physical areas to which this discharge component was ascribed were intentionally chosen to be away from known irrigated and riparian areas. The choice of 20 feet or less as the depth to groundwater at which losses to ET could occur was based on the observation that phreatophyte trees typically have rooting depths on the order of 10 meters (32.8 feet) (Bouwer, 1978) and phreatophyte shrubs commonly root to a depth of 3 meters (9.84 feet).

A depth to groundwater map, as shown in Figure 5-24, was used to estimate the areas where the depth to the water table was less than 20 feet, and the rate of evapotranspiration in these areas was estimated as the sub-basin PET rate minus mean annual precipitation. The resulting ET rate was multiplied by the above-mentioned area in each sub-basin where shallow groundwater was observed. A total of about 13,650 afy was estimated for this water budget component for the entire planning region (Table 5-4).

5.6.2.5 Discharge to Pumping

Pumping of groundwater in the planning region is mainly for municipal and domestic uses. As indicated in Table 3-13, a small amount of groundwater (about 730 afy) is diverted for irrigation use. Domestic pumping in areas without a major municipal water supply was estimated using population estimates for the various sub-basins, which are listed in Table 5-5. Not all of these estimates were used to derive groundwater withdrawals, as many of them apply to areas where the primary groundwater source is pumping from the municipal well fields in which pumping is monitored. It was assumed that the pumpages associated with small community water systems (i.e. systems that serve more than one household but not a major municipality) would be captured in the groundwater withdrawals based on estimated populations.

In those locales where domestic withdrawals were approximated using an estimated population, the pumping was computed as the product of population and a 100-120 gallon per day (gpd) per capita usage. The return flow to the groundwater system from domestic diversions was assumed to be 50 percent.

Table 5-3. Groundwater Flows Across Sub-basin Boundaries[1].

From \ To	Velarde (afy)	Santa Cruz (afy)	Santa Clara (afy)	Los Alamos (afy)	Pojoaque-Nambe (afy)	Tesuque (afy)	Caja del Rio (afy)	Santa Fe River (afy)	North Galisteo Creek (afy)	South Galisteo Creek (afy)	To the East (afy)	To the West (afy)	Total Subsur-face Outflow (afy)
Velarde	0	800											800
Santa Cruz		0			2300							4830	7130
Santa Clara			0	0							2740		2740
Los Alamos				0							2300		2300
Pojoaque- Nambe		960			0	3500						2500	6960
Tesuque					1500	0	2500						4000
Caja del Rio							0	0				2250	2250
Santa Fe River							1050	0	500			2570	4120
North Galisteo Creek								1000	0	1050			2050
South Galisteo Creek									1050	0		3550	4600
Outside Planning Region	4500												
Total Subsurface Inflow	4500	1760	0	0	3800	3500	3550	1000	1550	1050	5040	15700	

Notes:

afy = acre-feet per year

[1]Flows across sub-basin boundaries were initially estimated using Darcy's law with (a) saturated hydraulic conductivity = 0.5 ft/day, (b) a horizontal hydraulic gradient based on the post-1990 groundwater level map in Figure 5-8, and (c) a saturated thickness of 1000 feet. Subsequent adjustments were made based on local conditions such as potential effects of vertical gradients, variable saturated thickness, etc.

Table 5-4. Estimated Groundwater Evapotranspiration[1] by Sub-basin.

Sub-basin	Average Potential Evapotran-spiration[2] (PET) (in/yr)	Average Precipitation[3] (in/yr)	Groundwater Evapotran-spiration[4] (afy)
Velarde	22.1	12.2	1350
Santa Clara	21.2	18.3	1250
Santa Cruz	19.1	16.3	2400
Los Alamos	18.6	17.8	300
Pojoaque-Nambe	21.1	16.9	1850
Tesuque	21.8	15.3	2400
Caja del Rio	26.0	12.0	1100
Santa Fe River	24.0	12.4	1200
North Galisteo Creek	24.0	13.0	500
South Galisteo Creek	24.0	14.0	1300

Notes:
afy = acre-feet per year
in/yr = inches per year
[1]Groundwater evapotranspiration is calculated separately from riparian and irrigated area ET, and applies only to areas with depths to groundwater of less than 20 feet.
[2] Area-weighted average evapotranspiration, as determined from Figure 2-8.
[3] Area-weighted average precipitation for the entire sub-basin, as determined from Figure 5-23.
[4] Groundwater evapotranspiration = (annual PET – average annual precipitation) x land area with depth to groundwater less than 20 feet.

The information sources used to develop the population estimates in Table 5-5 ranged from the Rio Arriba County Planning Office to Wilson and Lucero (1997), DBS&A (1994a), and the Bureau of Business and Economic Research (BBER) (1997). Though not used to estimate domestic groundwater withdrawals, more recent estimates of population in the various sub-basins as developed by the BBER for the Jemez y Sangre Water Planning Council are also listed in Table 5-5.

The estimated population in the Velarde sub-basin was derived by multiplying the estimated number of houses in this area, as provided by the Rio Arriba County Planning Office, by an assumed 2.7 people per house (Vickers, 1990). In the Santa Clara sub-basin, it was assumed that the population comprised 83 percent of the 1990 Census population for the City of Española (which resulted in 8094 people) and the entire 1990 Census estimate for Santa Clara Pueblo (1156 people). The remaining 17 percent of the City of Española 1990 population was assumed to reside in the Santa Cruz sub-basin (Wilson and Lucero, 1997).

Estimates of local population by DBS&A (1994a) were adopted for the Pojoaque-Nambe, Tesuque, North Galisteo Creek and South Galisteo Creek sub-basins. In the Santa Fe River sub-basin, it was assumed that Sangre de Cristo Water served a population of 66,000 people, small community water systems served an additional 1600 people, and 1200 people were on private, domestic water systems (Wilson and Lucero, 1997).

Annual groundwater withdrawals in the major well fields of the planning region were discussed in Section 5.4. Inspection of these withdrawals (Table 5-1) indicates that about 70 percent of the total groundwater diversions in the planning region is due to pumping in the Los Alamos (Los Alamos well fields), Caja del Rio (Buckman Well Field) and Santa Fe River (City of Santa Fe Well Field) sub-basins. The average pumpages from each of these well fields during 1990-1999 were used in the development of groundwater budgets for the affected sub-basins. Table 5-6 lists the final calculated groundwater diversions for irrigation, domestic, and municipal purposes in each sub-basin, and corresponding estimated return flows.

Table 5-5. Estimated Populations by Sub-basin.

Sub-basin	Current Study Estimates	BBER Estimates for 1999
Velarde	7660[1]	4399
Santa Clara	9250[2]	4800
Santa Cruz	9926[3]	19,811
Los Alamos	18,700[4]	19,304
Pojoaque-Nambe	5150[5]	6107
Tesuque	2770[6]	4670
Caja del Rio	0[7]	514
Santa Fe River (city)	66,000[8]	85,981
Santa Fe River (not included in the city estimate)	2800[8]	
North Galisteo Creek	5950[9]	10,373
South Galisteo Creek	1887[10]	2743

Notes:

[1] Velarde population = estimated number of households (as provided by the Rio Arriba County Planning Office) x 2.7 persons per household.

[2] Santa Clara population = 83 percent of the 1990 City of Española population (83% of 9752 = 8094) + estimated 1990 Santa Clara population (1156).

[3] Santa Cruz population = 17 percent of the 1990 City of Española population (17% of 9752 = 1658) + (the estimated number of households outside Española [as provided by the Rio Arriba County Planning Office] x 2.7 persons per household).

[4] Wilson and Lucero (1997), Table 6.

[5] DBS&A (1994a)

[6] DBS&A (1994a)

[7] No previous estimates.

[8] Wilson and Lucero (1997), pages 23-24.

[9] DBS&A (1994a), El Dorado population = 5000, and population on private domestic wells = 950.

[10] DBS&A (1994a).

The techniques applied to develop the estimated diversions and return flows in Table 5-6 are explained in table footnotes. Most of these explanations are relatively easy to understand. However, a few of them may seem somewhat complex and are worthy of further explanation here. First, groundwater pumping for municipal purposes in the Santa Clara sub-basin is calculated at 83% of the average annual total pumping occurring in the Española Well Field during the period 1990-1997. The percentage value applied in this case is equivalent to that

ascribed to the portion of the total Española population thought to lie within the Santa Clara sub-basin. The average total annual pumpage from the Española Well Field during 1990-1997 is 1170 afy, 83% of which is 971 afy. Similarly, the annual groundwater diversion in the Santa Cruz sub-basin for municipal purposes is equal to 17% of the average annual withdrawal from the Española Well Field between 1990 and 1997.

As Table 5-6 indicates, zero return flow is assigned to the groundwater pumped for municipal purposes from the Caja del Rio and Santa Fe River sub-basins for use in the City of Santa Fe. Though return flows in this case do actually exist, they are accounted for in the stream loss components of the surface water budget for the Santa Fe River sub-basin, as presented in Chapter 3, and subsequently in the groundwater budgets presented later in this chapter. This approach is taken because municipal sewage is sent to the local waste water treatment plant (WWTP) located several miles west of the City, effluent from which is either used for irrigation purposes or discharged to the Santa Fe River. Downstream of the Santa Fe WWTP, the Santa Fe River both loses surface water to groundwater and gains in flow due to groundwater discharging to the ground surface in the La Cienega area (see Section 3.7.10).

5.7 Groundwater Storage

Groundwater storage in the Santa Fe Group aquifer system comprises the major source of municipal and domestic supply in the planning region. Estimates of groundwater in storage in the Santa Fe Group were developed in this study for each of the sub-basins. These estimates were made under the assumption that the aquifer system consists of a continuous, homogeneous porous medium. In reality, the assumption of homogeneity does not apply; however, the parameters adopted to represent a homogeneous system are believed to be generally representative of the Santa Fe Group as a whole.

5.7.1 Storage Estimates

Multiple steps were applied to prepare the storage estimates. First the study region was divided into 1000- by 1000-meter cells, and the saturated thickness within each cell was calculated as the difference between the local post-1990 groundwater elevation (Figure 5-8) and the comparable elevation of the base of the Santa Fe Group. Base elevations of the Santa Fe Group were provided by LANL personnel. Then the amount of water in storage for two selected depths of saturation, 1000 and 2000 feet, was calculated as the product of the cell area, the appropriate saturated thickness, and a specific yield of 0.1. Subsequently, the individual cell storage estimates were combined to develop a total groundwater storage volume for each sub-basin.

The parameters used in the calculations and the resulting storage estimates are presented in Table 5-7. The minimum and maximum saturated thicknesses listed for the Santa Fe Group in each sub-basin correspond to visual representations of this parameter shown in Figure 5-25. As indicated in both table and map, the thickness of the Santa Fe Group varies from zero at the eastern and southern boundaries of this geologic unit to more than 9500 feet beneath the Rio Grande in the northern part of the planning region. Obviously, actual saturated depths

were applied to any cells that did not exhibit the full 1000- or 2000-foot depths used in the respective storage calculations.

Table 5-7 indicates that the Los Alamos and Caja del Rio sub-basins contain the highest quantities of stored groundwater. Though the Santa Fe River sub-basin has almost the same area as the Los Alamos sub-basin, it contains noticeably less stored water, largely because saturated thicknesses of the Santa Fe Group in the former are generally not as large as the thicknesses in the latter (see Figure 5-25). The third largest quantities of computed groundwater storage occur in the Velarde sub-basin, where the total saturated thickness approaches 9000 feet or more. Total groundwater storage in the planning region is estimated at 57.8 million acre-feet for the top 1000 feet of the Santa Fe Group aquifer system, and 110 million acre-feet for the top 2000 feet.

5.7.2 Storage Retrievability

The groundwater storage estimate for the upper 1000 feet of saturated thickness in the combined Pojoaque-Nambe and Tesuque sub-basins, approximately 7 million acre-feet, is assumed to be recoverable water. In comparison, Reiland and Koopman (1975) estimated a total groundwater storage of 55 million acre-feet for the same area, but indicated that only a small percentage of this volume is recoverable.

Groundwater storage calculations were also applied to areas lying solely within Santa Fe County. This was done so that the resulting estimates could be compared with previous, alternative storage estimates limited to within county boundaries. Some of the comparisons are presented in Table 5-8. Two of the quantities listed are of interest because they are close in value. Specifically, DBS&A (1994a) estimated a total groundwater storage of about 56 million acre-feet for that part of the Santa Fe Group lying within Santa Fe County. The equivalent estimate developed in this study is 54 million acre-feet, as developed for the top 2000 feet of saturated thickness.

Groundwater storages in the North and South Galisteo Creek sub-basins were previously estimated to be about 182,000 acre-feet (DBS&A, 1994). No attempt was made in the present study to estimate the amount of water in storage in the Galisteo Formation that is located over much of the North Galisteo and South Galisteo Creek sub-basins. The Galisteo Formation is considered to be a poor aquifer; deeper Permian rocks, in the Glorieta and San Andres Formations, likely provide a more reliable source of groundwater in the southern part of the planning region.

Table 5-6. Groundwater Diversions and Return Flows Due to Pumping.

	Diversions (acre-feet per year)				Return Flows (acre-feet per year)			
Sub-basin	Irrigation[1]	Domestic[2]	Municipal[3]	Total[4]	Irrigation[1]	Domestic[5]	Municipal[6]	Total[7]
Velarde	46	858	0	904	7	429	0	436
Santa Clara	0	150[8]	971[9]	1121	0	75	777[10]	852
Santa Cruz	0	922	200[11]	1122	0	461	160	621
Los Alamos	0	0	4420[12]	4420	0	0	177[13]	177
Pojoaque-Nambe	366	577	0	943	142	288	0	430
Tesuque	0	310	0	310	0	155	0	155
Caja del Rio	0	0	4911[14]	4911	0	0	0	0
Santa Fe River (city + other)	318	315	2266[15]	2899	129	155	0	284
North Galisteo Creek	0	112	403[16]	515	0	56	202[17]	258
South Galisteo Creek	0	210	0	210	0	105	0	105

Notes:

afy = acre-feet per year

gpcd = gallons per capita per day.

[1] Refer to groundwater irrigation diversions and return flows in Table 3-13.

[2] Unless noted otherwise, domestic diversions are equal to the estimated population multiplied by 100-120 gallons per capita per day (gpcd). Groundwater diversions for small community water systems are assumed to be included in domestic diversions based on estimated population.

[3] Unless noted otherwise, municipal diversions represent the average annual pumping rate at pertinent municipal well fields during 1990-1999.

[4] Total diversions = irrigation + domestic + municipal.

[5] Unless noted otherwise, domestic return flow is assumed to be 50 percent of the domestic diversion.

[6] Municipal return flow factors taken from Wilson and Lucero (1997).

[7] Total return flow = irrigation return flow + domestic return flow + municipal return flow.

[8] Domestic diversions in Santa Clara Pueblo = estimated population (1156 persons) x 116 gpcd.

[9] City of Española pumping in the Santa Clara sub-basin = 83% of average annual withdrawals from the City of Española Well Field during1990-1997 (1170 afy).

[10] City of Española return flow assumed to be 80% of the municipal diversion, per estimates presented in Wilson and Lucero (1997).

[11] City of Española pumping in the Santa Cruz sub-basin = 17% of average annual withdrawals from the City of Española Well Field during1990-1997 (1170 afy).

[12] Average annual pumpage during 1990-1999 from the combined Los Alamos well fields.

[13] Los Alamos municipal return flow assumed to be 4% of diversions per information presented in Wilson and Lucero (1997).[13] Los Alamos return flow.

[14] Average annual pumpage during 1990-1999 from the Buckman Well Field.

[15] Average annual pumpage from the City of Santa Fe Well Field and the St. Michael well during 1990–1999.

[16] Average annual pumpage from the El Dorado Well Field during1990-1999.

[17] El Dorado return flow assumed to be 50% of municipal diversion, per information presented in Wilson and Lucero (1997).

Table 5-7. Estimated Volume of Groundwater in Storage[1] by Sub-basin.

Sub-basin	Area (acres)	Santa Fe Group Saturated Thickness[2] (feet)		Storage in Top 1000 Feet of Sediment[1]	Storage in Top 2000 Feet of Sediment[1]
		Maximum	Minimum	(million acre-feet)	(million acre-feet)
Velarde	97,100	9527	0	9.57	18.86
Santa Clara	54,600	8983	3094	5.46	10.92
Santa Cruz	59,300	6474	0	5.43	10.30
Los Alamos	110,200	7921	2058	11.02	22.04
Pojoaque-Nambe	42,500	5096	0	3.97	7.47
Tesuque	32,400	4463	0	2.93	5.39
Caja del Rio	101,500	3777	1980	10.16	20.31
Santa Fe River	111,000	2919	0	9.26	15.08
North Galisteo Creek		0	0	0	0
South Galisteo Creek		0	0	0	0
Total				**57.80**	**110.37**

[1]The planning region was divided into 1000- by 1000-meter cells, and the volume of groundwater storage in each cell was estimated by multiplying the cell area by the local saturated thickness and an assumed specific yield of 0.1.

[2]Santa Fe Group saturated thickness represents the difference between post-1990 groundwater level shown in Figure 5-8 and the elevation of the base of the Santa Fe Group as provided by LANL.

Table 5-8. Estimated Groundwater Storage in the Santa Fe Group in Santa Fe County.

Source of Estimate	Area (square miles)	Saturated Thickness (feet)	Specific Yield (dimensionless)	Groundwater in Storage (million acre-feet)
Spiegel and Baldwin (1963)	234	1000	0.2	30.00
Lee Wilson (1984)	234	500	0.1	0.75
DBS&A (1994a)	570	250-3500	0.1	56.30
Current Study	511	0-2000	0.1	54.00

5.8 Groundwater Budgets

Groundwater budgets for areas within the planning region are probably as important as, if not more important than, equivalent surface water budgets for water planning purposes. This importance is manifested in the fact that groundwater tends to represent a water source that can be depended upon from year to year, whereas surface water supplies fluctuate with time due to variations in climate. Much of the information and techniques described previously in this chapter were applied to develop groundwater budgets for each of the study sub-basins.

The purpose of these budgets was to give the reader a sense of the relative quantities that both enter and leave an area each year, and a measure of the rate at which storage in a sub-basin is either being accrued or depleted. As in the case of surface water supplies, groundwater flow processes were, on the whole, found to be very uncertain. Nonetheless, the analyses performed during the preparation of groundwater budgets were helpful either in confirming general trends that were previously disclosed in the surface water investigation or revealing other trends that could only be discerned through direct evaluation of groundwater.

The groundwater budgets presented herein are defensible in the sense that they have been developed using the principle of mass balance. That is, summed components of groundwater inflow are expected to equal the sum of outflow components and rates of change in groundwater storage. However, the techniques applied herein lack the advantage of determining whether the estimated budget components are mathematically consistent with measured hydraulic heads and/or measured stream/aquifer exchanges in a three-dimensional environment. To achieve such consistency, numerical models that are capable of simulating three-dimensional groundwater flow are most useful. To that end, the planning council should be aware of such a model that is currently being prepared by LANL and covers the entire Española Basin. If this model is developed to a resolution that facilitates the quantification of various groundwater flow processes on a relatively local level, it should ultimately provide much better estimates of budget components like interbasin subsurface flow, vertical groundwater movement, and stream-aquifer interaction.

5.8.1 Groundwater Budget Components

Groundwater inflow components consist of mountain-front recharge, areal recharge from precipitation, stream losses to groundwater, and inflow from adjacent sub-basins. The first three of these represent the total amount of direct recharge to a sub-basin stemming from processes originating at the ground surface. The reader should note that stream losses used in the groundwater budgets are identical to stream losses developed for the equivalent surface water budgets. Sub-basin outflow components consist of pumping diversions, evapotranspiration from shallow groundwater, groundwater flow to adjacent sub-basins, and groundwater discharge to surface water. The last of these is identical to the groundwater discharge component computed for the surface water budgets.

Table 5-9 presents the estimated groundwater budgets for each of the planning sub-basins. Footnotes to the table describe how the various budget components were estimated. Most items have been developed using procedures described earlier in this chapter or were taken from pertinent tables in Chapter 3.

5.8.2 General Summary of Budgets

Inspection of Table 5-9 indicates that total estimated groundwater inflow is essentially equal to total estimated outflow in five sub-basins: Velarde, Santa Cruz, Santa Clara, Pojoaque-Nambe, and Tesuque. In contrast, two of the sub-basins – Los Alamos and Caja del Rio – clearly show net reductions of groundwater storage on a yearly basis. The budgets for the

Santa Fe River, North Galisteo Creek and South Galisteo Creek sub-basins indicate that total estimated outflows slightly exceed total inflows; however, given the fact that all budget components are considered uncertain, the rate of reduction in storage computed for each of these latter sub-basins (285 to 485 afy) is certainly too small to conclude that groundwater is being mined in either.

The apparent major cause of groundwater storage decrease in the Los Alamos sub-basin is pumping from the Los Alamos well fields. As Table 5-9 indicates, the estimated depletion rate from the sub-basin, 2620 afy, is less than the estimated diversion rate due to pumping of 4420 afy. If these relative quantities can be considered indicative of what is occurring in the sub-basin, it is likely that pumping losses are being partly offset by either recharge sources or interception of groundwater that would normally discharge to the Rio Grande. The estimated stream loss to groundwater of 400 afy in the Los Alamos sub-basin potentially provides some of this offset, but drawdowns accumulated in the vicinity of the well fields (e.g., McLin et al., 1996) of the Los Alamos sub-basin suggest that interception of some groundwater discharge to the river is possible as well.

Pumping in the Buckman Well Field is the apparent cause of groundwater storage decline in the Caja del Rio sub-basin. Because the estimated net depletion rate for this sub-basin is less than the corresponding average annual pumping rate, the presumed offset of pumping losses again appears to be attributable to stream losses to groundwater and intercepted discharge to the Rio Grande. The close proximity of the Buckman Well Field to the river makes it likely that the quantity of offset caused by intercepted river discharge is considerably larger than the comparable amount occurring in the Los Alamos sub-basin, where the well fields involved are located relatively far from the river.

The rate of storage decrease in the Santa Fe River sub-basin is apparently being partly limited by the considerable quantity of water that is estimated to recharge the aquifer system via streambed seepage from the Santa Fe River. The 3770 afy of stream loss shown in Table 5-9 for this sub-basin represents estimated Santa Fe River losses above La Cienega. These infiltration quantities apparently occur in a part of the sub-basin such they can effectively help to offset groundwater withdrawals from the city of Santa Fe Well Field. In contrast, the remaining estimated Santa Fe River loss of 4730 afy (see Section 3.7.10) is believed to occur downstream of La Bajada, and to ultimately end up as groundwater dishcarge in the Cochiti Springs area. Consequently, this latter river loss takes place too far to the west of the City of Santa Fe Well Field to have much effect, if any, on local storage depletions.

A factor to consider in the Santa Fe River sub-basin is the possible gradual decrease in spring flow to the river near the community of La Cienega (CDM, 1998). If this trend is due to gradual declines in local water-table levels, the possibility exists that the water table will eventually drop below riverbed elevations, thus transforming the entire length of the river into a losing stream. Potential consequences of just this phenomenon alone, if it were to take place, include accelerated declines in groundwater storage in the Santa Fe River sub-basin, and perhaps neighboring sub-basins as well.

Two of the components listed in Table 5-9 need further elaboration with regard to how they relate to findings from other groundwater studies. The first component is that of the small annual increase in groundwater storage computed for the Tesuque sub-basin. As mentioned in Section 5.5.2, DBS&A (1994a) observed significant declines in the groundwater levels monitored by some of the observation wells in this sub-basin. If a decline in groundwater levels were indeed occurring, a decrease in groundwater storage would also be called for. This issue should be investigated more closely, particularly since the Tesuque sub-basin lies just to the north of the Santa Fe River sub-basin where pumping from the City of Santa Fe Well Field can potentially impact water levels in adjacent areas.

The second component of interest is mountain-front recharge in the Los Alamos sub-basin. As discussed in Section 5.6.1.2, this component was estimated through a mass balance method that made use of estimated volumes of precipitation, evapotranspiration, and runoff in the mountainous area found on the upstream end of the sub-basin. In the Los Alamos sub-basin, as in all watersheds, the upgradient boundary of the area to which this methodology was applied coincided with the west boundary of the sub-basin. However, recent investigations associated with the groundwater model being developed by LANL for the entire Española Basin has revealed the possibility that subsurface water may be moving into the sub-basin from sources lying west of the basin boundary. It is estimated that this quantity of water may be as small as zero afy, and possibly as large as 1200 afy (personal communication, Elizabeth Keating, LANL). If subsequent investigations do reveal a non-zero inflow from this type of source, the Los Alamos mountain-front recharge estimate might be increased accordingly.

5.8.3 Transient Nature of Groundwater Storage Depletions

It is important to note that the storage decreases estimated in Table 5-9 for the Los Alamos and Caja del Rio sub-basins are based solely on budget calculations, and are not calculated with the aid of contour maps of time-varying piezometric levels at various depths within the groundwater system. Accomplishing such calculations would require more refined groundwater level maps than those presented in Figures 5-7 and 5-8. An analysis aimed at better quantifying storage depletions would also benefit from the use of groundwater models applied at the scale of a single sub-basin or a few sub-basins.

It should also be stressed that the storage decrease rates computed for the Los Alamos and Caja del Rio sub-basins, if they are occurring, are potentially still evolving. As pointed out by Alley et al. (1999), all groundwater basins must undergo declines in groundwater storage when they are first pumped, simply due to the physical nature of processes that govern groundwater movement. However, it is possible that, after several years of pumping, a groundwater system may eventually reach a new equilibrium wherein total inflows to the system are equal to total outflows, and decreases in groundwater storage are no longer observed. This new equilibrium state is usually brought about by a combination of increased recharge and decreased discharge of groundwater to surface water (Alley et al., 1999).

In the Los Alamos area, it is possible that such a new equilibrium could result from reduced groundwater discharge to the Rio Grande. Measured groundwater levels in several test wells in the Los Alamos sub-basin have showed tendencies to level off during the past 4 to 5 years (e.g., McLin et al., 1998) rather than continuing to drop. It is not clear, however, whether such trends are indicative of a system beginning to reach a new equilibrium or the result of reduced pumping in the Los Alamos well fields in the 1990s (see Table 5-1 and Figure 5-4).

The computed rate of storage decrease for the Caja del Rio sub-basin (3860 afy, Table 5-9) and the groundwater levels measured in piezometer nests within the Buckman Well Field (Figures 5-15 and 5-16) would seem to indicate that the groundwater budget for this sub-basin, like the Los Alamos sub-basin, is still evolving. As mentioned in Section 5.5.2, groundwater levels in the shallowest piezometers installed at the well field have exhibited declines in hydraulic head that are significantly smaller than comparable head drops at greater depths from which the groundwater is being pumped. Further studies of the processes affecting river-aquifer exchange at the Buckman Well Field would help to discern whether river losses due to local pumping would eventually reach a level that helps the Caja del Rio sub-basin groundwater system to reach a new equilibrium state.

Using only the information presented in this report, it is difficult to discern whether groundwater levels in the Santa Fe River sub-basin are continuing to decline, which would indicate an ongoing decrease in the sub-basin's groundwater storage. The potential does exist for losses from the Santa Fe River downstream of the Santa Fe WWTP to be quite significant (see Section 3.7.10), thereby offsetting to some degree pumping from the City of Santa Fe Well Field.

5.9 Groundwater Budget Uncertainty Analysis

As with the surface water budgets discussed in Chapter 3, a cursory uncertainty analysis was also applied to the groundwater budgets. Table 5-12 presents estimated ranges for each of the budget components in the ten sub-basins. Footnotes to the table explain how minimum and maximum values for budget components were calculated.

Many of the more pronounced sources of uncertainty encountered during the computation of surface water budgets were also manifested in the development of groundwater budgets. In particular, the components comprising exchange of stream water and groundwater were typically surmised to comprise significant portions of the total volume of water involved in a sub-basin's groundwater system, yet few, if any, reliable means could be used to quantify them. The methods that were applied to arrive at either stream losses or groundwater discharge to streams ranged from using flows developed in groundwater models of parts of the planning region (e.g., McAda and Wasiolek, 1988; Frenzel, 1995) to computing a budget residual resulting from the comparison of all budget components that do not involve stream-aquifer exchange. Though both computed stream losses and gains from groundwater discharge in the modeling investigations helped to identify where these respective processes are likely to occur, they did not necessarily provide definitive quantification of them, partly because surface water models were not directly integrated with the groundwater models.

The Santa Fe River is one watercourse in the planning region for which considerable information had been gathered regarding stream-aquifer interaction (e.g., CDM, 1998). However, the stream losses and gains estimated for this watershed were also considered relatively uncertain.

Mountain-front recharge was also consistently perceived as being a very uncertain component of groundwater inflow. This observations stemmed mostly from the facts that (1) the mass balance techniques used to estimate mountain-front recharge rely greatly on the estimation of volumes of precipitation, evapotranspiration, and runoff for a specific area of mountainous terrain, all of which are likely to be very approximate; and (2) the processes leading to this form of influx occur in areas of each sub-basin for which limited data regarding subsurface hydraulic processes have been collected.

The most certain groundwater budget component in each of the sub-basins was the quantity of water attributed to diversions from pumping. Though estimated pumpages are, to a great extent, dependent on estimates of population and per capita water consumption rates, the information base upon which the estimates were made is still likely to be more reliable than the data upon which stream-aquifer exchange and mountain-front recharge estimates were formulated. However, there was some question as to whether the estimated return flows from groundwater pumping diversions could be considered as reliable as the diversions themselves. This observation was made because many of the return flow percentages adopted for the groundwater budgets did not appear to be based on extensive, local studies of return flow.

Estimated interbasin flows were considered to be of intermediate uncertainty. On the positive side, they were developed using maps of regional groundwater levels that appear to delineate distinct flow paths between basins and likely approximate horizontal hydraulic gradients reasonably well. However, they were not based on fully three-dimensional analyses groundwater flow, and, therefore, did not specifically account for sub-regional variations in saturated aquifer thickness and/or aquifer hydraulic properties.

Groundwater losses to evapotranspiration were also considered to be of intermediate uncertainty. But this observation was made under the qualification that the rates of evapotranspiration occurring in areas of shallow groundwater were close in magnitude to the rates adopted in this study, and that ET does indeed take place at locales where the depth to groundwater is 20 feet or less. Actual field studies of ET processes in such areas would help to clarify these issues.

Table 5-9. Groundwater Budgets by Sub-basin.

Sub-basin	Inflow (acre-feet/year)						Outflow (acre-feet/year)					Change in Storage[11] (afy)
	Mountain Front Recharge[1]	Stream Loss[2]	Areal Re-charge	Flow from Adjacent Sub-basins[3]	Return Flow[4] (Irr+Dom+ M&I)	Total Inflow[5]	Diversions[6] (Irr+Dom+ M&I)	Groundwater Evapotran-spiration[7]	Groundwater Discharge to Surface Water[8]	Subsurface Flow out of Sub-basin[9]	Total Outflow[10]	
Velarde	2100	1800	0	4500	435	8835	905	1350	5800	800	8855	-20
Santa Cruz	3080	5190	0	1760	620	10,650	1120	2400	0	7130	10,650	0
Santa Clara	3760	510	0	0	850	5120	1120	1250	0	2740	5110	10
Los Alamos	3820	400	0	0	180	4400	4420	300	0	2300	7020	-2620
Pojoaque-Nambe	4500	5000	0	3800	430	13,730	940	1850	4000	6960	13,750	-20
Tesuque	2460	2500	0	3500	155	8615	310	2400	1815	4000	8525	90
Caja del Rio	0	1150	0	3550	0	4700	4910	1100	0	2550	8560	-3860
Santa Fe River	5050	3770[12]	0	1000	285	10,105	2900	1200	2170	4120	10,390	-285
North Galisteo Creek	0	770	0	1550	260	2580	515	500	0	2050	3065	-485
South Galisteo Creek	5500	0	0	1050	105	6655	210	1300	890	4600	7000	-345

Notes:
Dom = Domestic
Irr = Irrigation
M&I = Municipal and Industrial
[1]Refer to Table 5-2.
[2]Unless noted otherwise, refer to "Stream Loss" column in Table 3-14.
[3]Refer to "Total Subsurface Inflow" row in Table 5-3.
[4]Refer to "Total Return Flow" column in Table 5-6.
[5]Total inflow = mountain front recharge + stream loss + areal recharge + flow from adjacent sub-basins + return flow.
[6]Refer to "Total Diversions" column in Table 5-6.
[7]Refer to "Groundwater Evaporation" column in Table 5-4.
[8]Refer to "Groundwater Discharge" column in Table 3-14.
[9]Refer to "Total Subsurface Outflow" column in Table 5-3.
[10] Total outflow = diversions + groundwater evapotranspiration + groundwater discharge to surface water + subsurface flow out of sub-basin.
[11] Change in storage = total inflow – total outflow.
[12] Stream losses on the Santa Fe River represent losses upstream of La Cienega.

Table 5-10. Estimated Ranges for Groundwater Budget Components.

Sub-basin	Inflow (acre-feet/year)						Outflow (acre-feet/year)				
	Mountain Front Recharge[1]	Stream Loss to Ground-water	Areal Re-charge	Subsurface Flow from Adjacent Sub-basins[3]	Return Flow[4] (Irr+Dom +M&I)	Total Inflow[7]	Diversions[5] (Irr+Dom+ M&I)	Ground-Water Evapo-transpiration[6]	Groundwater Discharge to Surface Water	Subsurface Flow out of Sub-basin[3]	Total Outflow[8]
Velarde	630-3360	1350-2250	0	900-9000	305-650	3185-15,260	645-1335	1350	2900-8690	160-1600	5055-12,975
Santa Cruz	925-4930	3890-6490	0	340-3400	485-875	5640-15,695	845-1610	2400	0	1390-13,900	4635-17,910
Santa Clara	1130-6015	380-635	0	0	820-1000	2330-7650	1060-1305	1250	0	550-5500	2860-8055
Los Alamos	1145-6110	300-500	0	0	175-210	1620-6820	4420-5195	300	0	460-4600	5180-10,095
Pojoaque-Nambe	1350-7200	3500-6250	0	760-7600	345-575	5955-21,625	770-1230	1850	3000-5000	1220-12,200	6840-20,280
Tesuque	740-3935	1875-3125	0	500-5000	110-235	3225-12,295	215-465	2400	1100-1750	700-7000	4415-11,615
Caja del Rio	0	860-1440	0	1100-11,000	0	1960-12,440	4910-5890	1100	0	700-7000	6710-13,990
Santa Fe River	1515-8080	2830-4730	0	200-2000	240-360	4785-15,170	2805-5410	1200	1630-2710	2000-20,000	7635-29,320
North Galisteo Creek	0	580-960	0	810-8100	240-380	1630-9,440	480-760	500	0	860-8600	1840-9860
South Galisteo Creek	960-5120	0	0	660-6600	75-160	1695-11,880	145-315	1300	665-1110	880-8800	2990-11,525

Notes:

The lower bound of each range is shown as the first number; the upper bound is shown as the second number.

[1]Lower bound of mountain front recharge was developed based on the ratio of minimum to average precipitation in the planning region (30% of average) and the upper bound was developed based on the ratio of maximum to average precipitation (160%).

[2] Minimum stream loss to groundwater or minimu groundwater discharge to surface water = 0.75 x applicable value shown in Table 5-9. Maximum stream loss or groundwater discharge = 1.25 x applicable value shown in Table 5-9.

[3] Lower bound was estimated using saturated hydraulic conductivity = 0.1 ft/day; upper bound was estimated using saturated hydraulic conductivity = 1.0 ft/day.

[4] Refer to Table 5-7; percent of return flow is the same as the average water budget table (5-10)

[5] Lower bound was estimated as follows: (a) no change in irrigation diversions; (b) 70 gpcd for domestic uses (Wilson and Lucero 1997); (c) average of 1990-1999 or 1990-1997 municipal pumping. Upper bound was developed as follows: (a) no change in irrigation diversions; (b) 150 gpcd for domestic uses (arbitrary higher limit); (c) maximum municipal pumping during the period of record.

[6] No range was developed for groundwater evapotranspiration because of the complexity of components used to estimate groundwater ET.

[7] Total inflow = mountain front recharge + stream loss + areal recharge + subsurface inflow + return flow.

[8] Total outflow = diversions + groundwater ET + groundwater discharge to streams + subsurface outflow.

5.10 Observed Trends in Groundwater Supply Processes

The groundwater budgets developed for this part of the study did not, in themselves, reveal distinct trends regarding groundwater supply in the planning region. However, many of the reports used to develop the budgets did provide insight to some important trends, as discussed in the following paragraphs.

One of the observations that have been made in studies during the past several years is that spring flows have been generally decreasing. This indicates that, on the whole, groundwater levels are declining. Though an study of stream losses and gains on the Santa Fe River has mentioned a possible decline in spring discharges near La Cienega (CDM, 1998), it is not clear whether such a decline is real or based on anecdotal evidence. Springs in the area have not been monitored and losses to groundwater from the river between the Santa Fe WWTP and La Cienega appear to have increased local groundwater levels during the past several years.

With a general decline in groundwater levels, it is likely that concomitant increases in stream losses to groundwater have helped to minimize the water level drops in some sub-basins. The Pojoaque-Nambe and Santa Cruz sub-basins, and possibly the Tesuque and Santa Fe River sub-basins are four areas where this offset of groundwater losses appears to have occurred.

The offset of storage decreases by increased stream losses infers that the quantity of groundwater that would have formerly discharged to surface water under pre-development conditions is being reduced. This, in turn, signifies that the base flows in many tributary streams may have been decreased during the past several decades. Water planning in the region should take into account any potential deleterious effects that might result from such base flow reductions.

5.11 Comparison of Groundwater Uses and Groundwater Rights

A summary of the Office of the State Engineer (OSE) groundwater rights database for the planning region, which is considered incomplete, is presented in Appendix K. Table 5-11 presents a compilation of the water rights in that database and also provides estimates of domestic water rights. The domestic rights were estimated by assuming that each domestic well is entitled to 3 afy. Estimated actual uses of groundwater in each sub-basin are also provided in Table 5-11 so that the approximate percent uses of available rights can be computed. The resulting percentages of use vary from 5 to 83 percent.

The OSE groundwater rights database is considered incomplete partly because more than forty percent of the wells listed within it do not have locations or the water rights quantities associated with them are unavailable. However, the water rights database is also lacking because it does not account for Federal, or Pueblo, water rights in the planning region. As previously mentioned, most Federal rights are unquantified. Yet it is likely that the estimates of actual groundwater use listed in Table 5-11 do include Federal uses.

Table 5-11. Summary of the OSE Groundwater Rights Database and Actual Groundwater Uses.

Sub-basin	Water Rights[1]				Estimated Ground-water Use[3] (afy)	Percent of Total Water Rights Used
	Irrigation Rights (afy)	Domestic & Municipal Rights (afy)	Commercial Rights (afy)	Total Water Rights[2] (afy)		
Velarde	1458	5048	175	6681	904	14
Santa Clara	440	954	20	1414	1120	79
Santa Cruz	255	3918	282	4455	1120	25
Los Alamos	0	5574	0	5574	4420	79
Pojoaque-Nambe	142	1603	45	1790	943	53
Tesuque	137	1656	142	1935	310	16
Caja del Rio	0	10,316	9	10,325	4910	48
Santa Fe River	566	11,474	589	12,629	2900	23
North Galisteo Creek	529	5760	85	6374	515	8
South Galisteo Creek	1045	3040	115	4200	210	5

Notes:

afy=acre-feet per year

[1] Source of information is the Office of the State Engineer (OSE) groundwater water rights database, which is incomplete; federal water rights are not included in this table.

[2] Total water rights = irrigation rights + domestic and municipal rights+ commercial rights.

[3] Refer to total groundwater diversions in Table 5-6.

[4] Percent of total water rights = [(estimated groundwater use)/(total water rights)] x 100.

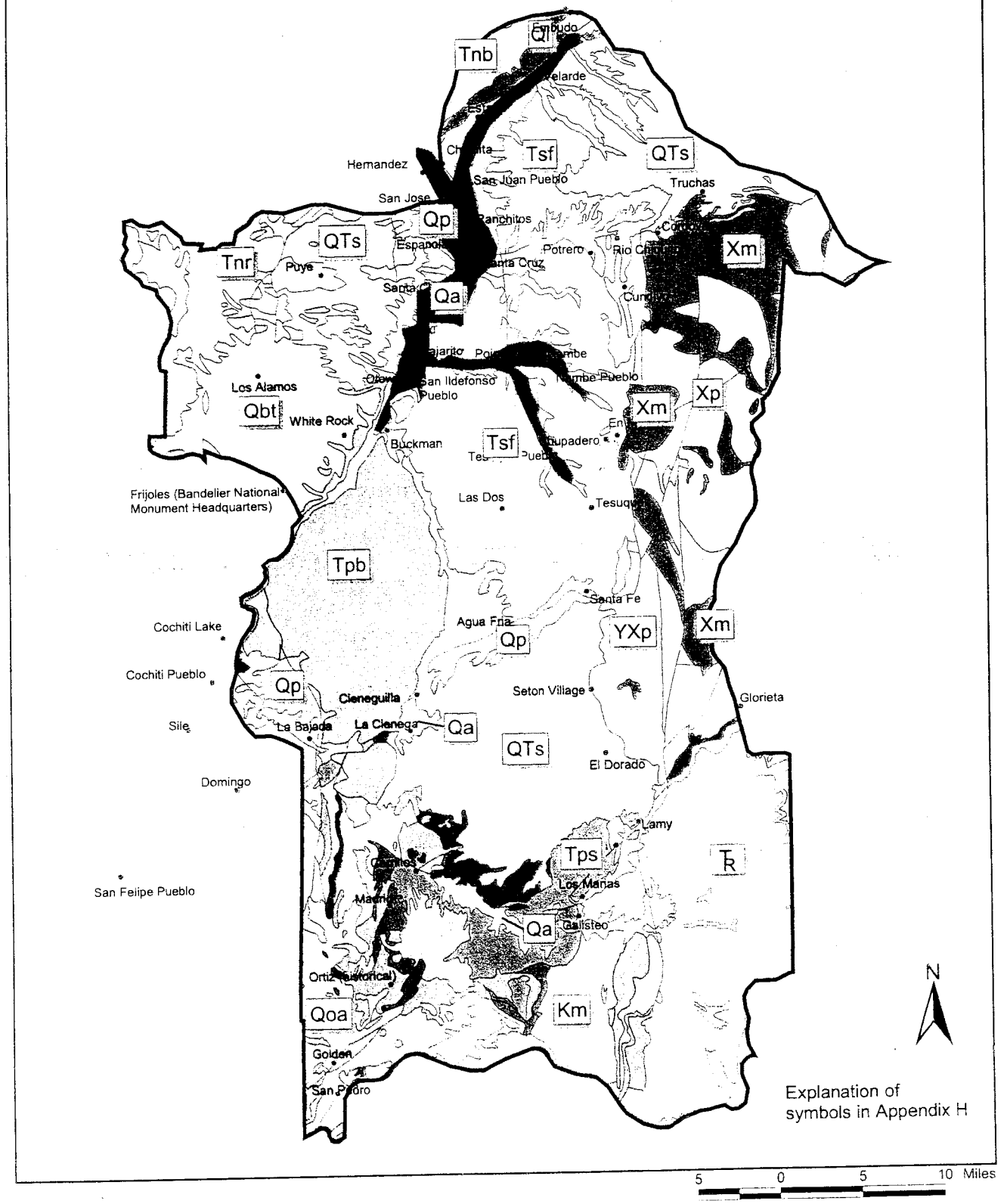

Figure 5-1 Regional Surface Geology

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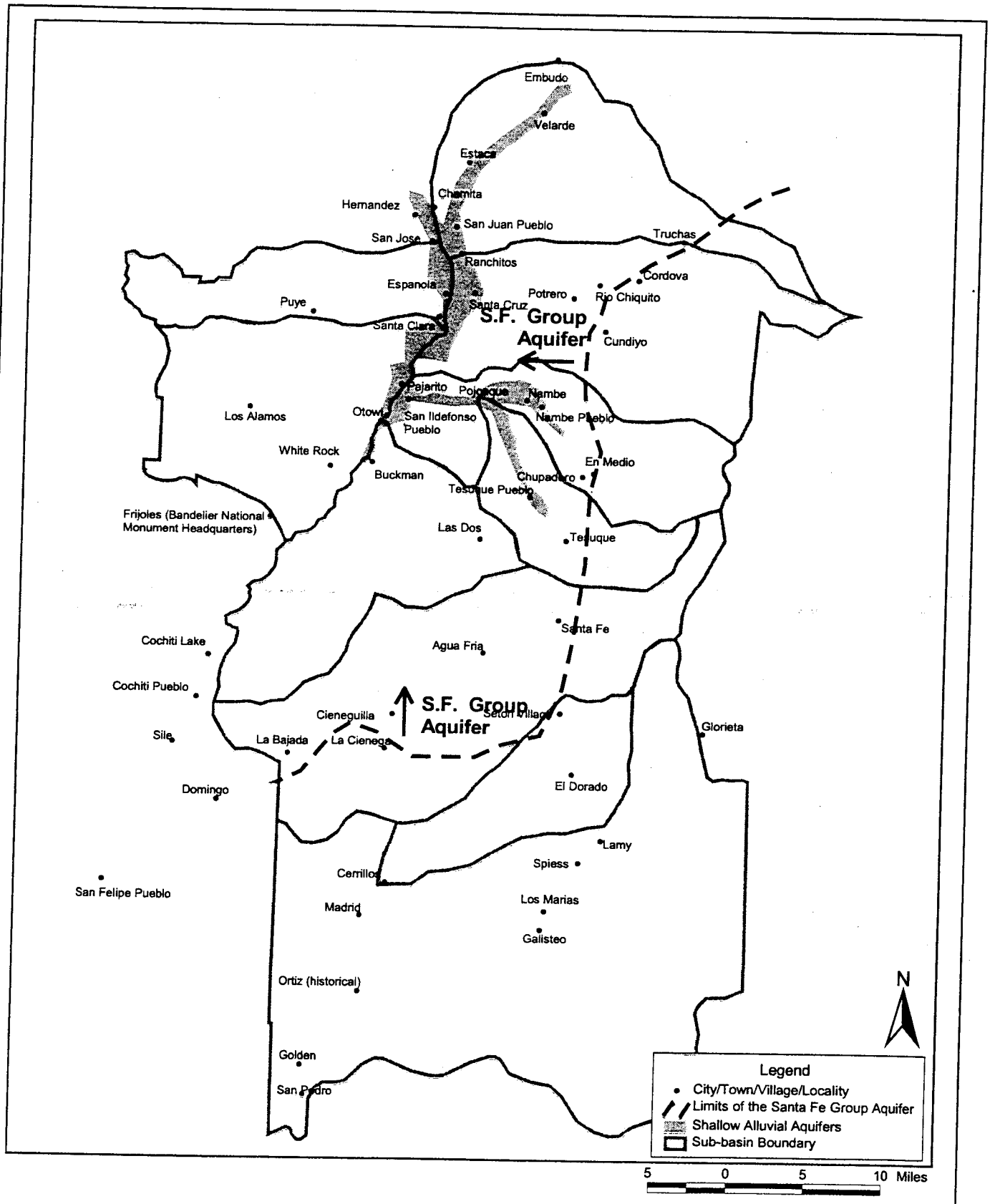

Figure 5-2 Southern and Eastern Extent of the Santa Fe Group and Distribution of Shallow Alluvial Aquifers

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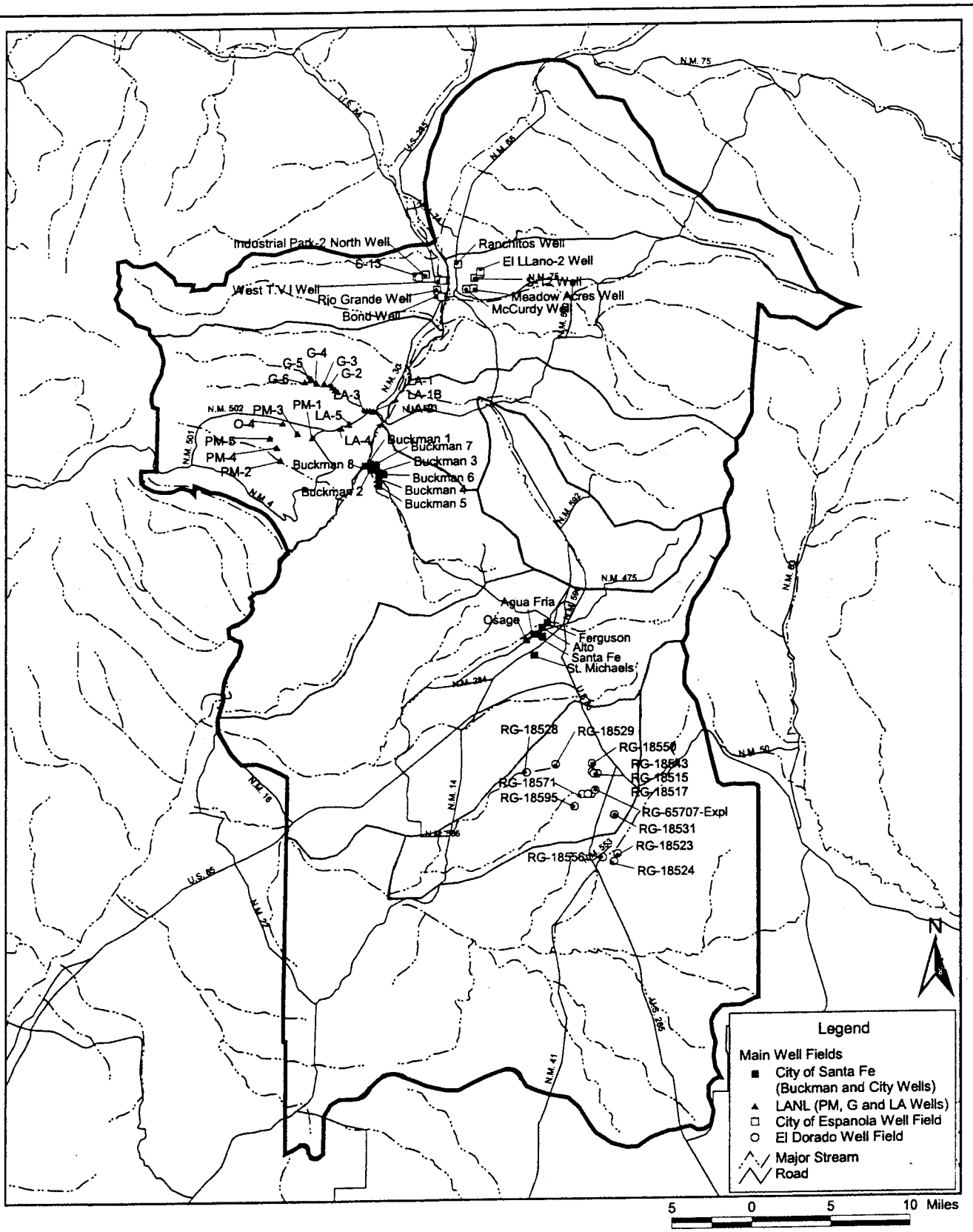

Figure 5-3 Municipal Well Field Locations

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FIGURE 5-4
LOS ALAMOS GROUNDWATER WITHDRAWALS

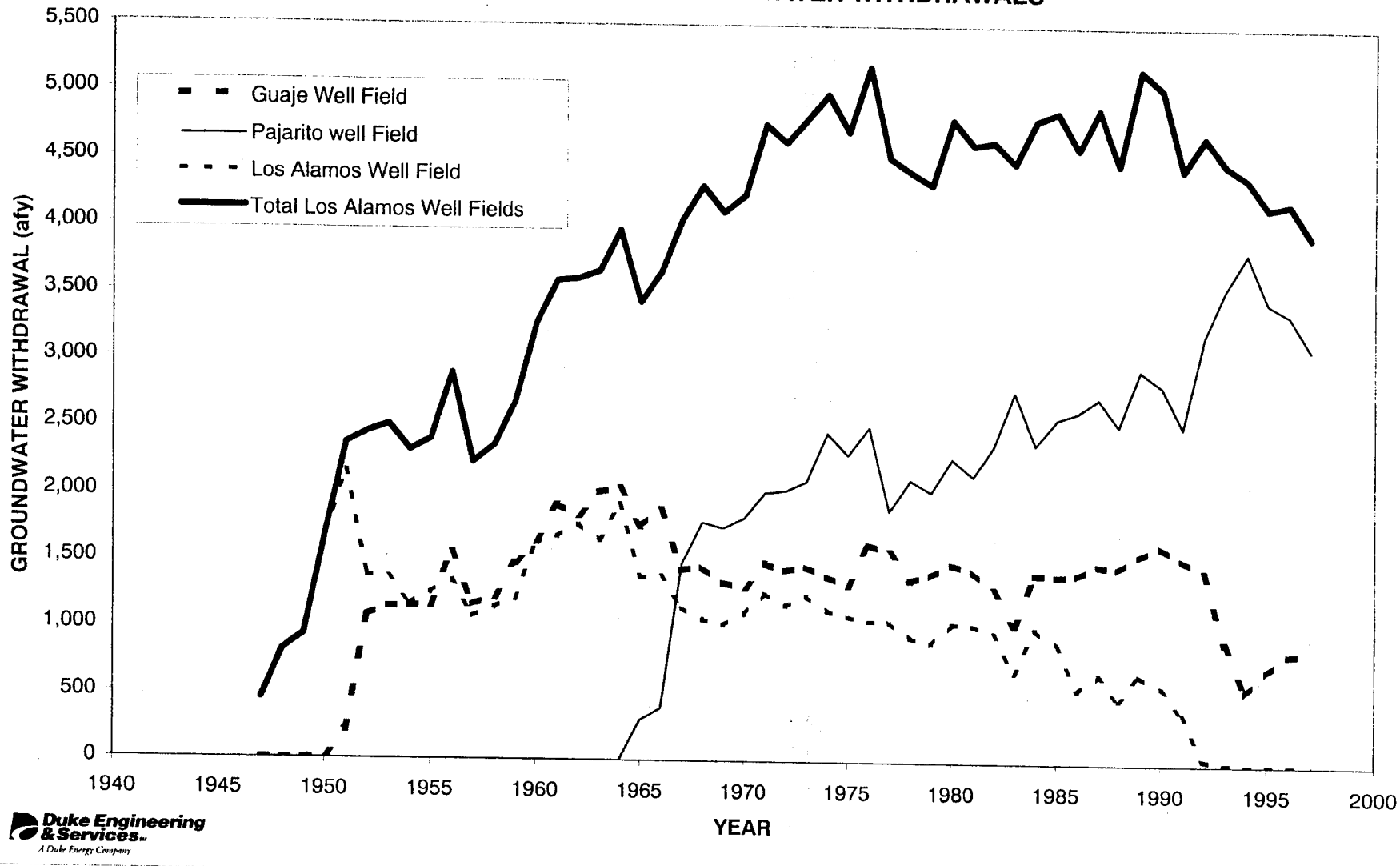

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FIGURE 5-5
CITY OF SANTA FE GROUNDWATER WITHDRAWALS

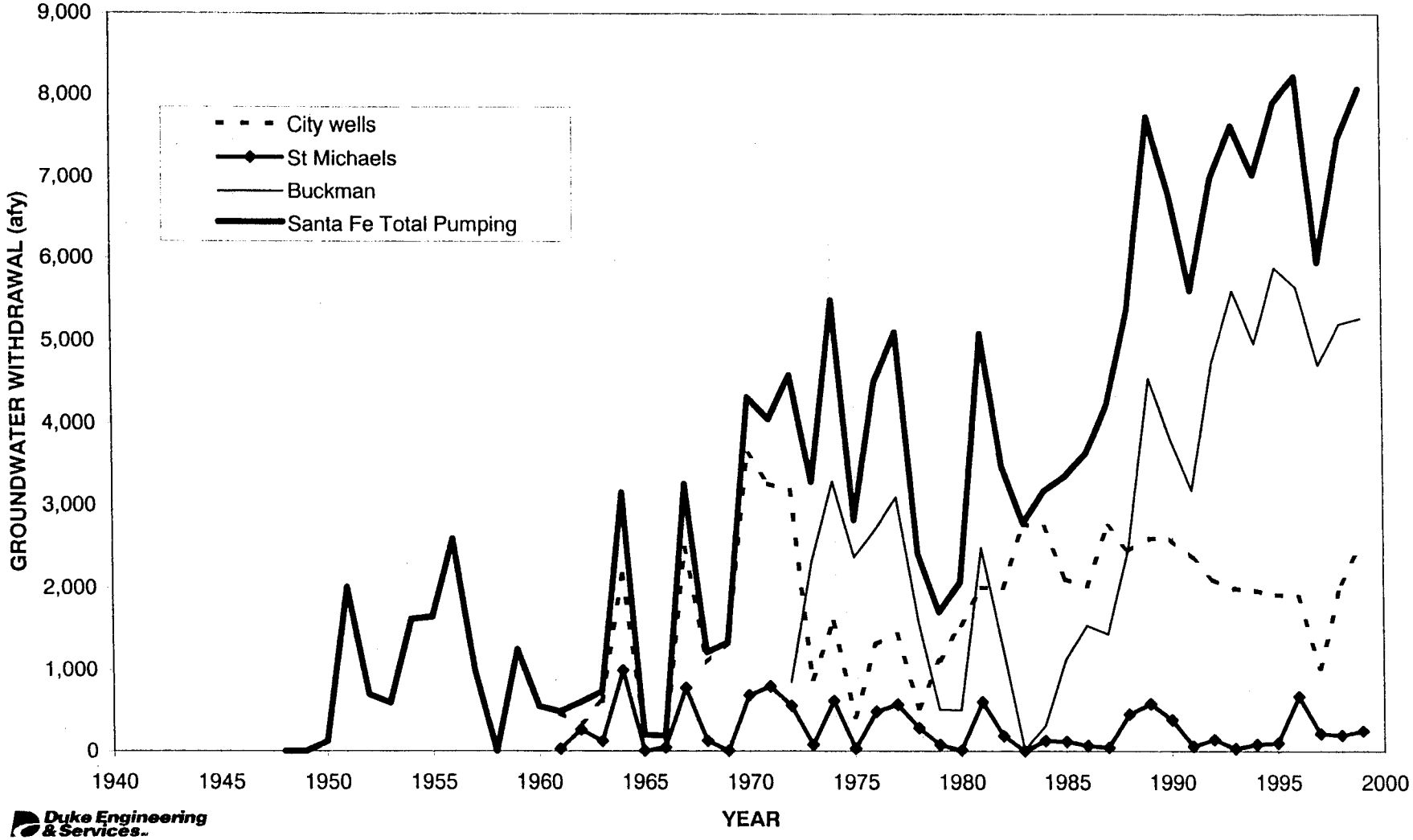

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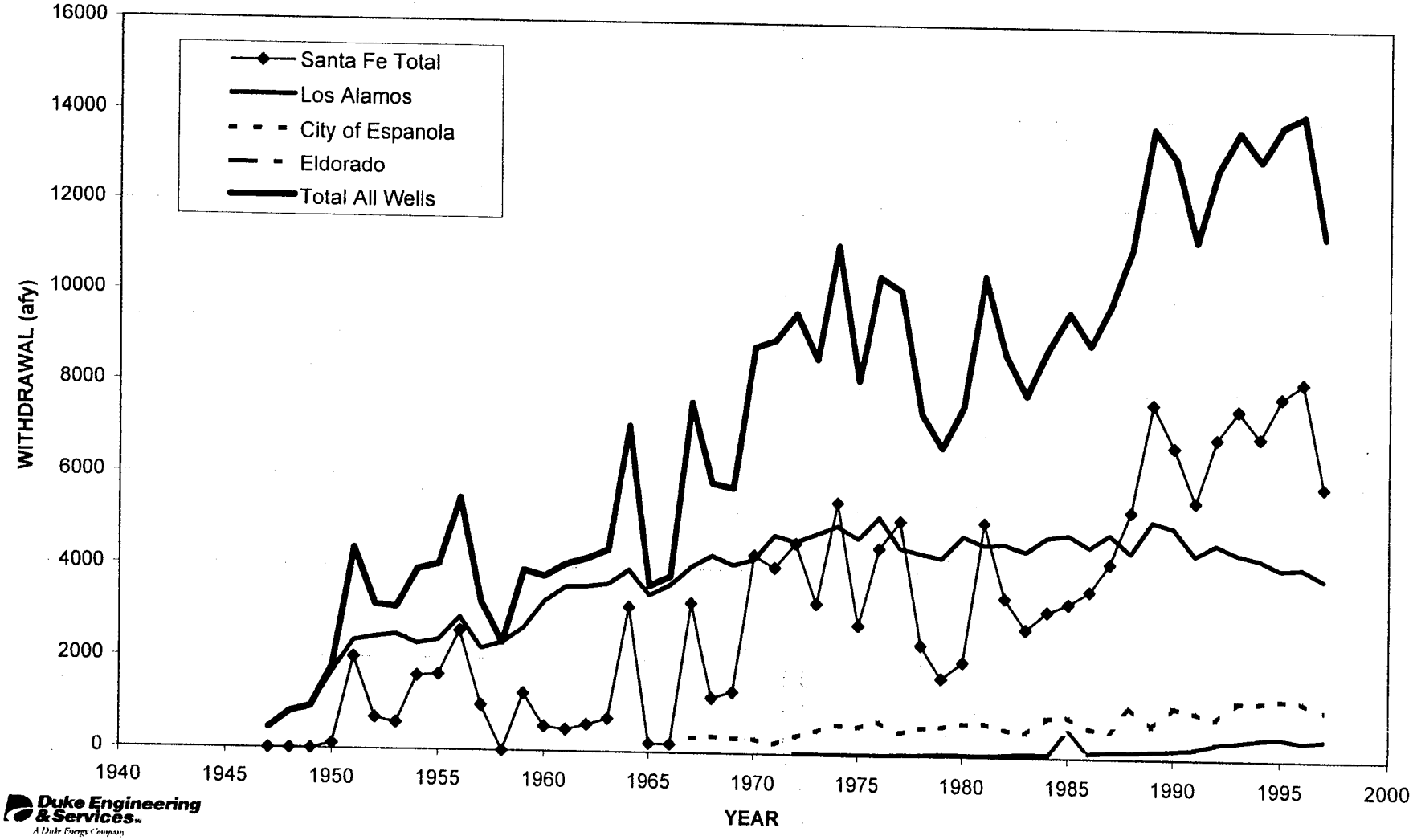
FIGURE 5-6
GROUNDWATER WITHDRAWALS FROM MAJOR WELL FIELDS IN THE PLANNING REGION



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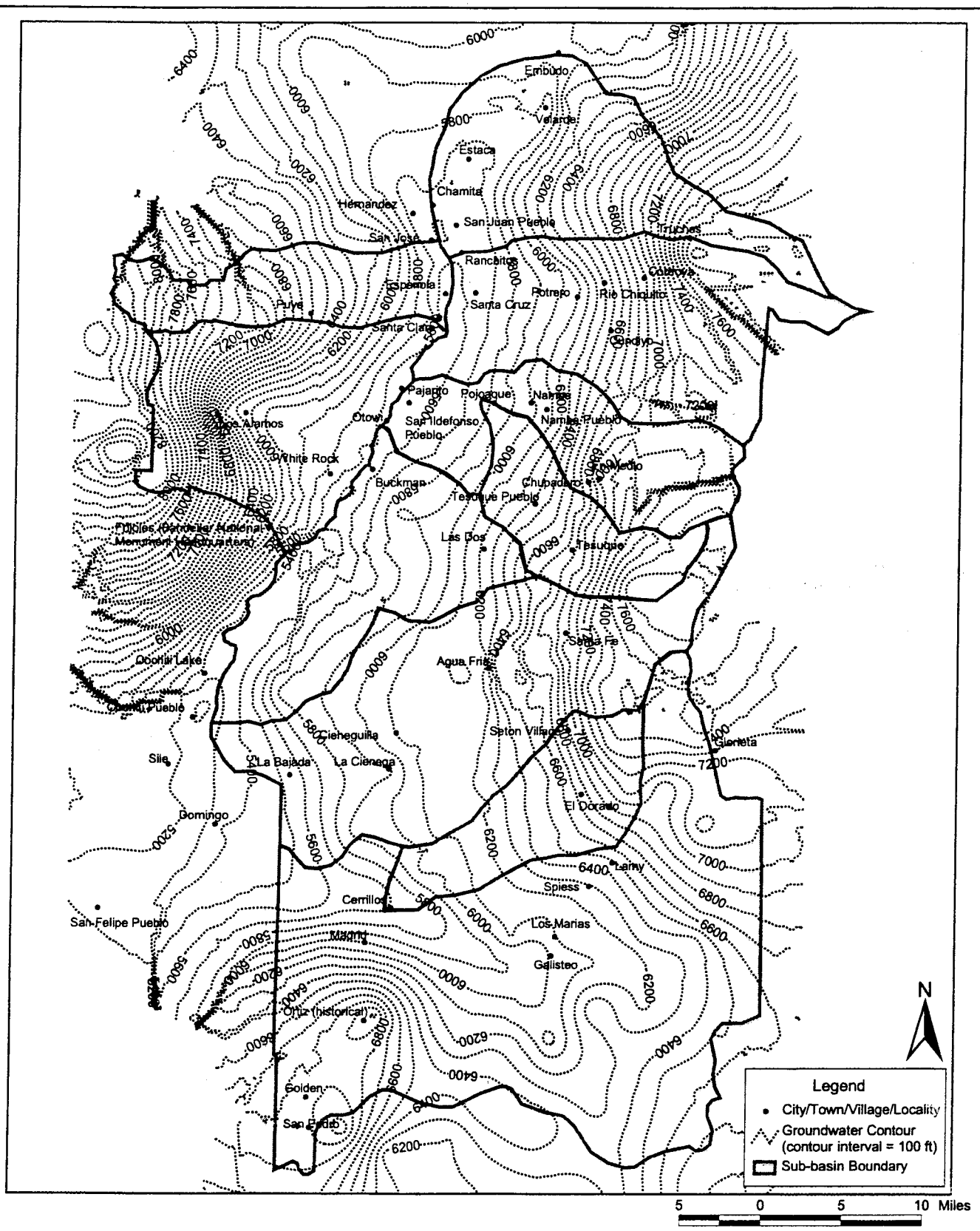

Figure 5-7 Groundwater Level Map (Before 1975)

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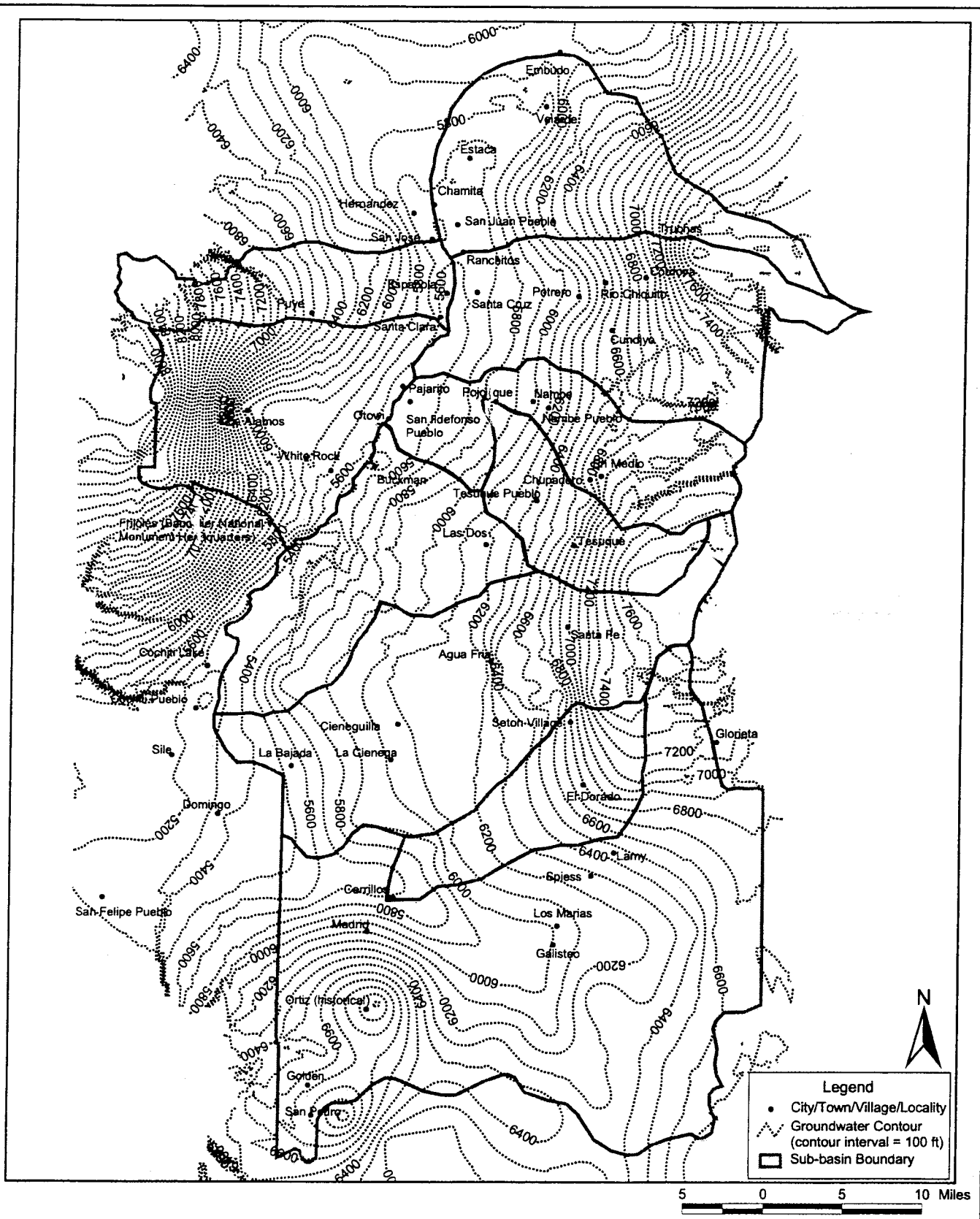

Figure 5-8 Groundwater Level Map (After 1990)

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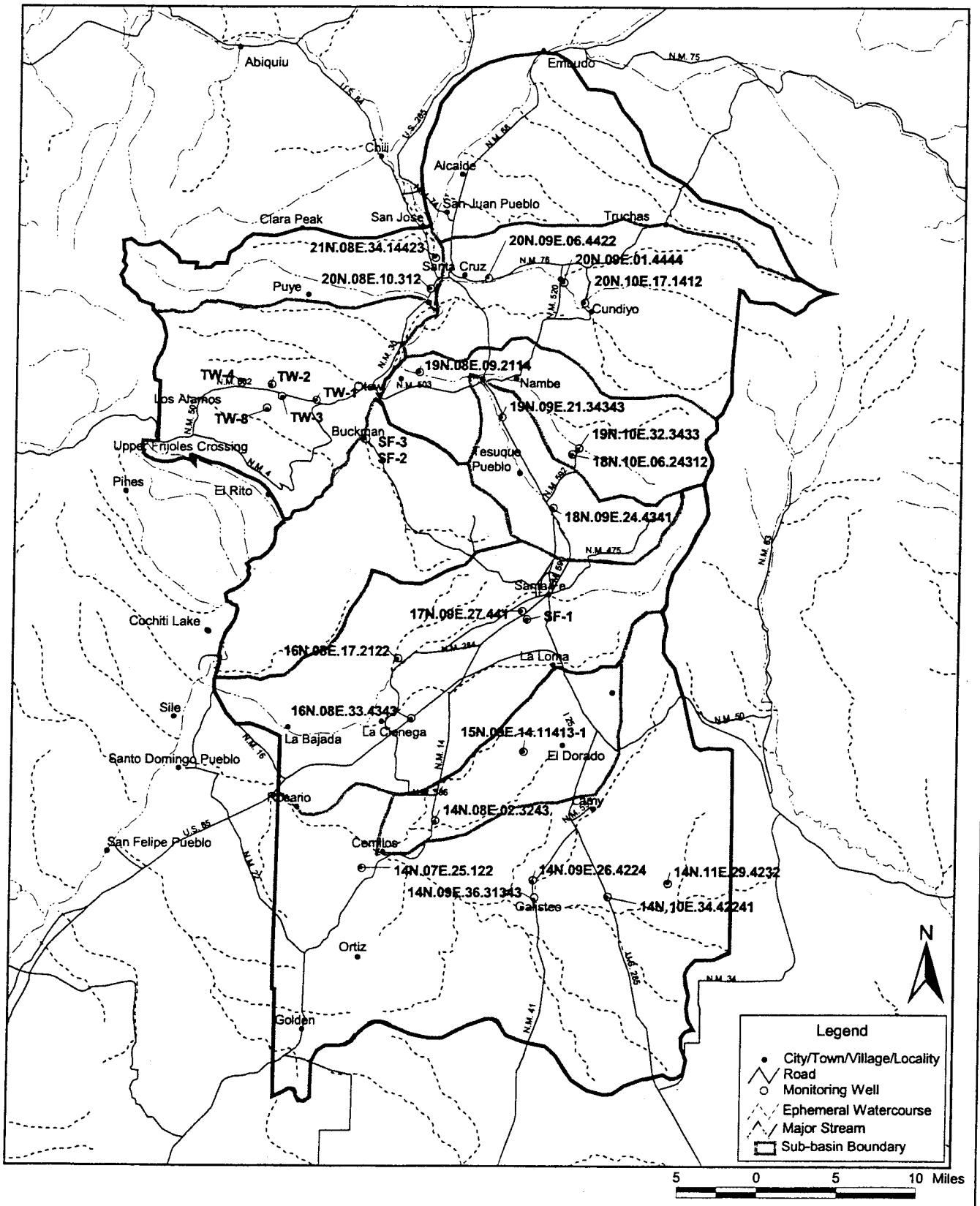

Figure 5-9 Representative Monitoring Wells in the Planning Region

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FIGURE 5-10
HYDROGRAPHS FOR SELECTED WELLS IN THE SANTA CRUZ SUB-BASIN

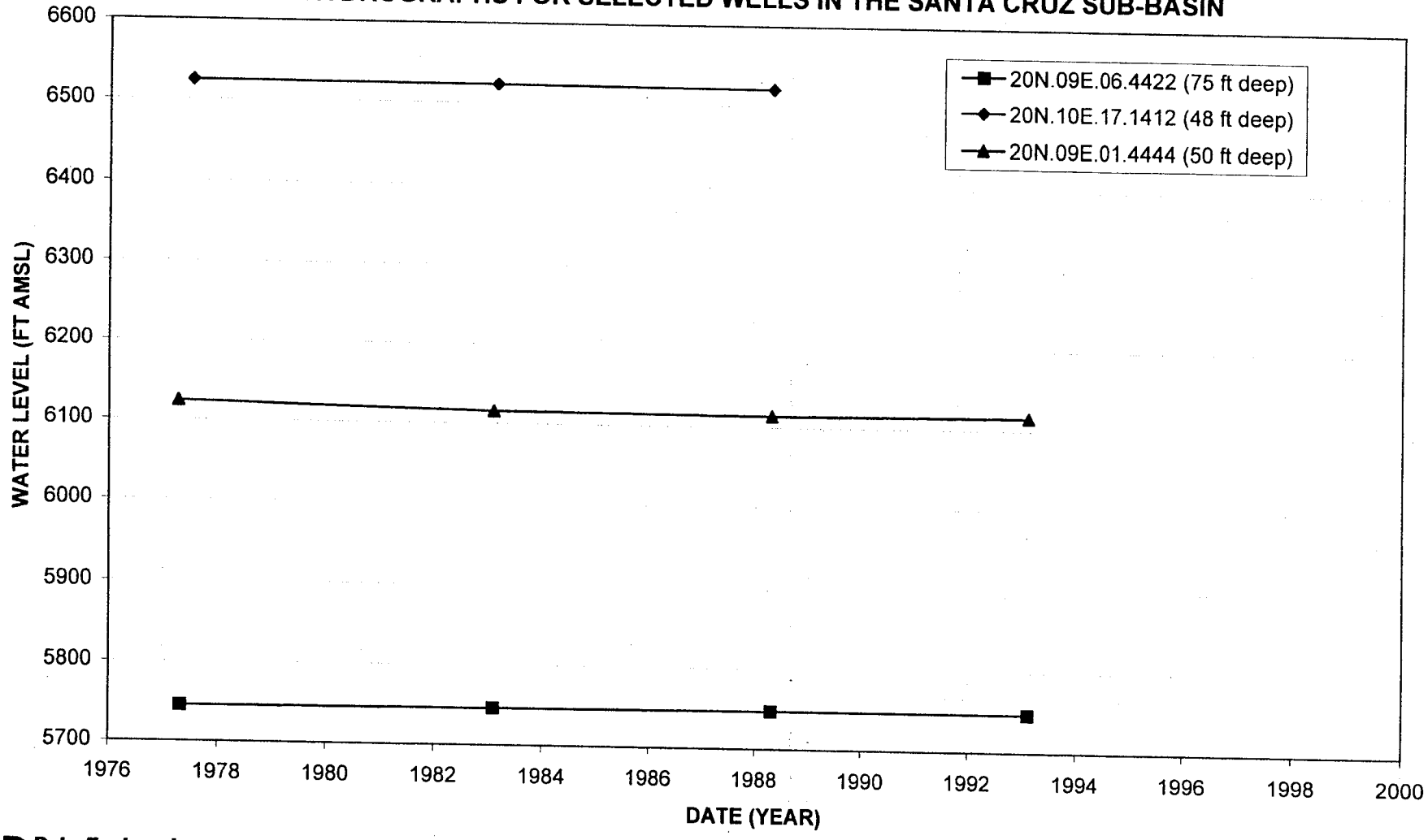

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FIGURE 5-11
HYDROGRAPHS FOR SELECTED WELLS IN THE SANTA CLARA SUB-BASIN

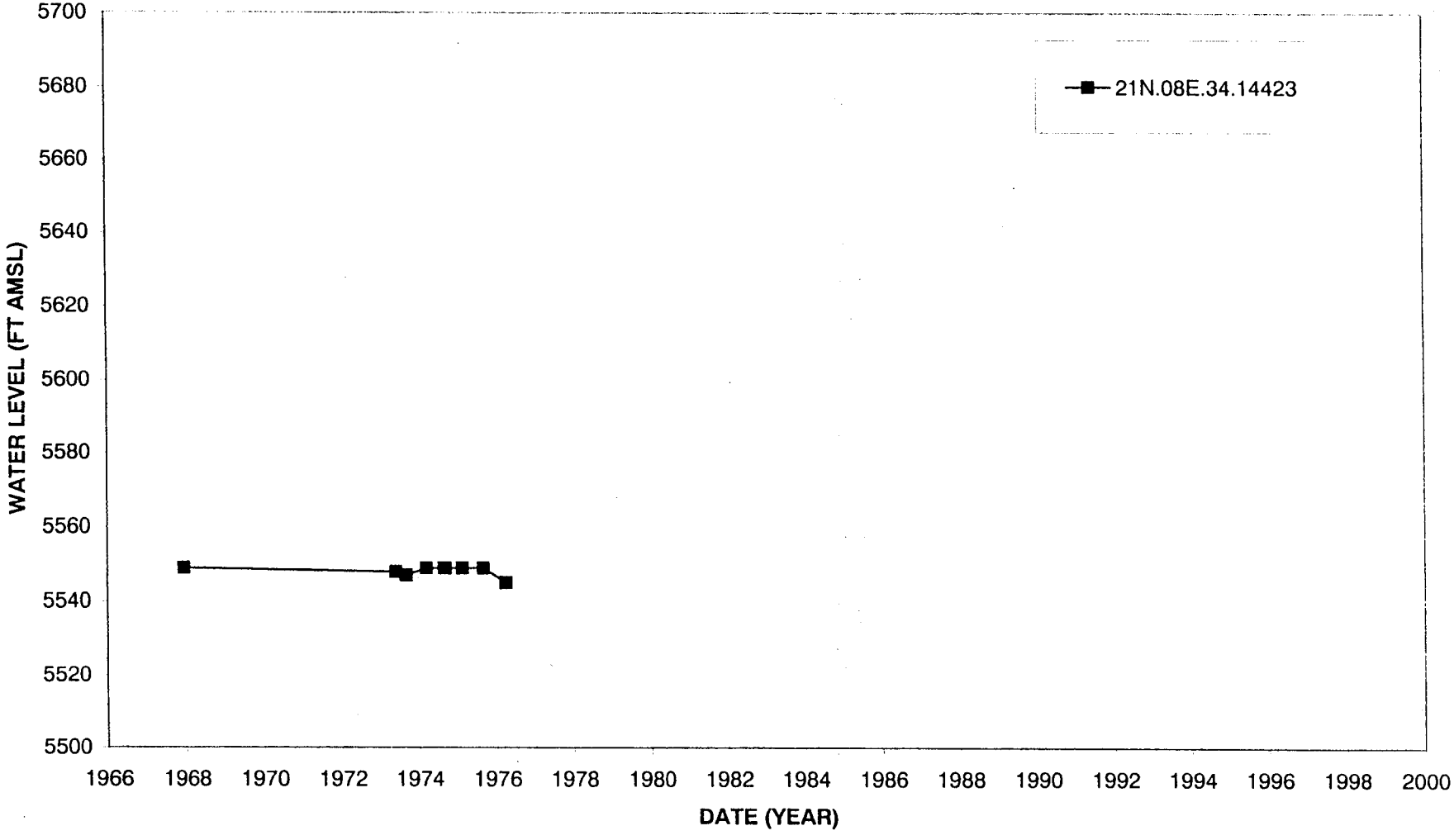

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FIGURE 5-12
HYDROGRAPHS FOR SELECTED WELLS IN THE LOS ALAMOS SUB-BASIN

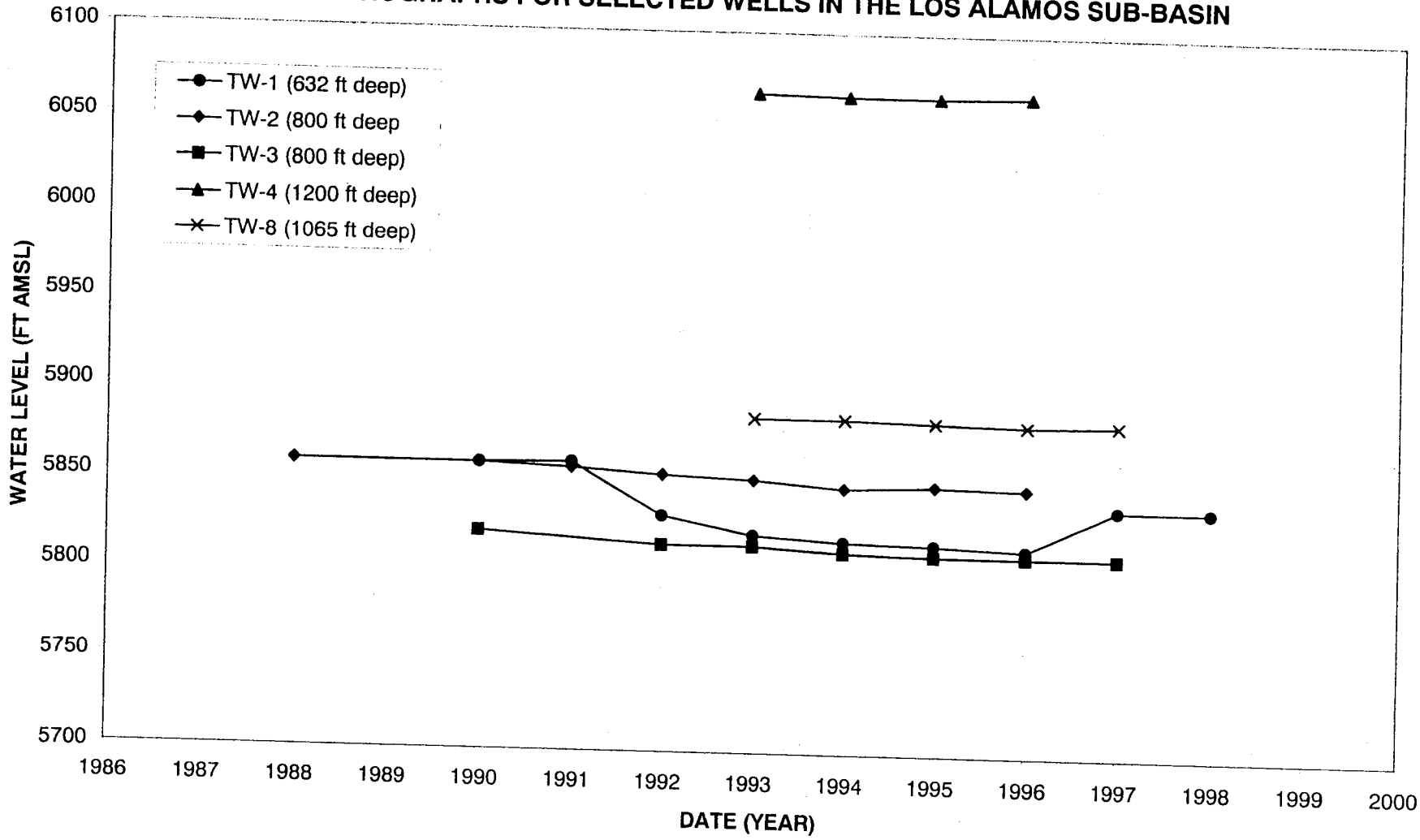

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FIGURE 5-13
HYDROGRAPHS FOR SELECTED WELLS IN THE POJOAQUE-NAMBE SUB-BASIN

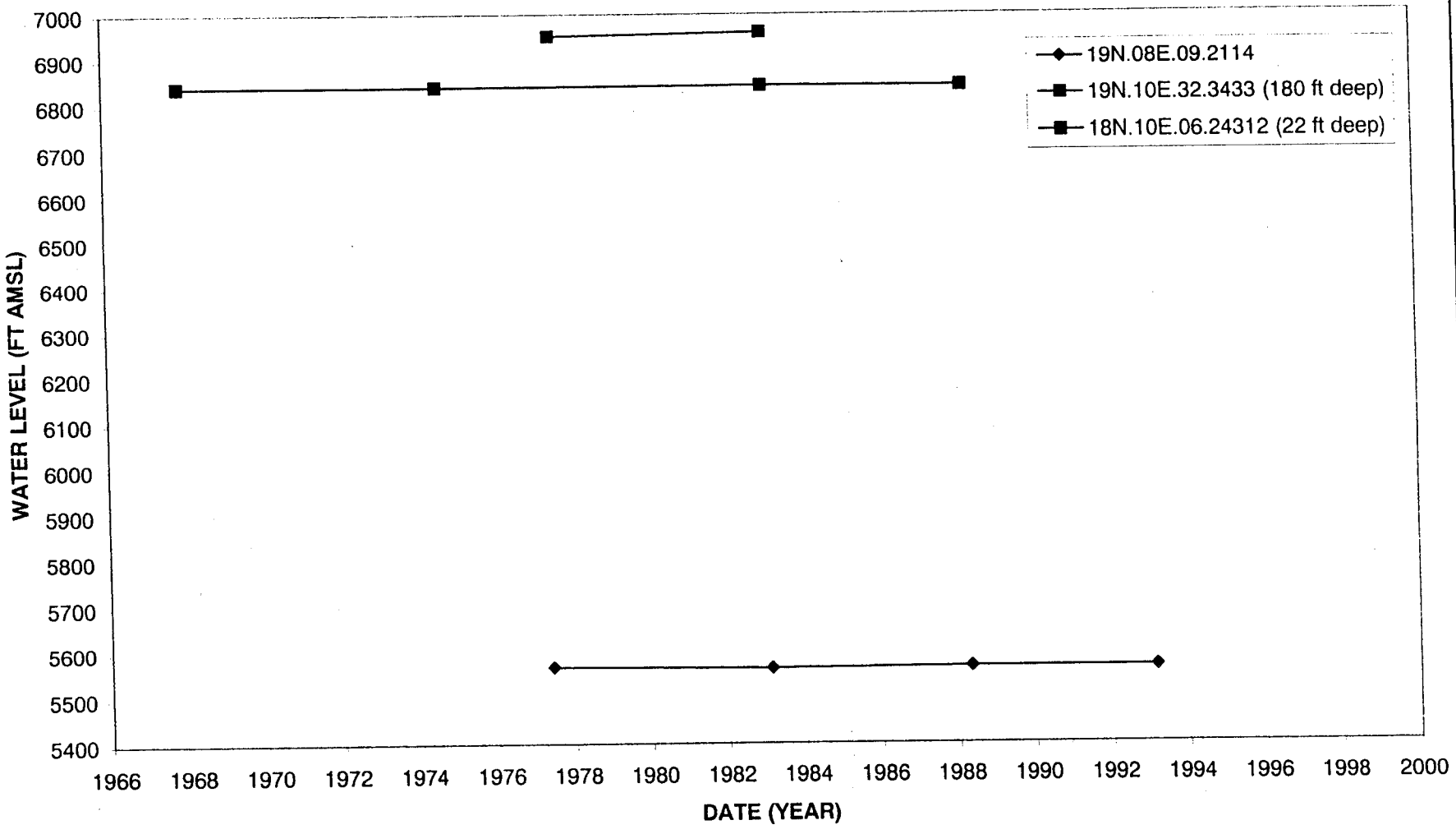

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FIGURE 5-14
HYDROGRAPHS FOR SELECTED WELLS IN THE TESUQUE SUB-BASIN

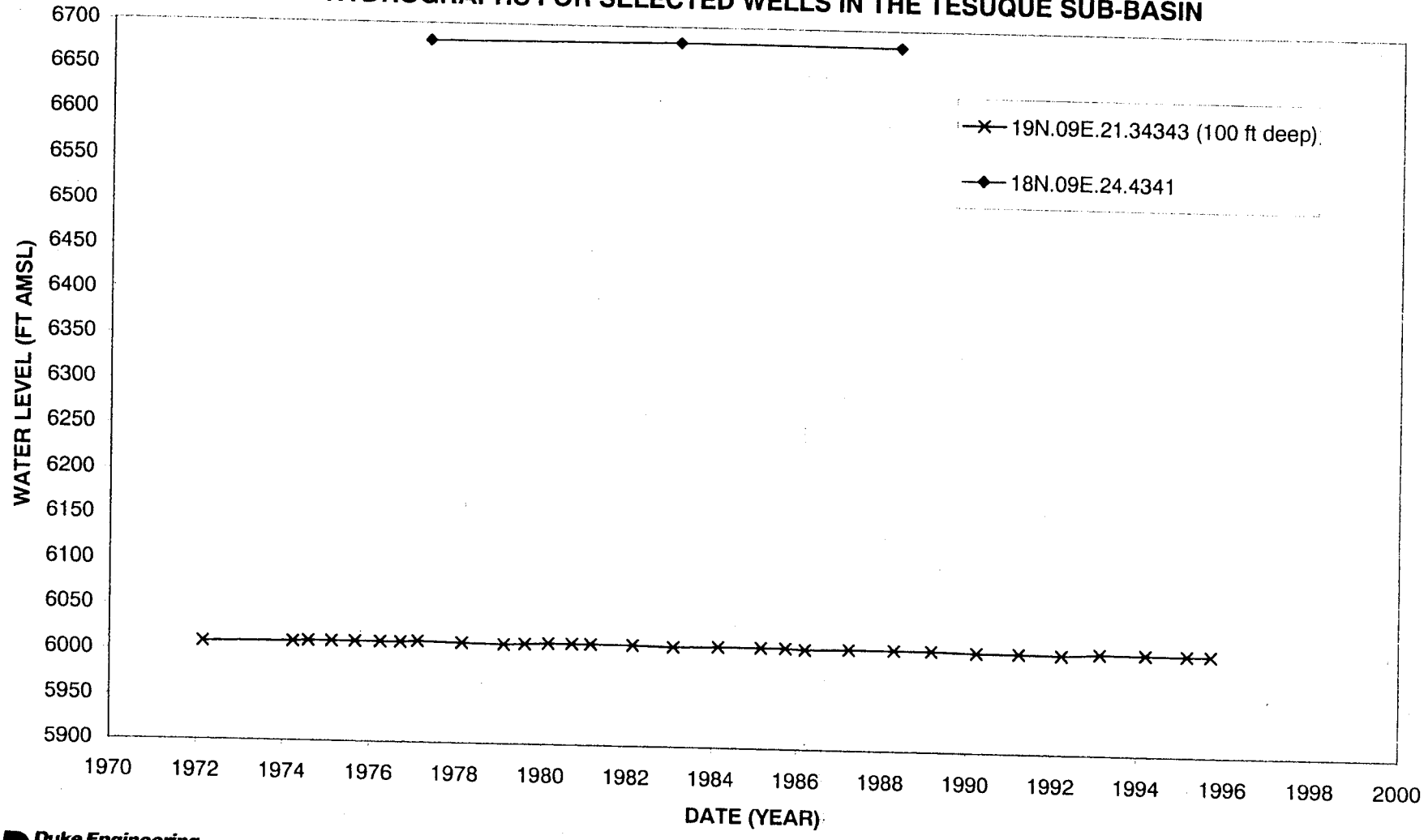

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FIGURE 5-15
HYDROGRAPHS FOR SF-3 PIEZOMETER NEST IN THE CAJA DEL RIO SUB-BASIN (AT BUCKMAN WELL FIELD)

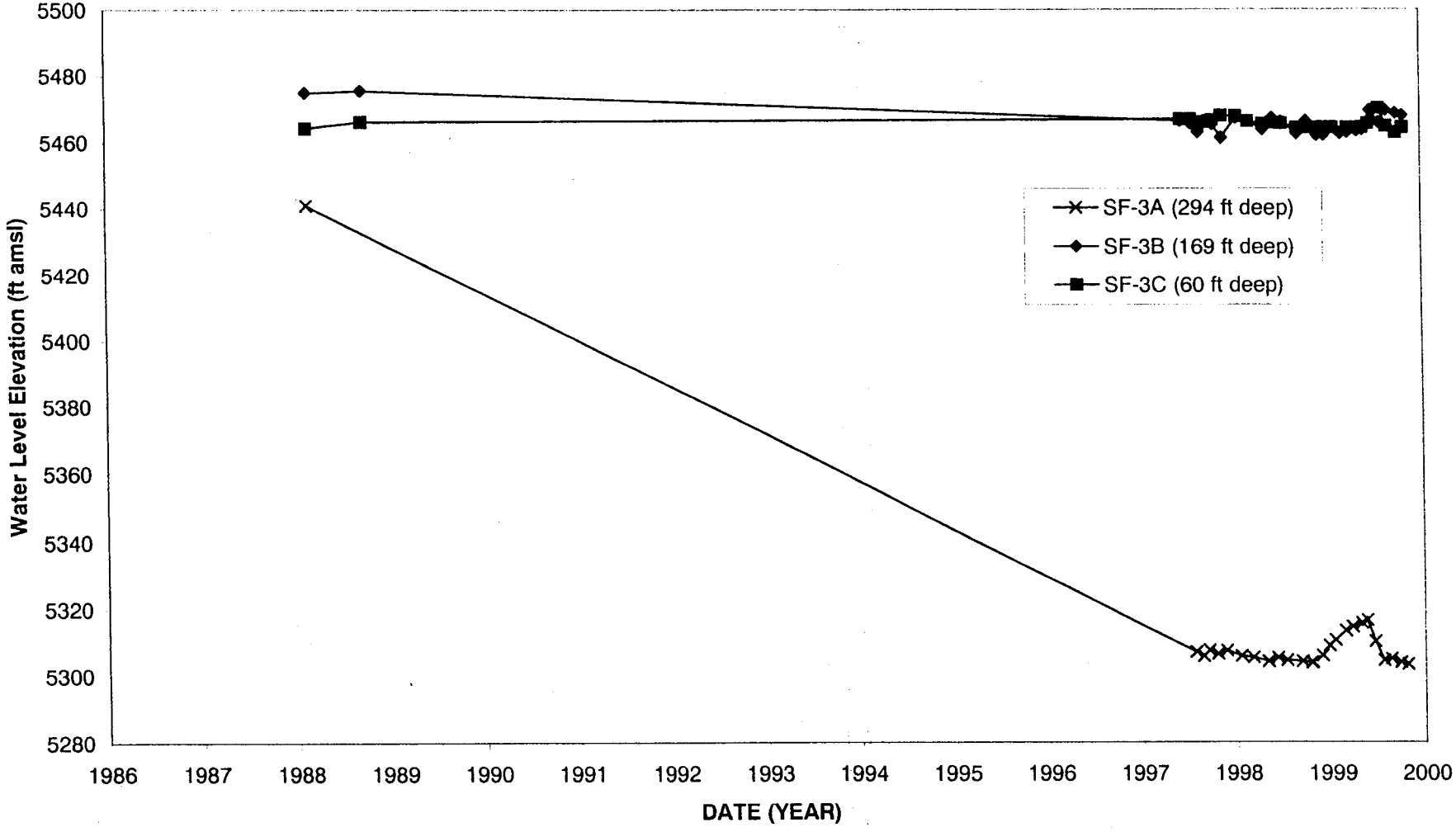

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FIGURE 5-16
HYDROGRAPHS FOR SF-2 PIEZOMETER NEST IN THE CAJA DEL RIO SUB-BASIN (AT BUCKMAN WELL FIELD)

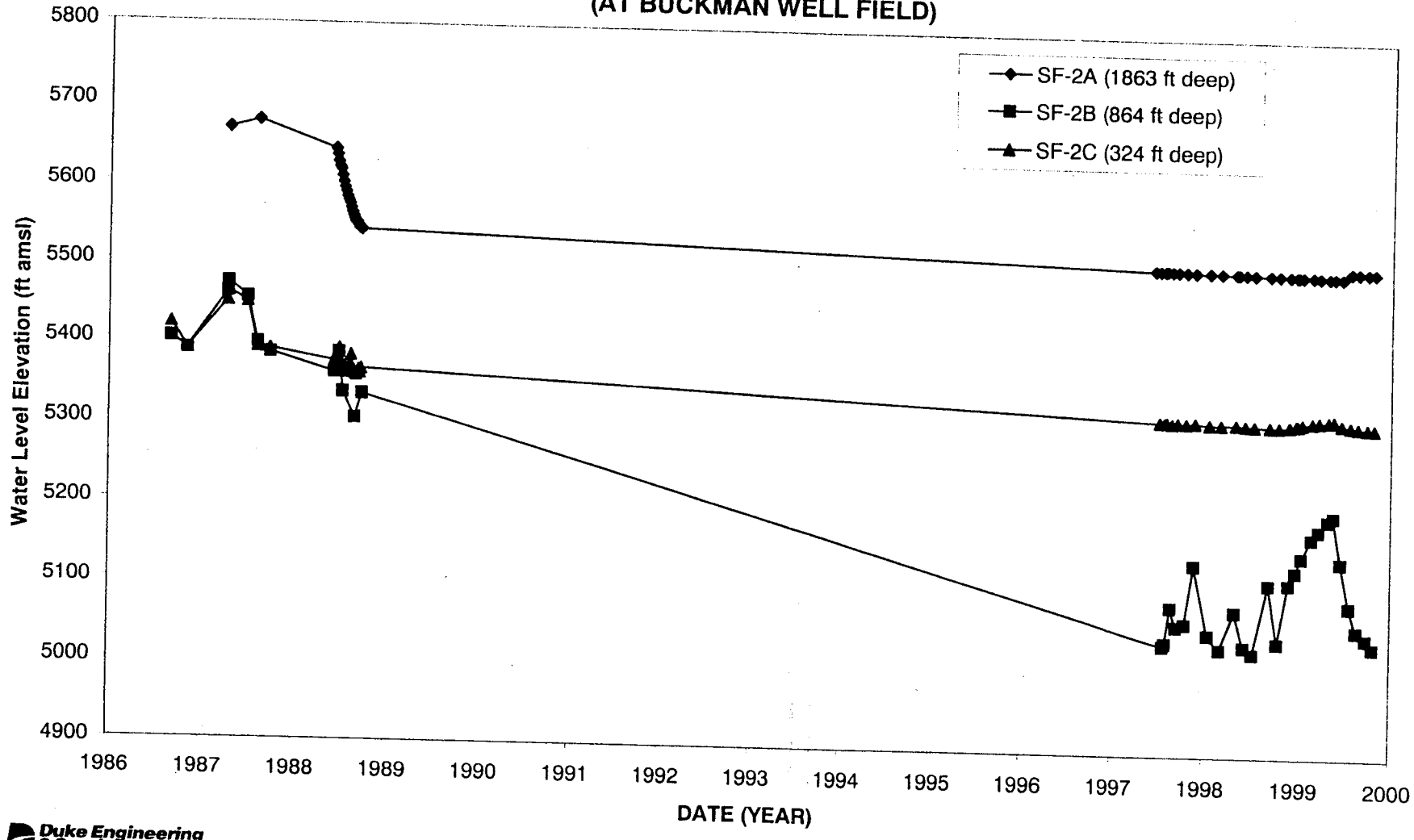

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FIGURE 5-17
HYDROGRAPHS FOR SELECTED WELLS IN THE SANTA FE SUB-BASIN

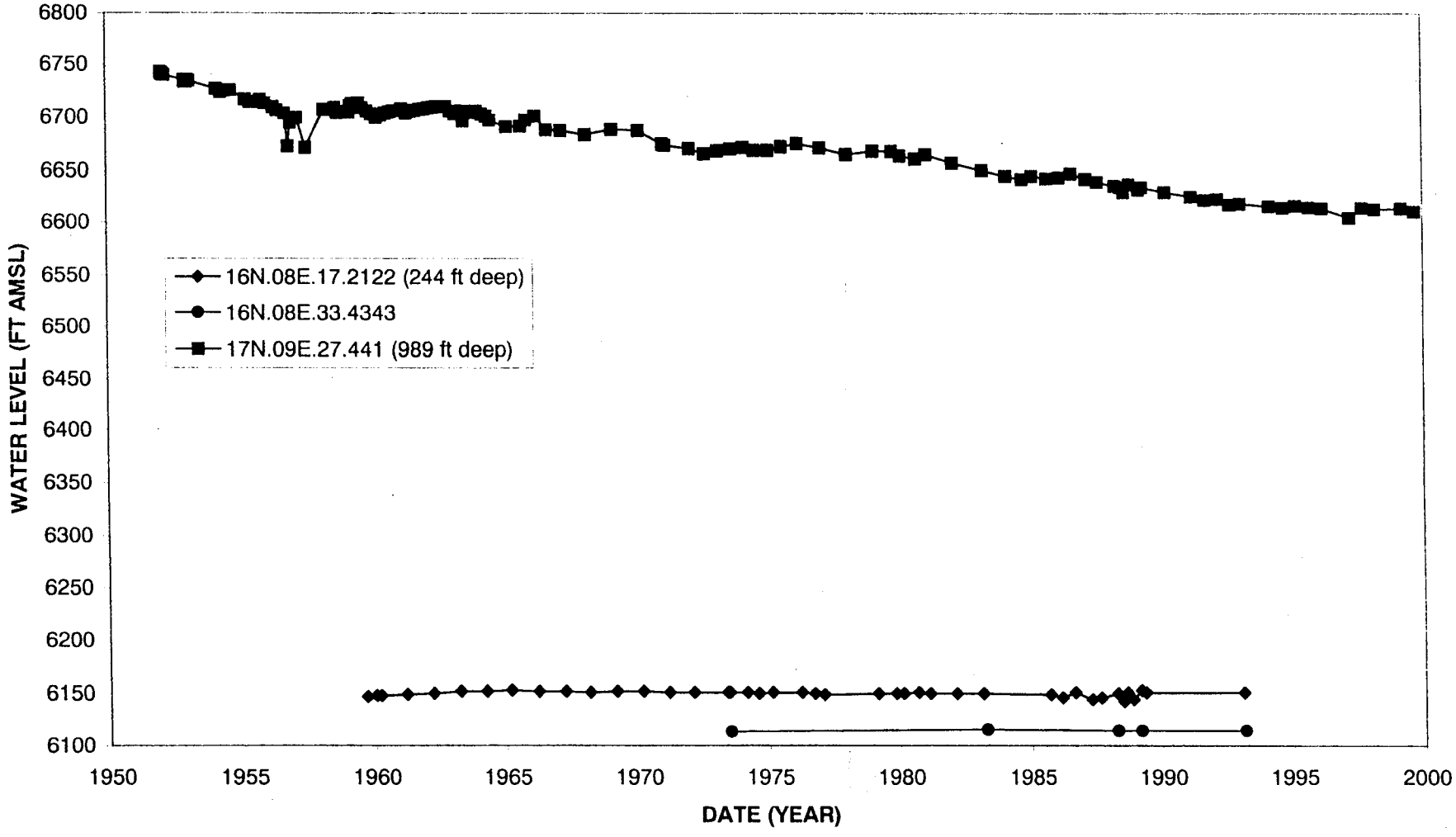

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FIGURE 5-18
HYDROGRAPHS FOR PIEZOMETER NEST SF-1 IN THE SANTA FE RIVER SUB-BASIN (NEAR CITY OF SANTA FE WELL FIELD)

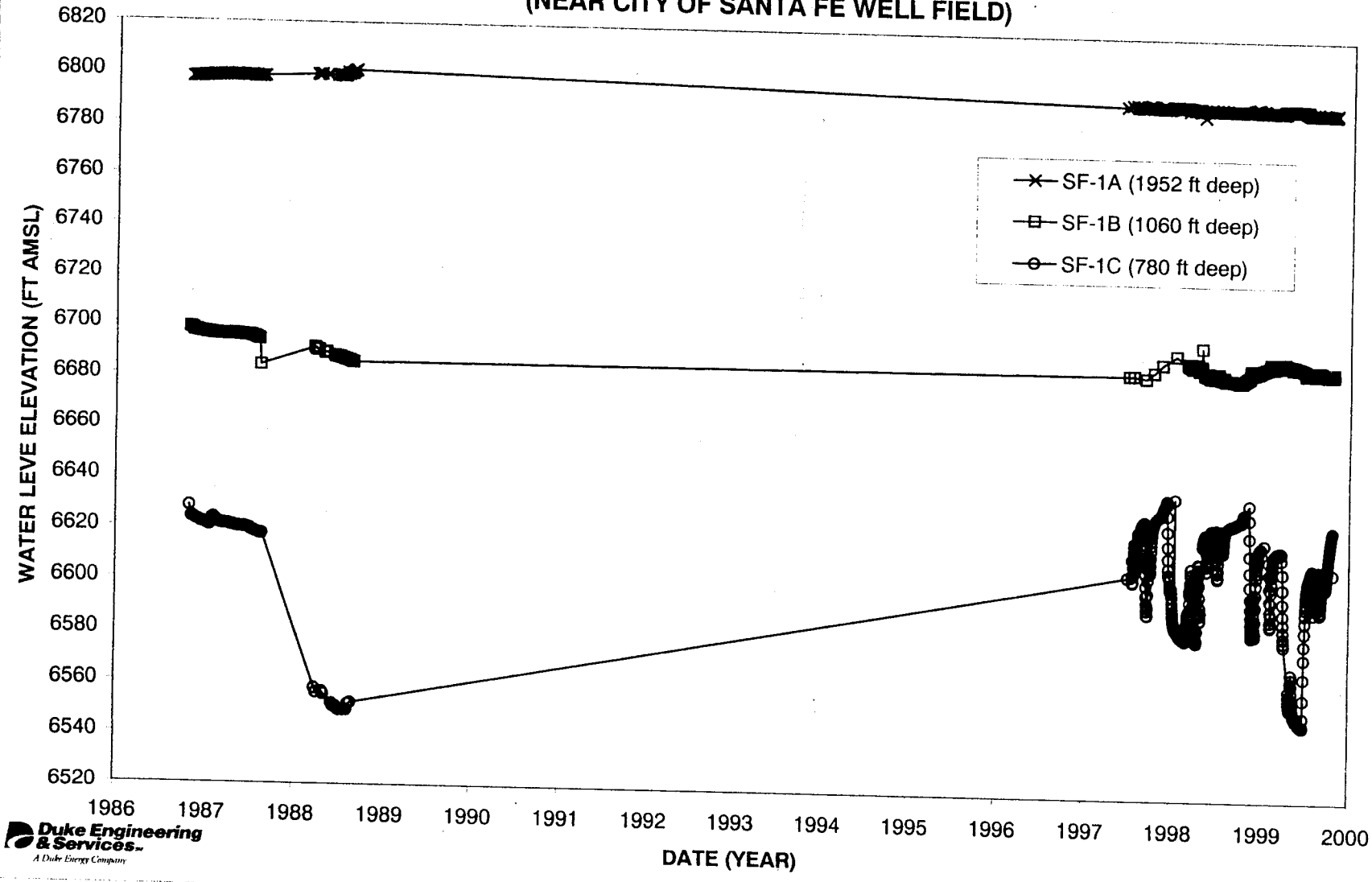

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FIGURE 5-19
HYDROGRAPHS FOR SELECTED WELLS IN THE NORTH GALISTEO CREEK SUB-BASIN

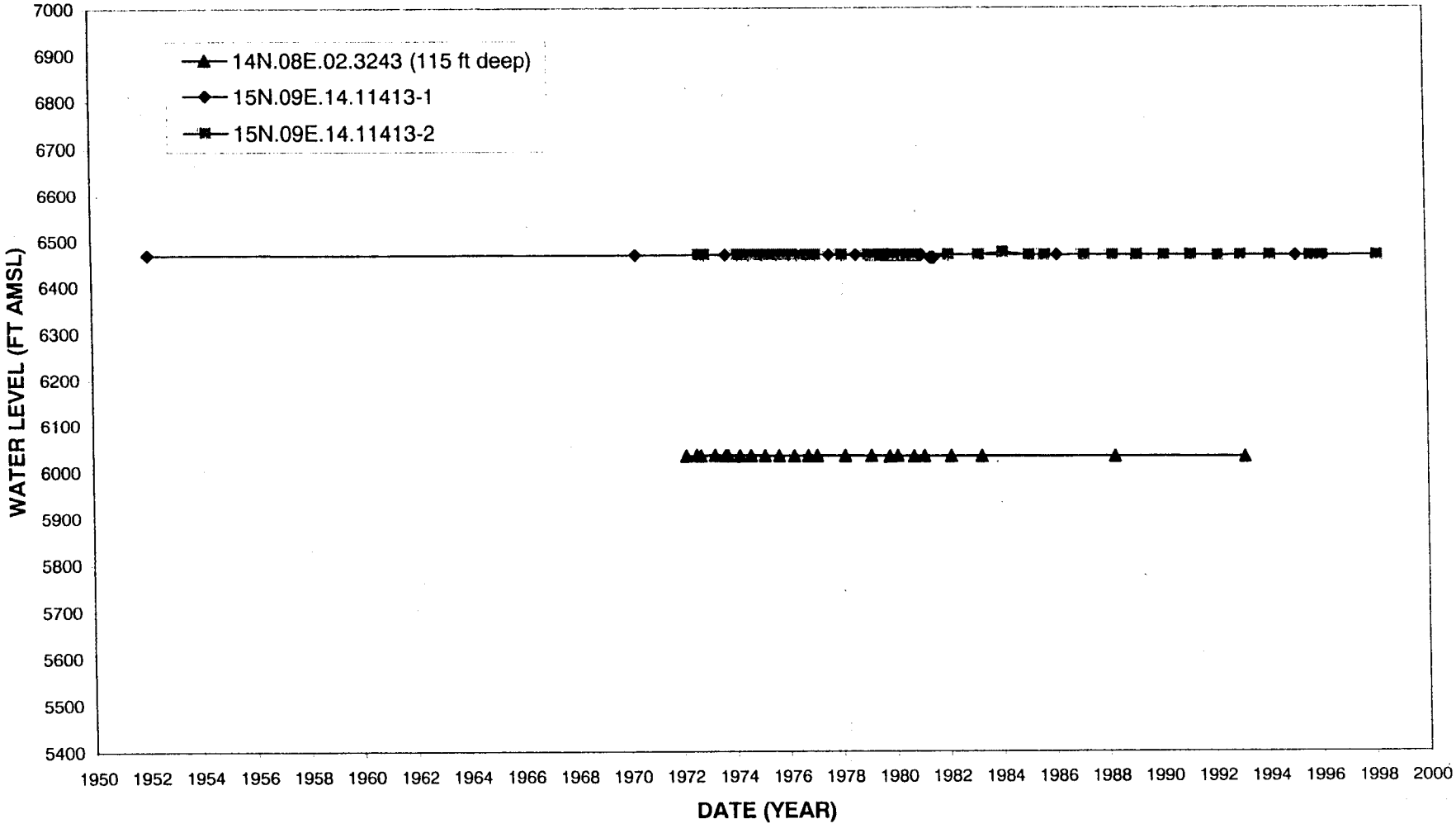

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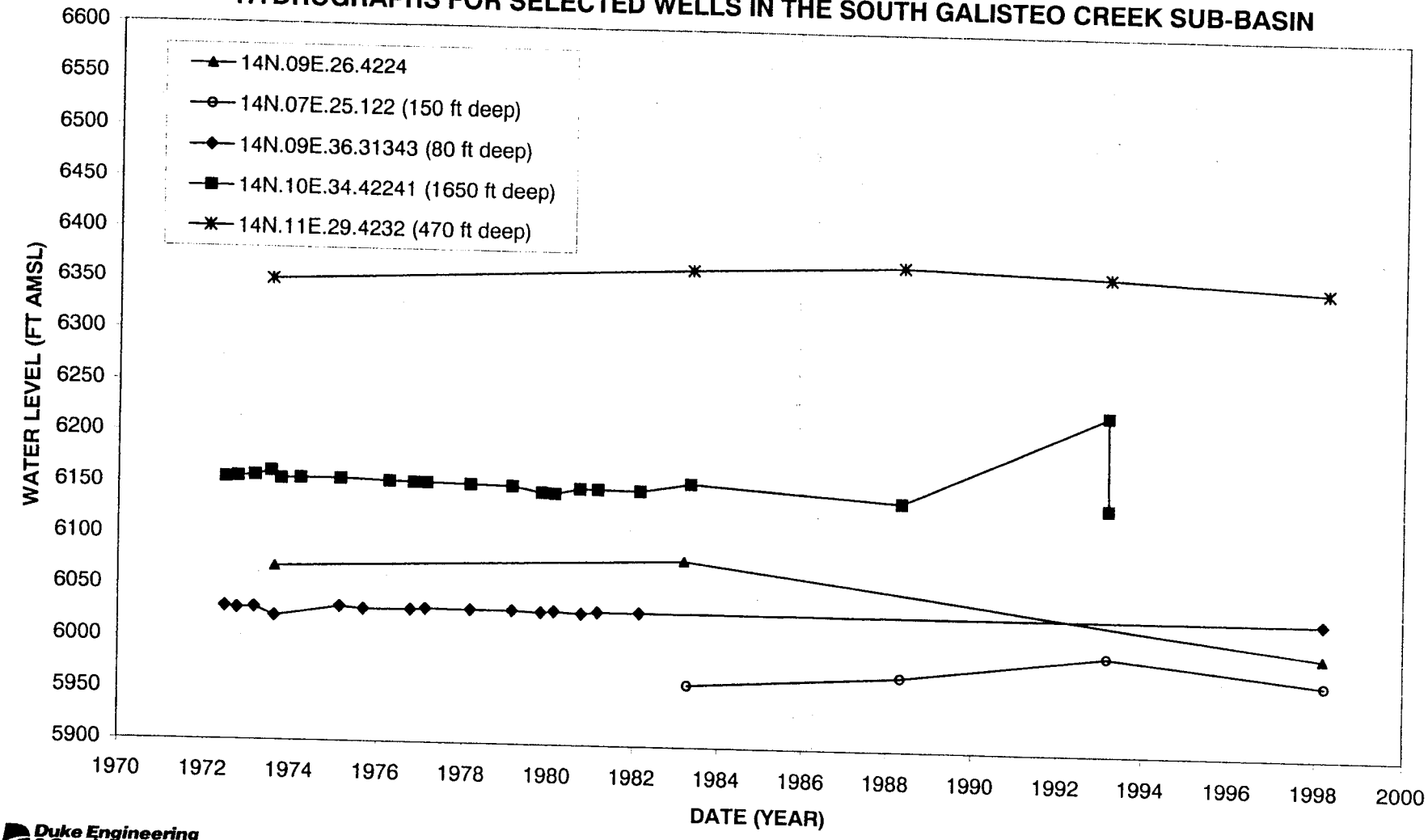
FIGURE 5-20
HYDROGRAPHS FOR SELECTED WELLS IN THE SOUTH GALISTEO CREEK SUB-BASIN



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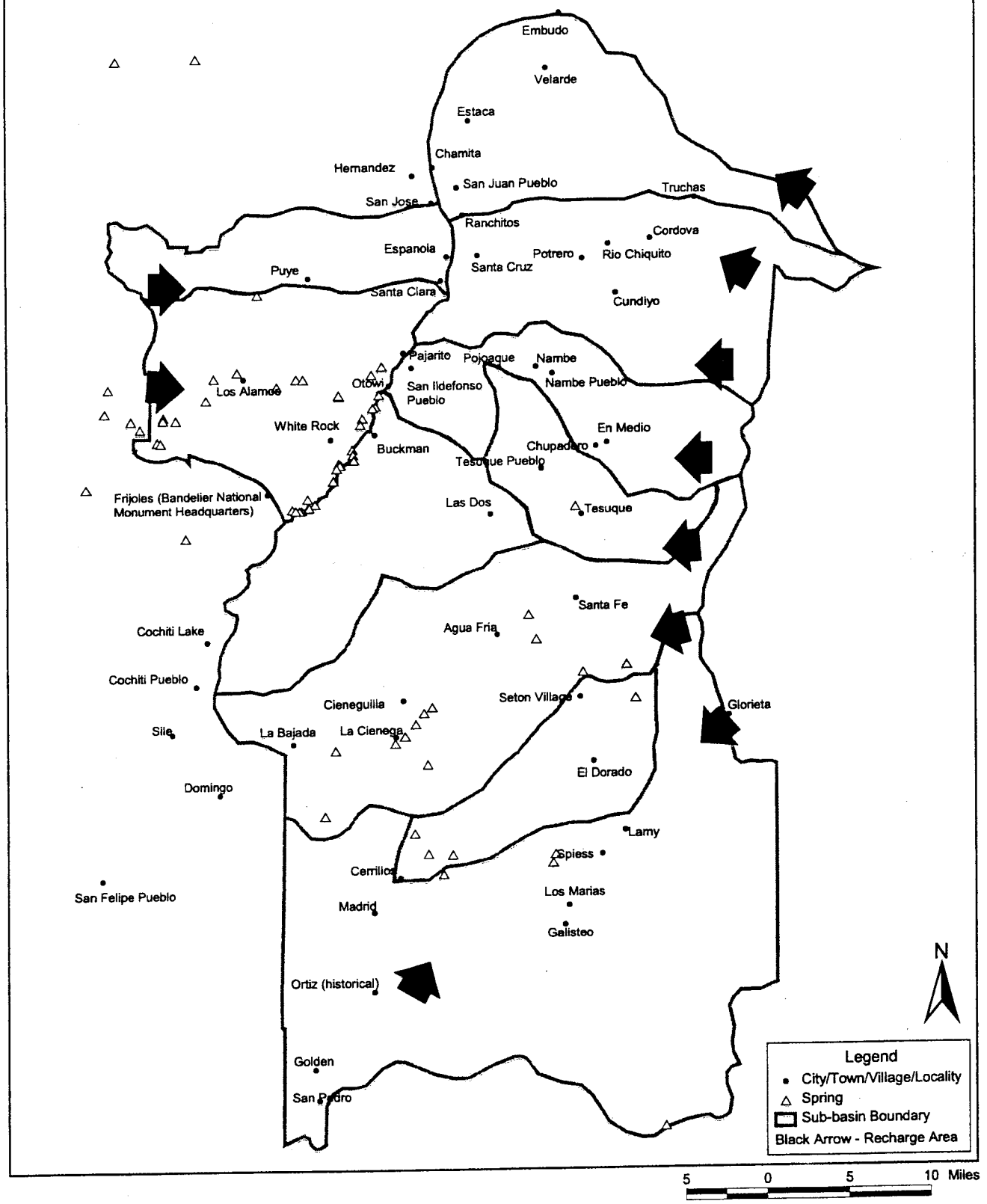

Figure 5-21 Springs and Recharge Areas

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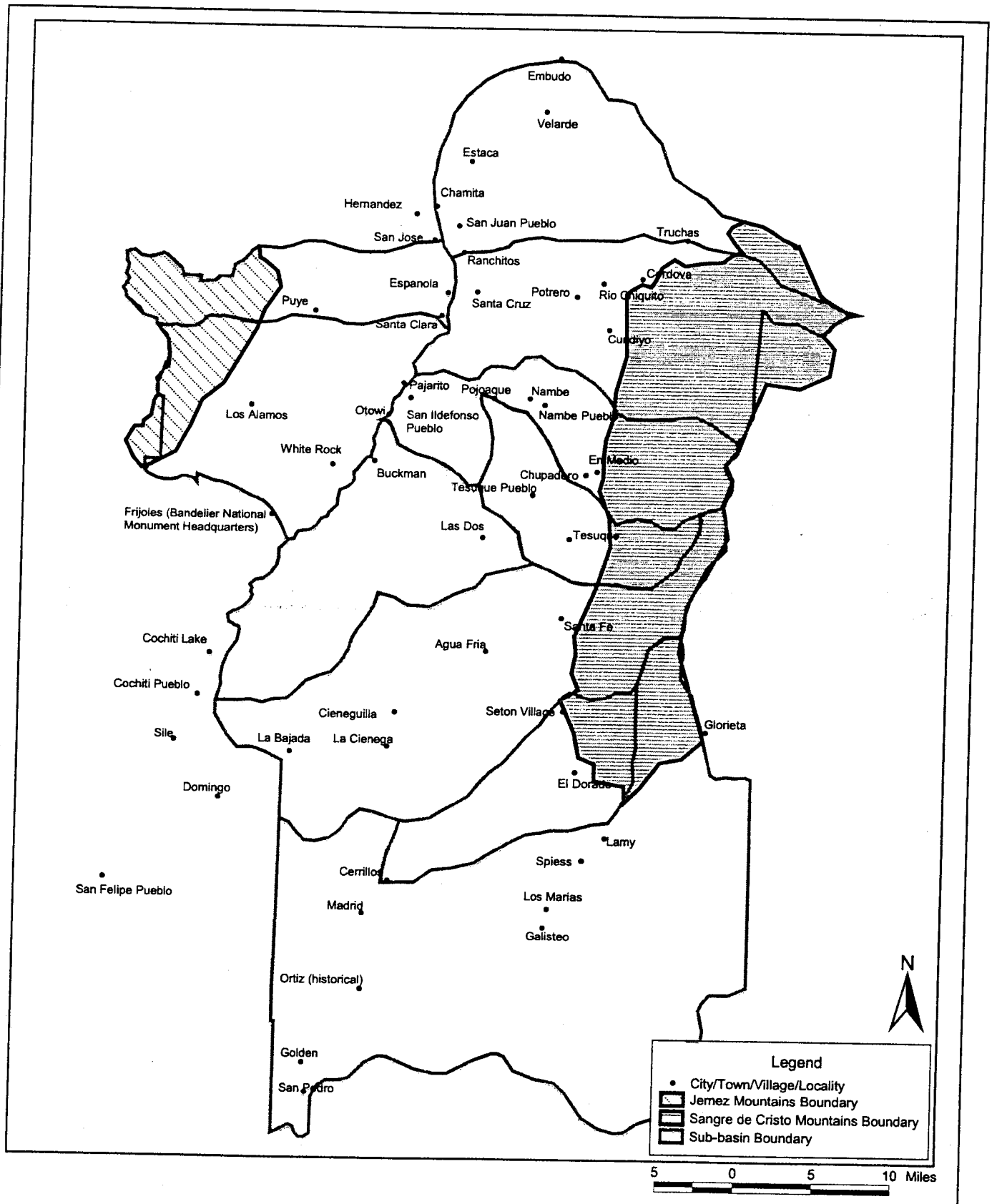

Figure 5-22 Mountain-front Extent

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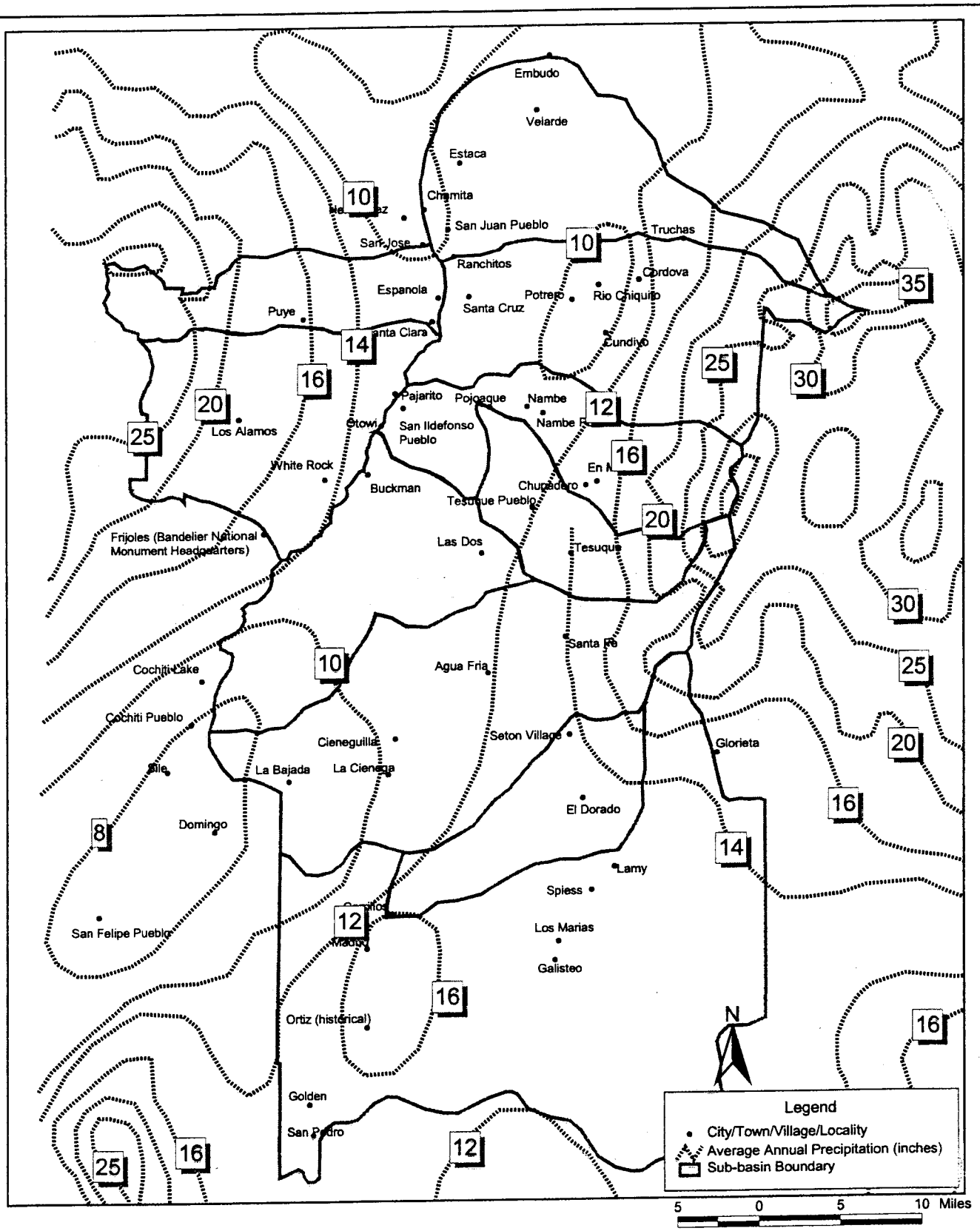

Figure 5-23 Average Annual Precipitation for the Planning Region
(Sources: Soil Conservation Service, 1972; Wasiolek, 1995)

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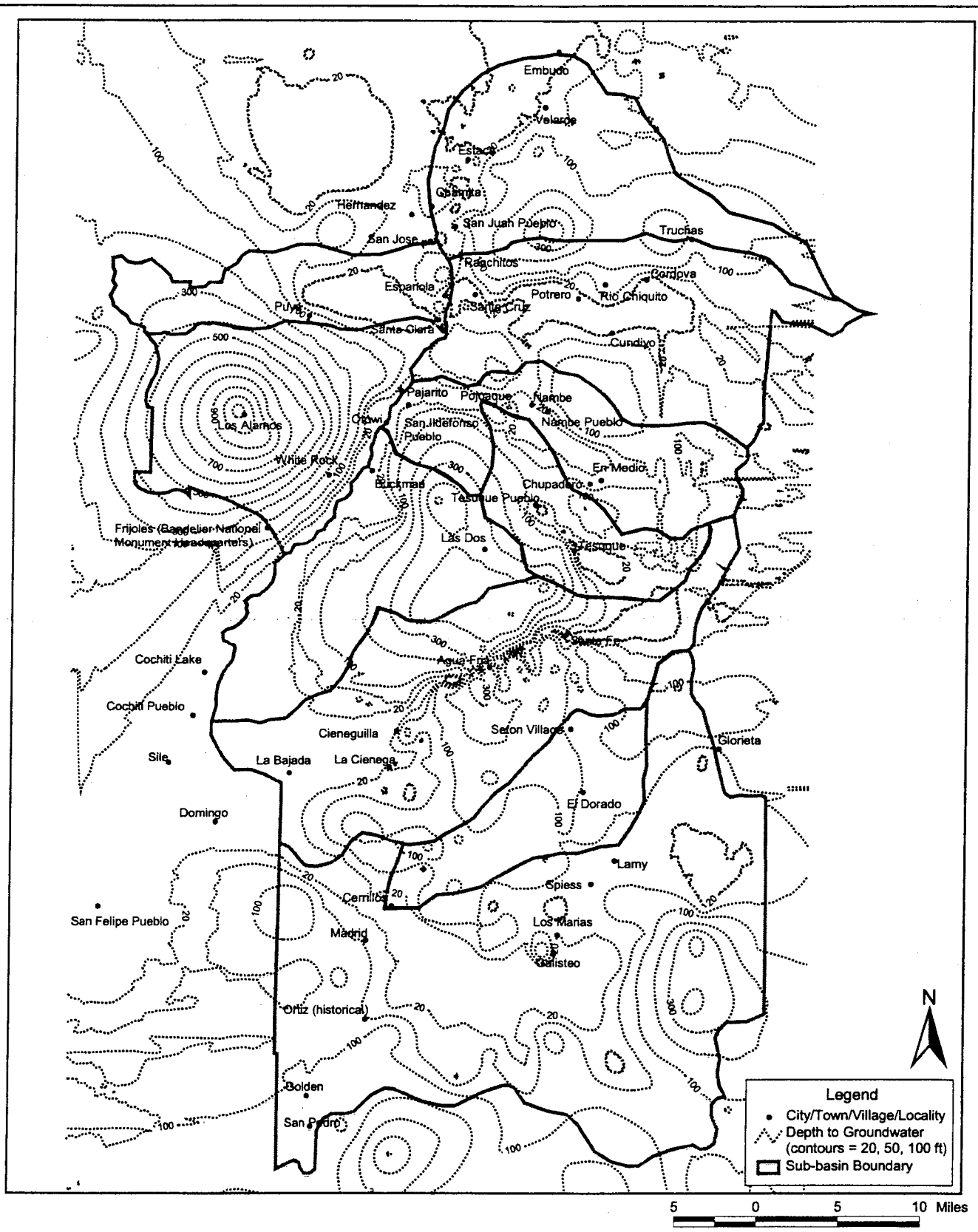

Figure 5-24 Depth to Groundwater Map

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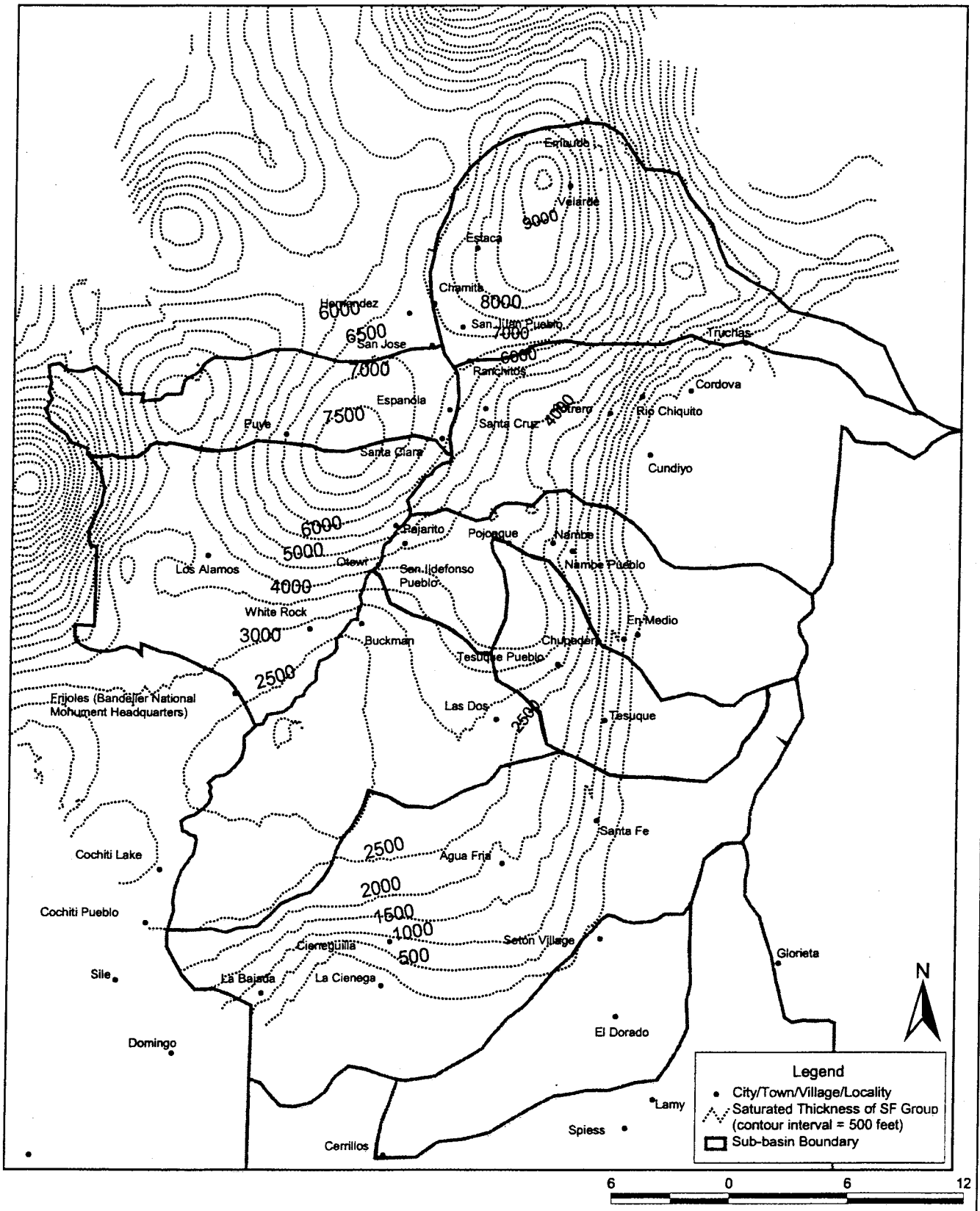

Figure 5-25 Saturated Thickness of the Santa Fe Group

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6.0 GROUNDWATER QUALITY

This chapter presents the results of Task 6, which comprised the characterization of groundwater quality in the Jemez y Sangre study region. This effort demonstrated that the quality of groundwater over most of the region is very good to excellent. The exceptions to this general rule were observed only in isolated locales where measured concentrations of some dissolved constituents have exceeded pertinent drinking water standards, the result of either natural groundwater geochemistry or anthropogenic causes.

The first portion of this chapter comprises a discussion of the general inorganic chemistry of groundwater in the Española geologic basin. This is followed by an assessment of regional groundwater quality with respect to measures of TDS. Subsequently, differences in major ion chemistry between portions of the planning region, if any, are demonstrated using both Stiff diagrams and trilinear (Piper) diagrams. Specific areas exhibiting elevated groundwater concentrations of both inorganic constituents and organic chemicals are then mentioned. This is followed by a short discussion of sites for which effluent discharge permits have been issued by the NMED. The chapter ends with a listing of known groundwater contamination sites in the planning region.

6.1 Sources of Groundwater Quality Information

Several potential sources of information regarding groundwater quality were examined during this phase of the study. These included a Tier 1 database containing the results of constituent analyses compiled by both the USGS as part of its National Water Information System (NWIS) and the New Mexico Drinking Water Bureau (NMDWB); reports by government agencies, including LANL; and reports by private consultants. Sites for which NMED Discharge Plan (NMED DP) permits have been issued were included in a Tier 2 dataset. Sites with known groundwater contamination were also identified in a Tier 2 database containing NMED-compiled lists of documented waste sites, such as leaking underground storage tanks (LUSTs).

6.2 Groundwater Inorganic Chemistry

On the whole, groundwater in the planning region is of high quality. With the exception of several isolated locations where either natural or human processes have led to elevated levels of specific dissolved constituents, groundwater is suitable for domestic consumption.

Within most of the Española geologic basin, particularly in the sub-basins draining the Sangre de Cristo Mountains, groundwater can be categorized as a calcium-bicarbonate type (DBS&A, 1994a; Blake et al., 1995; LANL, 1996; 1997; 1998; 1999). The exceptions to this rule usually occur in areas where sodium replaces calcium as the predominant cation. Locales where sodium-bicarbonate groundwater tends to predominate are the Buckman Well Field, the Pueblo of Pojoaque, and several areas in the Los Alamos sub-basin.

Nitrate is an inorganic constituent that is observed at relatively high concentrations at several locales in the study region. Though this constituent occurs naturally within regional groundwater, nitrate background levels are generally very low in comparison to its drinking water standard of 10 mg/L as N (see Table 6-1). Thus, elevated levels of nitrate are usually attributed to sources for it near land surface, such as fertilizer application, septic tank discharge, or surface water bodies receiving some form of effluent. Fluoride is another naturally occurring inorganic solute that sometimes occurs at elevated or problematic concentrations in groundwater.

The following sections provide more detailed descriptions of the inorganic chemistry of groundwater in the planning region. To help the reader put some of these discussions in perspective, the drinking water standards for several measures of groundwater quality, as promulgated by both the State of New Mexico and the EPA, are presented in Table 6-1. The state criteria consist of drinking water standards published by the NMED Ground Water Quality Bureau (GWQB). EPA's standards comprise maximum contaminant levels (MCL), secondary drinking water regulations (SDWR), and action levels (AL) (EPA, 2000).

6.2.1 Electrical Conductance and TDS Levels

As part of their assessment of general groundwater quality in Santa Fe County, DBS&A (1994a) developed mathematical relationships between measured TDS levels and corresponding measures of EC. These relationships were determined for five hydrogeologic units, two of which apply to the study region: (1) Santa Fe Group deposits, and (2) Precambrian rocks. For the most part, the resulting equations suggest that multiplying EC by a factor of about 0.6 to 0.7 will produce a viable estimate of TDS. Using this general rule, measurements of EC can be used to describe the spatial distribution of dissolved solids levels within the Santa Fe County portion of the study region. Additional insight into the dissolved solids levels that are observed on the western side of the Rio Grande is drawn from LANL reports that discuss groundwater quality (e.g., Blake et al., 1995; Purtymun et al., 1995; McLin et al., 1996; 1997a; 1997b; 1998).

EC levels in groundwater on the eastern side of the Rio Grande north of the town of Galisteo, particularly in areas where wells tap either the Tesuque Formation, the Ancha Formation, Precambrian rocks, or shallow alluvium adjacent to watercourses, usually range from about 100 to 500 micromhos per centimeter. Thus the TDS levels over most of this part of the study region can be expected to be 350 mg/L or less. Isolated wells showing EC measurements in excess of 700 micromhos per centimeter are observed near the City of Santa Fe, in a shallow aquifer near Española, in the Buckman well field, near the community of Pojoaque, and just south of the southernmost extent of Santa Fe Group deposits within the study region.

Most EC levels in the South Galisteo Creek sub-basin indicate that TDS levels in this southernmost portion of the planning region will exceed the NM State Standard of 1000 mg/L. Near the town of Galisteo, measured EC levels range from about 650 to 2200 micromhos per centimeter. Near the west boundary of the study region, in this same sub-basin, EC measurements generally range from 1000 to 5000 micromhos per centimeter.

Table 6-1. New Mexico Drinking Water Standards for Groundwater and EPA Standards for Drinking Water

Constituent	New Mexico Groundwater Standard	EPA Drinking Water Standard
pH	6-9	6.5-8.5[2]
Total Dissolved Solids (TDS)	1000 mg/L	500 mg/L[1]
Aluminum (Al)	5 mg/L	0.05-0.2 mg/L[2]
Arsenic (As)	0.1 mg/L	0.05 mg/L[1], 0.005 mg/L[4]
Barium (Ba)	1.0 mg/L	2 mg/L[1]
Boron (B)	0.75 mg/L	-
Chloride (Cal)	250 mg/L	250 mg/L[2]
Cyanide (CN)	0.2 mg/L	0.2 mg/L[1]
Fluoride (Fl)	1.6 mg/L	2 mg/L[2]
Iron (Fe)	1.0 mg/L	0.3 mg/L[2]
Lead (Pb)	0.05 mg/L	0.015 mg/L[3]
Manganese (Mn)	0.2 mg/L	0.05 mg/L[2]
Nickel (Ni)	0.2 mg/L	-
Nitrate as Nitrogen (NO_3 as N)	10 mg/L	10 mg/L[1]
Selenium (Se)	0.05 mg/L	0.05 mg/L[1]
Silver (Ag)	0.05 mg/L	0.1 mg/L[1]
Strontium (Sr)	8 pCi/L	
Sulfate (SO_4)	600 mg/L	250 mg/L[2]
Tritium (H_3)	20,000 pCi/L	
Uranium (U)	5 mg/L	0.02 mg/L[4]

Notes:

mg/L = milligram(s) per liter

pCi/L = picocurie(s) per liter

[1] EPA Maximum Contaminant Level (MCL) – the highest level of a contaminant that is allowed in drinking water. MCLs are enforceable.

[2] EPA Secondary Drinking Water Regulation (SDWR) – a non-enforceable health goal, which is set at a level at which no known or anticipated adverse effect on the health of persons occur and which allows an adequate margin of safety.

[3] EPA Action Level (AL) – the concentration of a contaminant, which, if exceeded, triggers treatment or other requirements that a water system must follow. For lead it is the level, which, if exceeded in over 10% of the homes tested, triggers treatment.

[4] Proposed MCL.

Within the Los Alamos sub-basin west of the Rio Grande, measured TDS levels are generally less than 350 mg/L. Groundwater associated with water supply wells that tap the so-called regional aquifer in the Pajarito Mesa, Guaje Canyon, and Otowi well fields typically has TDS concentrations of 150 to 500 mg/L. TDS concentrations exceeding 600 mg/L have been observed in some of the wells in the Los Alamos Well Field (Blake et al., 1995).

The Los Alamos Well Field was formerly used for water supply to the community of Los Alamos but is now owned by San Ildefonso Pueblo. An area of relatively high TDS concentrations, with values sometimes exceeding 1000 mg/L, has been observed in wells near the Rio Grande between the communities of Otowi and Pajarito, just north of where Guaje Canyon empties onto the Rio Grande Valley. These relatively high dissolved solids levels occur on the western side of San Ildefonso Pueblo in conjunction with anomalous concentrations of nitrate and sulfate, issues which are discussed further in a subsequent section.

6.2.2 Stiff Diagram Analysis

Originally, it was intended that NWIS data in the Tier 1 database would be used to develop Stiff diagrams for representative groundwater samples in the study sub-basins. Ultimately, however, data provided in DBS&A (1994a) for Santa Fe County and LANL reports (e.g., Blake et al., 1995; Purtymun et al., 1994; McLin et al., 1997; 1998) for Los Alamos County were used. Stiff diagrams were prepared for all sub-basins with the exception of the Velarde and Santa Clara sub-basins.

Figures 6-1 through 6-8 present the Stiff diagrams for selected groundwater samples in the eight sub-basins for which ionic data were analyzed. Each analysis is identified by a name, and the locations of many of the wells sampled in terms of latitude and longitude (degrees, minutes, seconds) are also given. The names used for all analyses of wells in Santa Fe County are variations on shorthand names used in the report by DBS&A (1994a). This naming convention gives the name of the hydrogeologic unit in which the well is screened followed by a sequence number. Names applied to some of the sampling sites in the Los Alamos sub-basin correspond to those used in Blake et al. (1995). A map showing the locations to which the Stiff diagrams apply, as well as smaller versions of the diagrams themselves, is presented in Figure 6-9.

The Stiff diagrams illustrate quite clearly the predominance of calcium-bicarbonate and sodium-bicarbonate groundwater in the study region. Areas where sodium-bicarbonate waters appear to be most abundant occur on the eastern end of the Los Alamos sub-basin (as indicated by the top two diagrams in Figure 6-2), in the Caja del Rio sub-basin in the Buckman Well Field, and in some parts of the Pojoaque-Nambe sub-basin. Figure 6-2 shows that groundwater in the municipal well fields in the Los Alamos sub-basin can also have sodium as the dominant cation. The occurrence of sodium-bicarbonate groundwater in the various Los Alamos well fields, rather than a calcium-bicarbonate water, appears to increase with increasing distance to the east (Purtymun et al., 1993; McLin et al., 1996; 1997a; 1997b; 1998). The phenomenon of sodium replacing calcium as water migrates downgradient is a

well documented one (e.g. Fetter, 1980, p. 330). Sodium replaces calcium through a process called ion exchange.

The analysis shown for the sample known as Tesuque Formation 22 in Figure 6-4 actually represents a relatively isolated occurrence of sodium-bicarbonate groundwater within the Tesuque sub-basin, as most groundwater in the sub-basin is of the calcium-bicarbonate type. This sample was collected from a well located near the outlet of the Tesuque sub-basin, where it joins the Pojoaque-Nambe sub-basin near the Pueblo of Pojoaque. As discussed in a later section, sodium-bicarbonate groundwater is relatively common in this area, and may be associated with elevated fluoride levels in nearby wells.

The sample identified as Unknown Formation 10 in Figure 6-8 is of interest because it shows sulfate being the dominant anion. The well from which the sample was taken is located in the South Galisteo Creek sub-basin, and the explanation for the high sulfate level relative to that of calcium is unknown.

6.2.3 Trilinear Diagram Analysis

Trilinear Piper diagrams were prepared using the major ion concentrations from at least two groundwater samples in each of the eight sub-basins included in the Stiff diagram analysis. The resulting plots, shown in Figures 6-10 through 6-17, do not indicate any major shifts in inorganic water chemistry. The most apparent feature of all of the graphs is the preponderance of bicarbonate (HCO_3) as the most dominant anion in regional groundwater. Otherwise, the figures simply aid in pointing out that the most dominant cations are calcium and sodium, and that both calcium-bicarbonate and sodium-bicarbonate water can be found in a single sub-basin.

6.2.4 Quality of Groundwater in the Los Alamos Sub-basin

Several reports have been produced by LANL (e.g., Blake et al., 1995; LANL, 1996; 1997; 1998; 1999; McLin et al., 1996; 1997a; 1997b; 1998) during the past 20 to 30 years that document the quality of groundwater in different parts of the Los Alamos sub-basin. Three different types of groundwater have generally been analyzed: (1) the regional aquifer (main aquifer), which is the primary source of drinking water in the area; (2) shallow alluvium in the base of canyons; and (3) perched groundwater systems. More documentation probably regarding groundwater quality probably exists for this sub-basin than for any other within the planning region.

The regional aquifer generally comprises the Santa Fe Formation and the overlying Puye Conglomerate (Purtymun, 1984), both of which occur below the volcanic materials that form the Pajarito Plateau. Three well fields in the Los Alamos Area – Pajarito, Otowi, and Guaje well fields – currently withdraw groundwater from the regional aquifer for drinking water purposes in Los Alamos. A fourth well field that was formerly tapped for drinking water – the Los Alamos well field – was transferred to the ownership of San Ildefonso Pueblo in 1992. The quality of groundwater withdrawn from the regional aquifer in the three fields

currently being used is, on the whole, very good to excellent. As previously mentioned, TDS levels in these well fields are generally below 250 mg/L. A test well that penetrates the regional aquifer near one of the easternmost wells in the Otowi Field frequently has nitrate concentrations that are often near the EPA maximum contaminant level (MCL) for this constituent of 10 mg/L as N. However, this well is used strictly for observation purposes, and is not pumped for the local water supply. The source of the elevated nitrate concentration is apparently either sewage effluent in Pueblo Canyon that has penetrated the subsurface or residual nitrates from a formerly utilized radioactive liquid waste treatment plant in Pueblo Canyon (LANL, 1999).

Shallow alluvial groundwater systems along the bases of canyons do contain constituents at relatively high levels as a result of the recharge of effluent from NPDES outfalls and other sources, which were previously discussed in Section 4.3.2. In 1998, shallow alluvial groundwater in Mortendad Canyon downstream from an outfall for Technical Area 50 effluent had fluoride and nitrate concentrations that either exceeded or approached New Mexico water quality standards for these constituents. As with surface water, the radionuclides tritium, strontium, and plutonium are sometimes observed in the shallow groundwater systems associated with the canyons.

All of the portion of San Ildefonso Pueblo located on the western side of the Rio Grande lies within the Los Alamos sub-basin. Groundwater from wells in this vicinity has historically contained several dissolved species at elevated concentrations, a topic that is discussed further in Section 6.3.3.

6.3 Areas of Elevated Concentrations

6.3.1 City of Española Well Field

A water system master plan prepared for the City of Española (Molzen-Corbin and Associates, 2000) discusses groundwater quality of the area and its impact on the city's municipal water supply. Groundwater withdrawn from wells drilled in relatively shallow river alluvium (100 to 300 feet deep) adjacent to the Rio Grande and the Rio Chama is generally hard, and may contain iron and/or nitrate at relatively high concentrations. A shallow municipal well has tapped groundwater with nitrate levels approaching 12 mg/L. Shallower wells in the vicinity of Española are also potentially subject to contamination by near-surface sources such as LUSTs. The NMED Underground Storage Tank Bureau reports 19 cases of LUST within Española city limits (Molzen-Corbin and Associates, 2000).

Water withdrawn from deeper wells completed in the Tesuque Formation tends to be relatively soft, but may be high in TDS. Another constituent that can be a problem in Española wells tapping the Tesuque Formation is fluoride. Groundwater from two City wells contains dissolved fluoride at concentrations exceeding EPA's established MCL for this constituent of 4 mg/L (Molzen-Corbin and Associates, 2000). The cause of elevated fluoride

in local groundwater, whether the result of groundwater production from specific zones or migration along geologic faults containing large concentrations of fluoride, is uncertain.

During the past 40 years, five City of Española wells have been abandoned due to problems that are either wholly or partially related to water quality issues. Three of the wells have experienced contamination by organic chemicals, two of which were contaminated by the solvents tetrachloroethene and trichloroethene. Elevated levels of dissolved iron affected two additional abandoned wells.

6.3.2 Pojoaque Valley

Groundwater in the Pojoaque Valley is affected by relatively high levels of uranium, nitrate, and fluoride (McQuillan and Montes, 1998). Uranium has been found in several wells less than 200 feet deep at levels exceeding the EPA drinking water standard (MCL) of 0.02 mg/L, and two of these shallow wells have contained dissolved uranium at a concentration greater than 0.9 mg/L. Wells owned and operated by the Pojoaque Pueblo are deeper, generally 500 feet or more below ground surface, and do not exhibit the high uranium concentrations observed in the shallow wells. The source of the elevated dissolved uranium appears to be natural ash-flow deposits in the Tesuque Formation (McQuillan and Montes, 1998). Groundwaters in the area are generally characterized as calcium-sodium-bicarbonate, to sodium-bicarbonate and calcium bicarbonate types.

Elevated nitrate also seems to a problem that is limited to shallow wells in the Pojoaque Valley. Nitrate has been measured at levels as large as 6.8 mg/L as N, which does not exceed the drinking water standards set by the EPA and NMED. The apparent source of this somewhat elevated nitrate concentration is septic-tank contamination.

Though fluoride levels at the Pojoaque Valley generally fall in the range of 0.4 to 1 mg/L, a few wells in the area have contained fluoride at concentrations exceeding 5 mg/L, which is well above both the NMED and EPA groundwater standards listed in Table 6-1. These relatively large concentrations are the result of cation exchange processes occurring in the area's groundwater. Elevated fluoride only occurs in wells where calcium is depleted and sodium is the dominant cation, thus making calcium unavailable to bond with aqueous fluoride and precipitate the solid mineral fluorite (McQuillan and Montes, 1998).

6.3.3 San Ildefonso Wells

Groundwater from wells on the western side of San Ildefonso Pueblo in the Los Alamos sub-basin has been shown to contain anomalously high concentrations of nitrate, sulfate (Blake et al., 1995), uranium, and fluoride (LANL, 1999). The elevated concentrations of sulfate and nitrate appear to mostly be the result of fertilizers applied in the area, and nitrate levels might also be attributed to resident livestock. The higher nitrate concentrations in the local groundwater supply typically range from about 4 to 8 mg/L as N, and a sample from one well contained nitrate at a concentration of 39 mg/L as N. The measured sulfate concentrations in wells on the western side of the Pueblo typically range from about 25 mg/L to 80 mg/L.

Though none of these levels exceed the drinking water standards shown in Table 4-1, they are considerably higher than the sulfate concentrations measured in most other wells in the Los Alamos area.

Uranium in the groundwater of this area is naturally occurring, and is observed at concentrations approaching and exceeding EPA's MCL for this constituent of 0.02 mg/L. Fluoride values in at least three of the Pueblo-owned wells west of the river tend to either approach or exceed the New Mexico drinking water standard for this constituent of 1.6 mg/L (LANL, 1999). One of the wells in this vicinity, Pajarito 1, had A TDS levels measured in 1998 that was greater than 900 mg/L.

6.3.4 Santa Fe River Sub-basin

Nitrate levels in groundwater downstream from the Santa Fe WWTP have been a subject of study since the plant began discharging treated effluent to the Santa Fe River. A study by Longmire (1985) indicated that groundwater below and adjacent to the river for several miles downstream of the plant's outfall does have elevated concentrations of nitrate. The largest nitrate concentrations measured in groundwater during his study (late 1984 – early 1985) approached values of 4 to 6 mg/L as N. These levels were significantly higher than background nitrate concentrations, which were typically less than 0.6 mg/L as N. The area impacted most was located just south of the treatment facility and north of La Cienega. Elevated levels of sulfate and choride were also found in groundwater in this area.

The apparent cause of the elevated nitrate levels was infiltration from the river to ambient, shallow groundwater, which, in the major impacted area, occurs within the Ancha Formation. Because the river apparently has been and continues to be primarily a losing watercourse downstream of the WWTP, the potential exists for elevated nitrate levels in groundwater for several miles downstream from the plant. However, Longmire (1985) pointed out that nitrate levels appeared to decline back to levels closer to those of background within two to three miles south and southwest of the outfall location.

Longmire (1985) reported that some of the nitrate reported in and near the La Cienega area might be attributed to septic tank effluent. He also raised the possibility that decay of nitrate to nitrogen gas via a denitrification process might cause nitrate concentrations to decline to values close to background within just a few miles from the treatment plant.

The City of Santa Fe has two wells - the Santa Fe and Alto wells - that have been affected by organic chemical contamination (City of Santa Fe Public Utilities Department, 1999). The contaminants in these wells are primarily petroleum-based products containing benzene, toluene, and xylene, and solvents like ethylene dibromide. Numerous contaminant plumes in and near the City, primarily from LUSTs, dry cleaners, and activities associated with the Santa Fe Railroad, are considered an ever-present threat to the City's groundwater supply.

Elevated levels of nitrate have also been detected in several of the City's municipal wells. The Torreon well, which is 700 feet deep, has shown nitrate levels ranging from 9 to 11 mg/L

as N. The Alto well, at 200 feet deep, has exhibited nitrate levels as high as 9 mg/L as N, and the Hickox Well, at 880 feet deep, showed nitrate levels as high as 9 mg/l as N. The sources of the nitrate in these wells are not fully known, but may include leaking septic or sewer systems, leachate from landfills, fertilizer runoff, or previous land use for dairies and chicken farms.

The City's Torreon well has also experienced elevated levels of barium. This well was deepened in 1997 and, since then, barium concentrations now fall within standards.

6.3.5 Caja del Rio Sub-basin

Groundwater in the Buckman Well Field has naturally occurring radiogical contaminants (City of Santa Fe Public Utilities Department, 1999). Gross alpha emissions from Buckman wells groundwater typically fall in the range of 10 to 20 picocuries per liter (pCi/L). The EPA MCL for gross alpha emissions from drinking water is 15 pCi/L.

6.4 NMED Discharge Plan Sites

Several sites exist within the study region for which permits have been issued by the NMED to discharge some form of effluent. Most of these NMED DP sites comprise a surface water storage body, such as a lagoon or evaporation basin. Because such stored water can infiltrate and eventually reach groundwater, the permitted sites represent potential sources of groundwater contamination. A list of the NMED DP sites in the study region is presented in Table 6-2, and their locations are shown in Figure 6-18.

6.5 Known Groundwater Contamination Sites

A list of known groundwater contamination sites within the planning region was included in the Tier 2 database. Of the 118 sites included in this list, 21 came with information indicating their locations. Table 6-3 lists all 118 sites and indicates the nature of the contamination at each, including whether the contamination is identified as stemming from point or non-point sources. As indicated, the types of contaminants that are observed range from gasoline components to chlorinated solvents, pesticides and radionuclides. A variety of contaminant source types are associated with the contaminants, including leaking underground storage tanks, laboratories at Los Alamos National Laboratory, dry cleaning facilities, sewage treatment plants, and railroad and mining operations. The Tier 2 database did not include concentrations of contaminants associated with each of the sites.

Figure 6-19 shows the contamination sites, as identified by site number, for which location information was available. As this figure indicates, most of the sites occur near urbanized areas, such as the City of Santa Fe, Española, and the Pueblo of Pojoaque.

Table 6-2. NMED Discharge Plan Sites.

Site Number	Facility	Owner	Township	Range	Section	Location	Closest Town	Discharge (gpd)	Waste Type/Source
1	LOS ALAMOS(BAYO)WWTP	LOS ALAMOS COUNTY	19N	6E	4	1 MILE NE OF LOS ALAMOS	LOS ALAMOS	1370000	DOMESTIC
2	SANTA FE WWTP-SLUDGE	CITY OF SANTA FE	16N	8E	10	AIRPORT RD.-SANTA FE	SANTA FE	55000	DOMESTIC/MUNICIPALITY
3	SANTA FE CAJA DEL RIO SWF	CITY OF SANTA FE	17N	8E	21	4 MILES WEST OF SANTA FE.	SANTA FE	500000	OTHER
4	SANTA FE COMM. COLL.	CITY OF SANTA FE	16N	9E	21	SANTA FE	SANTA FE	30000	DOMESTIC/INSTITUTIONAL
5	SANTA FE TRANSFER STATION	CITY OF SANTA FE	17N	09E	15	2 MILES WEST OF SANTA FE	SANTA FE	4125	OTHER
6	ARROYO HONDO UST CASE	HORN DISTRIBUTING CO	16N	10E	7	ARROYO HONDO OFF OLD LASVEGA	SANTA FE	30000	INDUSTRIAL
7	CUNNINGHAM HILL MINE RECLAMA	LAC MINERALS (USA) INC.	13N	8E	17	SEVEN MILES SO. OF CERRILLOS	CERRILLOS	10	MINING/OPEN PIT
8	SANTA FE SKI BASIN	SANTA FE SKI COMPANY	18N	11E	8	NORTH OF SANTA FE	SANTA FE	30000	DOMESTIC/OTHER
9	SOMBRILLO ELEMENTARY SCHOOL	ESPAÑOLA PUBLIC SCHOOLS	20N	8E	12	S. OF ESPAÑOLA	ESPAÑOLA	10900	DOMESTIC/INSTITUTIONAL
10	RANCHEROS DE SANTA FE	RANCHEROS DE SANTA FE	15N	10E	10	10.5 MI SE S.FE,LAMY TURNOFF	SANTA FE	6800	DOMESTIC/CAMPGRD-RV PARK
11	EL DORADO SCHOOL	EL DORADO SCHOOL	15N	10E	8	EL DORADO SUBDIVISON	SANTA FE	10000	DOMESTIC/INSTITUTIONAL
12	SANTA FE POLO GROUNDS	SANTA FE POLO GROUNDS	16N	8E	17	10 MILES SW OF SANTA FE	SANTA FE	100000	DOMESTIC/MUNICIPALITY
13	SWEENY SCHOOL	SANTA FE PUBLIC SCHOOLS	16N	8E	12	AIRPORT RD. SANTA FE	SANTA FE	7000	DOMESTIC/INSTITUTIONAL
14	VALLE VISTA SUBDIVISION	VALLE VISTA SUBDIVISION	16N	8E	36	1.5 MI. N. OF STATE PEN.	SANTA FE	64400	DOMESTIC/OTHER
15	PUEBLO ENCANTADO	PUEBLO ENCANTADO	18N	10E	7	10 MILES N OF SANTA FE,SR 22	SANTA FE	12000	DOMESTIC/UNINC. AREA
16	RIVERSIDE MHP	RIVERSIDE MHP	18N	9E	25	TESUQUE	SANTA FE	2750	DOMESTIC/OTHER
17	ESPAÑOLA EASTSIDE WWTP	ESPAÑOLA EASTSIDE WWTP	20N	8E	10	ESPAÑOLA	ESPAÑOLA	16000	SLUDGE
18	NM STATE PENITENTIARY	NM STATE PENITENTIARY	16N	8E	35	10 MI. SW OF SANTA FE-RT.14	SANTA FE	200000	DOMESTIC/INSTITUTIONAL
19	FRANKLIN INDUSTRIAL MINERALS	FRANKLIN INDUSTRIAL MINERALS	22N	9E	16	S. OF VELARDE ON HWY. 68	VELARDE	864000	MINING/MILLING
20	LAC-CARACHE CANYON DECLINE	LAC-CARACHE CANYON DECLINE	13N	7E	35	APPROX. 4 MILES NE OF GOLDEN	GOLDEN	144000	MINING/UNDERGROUND
21	CLUB AT EL GANCHO	EL GANCHO CASITAS	16N	10E	7	SOUTH OF SANTA FE	SANTA FE	13500	DOMESTIC/LODGING
22	SHADY COMFORT CAMPGROUND	SHADY COMFORT CAMPGROUND	19N	9E	28	10 MILES NORTH OF SANTA FE	SANTA FE	2200	DOMESTIC/CAMPGRD-RV PARK

Site Number	Facility	Owner	Township	Range	Section	Location	Closest Town	Discharge (gpd)	Waste Type/Source
23	A-1 CESSPOOL	A-1 CESSPOOL	21N	8E	9	CHAMITA	SAN JUAN PUEBLO	1000	DOMESTIC/INSTITUTIONAL
24	JACONA CAMPUS	POJOAQUE VALLEY SCHOOLS	19N	8E	14	2 MI W. OF US285 & SR4	ESPAÑOLA	3700	DOMESTIC
25	BAYO WWTP SLUDGE MONOFILL	LOS ALAMOS CO, SLUDGE MONFIL	19N	7E	18	AT BAYO WWTP	LOS ALAMOS	1	DOMESTIC
26	SOL Y SOMBRA TRAILER PARK	SOL Y SOMBRA TRAILER PARK	18N	9E	25	TESUQUE	TESUQUE	2900	DOMESTIC/UNINC. AREA
27	ESPAÑOLA WEST SIDE-SLUDGE	ESPAÑOLA WEST SIDE-SLUDGE	20N	8E	3	ESPAÑOLA	ESPAÑOLA	4000	DOMESTIC/MUNICIPALITY
28	EXXON UST ESPAÑOLA	EXXON UST ESPAÑOLA	20N	8E	2	SANTO NINO	ESPAÑOLA	7200	INDUSTRIAL
29	BIENVENIDOS RESORT	BONIFACIO VASQUEZ	21N	8	8	HERNANDEZ, NM	HERNANDEZ	7530	DOMESTIC/UNINC. AREA
30	NM HIGHWAY DEPT-PCB LAGOON	NM HIGHWAY DEPT-PCB LAGOON	16N	8E	35	SANTA FE PRISON WWTP	SANTA FE		
31	VILLA MARIKA RESORT HOTEL	VILLA MARIKA RESORT HOTEL	15N	8E	34	SOUTH OF STATE ROAD 22	SANTA FE	25000	DOMESTIC/LODGING
32	PNM SANTA FE SER. CEN.	PNM SANTA FE SERVICE CENTER	16N	8E	24	STATE HWY 14 AT I-25	SANTA FE	1000	INDUSTRIAL/SERVICE STATION
33	WESTGATE SUBDIVISION	WESTGATE SUBDIVISION	19N	5E	35		LOS ALAMOS	16000	DOMESTIC/UNINC. AREA
34	SUNRISE SPRINGS RESORT	SUNRISE SPRINGS RESORT	16N	8E	28	SOUTH OF SANTA FE, NORTH OF LA CIENEGUILLA	SANTA FE	12000	DOMESTIC/LODGING
35	WILLIAMS,T.C. LAGOONS	WILLIAMS,TC SEWAGE LAGOONS	16N	8E	9	SE OF SANTA FE	SANTA FE	1500000	DOMESTIC
36	BOYLAN MOBILE HOME PARK	BOYLAN MOBILE HOME PARK	17N	9E	33	AQUA FRIA, NEAR S.FE RIVER	SANTA FE	7500	DOMESTIC/UNINC. AREA
37	SANTA FE METRO CENTER	SANTA FE METRO CENTER	16N	8E	26	SANTA FE	SANTA FE	30000	DOMESTIC/INSTITUTIONAL
38	PILOT SEPTAGE TREAT. FAC.	PILOT SEPTAGE TREATMENT FAC	16N	9E	14	5 MILES SOUTH OF SANTA FE	SANTA FE	500	DOMESTIC
39	TESUQUE ELEMENTARY SCHOOL	TESUQUE ELEMENTARY SCHOOL	18N	9E	25	IN TESUQUE	TESUQUE	2948	DOMESTIC/INSTITUTIONAL
40	LANL WWTP TA-46	LANL WWTP TA-46	19N	6E	26	3.5 MILES SE OF LOS ALAMOS	LOS ALAMOS	600000	DOMESTIC/INSTITUTIONAL
41	OLD RD RANCH COUNTRY COMP	OLD RD RANCH COUNTRY COMP	15N	10E	21	12 MILES SOUTHEAST OF SANTA FE (ELDORADO AREA)	SANTA FE	4500	DOMESTIC/UNINC. AREA
42	WILD & WOOLEY MHP	WILD AND WOOLLEY TRAILER RAN	16N	8E	27	12 MILES SW OF SANTA FE	SANTA FE	2500	DOMESTIC/OTHER
43	WHITE ROCK WWTP	WHITE ROCK WWTP	19N	7E	34	WHITE ROCK	WHITE ROCK	500000	DOMESTIC/MUNICIPALITY
44	SANTA MARIA DE LA PAZ	SANTA MARIA DE LA PAZ CHURCH	16N	9E	20	5 MILES SW OF SANTA FE	SANTA FE	4000	DOMESTIC/OTHER

Site Number	Facility	Owner	Township	Range	Section	Location	Closest Town	Discharge (gpd)	Waste Type/Source
45	HIGGINSON COMMERCIAL PROP	HIGGINSON COMMERCIAL PROP	19N	9E	20	CUYAMUNGUE	SANTA FE	2010	DOMESTIC/REST.-BAR
46	LAS CAMPANAS DE SANTA FE	LAS CAMPANAS DE SANTA FE	17N	8E	10	6 MILES NW OF SANTA FE	SANTA FE	76000	DOMESTIC/OTHER
47	POJOAQUE SEPTAGE FACILITIES	SANTA FE COUNTY	19N	9E	18	SANTA FE COUNTY LANDFILL	JACONA	18000	DOMESTIC/SEPTAGE
48	SANTA FE OPERA	SANTA FE OPERA, INC.	18N	9E	26	UV-TREATED WETLANDS EFFLUENT APPLIED TO OPERA LANDSCAPING	TESUQUE	10000	DOMESTIC/OTHER
49	TANO SANTA FE	TANO SANTA FE PARTNERS & CITY OF SANTA FE	18N	9E	36	SANTA FE	SANTA FE	106000	DOMESTIC/SANITATION DISTRICT
50	CIELO LINDO MHP	TOM CORDOVA	19N	8E	12	1 MILE WEST OF POJOAQUE	POJOAQUE	6000	DOMESTIC/UNINC. AREA
51	EL RANCHO TRAILER PARK	RUDOLPHO VIGIL	19N	8E	10	3.5 MILES WEST OF POJOAQUE	POJOAQUE	6000	DOMESTIC/OTHER
52	AGORA SHOPPING CENTER	DOS GRIEGOS CORPORATION	14N	10E		EL DORADO SUBDIVISION	SANTA FE	3763	DOMESTIC/SEPTAGE
53	HENRY'S CHEVRON	HENRY CORDOVA	20N	8E	35	CORNER OF FAIRVIEW LN. AND RIVERSIDE DR.	ESPAÑOLA	7500	INDUSTRIAL/UST
54	TEN THOUSAND WAVES	TEN THOUSAND WAVES	17N	10E	9	15 MILES NE OF SANTA FE	SANTA FE	2000	DOMESTIC/OTHER
55	SANTA FE WWTP-EFFLUENT	CITY OF SANTA FE%	16N	8E	10		SANTA FE	8000000	DOMESTIC
56	BROWNCASTLE RANCH CAMPGROUND	JOHN BROWN	16N	8E	25	T16N, R8E, AT THE CENTER OF SECTION 25	SANTA FE	5220	DOMESTIC
57	DELANCY STREET	DELANCEY STREET FOUNDATION	21N	8E	2	NORTH OF SAN JUAN PUEBLO	SAN JUAN PUEBLO	12000	DOMESTIC/INSTITUTIONAL
58	HARRY'S ROADHOUSE	HARRY SHAPIRO	16N	10E	7	1 MILE SE OF SANTA FE	SANTA FE	3000	DOMESTIC/REST.-BAR
59	THE PONDS SUBDIVISION	CHARLES W ROBINSON, MANAGING PARTNER	15N	8E	5	11 MI. SW OF SANTA FE BETWEEN I-25 & LA CIENEGA	SANTA FE	39750	DOMESTIC/UNINC. AREA
60	WOLF CANYON BREWING COMPANY	CHARLES L NASHAN	16N	8E	24	SOUTH OF SANTA FE ON HIGHWAY-14	SANTA FE	6000	DOMESTIC/REST.-BAR
61	PINION HILLS	PINION HILLS RESIDENTIAL TREATMENT CENTER, INC.	22N	9E	17	2 MILES SW OF VELARDE,NM	VELARDE	7000	DOMESTIC/INSTITUTIONAL
62	SANGRE DE CRISTO CENTER	CHRISTIAN BROTHERS MAJOR SUPERIORS	18N	10E	8	4 MILES NE OF TESUQUE	TESUQUE	3000	DOMESTIC/INSTITUTIONAL
63	LANL TA-50 WASTE TREATMENT F	DENNIS ERICKSON				MORTANDAD CANYON	LOS ALAMOS	41770	INDUSTRIAL/OTHER
64	NM HIGHWAY DEPT LA BAJADA	NMSHTD DISTRICT 5	15N	7E	13	RESTSTOP LOCATED +/- 15 MI SOUTHWEST OF SANTA FE ON I-25	SANTA FE	4100	DOMESTIC/SEPTAGE
65	S.F. MOBILE HOME HACIENDA	PRENTISE PROPERTIES	16N	9E	18	1.5 M.'S OF CERRILLOS & AIRPORT RD WEST OFF CERRILLOS	SANTA FE	42000	DOMESTIC/UNINC. AREA

Site Number	Facility	Owner	Township	Range	Section	Location	Closest Town	Discharge (gpd)	Waste Type/Source
66	LAMY TOWN CENTER WASTEWATER	SARR, ROBERT	15N	10E	33	1.5 ACRES ON SF SOUTHERN PROPERTY	LAMY	6000	COMMERCIAL
67	NM ACADEMY FOR SCIENCE AND M	FERNADO MULTEDO	16N	10E	7	SANTA FE	SANTA FE	3750	DOMESTIC/INSTITUTIONAL
68	RANCHO VIEJO	ROBERT TAUNTON	16N	9E	20		SANTA FE	160000	DOMESTIC/UNINC. AREA
69	TURQUOISE TRAIL BUSINESS PAR	ROBERT TAUNTON	16N	8E	24	9 MILES SW OF SANTA FE	SANTA FE	12500	DOMESTIC/SEPTAGE
70	EDGEWOOD CENTER	SHERIDAN FUSS	10N	7E	22		EDGEWOOD	9900	COMMERCIAL
71	DOWNS AT SANTA FE	PTE, INC.	16N	8E	27	4 MI. SO. OF SANTA FE	SANTA FE	1250000	DOMESTIC/OTHER
72	RANCHO ENCANTADO	ENCANTADO LTD. CO.	18N	10E	7	2.5 MILES NORTH OF TESUQUE	SANTA FE	50000	DOMESTIC/UNINC. AREA
73	SANTA FE CHRISTIAN ACADEMY	RON SEBESTA	16N	9E	9	1.5 MILES SW OF SANTA FE	SANTA FE	4627	OTHER
74	LOS LUCEROS SUBDIVISION	WINSTAR, INC				LOS LUCEROS	LOS LUCEROS	6250	DOMESTIC/UNINC. AREA
75	BISHOP'S LODGE	C/O LEND LEASE REAL ESTATE INVESTMENTS, INC.	17N	10E	5	THREE MILES SE OF TESUQUE	TESUQUE	50000	DOMESTIC
76	SANTA FE GENERATING STATION	PNM	17N	9E	26	SANTA FE GENERATING STATION	SANTA FE	28800	OTHER
77	LAKESIDE MHP	DAVID FIELD	15N	8E	6	LA CIENEGA	LA CIENEGA	9000	DOMESTIC WASTE

Note:
gpd = gallons per day

As a result of the contamination of the Santa Fe Well mentioned earlier, and the City of Santa Fe's plans to develop Santa Fe Railyard and Baca Street Sites, numerous groundwater-related investigations have been completed in this area. The Santa Fe Railyard Site is located in the vicinity of St. Francis Drive and Cerrillos Road in the City of Santa Fe. The Baca Street Site is located in the vicinity of Baca Street and Cerrillos Road in the City of Santa Fe. DE&S completed three reports for the City of Santa Fe and the NMED which summarize the location of groundwater contamination and the results of an aquifer test involving the new Hickox Well (DE&S, 1999a; DE&S, 1999b; DE&S, 2000). The conclusions of these reports are as follows:

- Due to its extended industrial history, there are numerous potential sources of groundwater impacts associated with the Santa Fe Railyard Site. The City of Santa Fe is currently completing a soil sampling program to evaluate these potential sources.
- There are confirmed sources of petroleum (from LUSTs and bulk fuel storage) and solvent contamination (from bulk fuel storage and/or dry cleaning facilities) both on- and off-site. The City of Santa Fe and the NMED are currently overseeing the ongoing investigations of these groundwater issues.
- Due to the presence of low permeable layers separating the shallow and deep aquifers in this area, the new Hickox well is not currently threatened by shallow groundwater contamination.
- Due to the extended industrial history of the Baca Street Site, there are numerous potential sources of groundwater impacts also associated with this site. The City of Santa Fe is currently completing a soil sampling program to evaluate these potential sources.
- Groundwater contamination by hydrocarbon and chlorinated solvents also exists beneath the Baca Street Site. The Public Service Company of New Mexico (PNM) is currently operating a remediation system which involves using the Santa Fe Well as a recovery well. It is unclear at this time whether this approach will restore the aquifer to drinking water conditions in this area.

6.6 Issues Regarding Proposed Drinking Water Standards

Two inorganic constituents that occur naturally in groundwater will likely be of concern to the JySWP Council because of drinking water standards that have been proposed for them by the EPA. One of these constituents is arsenic, which currently is subject to a MCL of 0.05 mg/L. The EPA has proposed that the MCL for arsenic be reduced to 0.005 mg/L, a level that is commonly exceeded in regional groundwater under natural conditions. The second is uranium, for which the New Mexico drinking water standard is 5 mg/L. The EPA does not currently have a mass concentration standard for uranium in groundwater, but has proposed that a MCL of 0.02 mg/L be established for this constituent.

Most groundwater within the study region meets the current arsenic MCL of 0.05 mg/L. All of the NMDWB analyses for community water supply systems in the study region, as taken from the Tier 1 database, show arsenic occurring at concentrations less than this value. However, out of 290 NMDWB samples included in the database, 133 have arsenic levels that

are equal to or exceed the proposed MCL of 0.005 mg/L. Thus it appears that some community systems may have to provide treatment for arsenic if the proposed standard becomes final.

The potential effect of the proposed arsenic MCL can also be examined using data monitoring wells included in the USGS NWIS database. Out of 2929 samples for the study area that are included in the Tier 1 database, only 44 show arsenic levels that are greater than or equal to the current MCL of 0.05 mg/L. If a MCL of 0.005 mg/L was established, 1880 of the 2929 samples would equal or exceed this arsenic level.

The previously mentioned high levels of naturally occurring radiological constituents in the Buckman Well Field may lead to exceedances of the proposed uranium MCL of 0.02 mg/L. NMDWB samples included in the Tier 1 database show that uranium concentrations in the Buckman field currently range from 0.005 to 0.018 mg/L.

Table 6-3. Known Groundwater Contamination Sites in the Study Region.

Site Number	Site Name	County	City	Contaminants	Source Type	Point (P) or Non-Point (NP)	Town-ship	Range	Section	Latitude (ddmmss)			Longitude (ddmmss)		
1	LANL ACID CANYON	Los Alamos	LOS ALAMOS	Radionuclides; Nitrate	PLANT LAB	P									
2	LANL ANCHO CANYON	Los Alamos	LOS ALAMOS	Radionuclides	PLANT LAB	P									
3	LANL LOS ALAMOS CANYON	Los Alamos	LOS ALAMOS	Radionuclides; Nitrate	PLANT LAB	P									
4	LANL MORTENDAD CANYON	Los Alamos	LOS ALAMOS	Radionuclides; Nitrate; TDS	PLANT LAB	P									
5	LANL POTRILLO CANYON	Los Alamos	LOS ALAMOS	Radionuclides	PLANT LAB	P									
6	LANL PUEBLO CANYON	Los Alamos	LOS ALAMOS	Radionuclides; Nitrate	PLANT LAB	P									
7	LANL SR-90	Los Alamos	LOS ALAMOS	Radionuclides	PLANT LAB	P									
8	LANL TA-16	Los Alamos		RDX BA											
9	ALCALDE MDWCA	Rio Arriba		Nitrate	NP ST	NP									
10	BOND WELL	Rio Arriba	ESPAÑOLA	Chlorinated Solvents	PLANT DRY CLEANING	P	20N	08E	03.341	35	59	26	106	5	2
11	CAMINO SIN NOMBRE	Rio Arriba	ESPAÑOLA	Nitrate	NP ST	NP									
12	CHAMITA WF	Rio Arriba	CHAMITA	Nitrate	NP ST	NP									
13	CIRCLE K ESP	Rio Arriba	ESPAÑOLA	Leaded Gasoline	LUST	P									
14	DELANCY ST/NEW MEX INC	Rio Arriba	SAN JUAN PUEBLO	Nitrate	STP	P	21N	08E	02	36	5	12	106	3	14
15	EL LLANO	Rio Arriba		Nitrate	NP ST	NP									
16	FAIRVIEW	Rio Arriba	ESPAÑOLA	Nitrate	NP ST	NP									
17	GREYHOUND BUS	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
18	HERNANDEZ-GUACHE WF	Rio Arriba	HERNANDEZ	Nitrate; TDS	NP ST	NP									
19	JEMEZ WELL	Rio Arriba	ESPAÑOLA	Chlorinated Solvents	PLANT DRY CLEANING	P	20N	08E	03.312	35	59	34	106	5	6

Site Number	Site Name	County	City	Contaminants	Source Type	Point (P) or Non-Point (NP)	Town-ship	Range	Section	Latitude (ddmmss)			Longitude (ddmmss)		
20	LOWER SAN PEDRO	Rio Arriba	ESPAÑOLA	Gasoline	PLANT	P									
21	LOWER SAN PEDRO	Rio Arriba	ESPAÑOLA	Unleaded Gasoline	LUST	P									
22	PETACA MDWCA	Rio Arriba		Nitrate	NP	NP									
23	RANCHITOS	Rio Arriba		Nitrate	NP ST	NP									
24	SANTO NINO	Rio Arriba	ESPAÑOLA	ANOX	NP ST	NP									
25	SANTO NINO	Rio Arriba	ESPAÑOLA	ANOX	NP ST	NP									
26	VALLEY ESTATES	Rio Arriba		Nitrate	NP ST	NP									
27	VELARDE ELEM. SCHOOL	Rio Arriba	VELARDE	Nitrate	NP	NP									
28	VELARDE WELL	Rio Arriba	ESPAÑOLA	BTEX	PLANT	P									
29	ALLSUPS #333	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
30	BIG ROCK	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P	20N	08E	02.124						
31	BREWER SHELL	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
32	CIRCLE K #716	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
33	EXXON EL CENTRO	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
34	EXXON HWY 68	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
35	GREYHOUND/MINO'S	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
36	MARTINEZ WELL	Rio Arriba	VELARDE	Gasoline	LUST	P									
37	SAN PEDRO FOOD MART	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
38	THRIFTWAY #183	Rio Arriba	ESPAÑOLA	Gasoline	LUST	P									
39	EMBUDO GAS SPILL	Rio Arriba	EMBUDO		SPILL	P									

Site Number	Site Name	County	City	Contaminants	Source Type	Point (P) or Non-Point (NP)	Town-ship	Range	Section	Latitude (ddmmss)			Longitude (ddmmss)		
40	PARKER MINE	Rio Arriba	ESPAÑOLA	Diesel	AGST	P									
41	GIANT STOP N GO	Rio Arriba	ESPAÑOLA	Gasoline	AGST	P									
42	ABOVE AGUA FRIA	Santa Fe	SANTA FE	Nitrate	NP ST	NP									
43	AGUA FRIA	Santa Fe	AGUA FRIA	Nitrate	NP ST	NP									
44	AGUA FRIA AREA 6/17/91	Santa Fe	AGUA FRIA	Nitrate	NP ST	NP									
45	ARROYO HONDO	Santa Fe	ARROYO HONDO	Leaded Gasoline; Manganese; Selenium; Iron	AGST	P	16N	10E	07.3	35	37	25	105	55	43
46	ARROYO HONDO FINA	Santa Fe	ARROYO HONDO	Chlorinated Solvents	PLANT	P				35	37	44	105	55	17
47	BOBCAT BITE	Santa Fe	SANTA FE	Nitrate	STP	P				35	34	58	105	53	49
48	CANONCITO MDWCA ATRAZINE	Santa Fe	CANONCITO	Pesticides	NP PEST	NP									
49	CUYAMUNGE	Santa Fe	CUYAMUNGE	ANOX	NP ST	NP									
50	CUYAMUNGE	Santa Fe	CUYAMUNGE	Hydrocarbons	UNKNOWN	P									
51	EL RANCHO	Santa Fe	EL RANCHO	ANOX	NP ST	NP									
52	EL RANCHO	Santa Fe	EL RANCHO	Nitrate	NP ST	NP									
53	GALISTEO & WATER MANHOLE	Santa Fe	SANTA FE	Gasoline	LUST	P									
54	GIRLS RANCH ATRAZINE	Santa Fe		Pesticides	NP PEST	NP									
55	GLORIETTA MDWCA	Santa Fe	GLORIETTA	Nitrate	NP ST	NP									
56	GLORIETTA MDWCA ATRAZINE	Santa Fe	GLORIETTA	Pesticides	NP PEST	NP									
57	GOLD FIELDS MINING CORP	Santa Fe		Cyanide; Cobalt; Nitrate	MINING MILL GOLD	P	13N	08E	19	35	20	1	106	7	28
58	GOLDEN AREA I	Santa Fe	GOLDEN	Nitrate; TDS;	NP ST	NP									

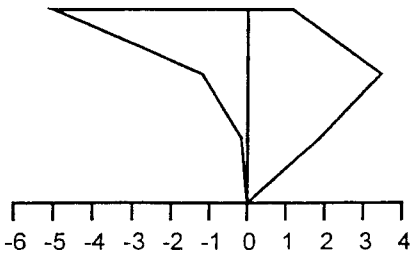
Site Number	Site Name	County	City	Contaminants	Source Type	Point (P) or Non-Point (NP)	Town-ship	Range	Section	Latitude (ddmmss)			Longitude (ddmmss)		
				Sulfate											
59	GOLDEN AREA II	Santa Fe	GOLDEN	Iron; Aluminum; Nitrate; TDS	NP ST	NP									
60	JACONA	Santa Fe	JACONA	ANOX	NP ST	NP									
61	LAMY JUNCTION	Santa Fe	WHITE LAKES	Leaded Gasoline; EDC	LUST	P									
62	LAMY JUNCTION Nitrate	Santa Fe	SANTA FE	Nitrate	NP ST	NP									
63	LAMY MDWCA ATRAZINE	Santa Fe	LAMY	Pesticides	NP PEST	NP									
64	LE FEVRE WELL ATRAZINE	Santa Fe	LAMY	Pesticides	NP PEST	NP									
65	NAMBE AREA	Santa Fe	NAMBE	Nitrate	NP ST	NP									
66	NAMBE WELL	Santa Fe	NAMBE	Radionuclides; Iron; Manganese	UNKNOWN	UNK									
67	NIFTY CAFE	Santa Fe	SANTA FE	Nitrate	STP	P				35	37	37	105	55	13
68	NMHTD POJOAQUE WEIGH STAT	Santa Fe	POJOAQUE	Nitrate	STP	P				35	52	54	106	0	45
69	OPPENHEIMER WELL	Santa Fe	SANTA FE	Nitrate	NP ST	NP									
70	PKG BUILDING	Santa Fe	SANTA FE	Gasoline	LUST	P									
71	PNM SANTA FE STATION	Santa Fe	SANTA FE	Chlorinated Solvents	PLANT PWR	P				35	40	31	105	57	39
72	POJOAQUE	Santa Fe	POJOAQUE	ANOX	NP ST	NP									
73	POJOAQUE WF	Santa Fe	POJOAQUE	ANOX	NP ST	NP									
74	QUARTALES	Santa Fe	QUARTALES	ANOX	NP ST	NP									
75	QUARTALES	Santa Fe	QUARTALES	Nitrate	NP ST	NP									

Site Number	Site Name	County	City	Contaminants	Source Type	Point (P) or Non-Point (NP)	Town-ship	Range	Section	Latitude (ddmmss)			Longitude (ddmmss)		
76	RANCHEROS DE SANTA FE	Santa Fe	SANTA FE	Nitrate	NP ST	NP									
77	RICHARDSON WELL	Santa Fe	SANTA FE	Nitrate	NP ST	NP									
78	RODRIQUEZ WELL	Santa Fe	SANTA FE	Barium	NP ST	NP									
79	RUBIN WELL	Santa Fe	SANTA FE	Chlorinated Solvents; BTEX	PLANT	P				35	40	23	105	55	26
80	SAN PEDRO MINE	Santa Fe	GOLDEN	Cadmium; Iron; Lead; Manganese; Selenium; TDS	MINING GOLD	P				35	14	36	106	11	22
81	SANTA FE STP	Santa Fe	SANTA FE	Nitrate	POTW	P	16N	08E	17	35	36	33	106	6	22
82	SANTANA WELL	Santa Fe	SANTA FE	Zinc	UNKNOWN	UNK	16S	09E	02	32	57	35	105	58	40
83	SANTA FE WELL	Santa Fe	SANTA FE	Leaded Gasoline	PLANT	P	17N	09E	26.133	35	40	35	105	57	47
84	TORREON WELL	Santa Fe	SANTA FE	Nitrate; Barium	NP ST	NP	17N	09E	22.442	35	41	6	105	58	3
85	TESUQUE AREA	Santa Fe	TESUQUE	Nitrate	NP ST	NP									
86	VISTA REDONDA	Santa Fe		Nitrate	NP ST	NP									
87	WOOD WELL	Santa Fe	SANTA FE	Nitrate; TDS	NP ST	NP	17S	09E	23	32	48	52	105	59	40
88	CERRILLOS & GUADALUPE	Santa Fe	SANTA FE	Gasoline	PLANT	P									
89	LAC/PEGUSUS	Santa Fe	CERILLOS	Cyanide; Acid; Metals	MINING TAILING	P	13N	08E	19	35	20	1	106	7	28
90	SANTA FE WEST MHP	Santa Fe	SANTA FE	Nitrate	UNKNOWN	UNK	17N	09E	32.442	35	39	19	106	0	7
91	ALTO WELL (SDC)	Santa Fe	SANTA FE	Ethylene Dibromide	UNKNOWN	P				35	41	8	105	57	41
92	PHILLIPS 66	Santa Fe	SANTA FE	Gasoline	AGST	P									
93	ALTO WELL-SANTA	Santa Fe	SANTA FE	Gasoline	LUST	P									

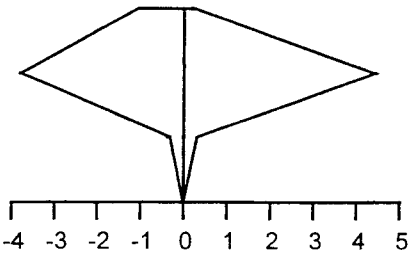
Site Number	Site Name	County	City	Contaminants	Source Type	Point (P) or Non-Point (NP)	Town-ship	Range	Section	Latitude (ddmmss)			Longitude (ddmmss)		
94	AMERICAN PUMICE	Santa Fe	SANTA FE	Gasoline	LUST	P									
95	ARROYO HONDO	Santa Fe	SANTA FE	Gasoline	LUST	P									
96	CAPITOL 66	Santa Fe	SANTA FE	Gasoline	LUST	P									
97	CHEVRON 75729 SFT	Santa Fe	SANTA FE	Gasoline	LUST	P									
98	EXXON W ALAMEDA	Santa Fe	SANTA FE	Gasoline	LUST	P									
99	GIANT STOP N GO #55C	Santa Fe	SANTA FE	Gasoline	LUST	P									
100	GIANT STOP N GO #58	Santa Fe	ESPAÑOLA	Gasoline	LUST	P									
101	GONZALES CHRYSLER	Santa Fe	ESPAÑOLA	Gasoline	LUST	P									
102	KOKOMAN LIQUOR	Santa Fe	POJOAQUE	Gasoline	LUST	P									
103	NEW MEXIGAS	Santa Fe	SANTA FE	Gasoline	LUST	P									
104	NMSHTD CUYAMUNGUE	Santa Fe	CUYAMUNGUE	Gasoline	LUST	P									
105	ROADRUNNER CAFE	Santa Fe	POJOAQUE	Gasoline	LUST	P									
106	SAMS TEXACO	Santa Fe	POJOAQUE	Gasoline	LUST	P									
107	SANTA FE PCE	Santa Fe	SANTA FE	Chlorinated Solvents	PLANT	P									
108	SPEEDY'S	Santa Fe	SANTA FE	Gasoline	LUST	P									
109	THE BUBBLE MACHINE	Santa Fe	SANTA FE	Gasoline	LUST	P									
110	WHITE LAKES STATION	Santa Fe	WHITE LAKES	Gasoline	LUST	P									
111	ORTIZ LANDFILL	Santa Fe	SANTA FE		LANDFILL	P									
112	HERMAN COOTS WELL	Rio Arriba	FAIRVIEW	Nitrate	NP	NP									
113	HENRY'S CHEVRON	Rio Arriba	FAIRVIEW	Gasoline	LUST	P									

Site Number	Site Name	County	City	Contaminants	Source Type	Point (P) or Non-Point (NP)	Town-ship	Range	Section	Latitude (ddmmss)			Longitude (ddmmss)		
114	GLORIETTA MDWCA	Santa Fe	GLORIETTA	Nitrate	NP ST	NP									
115	GLORIETTA MDWCA ATRAZINE	Santa Fe	GLORIETTA	Pesticides	NP PEST	NP									
116	CANONCITO MDWCA ATRAZINE	Santa Fe	CANONCITO	Pesticides	NP PEST	NP									
117	LA BAJADA MINE	Santa Fe	LA BAJADA	Uranium; TDS	MINING URANIUM	P									

Notes:
BTEX = Benzene, Toluene, Ethylbenzene, Xylene
LUST = Leaking Underground Storage Tank
NP = Non-point Source
P = Point Source
PEST = Pesticides
POTW = Publicly Owned Treatment Works
ST = Storage Tank
STP = Sewage Treatment Plant
ddmmss = degrees, minutes, seconds



Tesuque Formation 25
35.59.35 -105.59.15



Tesuque Formation 26
36.00.06 -105.54.11

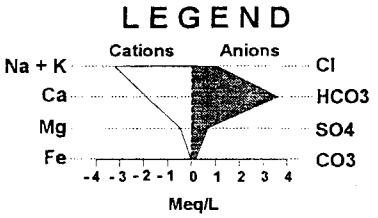
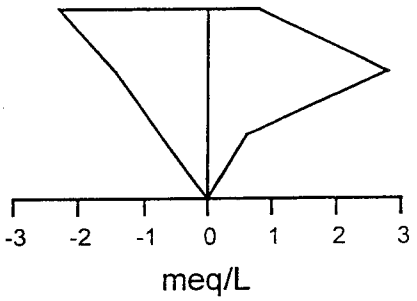
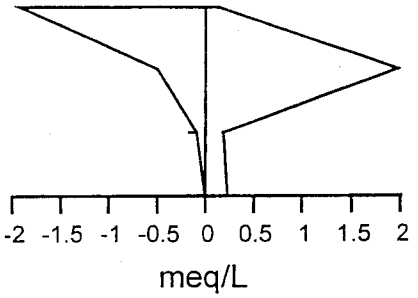


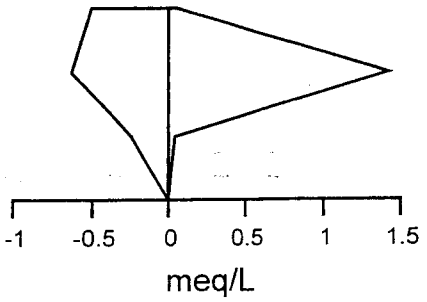
Figure 6-1. Stiff Diagrams for Wells in the Santa Cruz Sub-basin.



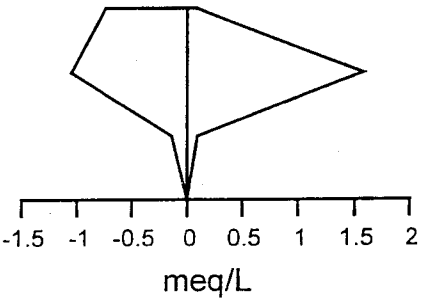
Unknown Formation 12
35.52.14 -106.12.53



Tesuque Formation 23
35.54.07 -106.11.47



White Rock Canyon Springs
Spring 3



White Rock Canyon Springs
Ancha Spring

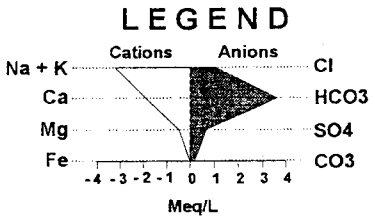
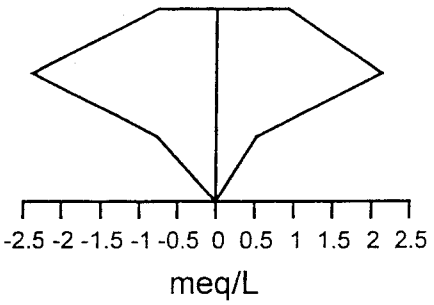
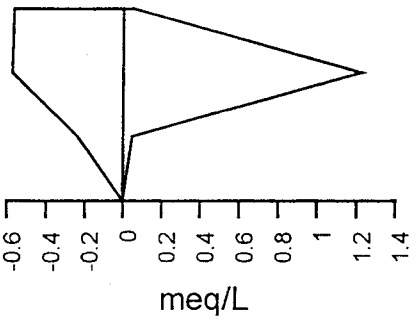


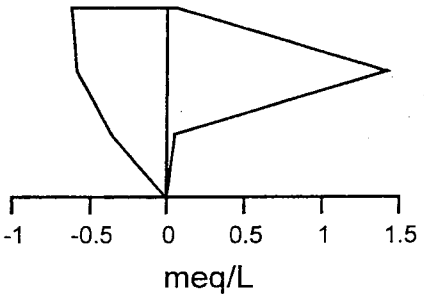
Figure 6-2. Stiff Diagrams for Groundwater Samples from the Los Alamos Sub-basin.



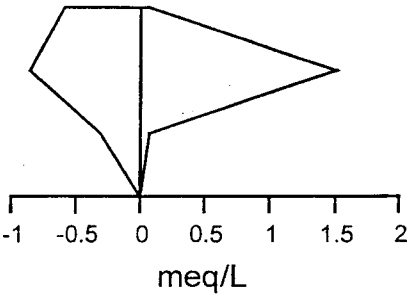
Pajarito Plateau Wells
Test Well #1, White Rock "Y"



Pajarito Plateau Wells
Test Well #2, "Pueblo Canyon



Pajarito Plateau Wells
Pajarito Mesa Well #5



Pajarito Plateau Wells
Guaje Canyon Well #5

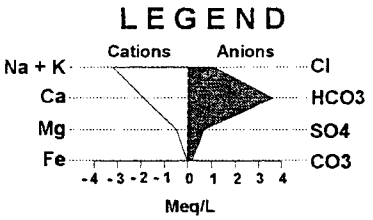
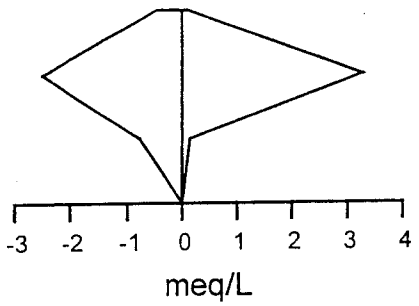
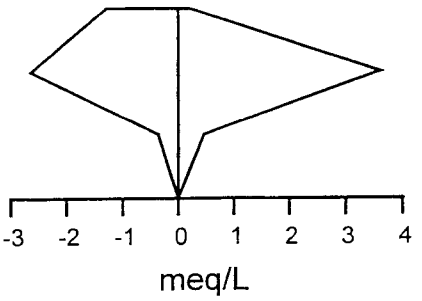


Figure 6-2 (continued). Stiff Diagrams for Groundwater Samples from the Los Alamos Sub-basin.



Tesuque Formation 17
35.49.31 -105.54.05



Alluvial Fill 7
35.54.04 –106.07.00

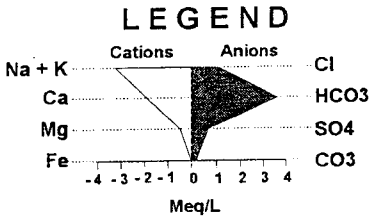
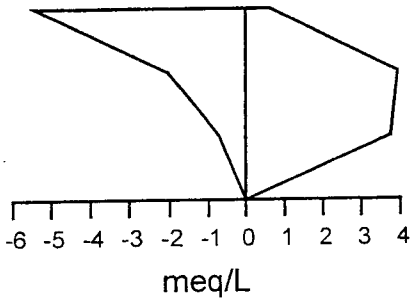
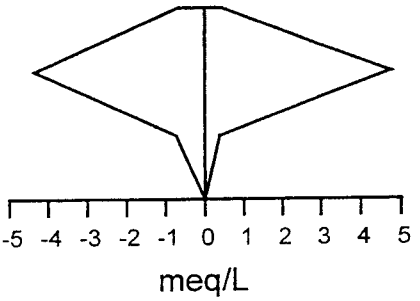


Figure 6-3. Stiff Diagrams for Wells in the Pojoaque-Nambe Sub-basin.



Tesuque Formation 22
35.53.35 -106.01.01



Alluvial Fill 6
35.48.05 -105.58.25

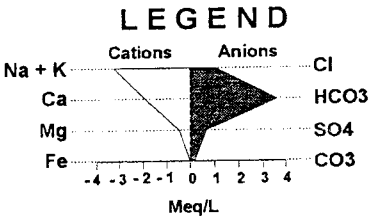
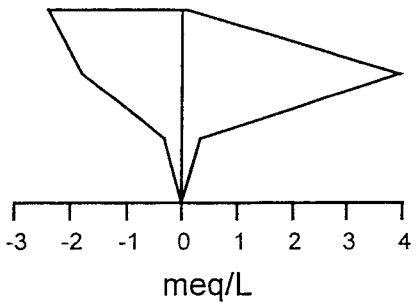
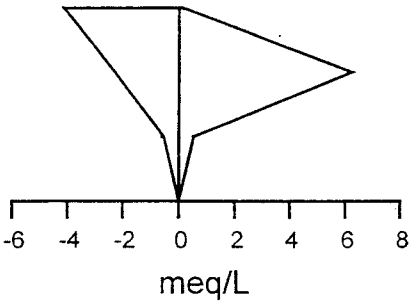


Figure 6-4. Stiff Diagrams for Wells in the Tesuque Sub-basin.



Tesuque Formation 16
35.49.12 -106.08.38



Tesuque Formation 19
35.49.35 -106.08.55

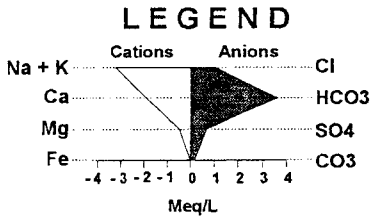
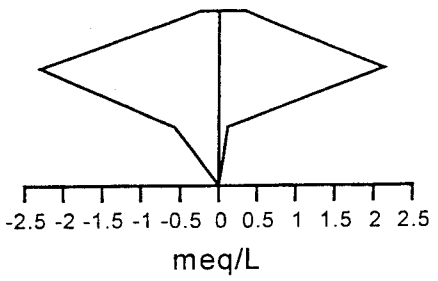
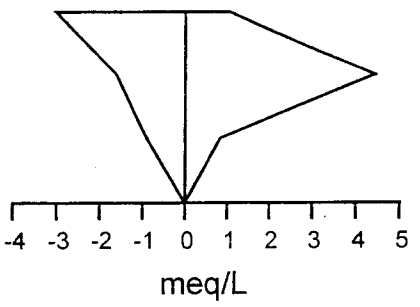


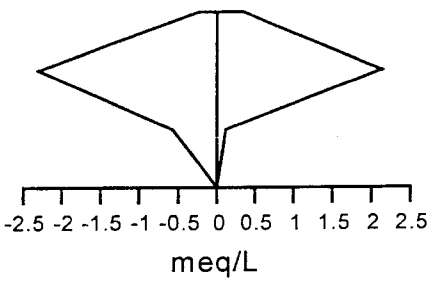
Figure 6-5. Stiff Diagrams for Wells in the Caja del Rio Sub-basin.



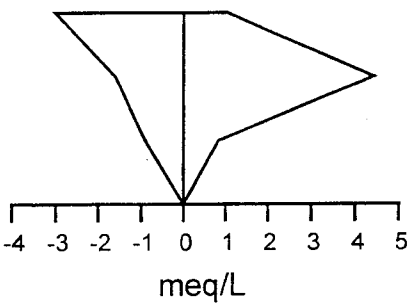
Tesuque Formation 5
35.39.46 -106.10.44



Tesuque Formation 6
35.40.19 -106.02.40



Tesuque Aquifer 8
35.41.05 -105.58.04



Cuerbio Basalt 2
35.34.06 -106.07.11

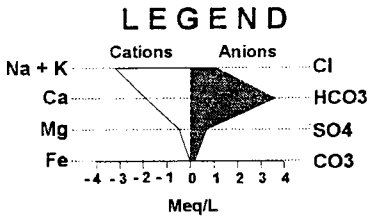
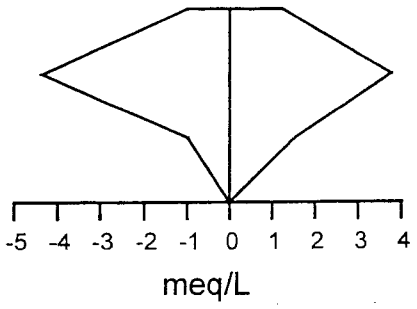
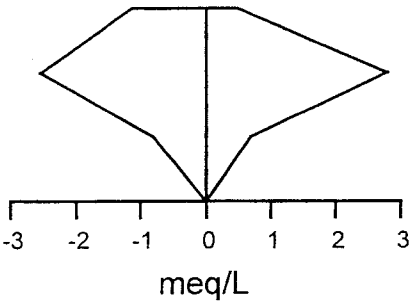


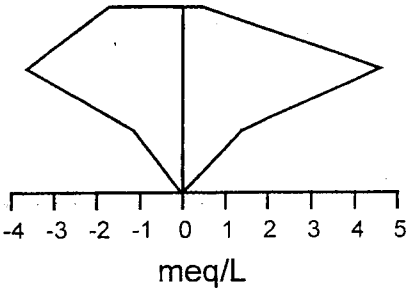
Figure 6-6. Stiff Diagrams for Wells in the Santa Fe River Sub-basin.



Precambrian 2
35.31.04 -105.51.08



Ancha Formation 2
35.28.46 -105.59.30



Alluvial Fill 2
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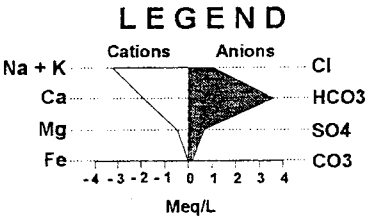
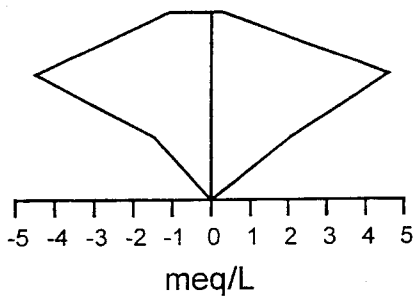
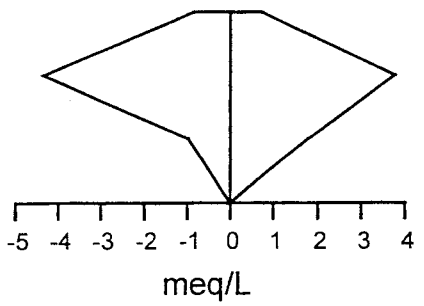


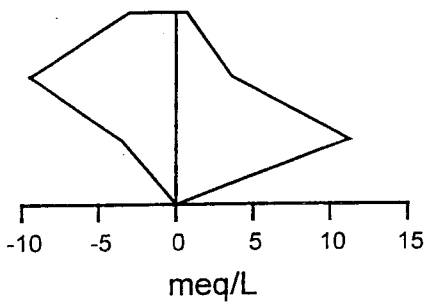
Figure 6-7. Stiff Diagrams for Wells in the North Galisteo Creek Sub-basin.



Alluvial Fill 1
35.23.43 -105.56.44



Alluvial Fill 3
35.28.45 -105.52.45



Unknown Formation 10
35.24.44 -106.05.41

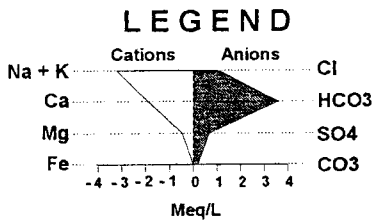


Figure 6-8. Stiff Diagrams for Wells in the South Galisteo Creek Sub-basin.

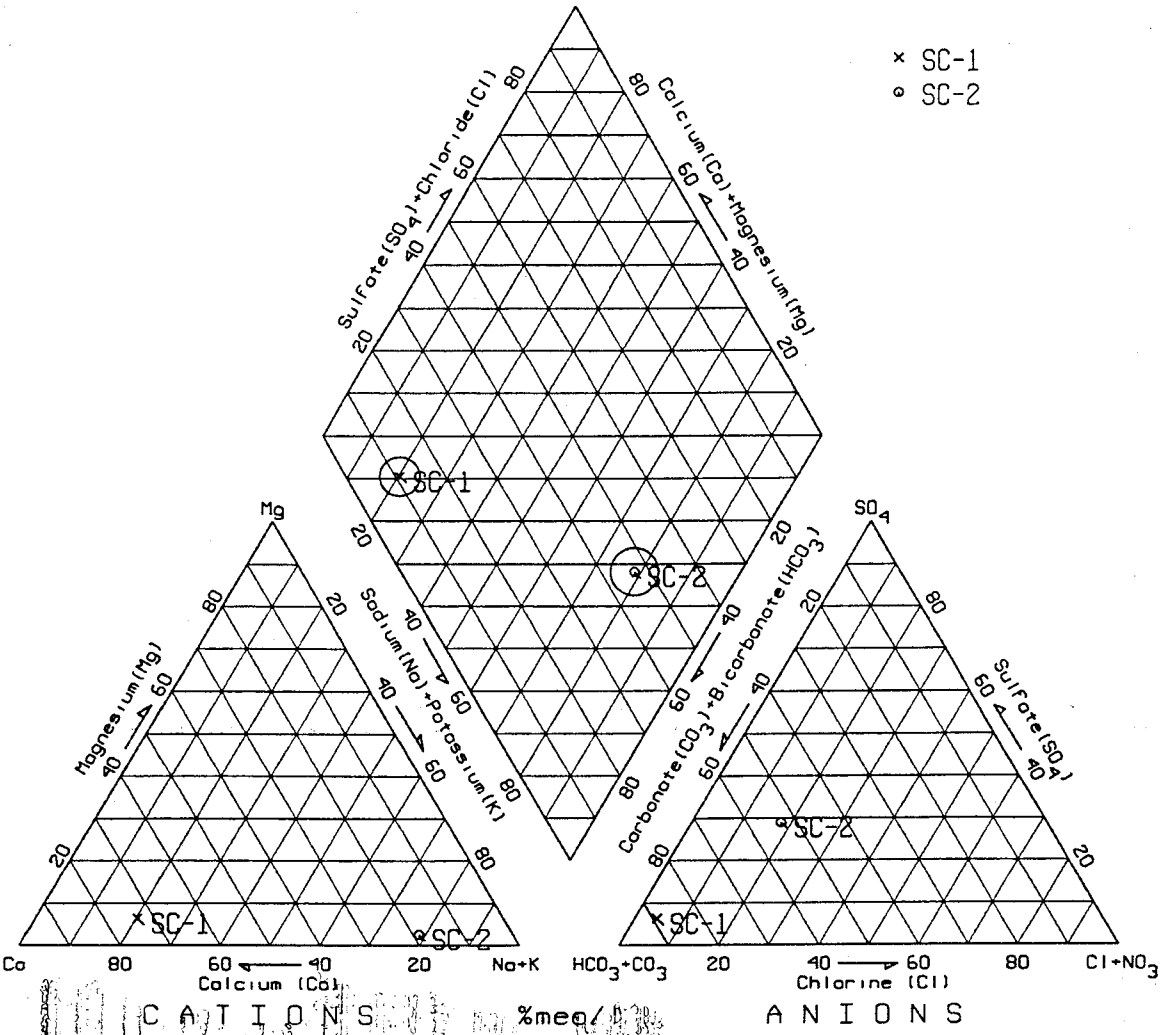


Figure 6-10. Trilinear Diagram for Groundwater Samples From the Santa Cruz Sub-basin

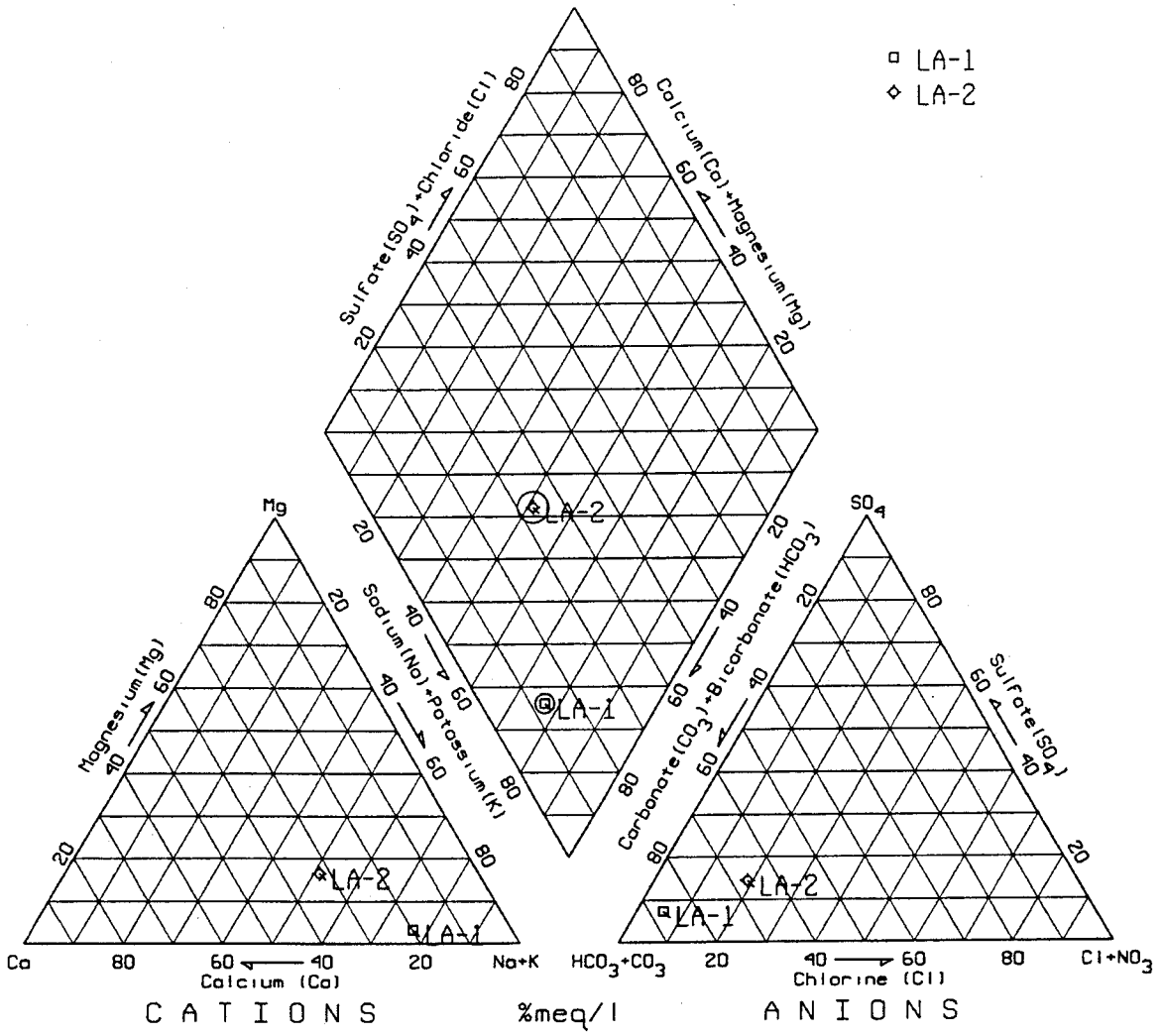


Figure 6-11. Trilinear Diagram for Groundwater Samples From the Los Alamos Sub-basin

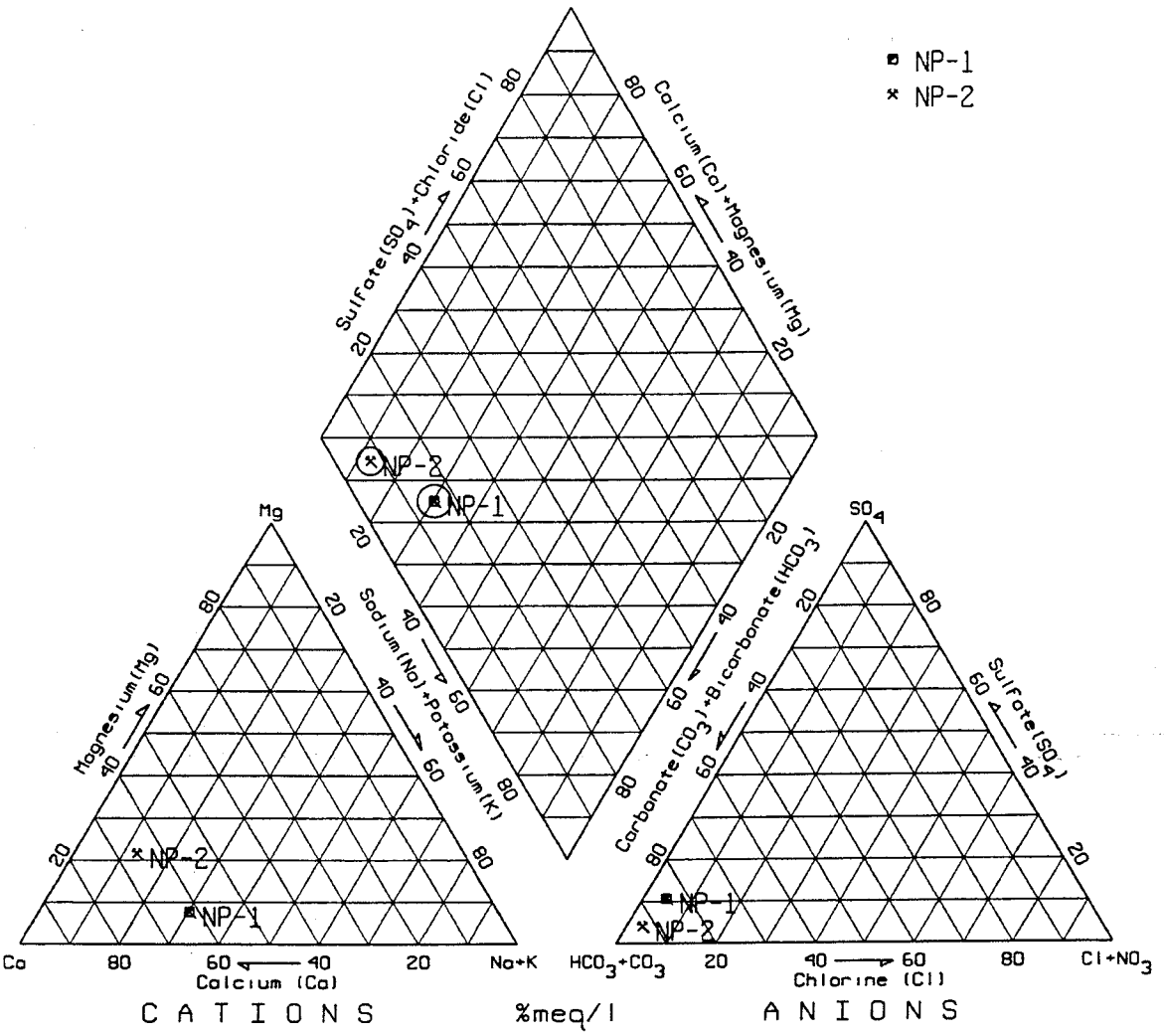


Figure 6-12. Trilinear Diagram for Groundwater Samples From the Pojoaque-Nambe Sub-basin.

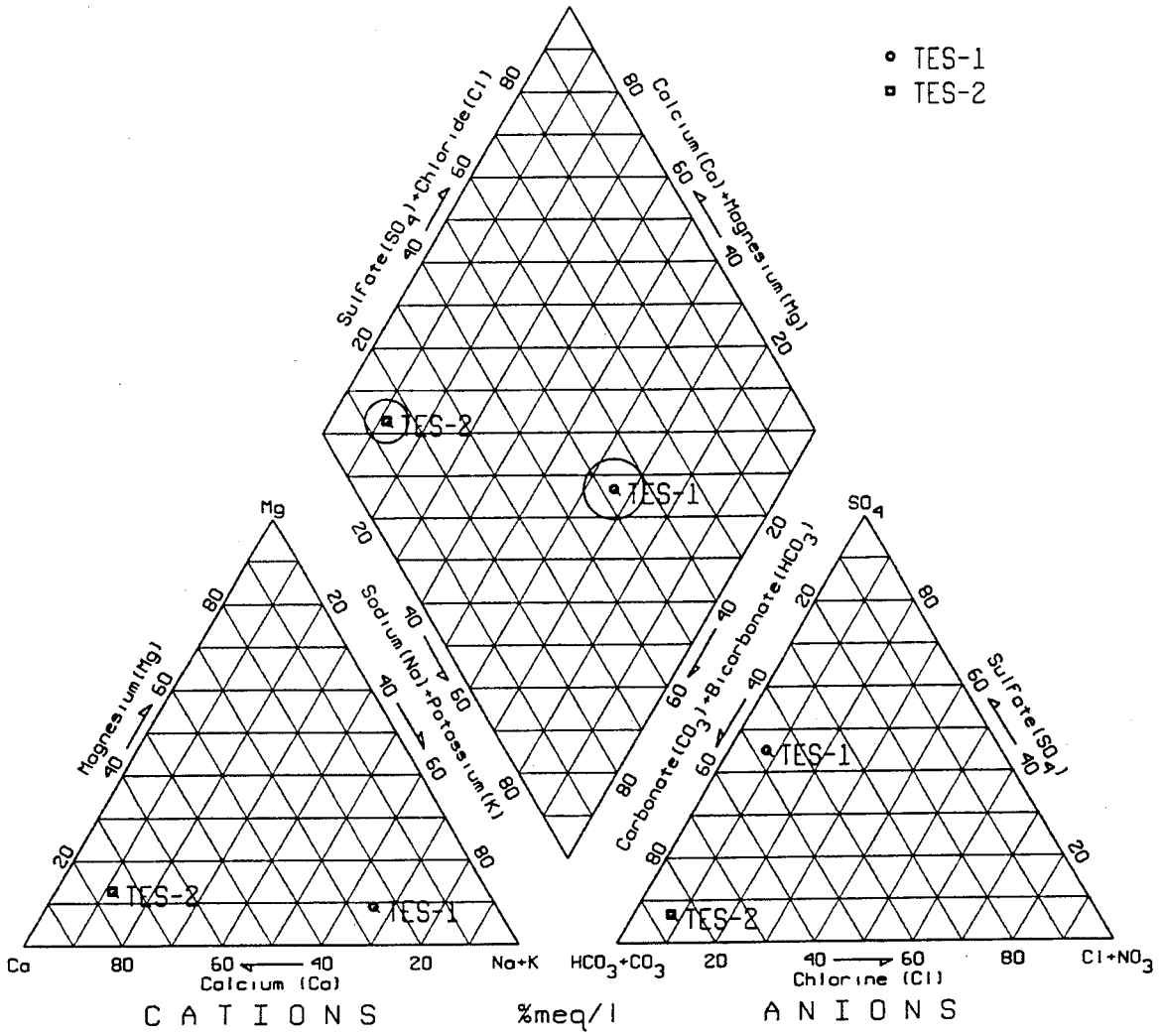


Figure 6-13. Trilinear Diagram for Groundwater Samples From the Tesuque Sub-basin.

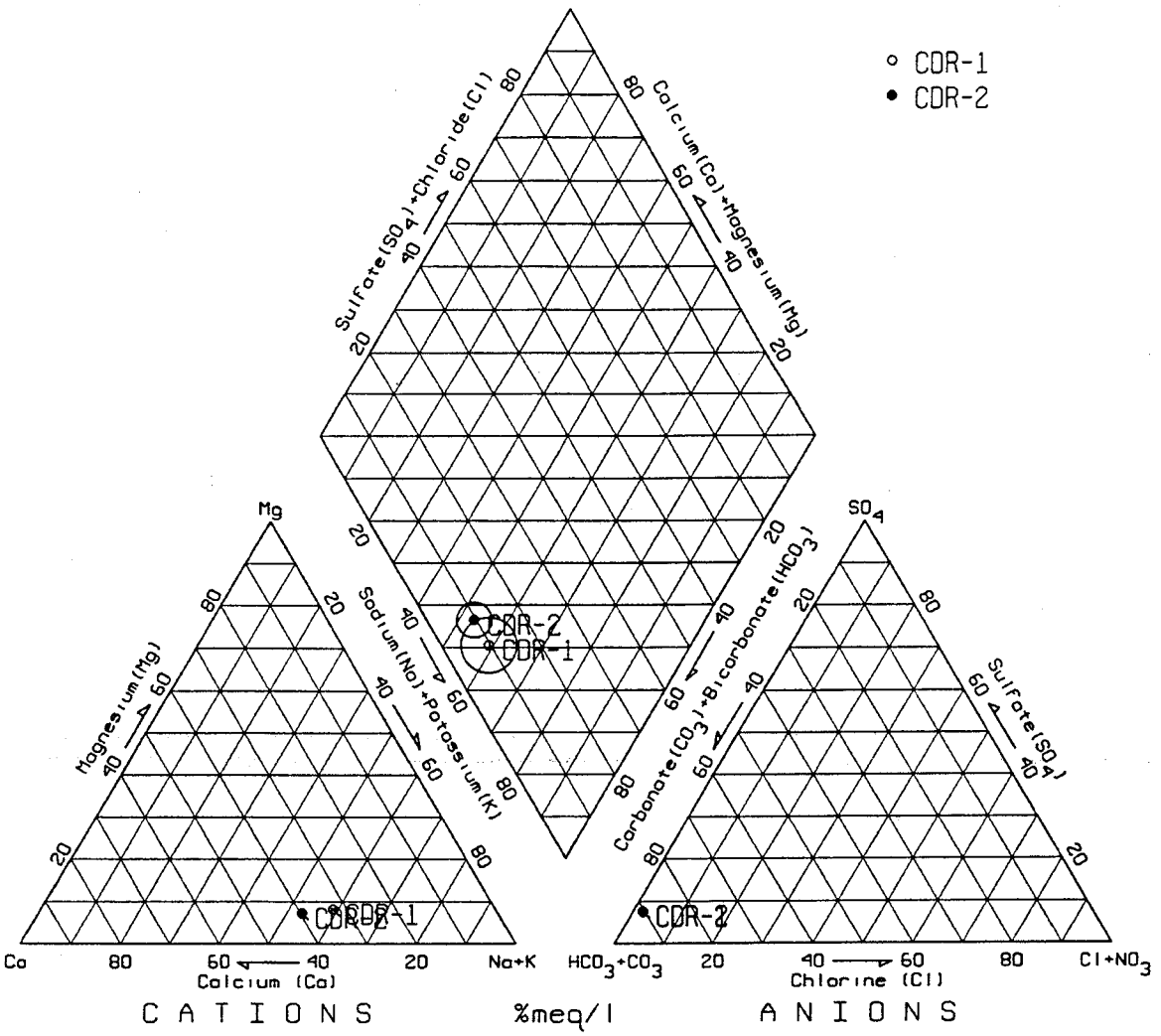


Figure 6-14. Trilinear Diagram for Groundwater Samples From the Caja del Rio Sub-basin.

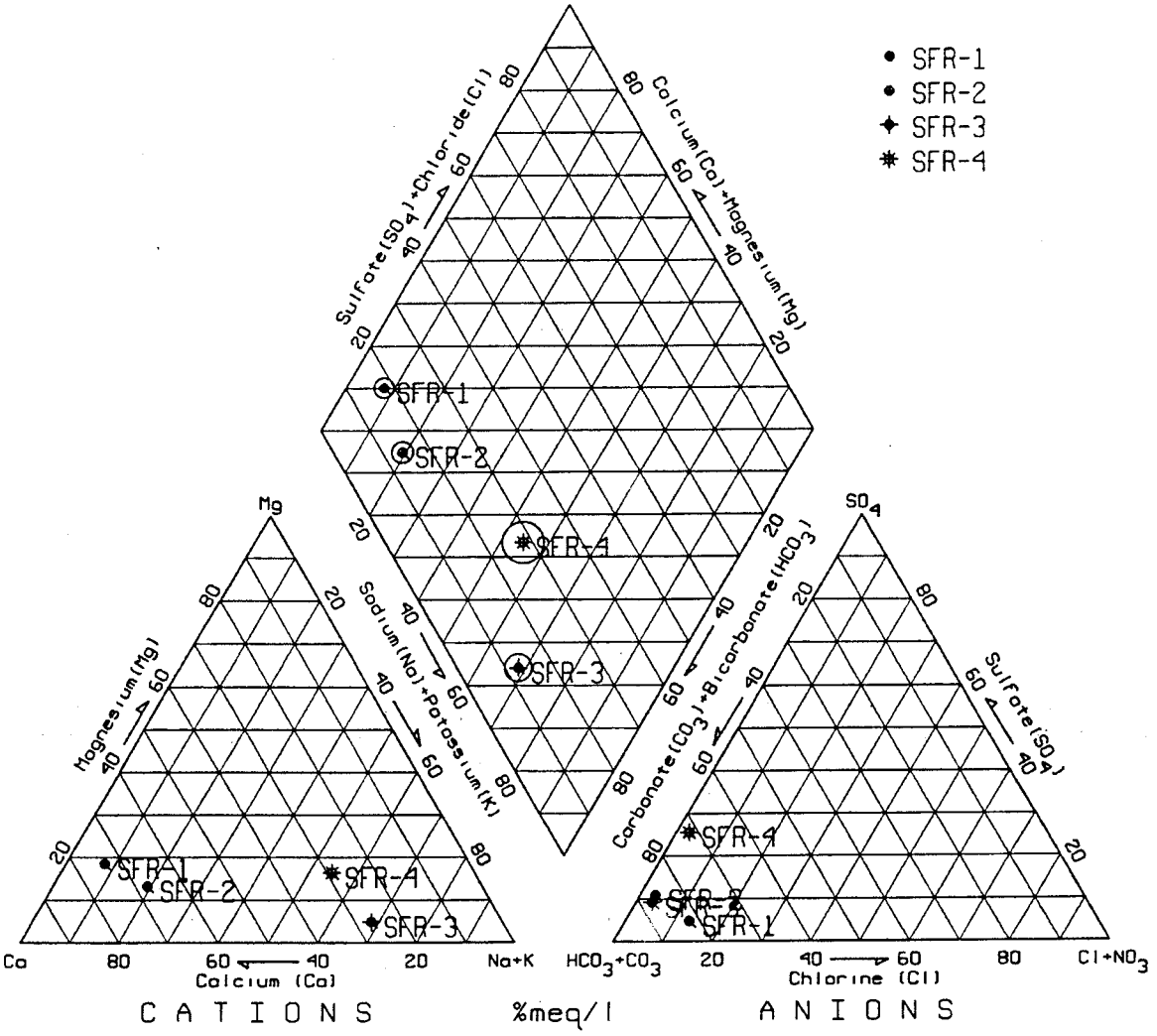
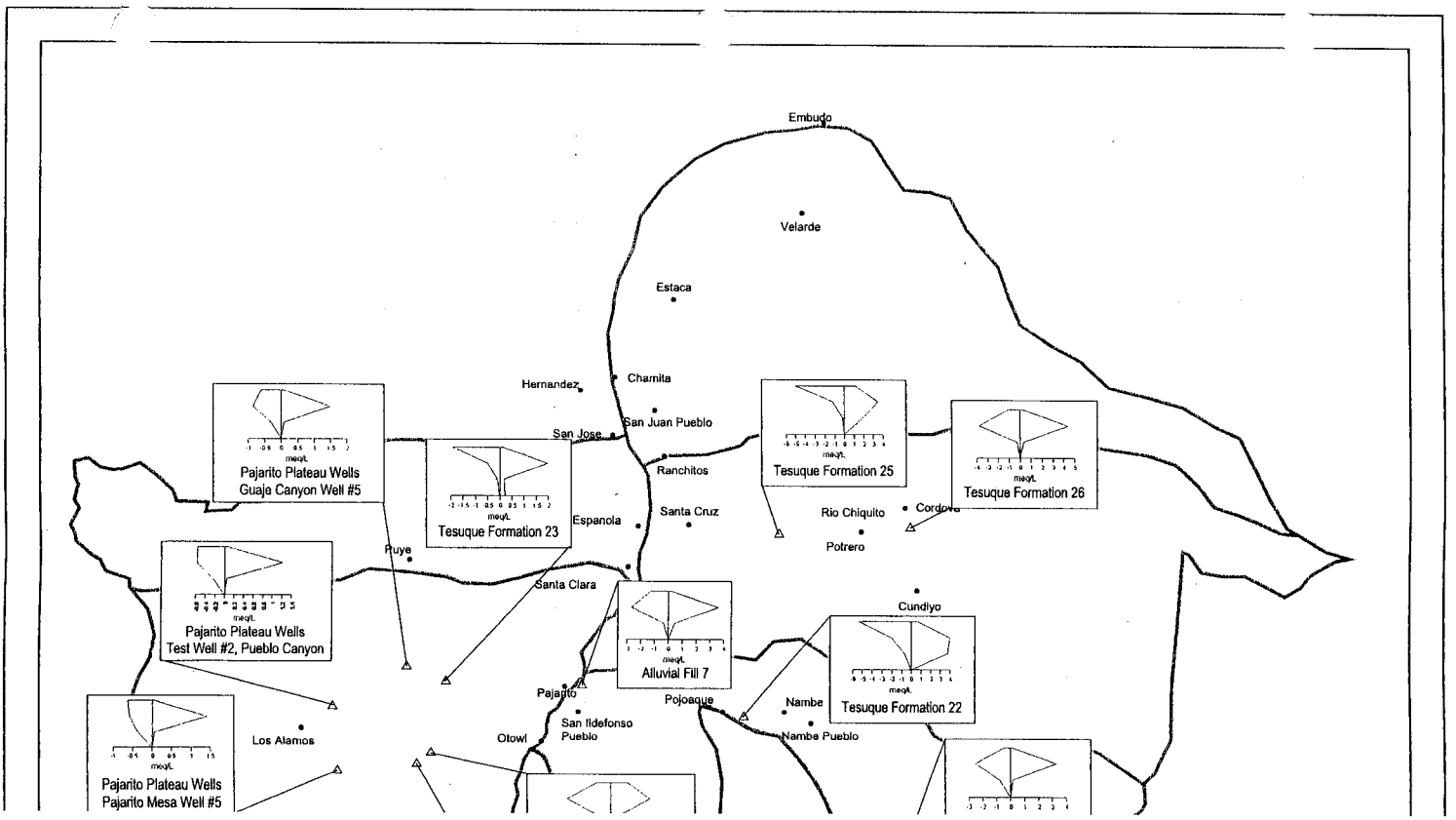


Figure 6-15. Trilinear Diagrams for Groundwater Samples from the Santa Fe River Sub-basin.


Embudo
Velarde
Estaca
Hernandez
Chamita
San Juan Pueblo
San Jose
Ranchitos
Pajarito Plateau Wells
Guaje Canyon Well #5
Tesuque Formation 23
Tesuque Formation 25
Tesuque Formation 26
Espanola
Santa Cruz
Rio Chiquito
Cordova
Potrero
Pueye
Santa Clara
Pajarito Plateau Wells
Test Well #2, Pueblo Canyon
Alluvial Fill 7
Cundiyo
Tesuque Formation 22
Pajarito
Pojoaque
Nambe
Nambe Pueblo
San Ildefonso
Pueblo
Otowi
Los Alamos
Pajarito Plateau Wells
Pajarito Mesa Well #5
meq/L

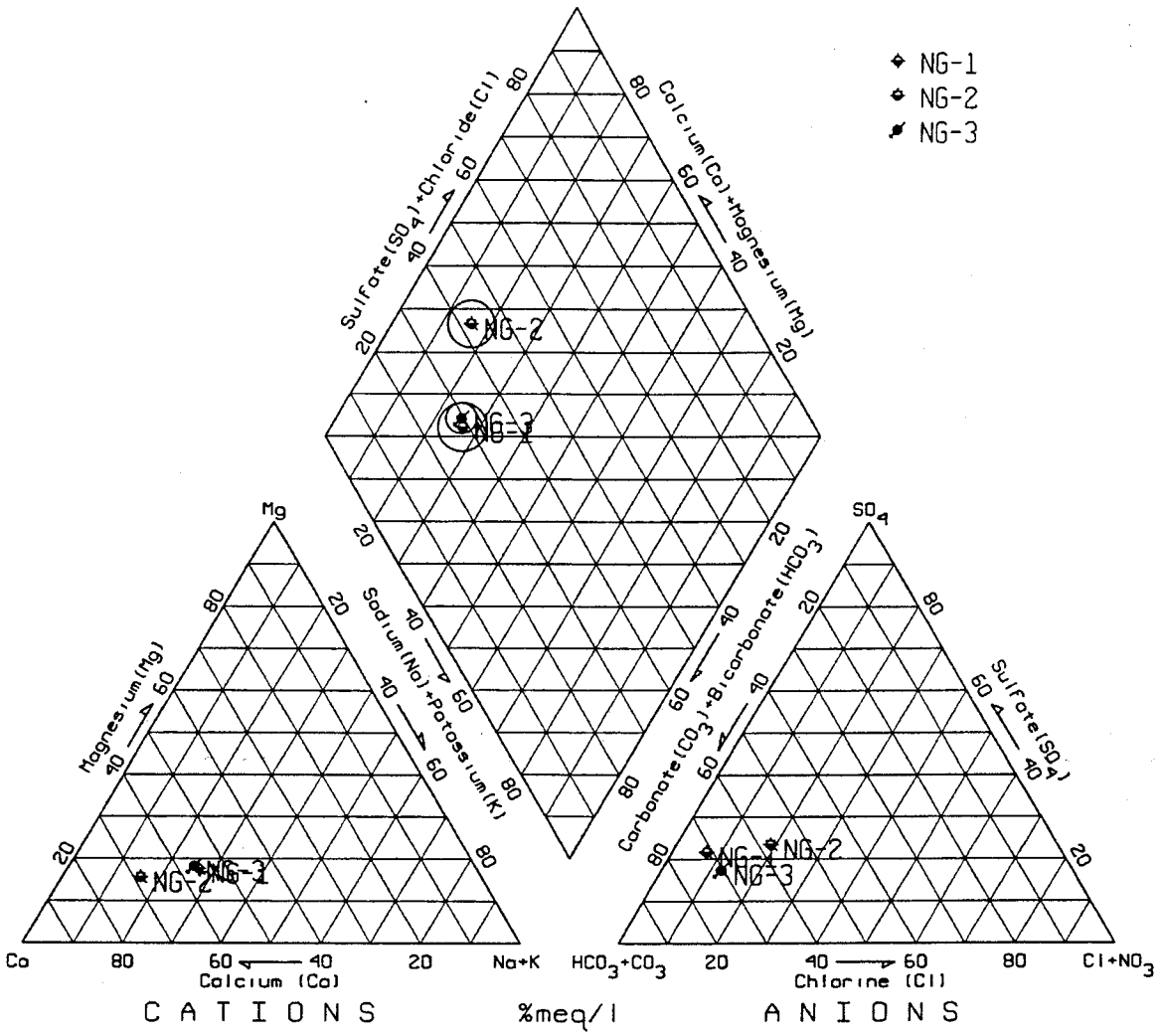


Figure 6-16. Trilinear Diagram for Groundwater Samples From North Galisteo Creek Sub-basin.

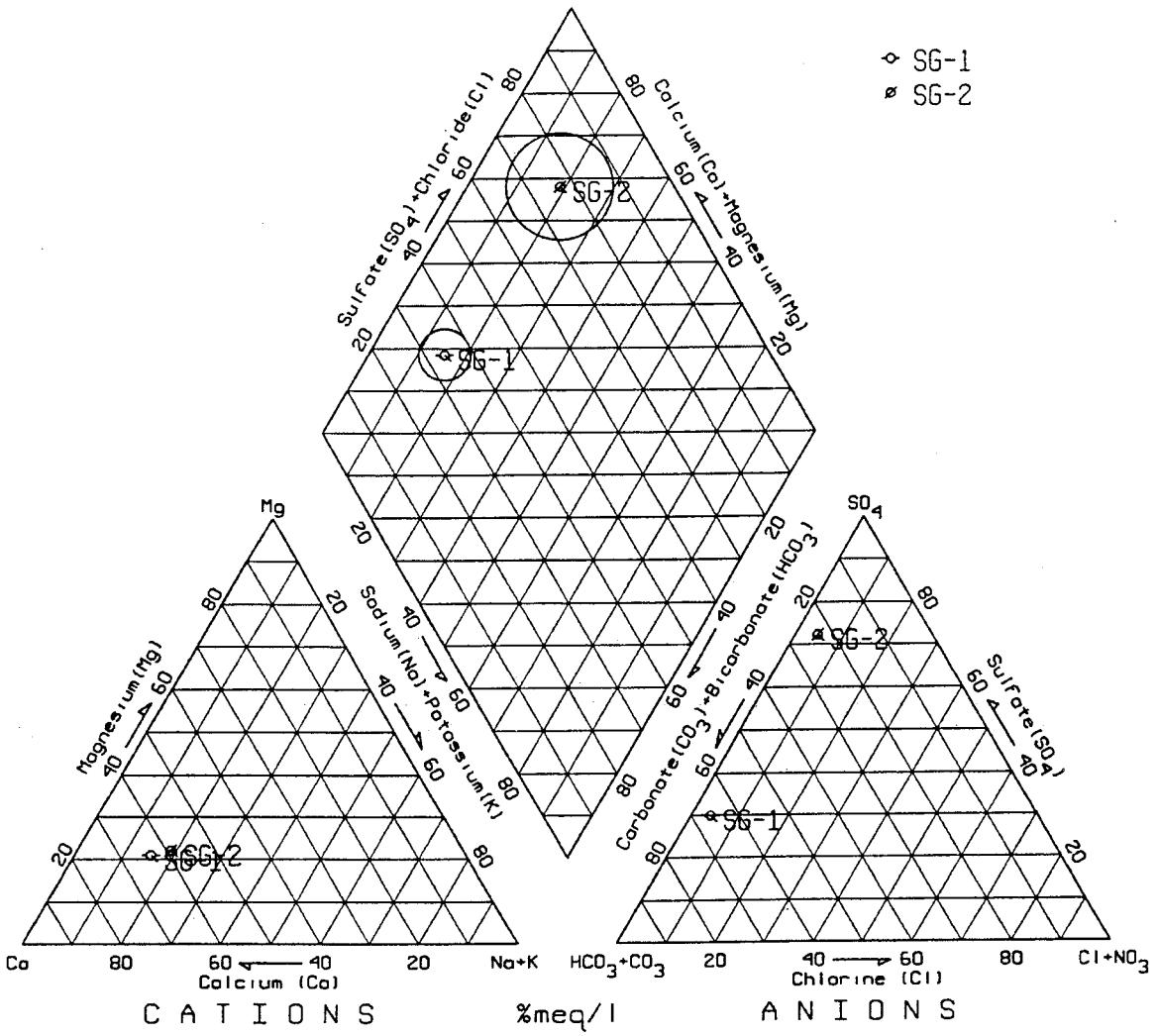


Figure 6-17. Trilinear Diagram for Groundwater Samples From the South Galisteo Creek Sub-basin.

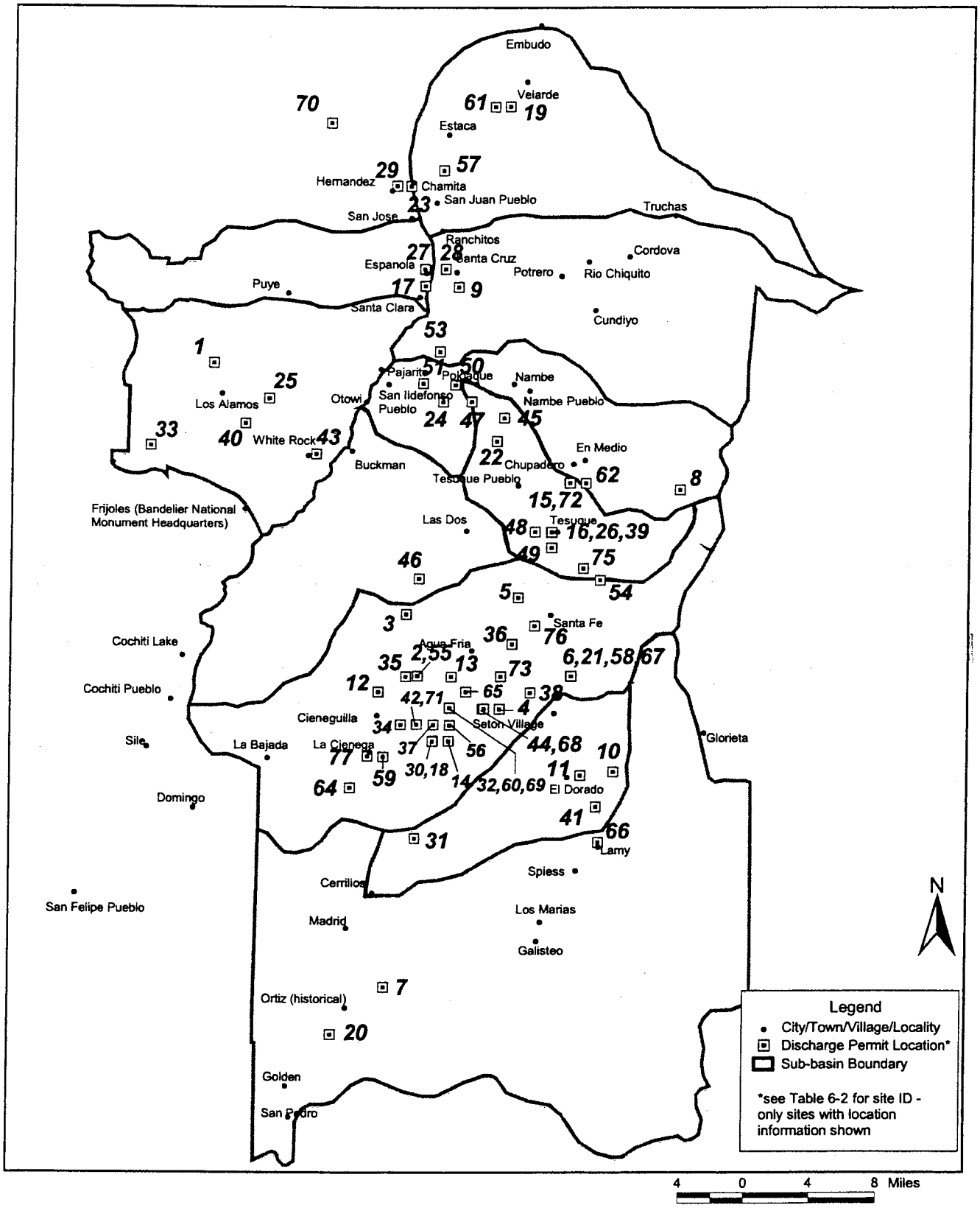


Figure 6-18 NMED Discharge Permit Locations

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A Duke Energy Company

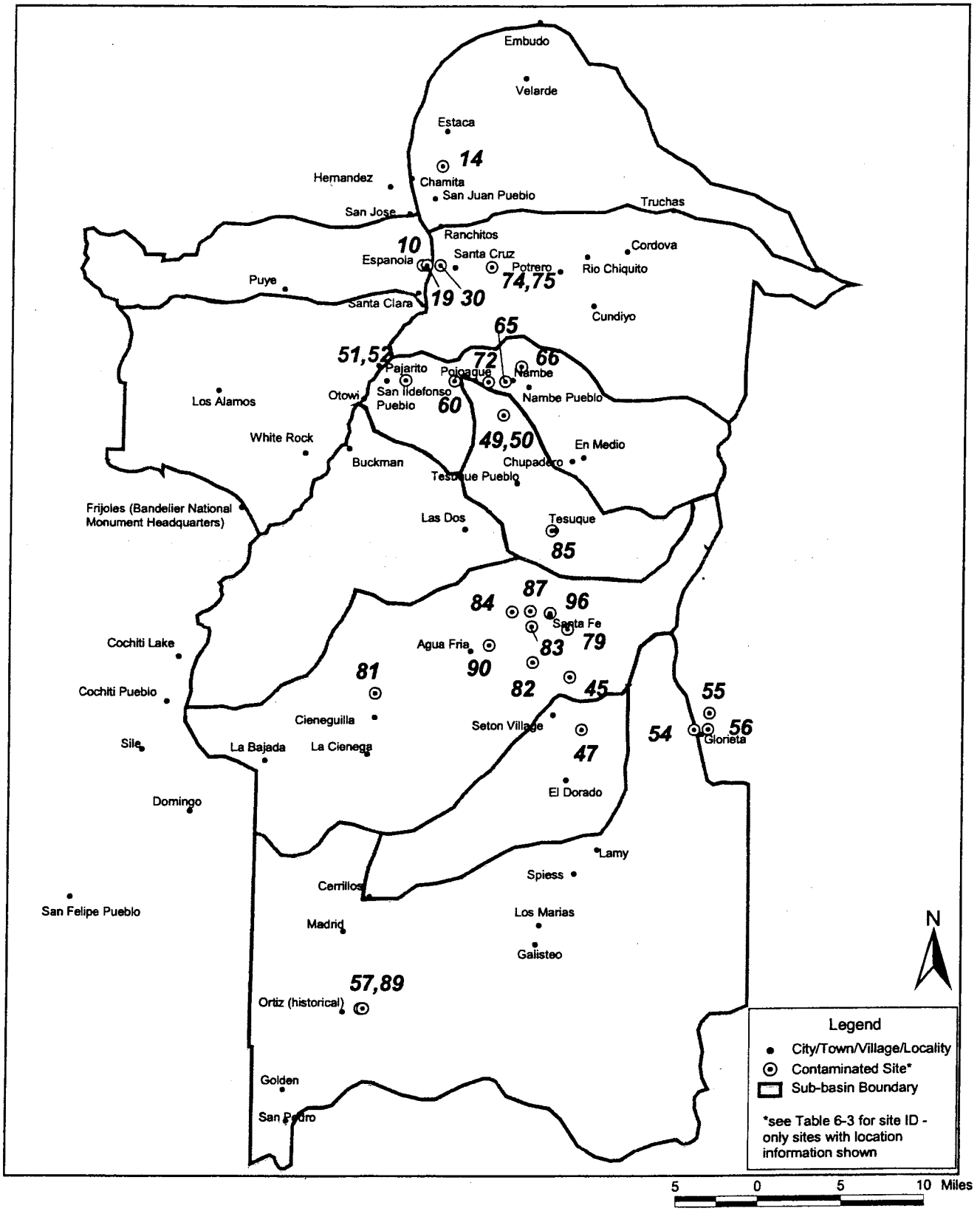

Figure 6-19 Known Groundwater Contamination Sites in the Study Region

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7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions Regarding Weather and Climate in the Planning Region

An understanding of spatial and temporal behavior of precipitation in the planning region is critical to developing prudent water management plans. Precipitation represents the source of surface water runoff in the sub-basins and also recharges the regional groundwater system. Historical data from several weather stations in and near the study region and other sources of weather information indicated that annual precipitation averages between 8 and 35 inches per year, with the precipitation volume generally increasing with increases in altitude. Most of the precipitation in the ten sub-basins occurs during the summer months of June through August.

Water planning must take into account the large temporal variability in precipitation that occurs in the Jemez y Sangre region, which is typical of climate in the southwestern United States. It is common for precipitation volumes to vary greatly from year to year, and for alternating periods of extended wet and dry weather to be observed. Analysis of precipitation records from several regional weather stations indicates that an extended dry period typically has a 10- to 15-year duration, which is then followed by a relatively wet period of similar duration. These relatively "short-term" cycles can be partly explained by episodes of temperature change in the central tropical Pacific Ocean, a phenomenon that is referred to as the El Niño-Southern Oscillation Cycle.

Perhaps even greater concerns regarding temporal variability of annual precipitation arise from paleoclimate evidence that suggests droughts in the region have the potential to extend over periods of a half-century or more. Tree ring studies for the southwestern United States have conclusively shown that an extended drought occurred in New Mexico and neighboring regions during most of the last half of the 16th Century.

7.2 Conclusions Regarding Water Supply in the Planning Region

Analyses of surface water and groundwater supplies yielded a reasonable qualitative understanding of the hydrologic processes that occur in each of the sub-basins and some measure of the quantities of water involved in each sub-basin's water budget relative to that of others. However, the development of both surface and groundwater budgets for each area examined demonstrated that most of the components comprising those budgets are very uncertain. Accordingly, one of the most important general conclusions resulting from this study is that work needs to be done to help refine the estimation of key budget components within both surface-water and groundwater media, particularly in several sub-basins that appear to be affected by relatively large flows.

Water supply budgets associated with the various sub-basins are summarized in Table 7-1. This table presents the total inflows and outflows estimated for surface water and groundwater media, as developed in Chapters 3 and 5, respectively. In addition to illustrating the relative quantities of water that are associated with the various sub-basins, this summary indicates that, on the whole and under recent conditions, the sub-basins are

experiencing more groundwater outflow than inflow. This leads to the general conclusion that, if surface water and groundwater can be considered a single water resource, the amount of water available to the study region is gradually decreasing. This conclusion is predicated upon the assumption that total surface inflows are equal to total surface outflows on an annual basis, and, therefore, that no significant accrual of surface water storage occurs in any given year.

Table 7-1. Water Budget Summary for All Sub-basins.

Sub-basin	Surface Water Budget		Groundwater Budget		
	Total Inflow[1] (acre-feet per year)	Total Outflow[1] (acre-feet per year)	Total Inflow[2] (acre-feet per year)	Total Outflow[2] (acre-feet per year)	Change In Groundwater Storage[2] (acre-feet per year)
Velarde (excluding the Rio Grande)	10,515[3]	16,135[4]	8835	8855	-20
Santa Cruz	37,040	37,040	10,650	10,650	0
Santa Clara	6460	6460	5120	5110	10
Los Alamos	2790	2790	4400	7020	-2620
Pojoaque-Nambe	18,995	18,995	13,730	13,750	-20
Tesuque	6430	6430	8615	8525	90
Caja del Rio	1350	1350	4700	8560	-3860
Santa Fe River	18,080	18,080	10,105	10,390	-285
North Galisteo Creek	900	900	5080	5315	-485
South Galisteo Creek	7300	7300	6605	6800	-345
Total	109,860	115,480	77,840	84,975	-7135

Notes:
[1] Unless noted otherwise, total surface water inflows and outflows taken from Table 3-14.
[2] Total groundwater inflows, outflows, and change in storage taken from Table 5-9.
[3] Total surface water inflow in the Velarde sub-basin = return flow from irrigation in the Rio de Truchas area (8095 acre-feet per year, Table 3-13) + surface water inflow from the western slope of the Sangre de Cristo Mountains (2420 acre-feet per year).
[4] Total surface water outflow in the Velarde sub-basin = diversions in the Rio de Truchas area (11,765 acre-feet per year, Table 3-13) + estimated net stream loss (1800 acre-feet per year) + estimated riparian evapotranspiration (2570 acre-feet per year)

The surface water budget items in Table 7-1 need further explanation. In all sub-basins but Velarde, the total sub-basin inflow is equal to the total outflow. This occurs because of the previously mentioned assumption regarding surface water supplies that no significant surface water storage accrues within the study region in any given year. In the nine sub-basins where this assumption is adhered to, the surface water budgets were developed by accounting only for flows in watersheds that are tributary to the Rio Grande. In contrast, the Velarde sub-basin budget was developed by accounting for inflows and outflows on the Rio Grande as well. Unfortunately, surface water diversions from and return flows to the river in the Velarde area were not accounted for as well.

The surface water totals for the Velarde sub-basin presented in Table 7-1 exclude the effects of Rio Grande flows; instead (1) total inflow to the sub-basin is computed as the

sum of estimated surface water inflow and irrigation return flow, and (2) total outflow is calculated as the sum of irrigation diversions, loss of surface water to evapotranspiration, and a net loss of surface water to groundwater (stream loss). Because the method originally applied to develop the sub-basin's surface water budget was based on combined Rio Grande flows and estimated tributary inflows, the difference in total inflow and outflow for the tributary portion of the watershed, as determined with two computations mentioned above, is unavoidable.

The totals presented for surface water inflows and outflows indicate that approximately 110,000 to 120,000 acre-feet per year of flow are associated with the combined sub-basins during average flow periods. Obviously, the actual quantity of surface water associated with each sub-basin's budget fluctuates from year to year.

With regard to surface water, on average, the largest quantities of surface water appear to move through the Santa Cruz, Pojoaque-Nambe, and Santa Fe River sub-basins. Accordingly, surface water diversions from Rio Grande tributaries in these sub-basins, and local exchanges between groundwater and surface water (see Table 3-14), are generally larger than comparable quantities estimated for these processes in other sub-basins. The smallest surface water flows appear to occur in the Caja del Rio and North Galisteo Creek sub-basins, whereas surface flows in the Santa Clara, Los Alamos, Tesuque, and South Galisteo Creek sub-basins appear to be of intermediate magnitudes. Though the total surface flows occurring in the Velarde sub-basin are unclear for reasons elucidated earlier, the flows presented for this sub-basin in Table 7-1 do suggest that the magnitude of its surface water processes is of the same general magnitude as those occurring in the Pojoaque-Nambe and Santa Fe River sub-basins. This preliminary conclusion is arrived at despite the fact that all tributary streams in the Velarde sub-basin are assumed in this study to be ephemeral.

The general magnitude of groundwater flows in the sub-basins appears to be about the same as the magnitude of comparable surface water budgets. It should be noted, however, that the groundwater budgets are strongly affected by estimated interbasin groundwater flows, which were largely based on groundwater levels and flow gradients developed for the upper 1000 feet of saturated aquifer system. Thus, it is possible that less-understood groundwater flows in deeper parts of the regional groundwater system may actually result in groundwater budgets that are generally larger than comparable surface water budgets.

In most sub-basins, the magnitude of computed groundwater inflows and outflows are generally less than comparable surface water inflows and outflows. The exceptions to this rule occur in the Caja del Rio and North Galisteo Creek sub-basins, where surface water flows are estimated to be relatively insignificant, and in the Los Alamos sub-basin, where the groundwater budget outflows are strongly affected by groundwater withdrawals for municipal use and surface water flows are again estimated to be relatively minor.

The groundwater budgets developed for the Velarde, Santa Cruz, Santa Clara, Pojoaque-Nambe, and Tesuque sub-basins suggest that total groundwater inflows are generally equal to total groundwater outflows in these areas. Sub-basins that are estimated to be experiencing net groundwater outflows include the Los Alamos and Caja del Rio sub-basins. Though slight net losses of groundwater are computed for Santa Fe River, North Galisteo Creek, and South Galisteo Creek sub-basins, large uncertainties associated with the budgets for each of these areas suggest that none of the quantities given for changes in storage for these sub-basins can be considered indicative of trends.

More specific conclusions regarding surface water and groundwater supplies are presented in the following sections.

7.2.1 Conclusions Regarding Surface Water Supplies

Several issues regarding the water supplies of specific sub-basins were identified that warrant further mention. Many of these issues involved limitations on the surface water budgets, which typically occurred in the form of inadequate data sources with which to quantify key budget components for sub-basins that apparently have large surface water resources. Other issues involved difficulties that repeatedly turned up in the course of developing all of the sub-basins' budgets.

7.2.1.1 Santa Cruz Sub-basin Water Supply

The surface water budget developed for the Santa Cruz sub-basin is somewhat limited in its utility because separate estimates of stream losses to groundwater and stream gains due to groundwater discharge could not be reliably developed. Rather a general net loss of surface water to groundwater of 5190 acre-feet per year is computed for this sub-basin. Given that the estimated total surface inflows and outflows for this area are larger than comparable quantities assigned to other sub-basins, and because stream losses and gains due to groundwater/surface water exchange are apparently quite large on the similar Pojoaque-Nambe and Santa Fe River sub-basins to the south, the Jemez y Sangre Council's understanding of surface water flow processes in the Santa Cruz sub-basin could be vastly improved through more detailed studies of stream-aquifer exchange in the sub-basin. Various groundwater models that have thus far been developed for the Española Basin do little to provide reasonable estimates of current stream losses and stream gains on the Santa Cruz drainage, either because they have been used to assess steady-state, pre-development conditions (Hearne, 1985), or do not fully include the Santa Cruz River and its tributaries within model boundaries (McAda and Wasiolek, 1988; Frenzel, 1995).

Flows on the Rio Grande are not explicitly taken into account in the Santa Cruz sub-basin surface water budget. Nonetheless, surface water flows are affected by several uses of Santa Cruz River water just to the east and north of the City of Española. More refined estimates of the surface water budget for the Santa Cruz River in this locale would help to distinguish the degree to which surface flow in the lower parts of the sub-basin are affected by human water uses relative to stresses on the system occurring farther upstream.

7.2.1.2 Velarde Sub-basin Water Supply

As in the case of the Santa Cruz sub-basin, there is a need to better quantify stream-aquifer exchange on the Velarde sub-basin. The surface water budget for this drainage area appears to be of the same general magnitude as those observed for the Pojoaque-Nambe and Santa Fe River sub-basins. This observation is not surprising given that the highest elevation of the sub-basin in the Sangre de Cristo Range exceeds 12,000 feet, as do the peak elevations in the Santa Cruz, Pojoaque-Nambe and Santa Fe River sub-basins; thus the potential exists for substantial spring runoff to enter this basin each year at its higher elevations. Despite the fact that all watercourses in the Velarde sub-basin are considered in this study to be ephemeral, it would be useful to identify any portions of the watersheds in this sub-basin, if any, where stream flow occurs during most of the year. Better understanding of surface water outflows from the sub-basin, such as those potentially associated with extremely wet years, is also desirable.

Development of a more refined surface water budget for the portion of the Velarde sub-basin that courses along the Rio Grande would also be helpful to the Council. Such a refined budget would account for processes like irrigation diversion on the Rio Grande flood plain and possible return flows to the Rio Grande stemming from irrigation diversions on either the Rio Grande or the Rio Chama.

7.2.1.3 Santa Clara Sub-basin Water Supply

Though estimated surface water inflows and outflows on the Santa Clara sub-basin fall into an intermediate range with respect to comparable estimates for other sub-basins, it is important to note that most of this watershed is located on Santa Clara Pueblo land. The disposition of surface water in this area is apparently at the discretion of the Pueblo. Like the Velarde and Santa Cruz sub-basins, the estimated surface water supply of the Santa Clara sub-basin could be substantially improved by assessing the effects of irrigation canals in the lower part of the watershed that convey water diverted from the Rio Grande.

7.2.1.4 Pojoaque-Nambe and Santa Fe River Sub-basins

Estimated quantities of stream-aquifer exchange are quite large on both the Pojoaque-Nambe and Santa Fe River sub-basins. On the former, surface water flows at lower elevations are apparently perennial, which can probably be partly attributed to stream gains from groundwater discharge. Stream-aquifer exchange on this sub-basin appears to be a major reason for the general balance of groundwater inflows and outflows presented in Table 7-1. The modeling studies of Hearne (1985), McAda and Wasiolek (1988), and Frenzel (1995) suggest that, even if groundwater diversions in the Pojoaque-Nambe sub-basin were to increase, groundwater levels would be maintained at a reasonably constant level because stream losses to groundwater would take place; this would result in a decline of groundwater discharge to surface water. Under current conditions, surface water outflows from the Pojoaque River to the Rio Grande are still relatively significant.

In contrast to the Pojoaque-Nambe sub-basin, stream losses to groundwater in the Santa Fe River sub-basin appear to far outweigh gains on the river due to groundwater discharge. This observation is not surprising given that most of the inflows to the sub-

basin on the Santa Fe River are diverted for municipal uses in the City of Santa Fe; groundwater discharge that may have naturally occurred within and downstream of the City has been virtually eliminated due to diversion of surface water and the reduction of groundwater levels west of the City by pumping in the city well field. Though a significant amount of groundwater discharge to surface water still occurs near the community of LaCienega, stream surface losses appear to predominate both upstream and downstream of this area. As a result, the estimated average inflow to Cochiti Lake from the Santa Fe River is relatively small (1110 acre-feet per year).

7.2.1.5 Los Alamos Sub-basin Water Supply

Surface water flows in the Los Alamos sub-basin are of interest because of their potential effect on the underlying groundwater system. There is evidence to indicate that much of the stream-aquifer exchange that occurs in this sub-basin is confined to local, shallow groundwater systems occurring in alluvium located at the base of several canyons that incise the sub-basin. Nonetheless, it has been estimated in this study that 400 acre-feet per year of stream loss recharges the main aquifer system in the Los Alamos sub-basin. More refined, spatially varied estimates of these local exchanges are needed, as are analyses of the degree to which surface runoff in the sub-basin is capable of recharging the deeper, regional aquifer system.

7.2.1.6 Information on Stream-Aquifer Exchange and Surface Water Rights

The foregoing discussions regarding surface water supply repeatedly demonstrate that budget components reflective of stream-aquifer exchange are some of the most uncertain in developing sub-basin budgets. The determination of more accurate estimates of groundwater discharge to surface water is particularly important for the Santa Cruz and Pojoaque-Nambe sub-basins because this component represents some measure of the degree to which additional groundwater withdrawals can occur in these areas before the lower reaches of the Santa Cruz and Pojoaque Rivers are drawn dry. An additional surface water component that is also generally very uncertain is surface water inflow from the headwaters of each sub-basin. Interestingly, surface water diversion for irrigation is one of the water budget components that stand the potential of being relatively certain, but is not. This observation stems from the fact that, in the Velarde, Santa Cruz, Pojoaque-Nambe, Tesuque, and Santa Fe River sub-basins, several different estimates exist for the irrigated acreages that exist within each. Of all estimated surface water budget components, total evapotranspiration due to combined stream surface evaporation and riparian evapotranspiration is probably one of the more certain ones.

Comparison of surface water rights with actual surface water uses was not possible in this study due to incomplete data regarding surface water rights. As difficult as it may be to compile such information, the Council would be better informed if a more complete surface water rights database were prepared. Such a database would account for both state-administered rights and the Federal Pueblo rights. Unfortunately, much of the latter type of rights remains unquantified; tabulation of the portion that has been quantified would be useful.

7.2.2 Conclusions Regarding Groundwater Supplies

The net reductions in groundwater storage presented in Table 7-1 for the Los Alamos and Caja del Rio sub-basins have been estimated mostly through comparison of all other groundwater budget components. Little has been done in this general study to confirm whether such depletions are reflected locally by changes in shallow groundwater levels within each sub-basin. Rather the analysis of groundwater levels in this study has focused on lumped values of measured hydraulic head in the uppermost 1000 feet of saturated thickness in each sub-basin. This approach facilitates preliminary determinations of horizontal subsurface flow between sub-basins, but does not lend itself to making reliable estimates of vertical flow within sub-basins. Moreover, maps that have been developed for this study showing groundwater levels for two distinct time periods (pre-1975 and post-1990) are too coarse to accurately portray declines in groundwater level that have tended to occur in relatively localized areas. Thus the planning council would greatly benefit from more refined studies of water-table decreases in the sub-basins for which net reductions in groundwater storage are identified.

Net reductions in groundwater storage in the Los Alamos sub-basin appear to be the result of pumping from well fields used to supply local communities and the Los Alamos National Laboratory. Net reductions in Caja del Rio sub-basin storage are mostly the result of pumping from the Buckman Well Field.

Groundwater storage in the Tesuque sub-basin deserves further study. Results from this study suggest that groundwater levels in this area are holding relatively steady, whereas a previous report by Daniel B. Stephens and Associates (1994a) states that groundwater storage is likely decreasing in the sub-basin.

As related in the summary of surface water processes, budget components stemming from stream-aquifer exchange processes remain some of the most uncertain of all groundwater budget processes. Mountain-front recharge appears to also be very uncertain. The most accurately quantified component is groundwater pumping for municipal purposes. Evapotranspiration of groundwater in non-irrigated areas where the water table lies relatively close to the ground surface is of intermediate uncertainty. Yet it is unlikely that groundwater budgets could be vastly improved by better quantifying this last process because it appears to be a relatively minor component of total groundwater flow.

7.3 Conclusions Regarding Water Quality in the Planning Region

The general quality of both surface water and groundwater in the planning region is very good to excellent. Total dissolved solids (TDS) concentrations in surface water are typically less than 250 milligrams per liter (mg/L). TDS levels in the main groundwater source of the region, the Tesuque Formation, are usually less than 350 mg/L. Both surface water and groundwater are mostly characterized as a calcium-bicarbonate type, but a great deal of the region's water is also characterized as a sodium-bicarbonate type.

Scattered cases occur in which the concentrations of specific inorganic ions in surface water either approach or exceed applicable drinking water standards. In nearly all instances, these cases are associated with either some form of wastewater discharge, such as at NPDES-permitted sites, or at the outfalls of wastewater treatment plants. The locations at which elevated surface water concentrations are occasionally observed are mostly found near urban areas, such as the City of Santa Fe and the City of Española. Wastewater effluent is also discharged to surface water at some locales within Los Alamos National Laboratory as well as outside the Laboratory boundary.

Currently, the Santa Fe River is the only watercourse within the study region for which TMDL-based limits have been established. Specifically, loading limits have been set for chlorine and stream bottom deposits along a reach of the river downstream from where the Santa Fe Wastewater Treatment Plant discharges its effluent. Though not falling under the purview of TMDL regulations, nitrate is another constituent of concern along this reach of the Santa Fe River because of the potential for surface water with elevated nitrate concentrations to recharge the local groundwater system where domestic wells are located.

Groundwater from a few specific areas within the planning region is affected by elevated levels of dissolved constituents. One of these comprises the Española area where nitrate in relatively shallow groundwater (100 to 300 feet deep) and fluoride at greater depths within the Tesuque Formation have been observed at levels that approach or exceed relevant drinking water standards. Anomalous concentrations of nitrate and fluoride also tend to occur in groundwater in the Pojoaque Valley. Naturally occurring uranium is also observed at elevated levels in Pojoaque Valley groundwater.

Elevated levels of naturally occurring uranium are observed in some wells on San Ildefonso Pueblo land on the western side of the Rio Grande. Anomalous concentrations of fluoride, sulfate, and nitrate also occur in San Ildefonso wells; high levels of the latter two of these constituents are generally attributed to the application of fertilizers in the region.

At least 118 sites of known groundwater contamination have been identified within the study region's boundaries. The types of contaminants observed in them range from chlorinated solvents to gasoline components and pesticides, and the apparent contaminant sources include leaking dry cleaning facilities, underground storage tanks, sewage treatment plants, and facilities at Los Alamos National Laboratory.

7.4 Recommendations

On the basis of foregoing conclusions and additional findings from this study, the following recommendations are made regarding water planning in the Jemez y Sangre Planning Region:

(1) Studies should be conducted to better quantify (a) water budget components stemming from groundwater/surface water exchange; (b) surface water inflow

to the sub-basins; (c) irrigated acreages and the surface water diversions associated with them; and (d) mountain-front recharge.

(2) Focus on better quantifying the amount of groundwater discharge to surface water that currently occurs in the Santa Cruz and Pojoaque-Nambe sub-basins since this budget component provides some measure of the degree to which groundwater pumping in these areas could increase before local perennial streams would tend to become ephemeral.

(3) Because of a relative paucity of information regarding both surface water and groundwater in the Velarde sub-basin, conduct additional studies of this area, paying special attention to the disposition of surface runoff emanating from the western slope of the Sangre de Cristo Mountains.

(4) Refine the surface water budgets for the Velarde, Santa Cruz, and Santa Clara sub-basins by conducting separate quantitative analyses of the surface water processes occurring in these areas in the vicinity of the Rio Grande and Rio Chama flood plains.

(5) Develop a more comprehensive database on surface water rights in the planning region, and attempt to facilitate the quantification of Pueblo water rights in the planning region.

(6) Use recent population estimates to refine the estimation of groundwater diversions by pumping in the sub-basins.

(7) Utilize sub-regional, multi-layered, three-dimensional models of groundwater flow in and around the Los Alamos, Buckman, and Santa Fe well fields to better understand groundwater level declines in these areas and the degree to which local groundwater storage is being depleted.

(8) Investigate the possibility of ancillary, deleterious effects of declines in groundwater levels and storage, such as land subsidence.

(9) Utilize comprehensive groundwater models of the Española Basin to better understand groundwater flows between sub-basins, and the interconnection of groundwater and surface water; a regional model currently being prepared by personnel at Los Alamos National Laboratory is a likely candidate for this type of analysis.

(11) Update hydrologic and water quality database for the region on a yearly basis for the purpose of identifying relevant trends in water supply and possible declines in surface water and groundwater quality.

(12) Integrate the findings from this study with state-wide water planning efforts overseen by the New Mexico Interstate Stream Commission.

(13) As part of the water planning process, initiate efforts that will ultimately allow the integration of surface water models of the region with groundwater models. Two potential candidates for this type of work are the Española Basin groundwater model being prepared by Los Alamos National Laboratory and the Upper Rio Grande Water Operation Model that is being developed jointly by personnel from the USBR, the Corps, and the USGS.

8.0 REFERENCES

Allen, C., 1999. Ecological patterns and environmental change in the Bandelier landscape. Chapter 2 in Village Formation of the Pajarito Plateau, New Mexico: The Archeology of Bandelier National Monument, T.A. Kohler (ed.), University of New Mexico Press, Albuquerque (in progress).

Alley, W.M., T.E. Reilly, and O.L. Franke, 1999. Sustainability of ground-water resources. U.S. Geological Survey Circular 1186, 79 p.

Anderholm, S.K., 1994. Ground-water recharge near Santa Fe, north-central New Mexico: U.S. Geological Survey Water-Resources Investigations Report 94-4078, 68 p.

BBER - See Bureau of Business and Economic Research.

Berg, R., E. Keating, and C. Kerven, 2000. Documentation of ACCESS Database, Sangre y Jemez Regional Water Planning District.

Blake, W.D., F. Goff, A.I. Adams, and D. Counce, 1995. Environmental geochemistry for surface and subsurface waters in the Pajarito Plateau and outlying areas, New Mexico. Los Alamos National Laboratory; Los Alamos, NM, LA-12912-MS.

Bolton, S.M., 1991. A methodology for predicting water, sediment, and nutrients from New Mexico watersheds. Ph.D. Dissertation, New Mexico State University, Las Cruces.

Bouwer H. 1978. Groundwater hydrology. McGraw-Hill, Inc., 1978, 480 p.

Bowen, B.M., 1990. Los Alamos climatology. Los Alamos National Laboratory, LA-11735-MS.

Bureau of Business and Economic Research (BBER), 1997. New Mexico population outlook in the 21st century, Vol. B. BBER, University of New Mexico, Albuquerque, New Mexico.

Bureau of Business and Economic Research (BBER), 2000. Population projections for the Jemez y Sangre Water Planning Council.

Camp, Dresser and McKee, Inc. (CDM), 2000. City of Santa Fe treated effluent management plan. Prepared in association with Lee Wilson and Associates.

CDM – See Camp Dresser and McKee, Inc.

Chestnut, P., 2000. Presentation on Pueblo water rights for the Jemez y Sangre Water Planning Council. March 13, 2000.

City of Santa Fe Public Utilities Department, 1999. 1998 water quality report. Sangre de Cristo Water Division.

Corps – see U.S. Army Corps of Engineers

Crowley, T.J., 2000. Causes of climate change over the past 1000 years. Science, 289, pp. 270-277.

Daniel B. Stephens & Associates, Inc. 1994a. Santa Fe County water resource inventory, volume 1: text and plates. Prepared for Santa Fe County Land Use and Planning Department, Santa Fe, New Mexico, July 13, 1994.

Daniel B. Stephens & Associates, Inc. 1994b. Santa Fe County water resource inventory, volume 2: appendices. Prepared for Santa Fe County Land Use and Planning Department, Santa Fe, New Mexico, July 13, 1994.

DBS&A – see Daniel B. Stephens & Associates, Inc.

DE&S – see Duke Engineering and Services.

Duke Engineering and Services (DE&S), 1999a. Phase I environmental site assessment and a preliminary evaluation of groundwater impacts for the Northern Santa Fe Railyard site, Santa Fe, New Mexico. June, 1999.

Duke Engineering and Services (DE&S), 1999b. New Hickox Well aquifer test results and analysis of potential groundwater impacts for the Santa Fe Railyard site, Santa Fe, New Mexico. December, 1999.

Duke Engineering and Services (DE&S), 2000. Phase I environmental site assessment, Baca Street Railyard property, Santa Fe, New Mexcio. March, 2000.

EPA – see U.S. Environmental Protection Agency

Farnsworth, R.K., and E.S. Thompson, 1982. Mean monthly, seasonal, and annual pan evaporation for the United States. NOAA Technical Report NWS 34, U.S. Department of Commerce, National Weather Service, Washington, D.C.

Farnsworth, R.K., E.L. Peck, and E.S. Thompson, 1982. Evaporation atlas for the contiguous 48 states. NOAA Technical Report NWS 33, U.S. Department of Commerce, National Weather Service, Washington, D.C.

Fetter, C.W., 1980. Applied hydrogeology. Merrill Publishing Company, Columbus, Ohio.

Frenzel, P.F. 1995. Geohydrology and simulation of ground water flow near Los Alamos, north central New Mexico. United States Geological Survey, Water Resource Investigation Report 95-4091, prepared in cooperation with Los Alamos National Laboratory.

Frost, J.P., 1994. Regional cross-sections of the Ancha Tesuque aquifer system. Santa Fe, NM: College of Santa Fe, March 1994.

Frost, J.P., 1995. Schematic model of the Ancha-Alluvial Flow System, T15 and 16N, R8 and 9E, Santa Fe County, New Mexico.

Frost & Associates Hydrologists, Geologists, Ltd. Co, 1996. Isotope ground water study, Santa Fe area. Prepared for City of Santa Fe.

Frost & Associates Hydrologists, Geologists, Ltd. Co, 1996. Review of El Dorado area water production and groundwater resource. Prepared for Santa Fe County.

Galusha, T., and J.C. Black, 1971. Stratigraphy of the Santa Fe Group, New Mexico. American Museum of Natural History Bulletin, v.144, Article 1, 127 p.

Green, G.N. and Jones, G.E., 1997. The digital geologic map of New Mexico in ARC/INFO format. U.S. Geological Survey, Open-file Report OF-97-52.

Griggs, R.L., 1964. Geology and ground-water resources of the Los Alamos area, New Mexico: U.S. Geological Survey Water-Supply Paper 1753, 107 p., 1 pl.

Grissino-Mayer, H.D., 1996. A 2129-year reconstruction of precipitation for northwestern New Mexico, USA. In Tree Rings, Environment, and Humanity, edited by J.S. Dean, D.M. Meko, and T.W. Swetman, Radiocarbon, pp. 191-204.

Harrigan, B., 1992. Water Supply at Los Alamos during 1989. Los Alamos National Laboratory, May 1992.

Harrigan, B., 1993. Water supply at Los Alamos during 1990. Los Alamos National Laboratory, February 1993.

Healy, D.F., 1997. Water-quality assessment of the Rio Grande Valley, Colorado, New Mexico, and Texas – summary and analysis of water-quality data for the basic fixed-site network, 1993-1995. U.S. Geological Survey, Water Resources Investigations Report 97-4212, 82 p.

Hearne, G.A., and J.D. Dewey, 1988. Hydrologic analysis of the Rio Grande Basin, north of Embudo, New Mexico, Colorado and New Mexico. U.S. Geological Survey Water Resources Investigation Report 86-4113.

Hearne, G.A., 1985. Mathematical Model of the Tesuque Aquifer System near Pojoaque, New Mexico. U.S. Geological Survey, Water-Supply Paper 2205, 75 p.

Hem, J.D., 1989. Study and interpretation of the chemical characteristics of natural water. U.S. Geological Survey, Water Supply Paper 2254.

ISC – see New Mexico Interstate Stream Commission

Kelley, V.C., 1952. Tectonics of the Rio Grande depression of central New Mexico. In Guidebook of the Rio Grande Country, New Mexico Geological Society, pp. 93-105.

Kelley, V.C., 1977. Geology of the Albuquerque Basin, New Mexico. New Mexico Bureau of Mines and Mineral Resources, Memoir 33.

Kelley, V.C., 1978. Geology of Española Basin, New Mexico. New Mexico Bureau of Mines and Mineral Resources Geologic Map 48, scale 1:125,000.

LANL – see Los Alamos National Laboratory

LeeWilson, 1978. Santa Fe County water plan, Santa Fe County, New Mexico.

Lee Wilson and Associates, Inc., 1984a. Santa Fe regional water supply system: Parts I through V. Santa Fe Metropolitan Water Board staff with hydrological report prepared by Lee Wilson and Associates, 1978, June 1984.

Lee Wilson and Associates, Inc., 1984b. Water supplies for the Santa Fe area, New Mexico. Hydrologic support document prepared for the Santa Fe Metropolitan Water Board, Santa Fe, NM, November 20, 1984.

Lee Wilson and Associates, Inc., 1997. Letter report regarding infiltration studies on the Santa Fe River. Dated July 15, 1997.

Lewis, A.C., and F. West, 1995. Conceptual hydrologic systems for Santa Fe County. NM Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, pp. 229-306.

Longmire, P., 1985. A hydrogeochemical study along the valley of the Santa Fe River, Santa Fe and Sandoval Counties, New Mexico. New Mexico Environment Department, Ground Water and Hazardous Waste Bureau, EID/GWH-85/3, 35 p.

Los Alamos National Laboratory, 1996. Environmental surveillance at Los Alamos during 1995. LA-13210-ENV.

Los Alamos National Laboratory, 1997. Environmental surveillance and compliance at Los Alamos during 1996. LA-13343-ENV.

Los Alamos National Laboratory, 1998. Environmental surveillance at Los Alamos during 1996. LA-13487-ENV.

Los Alamos National Laboratory, 1999. Environmental surveillance at Los Alamos during 1998. LA-13633-ENV.

Lumb, A.M., Kittle, J.L., Jr., and Flynn, K.M., 1990. Users manual for ANNIE, a computer program for interactive hydrologic analyses and data management: U.S. Geological Survey Water-Resources Investigations Report 89-4080, 236 p.

McAda, D.P., 1988. Listings of values for the simulation of the regional geohydrology of the Tesuque aquifer system near Santa Fe, New Mexico: U.S. Geological Survey, Open File Report 88-326. (Supplement to Water-Resources Investigations Report 87-4056), prepared in cooperation with the Santa Fe Metropolitan Water Board.

McAda, D.P, 1990. Simulation of the effects of ground-water withdrawal from a well field adjacent to the Rio Grande, Santa Fe County, New Mexico. U.S. Geological Survey, Water-Resources Investigations Report 89-4184, prepared in cooperation with the Santa Fe Metropolitan Water Board.

McAda, D.P. and M. Wasiolek, 1988. Simulation of the regional geohydrology of the Tesuque aquifer system near Santa Fe, New Mexico. U.S. Geological Survey, Water-Resources Investigations Report 87-4056, prepared in cooperation with the New Mexico State Engineer Office and the Santa Fe Metropolitan Water Board.

McLin, 1996, W.D. Purtymun, A.K. Stoker, and M.N. Maes, 1996. Water supply at Los Alamos during 1994. Los Alamos National Laboratory, LA-13057-PR.

McLin, S.G., W.D. Purtymun, M.N. Maes, 1997a. Water supply at Los Alamos during 1995. Los Alamos National Laboratory, LA-13216-PR.

McLin, S.G., W.D. Purtymun, M.N. Maes, and P.A. Longmire, 1997b. Water supply at Los Alamos during 1996. Los Alamos National Laboratory, LA-13371-PR.

McLin, S.G., W.D. Purtymun, and M.N. Maes, 1998. Water supply at Los Alamos During 1997. Los Alamos National Laboratory, LA-13548-PR.

McMahon, T.A., 1993. Hydrologic design for water use. Chapter 27 in Handbook of Hydrology, D.R. Maidment, Editor in Chief, McGraw-Hill.

McQuillan, D., and R. Montes, 1998. Ground-water geochemistry, Pojoaque Pueblo, New Mexico. New Mexico Environment Department, Ground Water Quality Bureau, NMED/GWB-98/1.

Miller, J.P., 1960. Solutes in small streams draining single rock types, Sangre de Cristo Range, New Mexico. U.S. Geological Survey, Water-Supply Paper 1535-F, 23 p.

Molzen-Corben and Associates, 2000. City of Española, water system master plan, phase 1, final report.

Mourant, W.A., 1980. Hydrologic maps and data for Santa Fe County, New Mexico: New Mexico State Engineer Office Basic Data Report, 180 p., 2 pls.

New Mexico Interstate Stream Commission (ISC), 1994. Regional water planning handbook.

New Mexico Water Quality Control Commission, 2000a. State of New Mexico standards for interstate and intrastate surface waters. 20.6.4 NMAC.

New Mexico Water Quality Control Commission, 2000b. Water quality and water pollution control in New Mexico. NMED/SWQ-00/1.

NM ISC – see New Mexico Interstate Stream Commission.

NMWQCC – see New Mexico Water Quality Control Commission.

Ortiz, D., K. Lange, and L. Beal, 1998. Water resources data, New Mexico, water year 1997: U.S. Geological Survey, Water-Data Report NM-97-1, 574 p.

Purtymun, W. D. and H. Adams, 1980. Geohydrology of Bandelier National Monument, New Mexico.LA-8461-MS.LANL.

Purtymun, W.D. 1984. Hydrologic characteristics of the main aquifer in the Los Alamos area: Development of ground water supplies. Los Alamos, NM: Los Alamos National Laboratory, January 1984.

Purtymun, W.D. and A.K. Stoker. 1988. Water supply at Los Alamos current status of wells and future water supply. Los Alamos, NM: Los Alamos National Laboratory, August 1988.

Purtymun, W.D., and S. Johansen, 1974. General geohydrology of the Pajarito Plateau, in Guidebook to Ghost Ranch (central-northern New Mexico): New Mexico Geological Society, 25t^{h} Field Conference, p. 347-349.

Purtymun, W. D., S. McLin and A. Stoker, 1990. Water supply at Los Alamos during 1990. LA-12471-PR, Los Alamos National Laboratory.

Purtymun, W. D., S. McLin and A. Stoker, 1992. Water supply at Los Alamos during 1992. LA-12926-PR, Los Alamos National Laboratory.

Purtymun, W. D., R. J. Peters and J. W. Owens, 1980. Geohydrology of White Rock Canyon of the Rio Grande from Otowi to Frijoles Canyon. LA-8635-MS, Los Alamos National Laboratory.

Purtymun, W. D., A. K. Stoker and S. G. McLin, 1993. Water supply at Los Alamos during 1993. LA-12951-PR, Los Alamos National Laboratory.

Rasmusson, E.M., R.E. Dickinson, J.E. Kutzback, M.K. Cleaveland, 1993. Climatology. Chapter 2 in Handbook of Hydrology, McGraw Hill.

Reiland, L.J., 1975. Estimated mean-monthly and annual runoff at selected sites in the Pojoaque River drainage basin, Santa Fe County, New Mexico. U.S. Geological Survey Open File Report 74-150, 21 p.

Reiland, Louis J. and Francis C. Koopman. 1975. Estimated availability of surface and ground water in the Pojoaque River drainage basin, Santa Fe County, New Mexico. U.S. Geological Survey Open File Report 74-151, 35 p.

SCS - See U.S. Soil Conservation Service

Shaull, D. A., M.R. Alexander and R.P. Reynolds, 1996a. Surface water data at Los Alamos National Laboratory, 1995 water year. Los Alamos National Laboratory, LA-13177-PR.

Shaull, D.A., M.R. Alexander, R.P. Reynolds and C.T. McLean, 1996b. Surface water data at Los Alamos National Laboratory, 1996 water year. Los Alamos National Laboratory, LA-13234-PR.

Shaull, D.A., M.R. Alexander, R.P. Reynolds and C.T. McLean, 1998. Surface water data at Los Alamos National Laboratory, 1997 water year. Los Alamos National Laboratory, LA-13403-PR.

Shaull, D.A., M.R. Alexander, R.P. Reynolds, C.T. McLean, 1999. Surface water data at Los Alamos National Laboratory, 1998 water year. Los Alamos National Laboratory, LA-13403-PR.

Shaull, D.A., M.R. Alexander, R.P. Reynolds and C.T. McLean, 2000. Surface water data at Los Alamos National Laboratory, 1999 water year. Los Alamos National Laboratory, LA-13403-PR.

Shomaker and Associates, 1996. Hydrogeologic study for a new supply well in the northwest quadrant of the Santa Fe Grant. August 1996.

Shuttleworth, W.J., 1993. Evaporation. Chapter 8 in Handbook of Hydrology, McGraw Hill.

Spell, T.L., T.M. Harrison, and J.A. Wolf, 1990. 40Ar/39Ar dating of the Bandelier Tuffs and San Diego Canyon ignimbrites, Jemez Mountains, New Mexico: temporal constraints on magmatic evolution. Journal of Volcanology and Geothermal Research, v 43, pp. 175-193.

Spiegel, Z., and B. Baldwin, 1963. Geology and water resources of the Santa Fe area, New Mexico. U.S. Geological Survey, Water Supply Paper 1525, prepared with the New Mexico Bureau of Mines and Mineral Resources and Geophysics Laboratory of the New Mexico Institute of Mining and Technology, in cooperation with the State Engineer of New Mexico.

Stahle, D.W., E.R. Cook, M.K. Cleaveland, M.D. Therrel, D.M. Meko, H.D. Grissino-Mayer, E. Watson, and B.H. Luckman, 2000. EOS Transactions, vol. 81, no. 12, March 21, 2000.

Stedinger, J.R., R.M. Vogel, and E. Foufia-Georgiou, 1993. Frequency analysis of extreme events. Chapter 18 in Handbook of Hydrology, McGraw-Hill.

Suhr, W., 1999. A water budget model for estimating runoff in the Tesuque-Nambe area. Presentation to the Technical Subcommittee for the Jemez y Sangre Water Planning Council, August, 1999.

Thomas, C.L., A.E. Stewart, and J. Constantz, 1999. Comparison of methods to determine infiltration and percolation rates along a reach of the Santa Fe River near La Bajada, New Mexico. Proceedings of the USGS Third Annual Workshop on the Middle Rio Grande Basin, Albuquerque, New Mexico, February 24-25, 1999.

Thomas, C.L., A.E. Stewart, and J. Constantz, 2000. Determination of infiltration and percolation rates along a reach of the Santa Fe River near La Bajada, New Mexico. U.S. Geological Survey, Water Resources Investigations Report 00-4141.

Tuan, Y-F, C.E. Everald, and J.G. Widdison, 1969. The climate of New Mexico. New Mexico State Planning Office.

U.S. Army Corps of Engineers, 2000. Upper Rio Grande water operations model (URGWOM), physical model documentation, technical review committee draft. Prepared under cooperative agreement by U.S. Army Corps of Engineers, Albuquerque District, United States Geological Survey, New Mexico District, U.S. Bureau of Reclamation, Albuquerque Area Office, U.S. Fish and Wildlife Service, NM Ecological Field Office, U.S. Bureau of Indian Affairs, Albuquerque Area Office, International Boundary and Water Commission, U.S. Section, January 26, 2000.

U.S. Bureau of Reclamation, 1982. San Juan-Chama Project, Colorado: Archuleta and Mineral Counties, New Mexico: Rio Arriba and Santa Fe Counties. Southwest Region, Bureau of Reclamation, 8 p.

U.S. District Court, 1994. Order of the Court relating to (1) provisions of subfile order adjudicating the amount of water of non-Pueblo defendants' irrigation water rights and (2) provisions for subfile orders describing the purpose of use of non-Pueblo defendants' domestic and livestock well rights. In State of New Mexico, ex rel., State Engineer vs. R. Lee Aamodt et al.

U.S. District Court, 1997. Special Master's report to the Court recommending adoption of findings of fact pertaining to hydrology and denial of the Pueblos' motion for an evidentiary hearing. In State of New Mexico, ex rel., State Engineer vs. R. Lee Aamodt et al.

U.S. Environmental Protection Agency (EPA), 1976. Quality criteria for water.

U.S. Environmental Protection Agency (EPA), 1986. Quality criteria for water – 1986. EPA 440/5-80.

U.S. Environmental Protection Agency (EPA), 2000a. STORET database.

USGS – see U.S. Geological Survey.

U.S. Environmental Protection Agency (EPA), 2000b. Drinking water standards and health advisories. Office of Water, EPA 822-B-00-001.

U.S. Geological Survey (USGS), 1999. The quality of our nation's waters, nutrients and pesticides. U.S. Geological Survey Circular 1225, 82 p.

U.S. Soil Conservation Service (SCS), 1972. Normal annual precipitation, New Mexico: U.S. Department of Agriculture Map 4-R-33714.

Vickers, A., 1990. Water-use efficiency standards for plumbing fixtures: benefits of national legislation. In Journal of the American Water Works Association, 82(5), p. 51-54, American Water Works Association, Denver, CO.

Wasiolek, M., 1995. Subsurface recharge to the Tesuque aquifer system from selected drainage basins along the western side of the Sangre de Cristo Mountains near Santa Fe, New Mexico. U.S. Geological Survey, prepared in cooperation with the Santa Fe Metropolitan Water Board and the New Mexico State Engineer Office, Water-Resources Investigations Report 94-4072.

White, W.E. and G.E. Kues. 1992. Inventory of springs in the State of New Mexico. Albuquerque, NM: U.S. Geological Survey, prepared in cooperation with the New Mexico State Engineer 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, September 1997.

Wilson, B.C., 1992. Water use by categories in New Mexico counties and river basins, and irrigated acreage in 1990. Santa Fe, NM: New Mexico State Engineer Office Technical Report 47, July 1992.

APPENDIX A

GLOSSARY

GLOSSARY

ACRE-FOOT: Volume of water required to cover 1 acre of land (43,560 square feet) to a depth of 1 foot, equivalent to 325,851 gallons.

ALLUVIUM: General term for deposits of clay, silt, sand, gravel, or other particulate material deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at a base of a mountain.

AQUIFER: A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

ARTESIAN WATER: Groundwater under sufficient pressure to rise above the level at which the water-bearing bed is reached in a well. The pressure in such an aquifer commonly is called artesian pressure, and the formation containing artesian water is an artesian aquifer.

ARTIFICIAL RECHARGE: The addition of water to the groundwater reservoir by man's activities, such as irrigation or induced infiltration from stream or wells.

AVERAGE ANNUAL YIELD (WATER): The average annual supply of water produced by a given stream or water development over a period of 12 months.

BANK STORAGE: Water absorbed and stored in the banks of a stream, lake, or reservoir when the stage rises above the water table in the bank formations and stays there for an appreciable length of time. Bank storage may be returned in whole or in part as seepage back to the water body when the level of the surface water returns to a lower stage.

BASE FLOW: Sustained or fair-weather runoff – generally that portion of the streamflow derived from discharging groundwater or other delayed sources such as lakes or snow fields.

BEDLOAD: That part of the sediment load in which the particles of material move on or near the streambed.

BENEFICIAL USE OF WATER: The use of water by man for any purpose from which benefits are derived, such as domestic, municipal, irrigation, livestock, industrial, power development, and recreation. Under the New Mexico Constitution, beneficial use is the basis, the measure, and the limit of the right to use water; therefore, beneficial use of public water diverted or impounded by man-made works is an essential element in the development of a water right.

BOLSON: An alluvium-floored basin, depression, or wide valley, mostly surrounded by mountains and drained by a system that has no surface outlet. Bolson fill is the alluvial detritus that fills a bolson - - also commonly called bolson deposits.

CLOSED BASIN: A basin is considered a closed basin with respect to surface flow if its topography prevents the occurrence of visible outflow. It is closed hydrologically if neither surface nor underground outflow can occur.

CONFINING BED: A rock formation that will not readily transmit water and which retards or stops the free movement of water underground. Confining beds have also been called aquicludes, aquitards, or semiconfining beds.

CONJUNCTIVE WATER USE: Combined use of groundwater and surface water.

CONSUMPTIVE IRRIGATION REQUIREMENT (CIR): The quantity of water, exclusive of precipitation, stored soil moisture, or groundwater that is required consumptively for crop production.

CONSUMPTIVE USE (EVAPOTRANSPIRATION): The quantity of water used in a given area in transpiration, building of plant tissue, and evaporated from adjacent soil, water surface, snow, or intercepted precipitation in a specific period to time.

CONVEYANCE LOSS: Water that is lost in transit from a canal, conduit, or ditch by leakage or evaporation. Generally, the water is not available for further use; however, leakage from an irrigation ditch, for example, can percolate to a groundwater source and be available for further use.

CUBIC FOOT PER SECOND: The rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second. It is equivalent to 7.48 gallons per second, or 448.8 gallons per minute.

DECLARED UNDERGROUND WATER BASIN: An area of the state proclaimed by the State Engineer to be underlain by a groundwater source having reasonably ascertainable boundaries. By such proclamation, the State engineer assumes jurisdiction over the appropriation and use of groundwater from the source.

DEPLETION: That part of a withdrawal that has been evaporated, transpired, incorporated into crops or products, consumed by man or livestock, or otherwise removed.

DISCHARGE: Rate of flow at a given instance in terms of volume per unit of time; pumping discharge equals pumping rate, usually given in gallons per minute (gal/min); stream discharge; usually given in cubic feet per second (ft^3/s). With respect to water underground, the movement of water out of an aquifer. Discharge may be

natural, as from springs, as by seepage, or by evapotranspriation, or it may be artificial as by constructed drains or from wells.

DISSOLVED OXYGEN: The amount of free (not chemically combined) oxygen in water. Usually expressed in milligrams per liter.

DISSOLVED SOLIDS: Chemical compounds in solution.

DIVERSION: A turning aside or alteration of the natural course of a flow of water, normally considered physically to leave the natural channel. In some States, this can be a consumptive use direct from a stream, such as by livestock watering. In other States, a diversion must consist of such actions as taking water through a canal or conduit.

DOMESTIC WATER USE: Water for normal household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns, gardens and livestock supplied from a domestic source. Also called residential water use. The water can be obtained from a public supply or self-supplied.

DRAINAGE BASIN: A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

DRAWDOWN (GROUNDWATER): The depression or decline of the water level or potentiometric surface in a pumped well or in nearby wells caused by pumping. At the well, it is the vertical distance between the static and the pumping level.

EPHEMERAL STREAM: A stream or portion of a stream which flows only in direct response to precipitation. Such flow is usually of short duration. Most of the dry washes of the region may be classified as ephemeral streams.

EVAPORATION: Process by which water is changed from the liquid state to the vapor state. See also Evapotranspiration; Transpiration.

EVAPORATION, NET RESERVOIR: The evaporative water loss from a reservoir after making allowances for precipitation on the reservoir. Net reservoir evaporation equals the total evaporation minus the precipitation on the reservoir surface.

EVAPOTRANSPIRATION: The process by which water is returned to the air through direct evaporation or by transpiration of vegetation.

FALLOW: Cropland, either tilled or untilled, allowed to lie idle, during the whole or greater

part of the growing season.

FARM EFFICIENCY: The consumptive crop irrigation requirement divided by the farm delivery.

FLOOD PLAIN: Land bordering a stream. The land was built up of sediment from overflow of the stream and is still subject to flooding when the stream is at flood stage.

FREE-FLOWING WELL: An artesian well in which the potentiometric surface is above the Land. See also Potentiometric surface.

FRESHWATER: Water that contains less than 1,000 mg/L (milligrams per liter) of dissolved solids; generally, more than 500 mg/L is considered undesirable for drinking and many industrial uses.

FURROW IRRIGATION: See Irrigation.

GAGING STATION: A particular site on a stream, canal, lake or reservoir where systematic observations of gage height or discharge are made.

GAINING STREAM: A river, reach of a stream or river, that gains in flow from groundwater seepage or from springs in, or alongside, the channel – sometimes called an effluent stream.

GROUNDWATER: Generally, all subsurface water as distinct from surface water, specifically, that part of the subsurface water in the saturated zone (a zone in which all voids, large and small, ideally are filled with water under pressure equal to or greater than atmospheric).

GROUNDWATER MINING: The condition that exists when the withdrawal of water from an aquifer exceeds the recharge causing a decline in the groundwater level.

GROUNDWATER RECHARGE: The addition of water to the zone of saturation. Infiltration of precipitation and its movement to the water table is one form of natural recharge.

GROUNDWATER RESERVOIR STORAGE: The amount of water in storage within the defined limit of the aquifer.

HYDRAULIC GRADIENT (GROUNDWATER): The gradient or slope of the water table or potentiometric surface in a specific direction.

HYDROGRAPH: A graph showing the stage, flow, velocity, or other property of water with

respect to the passage of time. Hydrographs of wells show the changes in water levels during the period of observation.

IMPERMEABLE: Not capable of transmitting fluids or gases in appreciable quantities. Few rocks are completely impermeable; but some – such as unweathered granite, dense basalt, welded tuff, dense limestone, and well-cemented conglomerate – may be so considered impermeable for practical purposes.

INTERBASIN TRANSFER OF WATER: See water exports; Water imports.

INTERMITTENT STREAM: A stream which flows for only part of the time. Flow generally occurs for several weeks or months in response to seasonal precipitation, due to groundwater discharge, in contrast to the ephemeral stream that flows but a few hours or days following a single storm.

IRRIGATED AREA: The gross area upon which water is artificially applied.

IRRIGATION: Generally, the controlled application of water to arable lands to supply water requirements of crops not satisfied by rainfall. (See also Irrigation water use.) Systems used include the following:

Drip: An irrigation system in which water is applied directly to the root zone of plants by means of applicators (orifices, emitters, porous tubing, perforated pipe, and so forth) operated under low pressure. The applicators can be placed on or below surface of the ground or can be suspended from supports.

Flood: The application of irrigation water where the entire surface of the soil is covered by ponded water.

Furrow: A partial surface flooding method of irrigation normally used with clean-tilled crops where water is applied in furrows or rows of sufficient capacity to contain the design irrigation stream.

Gravity: Irrigation in which the water is not pumped but flows in ditches or pipes and is distributed by gravity.

IRRIGATION CONVEYANCE LOSS: The loss of water in transit from a reservoir, point of diversion, or groundwater pump, to the point of use, whether in natural channels or in artificial ones, such as canals, ditches, and laterals.

IRRIGATION EFFICIENCY: The percentage of the water diverted from a water source that is consumed. It is the product of the distribution efficiency and the farm efficiency.

IRRIGATION LEACHING REQUIREMENT: The amount of water required to move residual

salts out of the root zone and maintain and adequate soil-salt balance for crop production.

IRRIGATION REQUIREMENT: The quantity of water, exclusive of precipitation, that is required for production of a specific crop.

IRRIGATION RETURN FLOW: Part of irrigation water that is not consumed by evapotranspiration and that drains from the irrigated area to an aquifer or surface-water body.

IRRIGATION WATER USE: Artificial application of water on lands to assist in the growing of crops and pastures or to maintain vegetative growth on recreational lands such as parks and golf courses. See also Irrigation.

LOSSES INCIDENTAL TO IRRIGATION: The quantity of water depleted by irrigation in excess of the beneficial irrigation consumptive use.

MILLIGRAMS PER LITER: The weight in milligrams of any substance contained in 1 liter of liquid. (Equivalent to parts per million for values less than about 7,000 mg/L.)

MILLIONS GALLONS PER DAY: A rate of flow of water of one million gallons per twenty four hour period.

OVERDRAFT: Withdrawals of groundwater at rates perceived to be excessive. See also Groundwater mining.

PER CAPITA USE: The average amount of water used per person during a standard time period, generally a day.

PERCHED GROUNDWATER: Water in a saturated zone of material underlain by a relatively impervious stratum which acts as barrier to downward flow and which is separated from the main groundwater body by a zone of unsaturated material above the main groundwater body.

PERENNIAL STREAM: A stream that normally has water in its channel at all times.

PHREATOPHYTE: A plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe.

PLAYA: Flat-floored bottom of an undrained desert plains basin.

POROSITY: The ratio of the total volume of pore space (voids) in a rock or soil to its total

volume, usually stated as a percentage. Effective porosity is the ration of the volume of interconnected voids to the total volume. Unconnected voids contribute to total porosity but are ineffective in transmitting water through the rock.

POTENTIOMETRIC SURFACE: An imaginary surface representing the static head of ground water in tightly cased wells that tap a water-bearing rock unit (aquifer); or in the case of unconfined aquifers, the water table.

PRECIPITATION: Includes atmospheric hail, mist, rain, sleet and snow which descends upon the earth; the quantity of water accumulated from the above events.

RECHARGE: The addition of water to an aquifer by infiltration, either directly into the aquifer or indirectly by way of another rock formation. Recharge may be natural, as when precipitation infiltrates to the water table, or artificial, as when water is injected through wells or spread over permeable surfaces for the purpose of recharging an aquifer.

RECOVERABLE GROUNDWATER: The amount of water which may be physically and economically withdrawn from the groundwater reservoir.

RETURN FLOW: That part of a diverted flow which is not consumptively used and which returns to a water body.

RIPARIAN VEGETATION: Vegetation growing on the banks of a stream or other body of surface water.

RUNOFF: The part of the precipitation that appears in the surface streams.

SALINE WATER: Water that contains more than 1,000 milligrams per liter of dissolved solids. It generally is considered unsuitable for human consumption and less desirable for irrigation because of its high content of dissolved solids. Salinity generally is expressed as milligrams per liter (mg/L) of dissolved solids, with 35,000 mg/L defined as seawater. A general salinity scales is:

SALINITY	DISSOLVED SOLIDS (MG/L)
Slight	1,000 – 3,000
Moderate	3,000 – 10,000
Very	10,000 – 35,000
Brine	More than 35,000.

SALT WATER INTRUSION: Replacement of freshwater by saline water in an aquifer or body

of water.

SEWAGE: Waste matter carried off by sewer and drains.

SEWAGE TREATMENT: The processing of wastewater for the removal or reduction of the level of dissolved solids or other undesirable constituents.

SEWAGE-TREATMENT RETURN FLOW: Water returned to the hydrologic system by sewage-treatment facilities.

STREAM, PERENNIAL: A stream that flows continuously.

STREAMFLOW: The discharge that occurs in a natural channel of a surface stream course.

SURFACE WATER: An open body of water, such as a stream or a lake.

SUSPENDED SEDIMENT: Sediment that is transported in suspension by a stream. Fragmental material, and organic material, that is maintained in suspension in water by the upward components of turbulence and currents and (or) by colloidal suspension.

TAILWATER RECOVERY: Process of collecting irrigation water runoff for reuse.

TOTAL DISSOLVED SOLIDS (TDS): An aggregate of carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates, etc., of calcium, magnesium, manganese, sodium, potassium, and other cations which form salts. High TDS solutions have the capability of changing the chemical nature of water. High TDS concentrations exert varying degrees of osmotic pressures and often become lethal to the biological in habitants of an aquatic environment. The common and synonymously used term for TDS is "salt."

TRANSMISSIBILITY (GROUNDWATER): The rate at which water at the prevailing water temperature is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is generally expressed as gallons per day through a vertical strip of the aquifer 1 foot wide under a gradient of 1 foot per foot, or more recently as cubic feet per day under the same conditions. It replaces the term "coefficient of transmissibility."

TRANSPIRATION: Process by which water is absorbed by plants, usually through the roots. The residual water vapor is emitted into the atmosphere from the plant surface. See also Evaporation; Evapotranspiration.

TURBIDITY: The opaqueness or reduced clarity of a fluid due to the presence of suspended

matter.

WASTEWATER: Water that contains dissolved or suspended solids as a result of human waste.

WATER BUDGET: An accounting of the inflow to, outflow from, and storage changes of water in a hydrologic unit.

WATER EXPORTS: Artificial transfer (pipe, canals) of water to one region or subregion from another.

WATER RIGHT: Legal rights to use a specific quantity of water, on a specific time schedule, at a specific place, and for a specific purpose.

WATER TABLE: The upper surface of zone saturation. See also Potentiometric Surface.

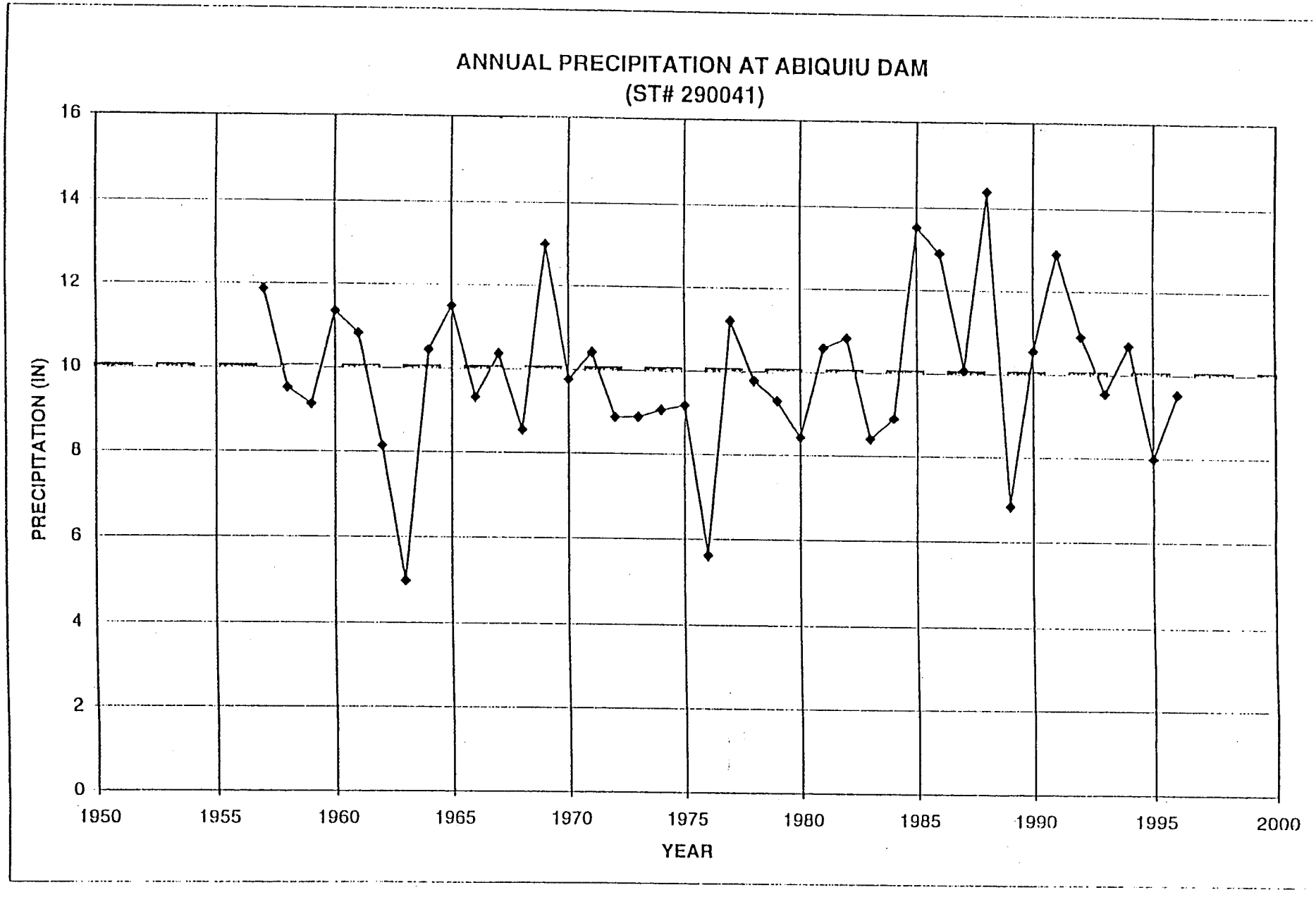
WETLANDS: Lands that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support and that, under normal circumstances, do support a prevalence of vegetation typically adapted for life in saturated soil conditions.

WITHDRAWAL: Water removed from the ground or diverted from a surface-water source for use.

ZONE OF SATURATION: The zone in which all the connected interstices or voids in permeable rock or soil formations are filled with water under pressure equal to, or greater than atmospheric pressure.

APPENDIX B

ANNUAL PRECIPITATION AT NOAA WEATHER STATIONS AND MOVING AVERAGE ANALYSES


ANNUAL PRECIPITATION AT ABIQUIU DAM
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16
14
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4
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1960
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1970
1975
1980
1985
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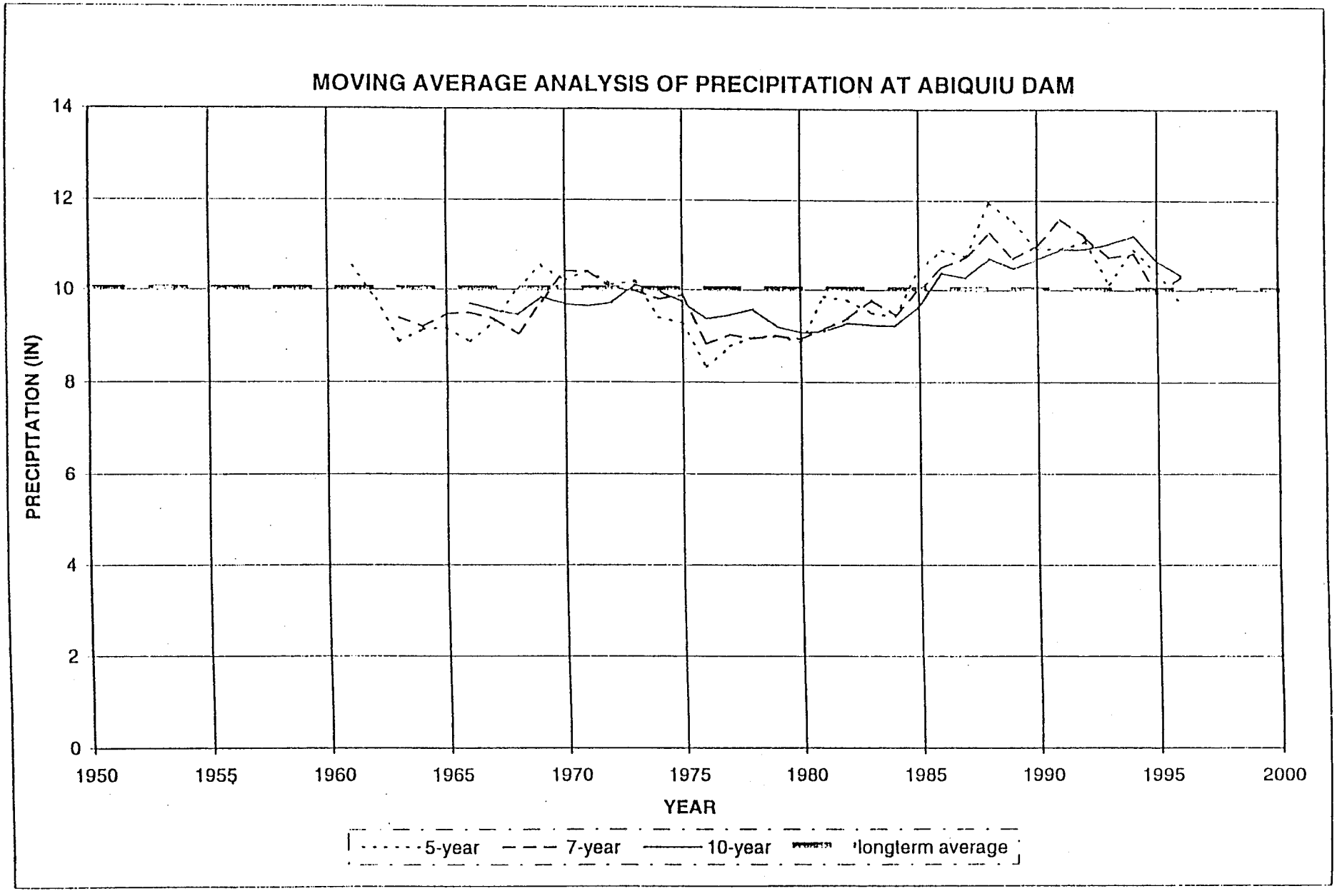
1995
2000
YEAR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PRECIPITATION (IN)
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1960
1965
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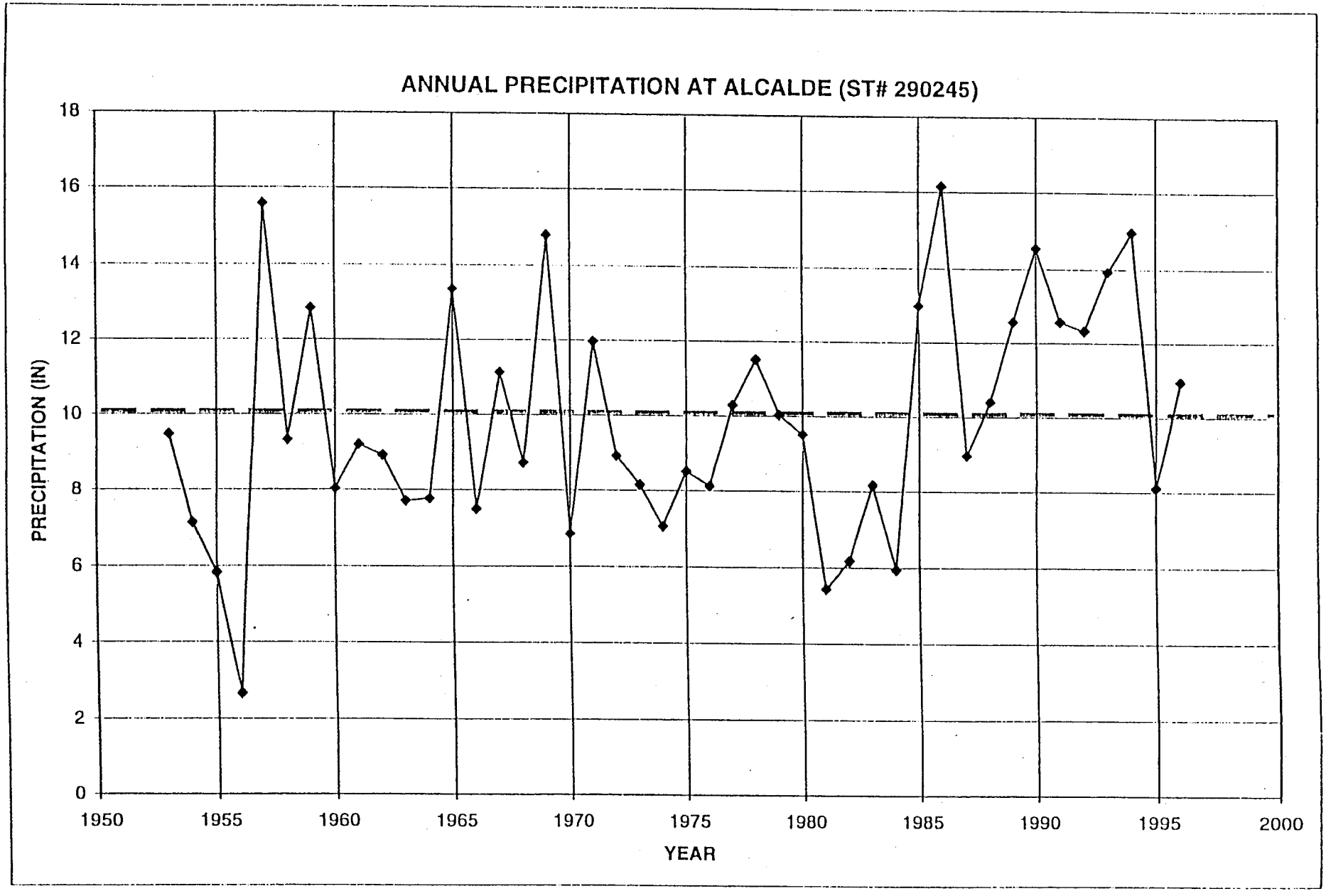
1980
1985
1990
1995
2000
YEAR
5-year
7-year
10-year
longterm average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16
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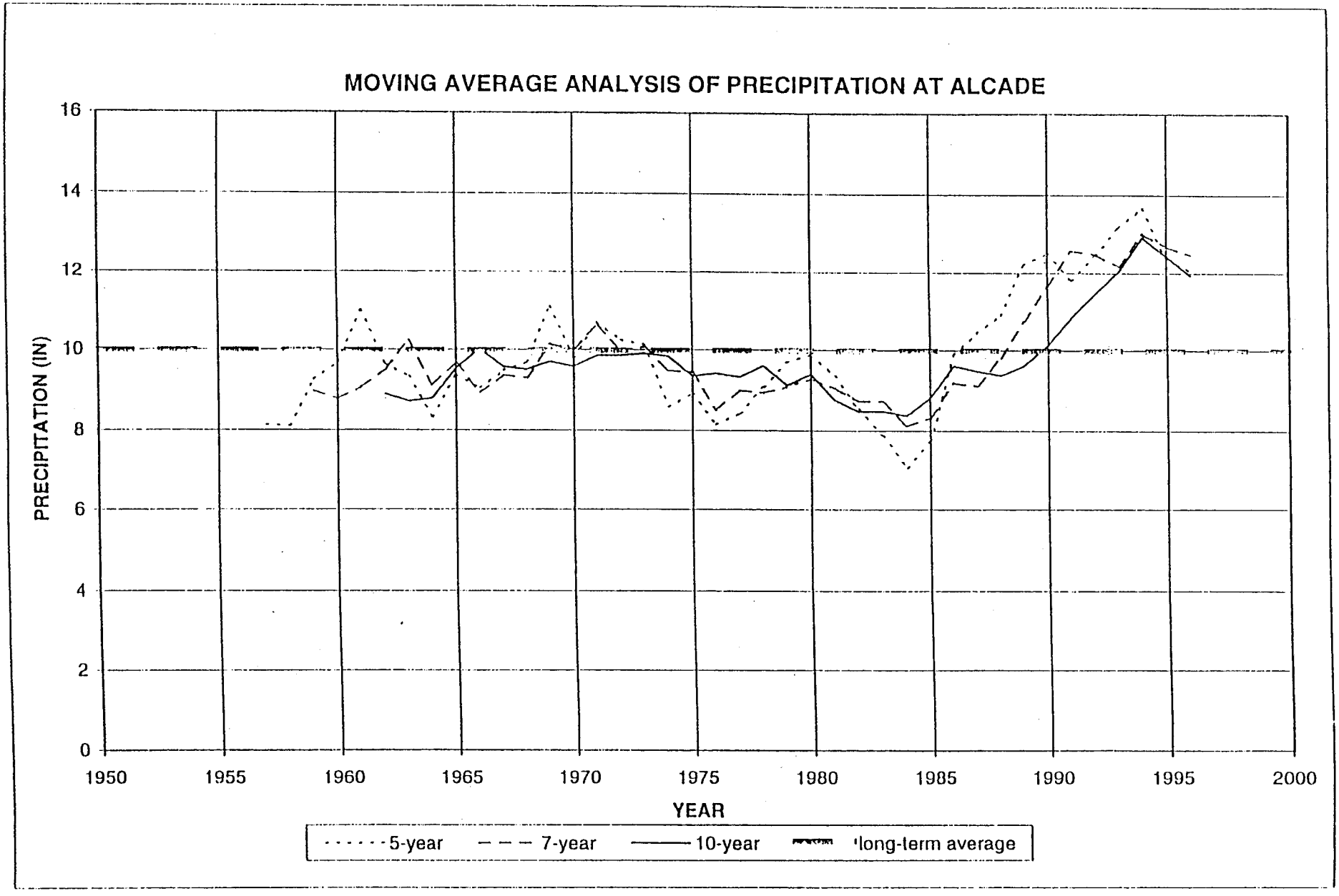
1995
2000
YEAR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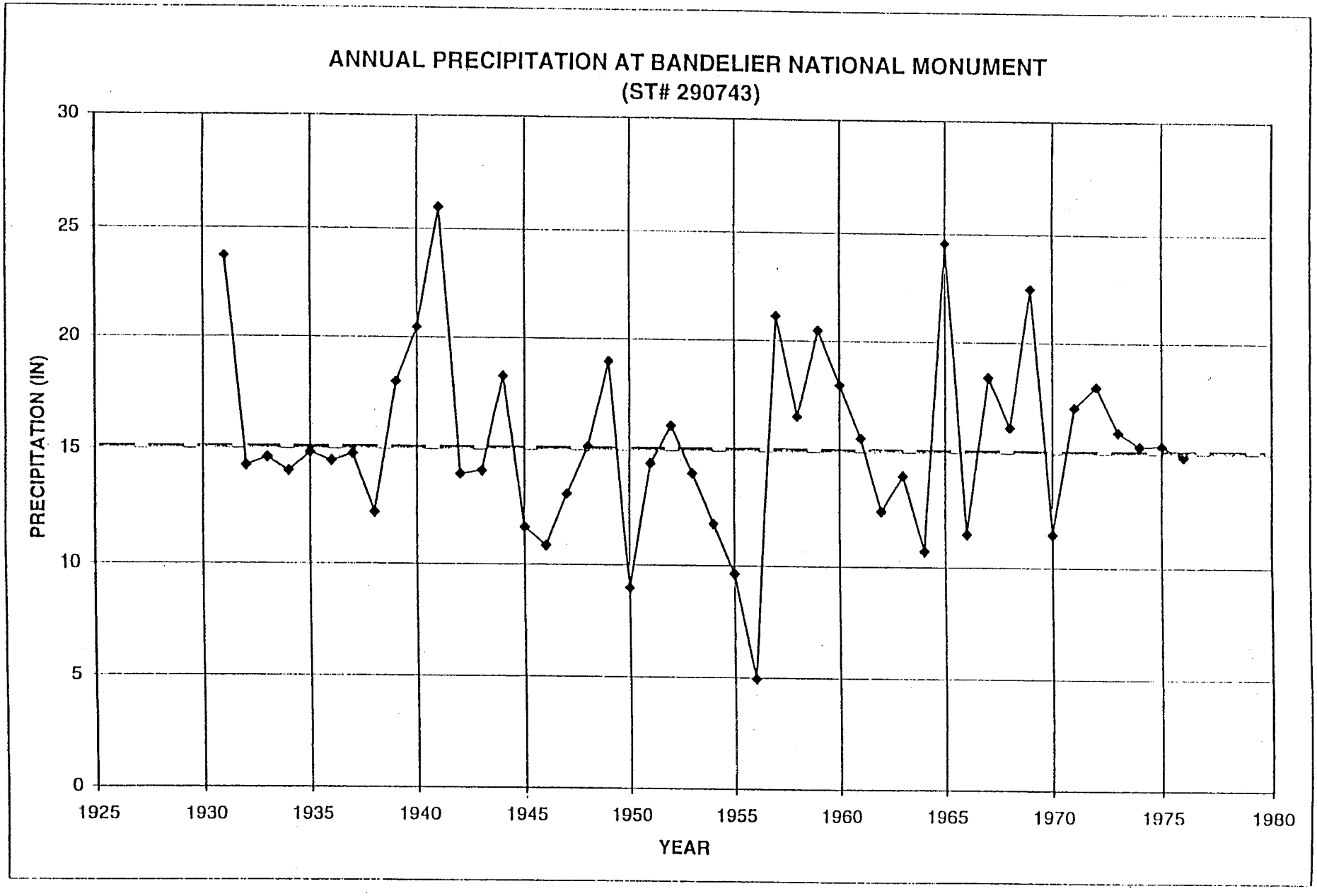
YEAR
5-year
7-year
10-year
long-term average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PRECIPITATION (IN)
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5
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1925
1930
1935
1940
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1975
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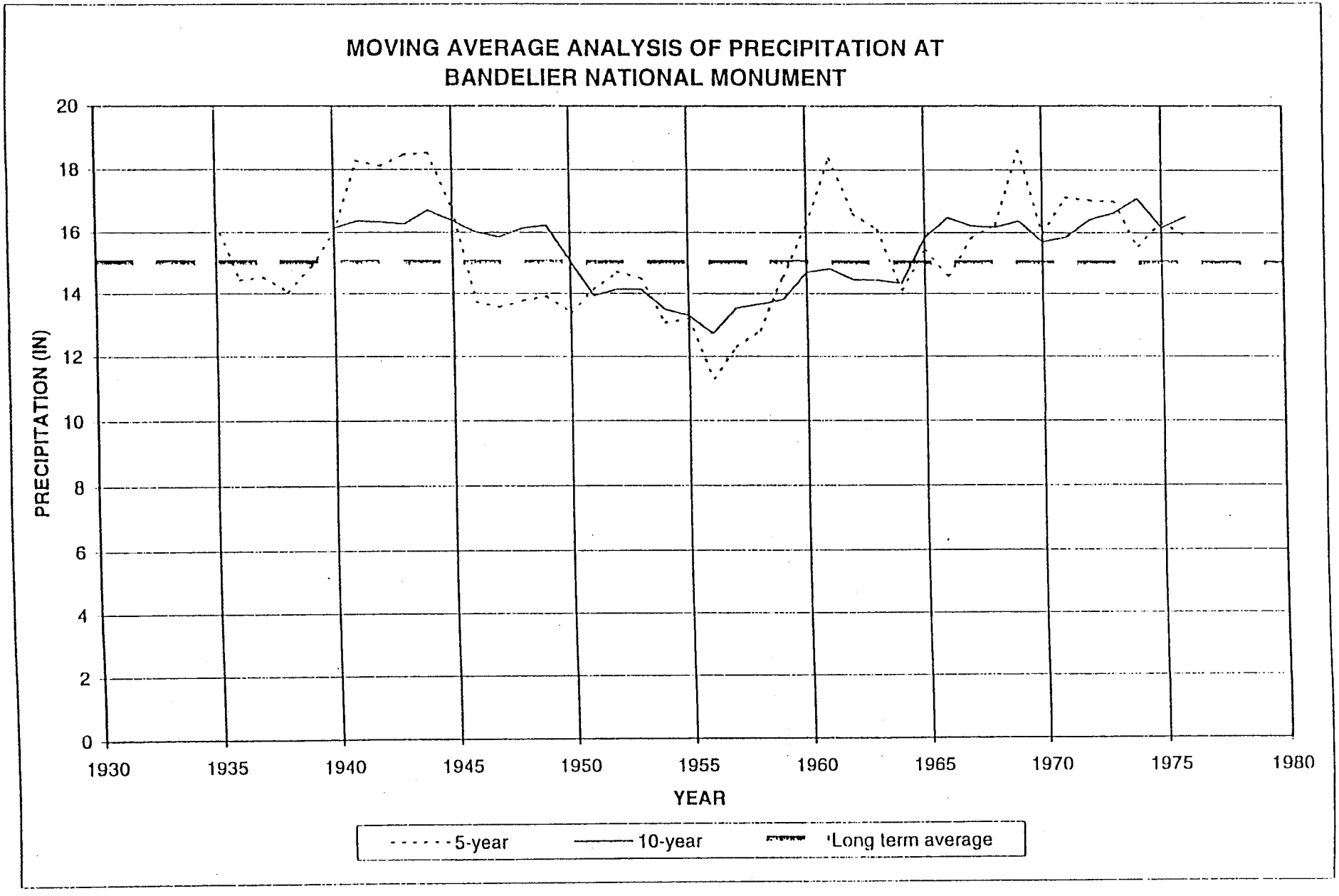
YEAR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BANDELIER NATIONAL MONUMENT
PRECIPITATION (IN)
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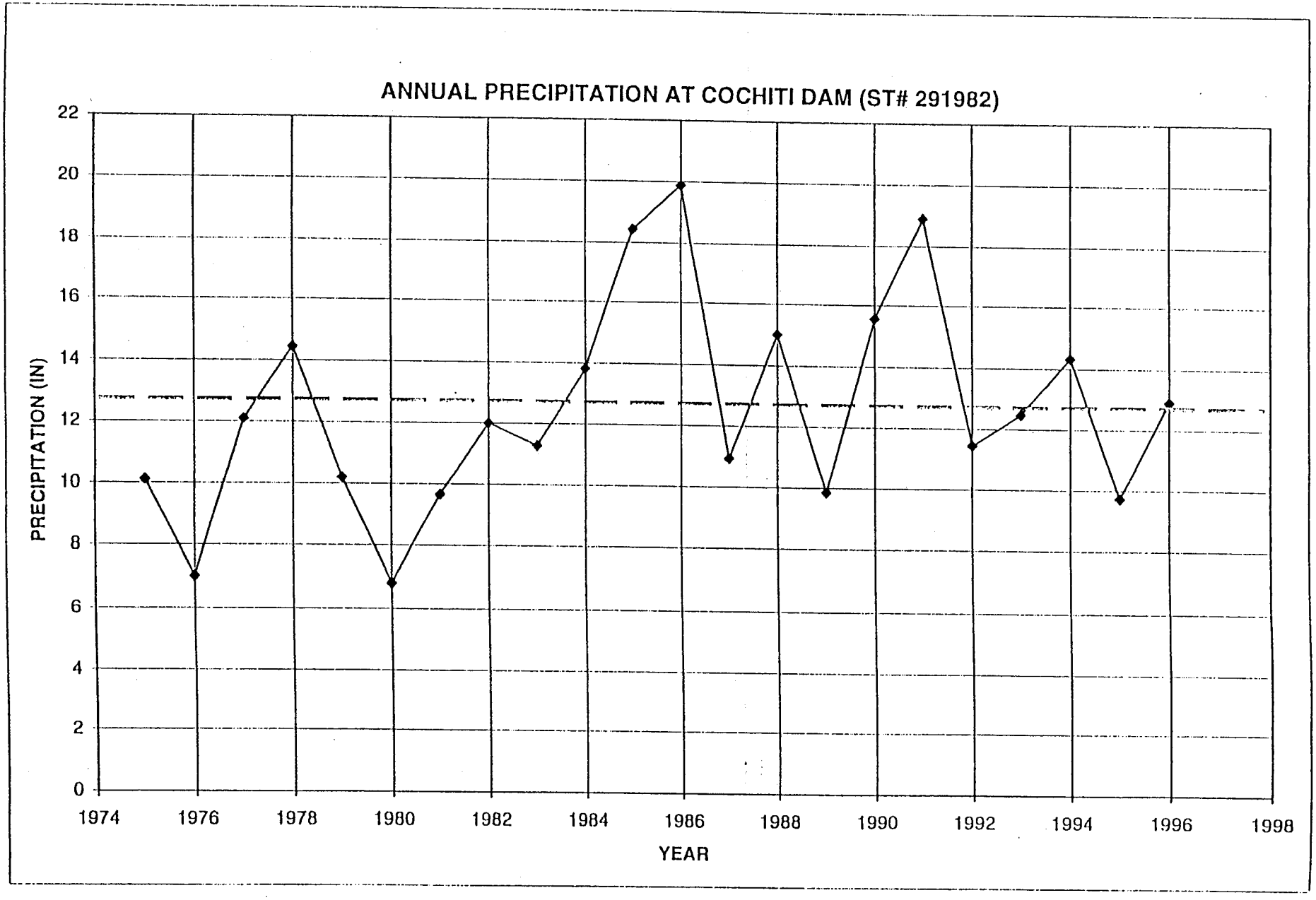
YEAR
5-year
10-year
Long term average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PRECIPITATION (IN)
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1976
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1982
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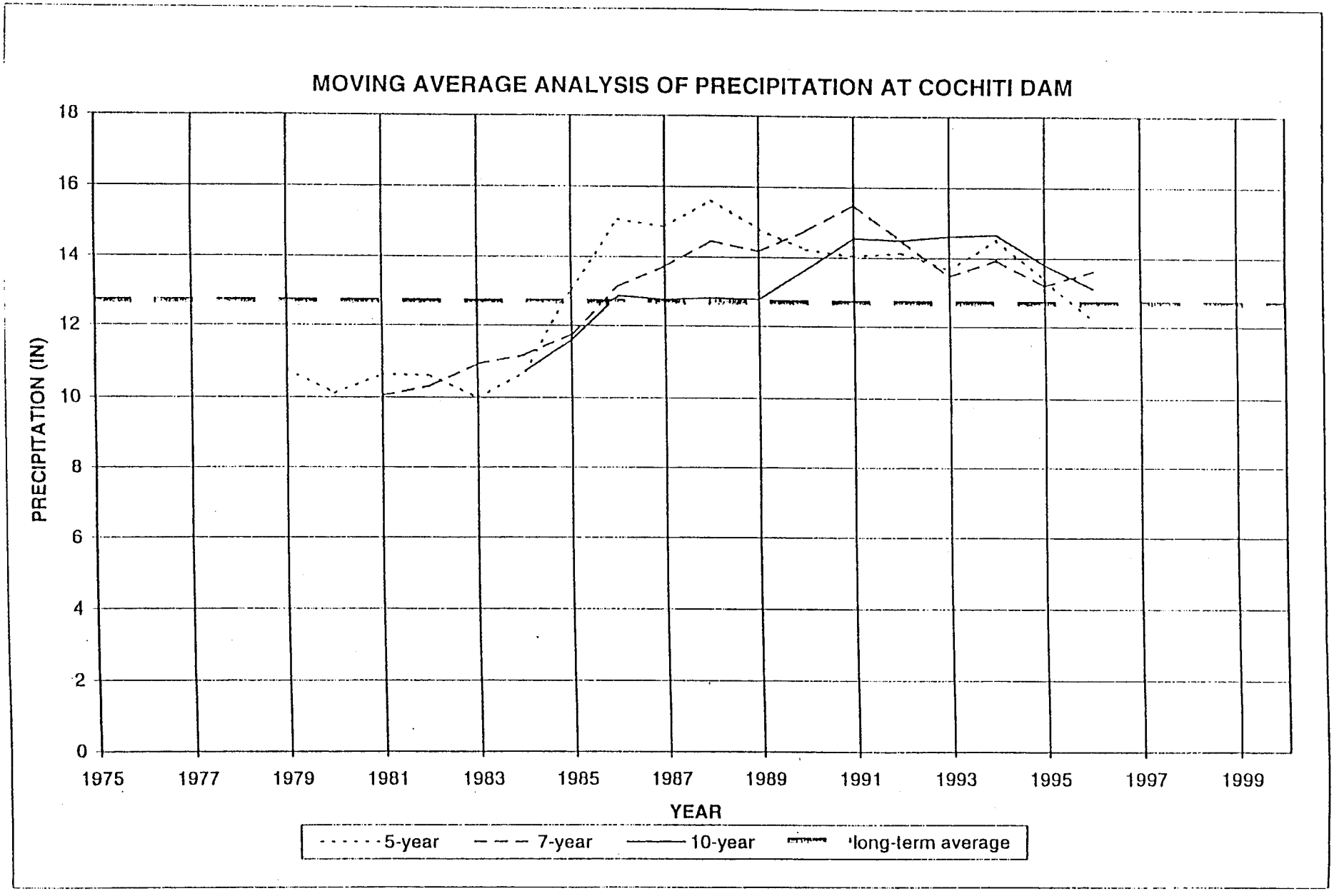
1998
YEAR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PRECIPITATION (IN)
18
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1995
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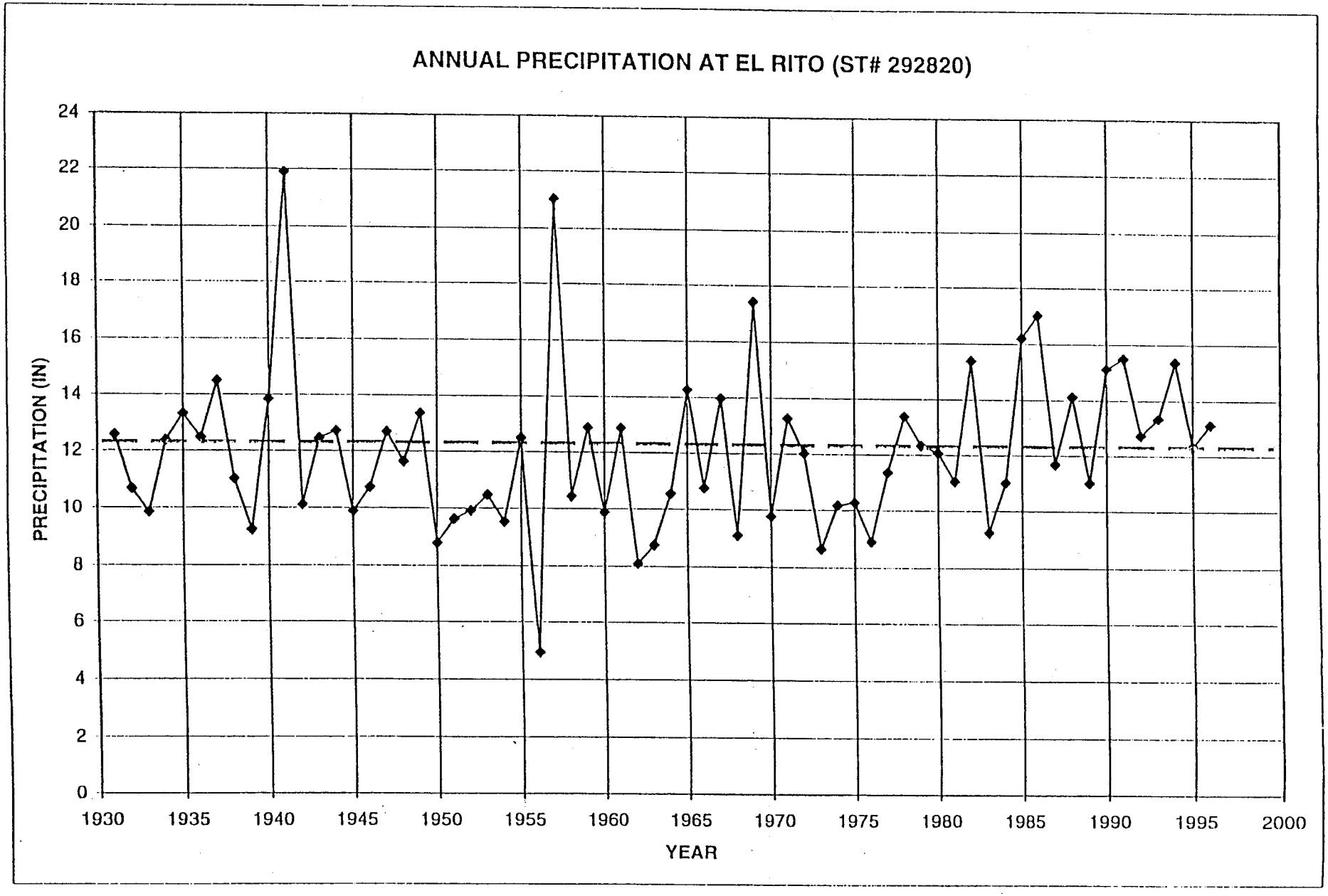
YEAR
5-year
7-year
10-year
long-term average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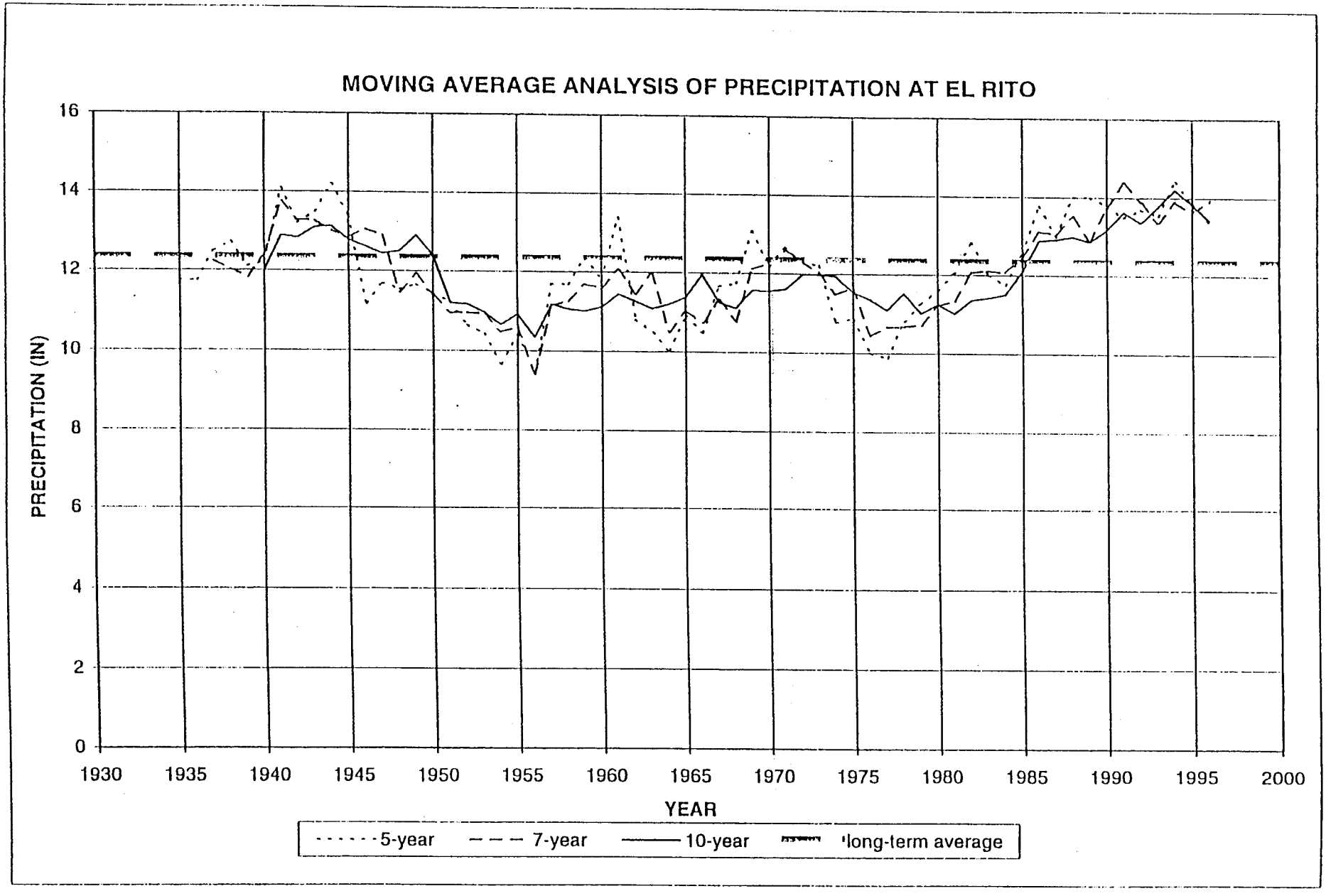
YEAR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PRECIPITATION (IN)
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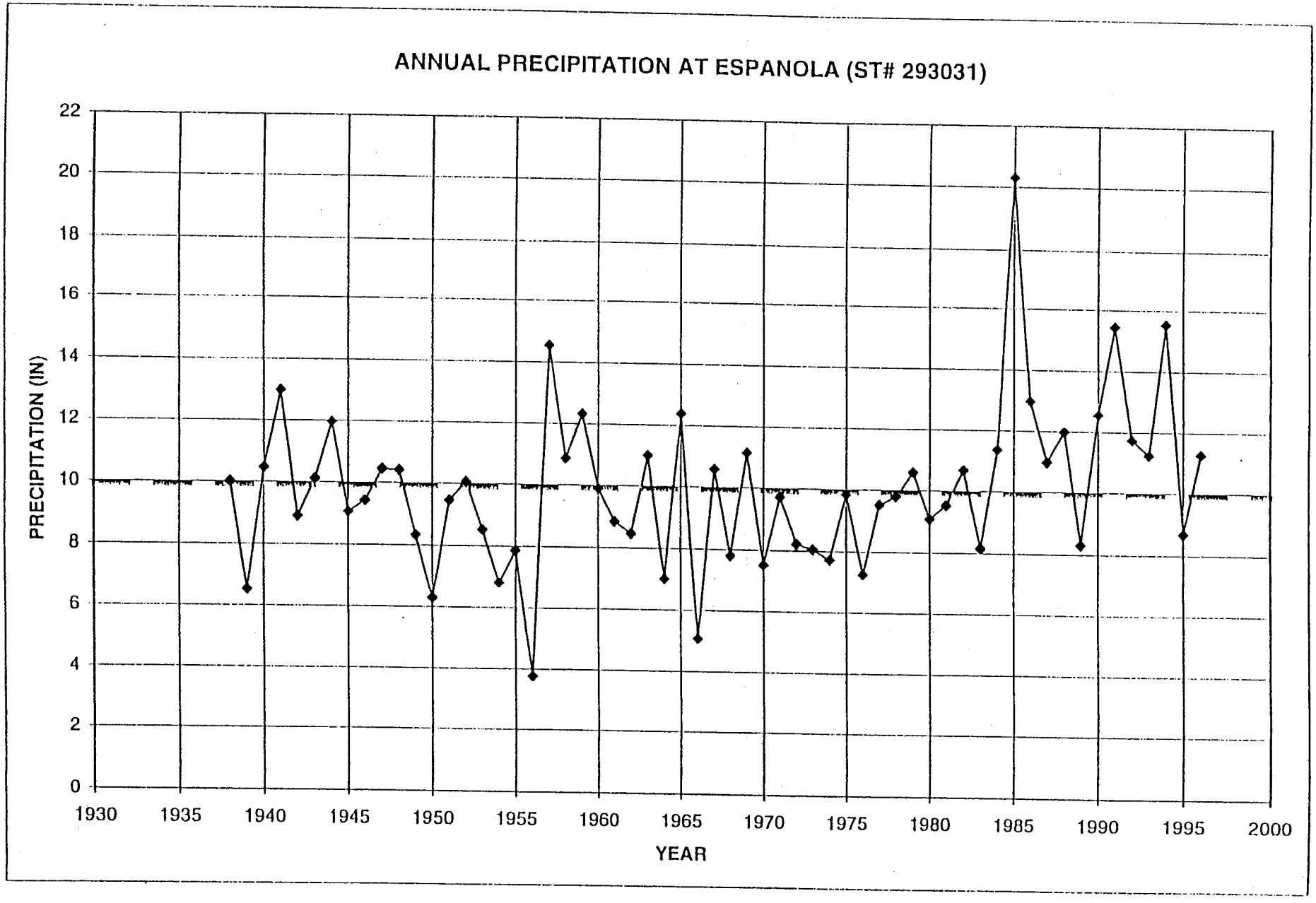
YEAR
5-year
7-year
10-year
long-term average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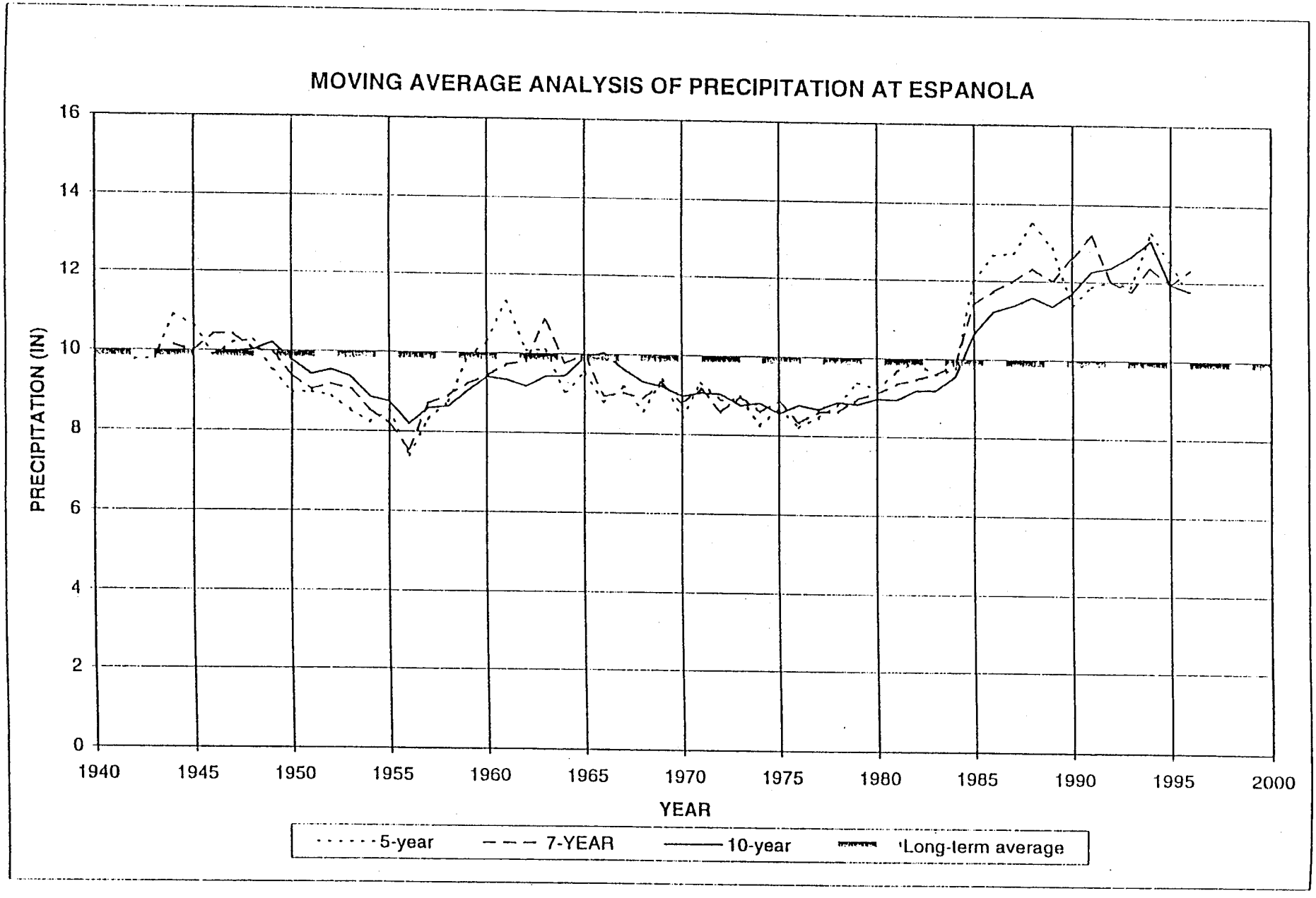
YEAR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YEAR
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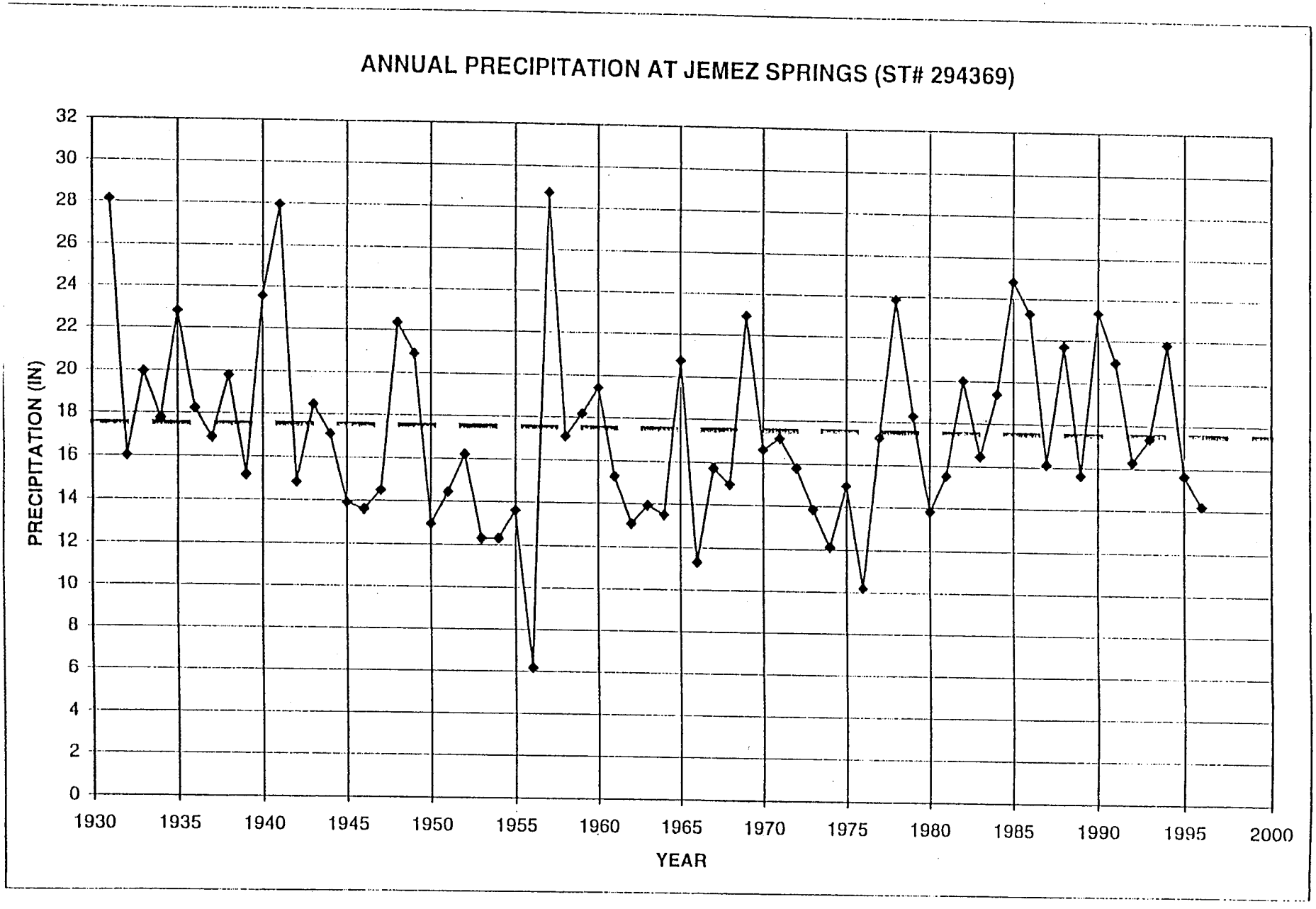
10-year
Long-term average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PRECIPITATION (IN)
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28
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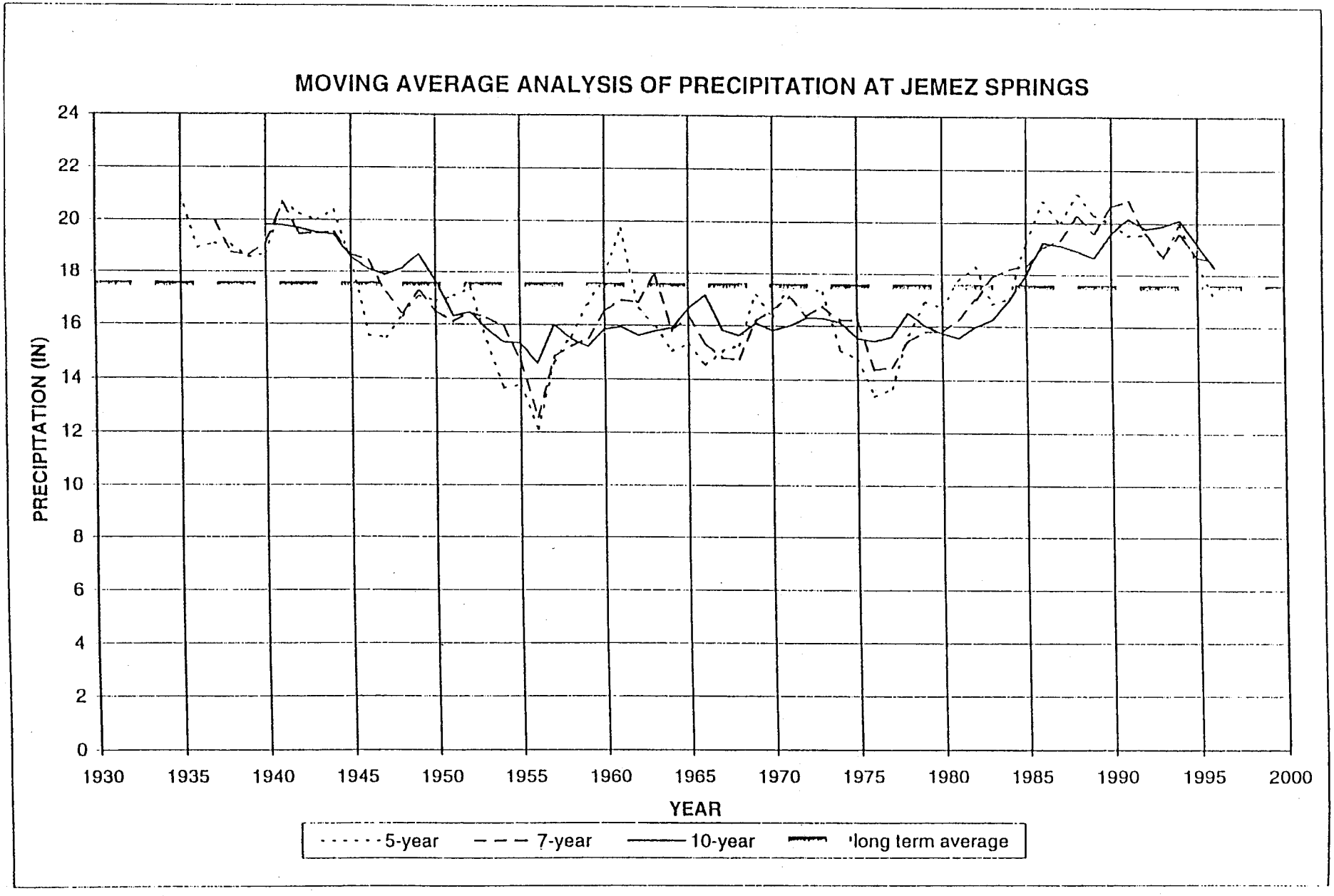
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PRECIPITATION (IN)
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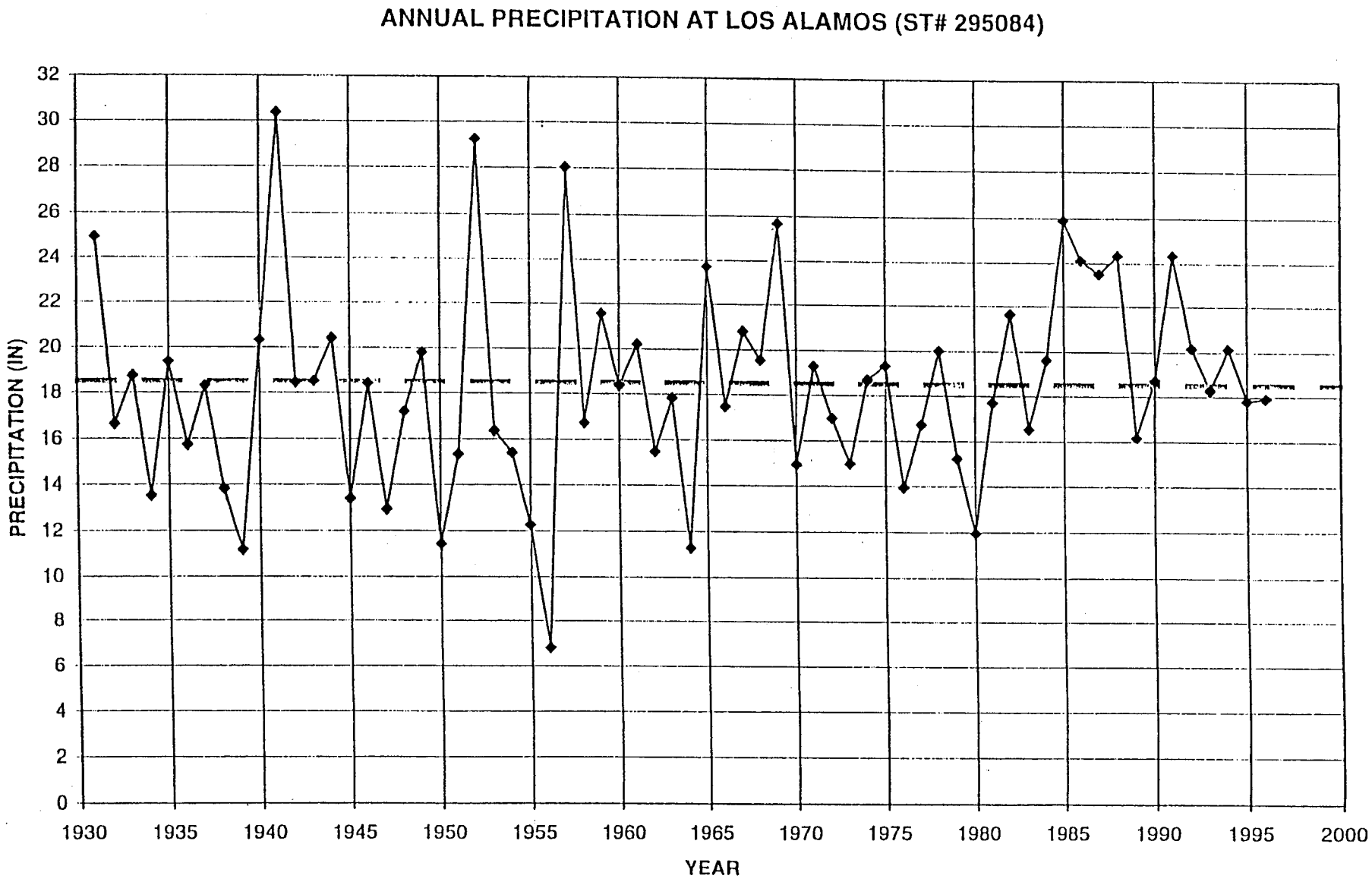
10-year
long term average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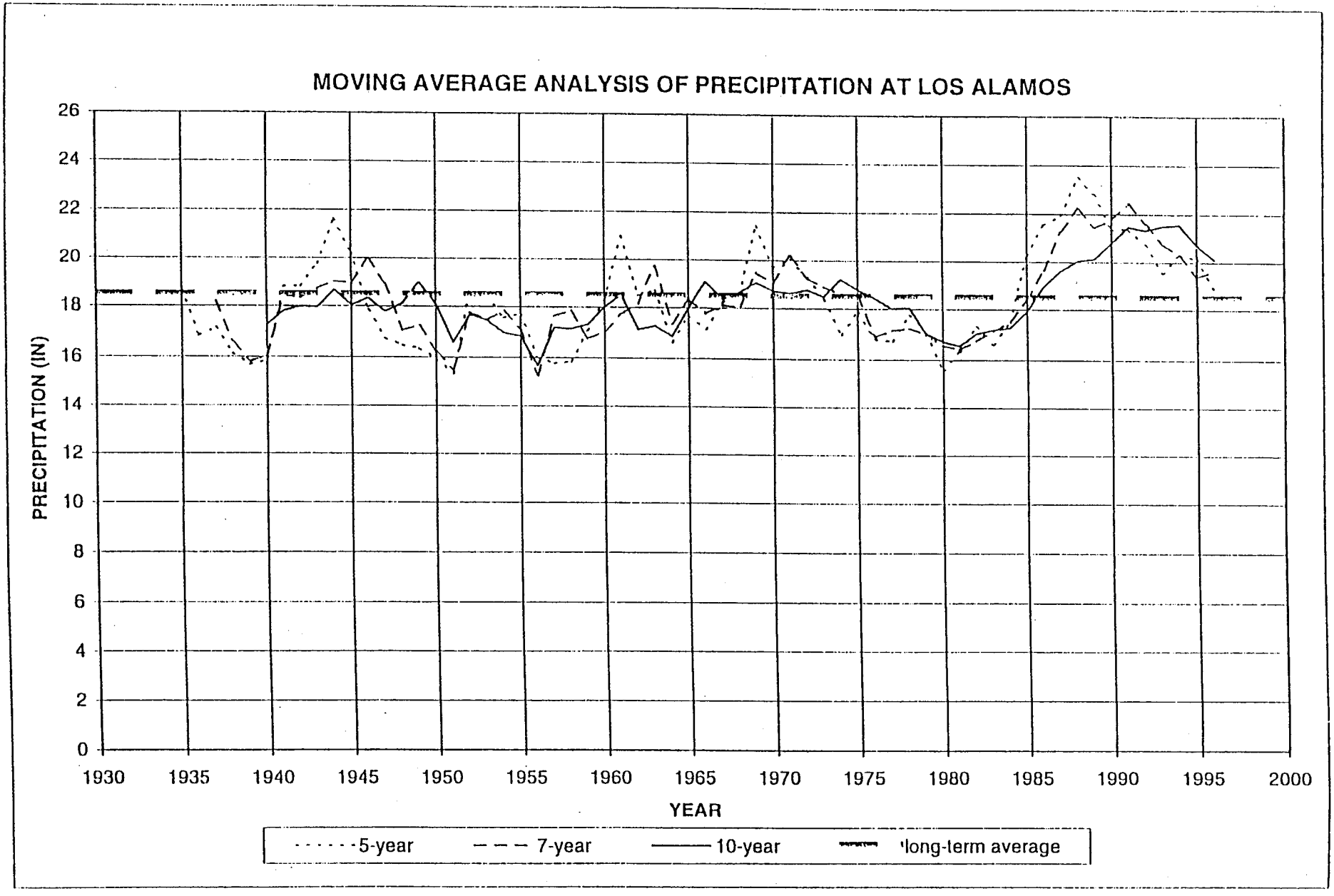
MOVING AVERAGE ANALYSIS OF PRECIPITATION AT LOS ALAMOS
PRECIPITATION (IN)
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22
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1930
1935
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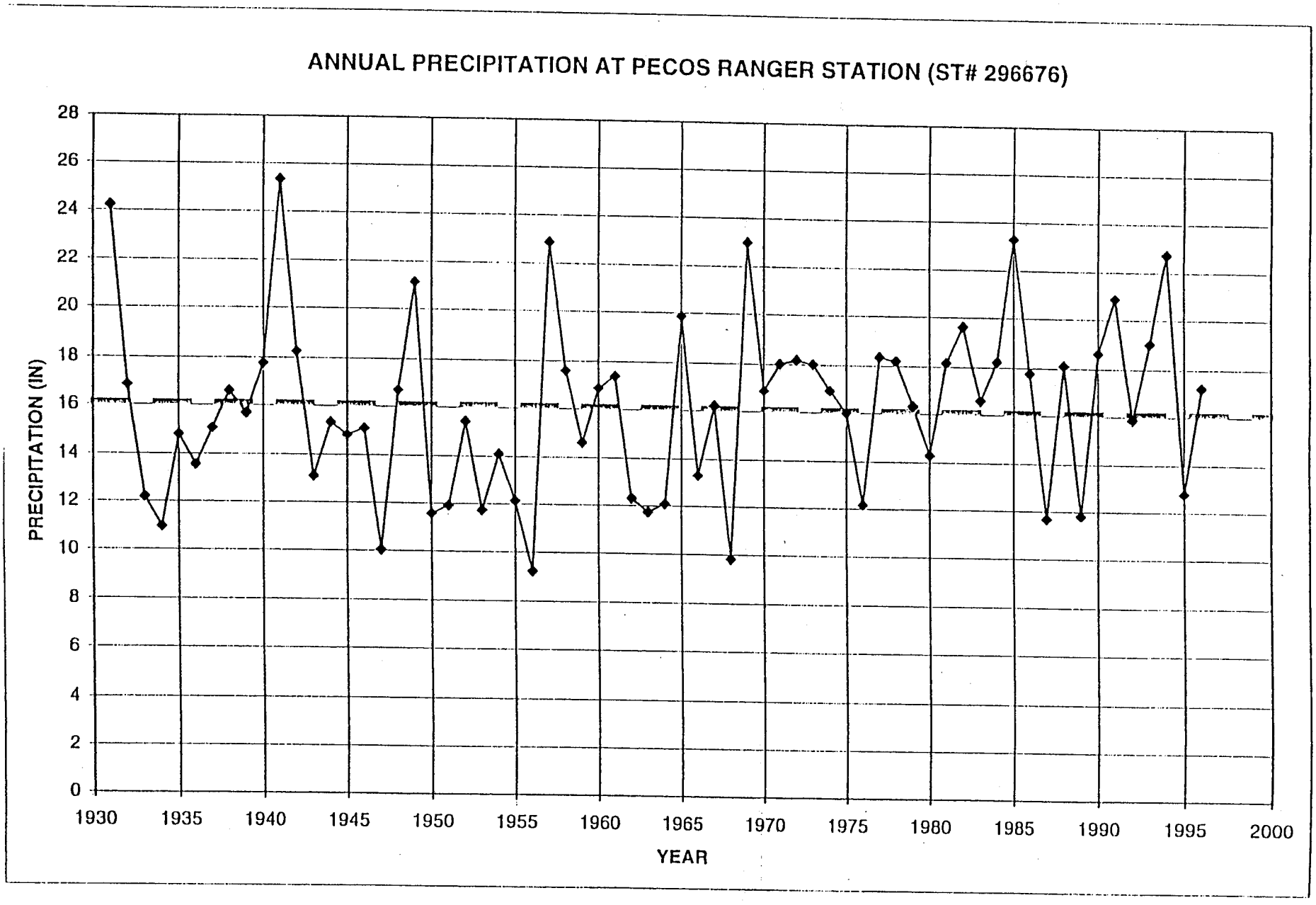
7-year
10-year
long-term average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1930
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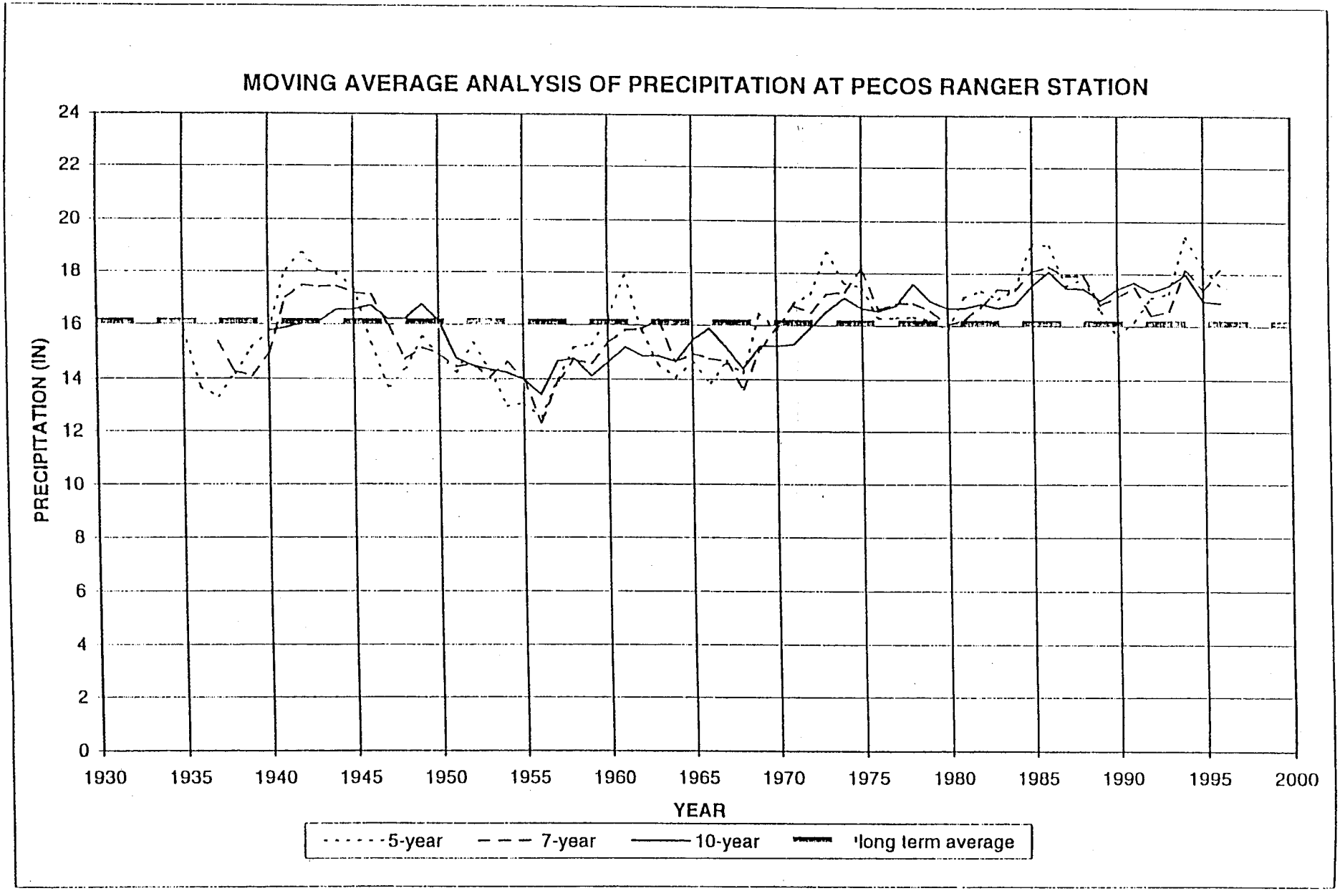
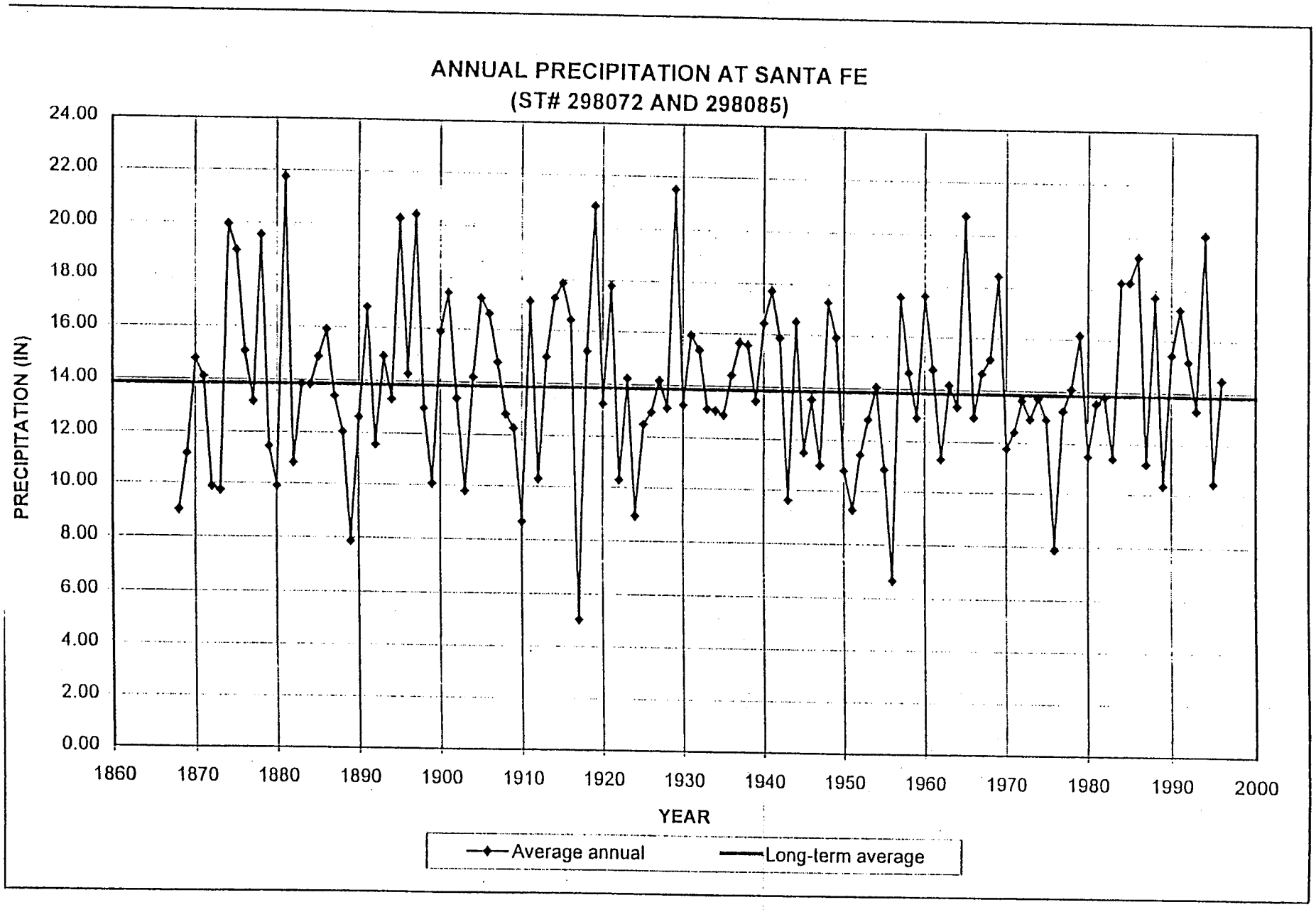
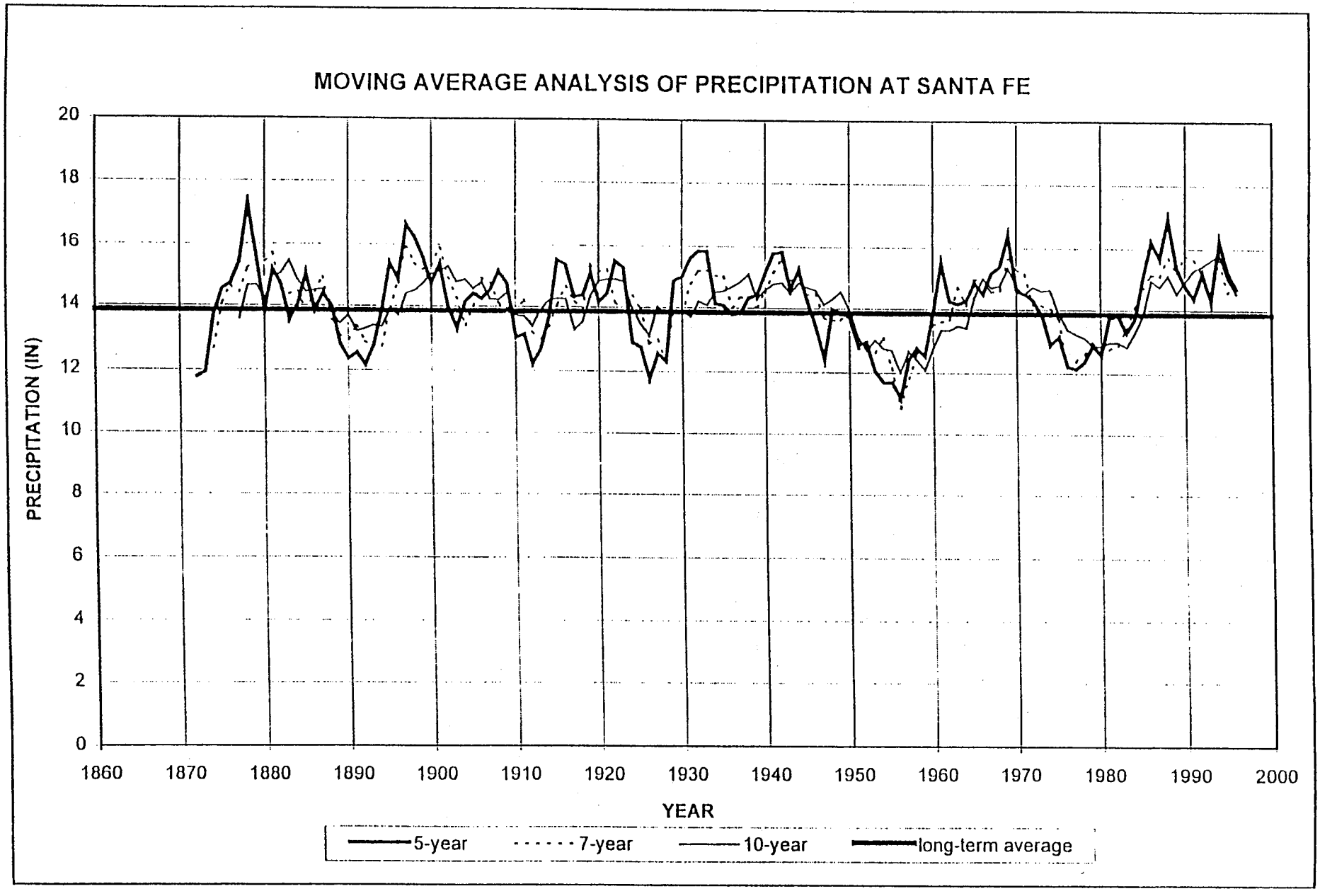
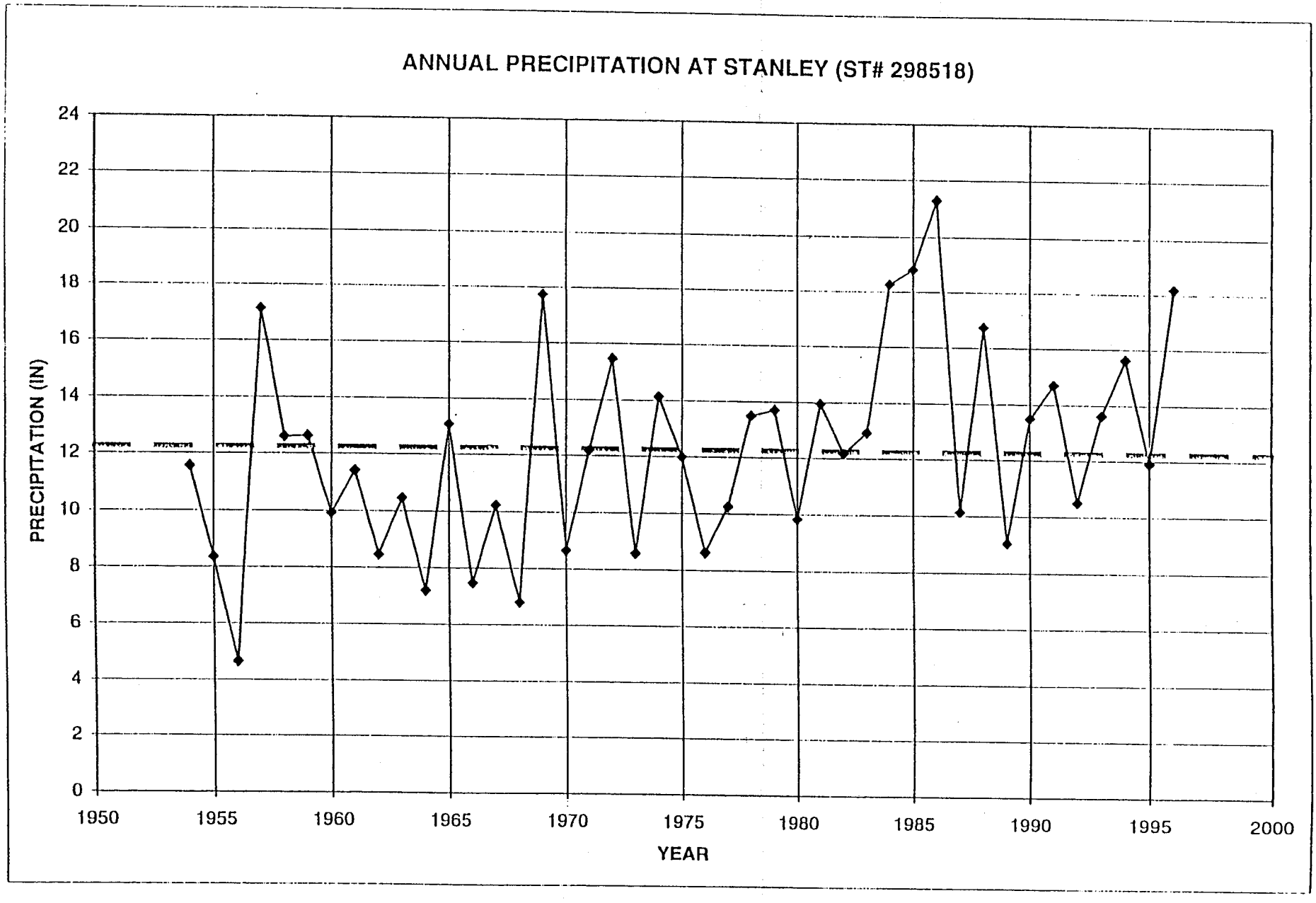
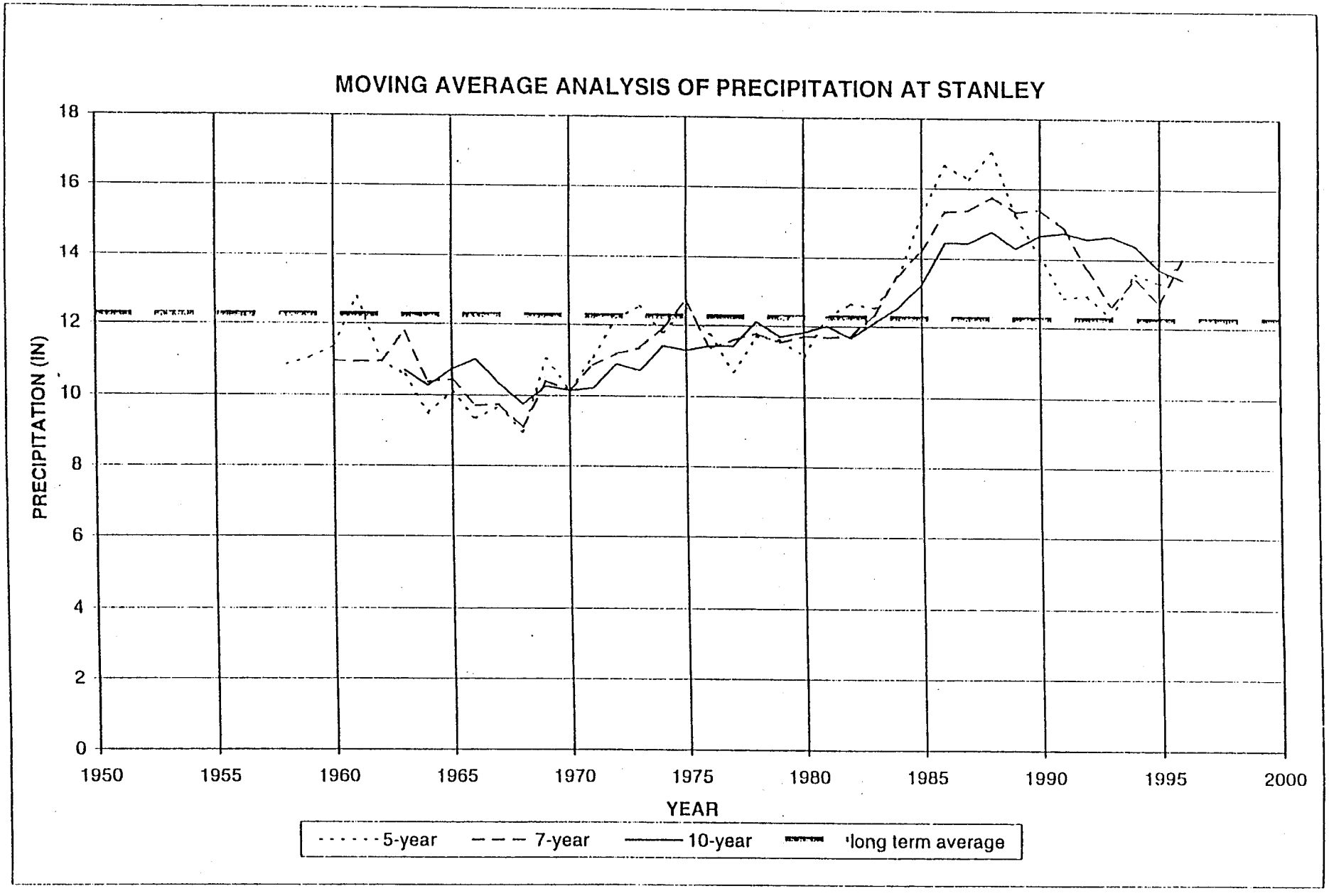
2000
YEAR


MOVING AVERAGE ANALYSIS OF PRECIPITATION AT PECOS RANGER STATION
PRECIPITATION (IN)
24
22
20
18
16
14
12
10
8
6
4
2
0
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEAR
5-year
7-year
10-year
long term average


ANNUAL PRECIPITATION AT SANTA FE
(ST# 298072 AND 298085)
PRECIPITATION (IN)
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEAR
Average annual
Long-term average

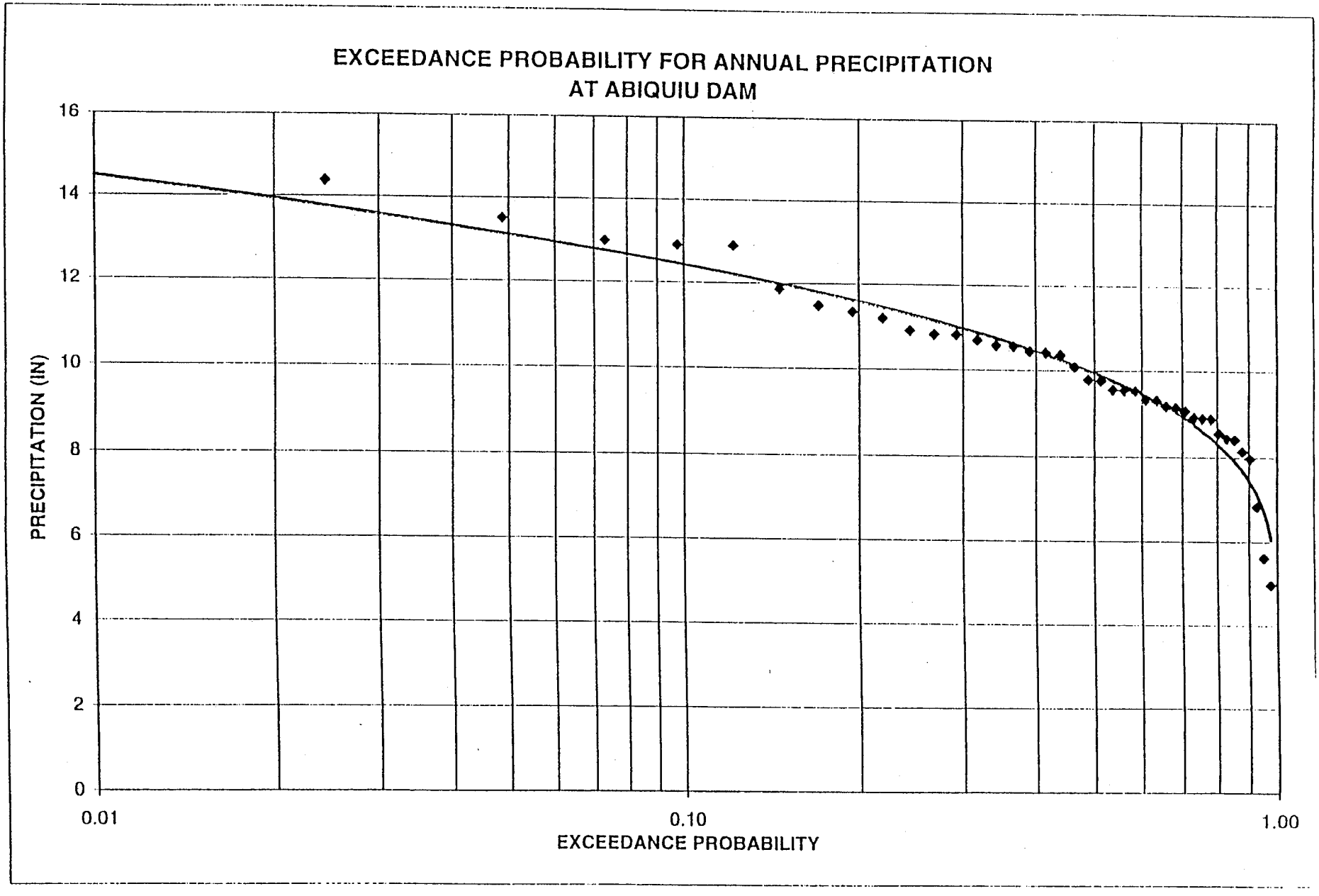

MOVING AVERAGE ANALYSIS OF PRECIPITATION AT SANTA FE
PRECIPITATION (IN)
20
18
16
14
12
10
8
6
4
2
0
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEAR
5-year
7-year
10-year
long-term average

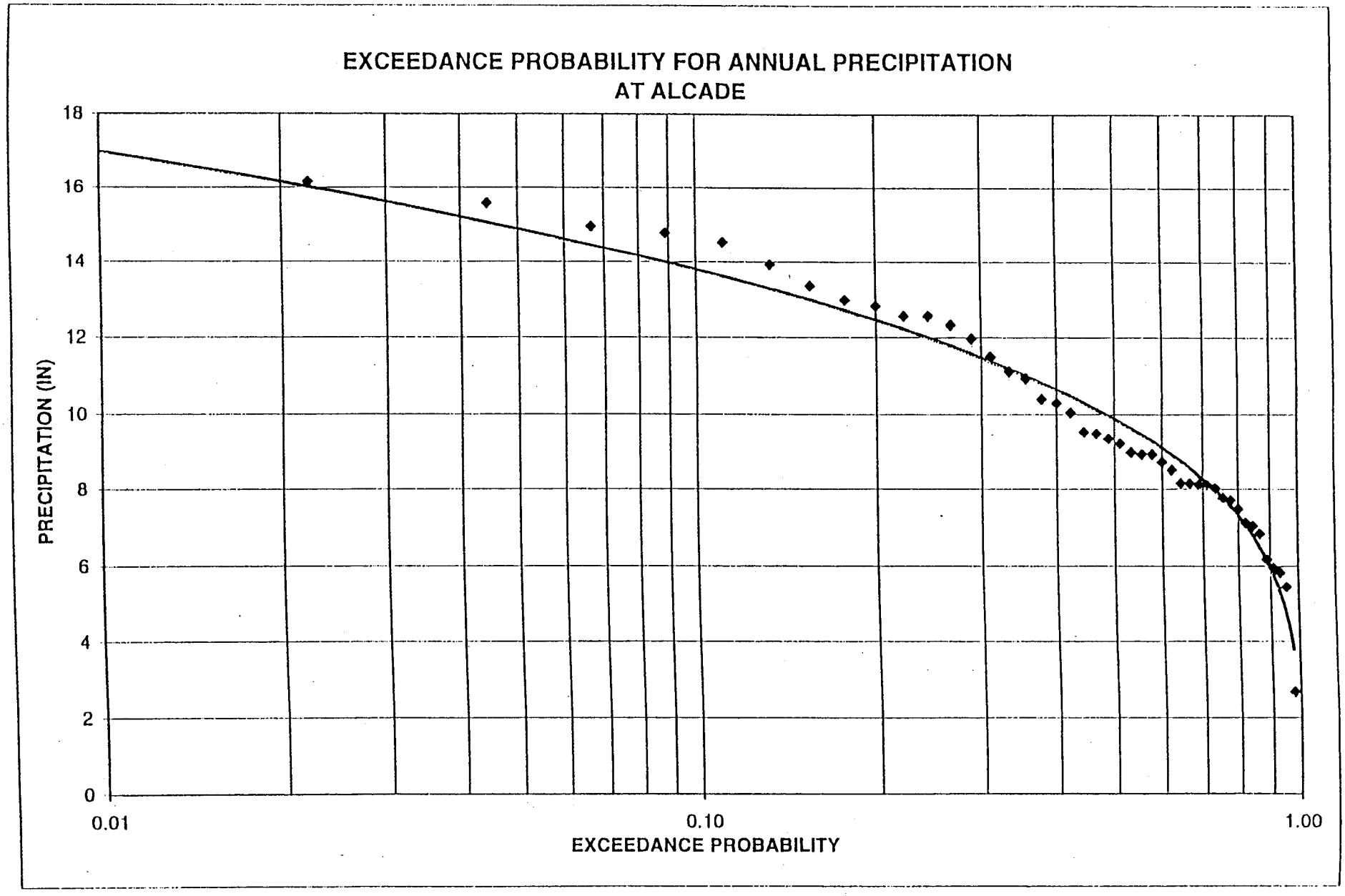

ANNUAL PRECIPITATION AT STANLEY (ST# 298518)
PRECIPITATION (IN)
24
22
20
18
16
14
12
10
8
6
4
2
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEAR

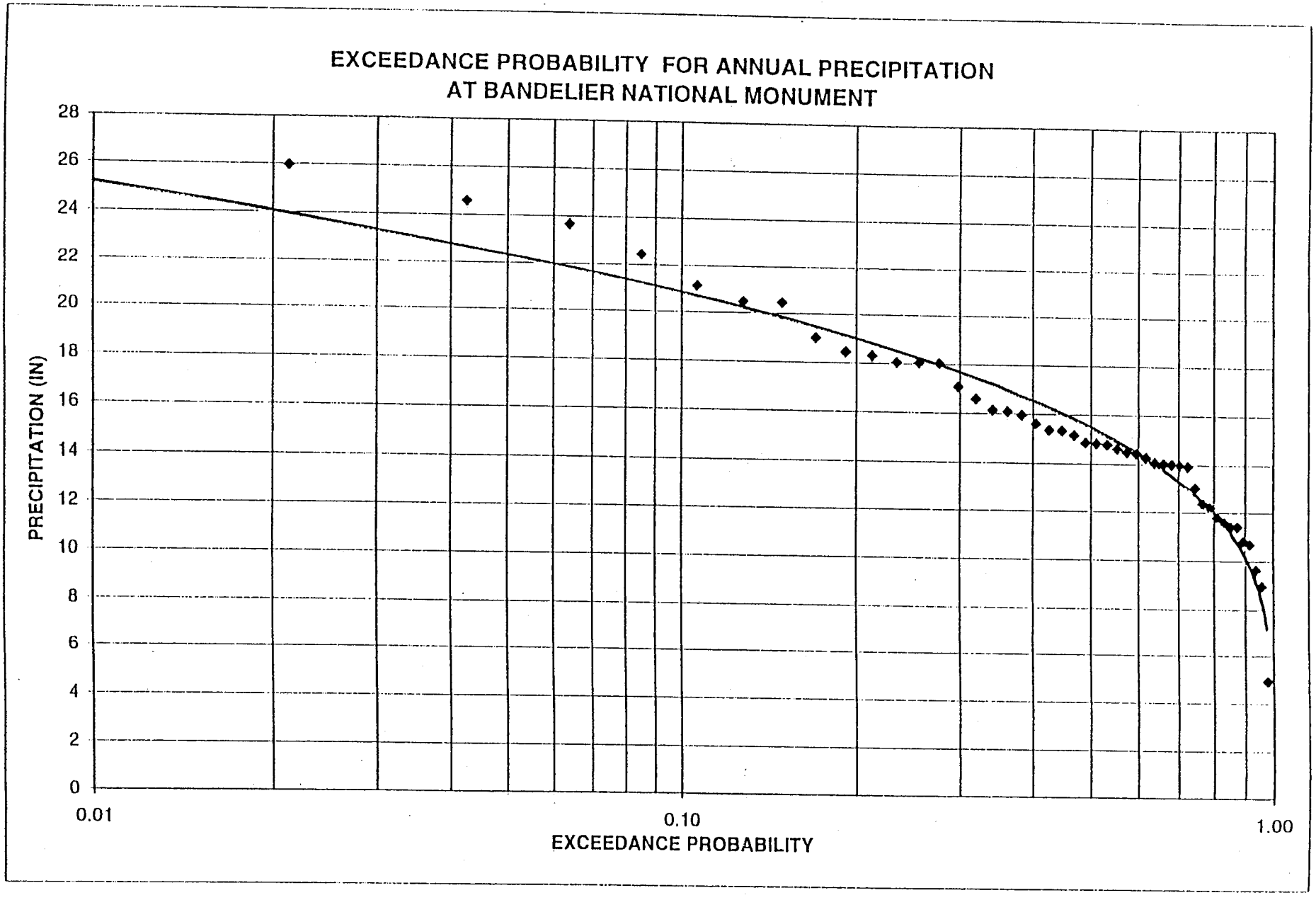

MOVING AVERAGE ANALYSIS OF PRECIPITATION AT STANLEY
PRECIPITATION (IN)
18
16
14
12
10
8
6
4
2
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEAR
5-year
7-year
10-year
long term average

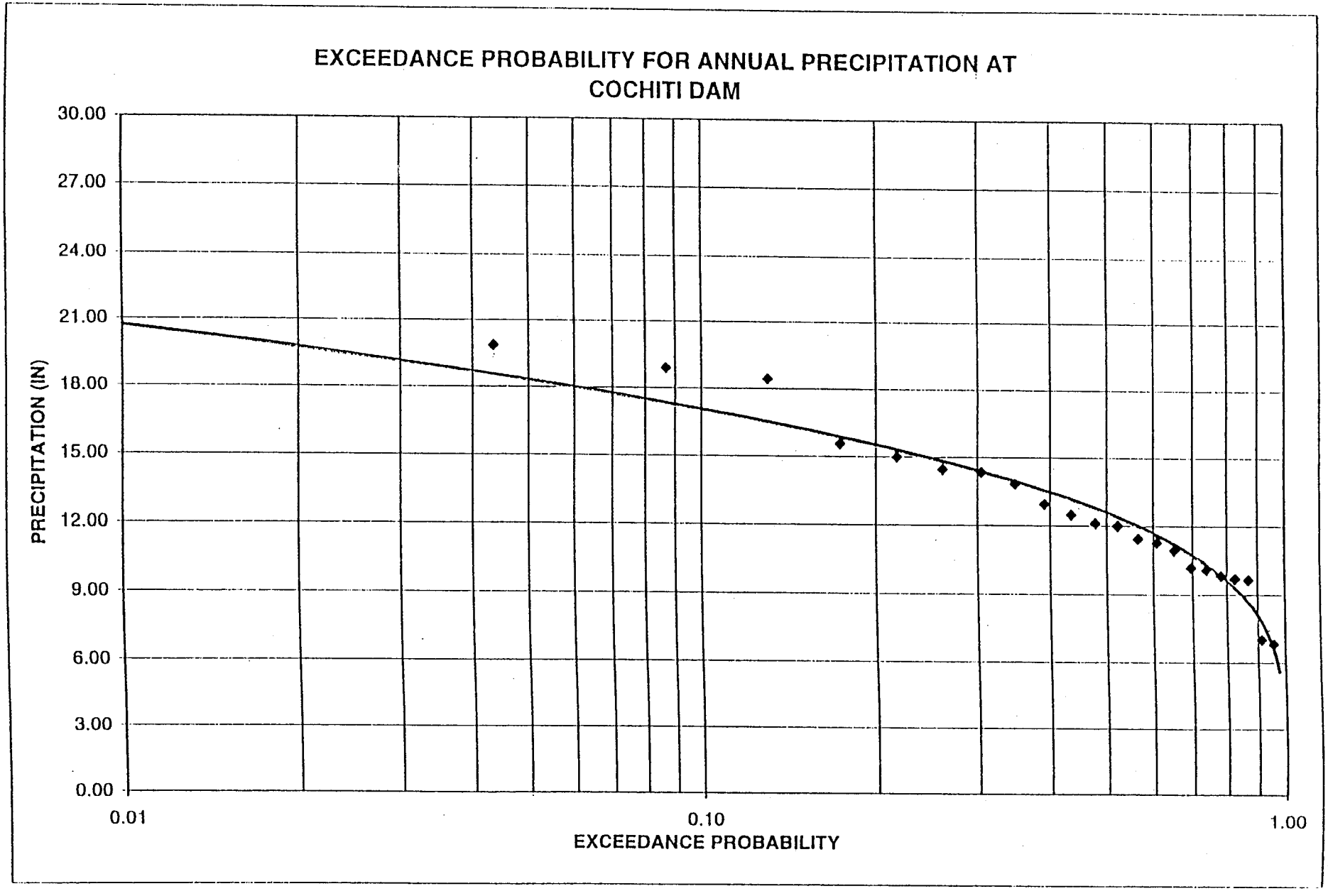
APPENDIX C

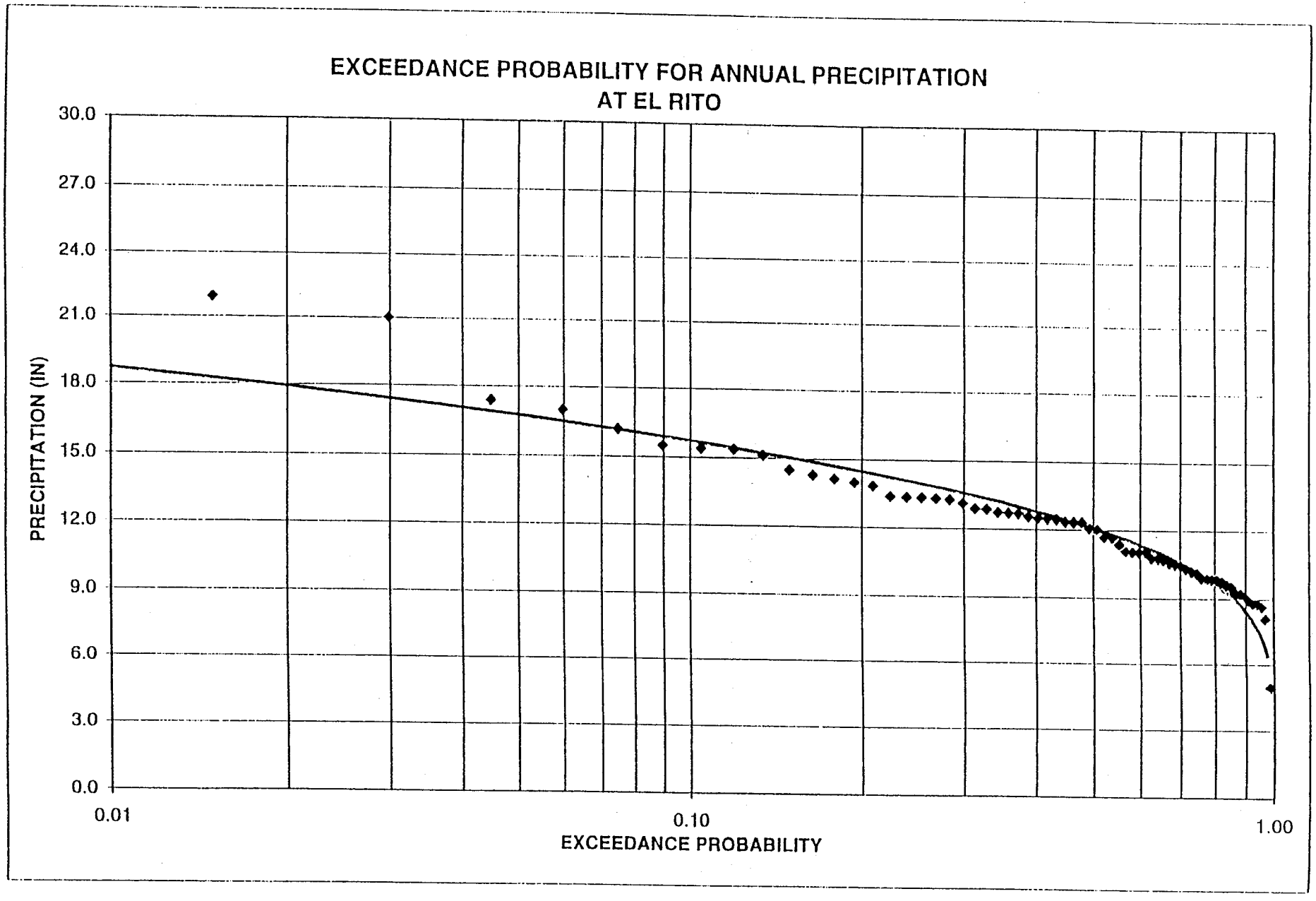
PROBABILITY PLOTS FOR EXCEEDING ANNUAL PRECIPITATION

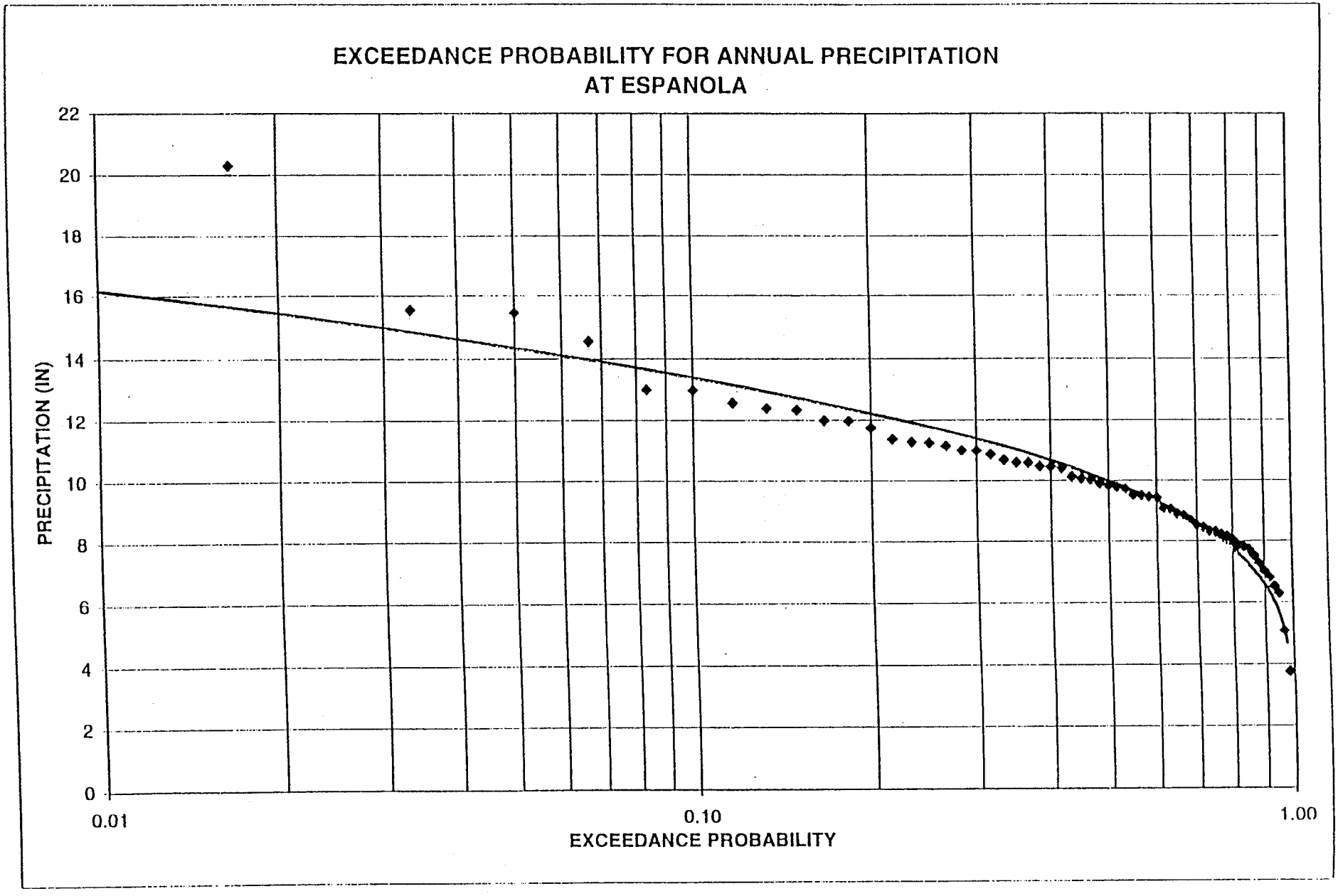

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION
AT ABIQUIU DAM
PRECIPITATION (IN)
16
14
12
10
8
6
4
2
0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY

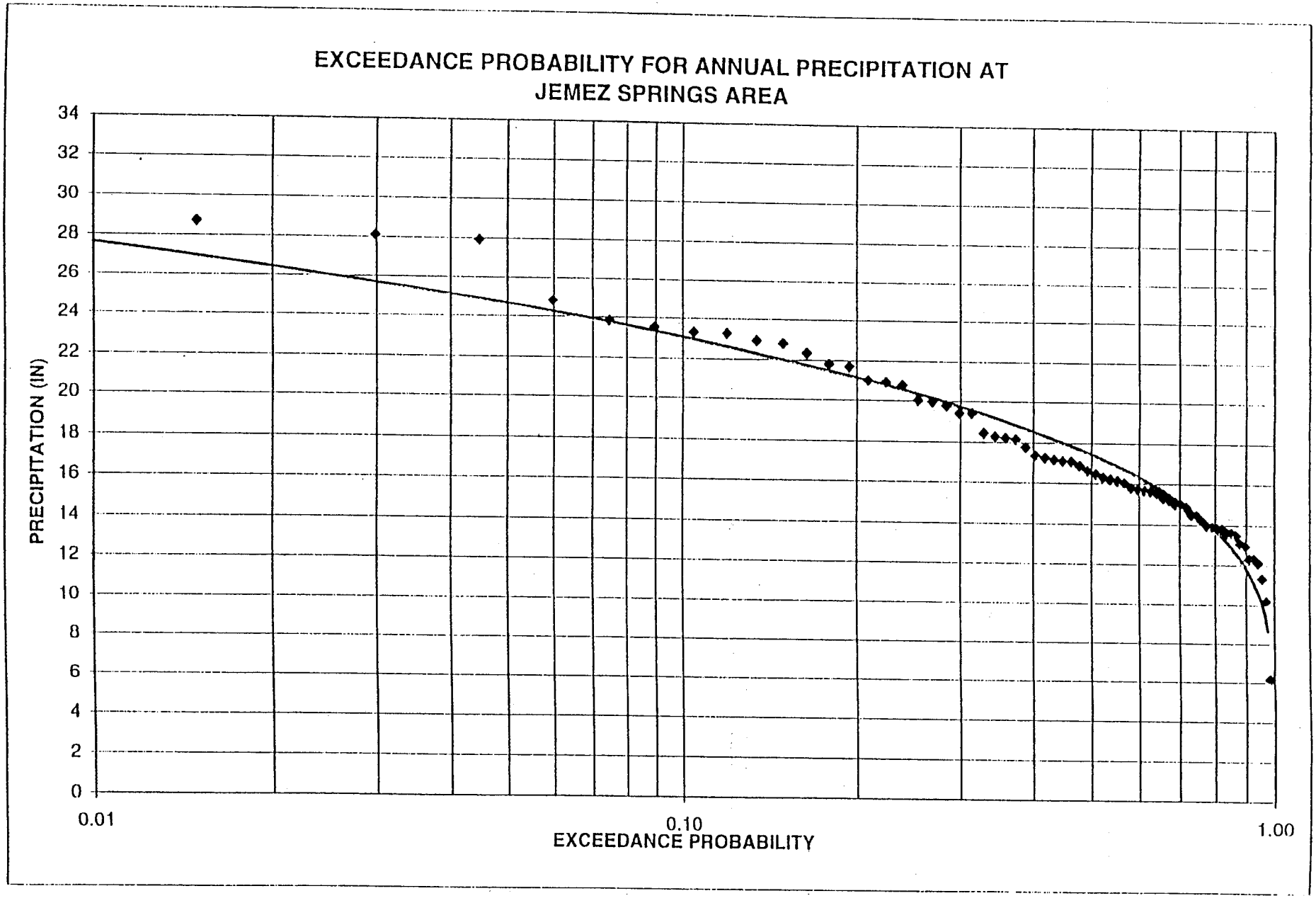

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION
AT ALCADE
PRECIPITATION (IN)
18
16
14
12
10
8
6
4
2
0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY

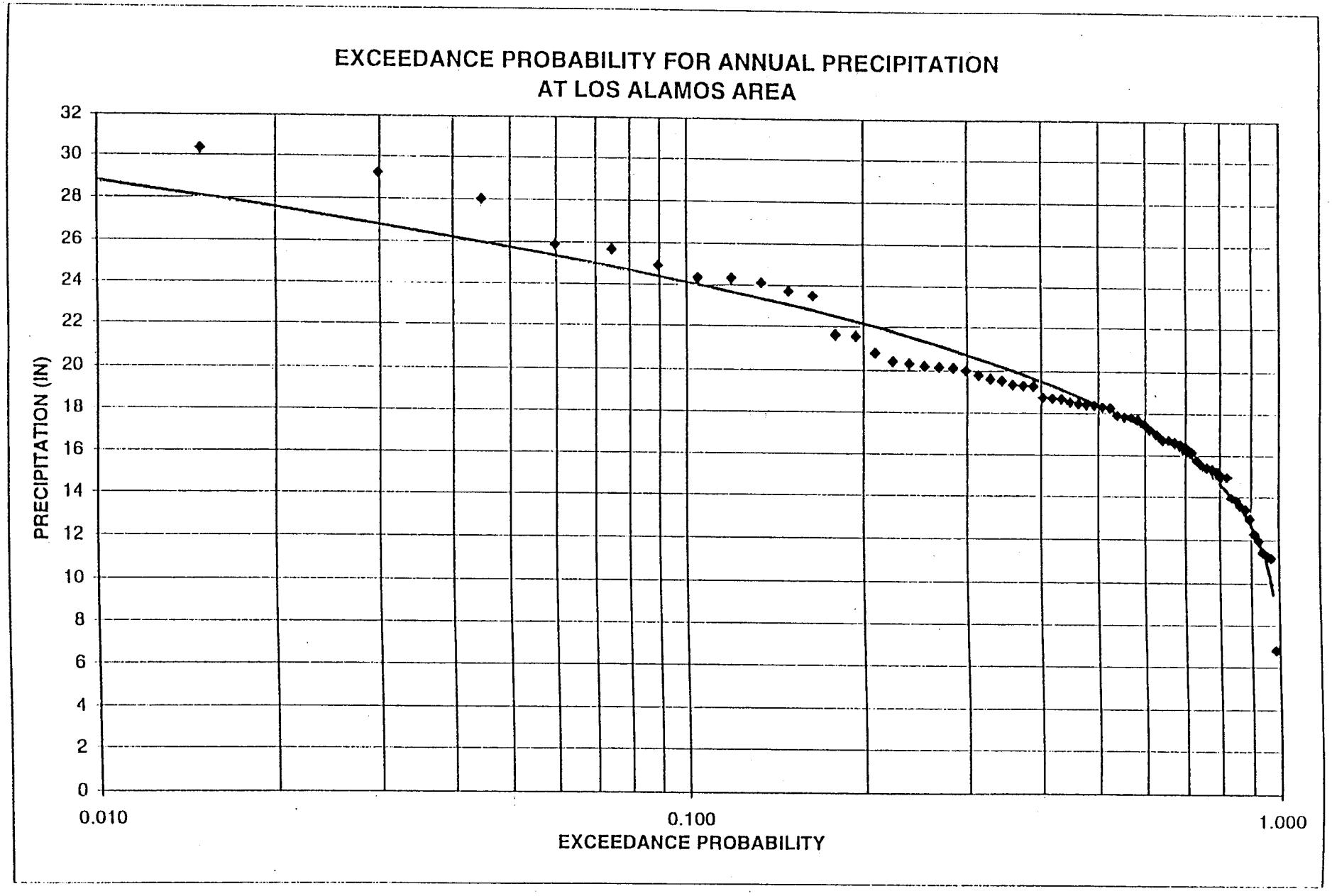

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION
AT BANDELIER NATIONAL MONUMENT
PRECIPITATION (IN)
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY

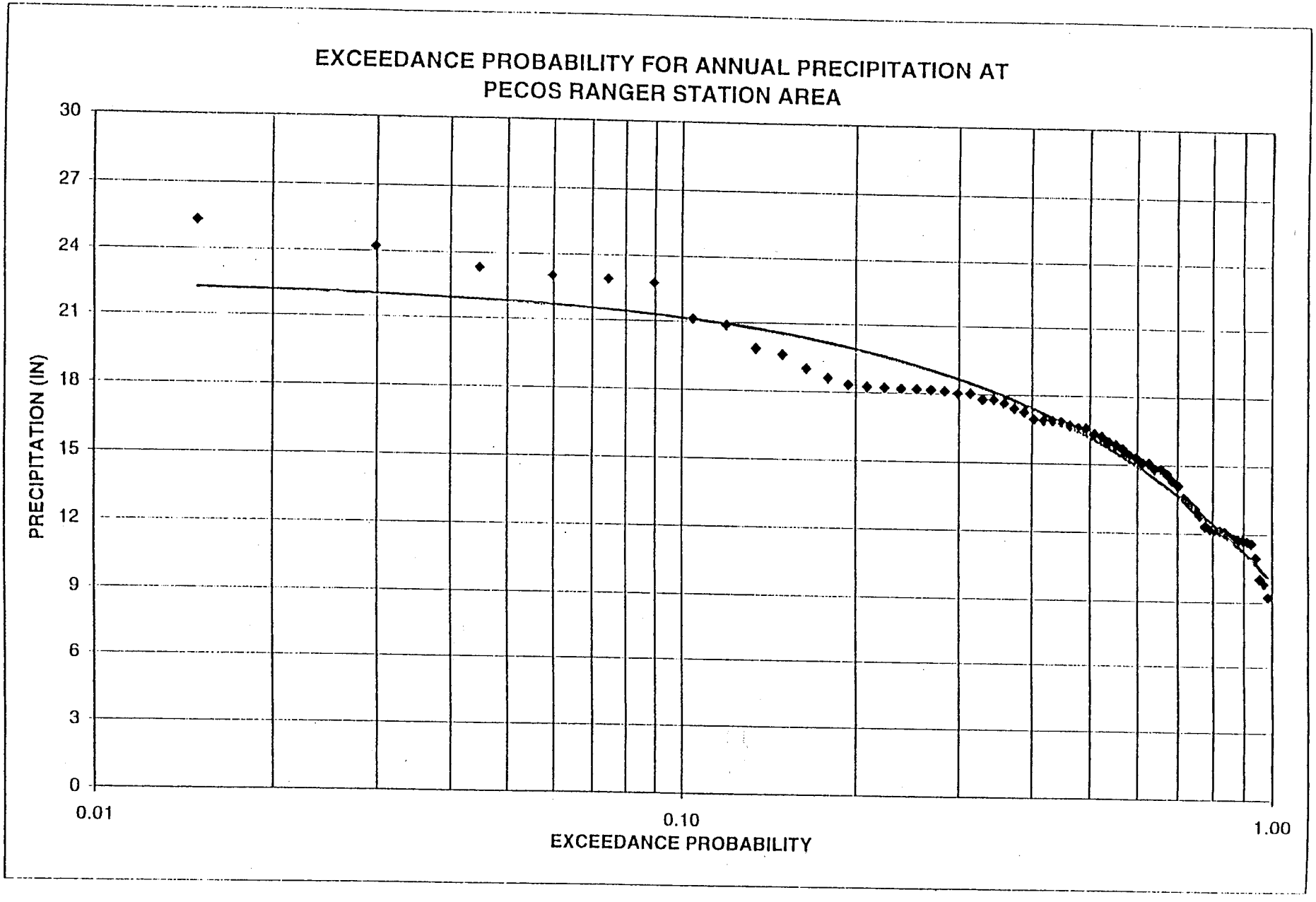

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION AT
COCHITI DAM
30.00
27.00
24.00
21.00
18.00
15.00
12.00
9.00
6.00
3.00
0.00
PRECIPITATION (IN)
0.01
0.10
1.00
EXCEEDANCE PROBABILITY

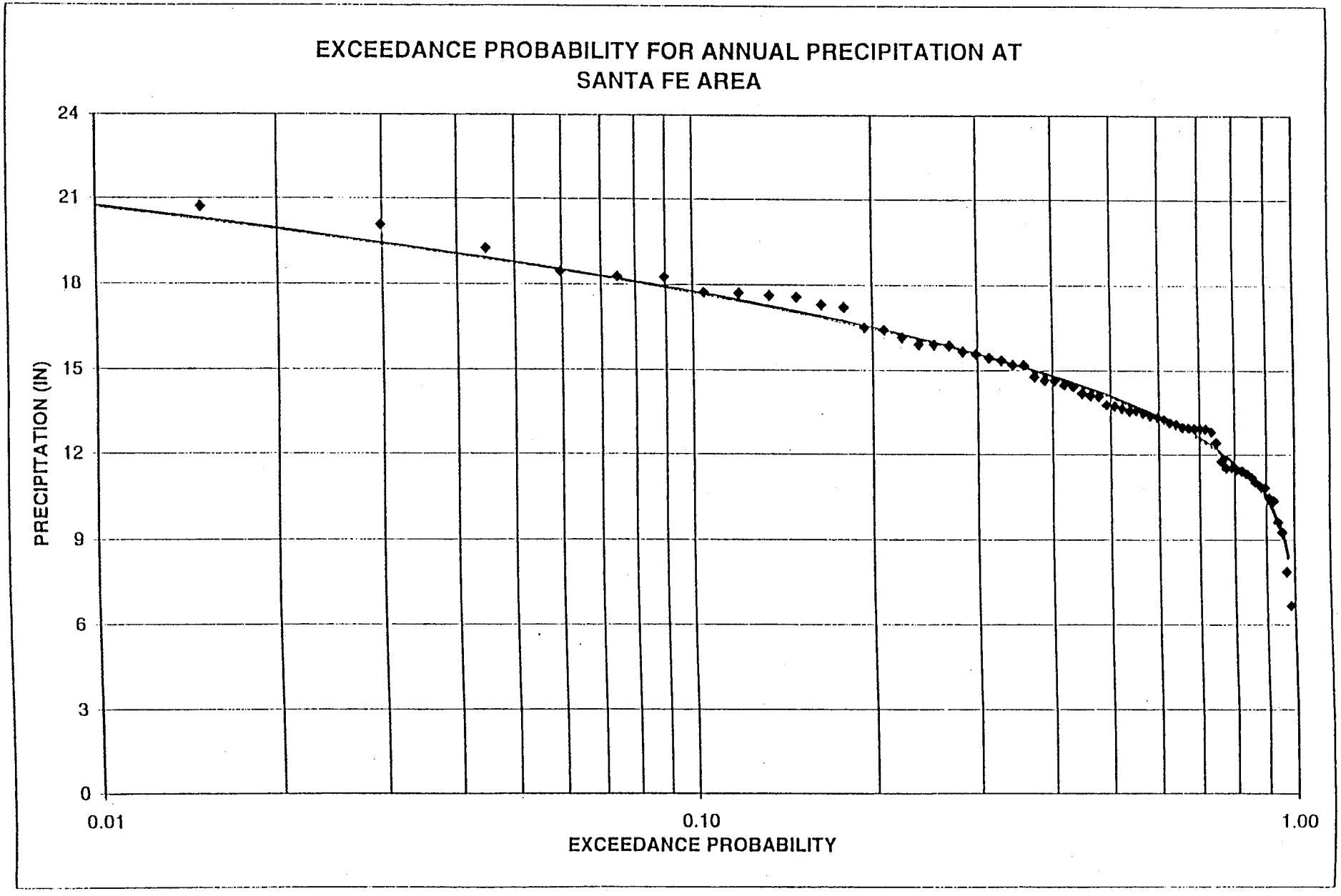

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION
AT EL RITO
PRECIPITATION (IN)
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY

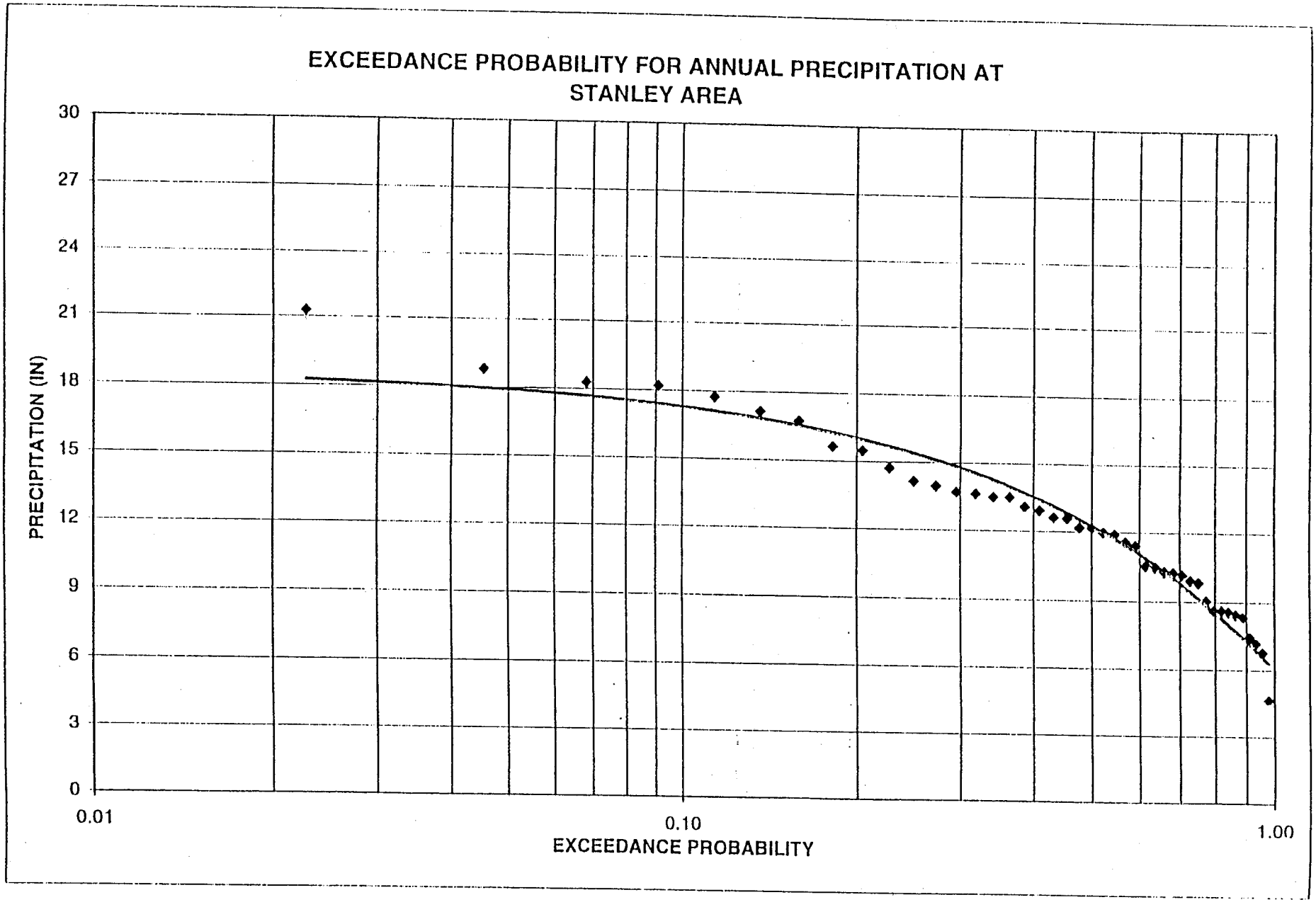

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION
AT ESPANOLA
PRECIPITATION (IN)
22
20
18
16
14
12
10
8
6
4
2
0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY


EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION AT
JEMEZ SPRINGS AREA
PRECIPITATION (IN)
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY


EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION
AT LOS ALAMOS AREA
PRECIPITATION (IN)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0.010
0.100
1.000
EXCEEDANCE PROBABILITY

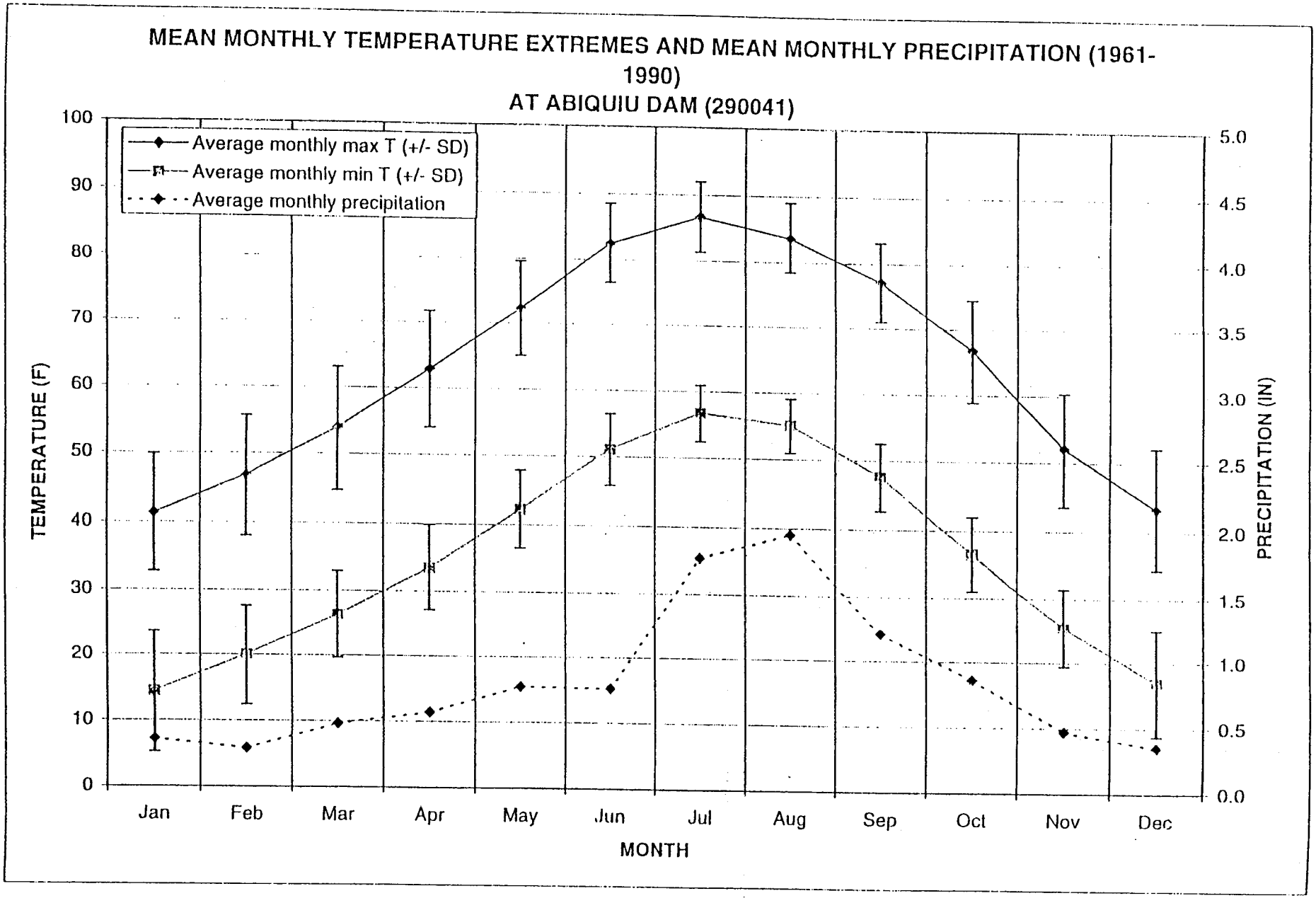

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION AT
PECOS RANGER STATION AREA
PRECIPITATION (IN)
30
27
24
21
18
15
12
9
6
3
0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY

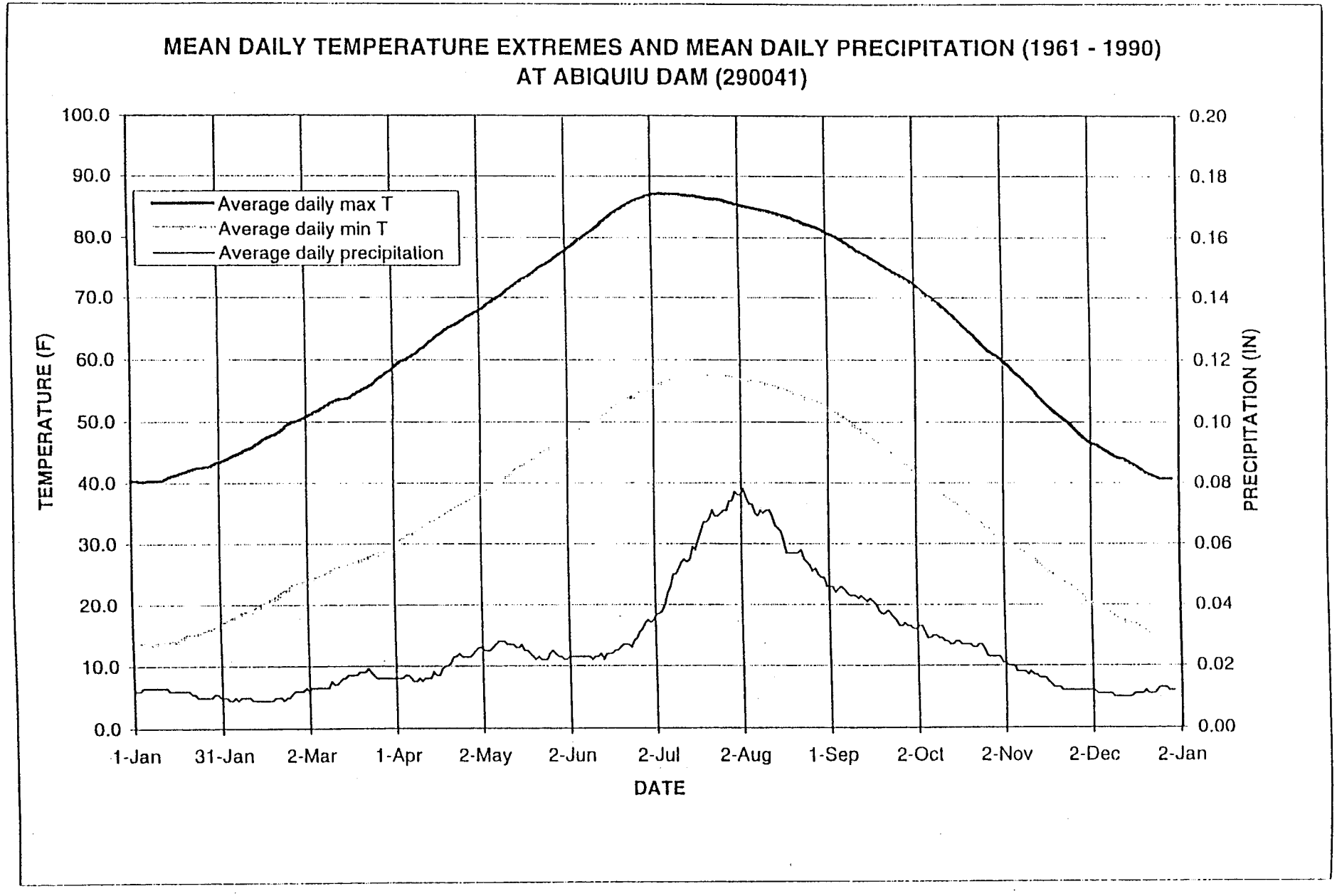

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION AT
SANTA FE AREA
PRECIPITATION (IN)
24
21
18
15
12
9
6
3
0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY

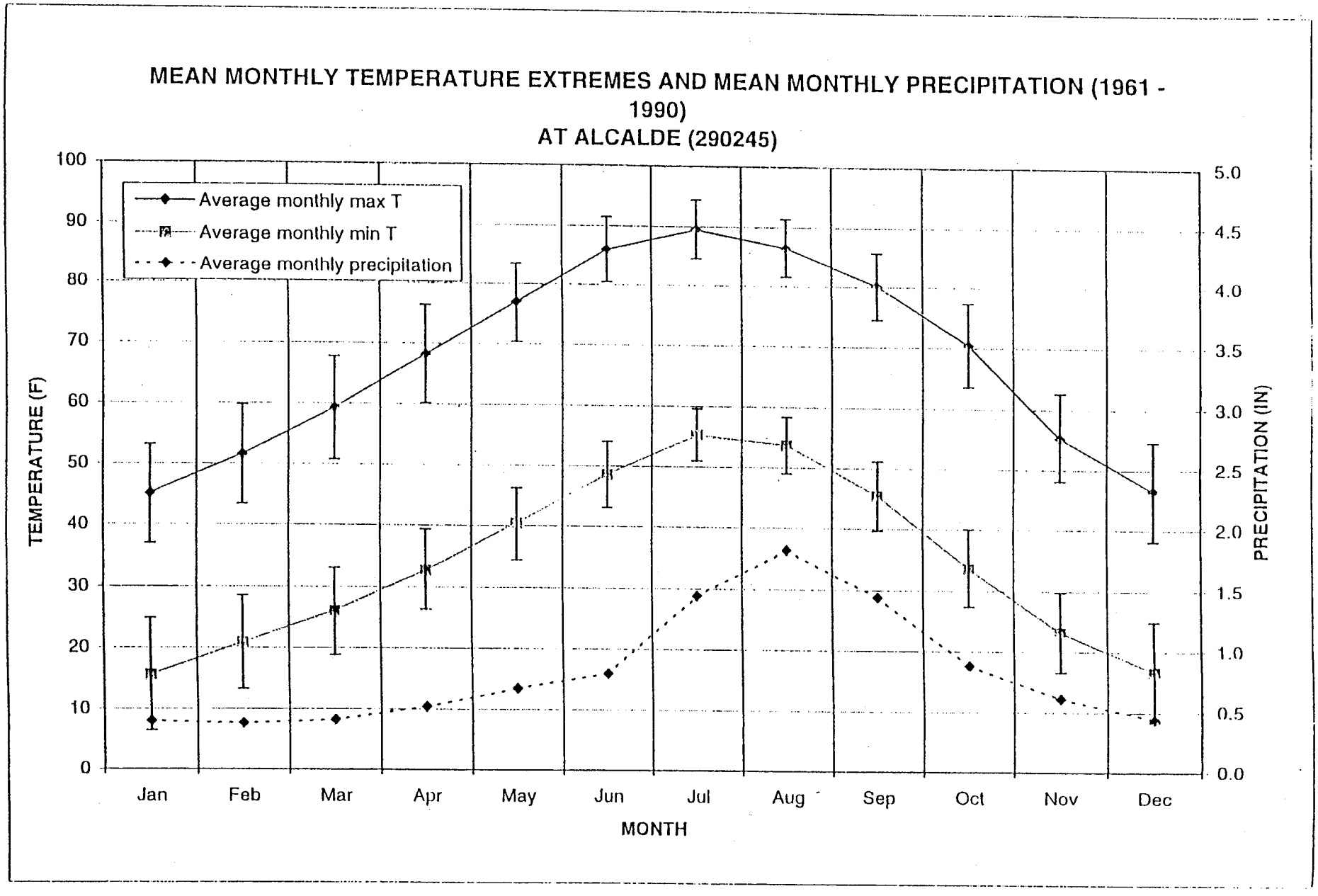

EXCEEDANCE PROBABILITY FOR ANNUAL PRECIPITATION AT STANLEY AREA
PRECIPITATION (IN)
30
27
24
21
18
15
12
9
6
3
0
0.01
0.10
1.00
EXCEEDANCE PROBABILITY

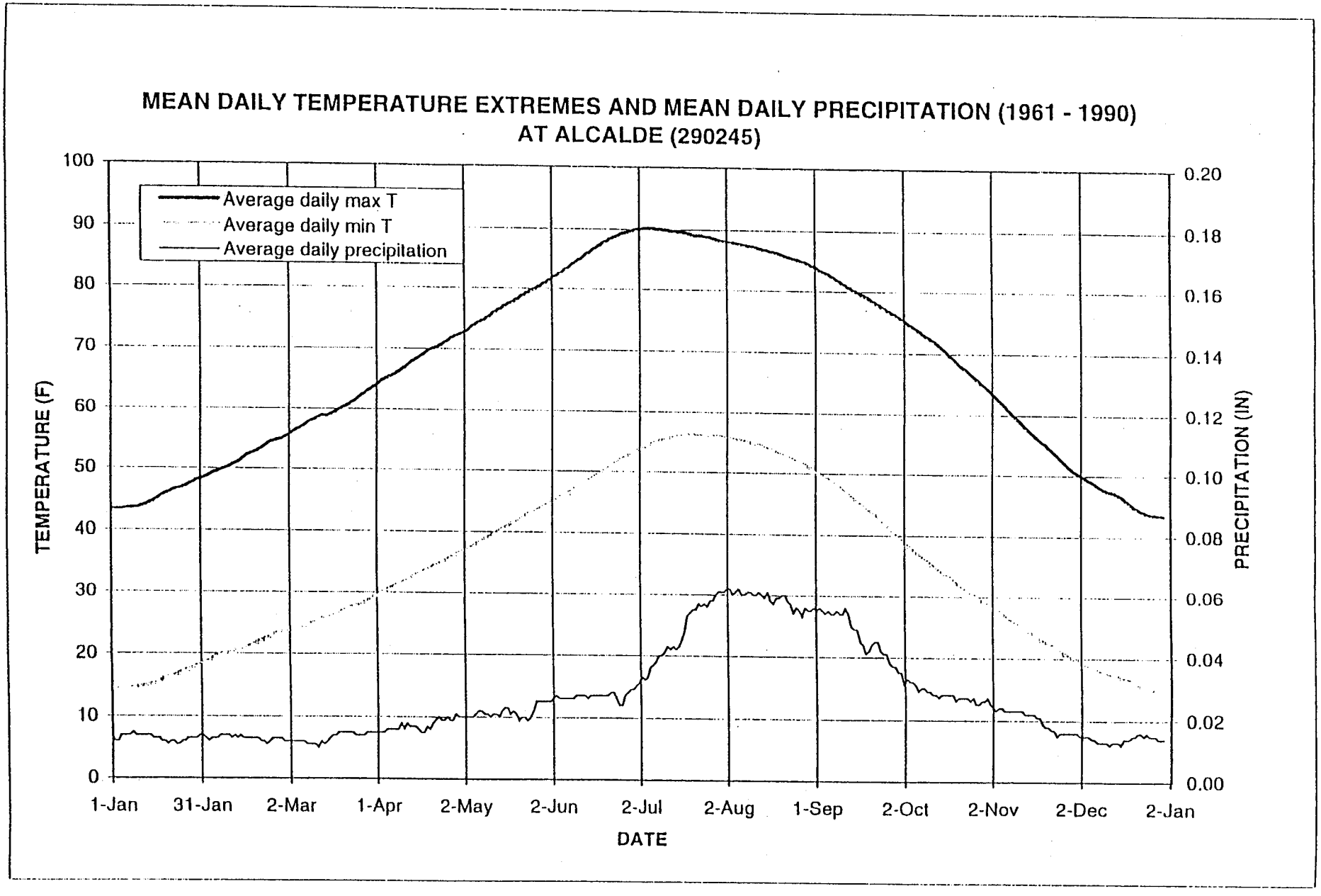
APPENDIX D

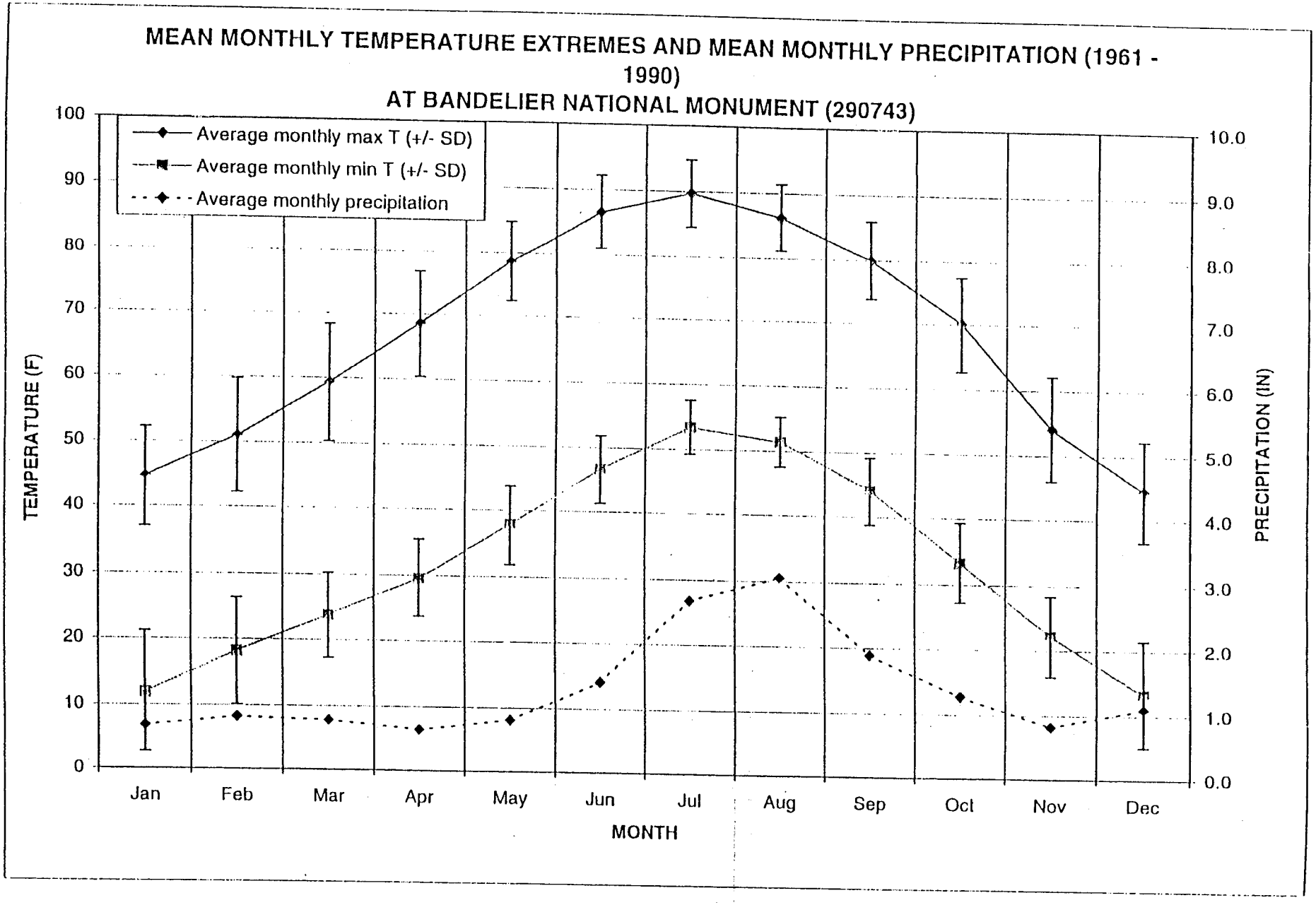
MEAN MONTHLY AND DAILY WEATHER VARIABLES AT NOAA WEATHER STATIONS

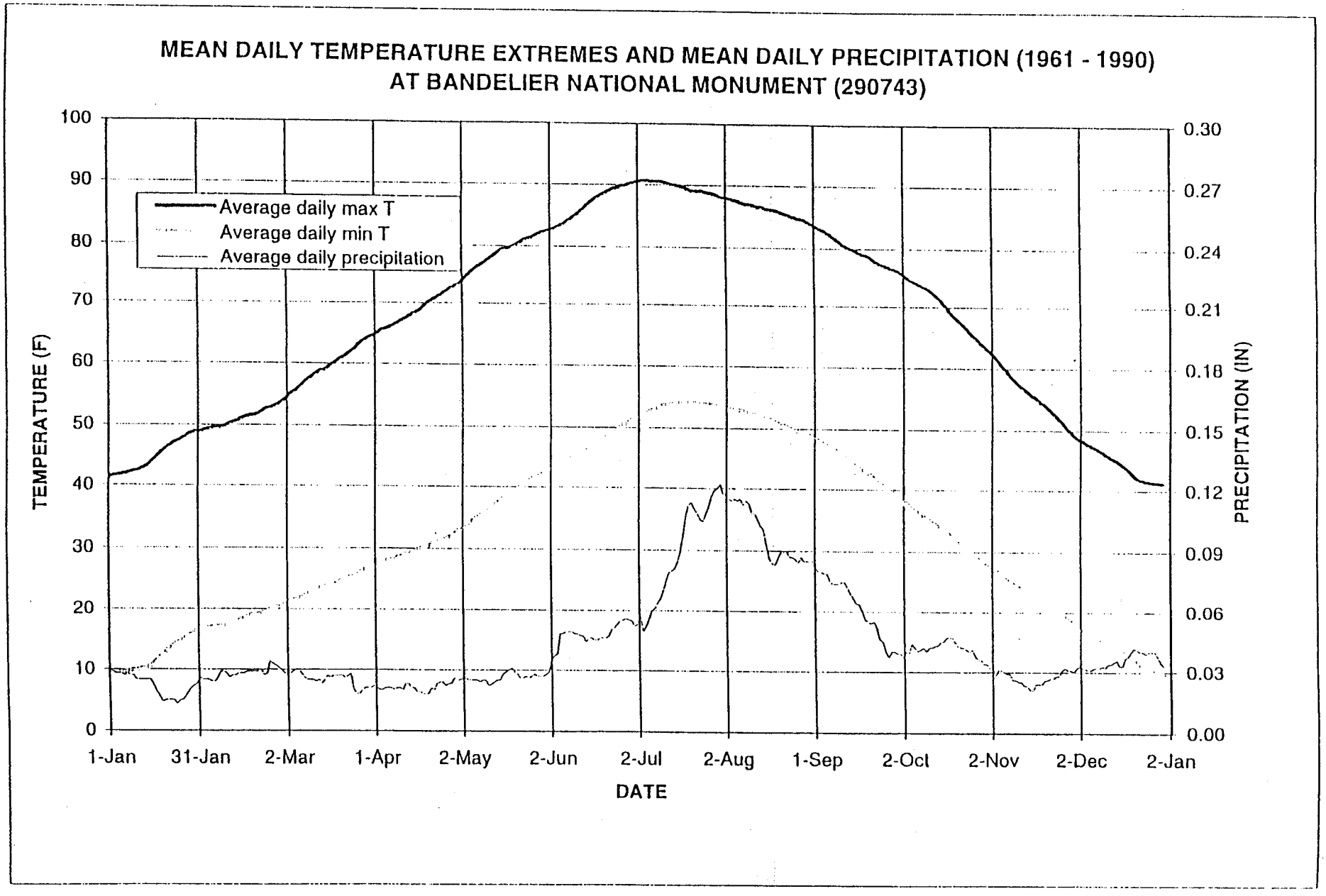

MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961-1990)
AT ABIQUIU DAM (290041)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

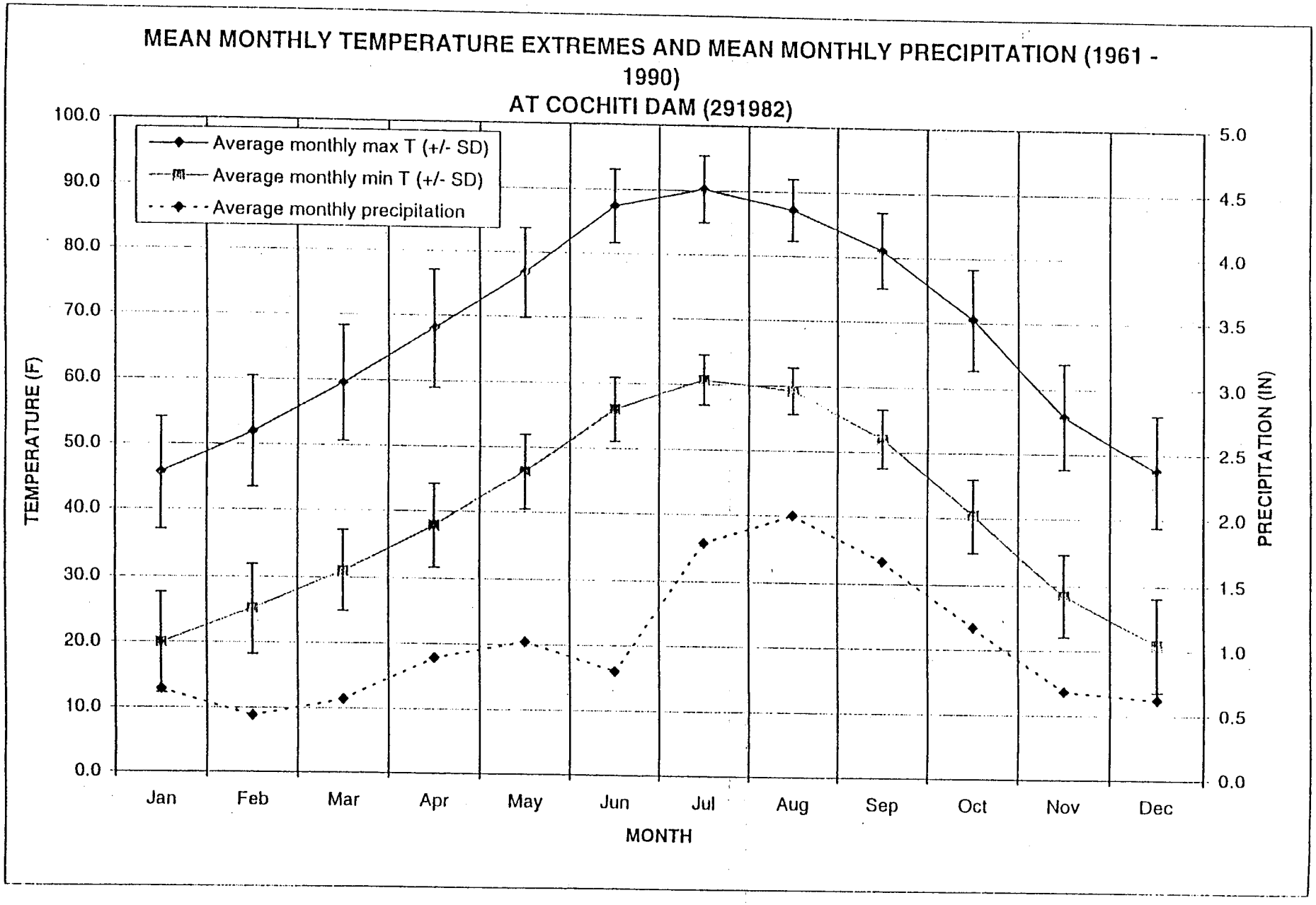

MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT ABIQUIU DAM (290041)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan

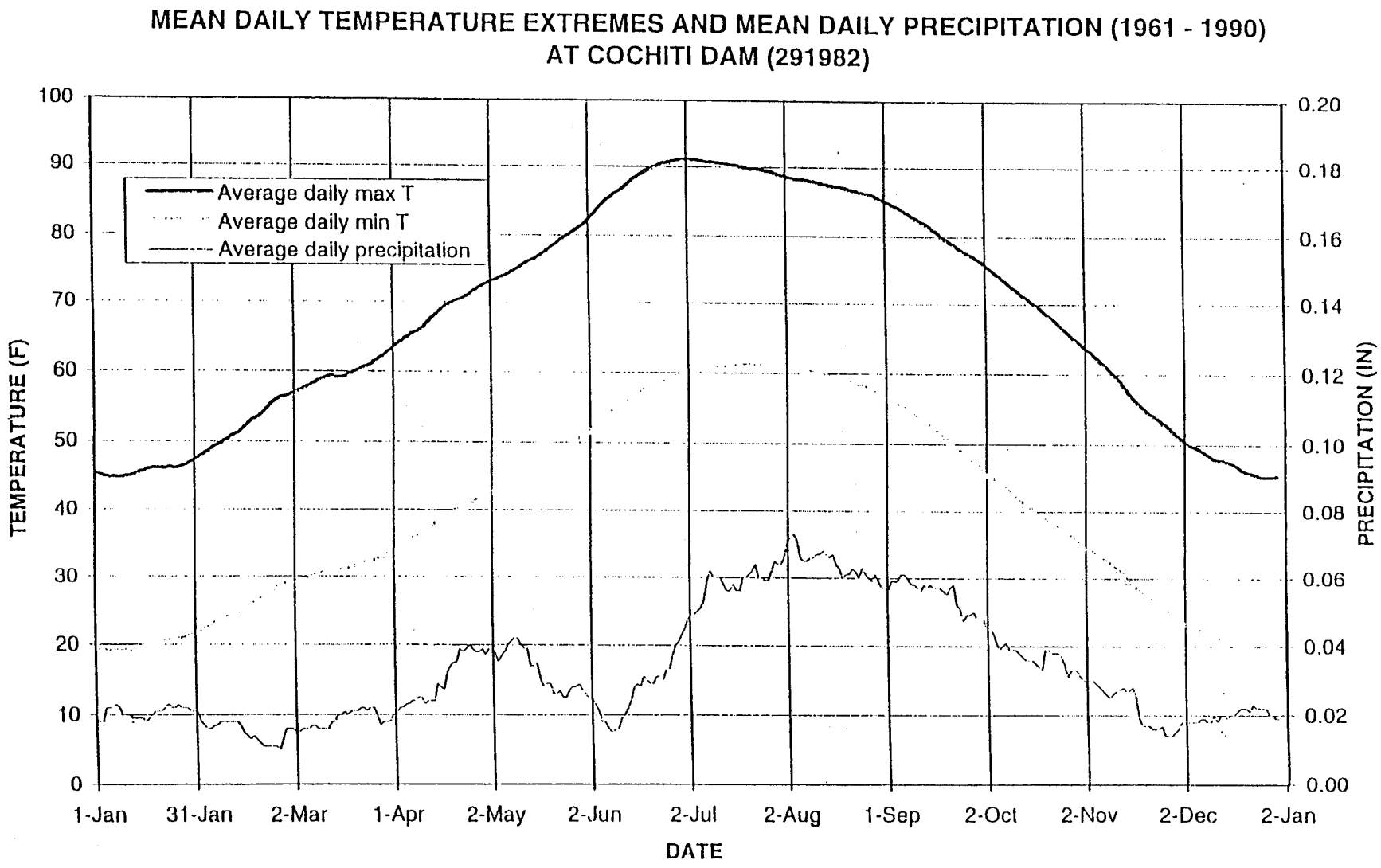

MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT ALCALDE (290245)
Average monthly max T
Average monthly min T
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

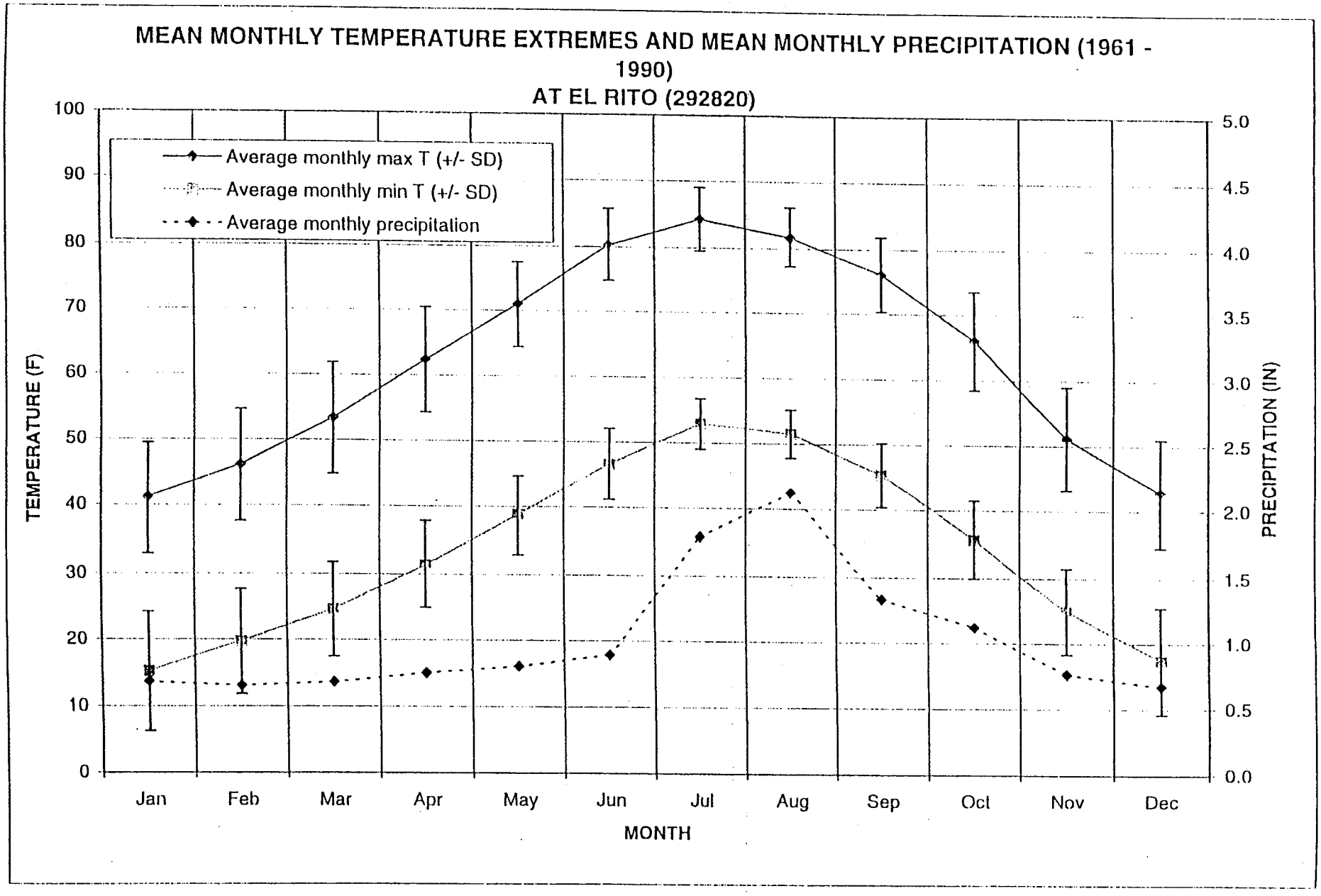

MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT ALCALDE (290245)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan

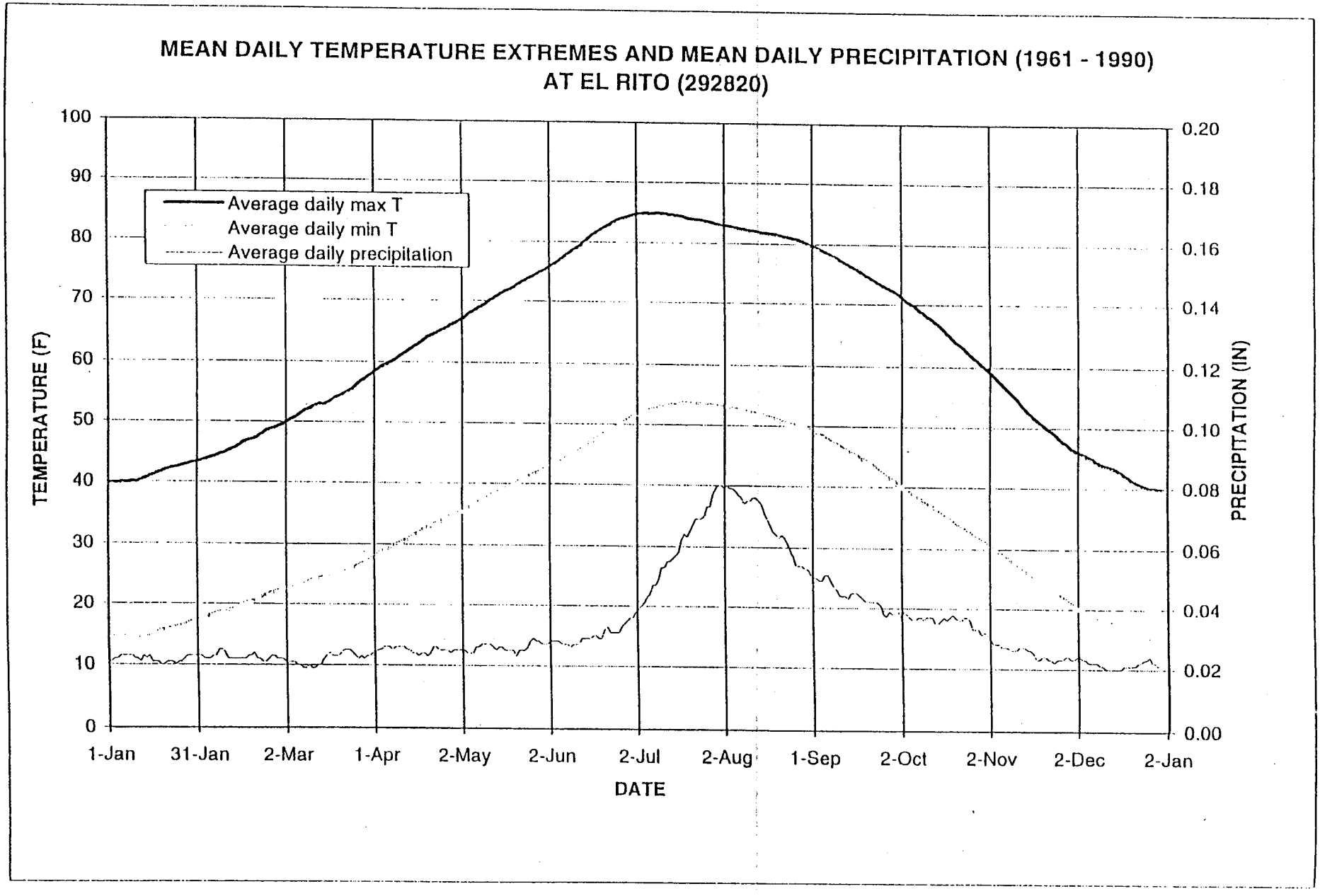

MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT BANDELIER NATIONAL MONUMENT (290743)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
10
20
30
40
50
60
70
80
90
100
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0

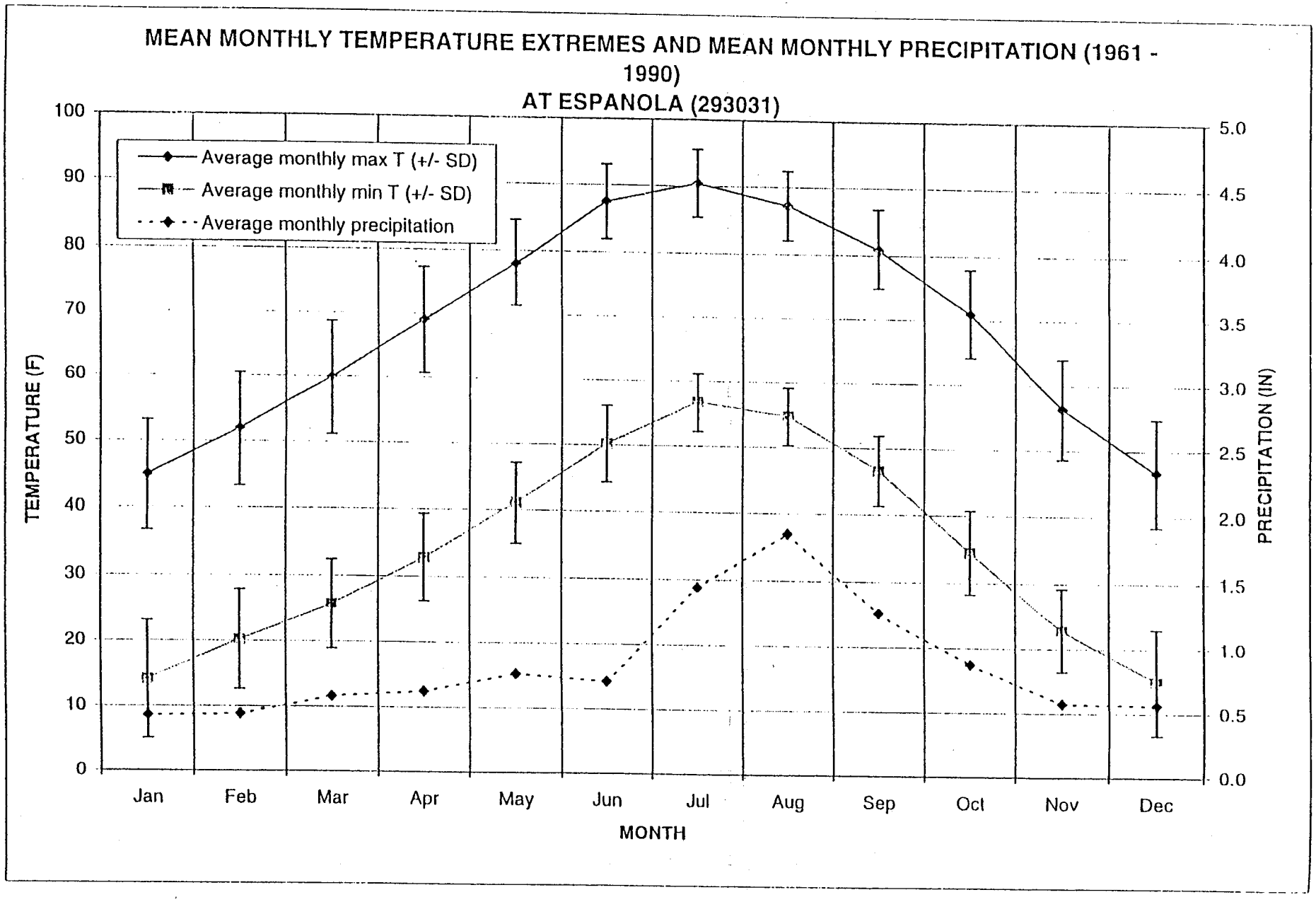

MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT BANDELIER NATIONAL MONUMENT (290743)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.30
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan

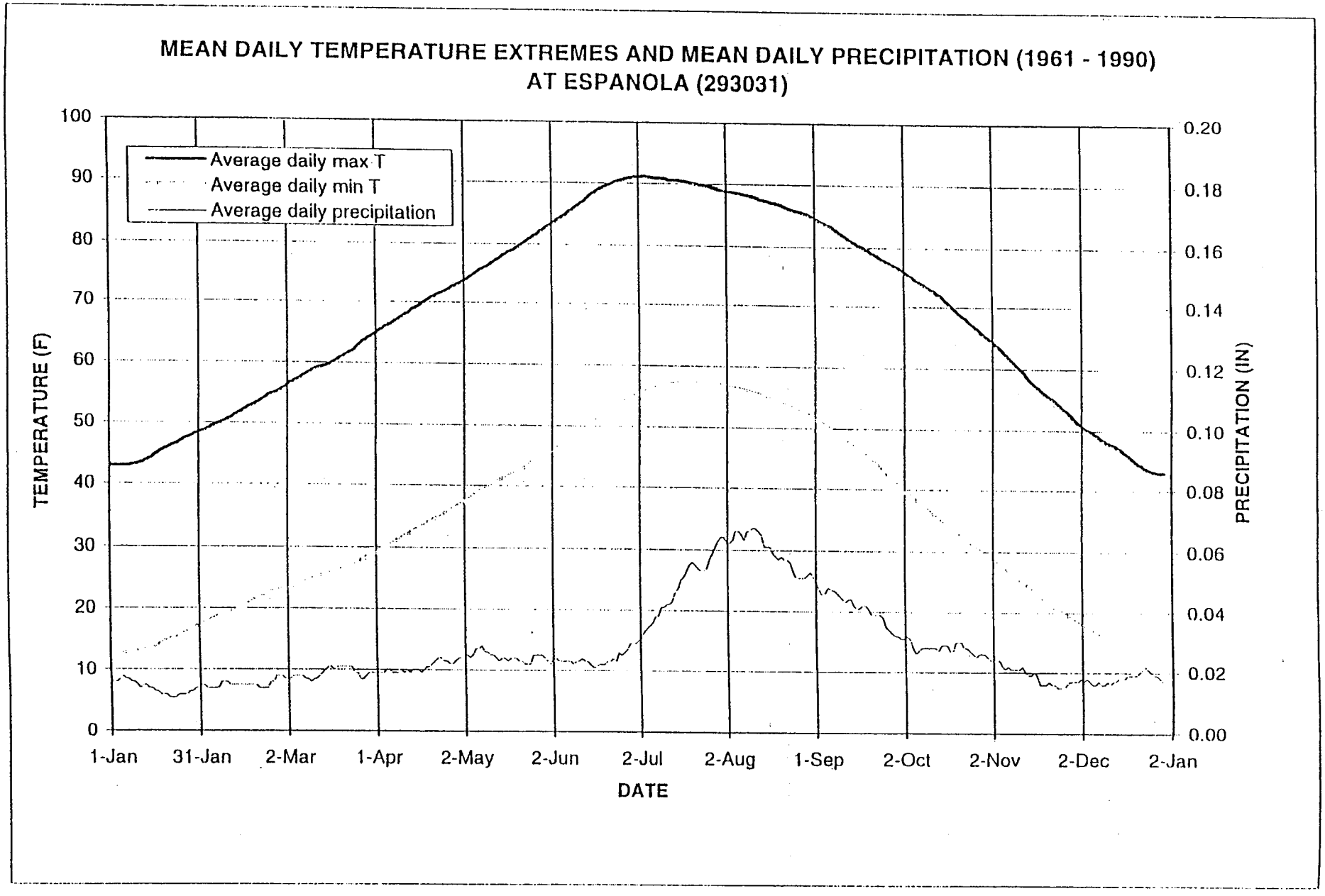

MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT COCHITI DAM (291982)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

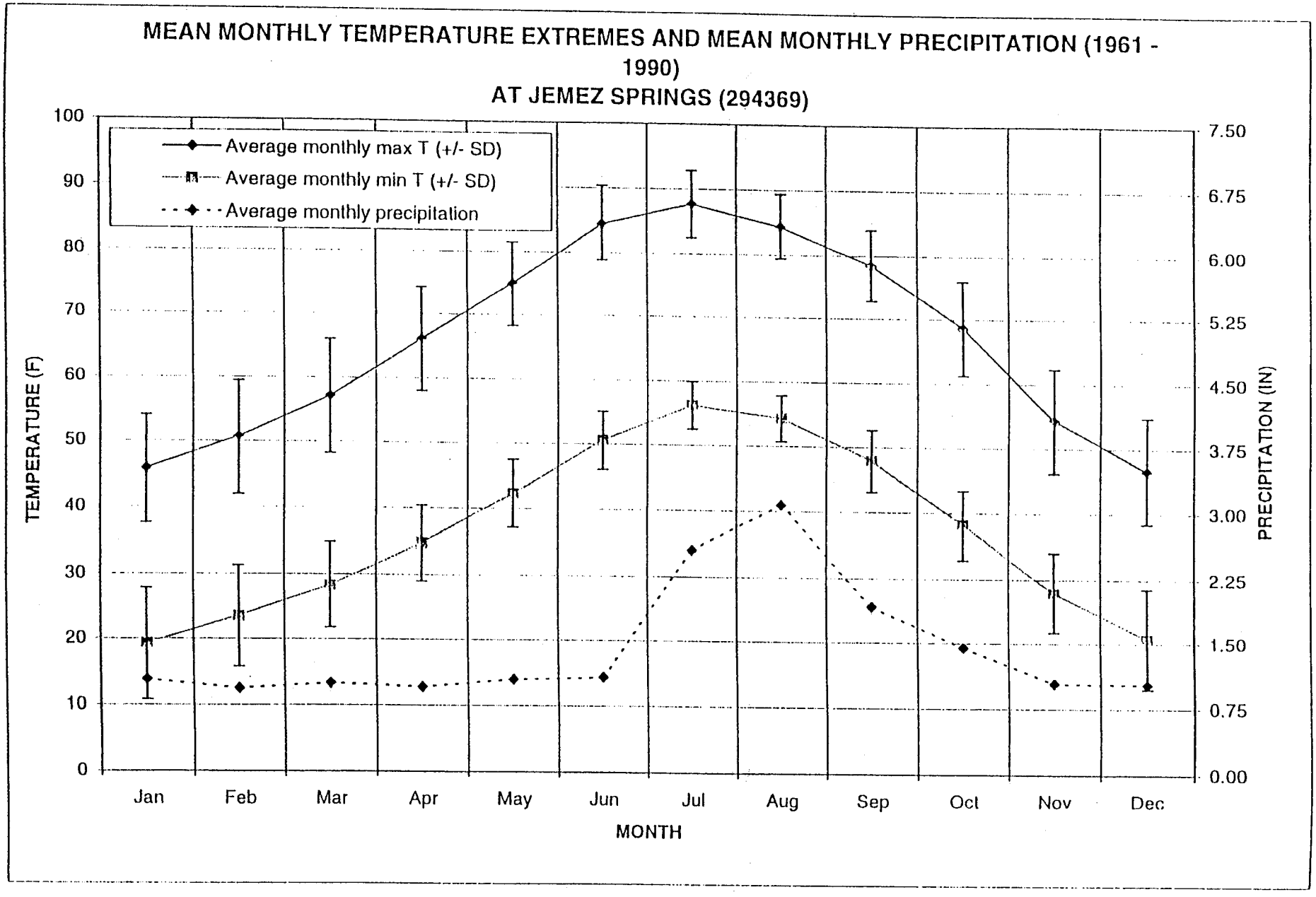

MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT COCHITI DAM (291982)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan

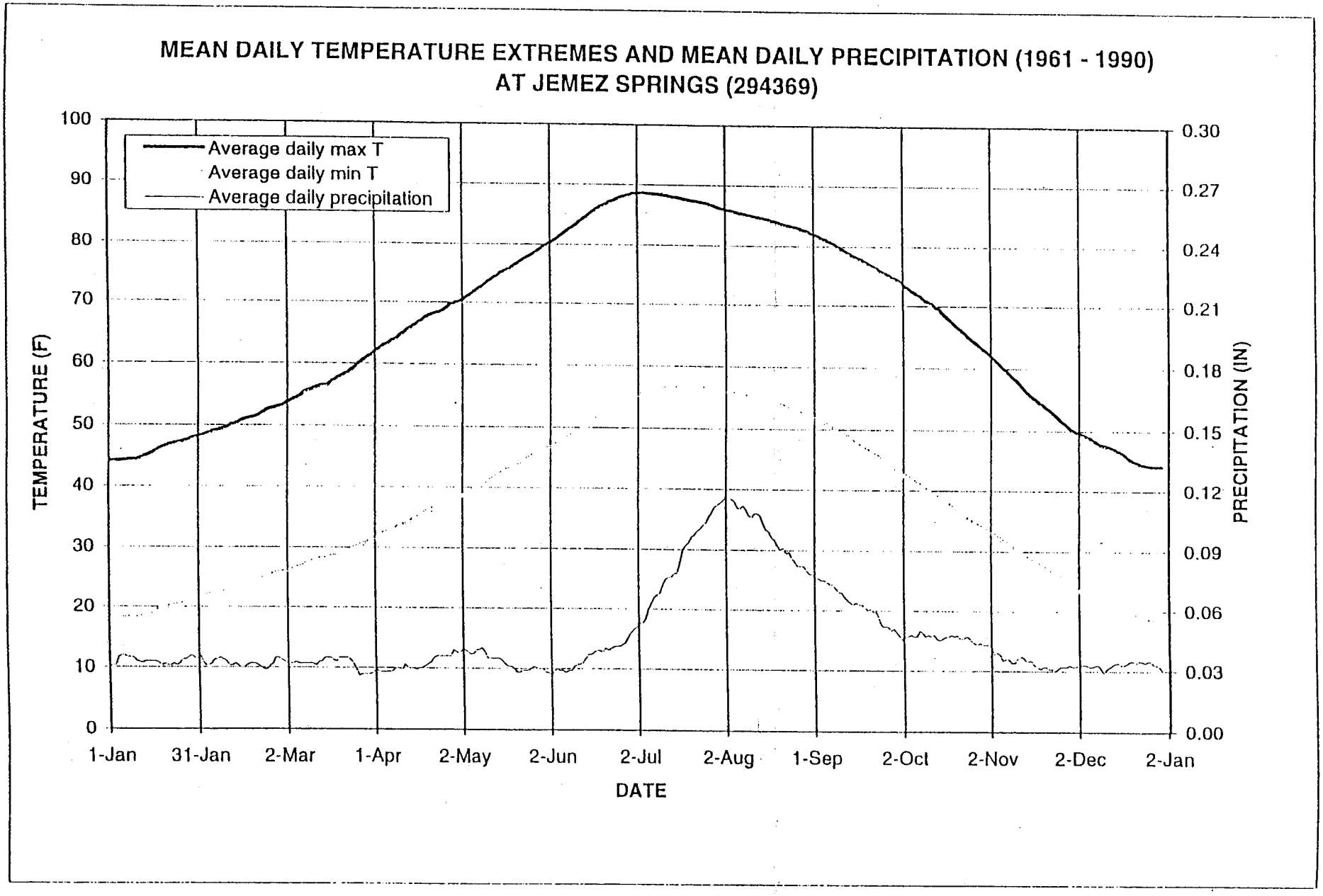

MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT EL RITO (292820)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
10
20
30
40
50
60
70
80
90
100
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

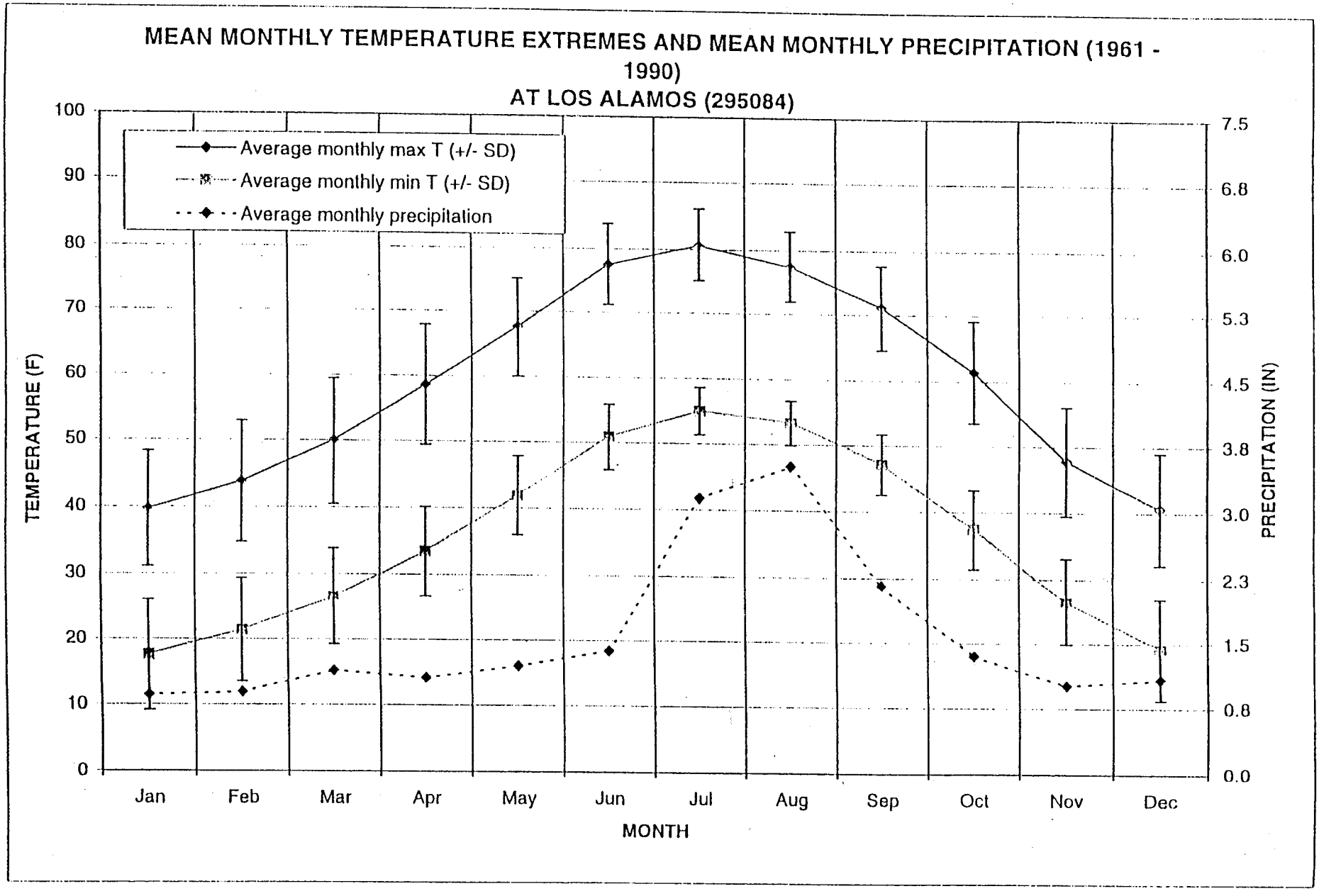

MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT EL RITO (292820)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan

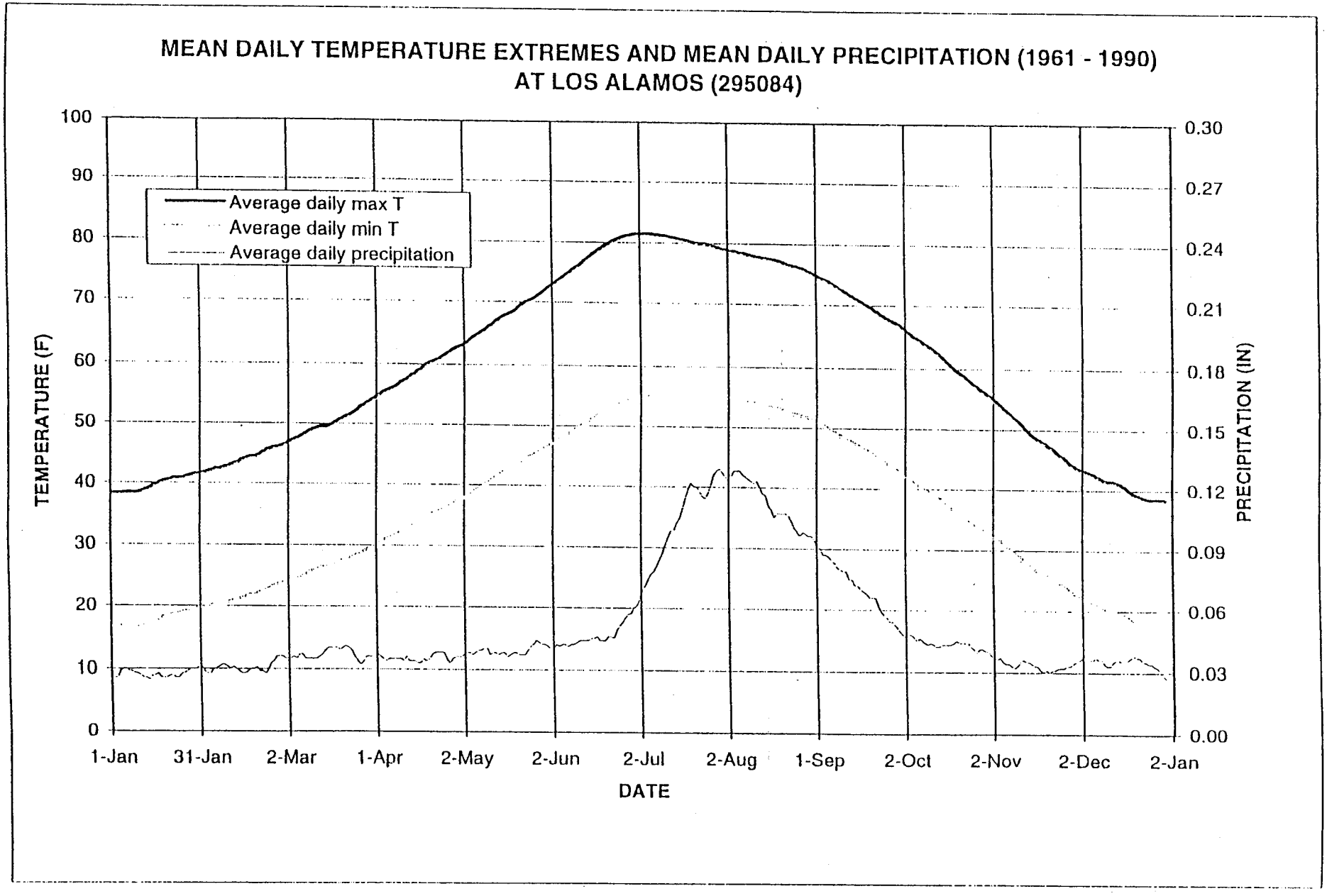

MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT ESPANOLA (293031)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT ESPANOLA (293031)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan


MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT JEMEZ SPRINGS (294369)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
7.50
6.75
6.00
5.25
4.50
3.75
3.00
2.25
1.50
0.75
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT JEMEZ SPRINGS (294369)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.30
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan


MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT LOS ALAMOS (295084)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
7.5
6.8
6.0
5.3
4.5
3.8
3.0
2.3
1.5
0.8
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT LOS ALAMOS (295084)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.30
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
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2-Aug
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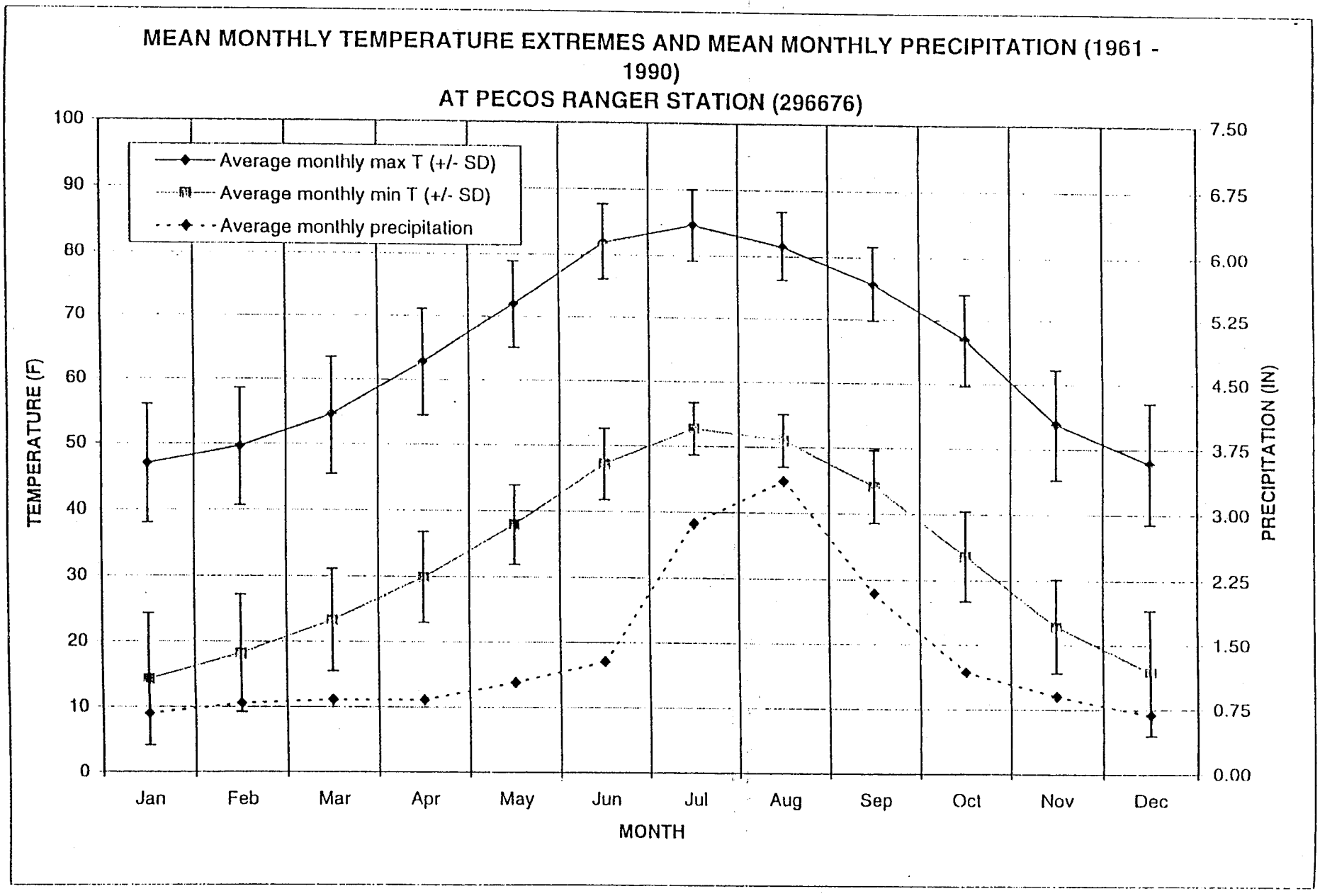
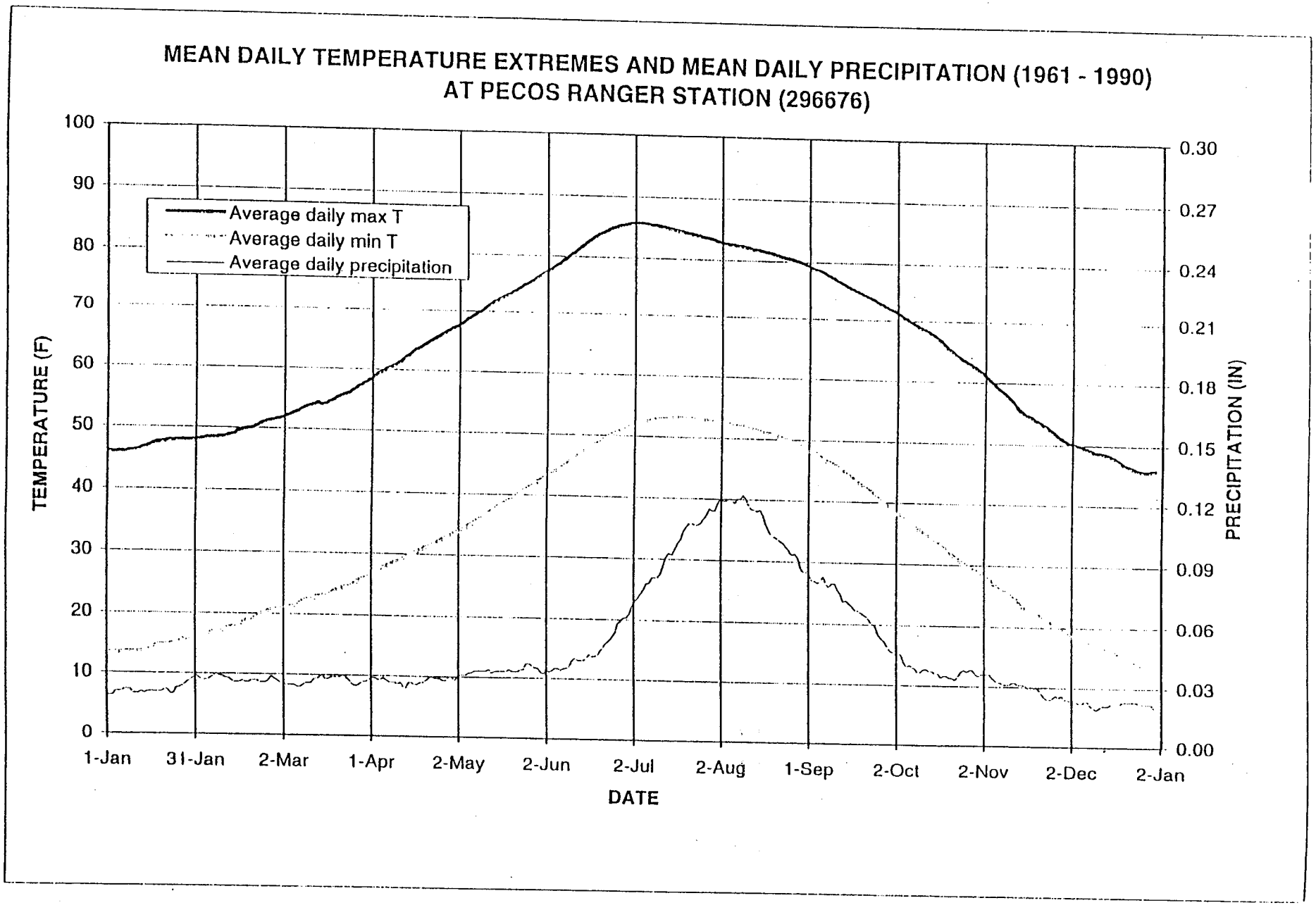
2-Oct
2-Nov
2-Dec
2-Jan


MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT PECOS RANGER STATION (296676)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
7.50
6.75
6.00
5.25
4.50
3.75
3.00
2.25
1.50
0.75
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990)
AT PECOS RANGER STATION (296676)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.30
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
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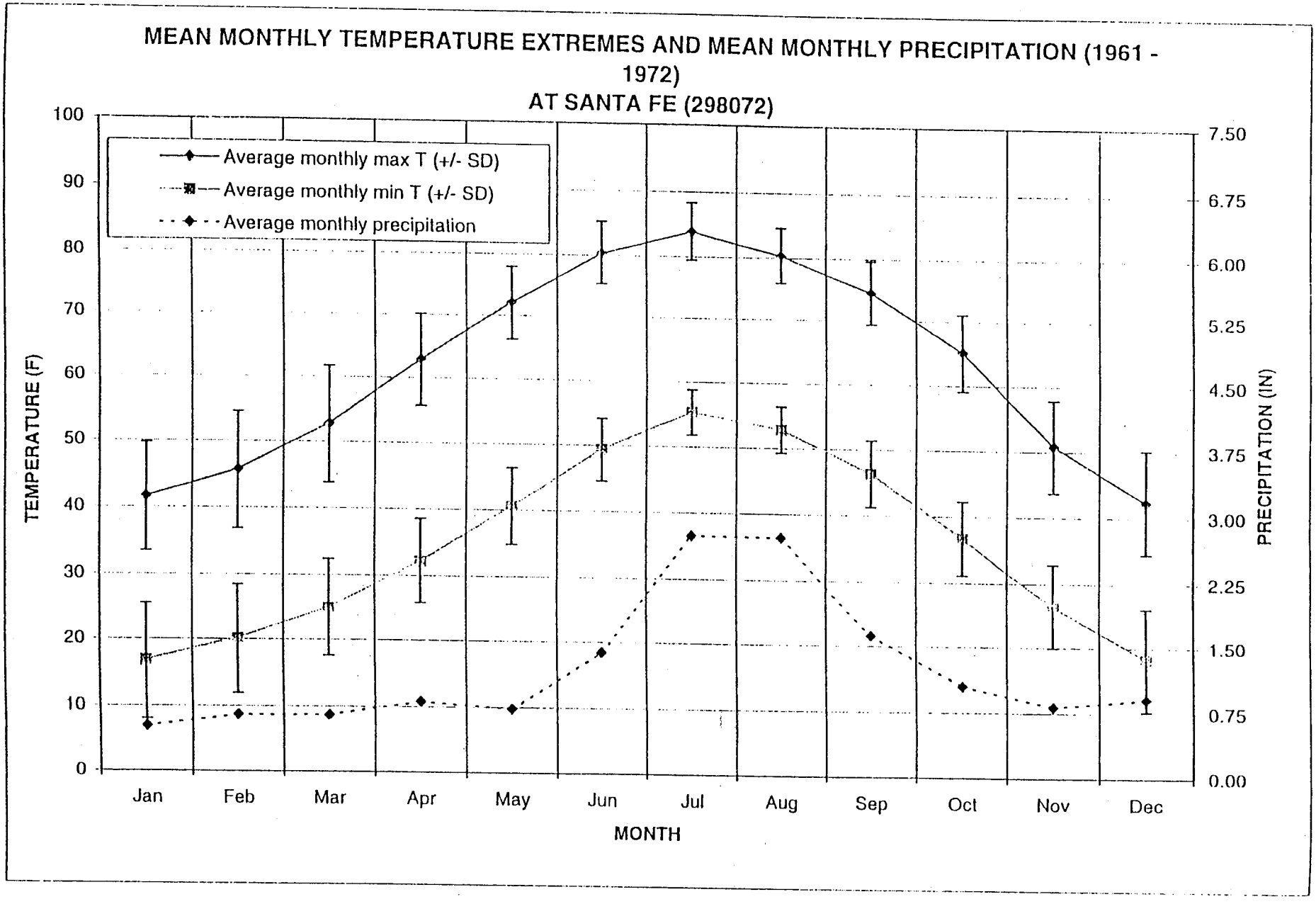
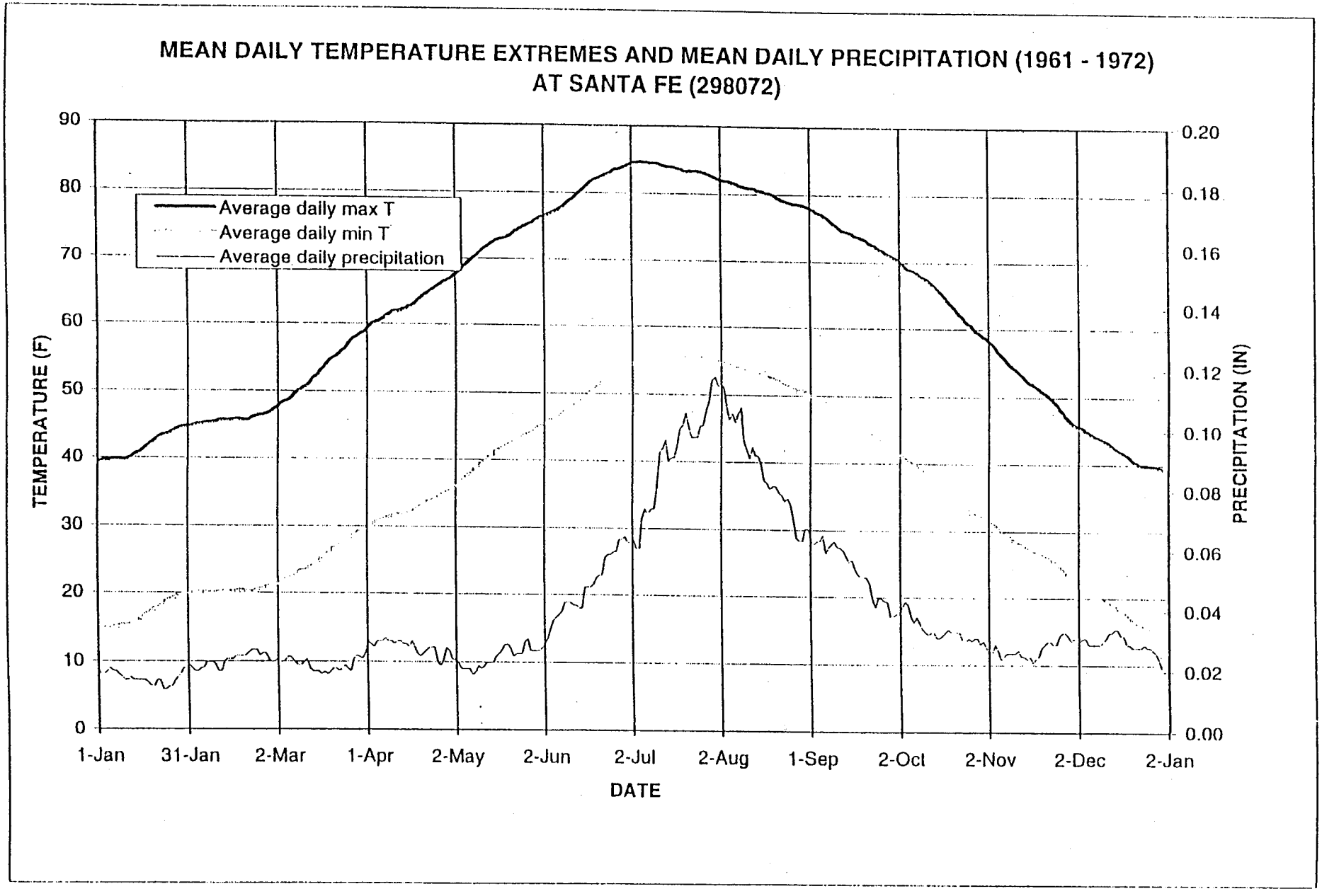
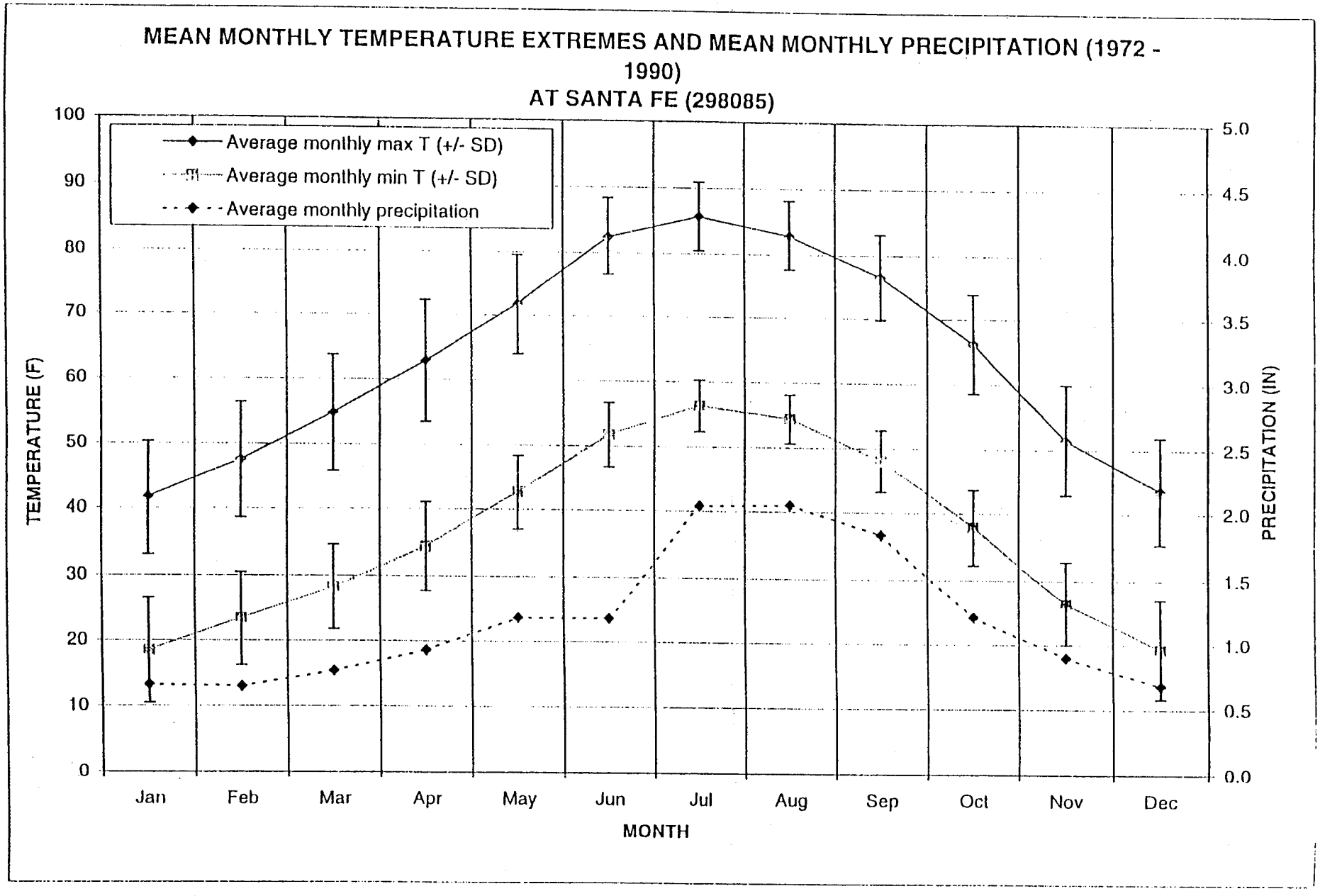
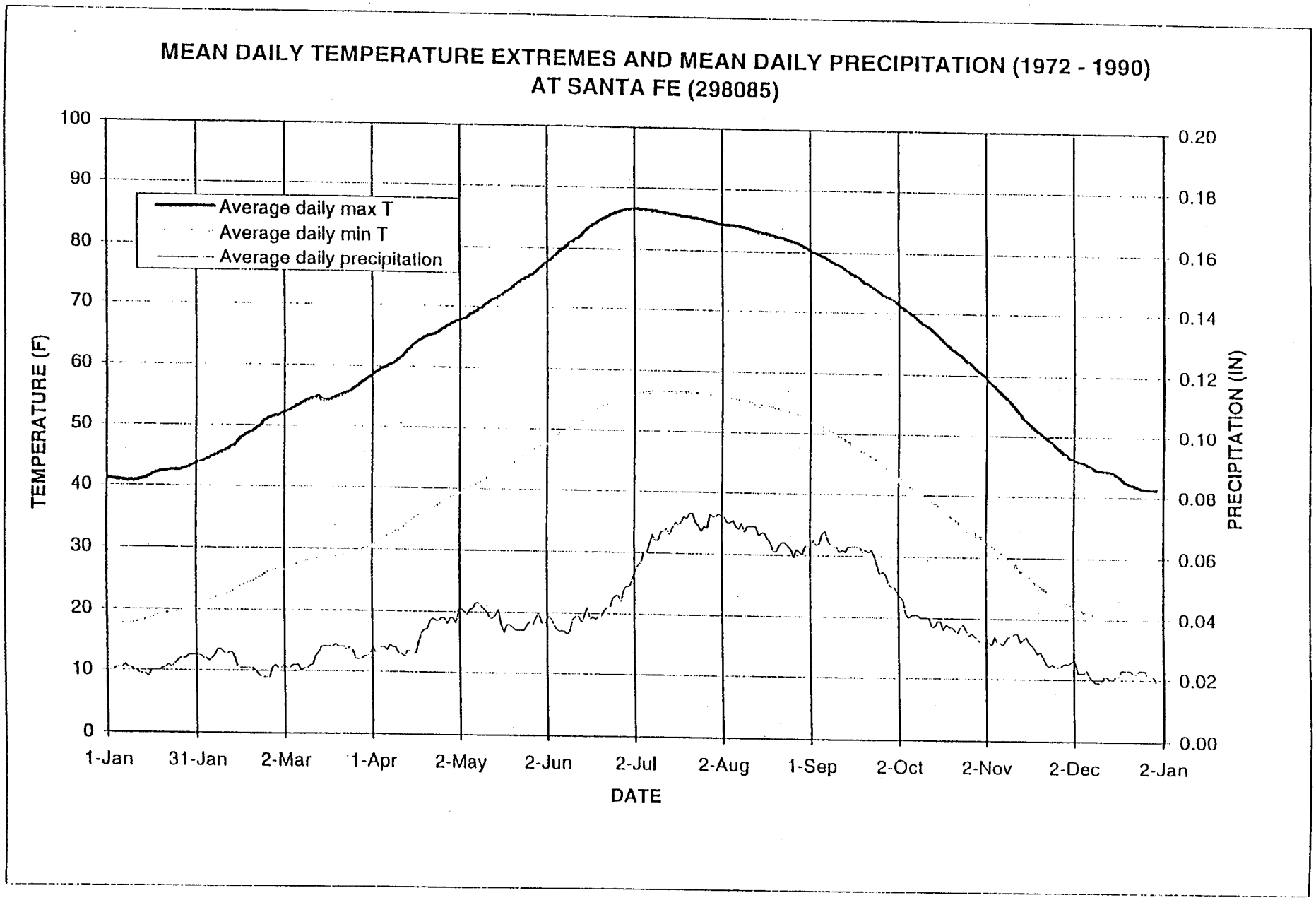
2-Oct
2-Nov
2-Dec
2-Jan


MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1972)
AT SANTA FE (298072)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
7.50
6.75
6.00
5.25
4.50
3.75
3.00
2.25
1.50
0.75
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1972)
AT SANTA FE (298072)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
90
80
70
60
50
40
30
20
10
0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan


MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1972 - 1990)
AT SANTA FE (298085)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1972 - 1990)
AT SANTA FE (298085)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
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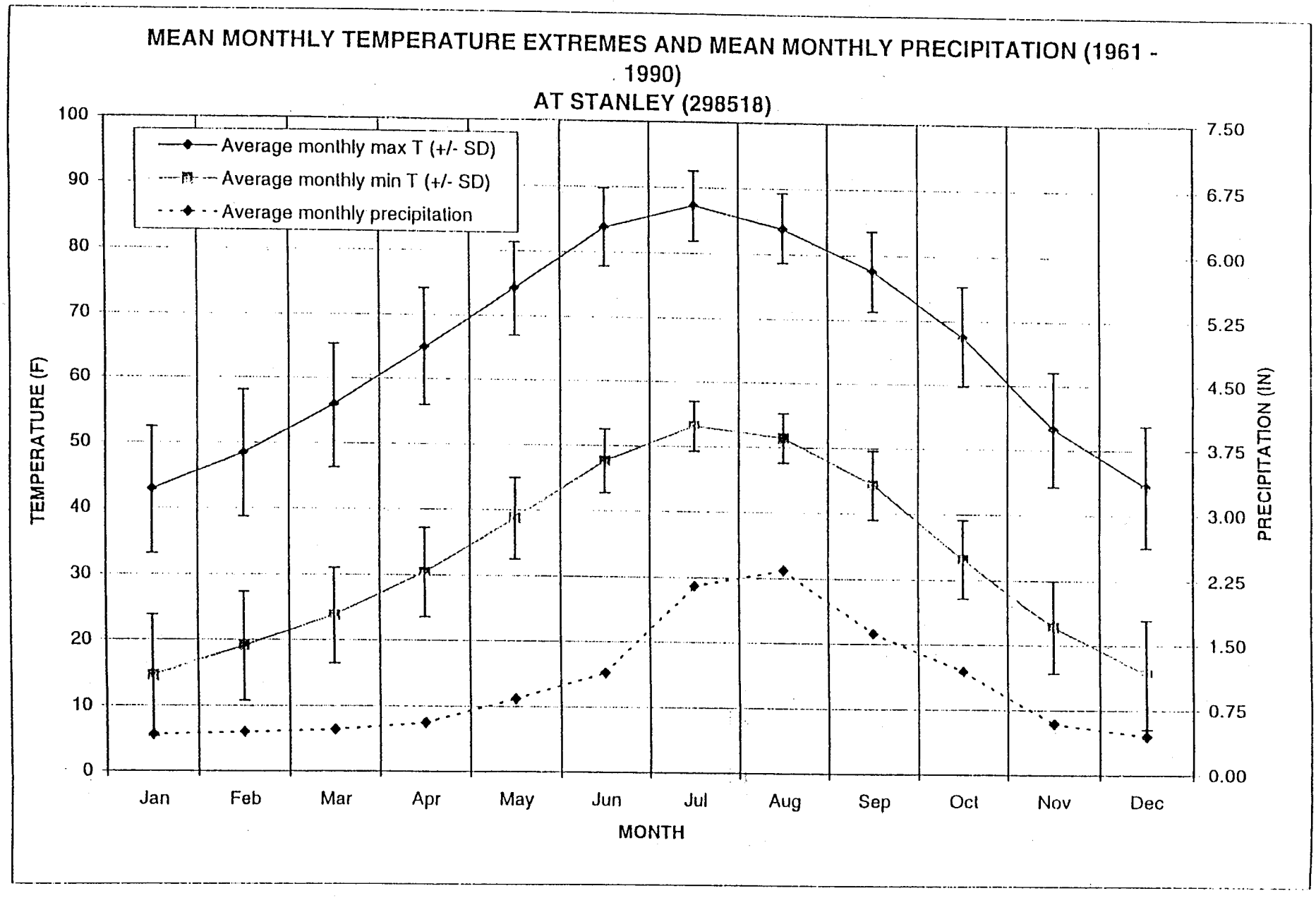
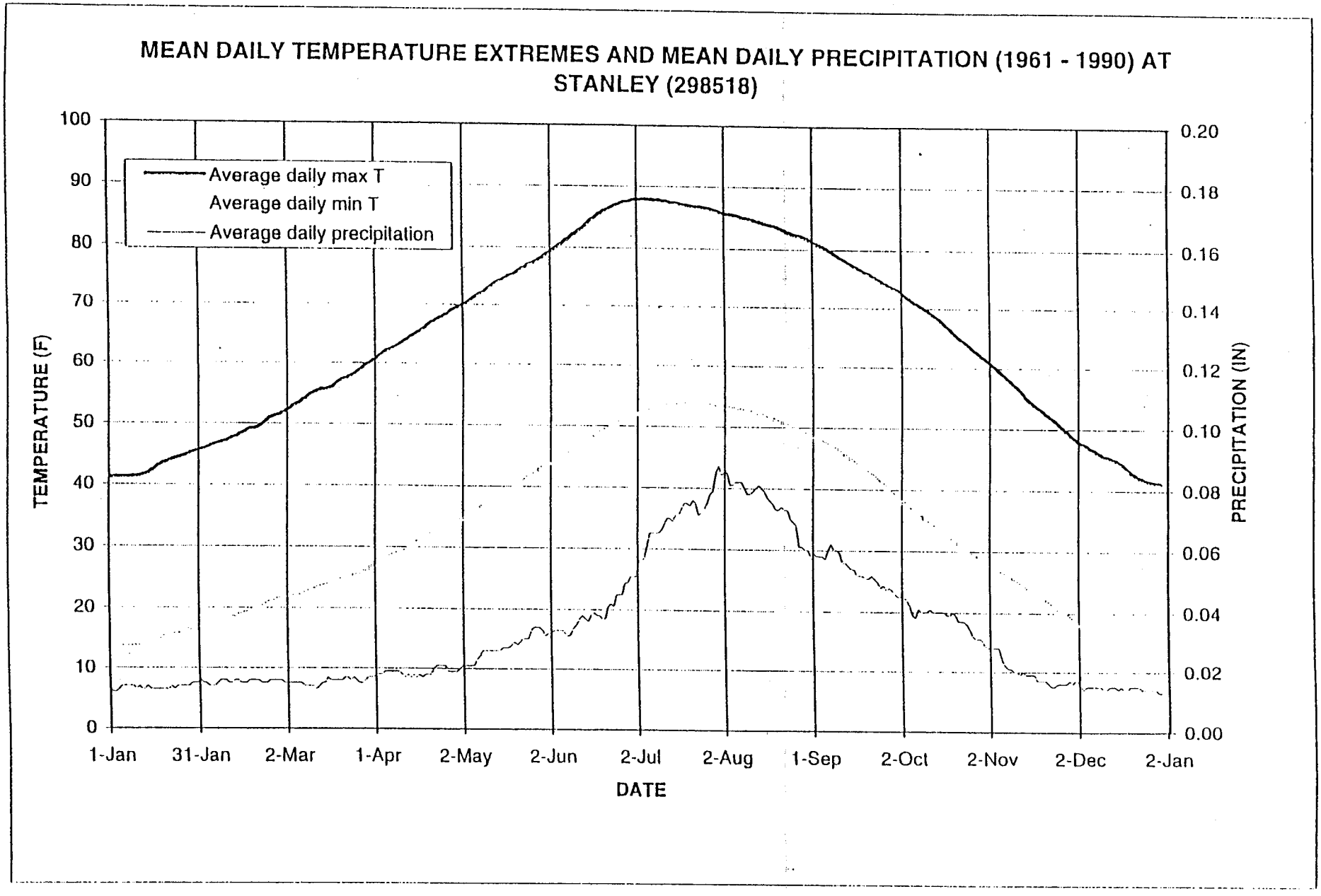
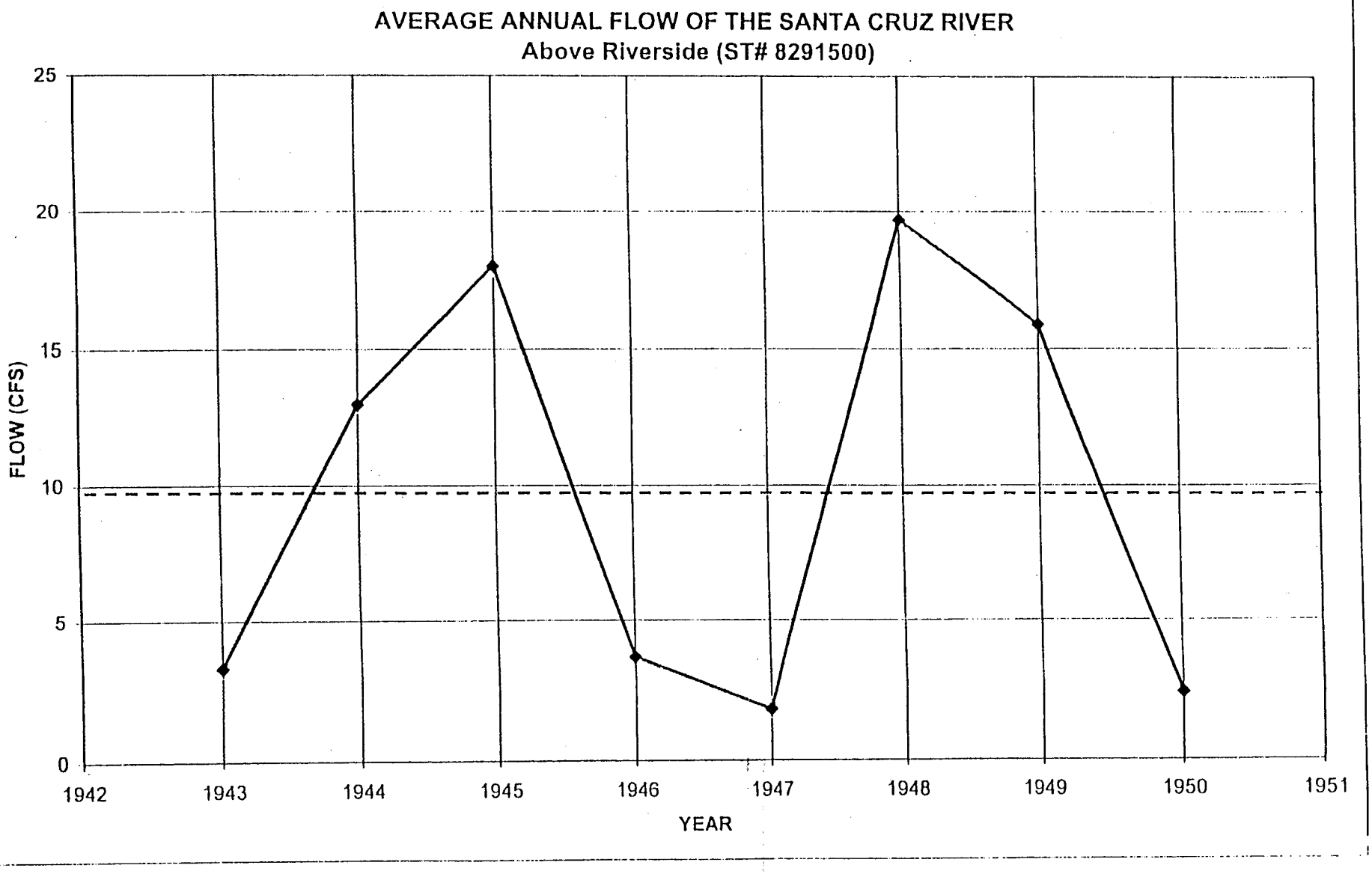
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan

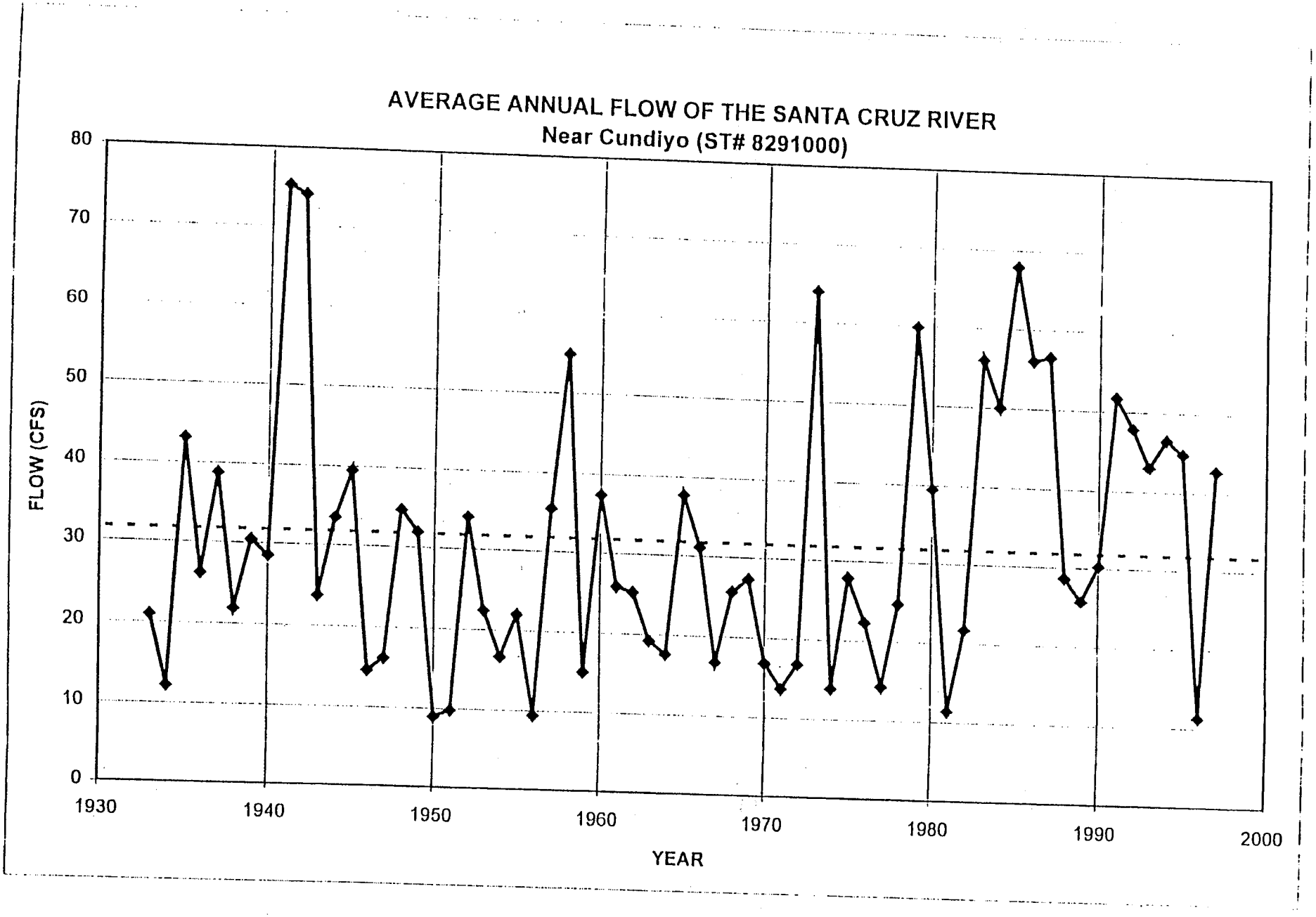

MEAN MONTHLY TEMPERATURE EXTREMES AND MEAN MONTHLY PRECIPITATION (1961 - 1990)
AT STANLEY (298518)
Average monthly max T (+/- SD)
Average monthly min T (+/- SD)
Average monthly precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
MONTH
100
90
80
70
60
50
40
30
20
10
0
7.50
6.75
6.00
5.25
4.50
3.75
3.00
2.25
1.50
0.75
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

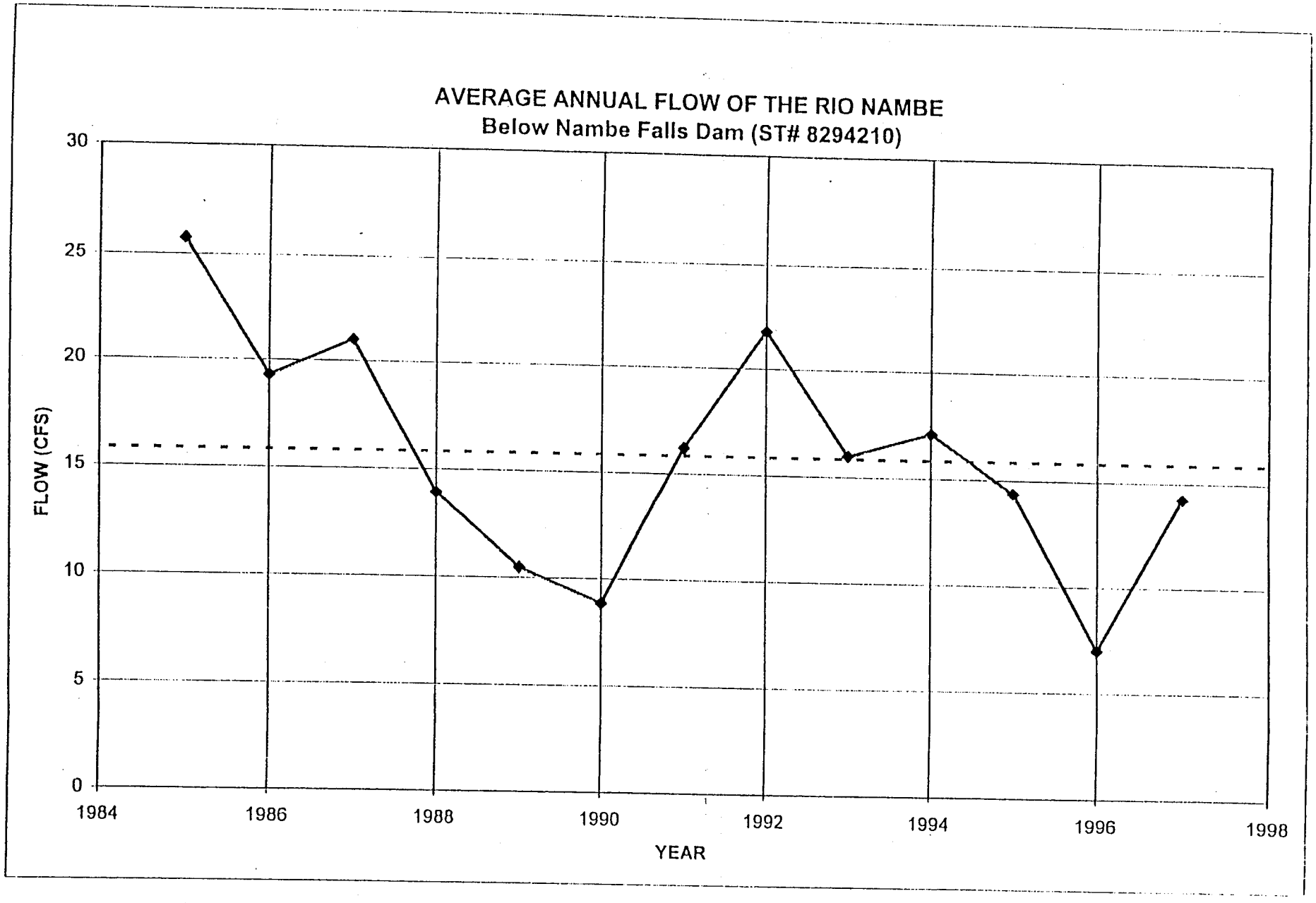

MEAN DAILY TEMPERATURE EXTREMES AND MEAN DAILY PRECIPITATION (1961 - 1990) AT STANLEY (298518)
Average daily max T
Average daily min T
Average daily precipitation
TEMPERATURE (F)
PRECIPITATION (IN)
DATE
100
90
80
70
60
50
40
30
20
10
0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2-Nov
2-Dec
2-Jan

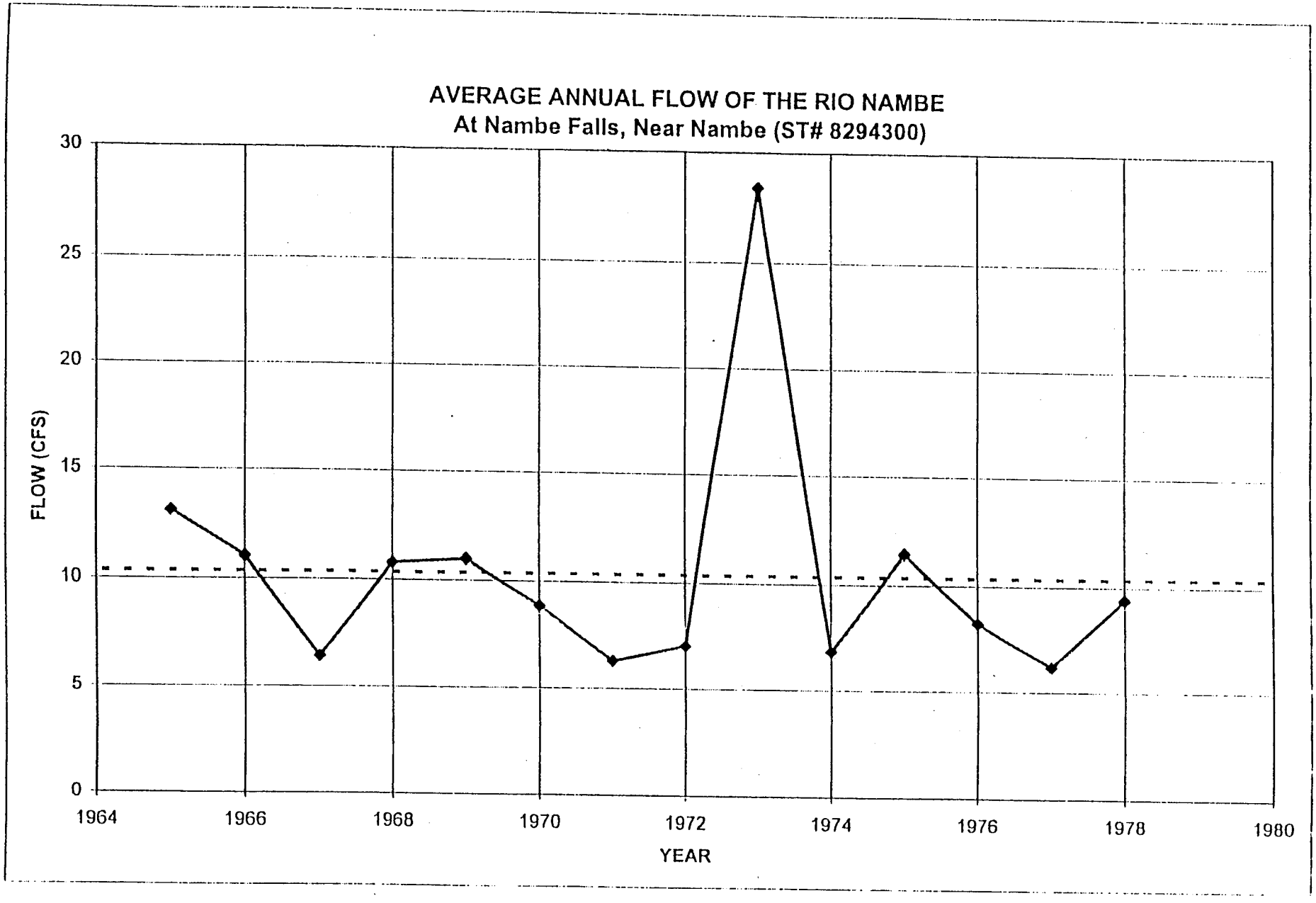
APPENDIX E

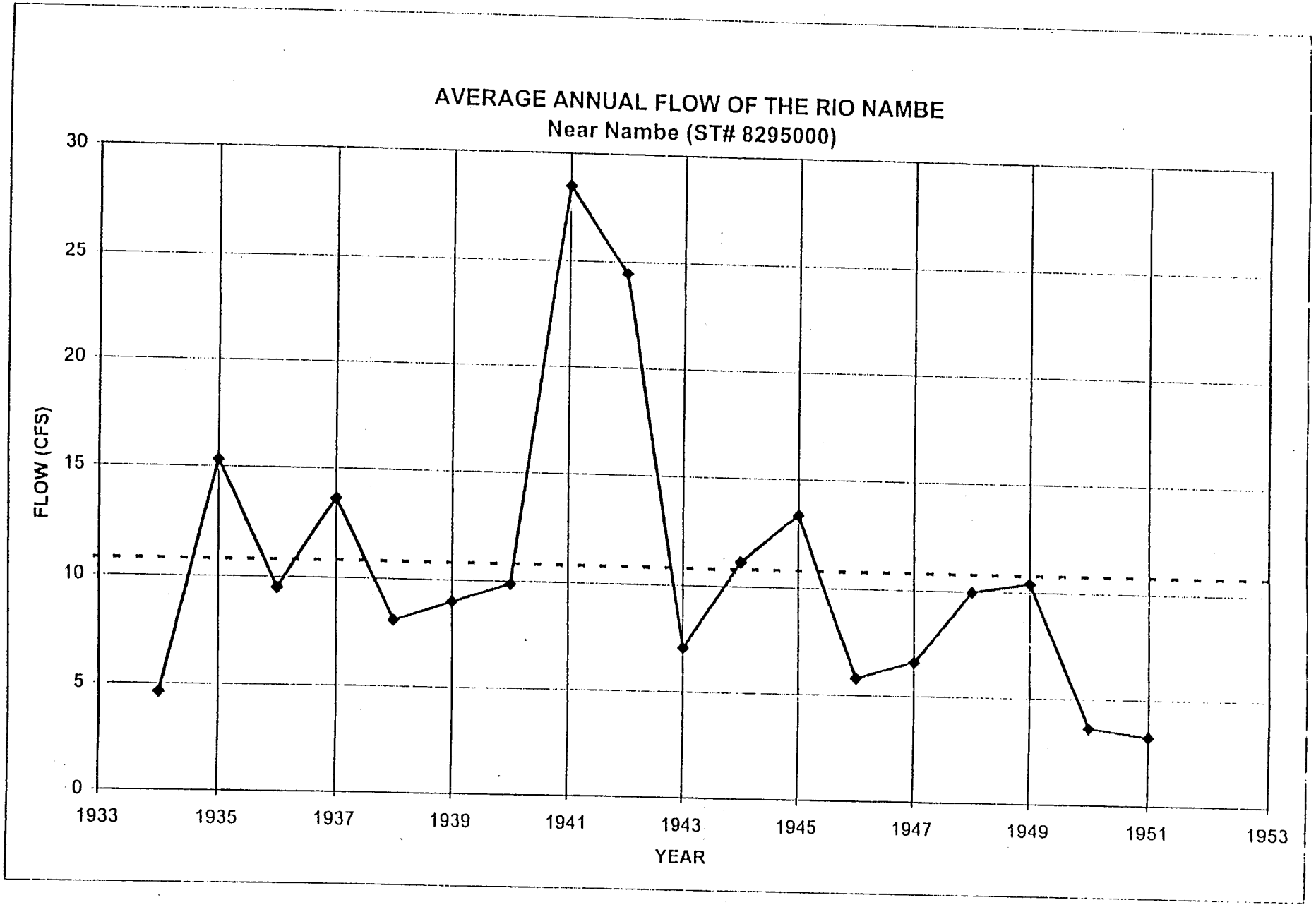
MEAN ANNUAL FLOWS AT USGS GAGING STATIONS

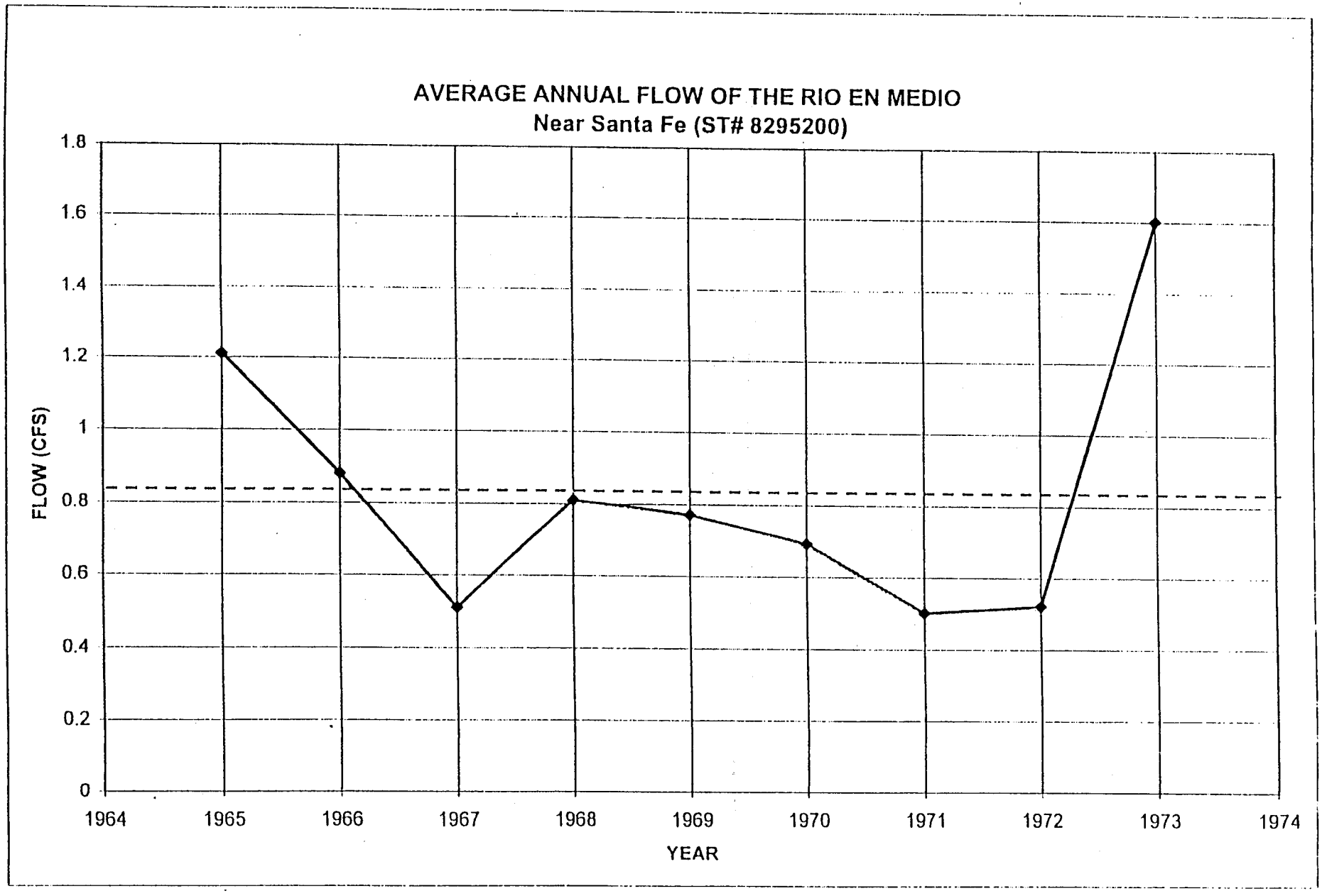

AVERAGE ANNUAL FLOW OF THE SANTA CRUZ RIVER
Above Riverside (ST# 8291500)
FLOW (CFS)
25
20
15
10
5
0
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
YEAR

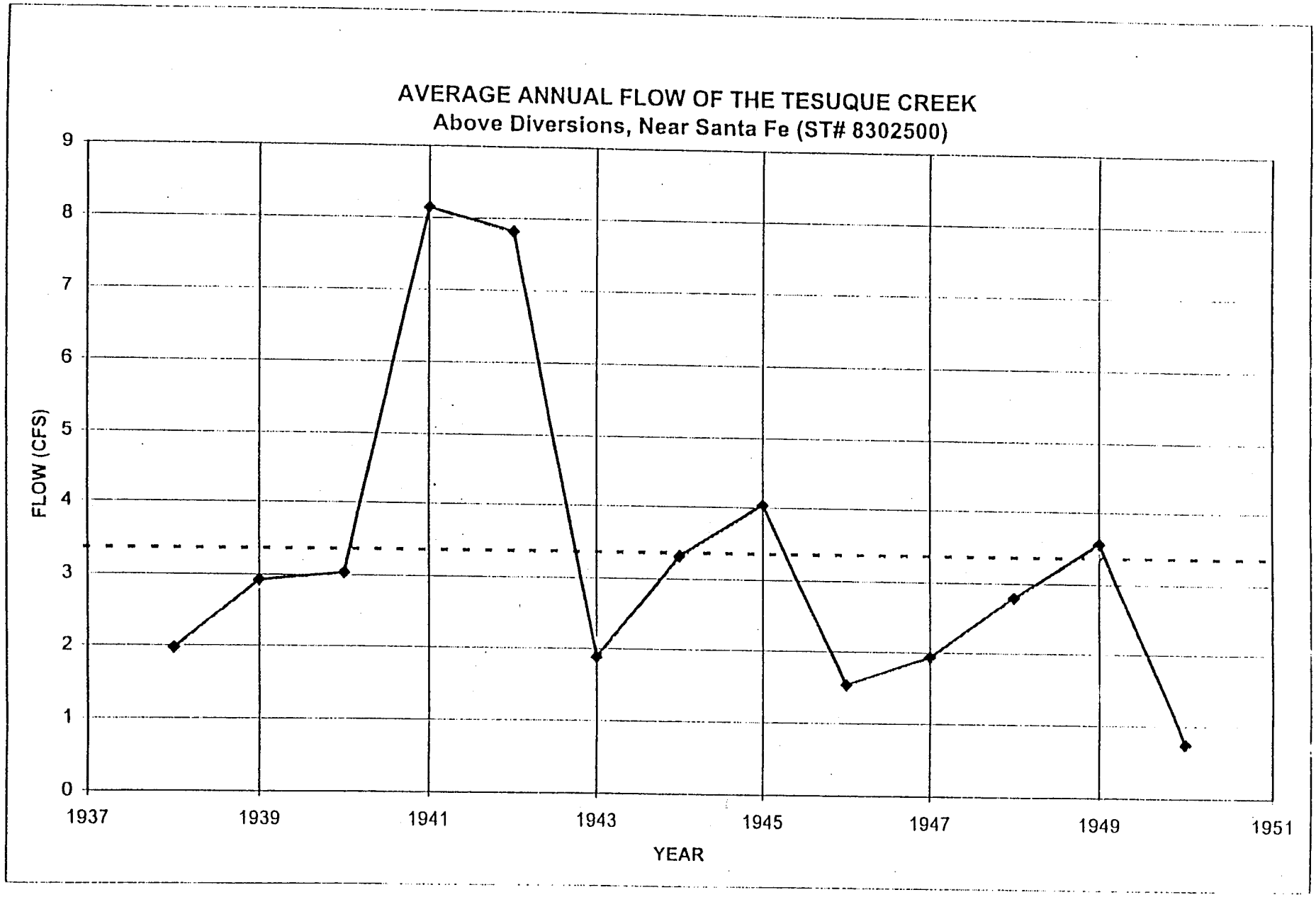

AVERAGE ANNUAL FLOW OF THE SANTA CRUZ RIVER
Near Cundiyo (ST# 8291000)
FLOW (CFS)
80
70
60
50
40
30
20
10
0
1930
1940
1950
1960
1970
1980
1990
2000
YEAR

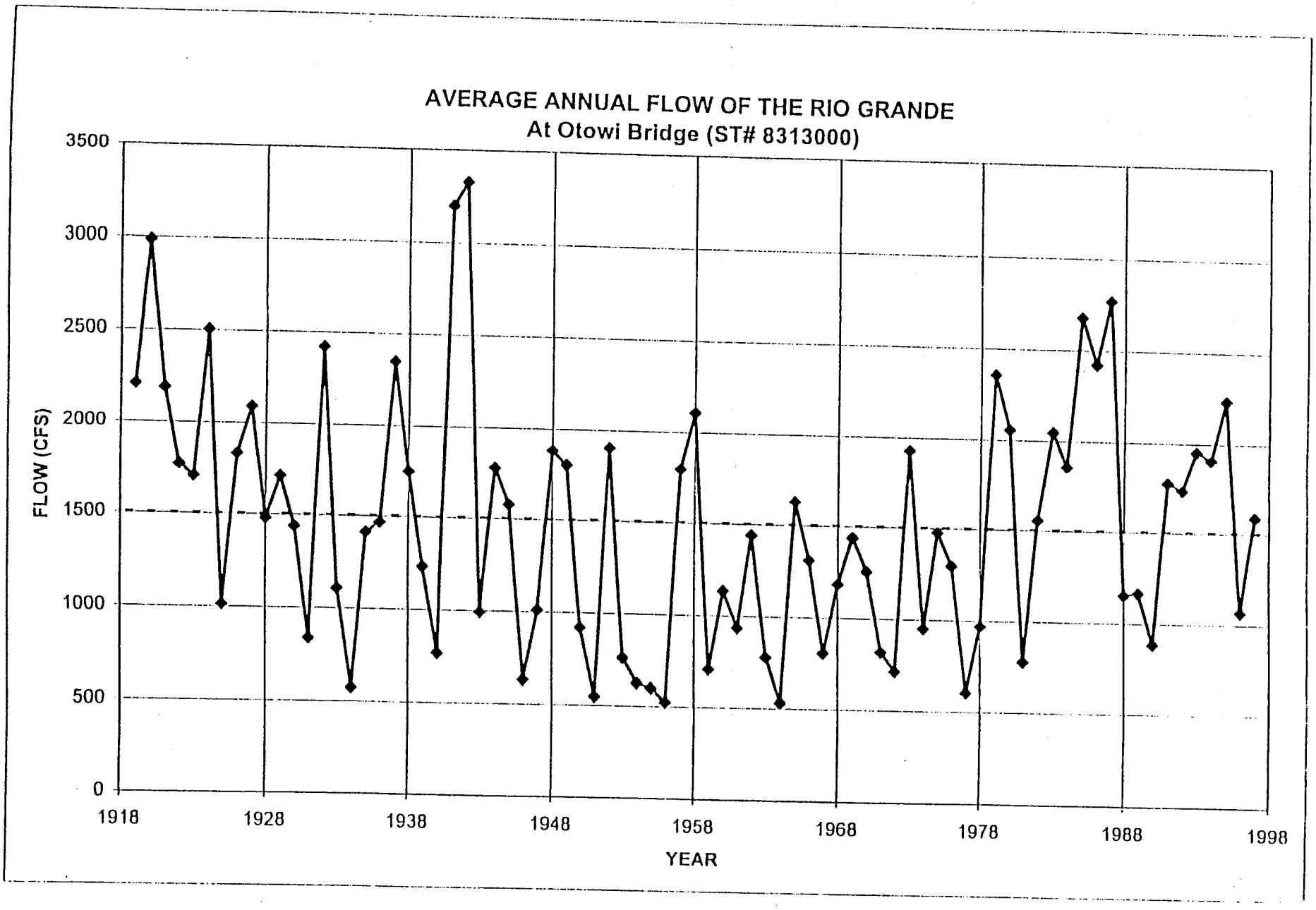

AVERAGE ANNUAL FLOW OF THE RIO NAMBE
Below Nambe Falls Dam (ST# 8294210)
FLOW (CFS)
30
25
20
15
10
5
0
1984
1986
1988
1990
1992
1994
1996
1998
YEAR

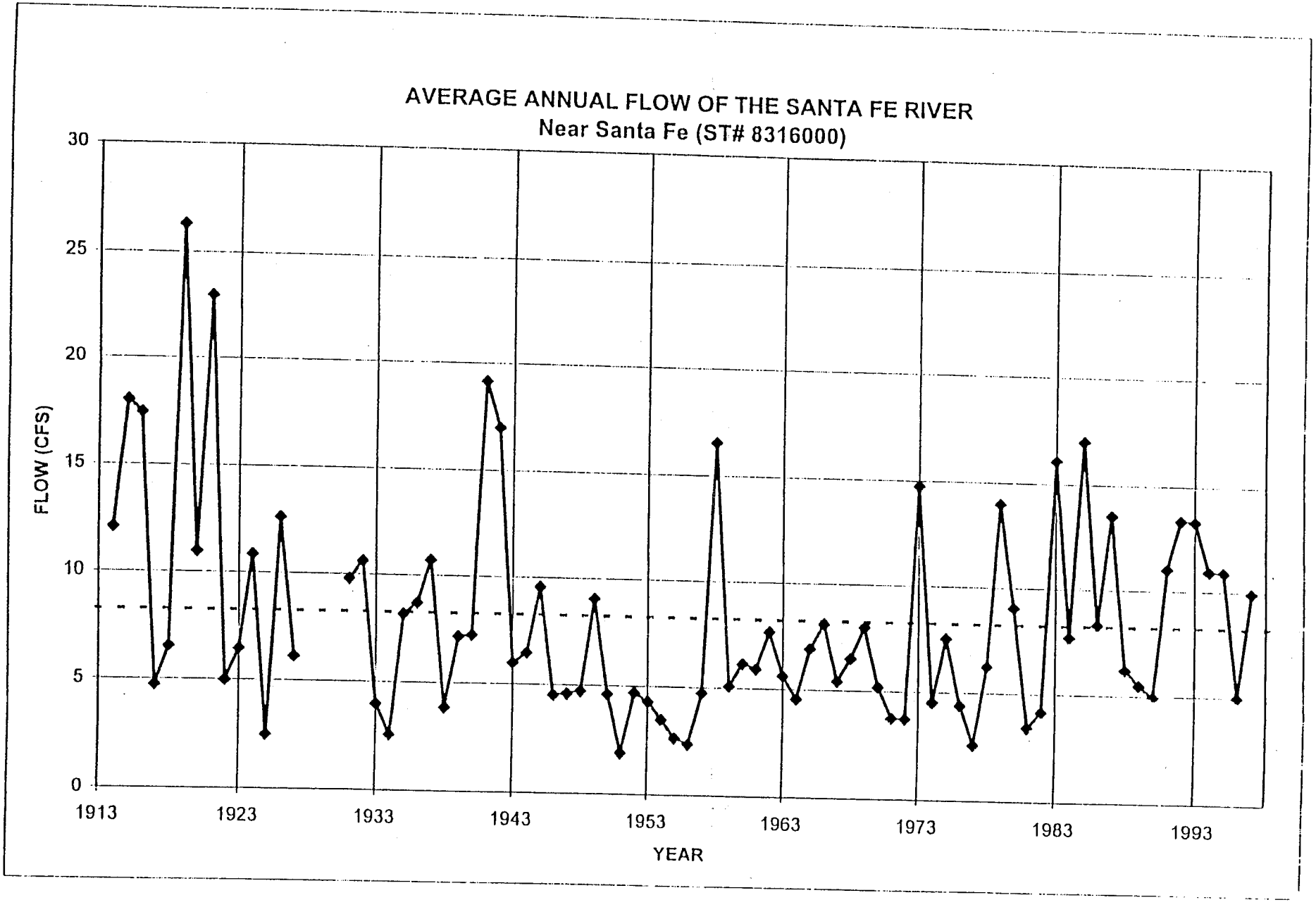

AVERAGE ANNUAL FLOW OF THE RIO NAMBE
At Nambe Falls, Near Nambe (ST# 8294300)
FLOW (CFS)
30
25
20
15
10
5
0
1964
1966
1968
1970
1972
1974
1976
1978
1980
YEAR

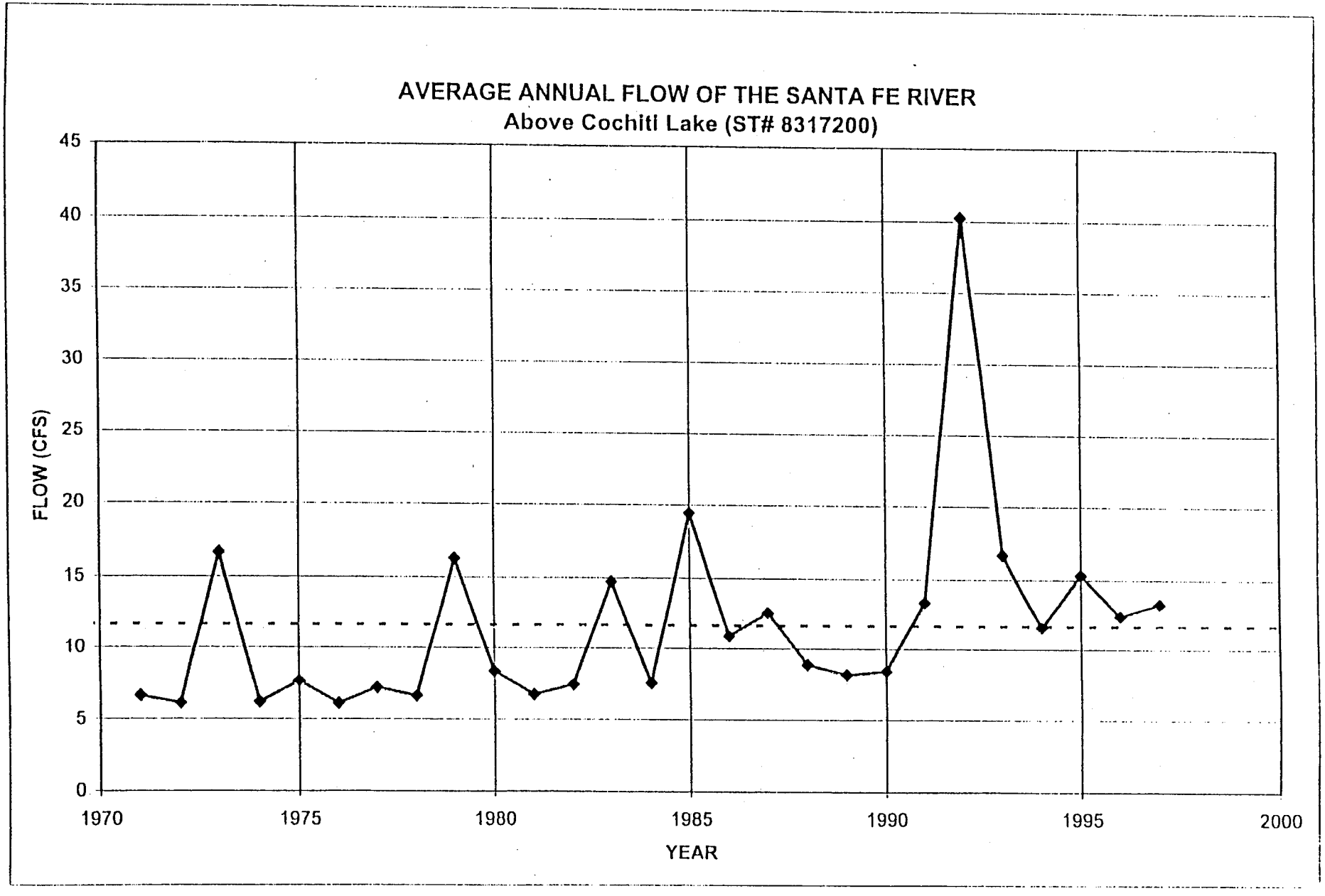

AVERAGE ANNUAL FLOW OF THE RIO NAMBE
Near Nambe (ST# 8295000)
FLOW (CFS)
30
25
20
15
10
5
0
1933
1935
1937
1939
1941
1943
1945
1947
1949
1951
1953
YEAR

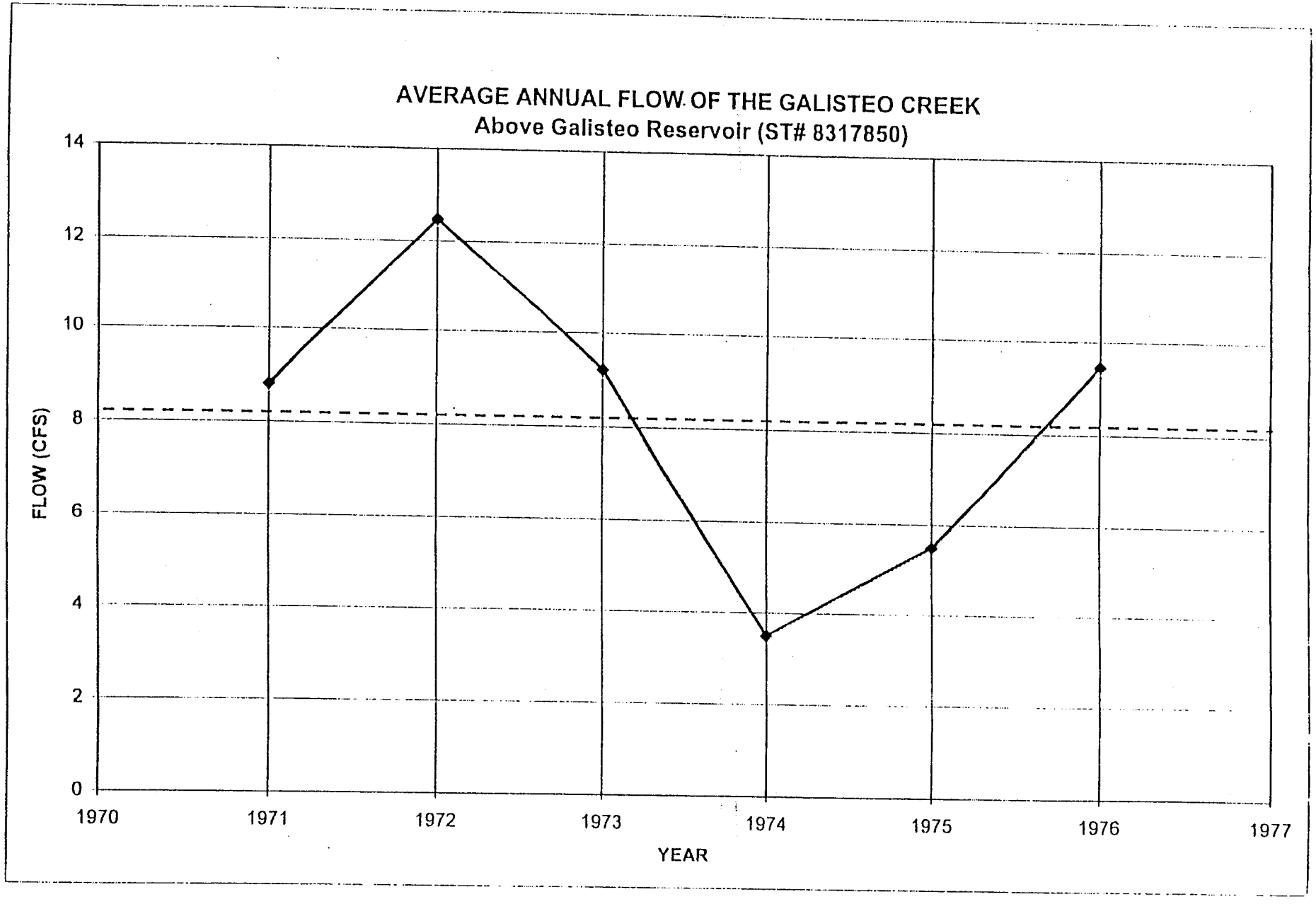

AVERAGE ANNUAL FLOW OF THE RIO EN MEDIO
Near Santa Fe (ST# 8295200)
FLOW (CFS)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
YEAR

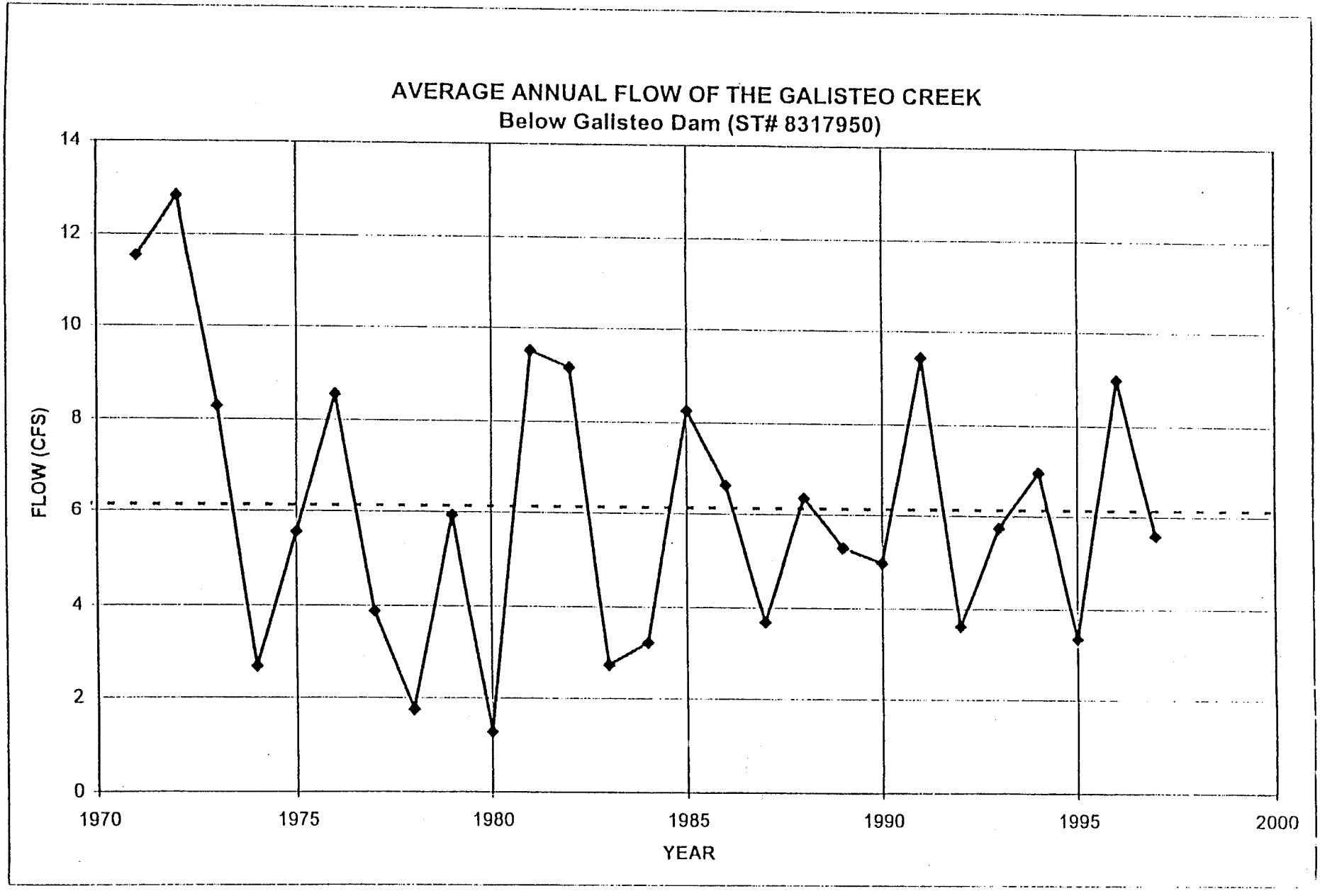

AVERAGE ANNUAL FLOW OF THE TESUQUE CREEK
Above Diversions, Near Santa Fe (ST# 8302500)
FLOW (CFS)
0
1
2
3
4
5
6
7
8
9
1937
1939
1941
1943
1945
1947
1949
1951
YEAR

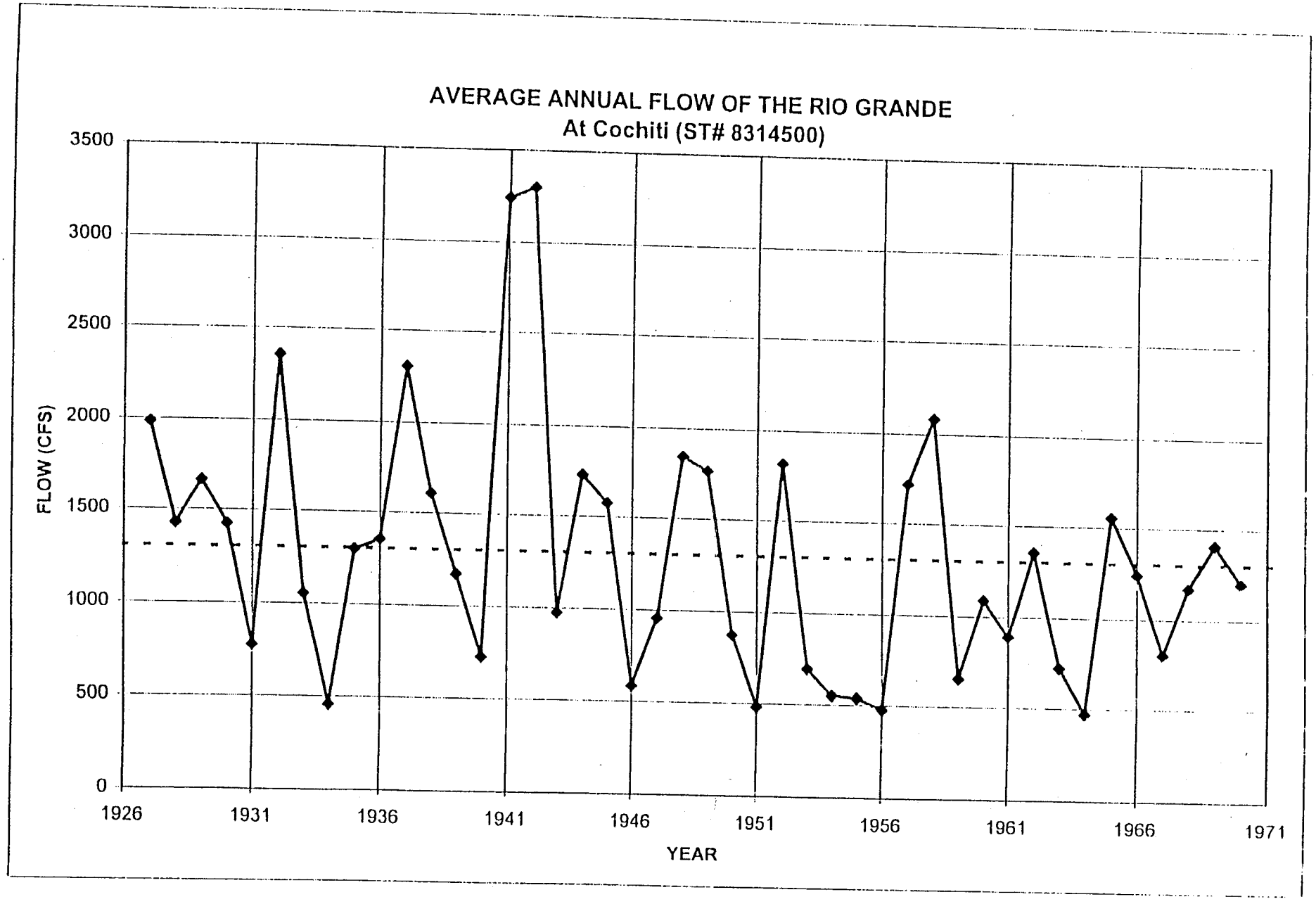

AVERAGE ANNUAL FLOW OF THE RIO GRANDE
At Otowi Bridge (ST# 8313000)
FLOW (CFS)
3500
3000
2500
2000
1500
1000
500
0
1918
1928
1938
1948
1958
1968
1978
1988
1998
YEAR

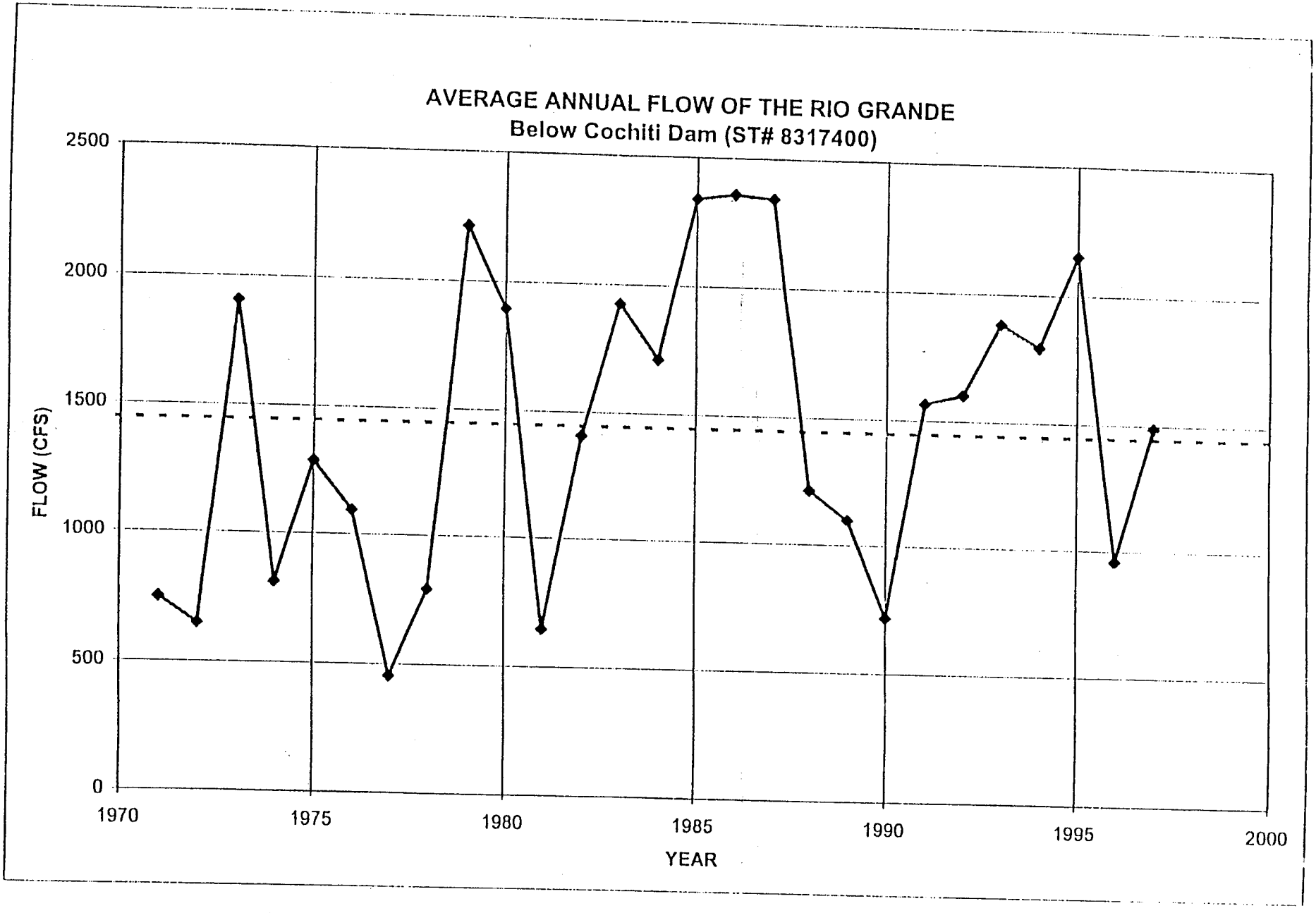

AVERAGE ANNUAL FLOW OF THE SANTA FE RIVER
Near Santa Fe (ST# 8316000)
FLOW (CFS)
30
25
20
15
10
5
0
1913
1923
1933
1943
1953
1963
1973
1983
1993
YEAR

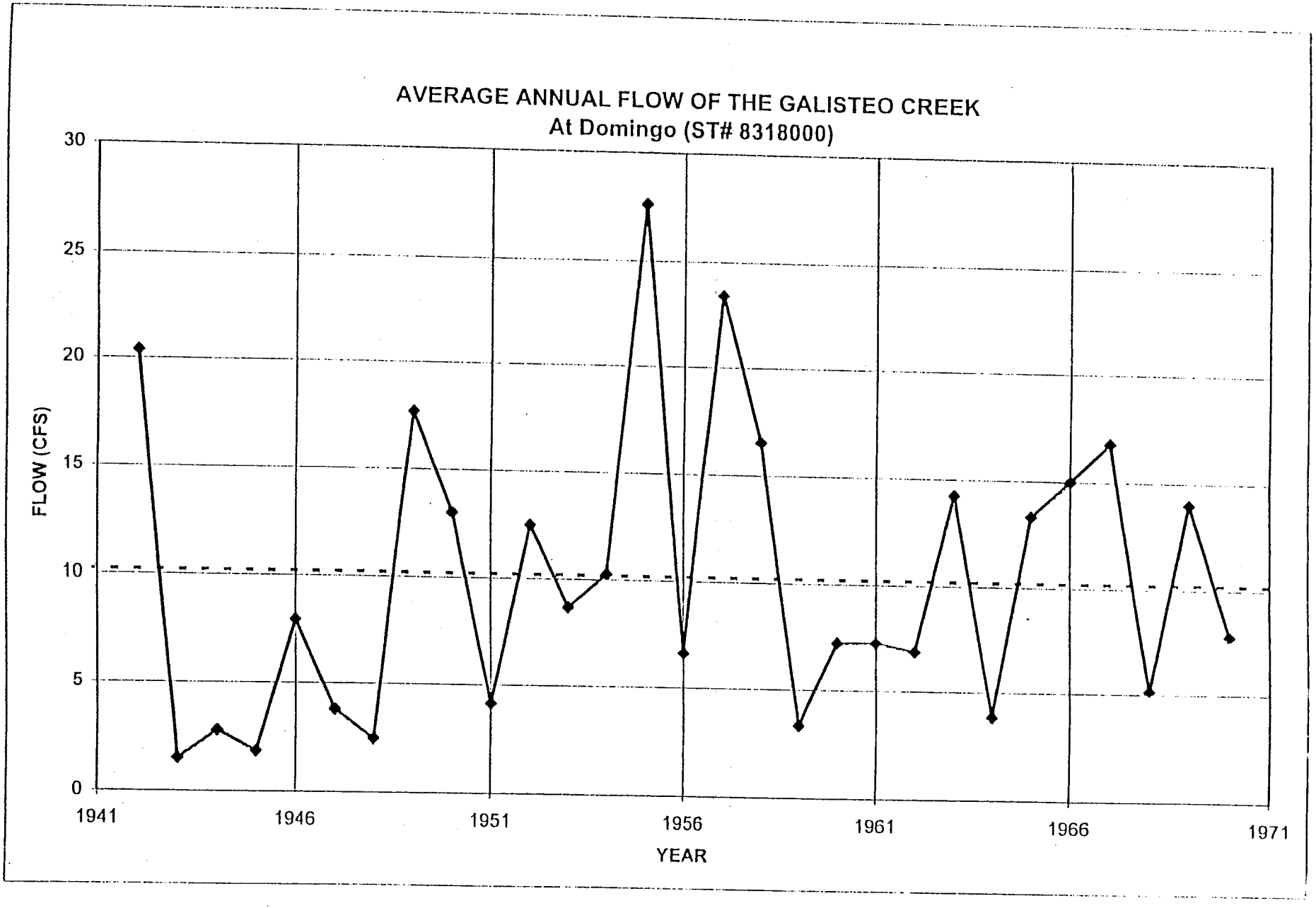

AVERAGE ANNUAL FLOW OF THE SANTA FE RIVER
Above Cochiti Lake (ST# 8317200)
FLOW (CFS)
45
40
35
30
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
YEAR

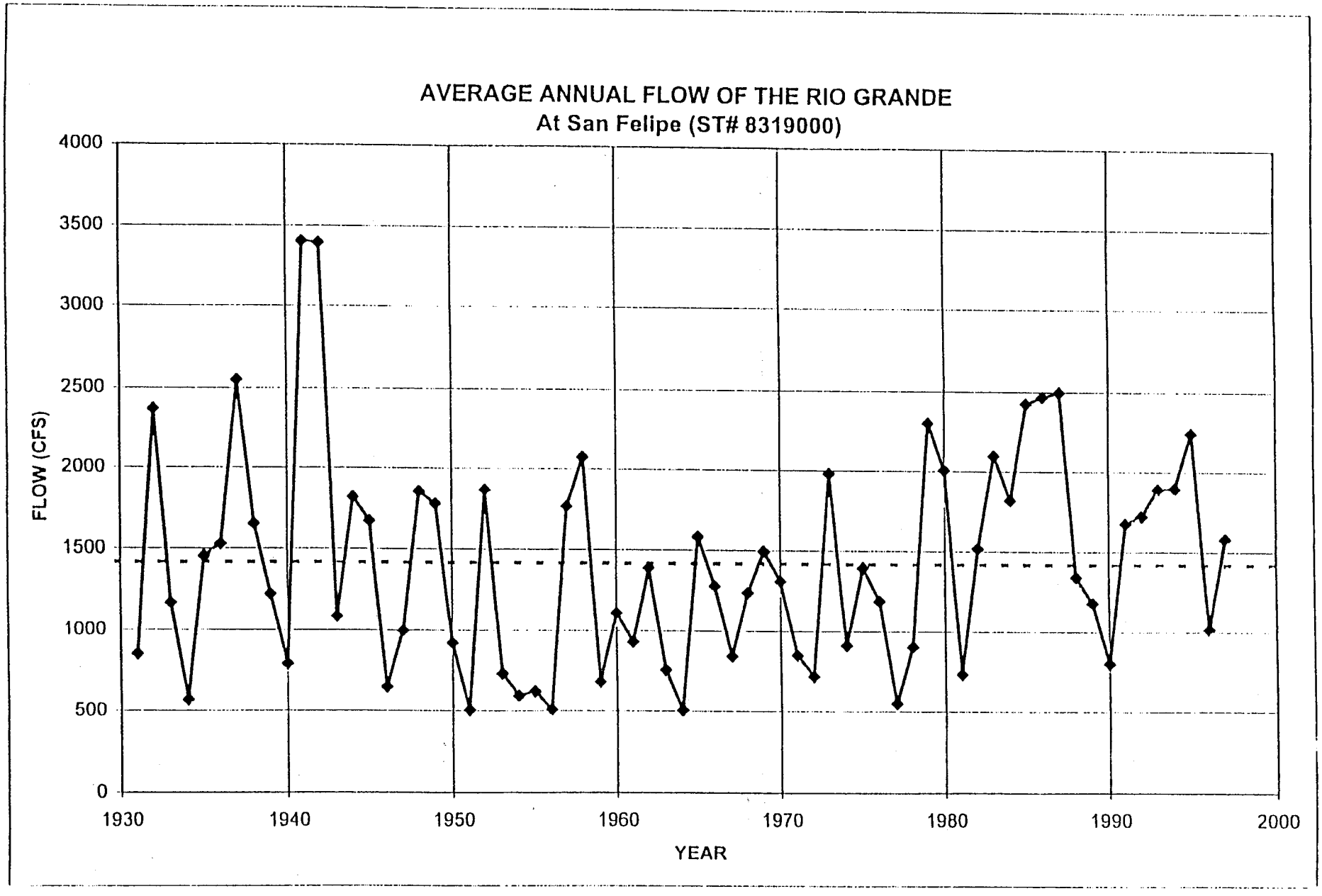

AVERAGE ANNUAL FLOW OF THE GALISTEO CREEK
Above Galisteo Reservoir (ST# 8317850)
FLOW (CFS)
14
12
10
8
6
4
2
0
1970
1971
1972
1973
1974
1975
1976
1977
YEAR

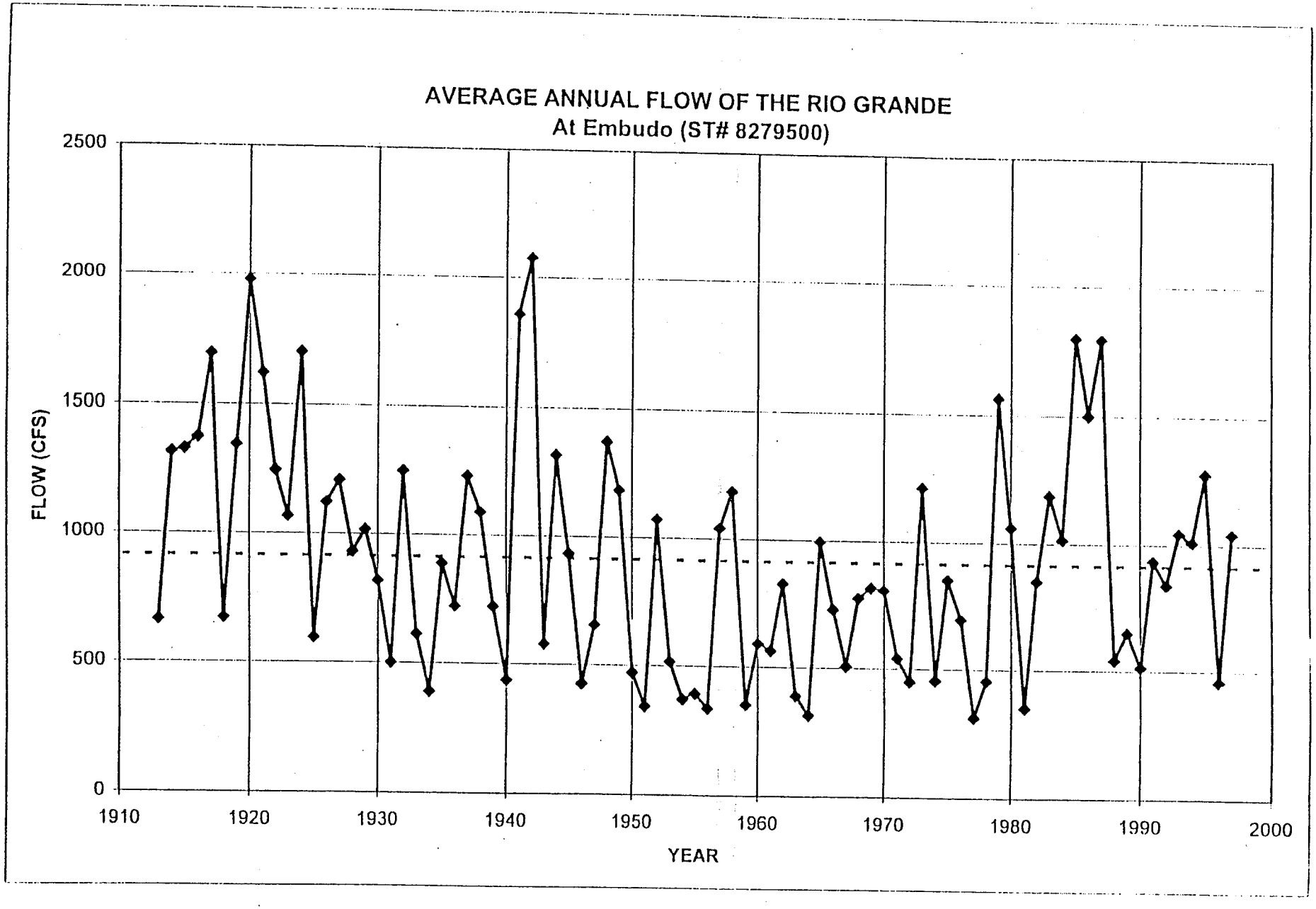

AVERAGE ANNUAL FLOW OF THE GALISTEO CREEK
Below Galisteo Dam (ST# 8317950)
FLOW (CFS)
0
2
4
6
8
10
12
14
1970
1975
1980
1985
1990
1995
2000
YEAR

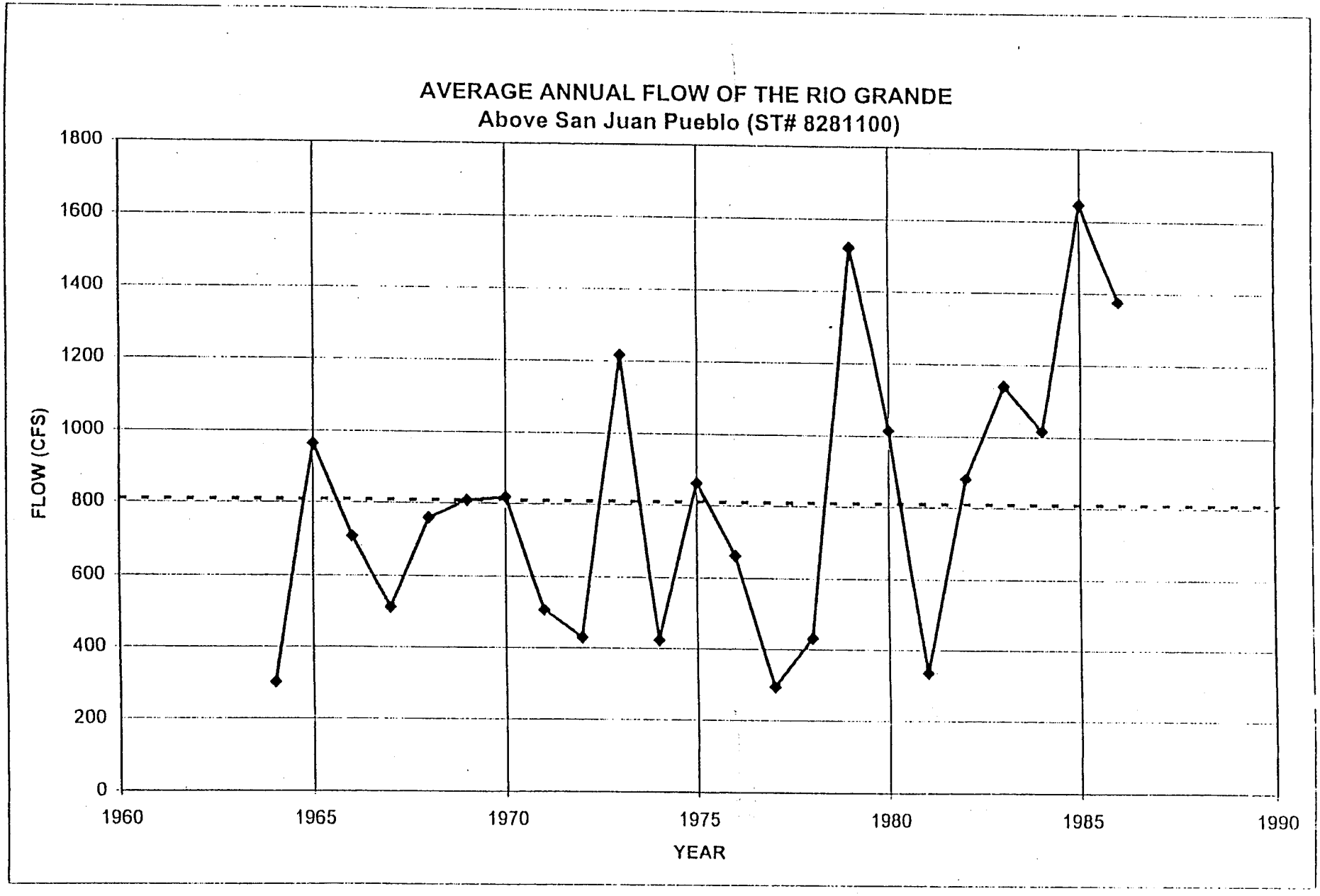

AVERAGE ANNUAL FLOW OF THE RIO GRANDE
At Cochiti (ST# 8314500)
FLOW (CFS)
3500
3000
2500
2000
1500
1000
500
0
1926
1931
1936
1941
1946
1951
1956
1961
1966
1971
YEAR

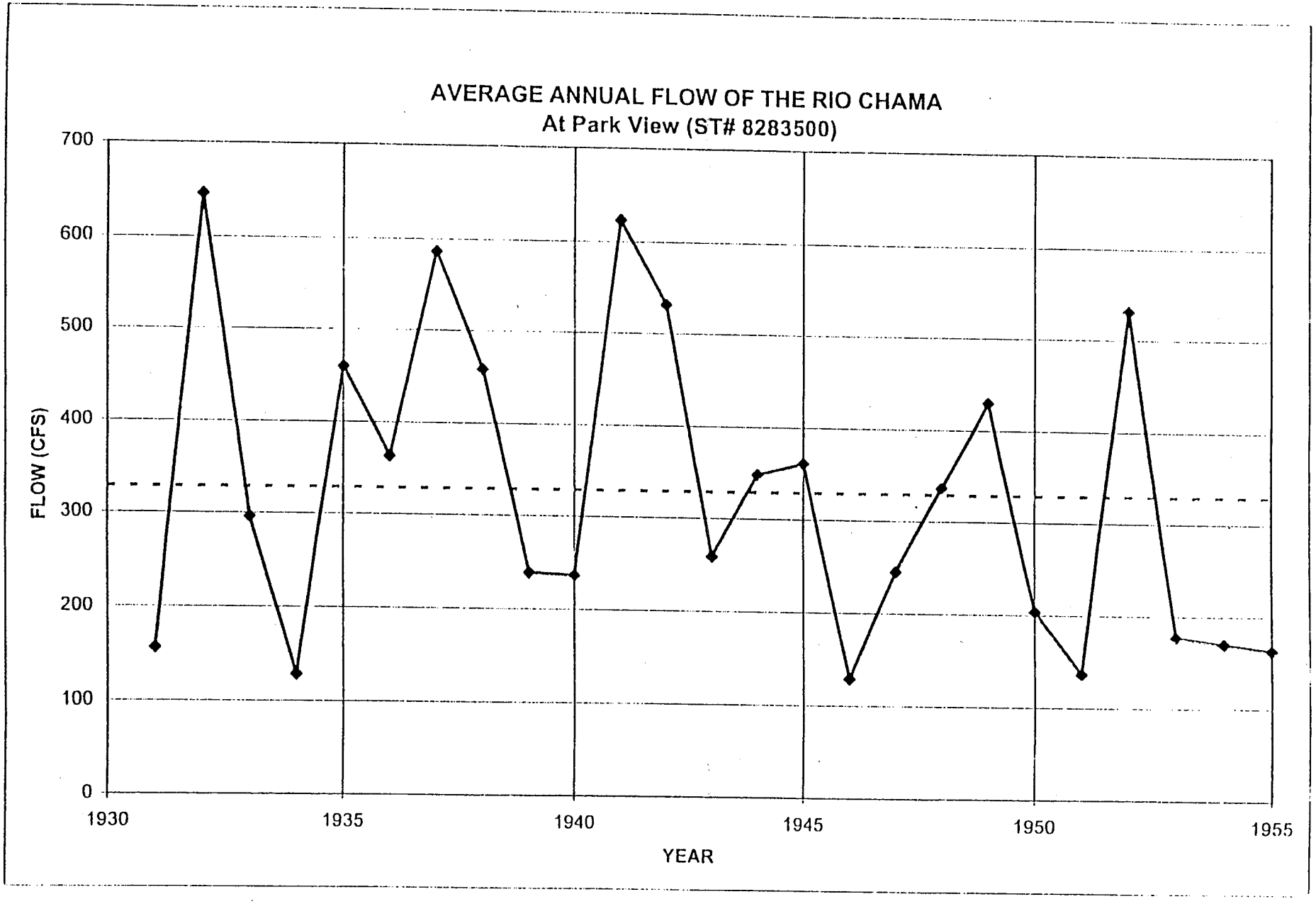

AVERAGE ANNUAL FLOW OF THE RIO GRANDE
Below Cochiti Dam (ST# 8317400)
FLOW (CFS)
2500
2000
1500
1000
500
0
1970
1975
1980
1985
1990
1995
2000
YEAR

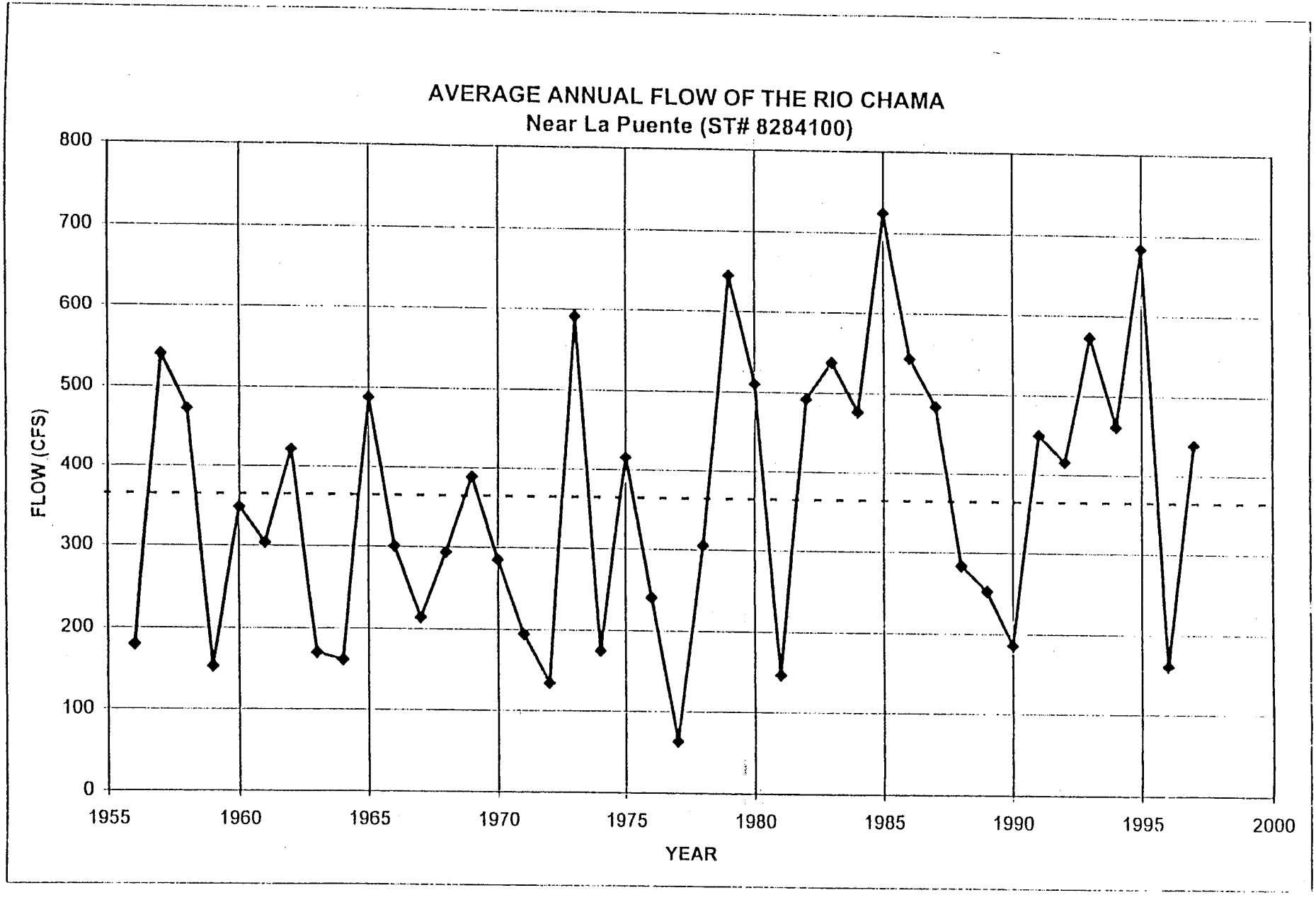

AVERAGE ANNUAL FLOW OF THE GALISTEO CREEK
At Domingo (ST# 8318000)
FLOW (CFS)
30
25
20
15
10
5
0
1941
1946
1951
1956
1961
1966
1971
YEAR

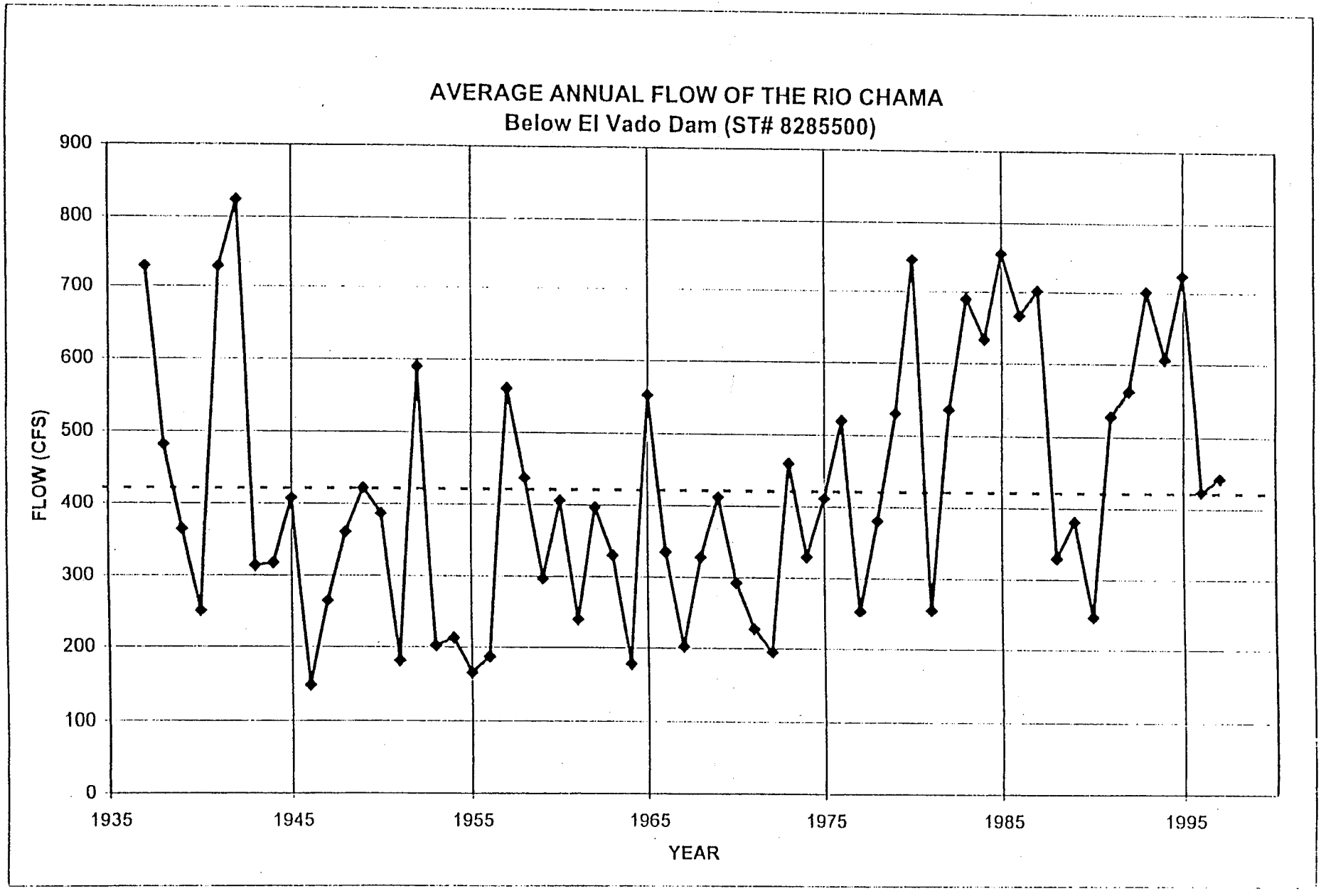

AVERAGE ANNUAL FLOW OF THE RIO GRANDE
At San Felipe (ST# 8319000)
FLOW (CFS)
4000
3500
3000
2500
2000
1500
1000
500
0
1930
1940
1950
1960
1970
1980
1990
2000
YEAR

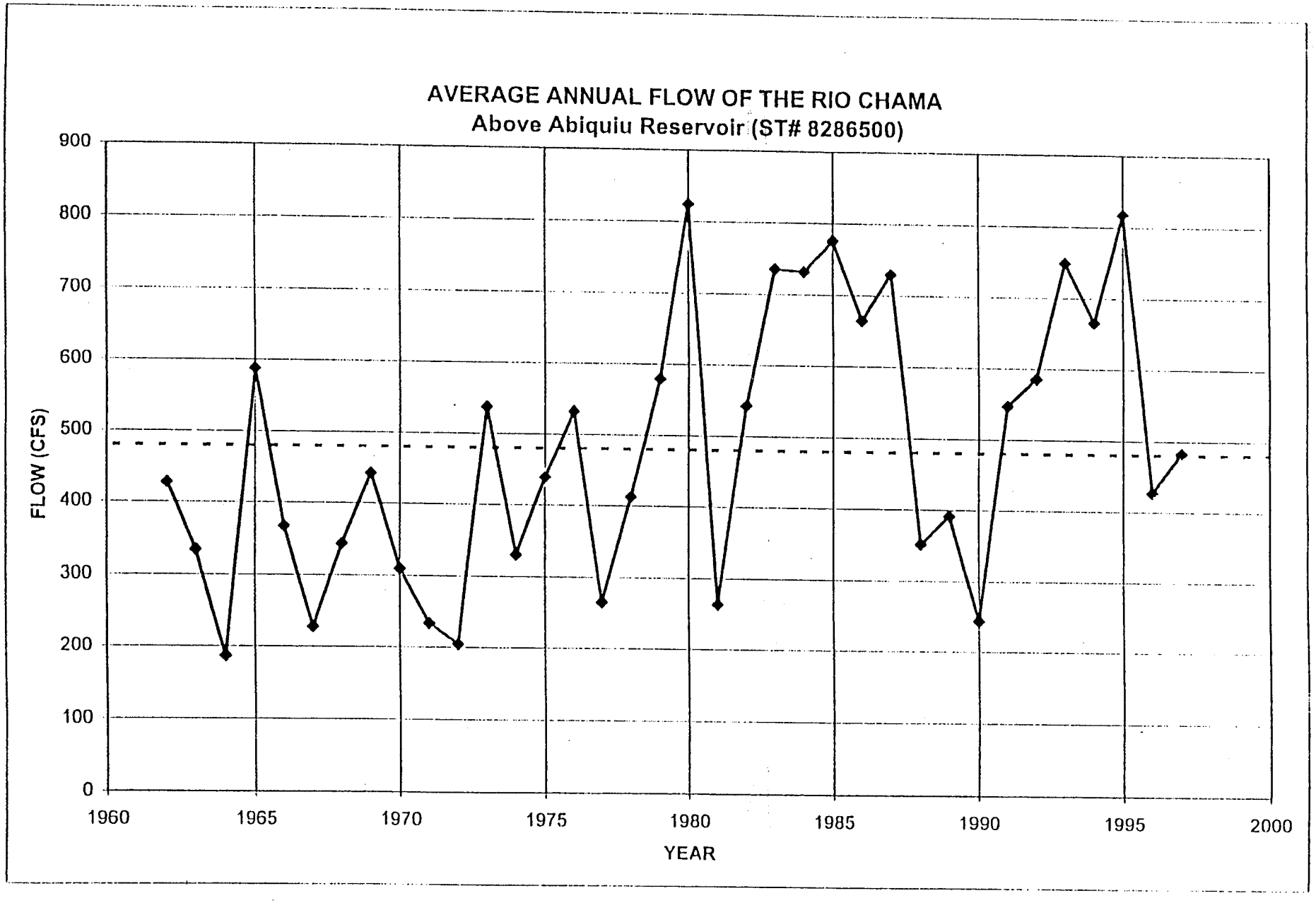

AVERAGE ANNUAL FLOW OF THE RIO GRANDE
At Embudo (ST# 8279500)
FLOW (CFS)
2500
2000
1500
1000
500
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEAR

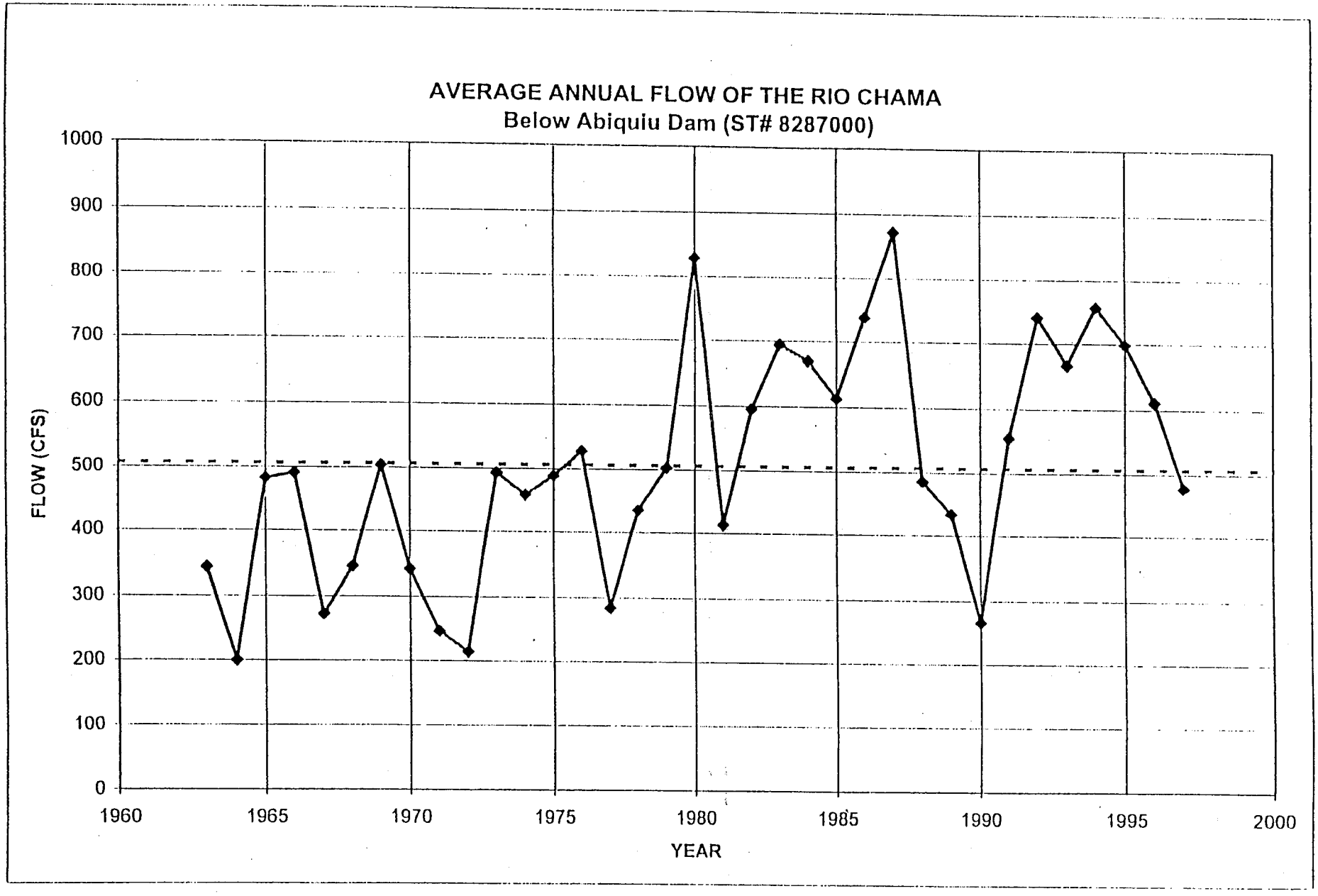

AVERAGE ANNUAL FLOW OF THE RIO GRANDE
Above San Juan Pueblo (ST# 8281100)
FLOW (CFS)
1800
1600
1400
1200
1000
800
600
400
200
0
1960
1965
1970
1975
1980
1985
1990
YEAR

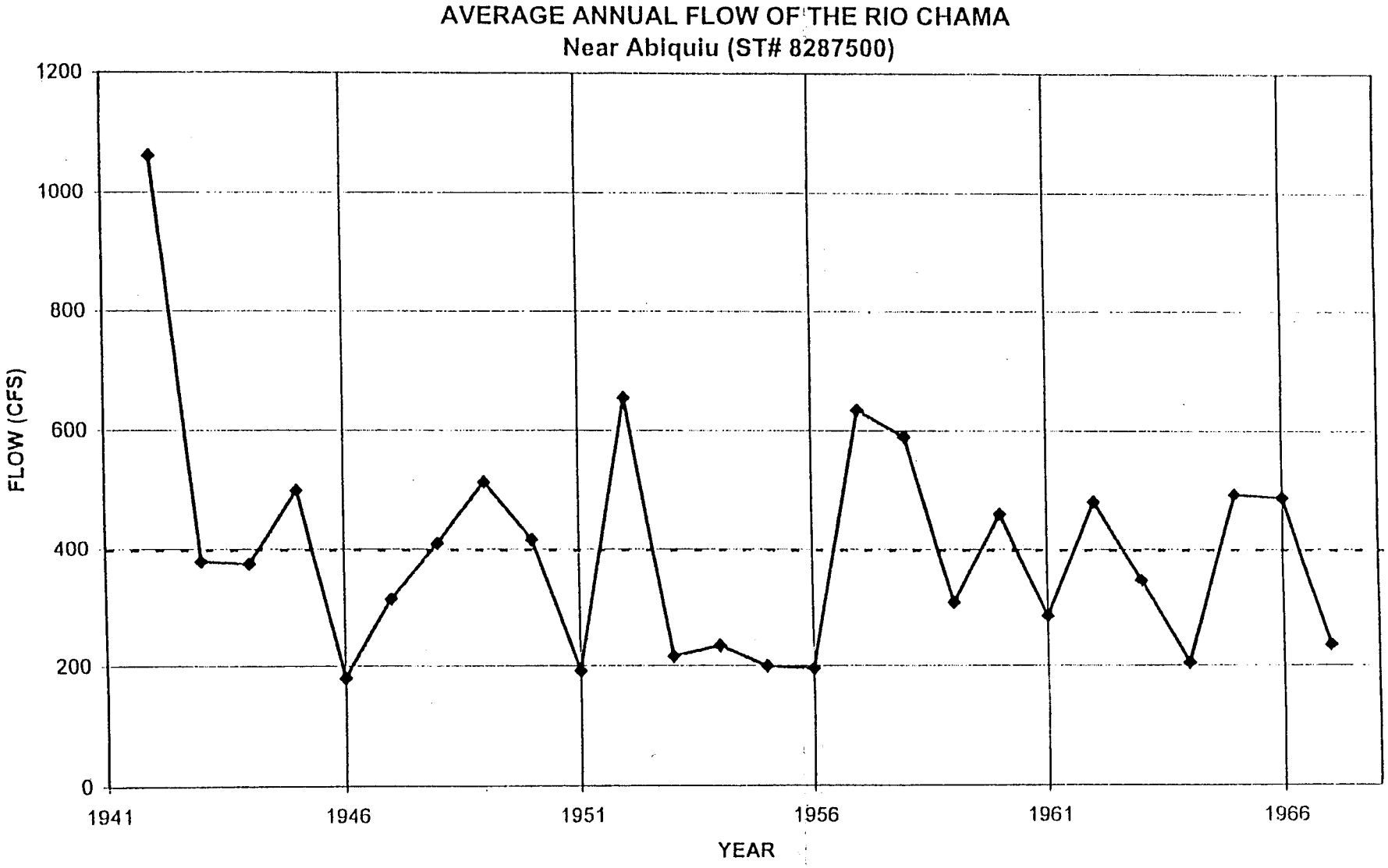

AVERAGE ANNUAL FLOW OF THE RIO CHAMA
At Park View (ST# 8283500)
FLOW (CFS)
700
600
500
400
300
200
100
0
1930
1935
1940
1945
1950
1955
YEAR

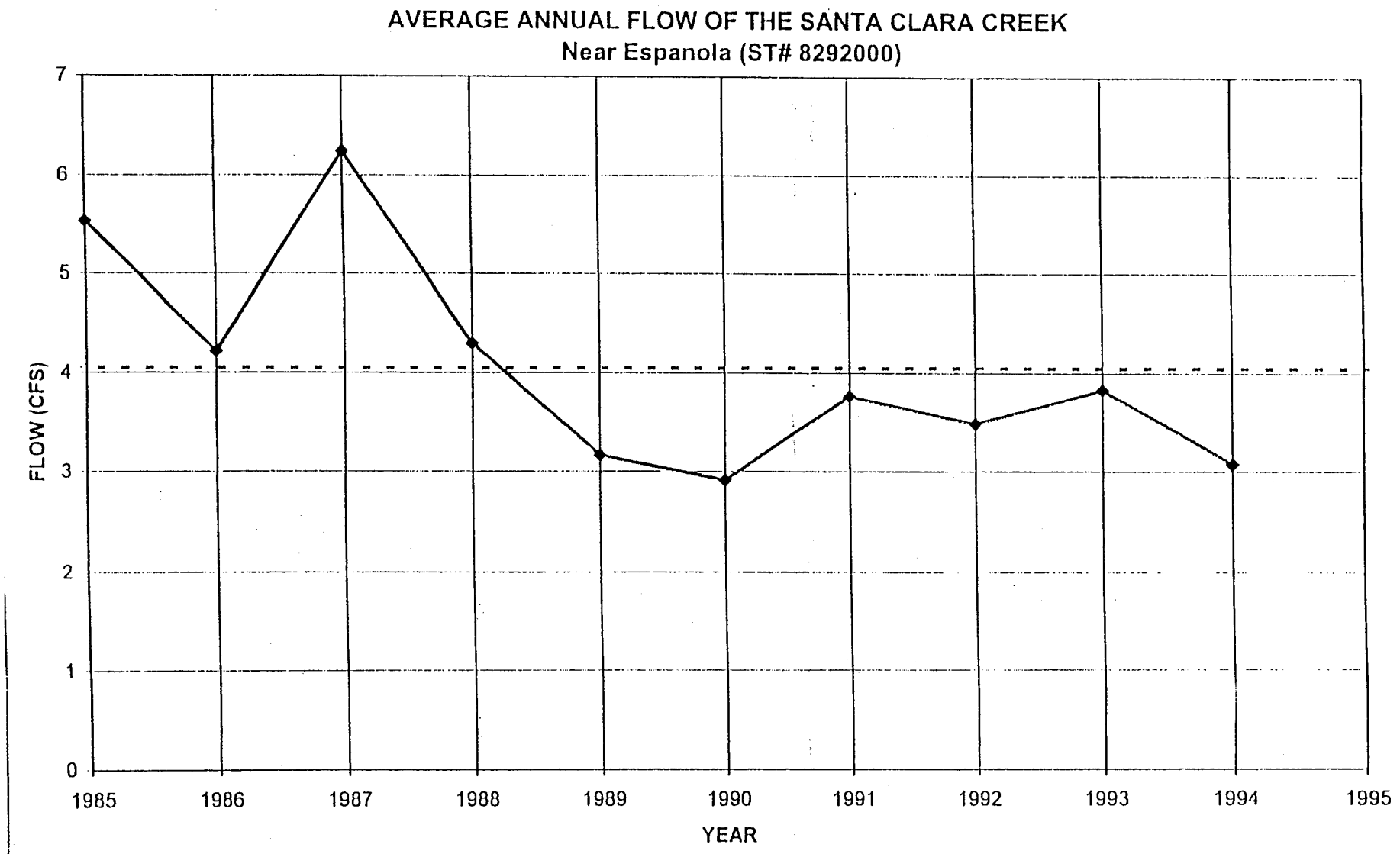

AVERAGE ANNUAL FLOW OF THE RIO CHAMA
Near La Puente (ST# 8284100)
FLOW (CFS)
800
700
600
500
400
300
200
100
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEAR

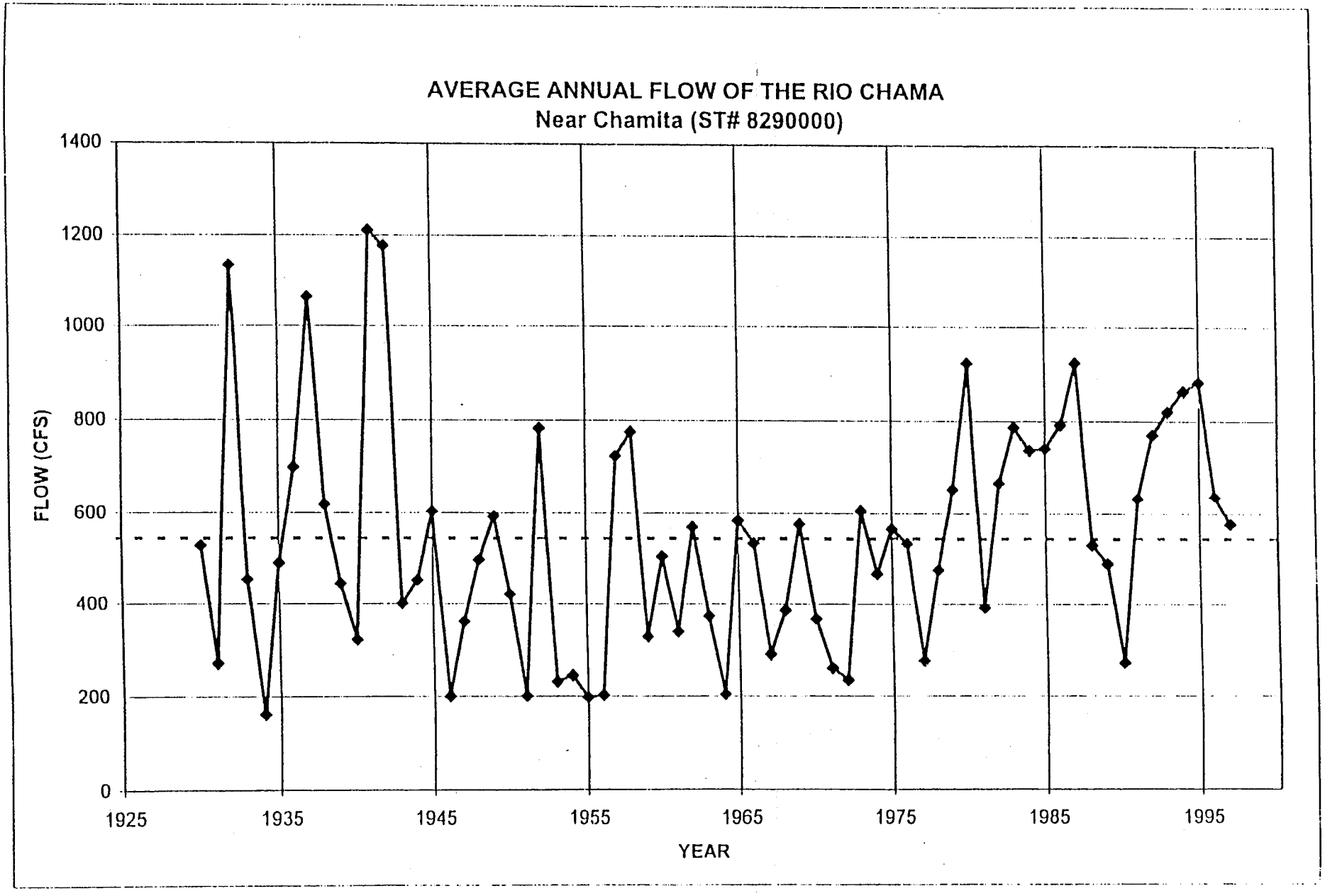

AVERAGE ANNUAL FLOW OF THE RIO CHAMA
Below El Vado Dam (ST# 8285500)
FLOW (CFS)
900
800
700
600
500
400
300
200
100
0
1935
1945
1955
1965
1975
1985
1995
YEAR


AVERAGE ANNUAL FLOW OF THE RIO CHAMA
Above Abiquiu Reservoir (ST# 8286500)
FLOW (CFS)
900
800
700
600
500
400
300
200
100
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEAR


AVERAGE ANNUAL FLOW OF THE RIO CHAMA
Below Abiquiu Dam (ST# 8287000)
FLOW (CFS)
1000
900
800
700
600
500
400
300
200
100
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEAR

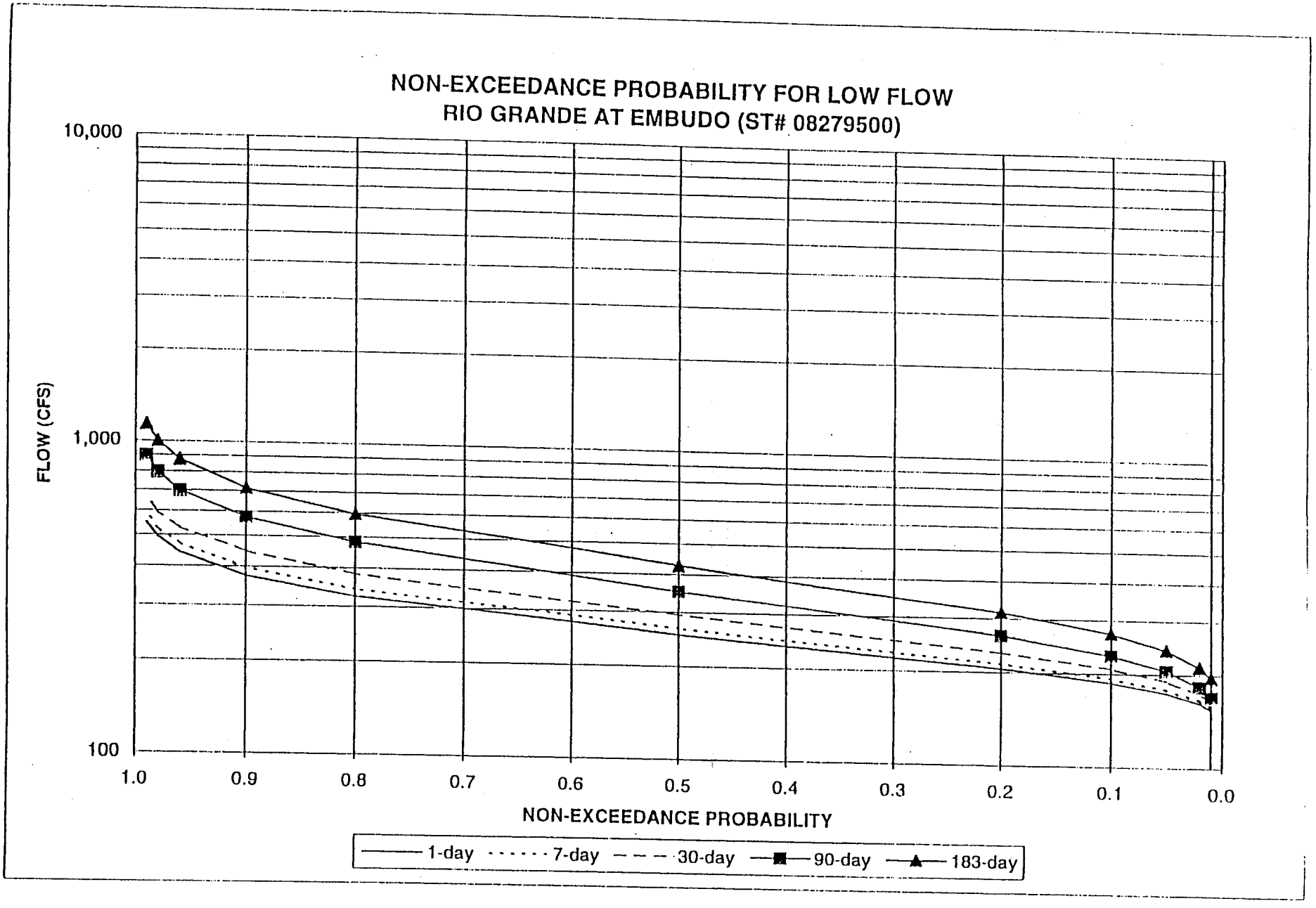

AVERAGE ANNUAL FLOW OF THE RIO CHAMA
Near Abiquiu (ST# 8287500)
FLOW (CFS)
1200
1000
800
600
400
200
0
1941
1946
1951
1956
1961
1966
YEAR

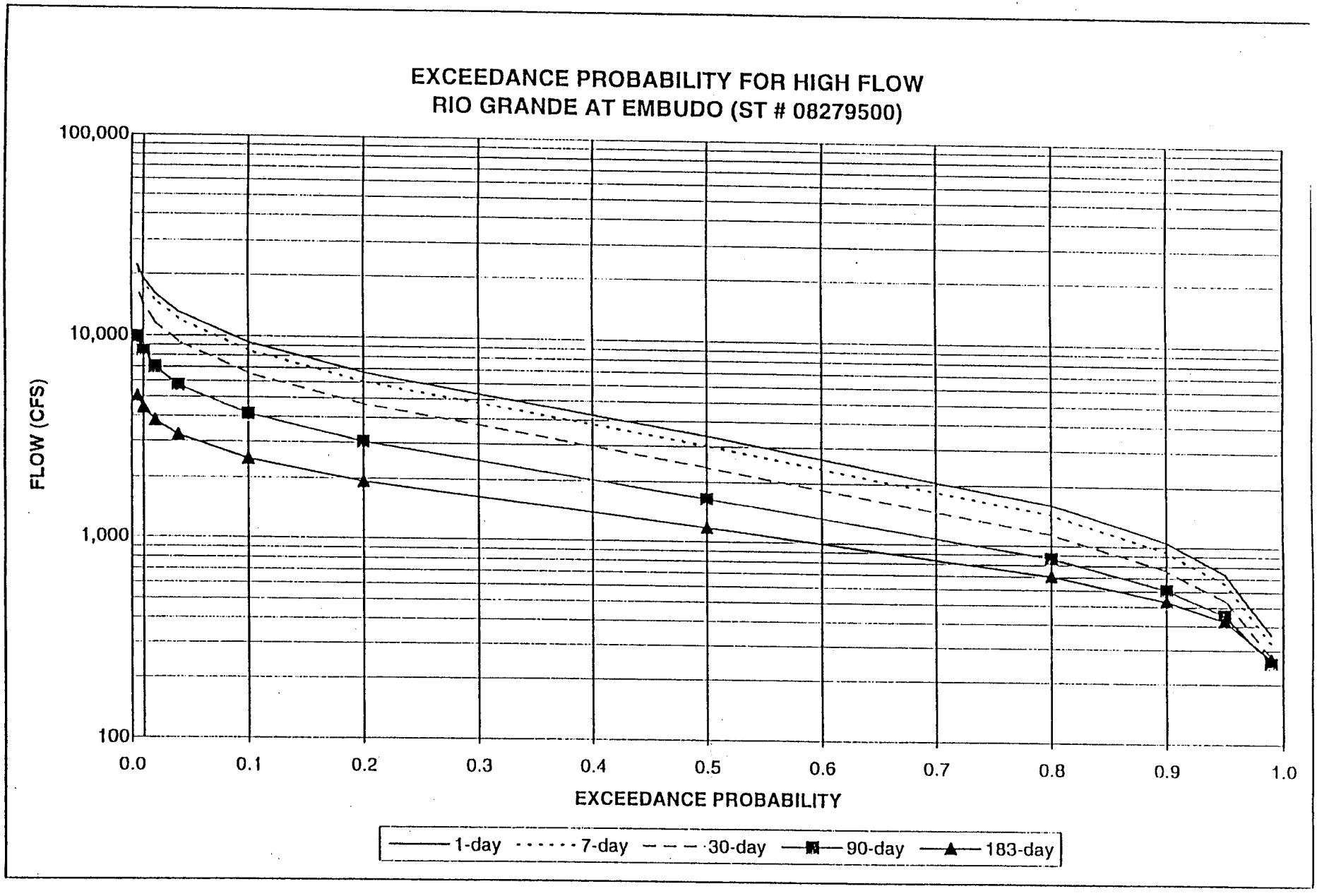

AVERAGE ANNUAL FLOW OF THE SANTA CLARA CREEK
Near Espanola (ST# 8292000)
FLOW (CFS)
0
1
2
3
4
5
6
7
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
YEAR

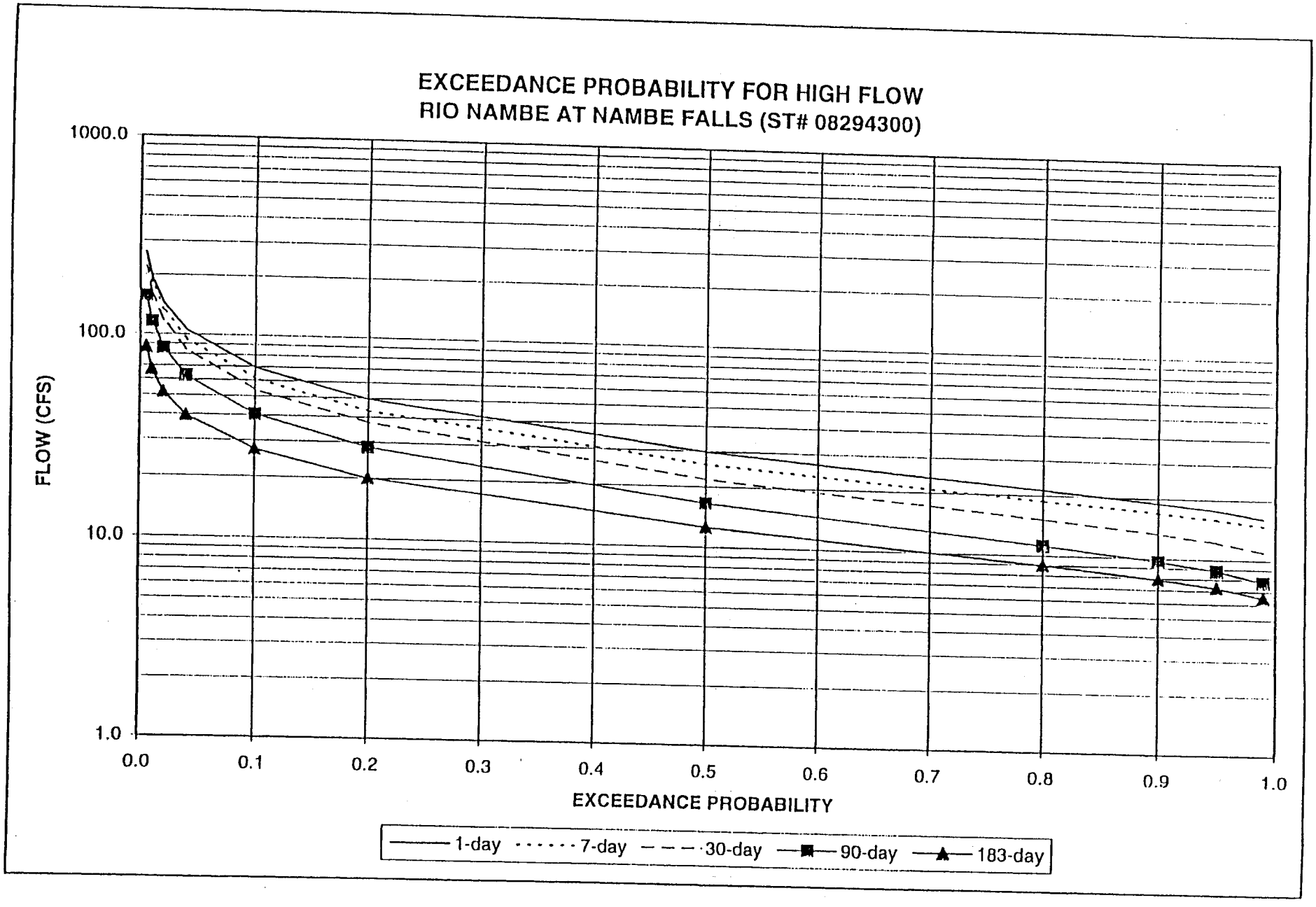

AVERAGE ANNUAL FLOW OF THE RIO CHAMA
Near Chamita (ST# 8290000)
FLOW (CFS)
1400
1200
1000
800
600
400
200
0
1925
1935
1945
1955
1965
1975
1985
1995
YEAR

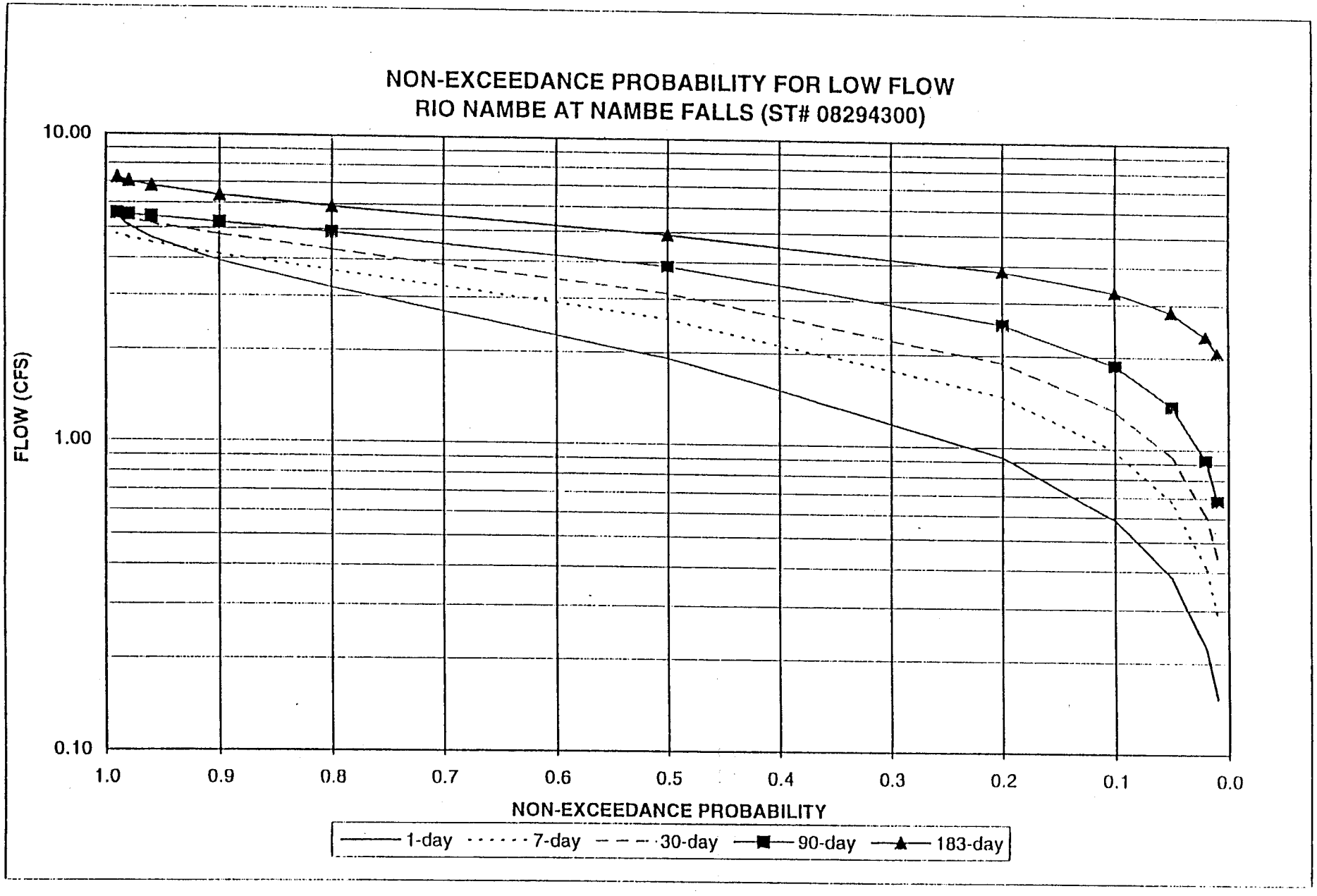
APPENDIX F

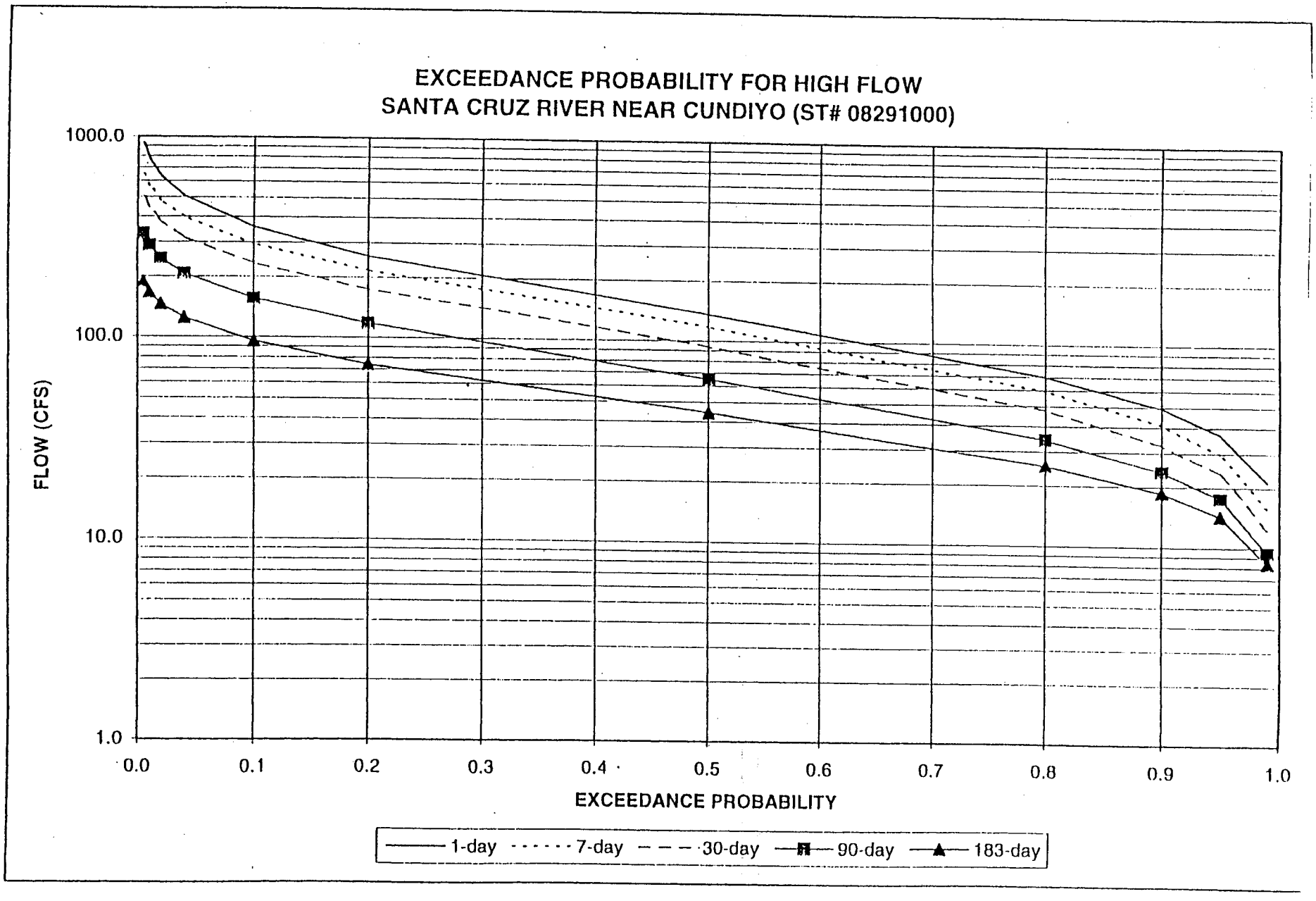
PROBABILISTIC ANALYSES OF LOW AND HIGH FLOWS AT USGS GAGING STATIONS

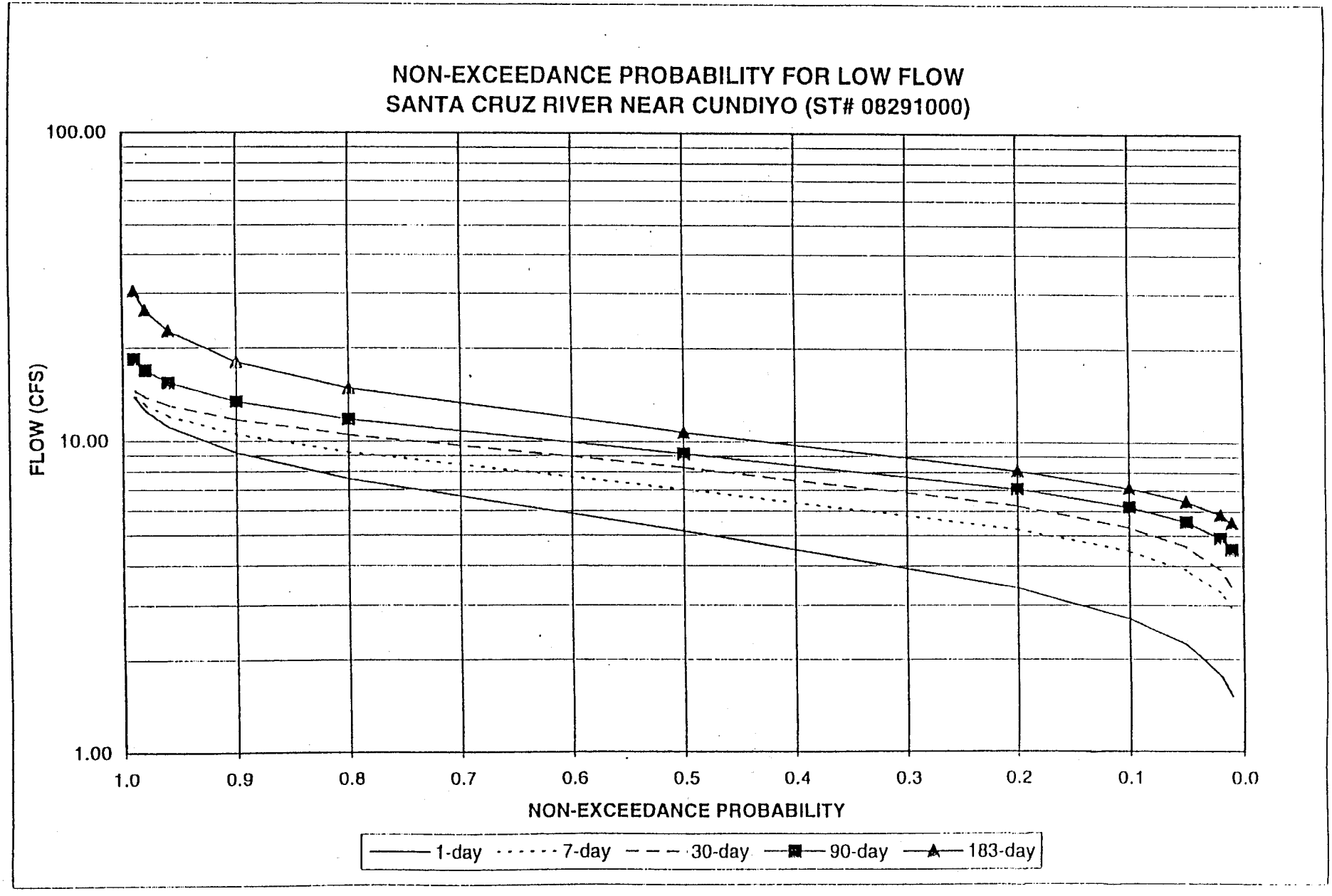

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO GRANDE AT EMBUDO (ST# 08279500)
FLOW (CFS)
10,000
1,000
100
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

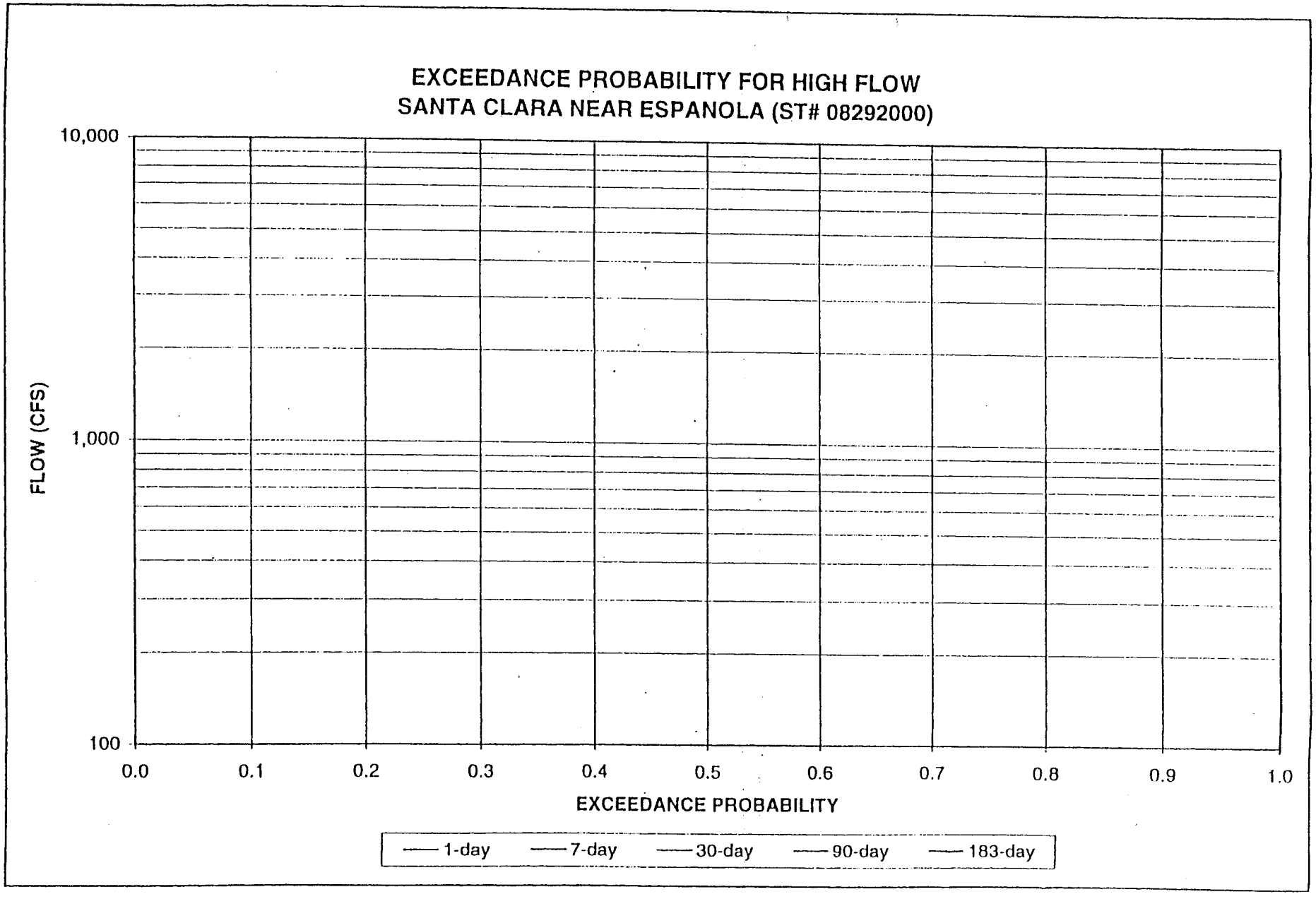

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO GRANDE AT EMBUDO (ST # 08279500)
FLOW (CFS)
100,000
10,000
1,000
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

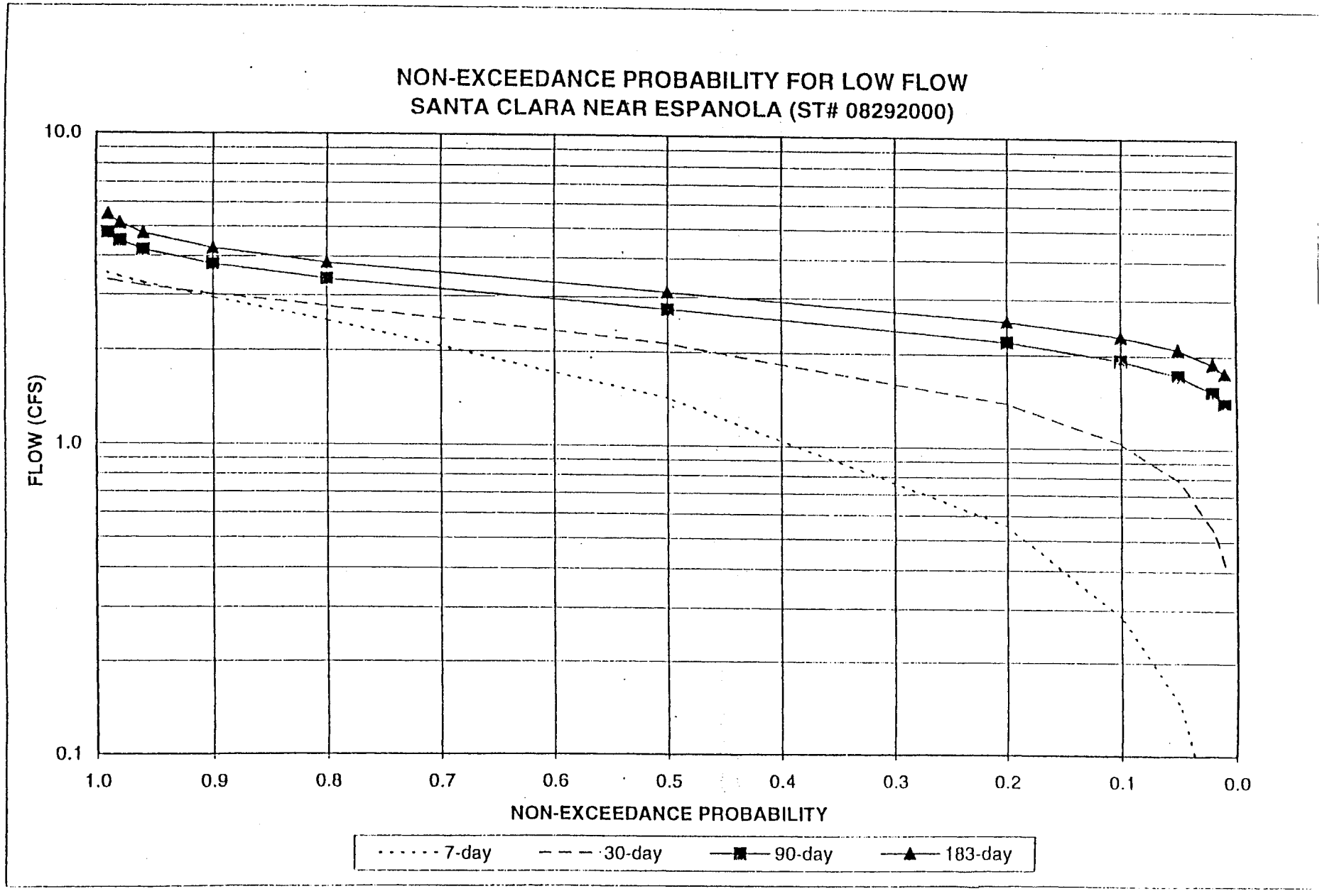

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO NAMBE AT NAMBE FALLS (ST# 08294300)
FLOW (CFS)
1000.0
100.0
10.0
1.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

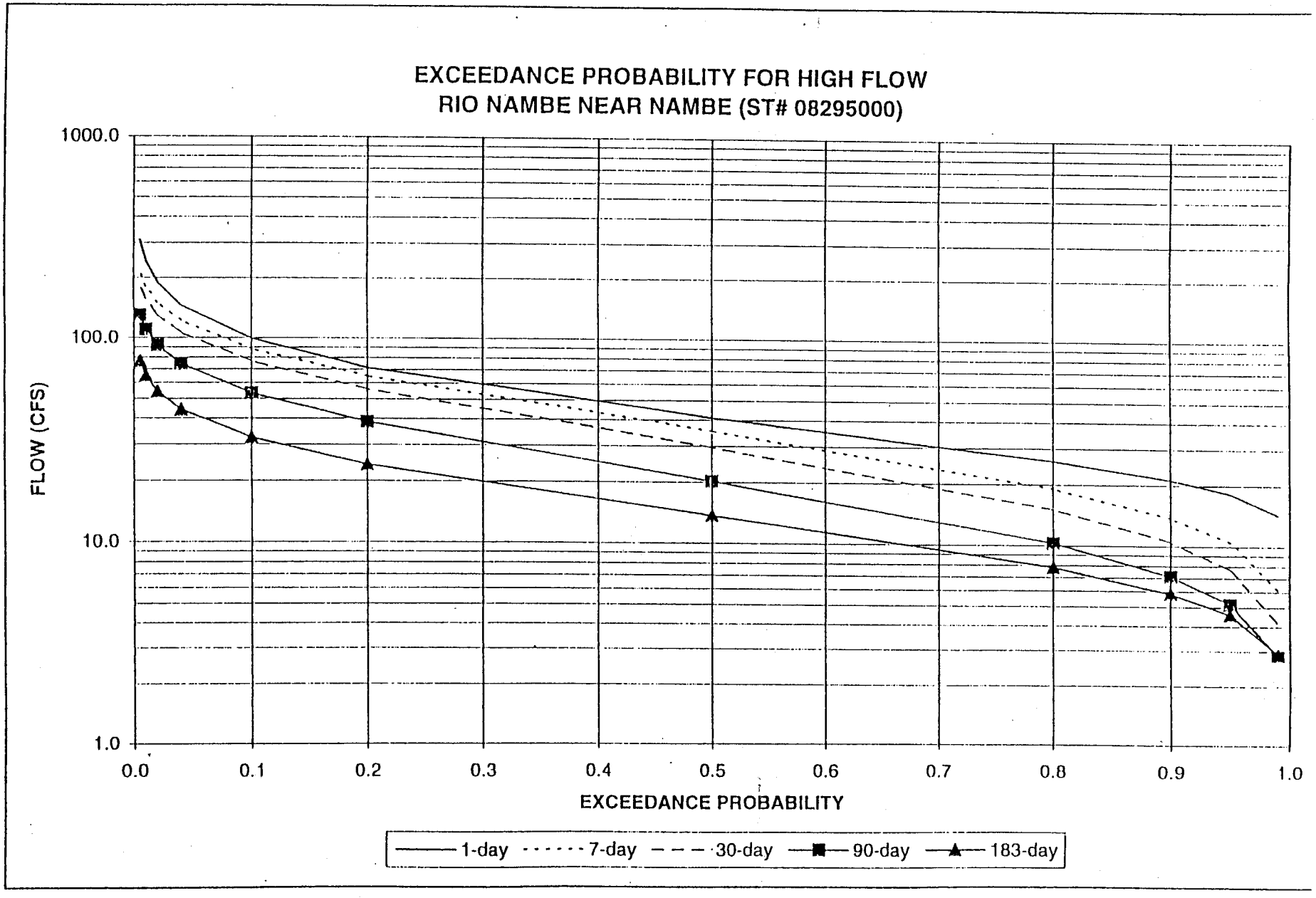

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO NAMBE AT NAMBE FALLS (ST# 08294300)
FLOW (CFS)
10.00
1.00
0.10
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

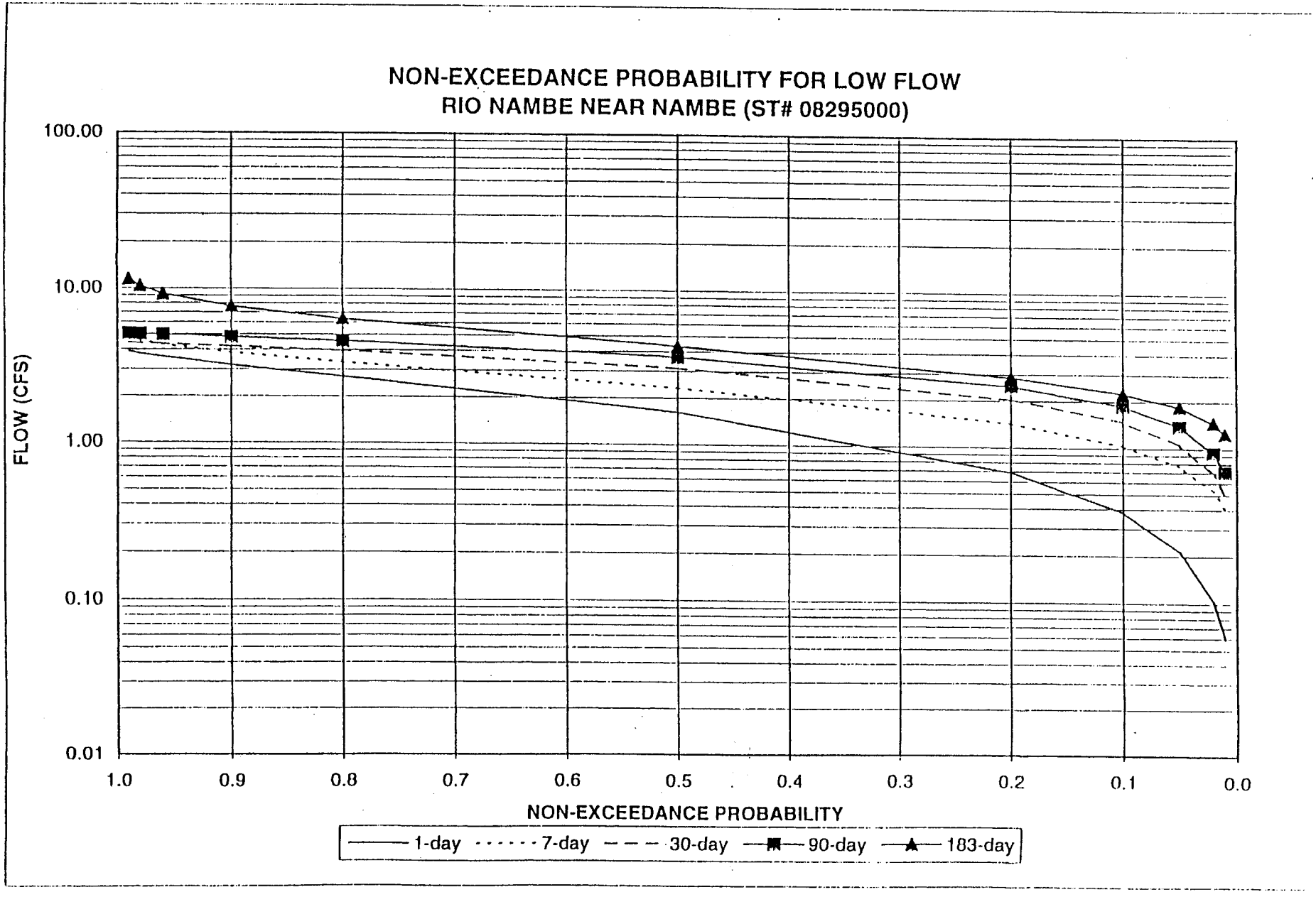

EXCEEDANCE PROBABILITY FOR HIGH FLOW
SANTA CRUZ RIVER NEAR CUNDIYO (ST# 08291000)
FLOW (CFS)
1000.0
100.0
10.0
1.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

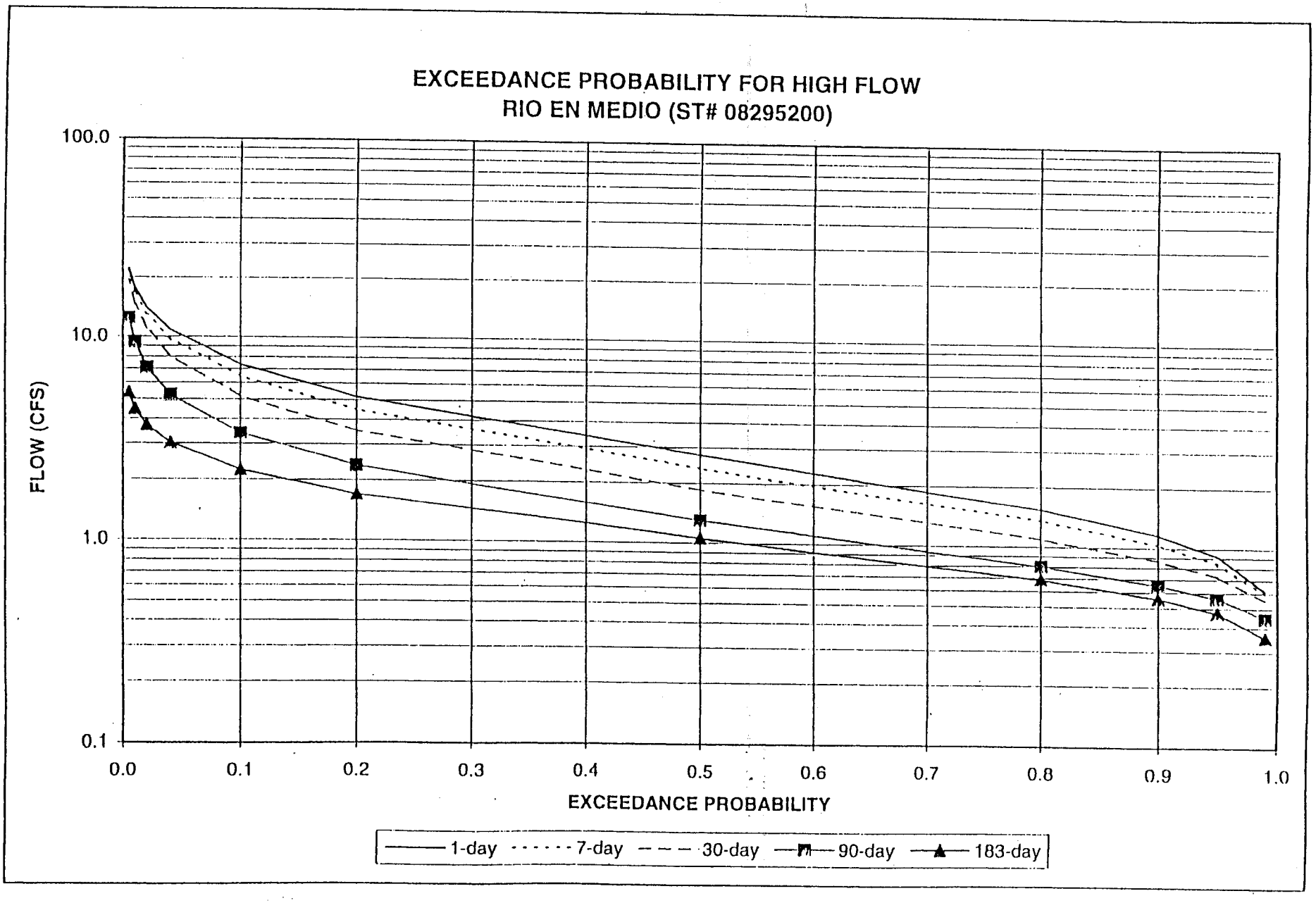

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
SANTA CRUZ RIVER NEAR CUNDIYO (ST# 08291000)
100.00
10.00
1.00
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

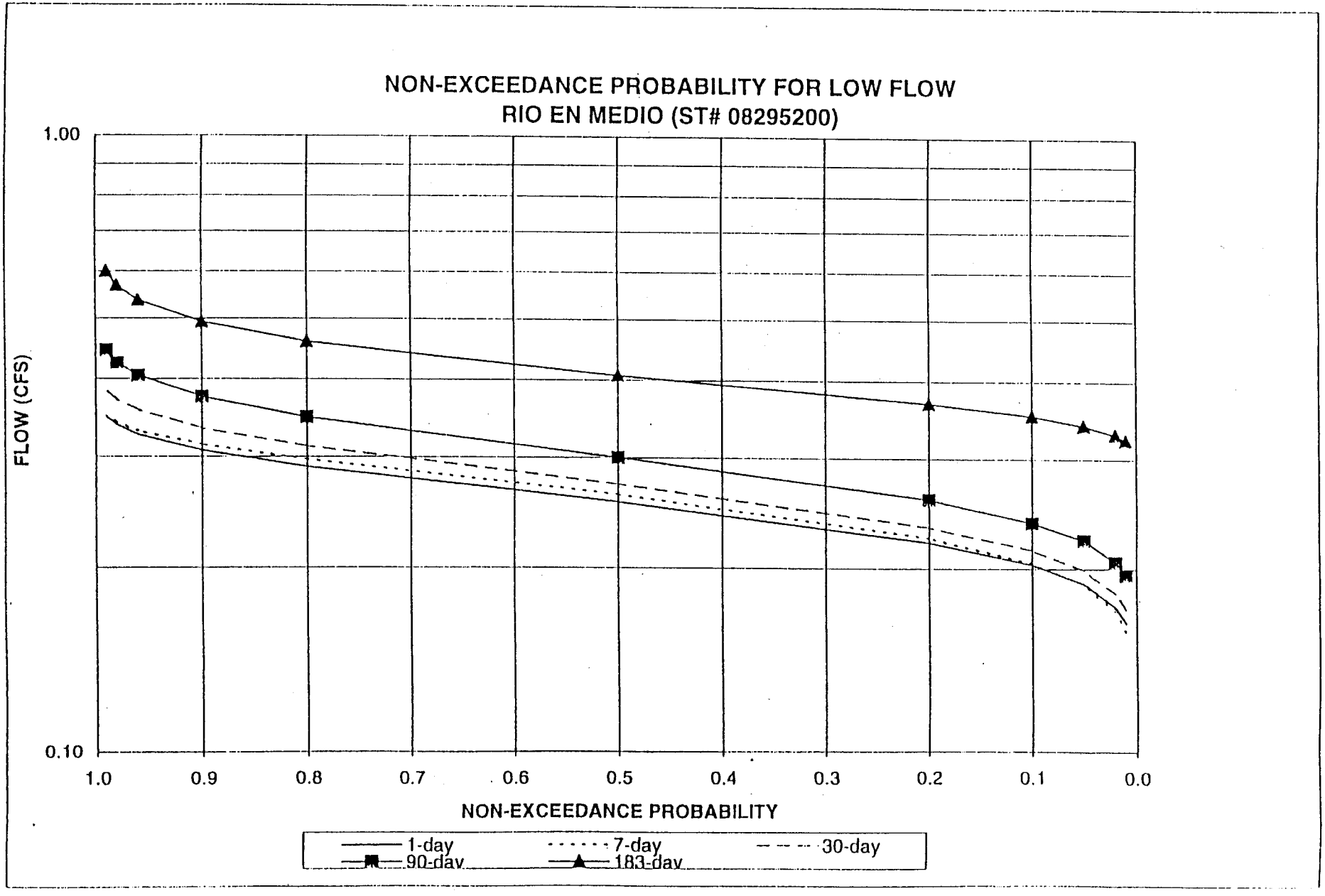

EXCEEDANCE PROBABILITY FOR HIGH FLOW
SANTA CLARA NEAR ESPANOLA (ST# 08292000)
10,000
1,000
100
FLOW (CFS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

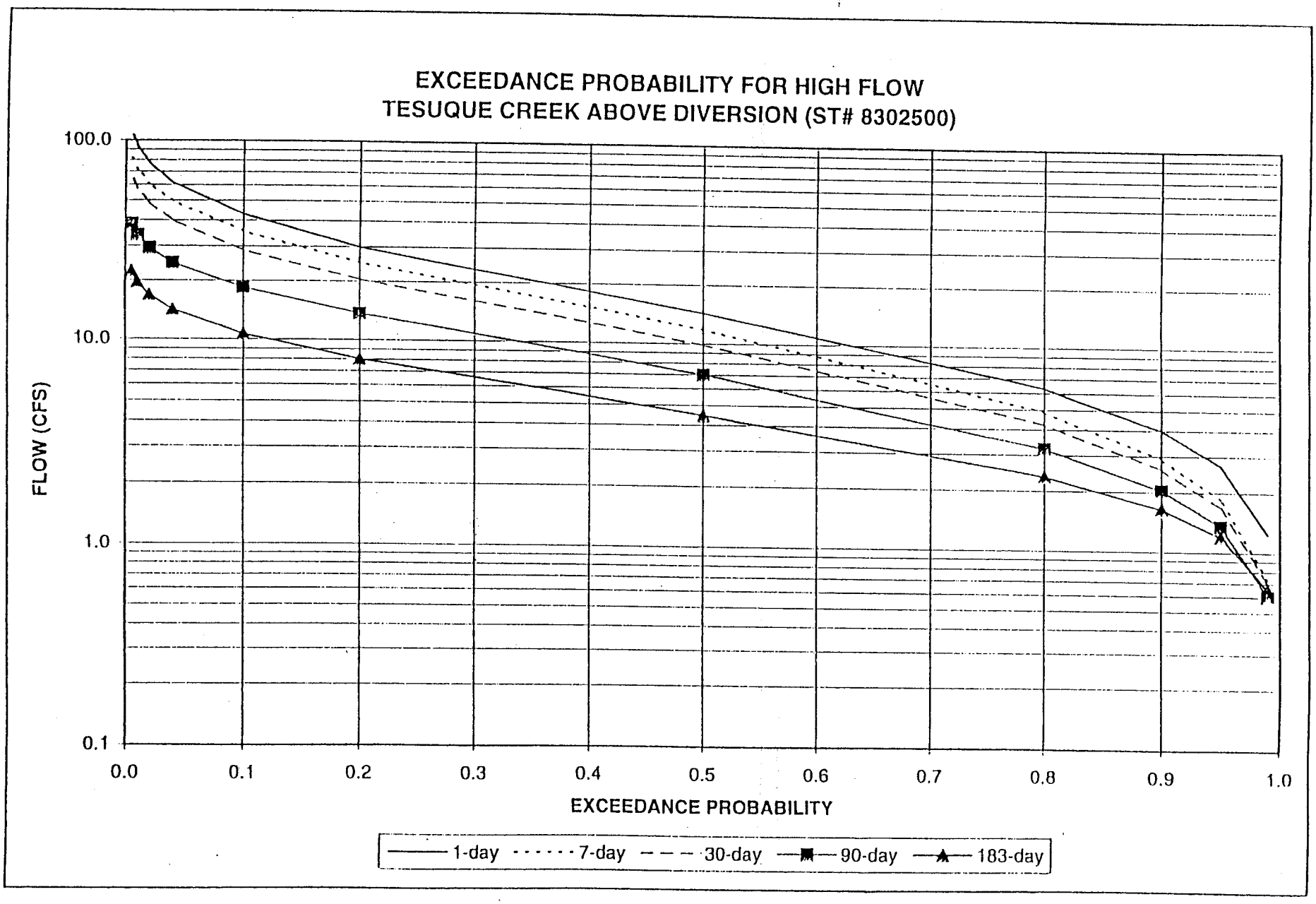

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
SANTA CLARA NEAR ESPANOLA (ST# 08292000)
10.0
1.0
0.1
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
7-day
30-day
90-day
183-day

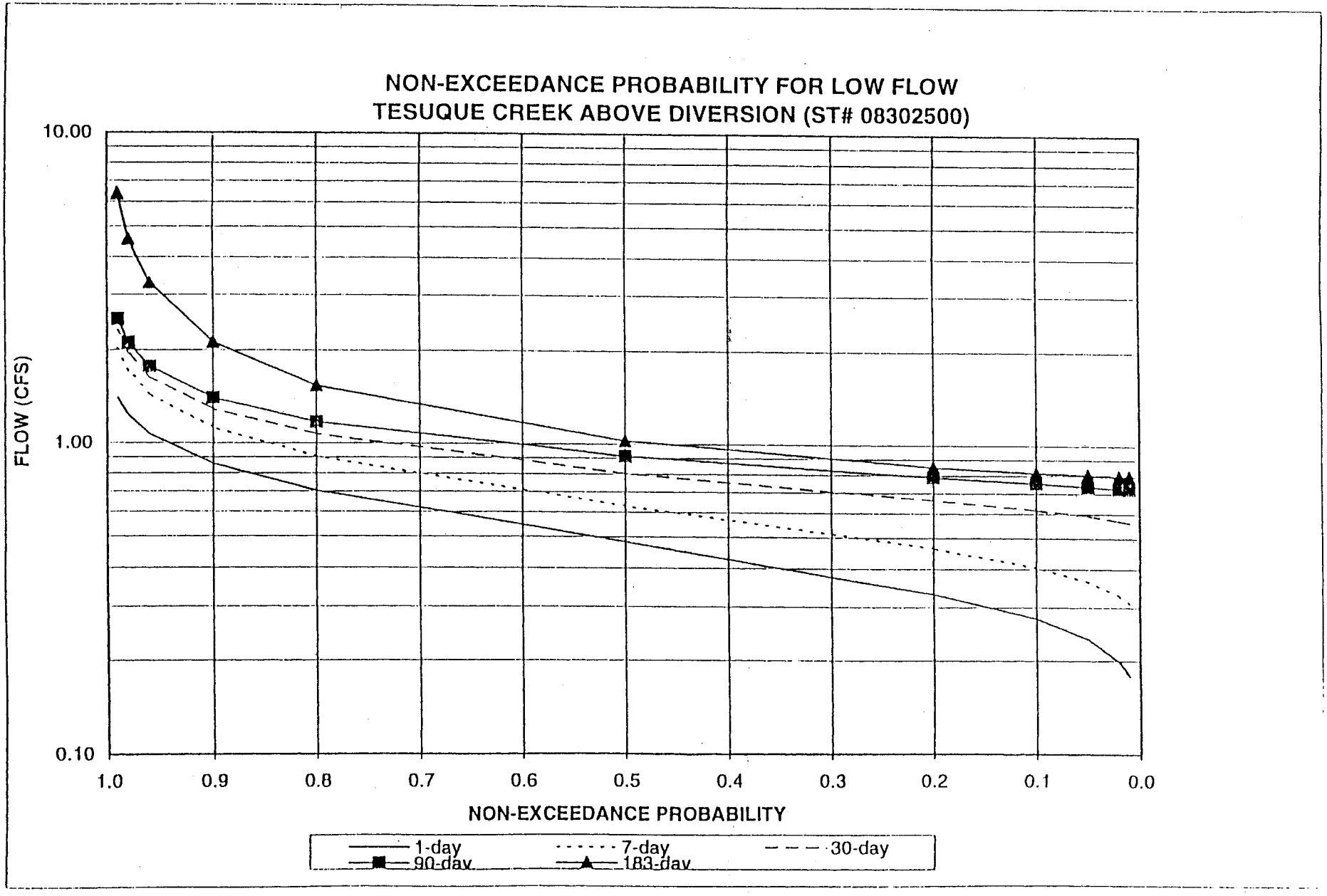

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO NAMBE NEAR NAMBE (ST# 08295000)
1000.0
100.0
10.0
1.0
FLOW (CFS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

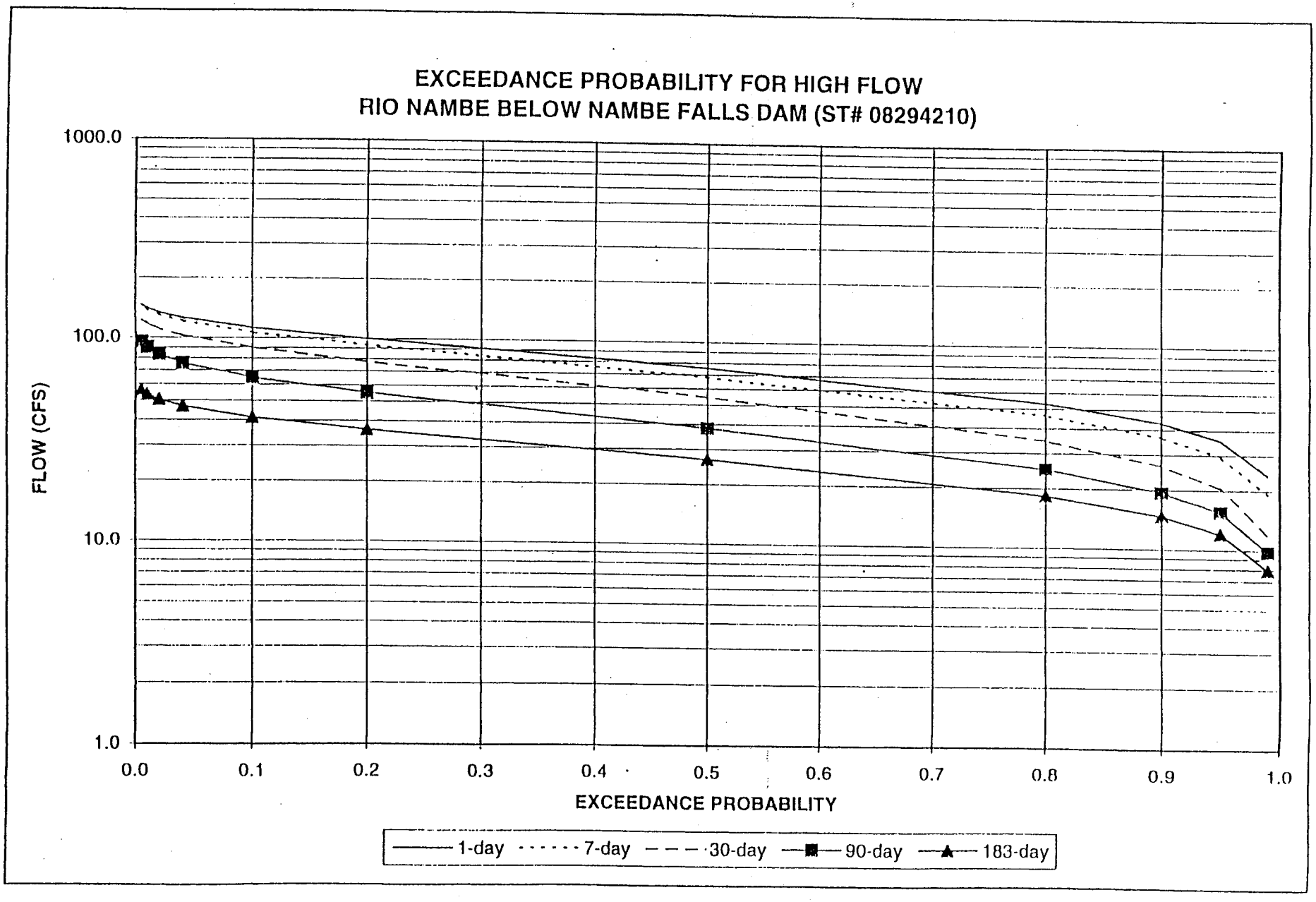

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO NAMBE NEAR NAMBE (ST# 08295000)
FLOW (CFS)
100.00
10.00
1.00
0.10
0.01
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

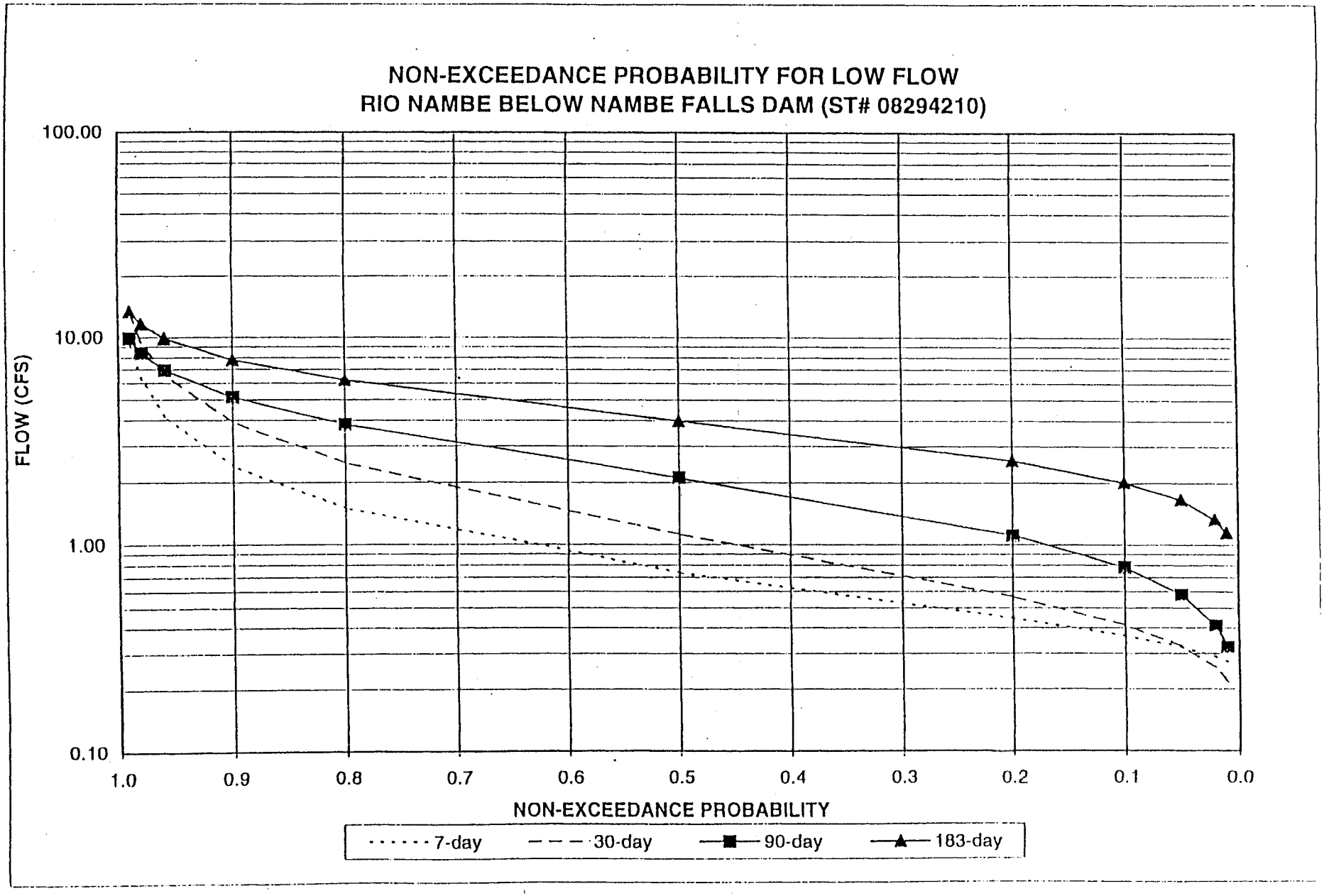

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO EN MEDIO (ST# 08295200)
FLOW (CFS)
100.0
10.0
1.0
0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

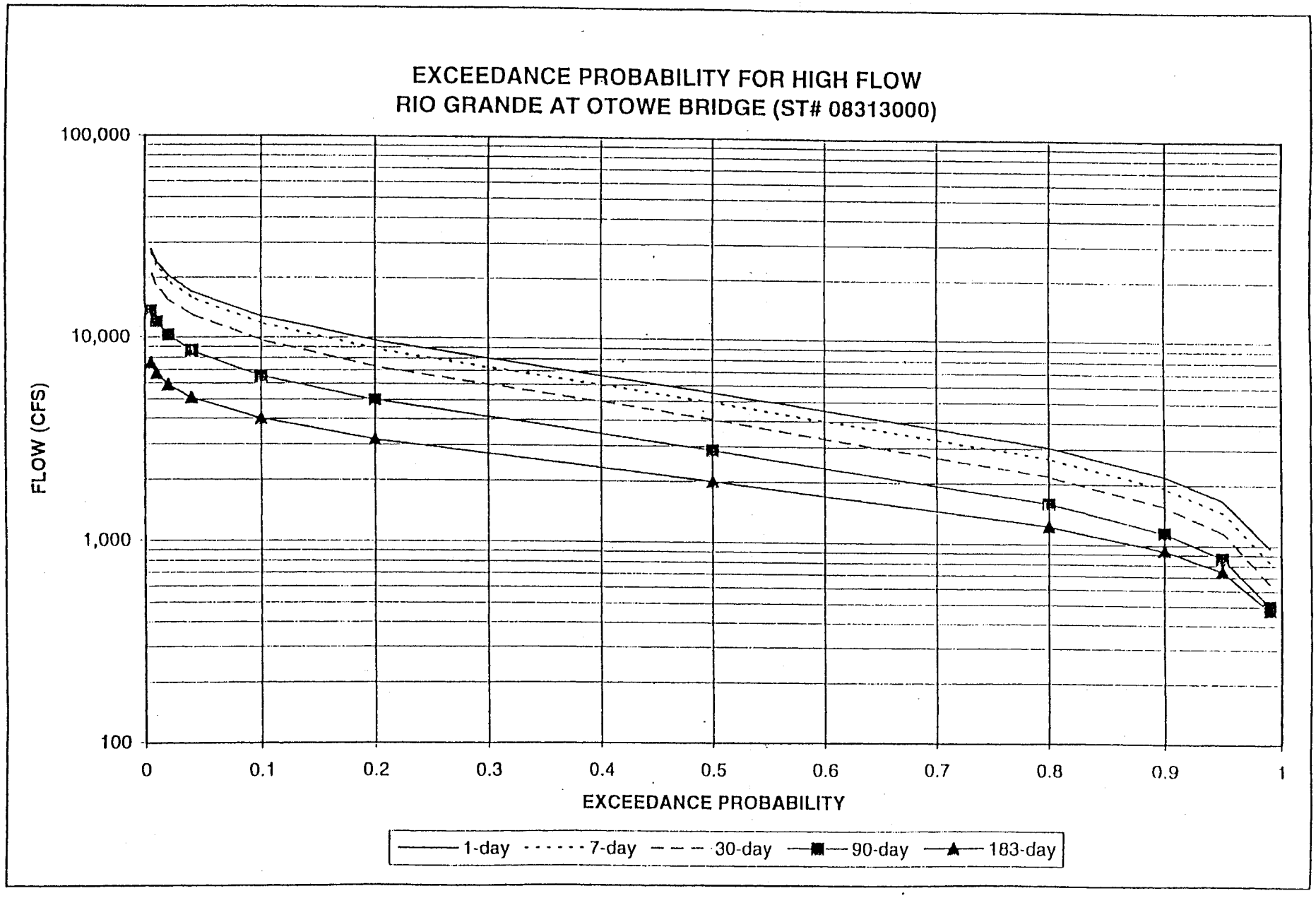

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO EN MEDIO (ST# 08295200)
1.00
0.10
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

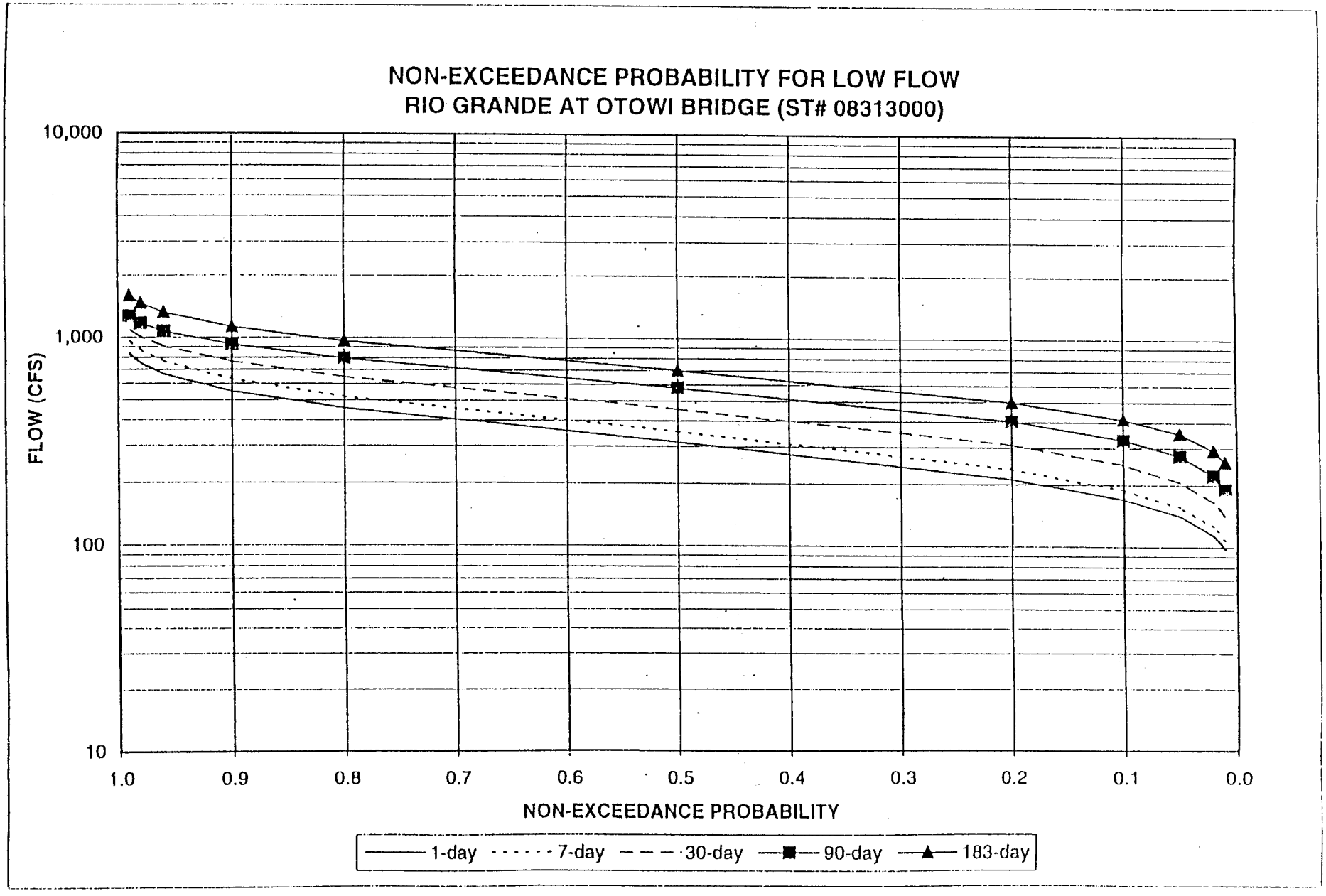

EXCEEDANCE PROBABILITY FOR HIGH FLOW
TESUQUE CREEK ABOVE DIVERSION (ST# 8302500)
FLOW (CFS)
100.0
10.0
1.0
0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

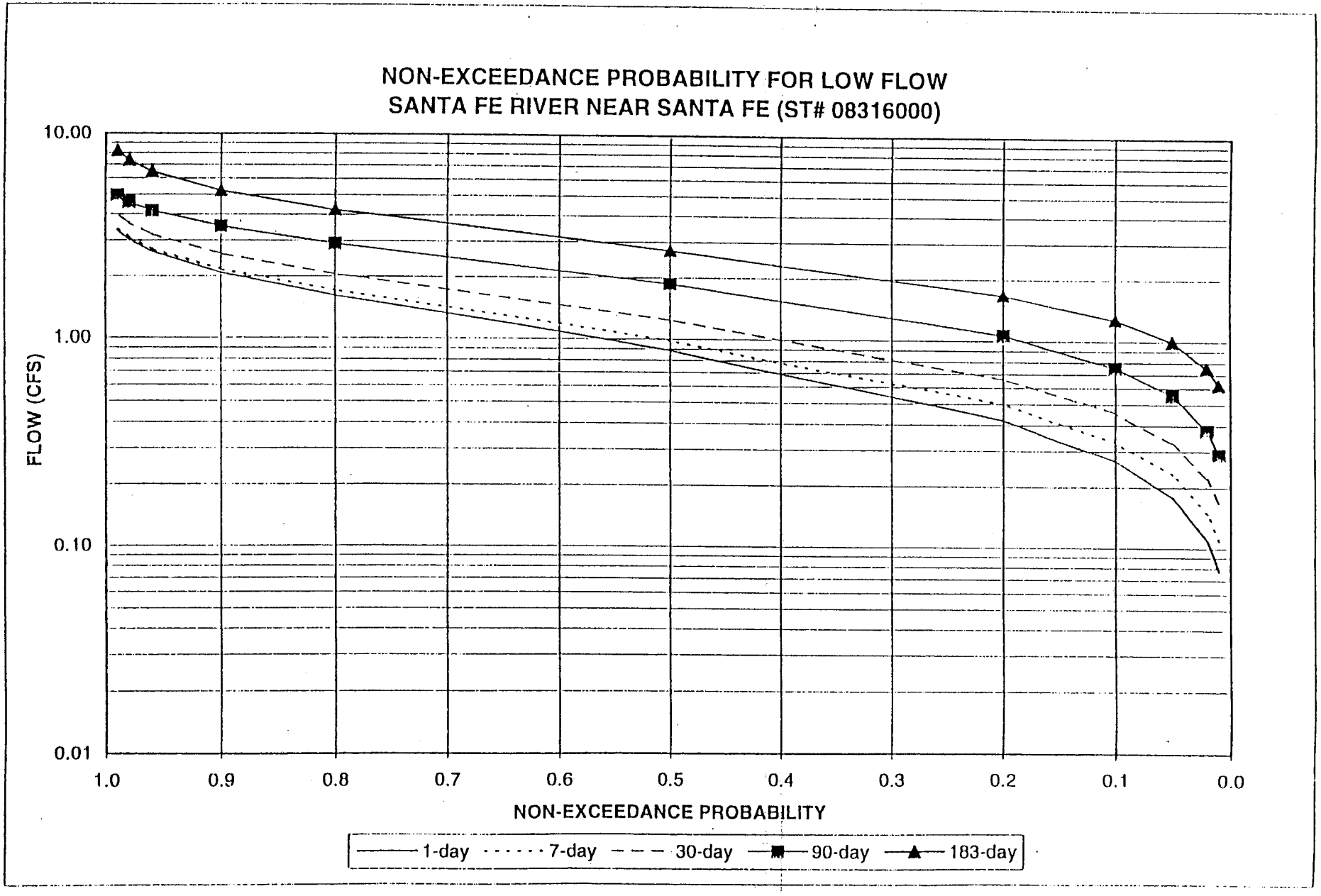

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
TESUQUE CREEK ABOVE DIVERSION (ST# 08302500)
10.00
1.00
0.10
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

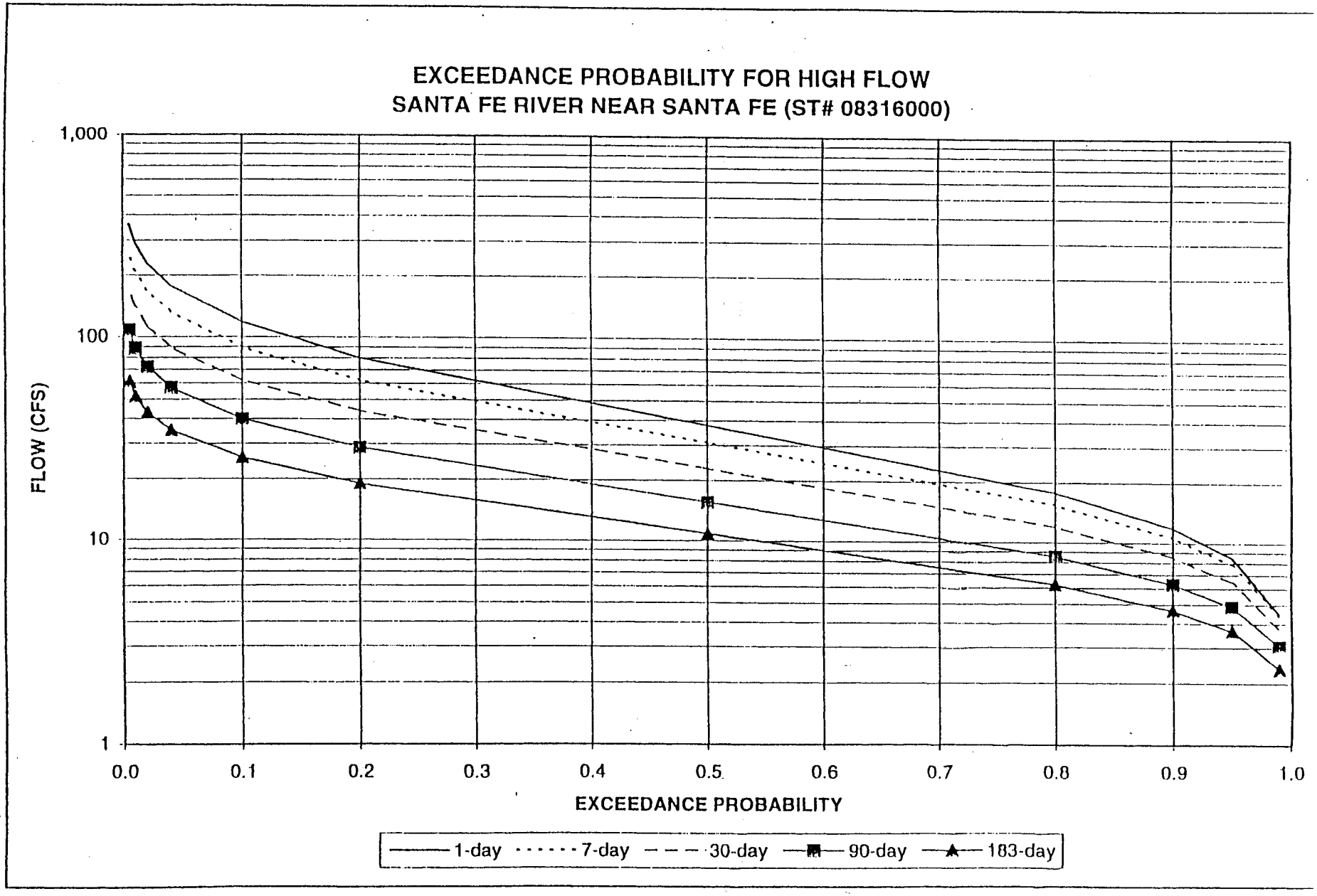

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO NAMBE BELOW NAMBE FALLS DAM (ST# 08294210)
1000.0
100.0
10.0
1.0
FLOW (CFS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

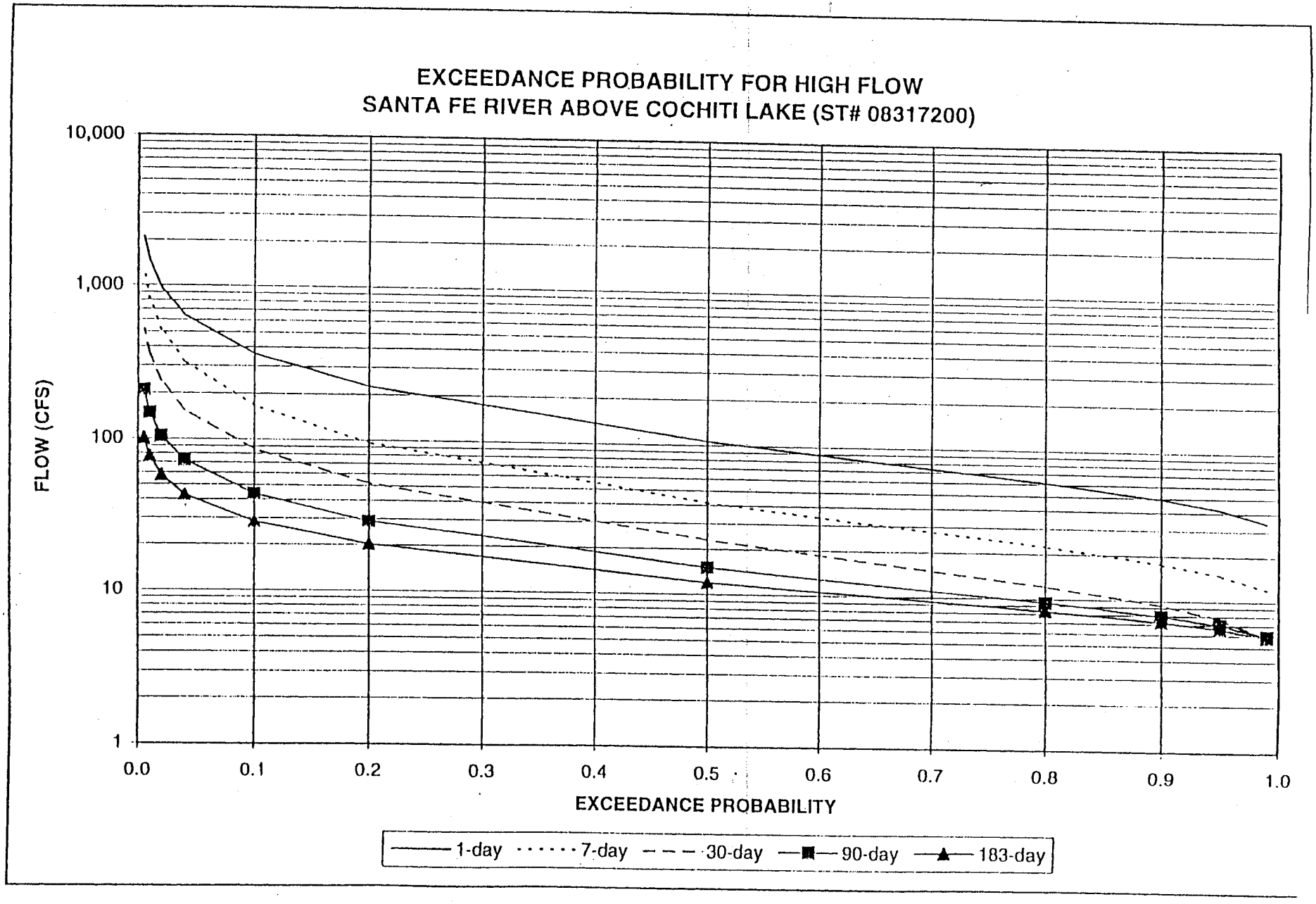

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO NAMBE BELOW NAMBE FALLS DAM (ST# 08294210)
FLOW (CFS)
100.00
10.00
1.00
0.10
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
7-day
30-day
90-day
183-day

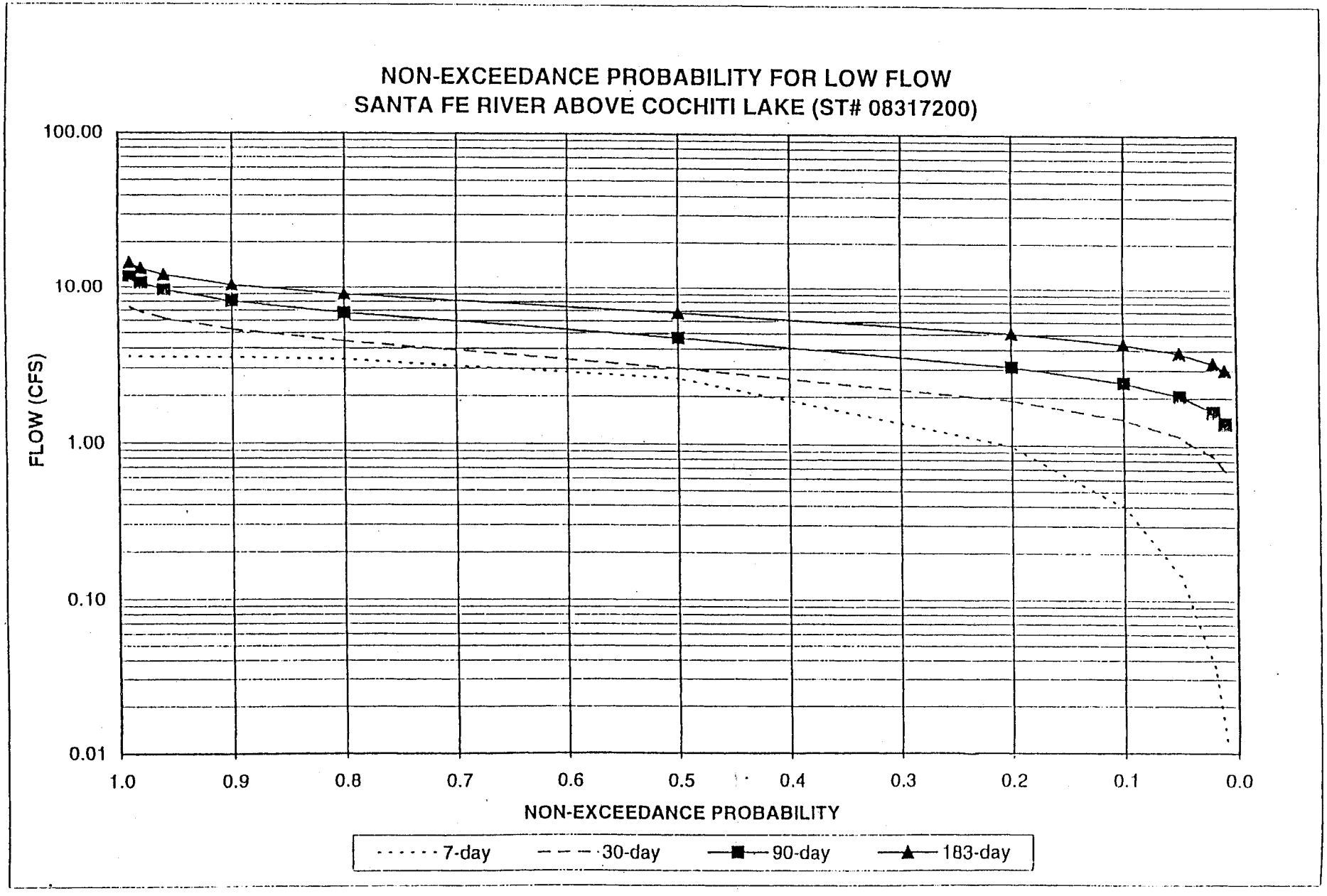

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO GRANDE AT OTOWE BRIDGE (ST# 08313000)
FLOW (CFS)
100,000
10,000
1,000
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

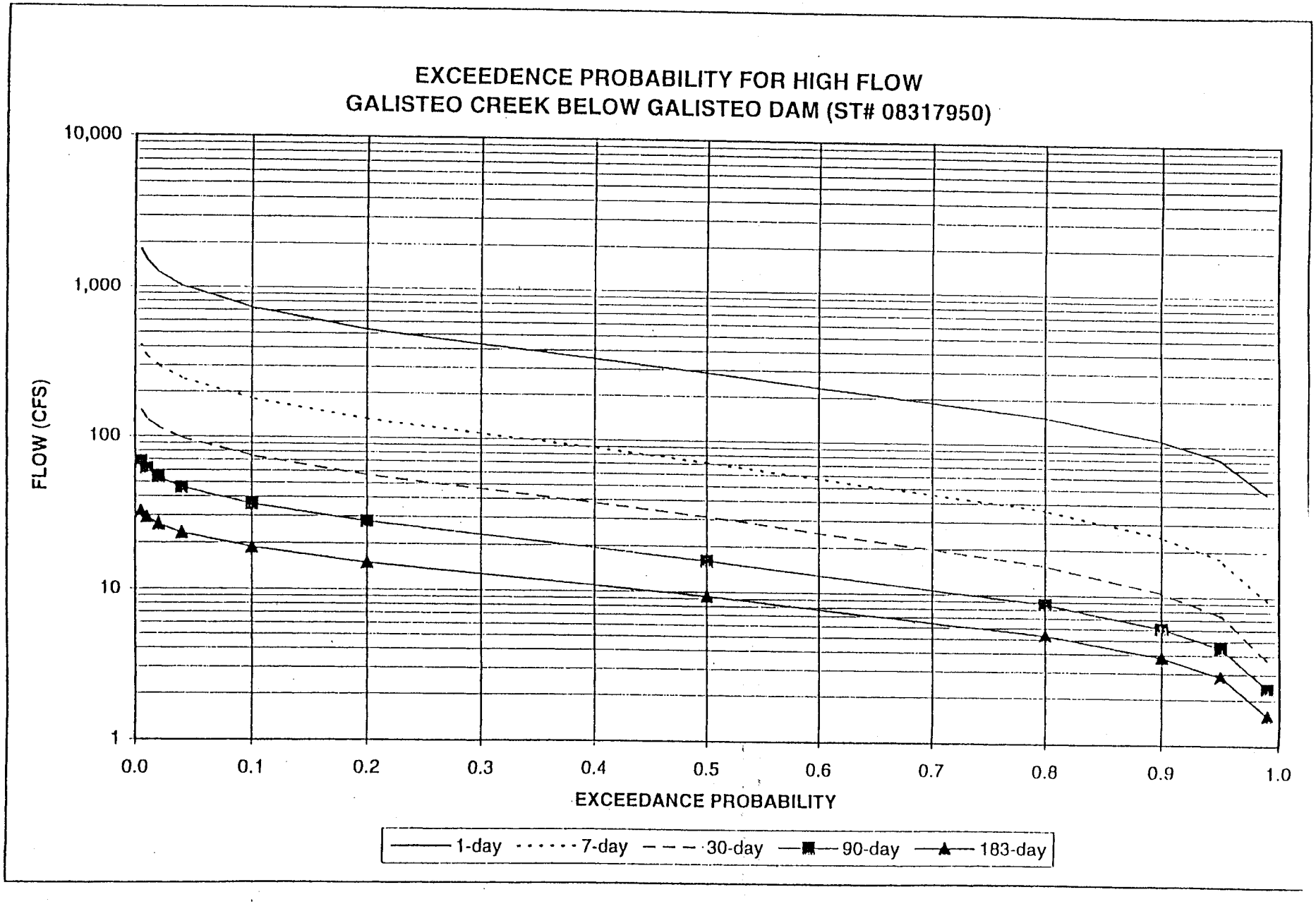

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO GRANDE AT OTOWI BRIDGE (ST# 08313000)
10,000
1,000
100
10
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

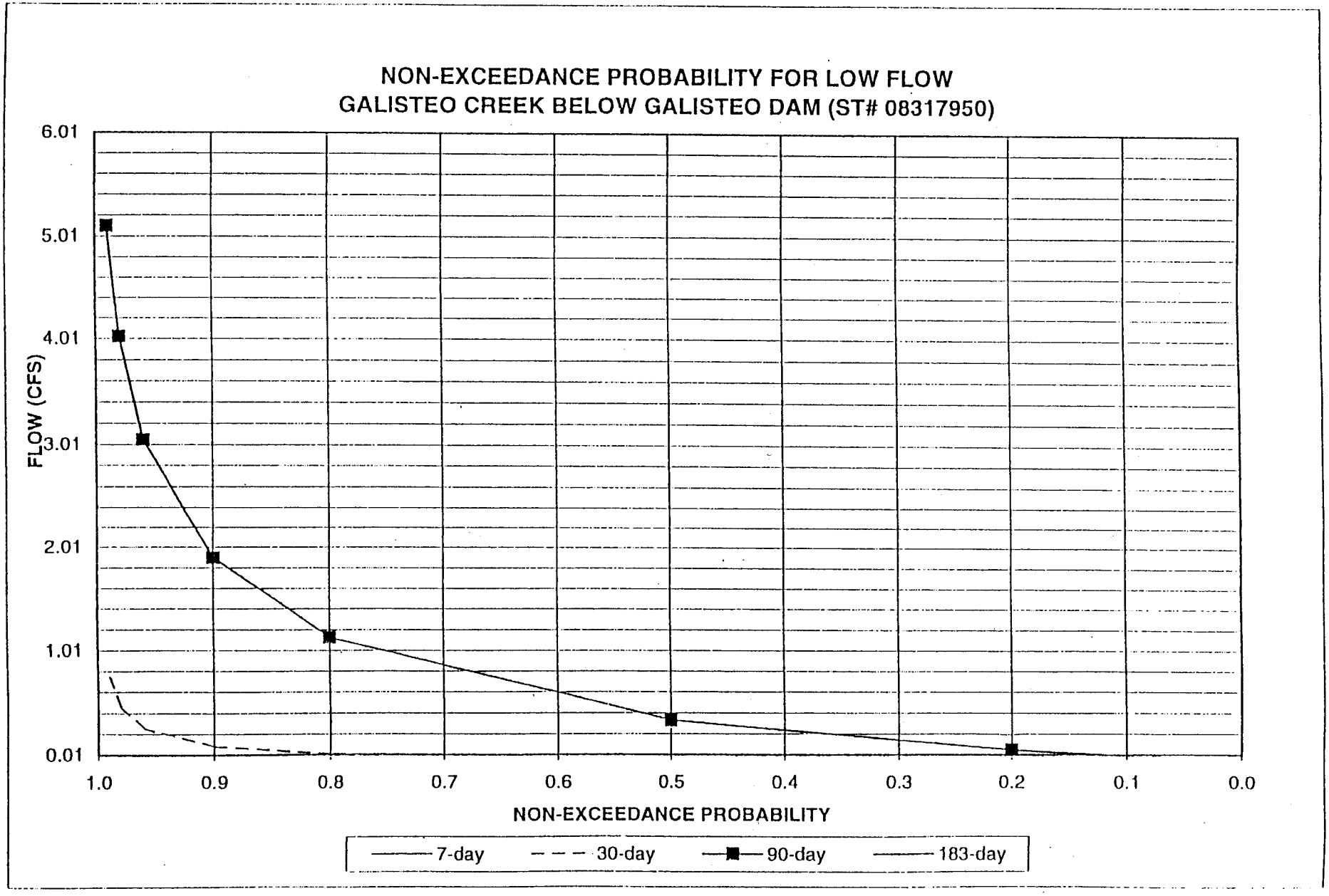

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
SANTA FE RIVER NEAR SANTA FE (ST# 08316000)
10.00
1.00
0.10
0.01
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

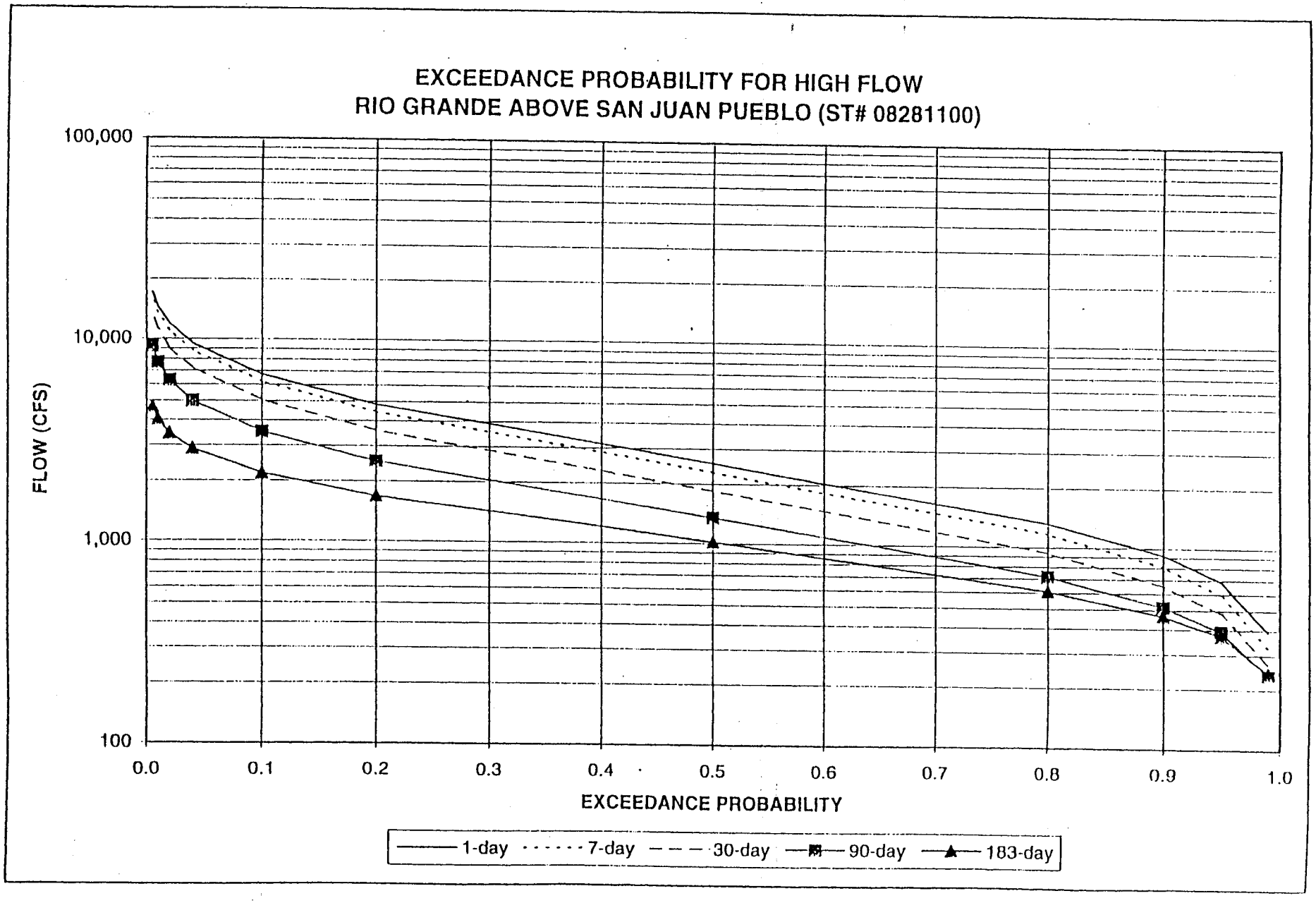

EXCEEDANCE PROBABILITY FOR HIGH FLOW
SANTA FE RIVER NEAR SANTA FE (ST# 08316000)
1,000
100
10
1
FLOW (CFS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

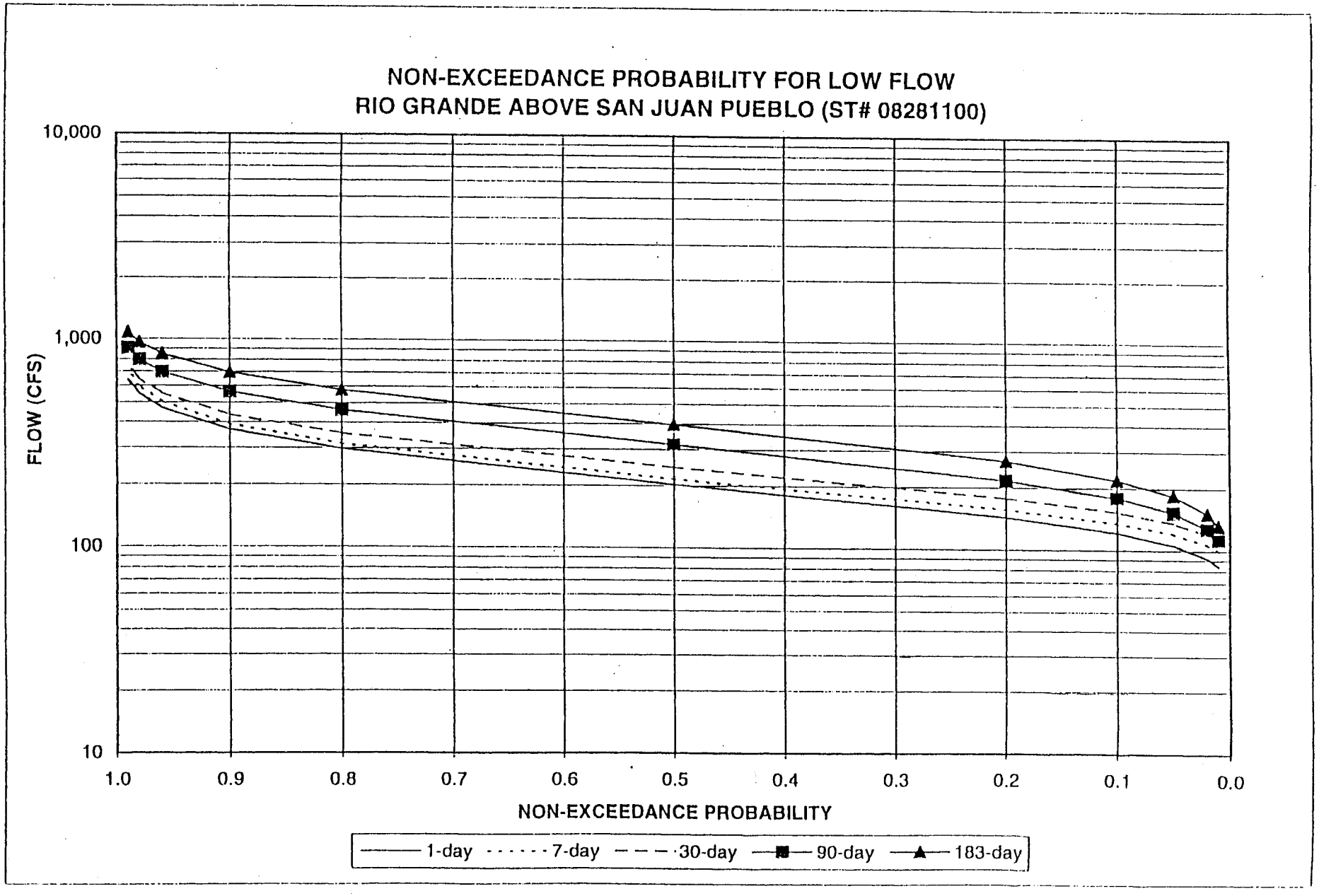

EXCEEDANCE PROBABILITY FOR HIGH FLOW
SANTA FE RIVER ABOVE COCHITI LAKE (ST# 08317200)
FLOW (CFS)
10,000
1,000
100
10
1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

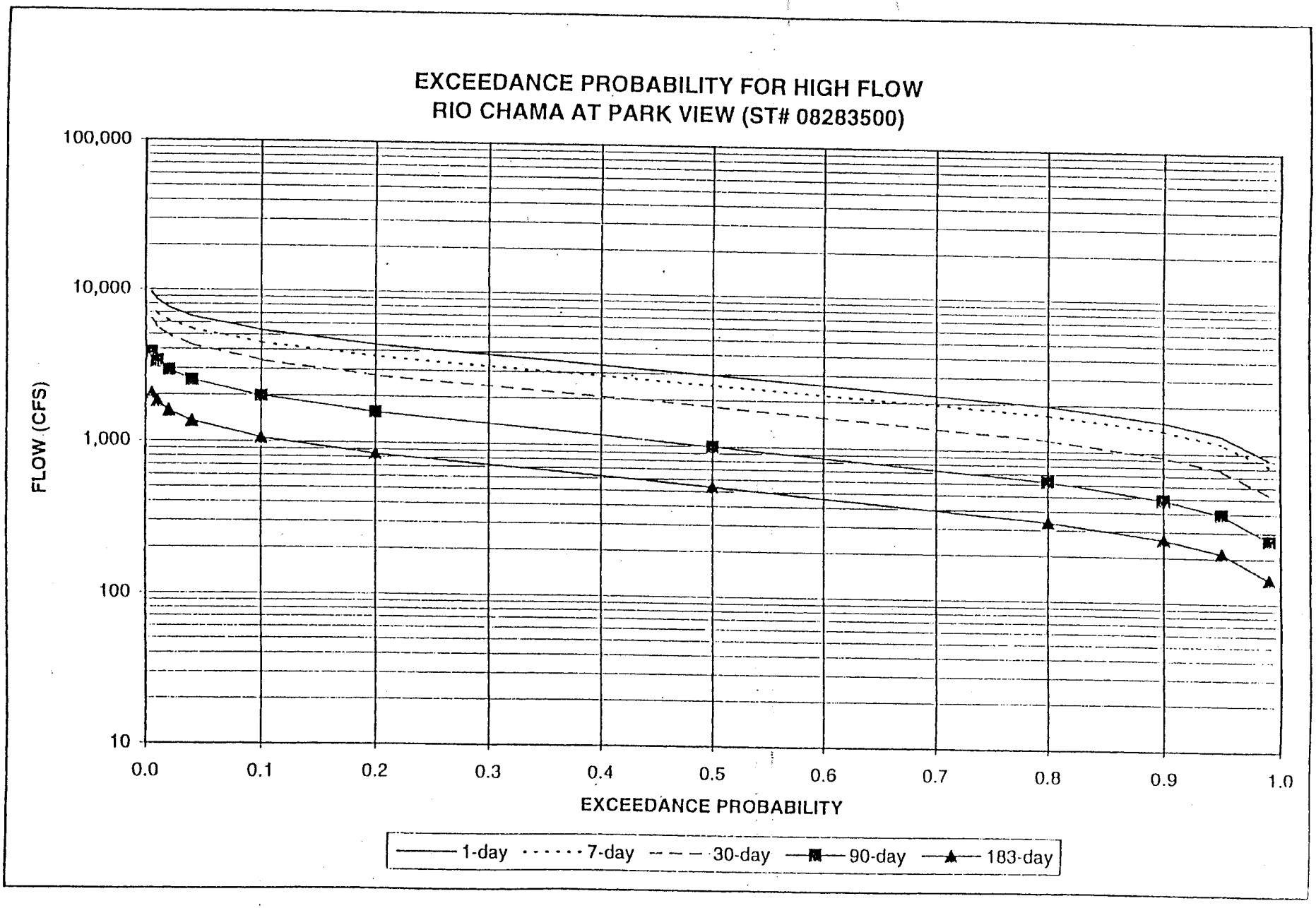

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
SANTA FE RIVER ABOVE COCHITI LAKE (ST# 08317200)
100.00
10.00
1.00
0.10
0.01
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
7-day
30-day
90-day
183-day

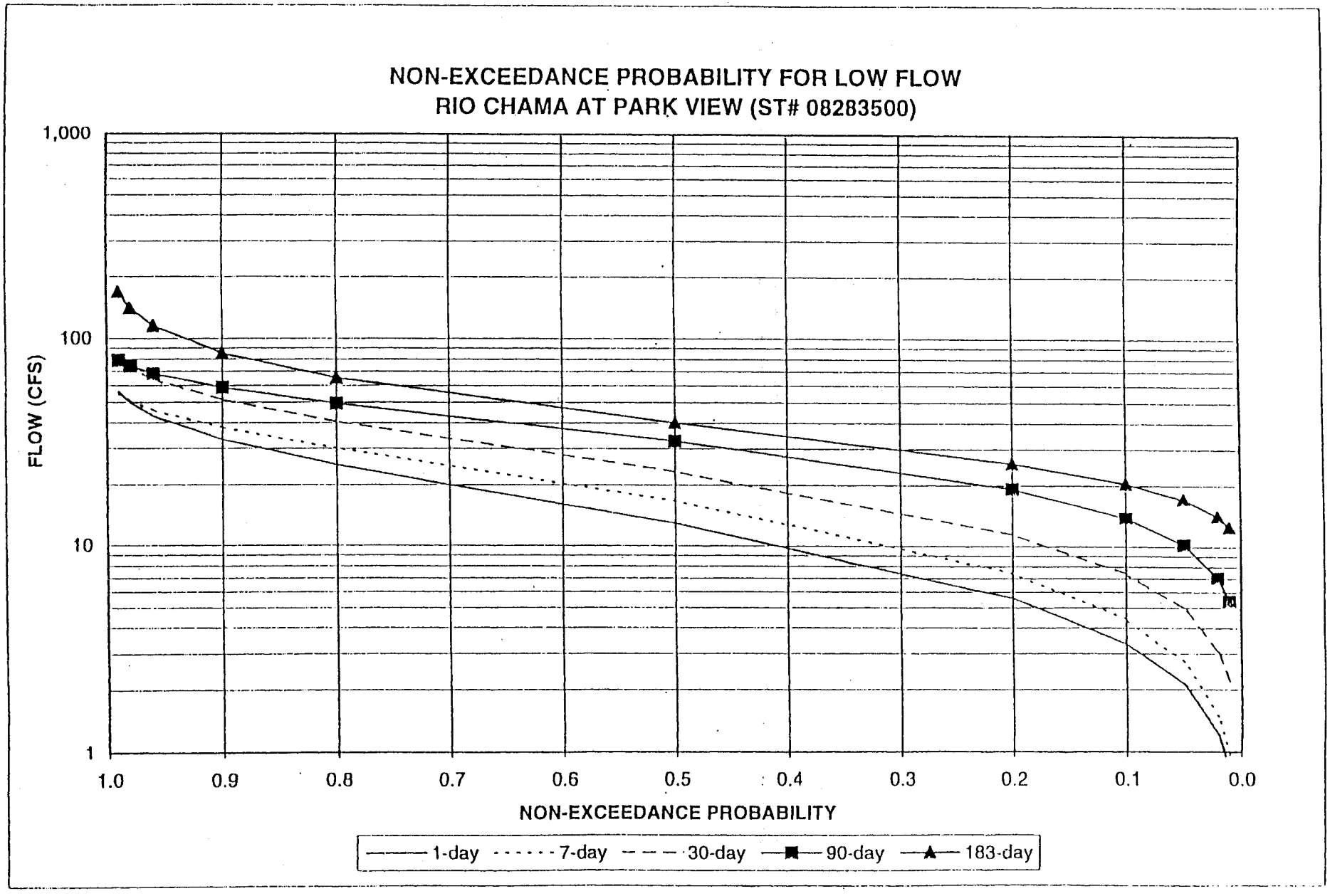

EXCEEDENCE PROBABILITY FOR HIGH FLOW
GALISTEO CREEK BELOW GALISTEO DAM (ST# 08317950)
FLOW (CFS)
10,000
1,000
100
10
1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

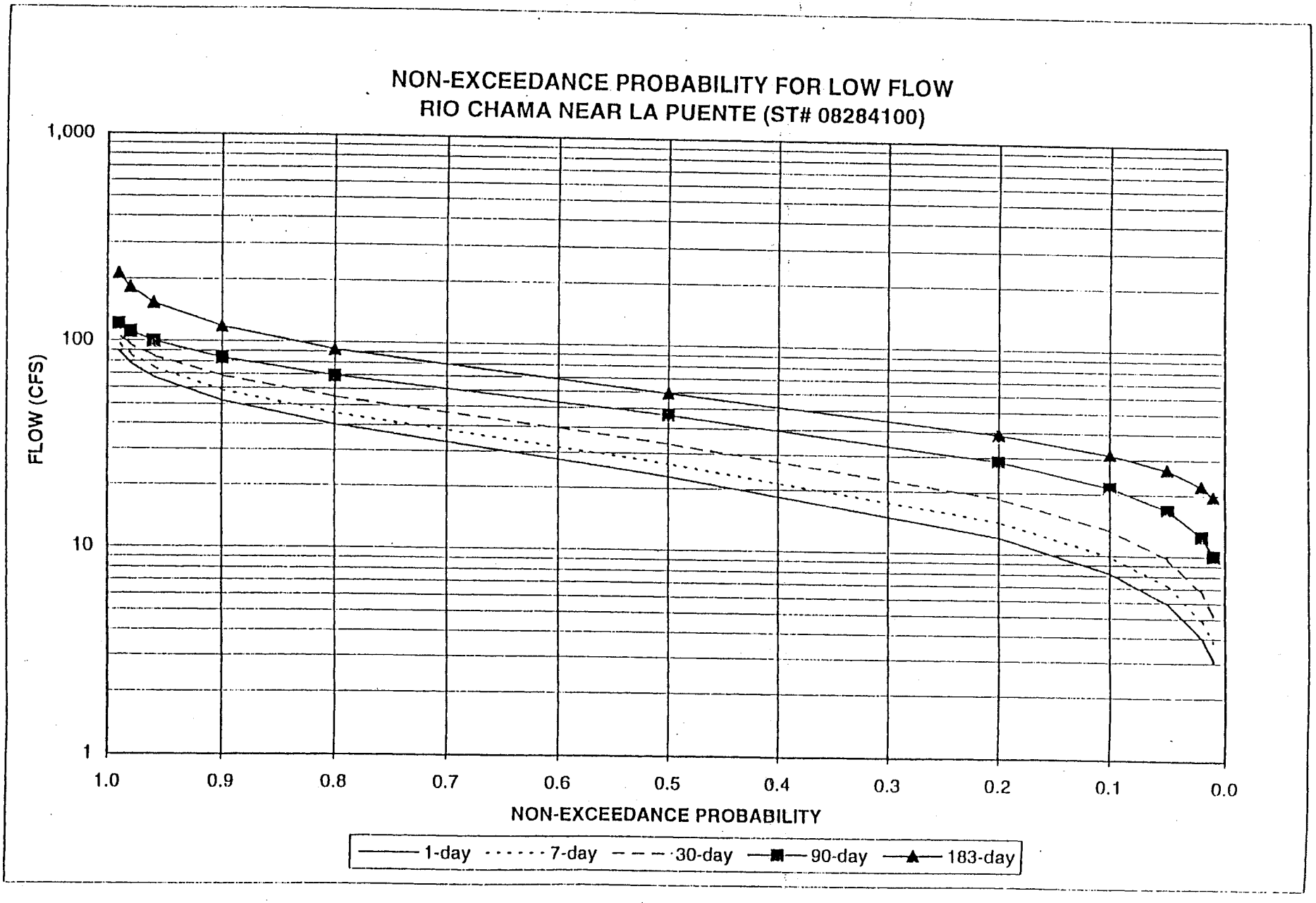

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
GALISTEO CREEK BELOW GALISTEO DAM (ST# 08317950)
FLOW (CFS)
6.01
5.01
4.01
3.01
2.01
1.01
0.01
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
7-day
30-day
90-day
183-day

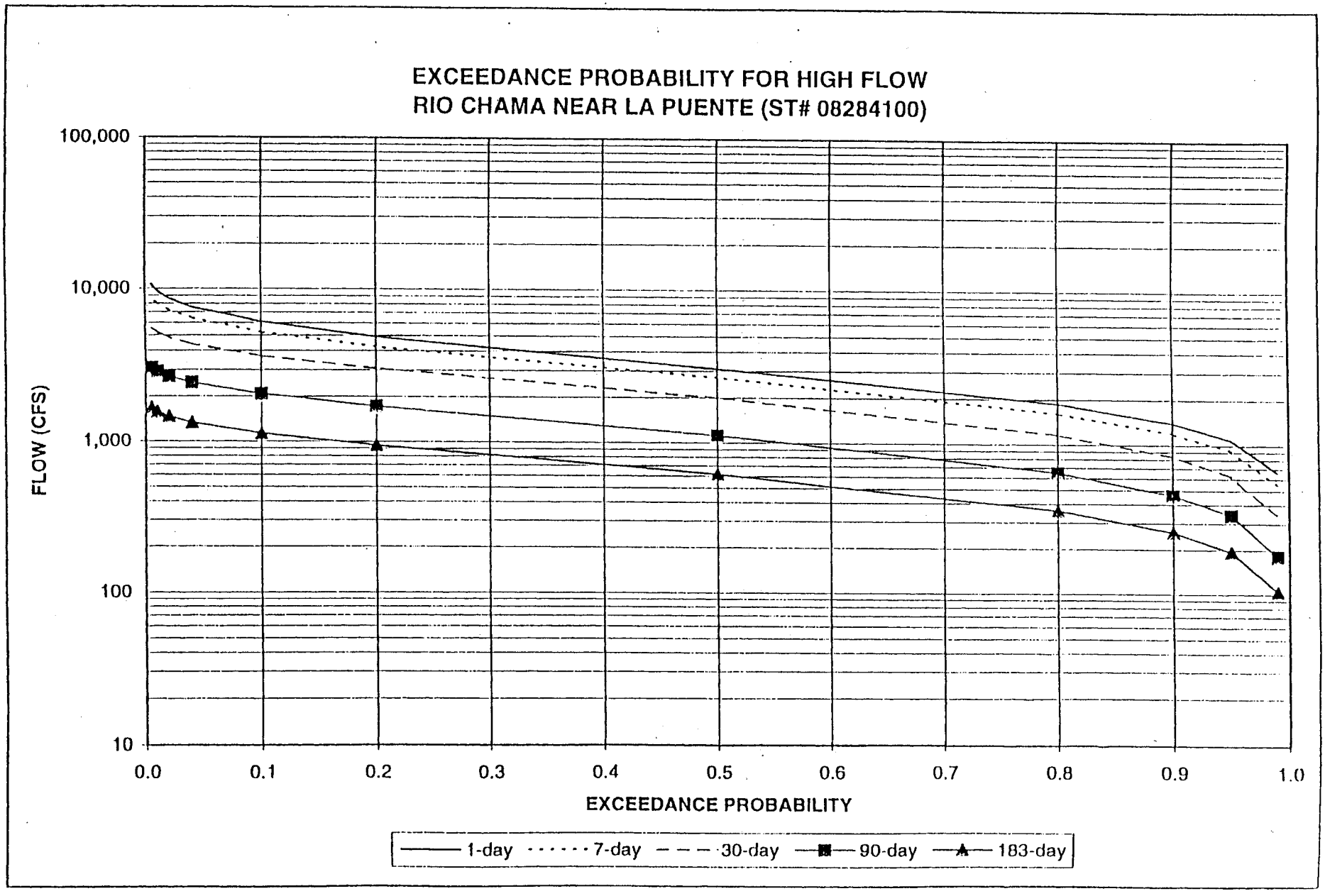

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO GRANDE ABOVE SAN JUAN PUEBLO (ST# 08281100)
FLOW (CFS)
100,000
10,000
1,000
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

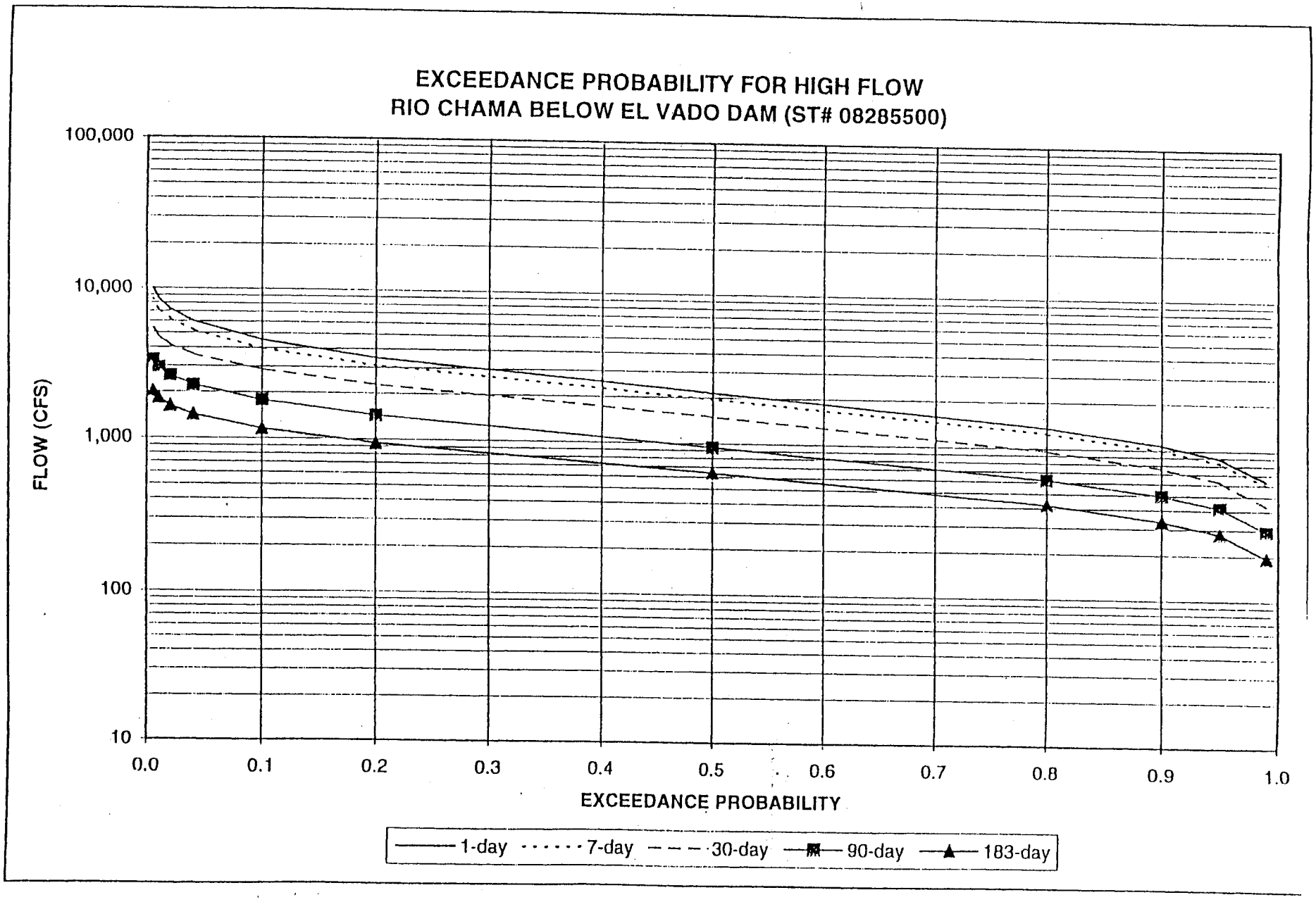

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO GRANDE ABOVE SAN JUAN PUEBLO (ST# 08281100)
10,000
1,000
100
10
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

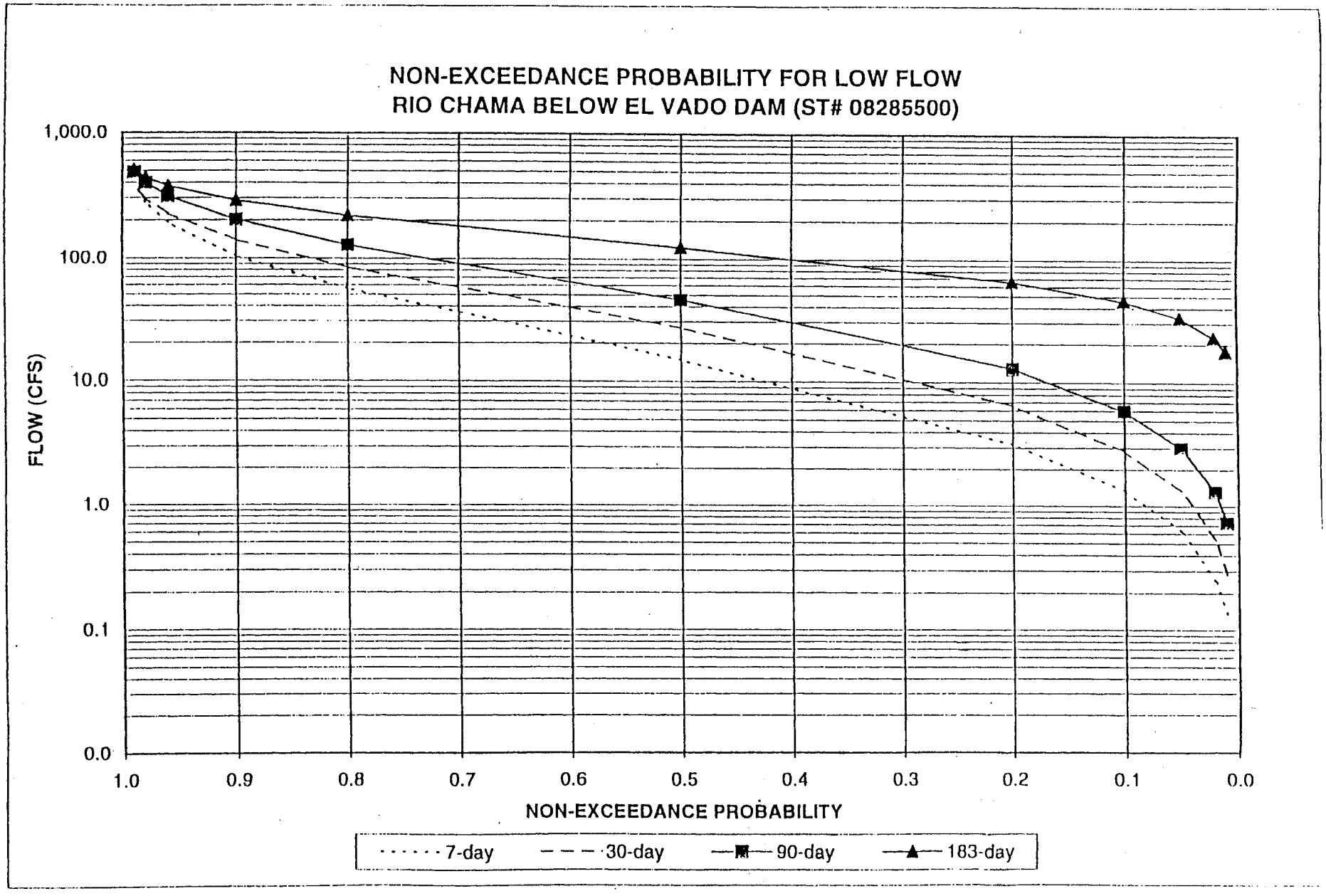

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO CHAMA AT PARK VIEW (ST# 08283500)
FLOW (CFS)
100,000
10,000
1,000
100
10
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

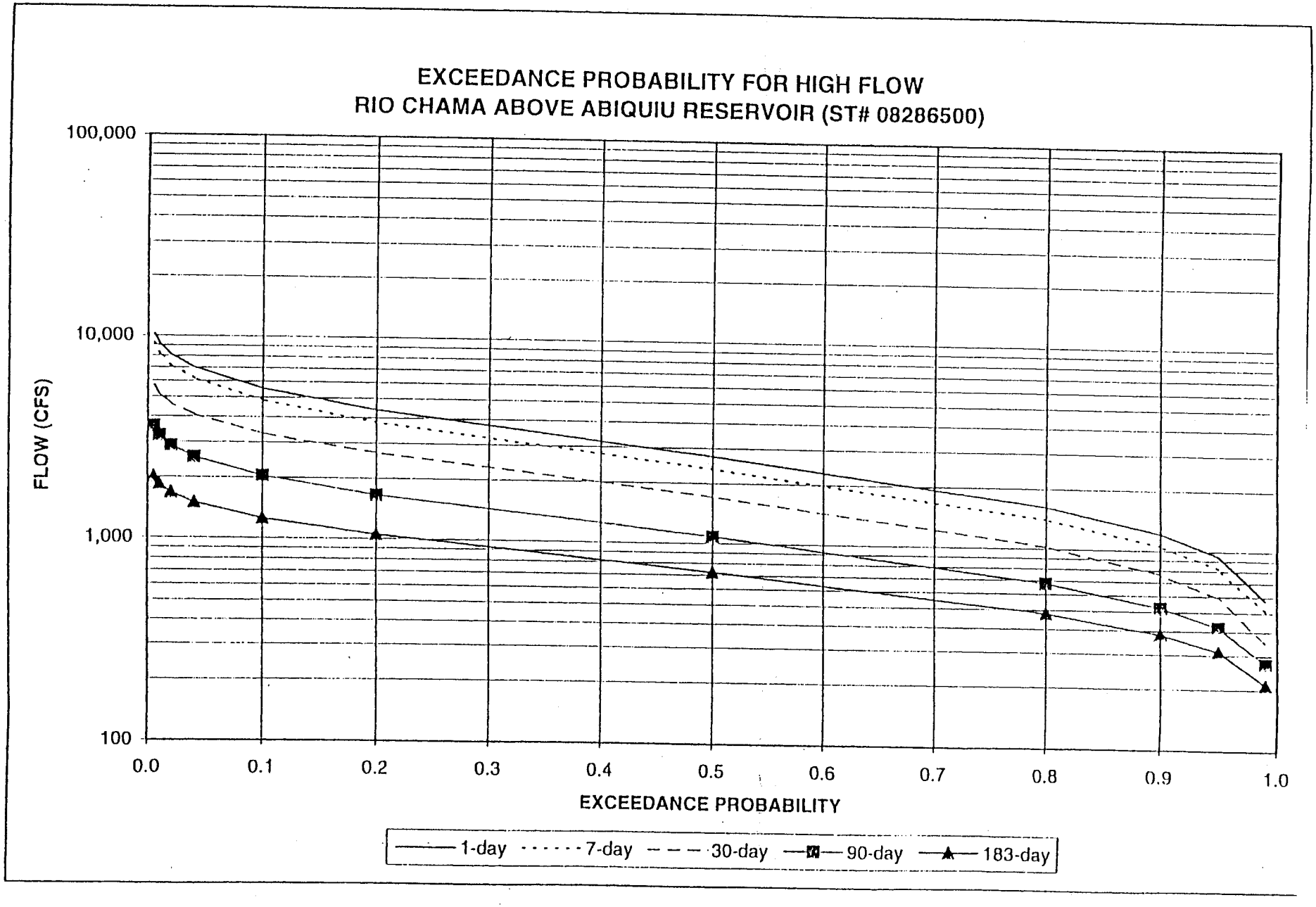

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO CHAMA AT PARK VIEW (ST# 08283500)
1,000
100
10
1
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

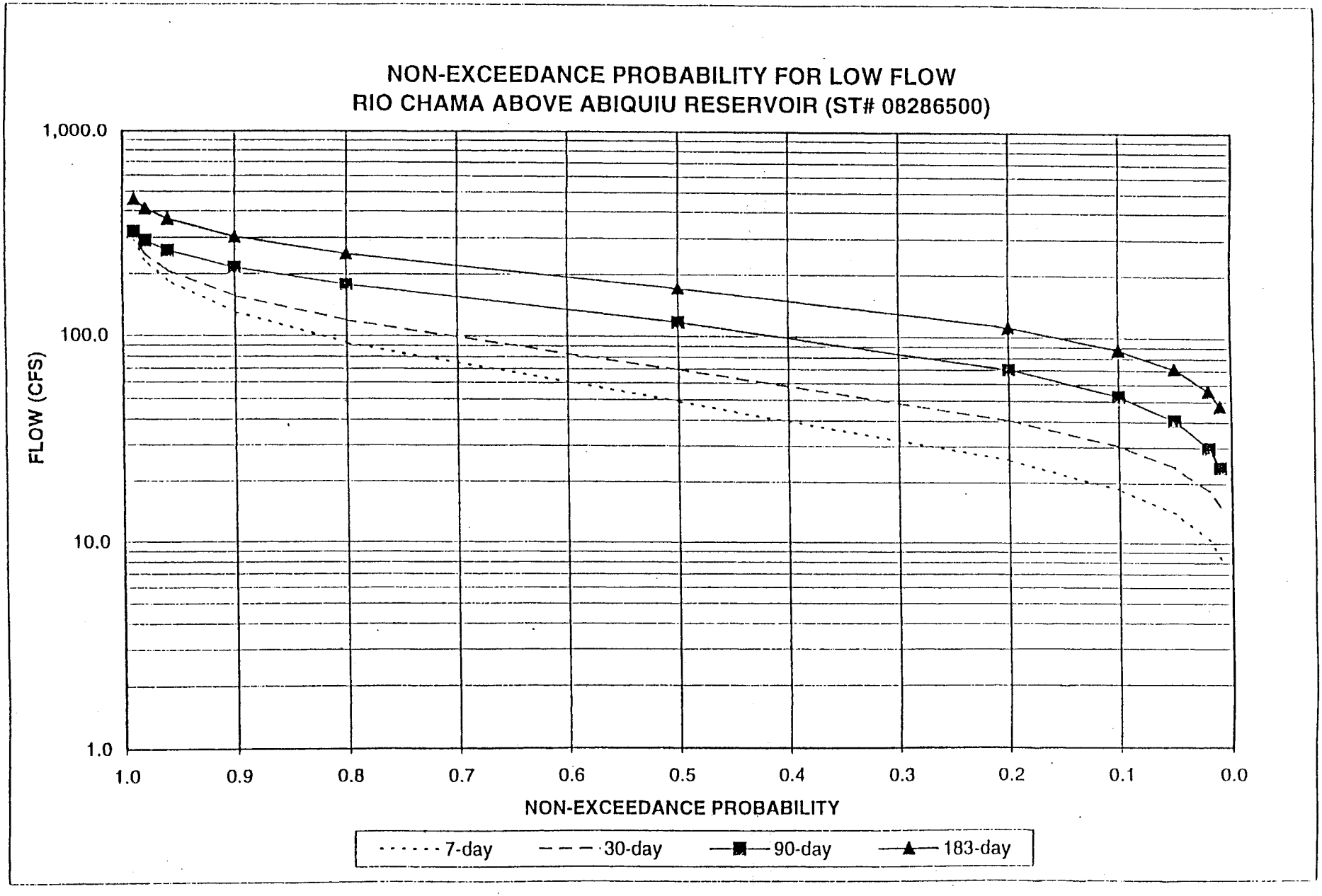

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO CHAMA NEAR LA PUENTE (ST# 08284100)
FLOW (CFS)
1,000
100
10
1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

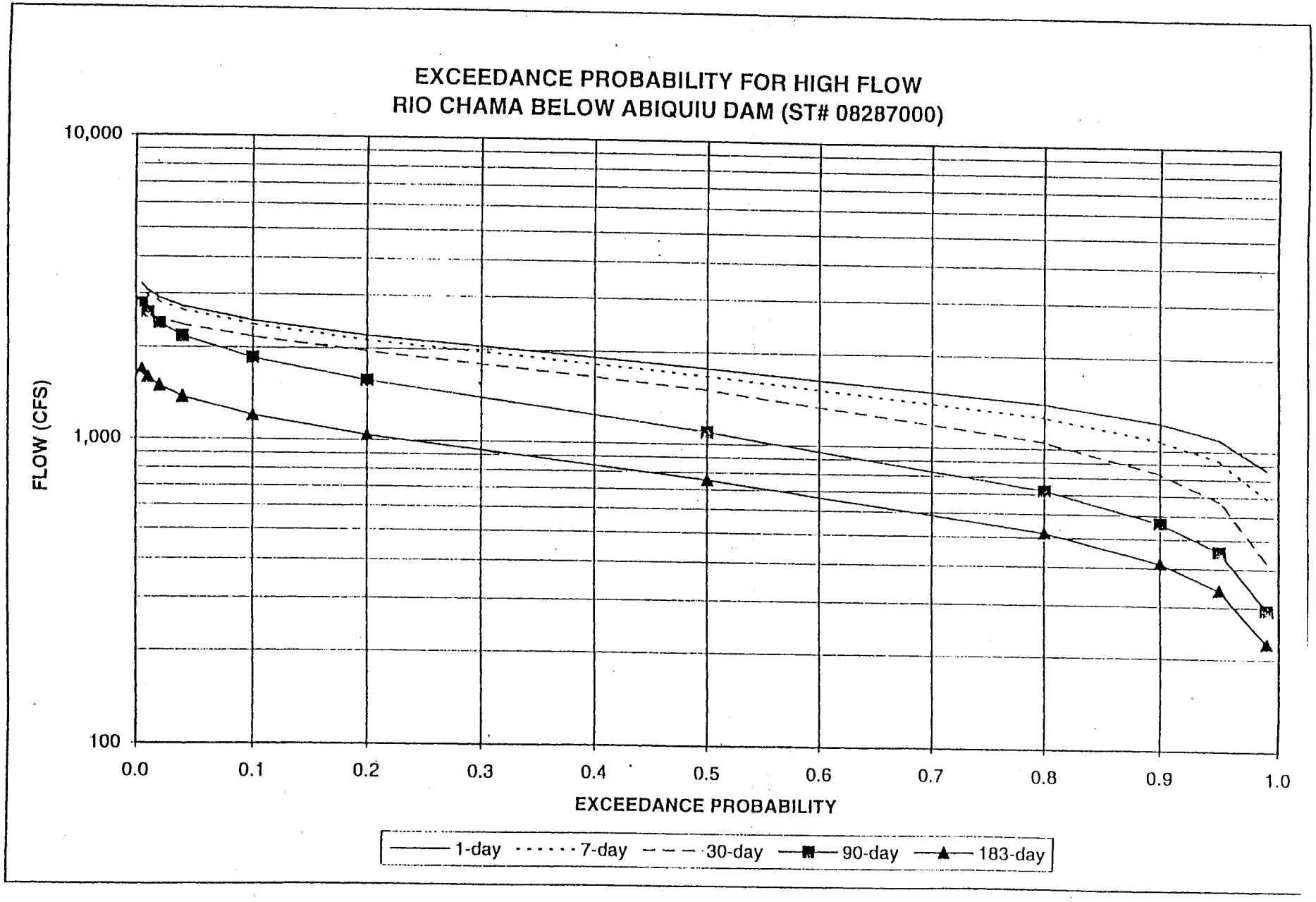

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO CHAMA NEAR LA PUENTE (ST# 08284100)
100,000
10,000
1,000
100
10
FLOW (CFS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

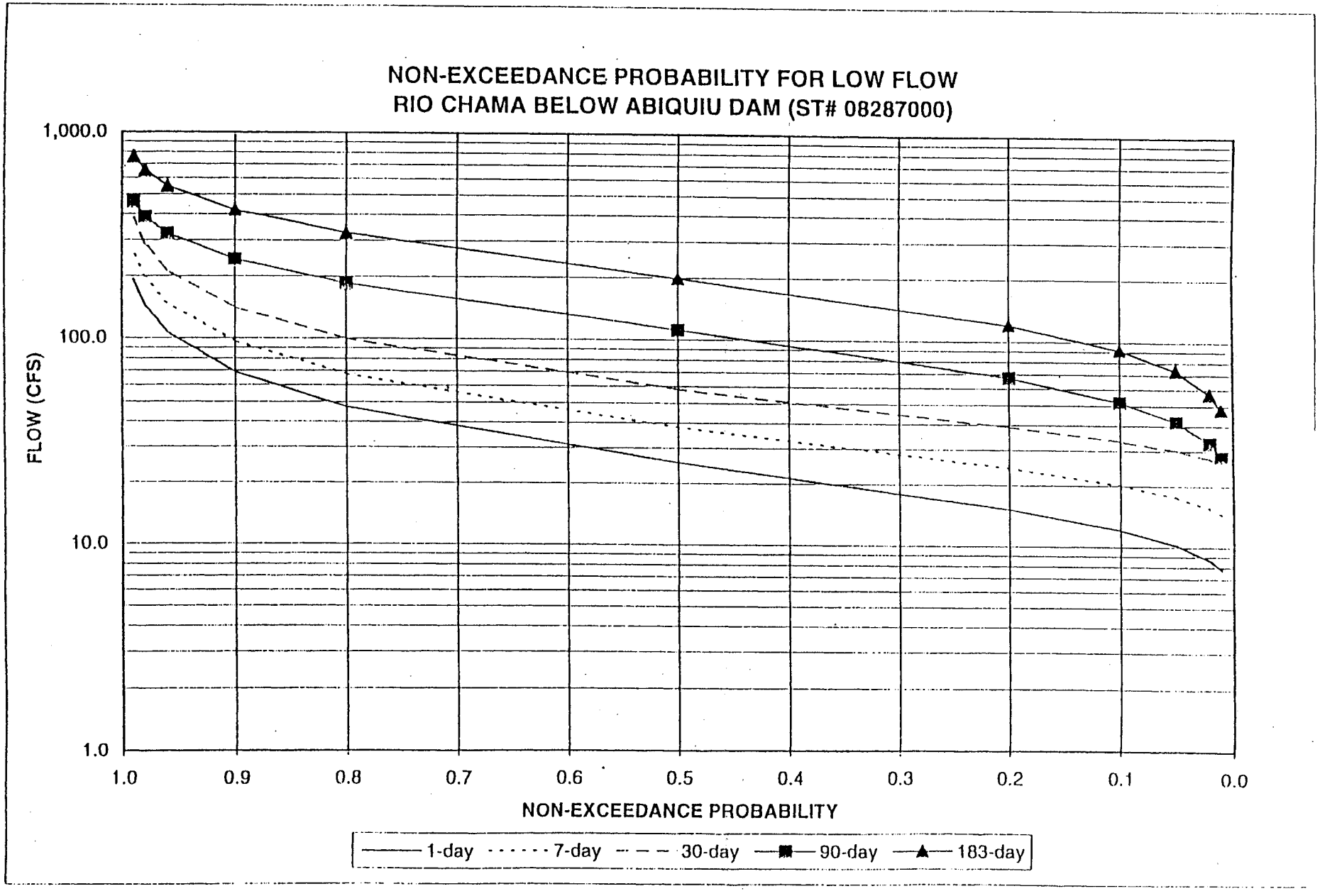

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO CHAMA BELOW EL VADO DAM (ST# 08285500)
FLOW (CFS)
100,000
10,000
1,000
100
10
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

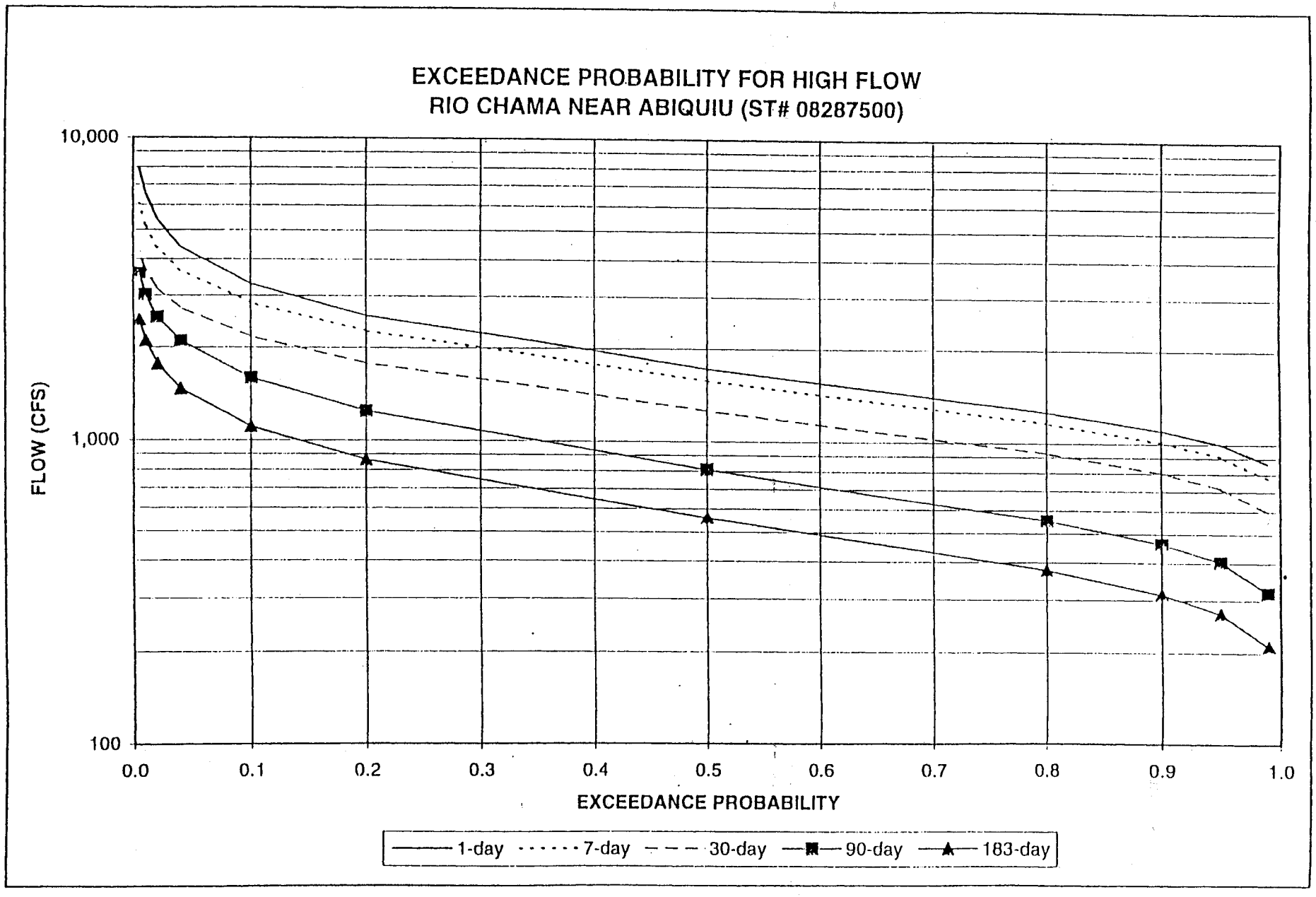

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO CHAMA BELOW EL VADO DAM (ST# 08285500)
FLOW (CFS)
1,000.0
100.0
10.0
1.0
0.1
0.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
7-day
30-day
90-day
183-day

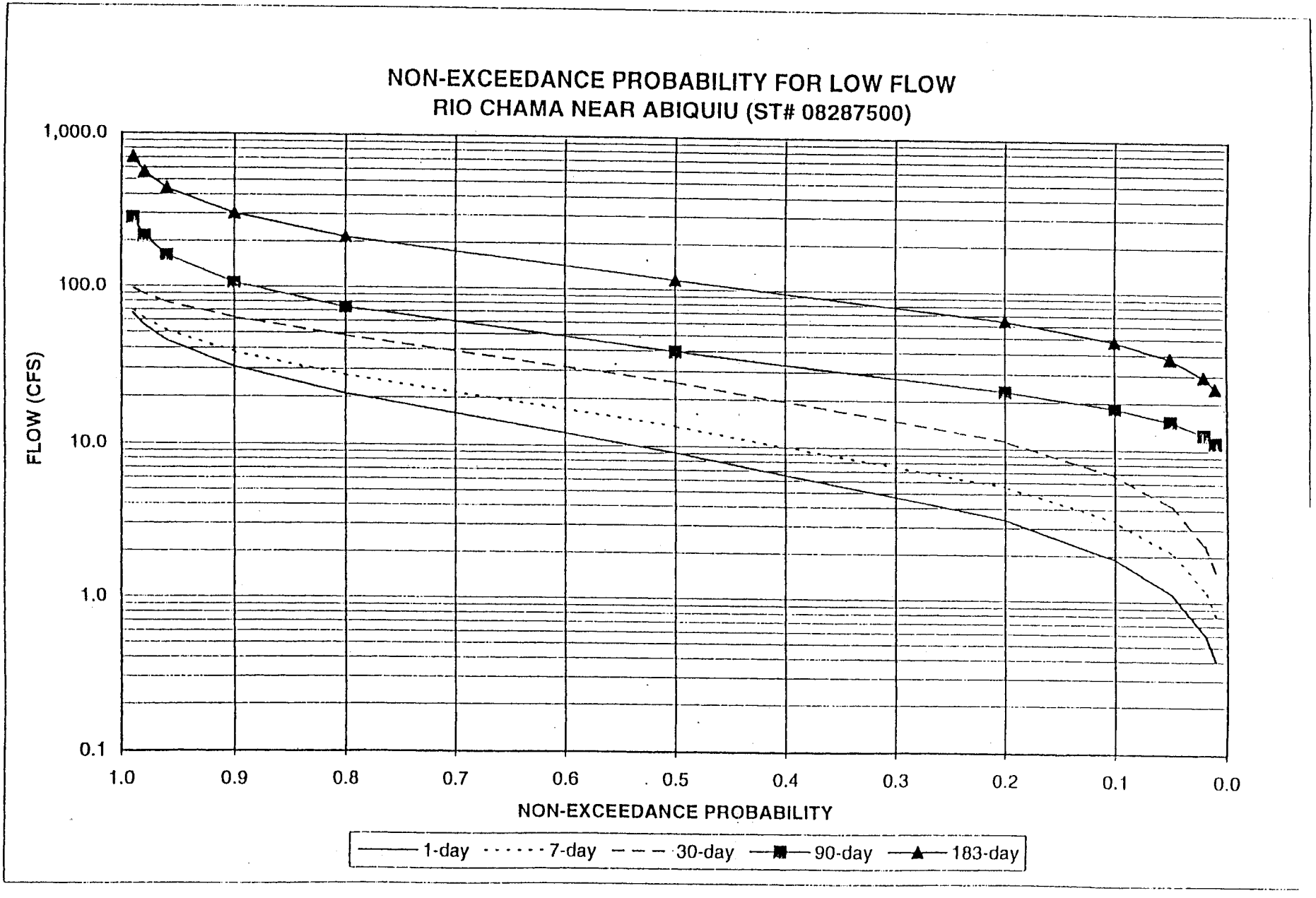

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO CHAMA ABOVE ABIQUIU RESERVOIR (ST# 08286500)
FLOW (CFS)
100,000
10,000
1,000
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

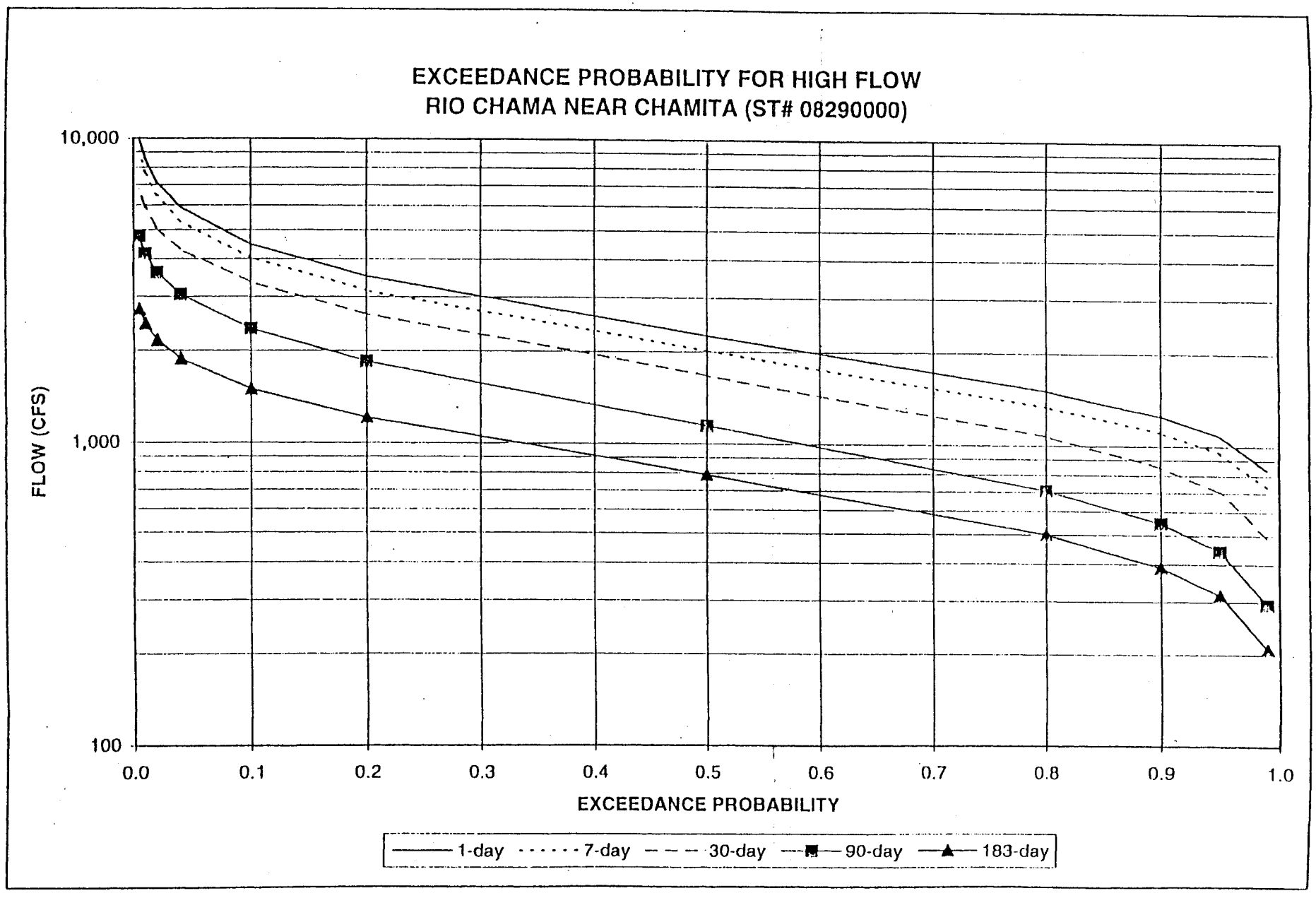

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO CHAMA ABOVE ABIQUIU RESERVOIR (ST# 08286500)
1,000.0
100.0
10.0
1.0
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
7-day
30-day
90-day
183-day

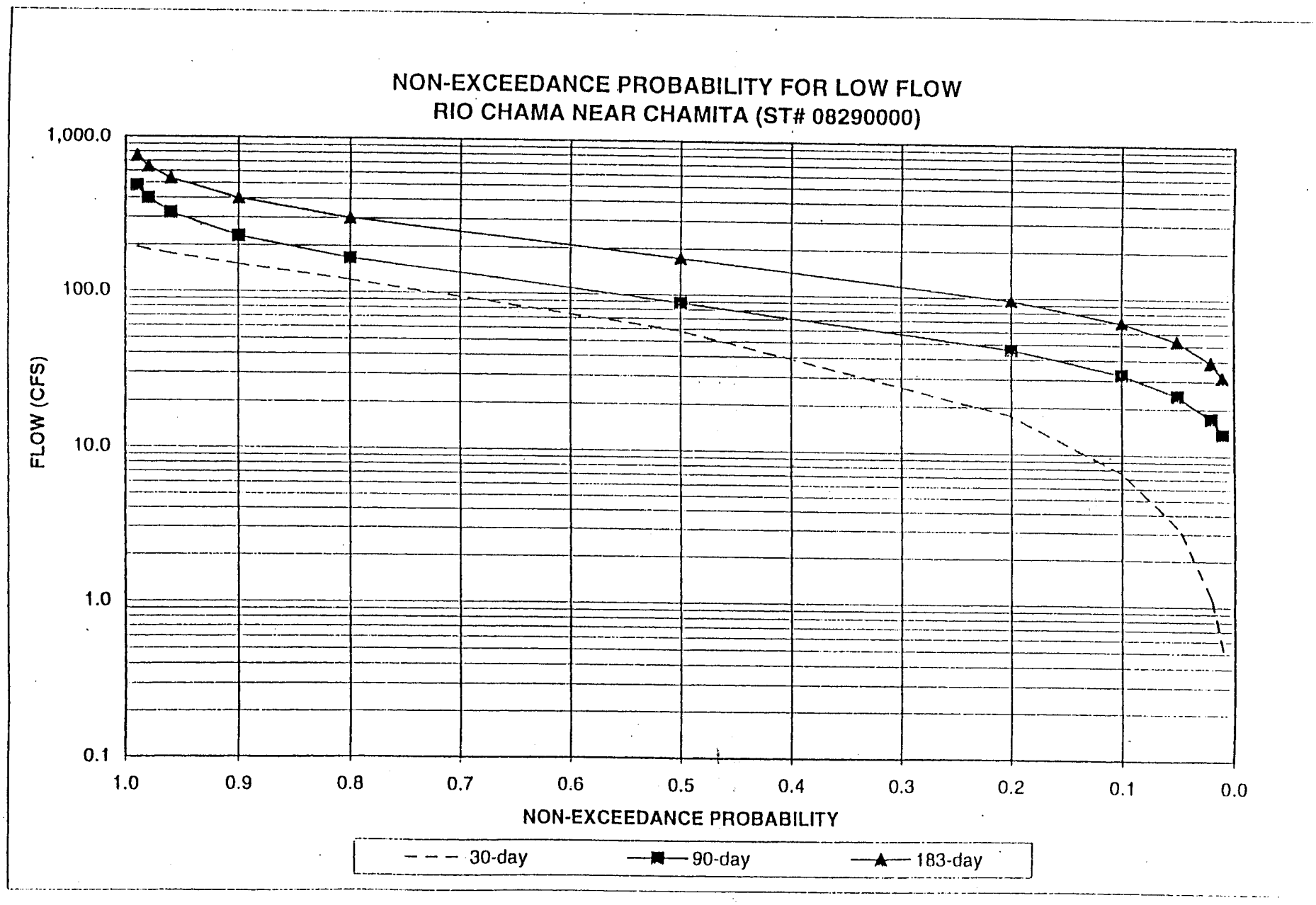

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO CHAMA BELOW ABIQUIU DAM (ST# 08287000)
FLOW (CFS)
10,000
1,000
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

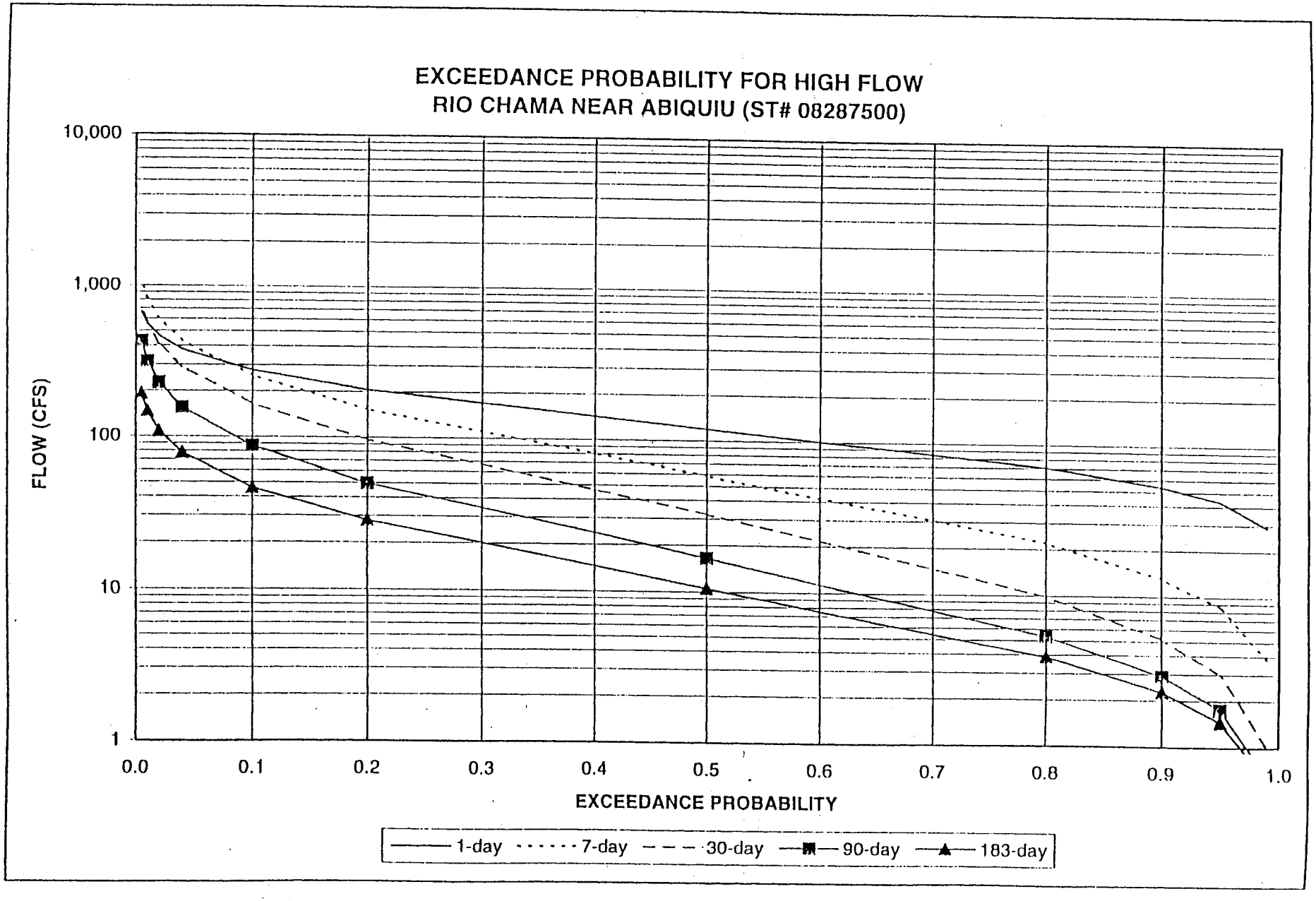

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO CHAMA BELOW ABIQUIU DAM (ST# 08287000)
1,000.0
100.0
10.0
1.0
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

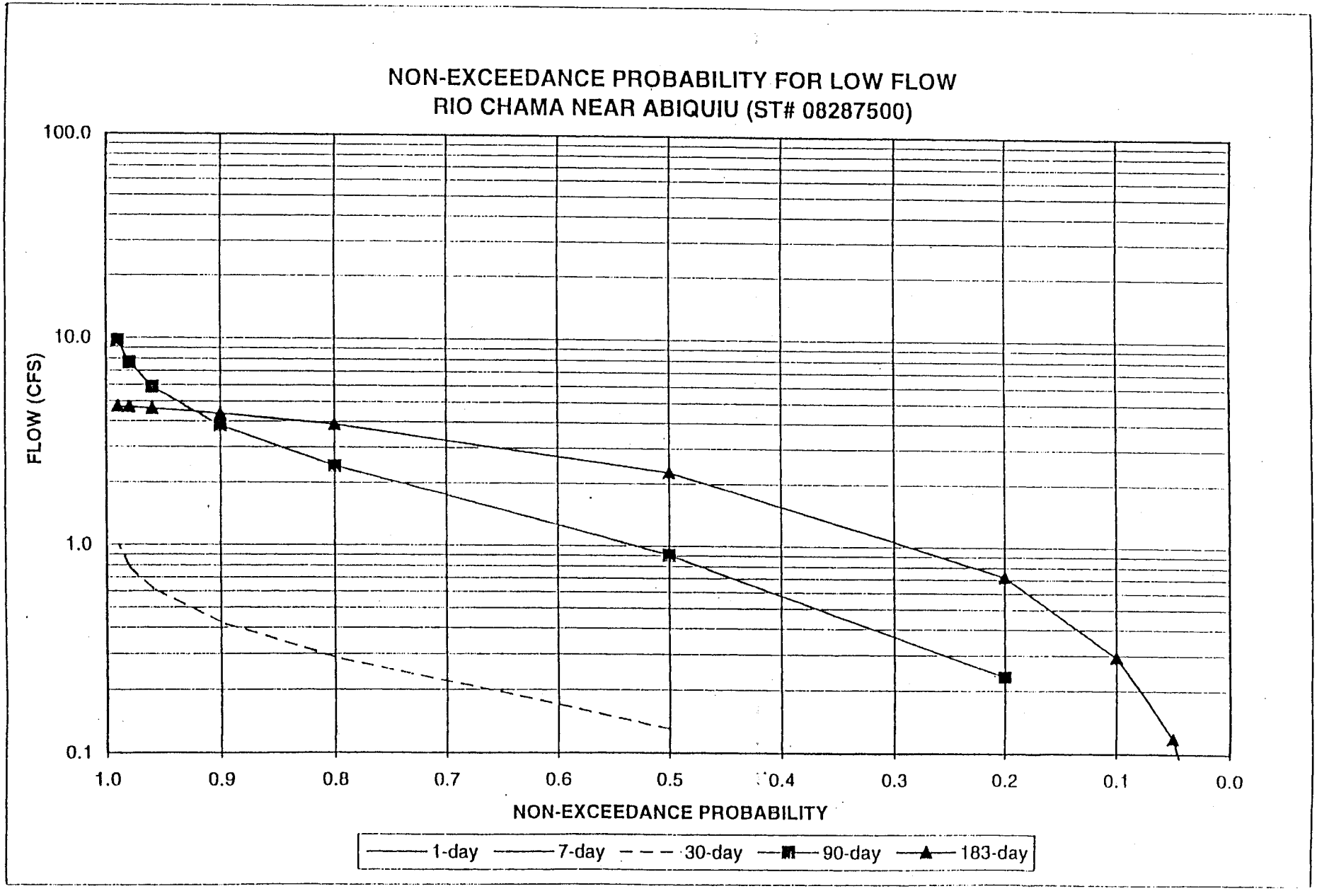

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO CHAMA NEAR ABIQUIU (ST# 08287500)
FLOW (CFS)
10,000
1,000
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

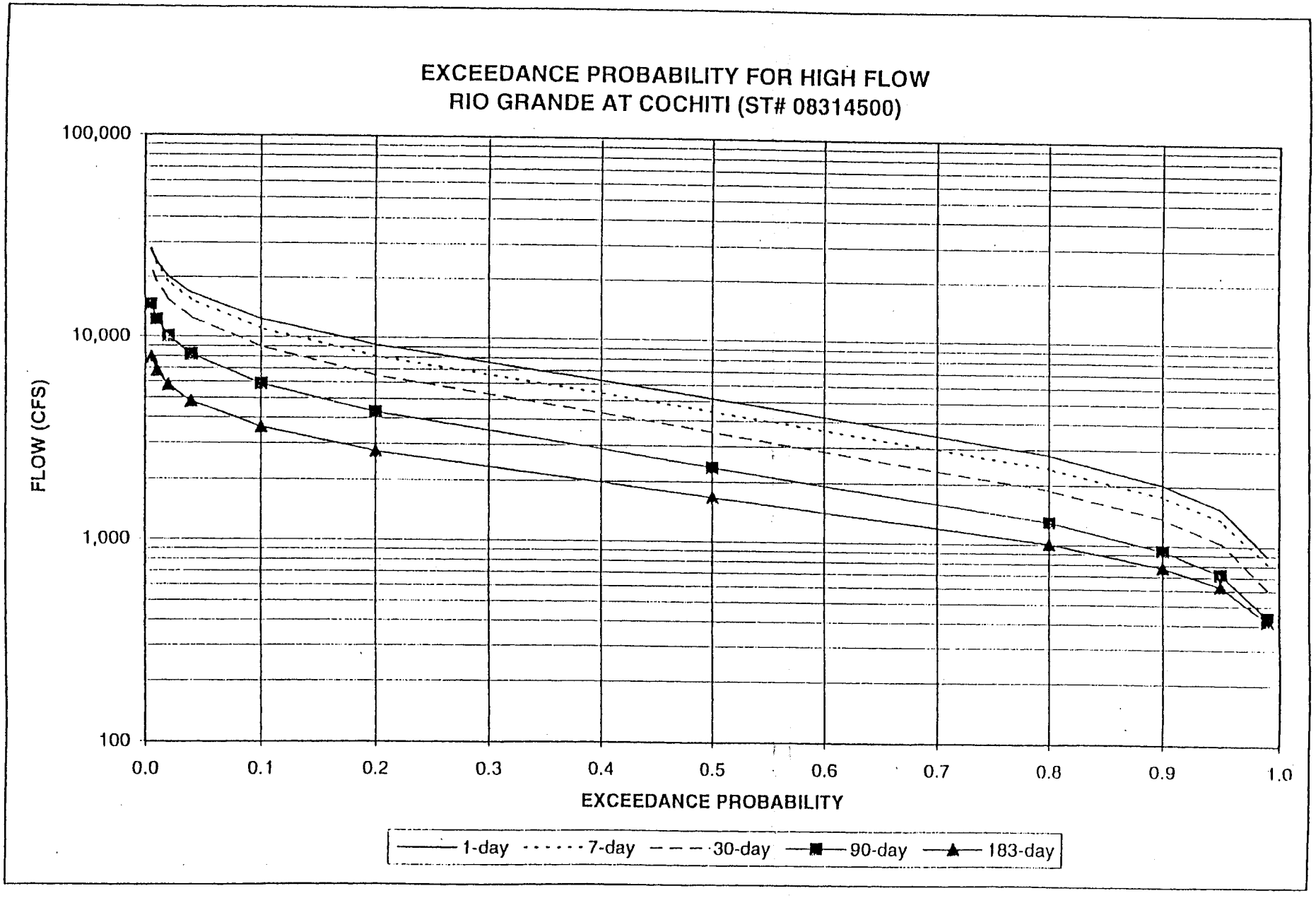

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO CHAMA NEAR ABIQUIU (ST# 08287500)
FLOW (CFS)
1,000.0
100.0
10.0
1.0
0.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

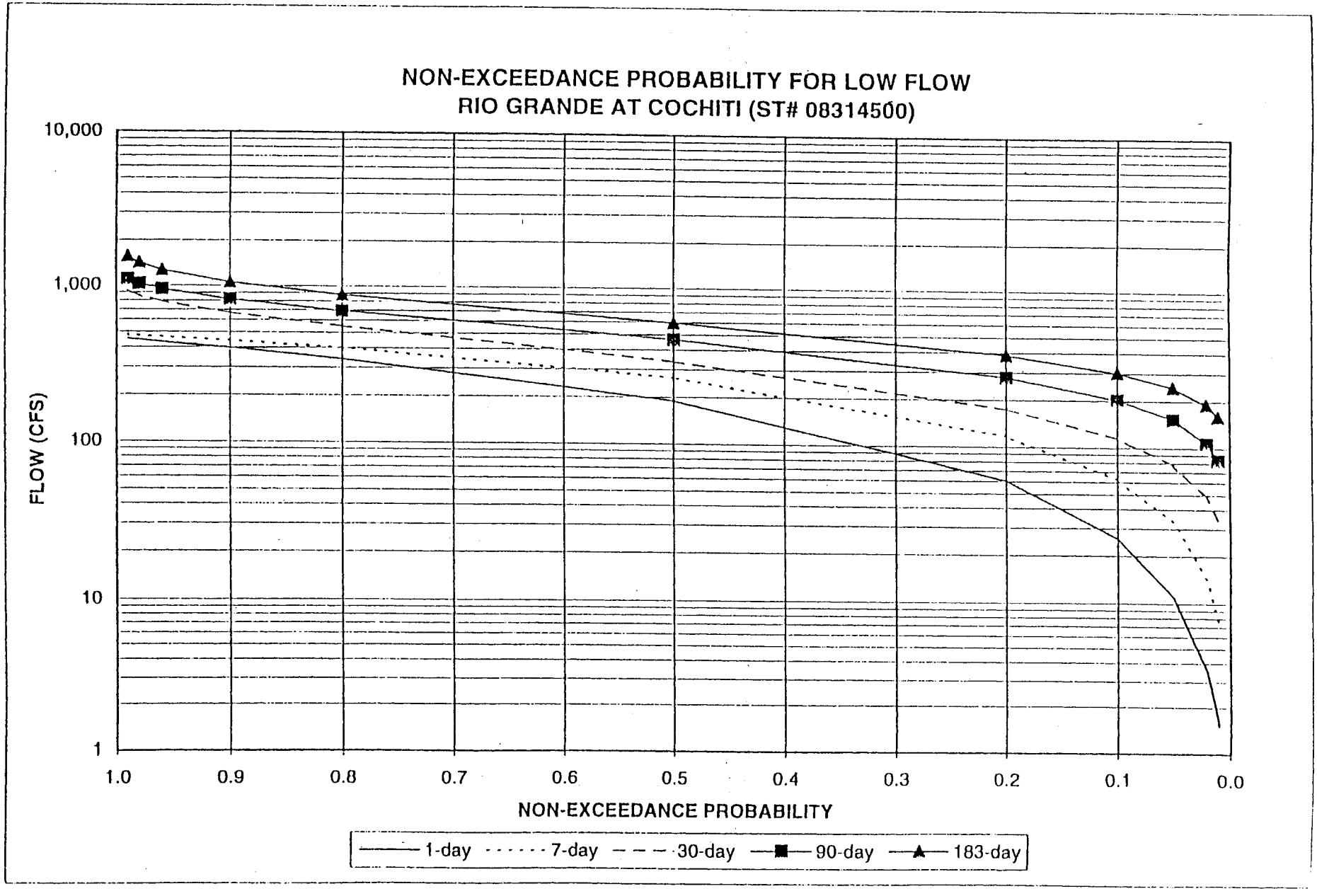

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO CHAMA NEAR CHAMITA (ST# 08290000)
FLOW (CFS)
10,000
1,000
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

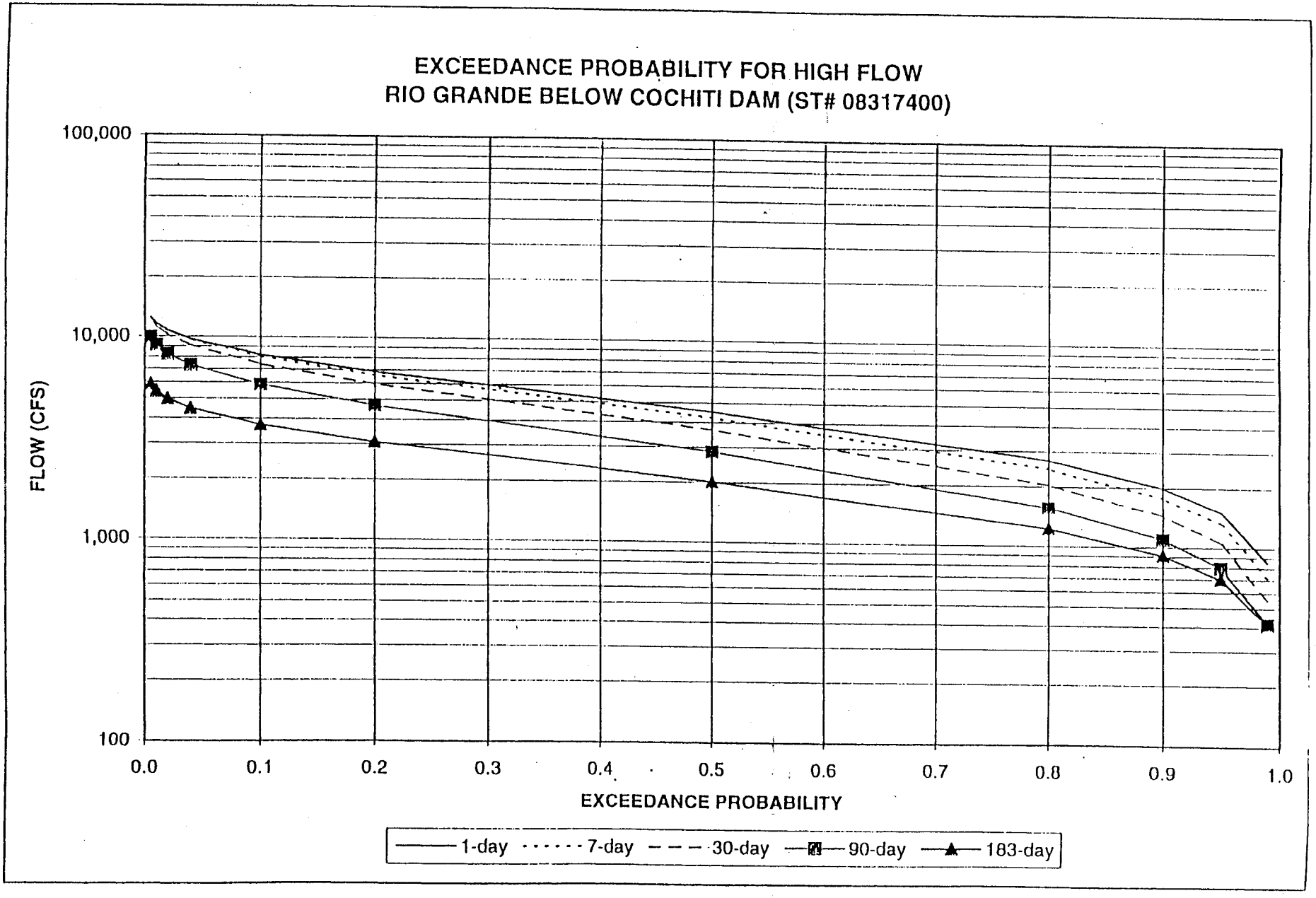

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO CHAMA NEAR CHAMITA (ST# 08290000)
FLOW (CFS)
1,000.0
100.0
10.0
1.0
0.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
30-day
90-day
183-day

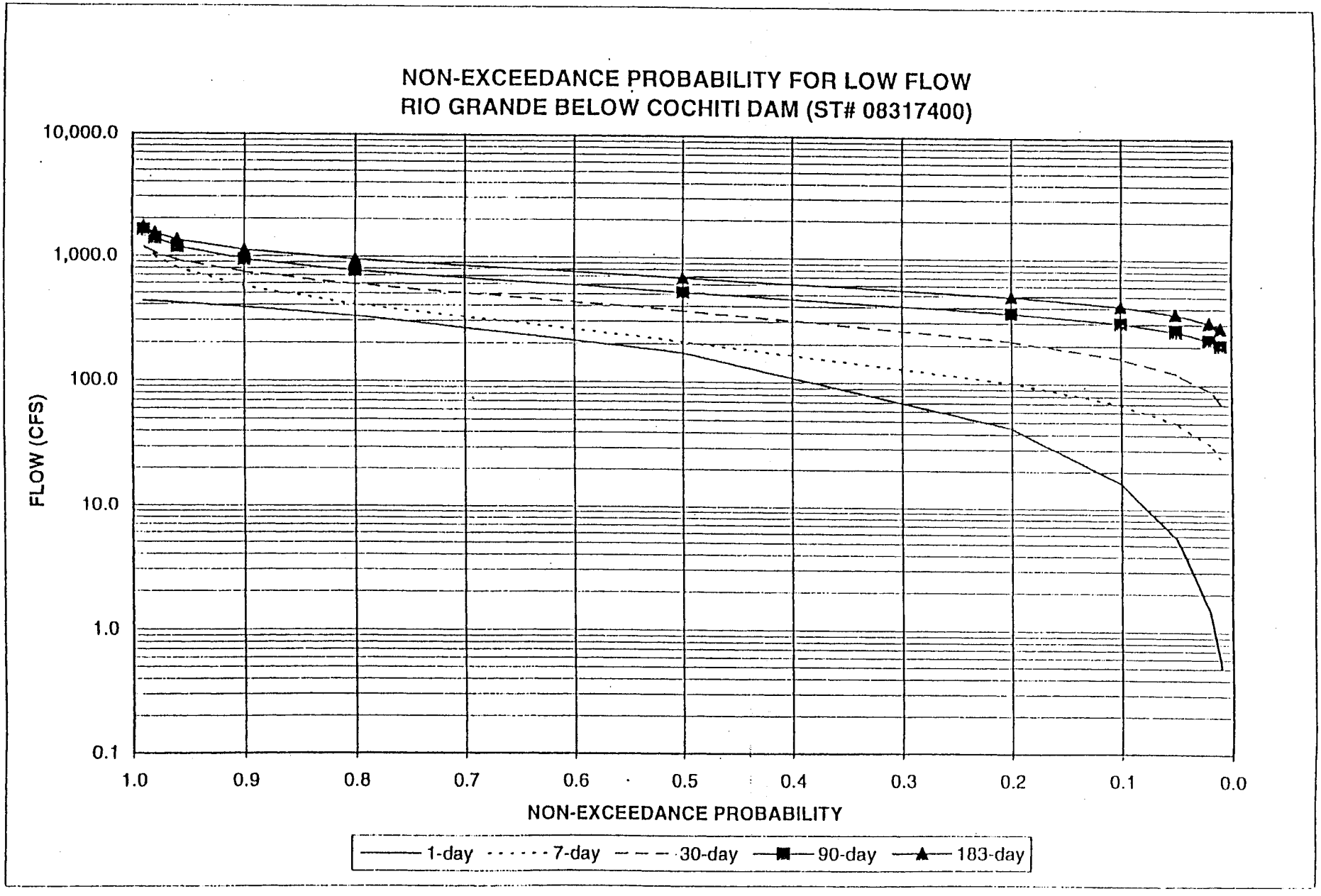

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO CHAMA NEAR ABIQUIU (ST# 08287500)
FLOW (CFS)
10,000
1,000
100
10
1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

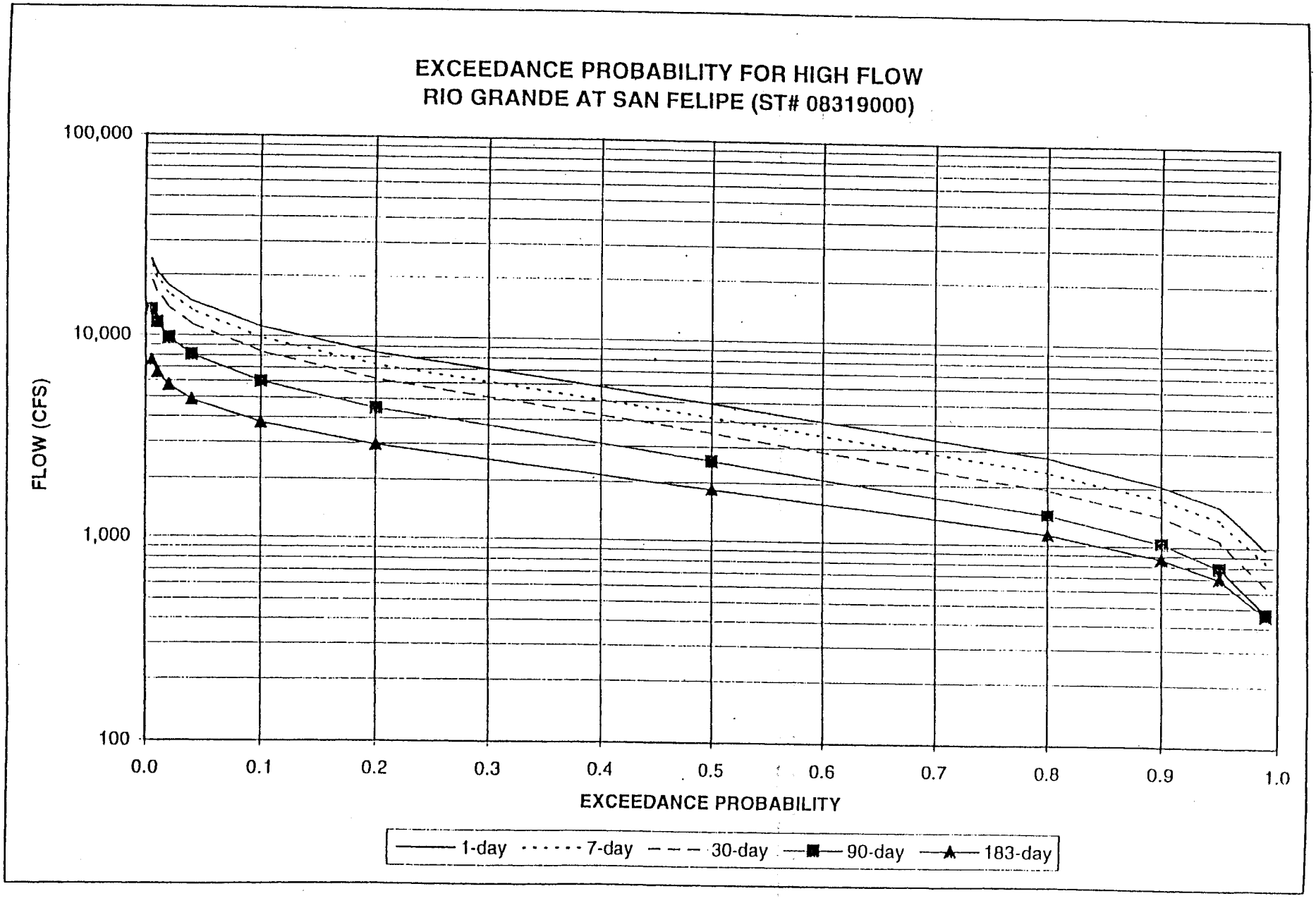

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO CHAMA NEAR ABIQUIU (ST# 08287500)
100.0
10.0
1.0
0.1
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

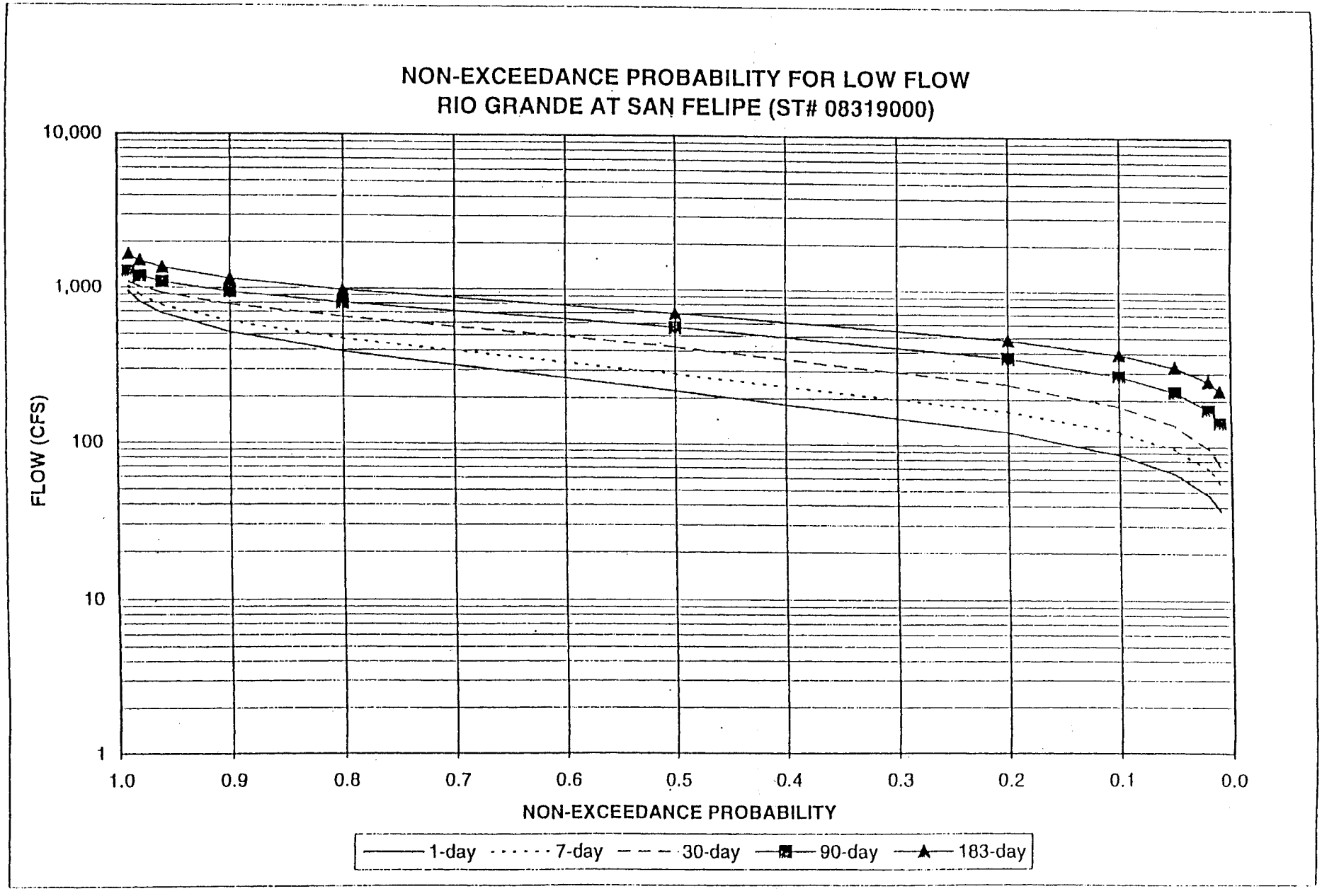

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO GRANDE AT COCHITI (ST# 08314500)
100,000
10,000
1,000
100
FLOW (CFS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

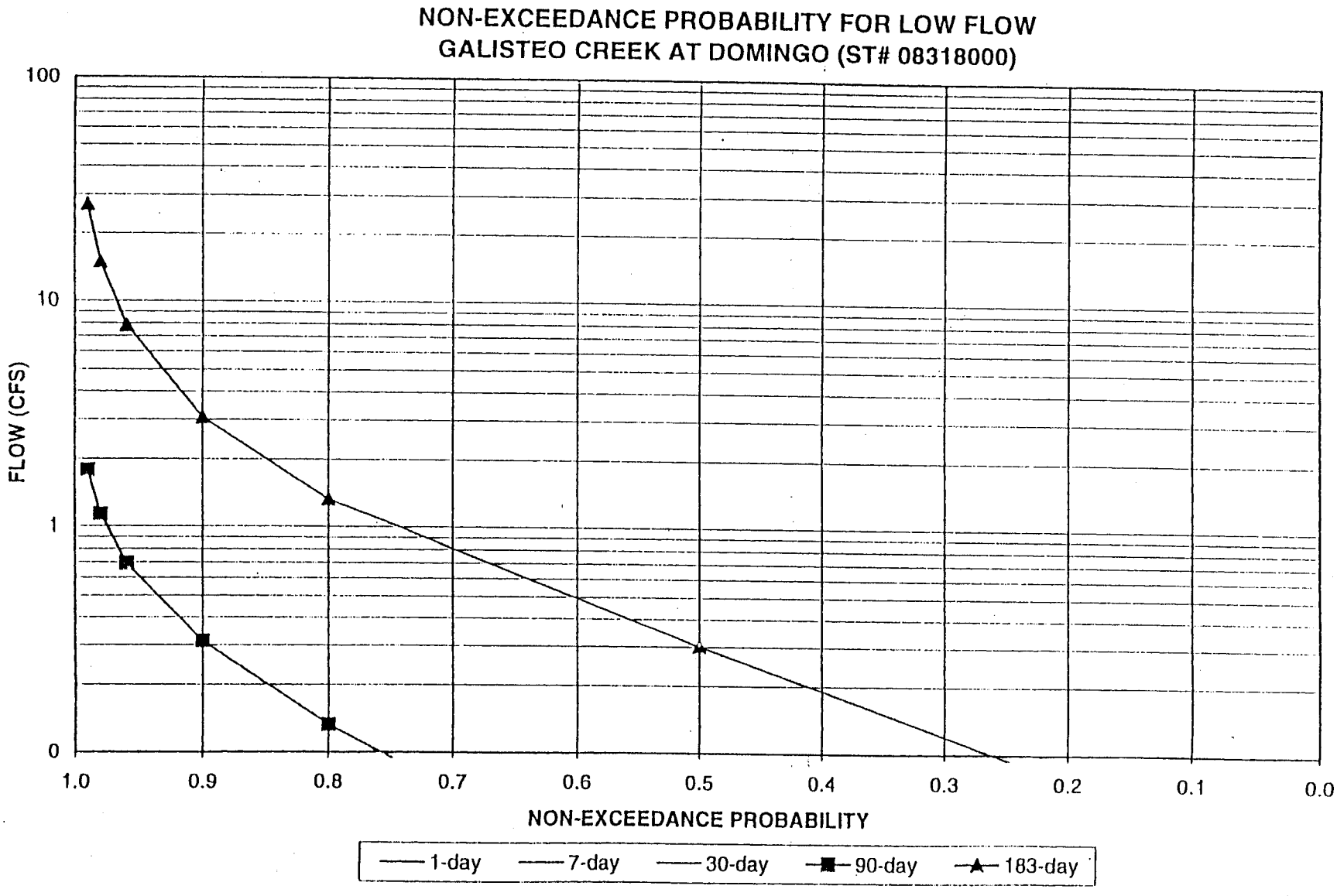

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO GRANDE AT COCHITI (ST# 08314500)
10,000
1,000
100
10
1
FLOW (CFS)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

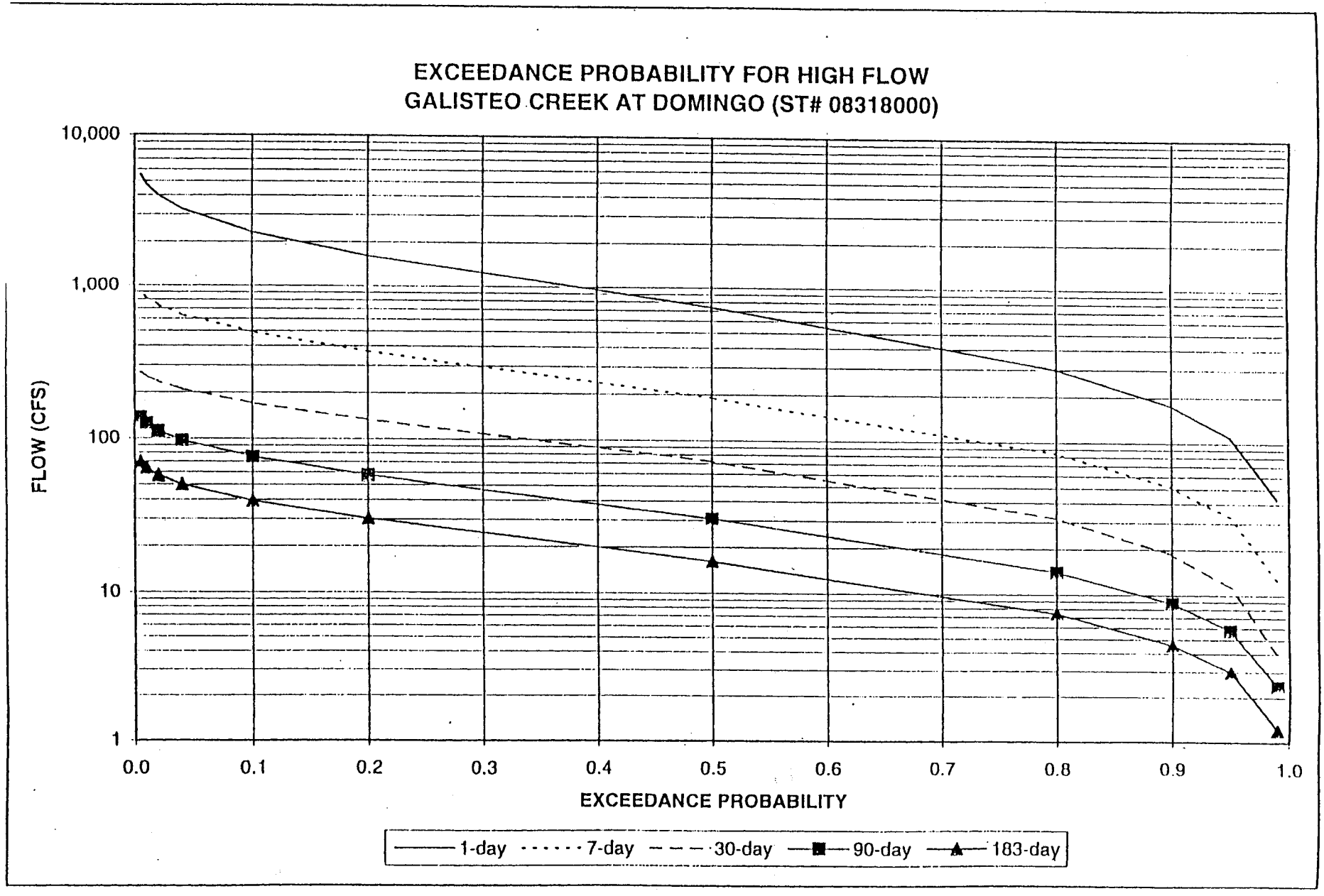

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO GRANDE BELOW COCHITI DAM (ST# 08317400)
100,000
10,000
1,000
100
FLOW (CFS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

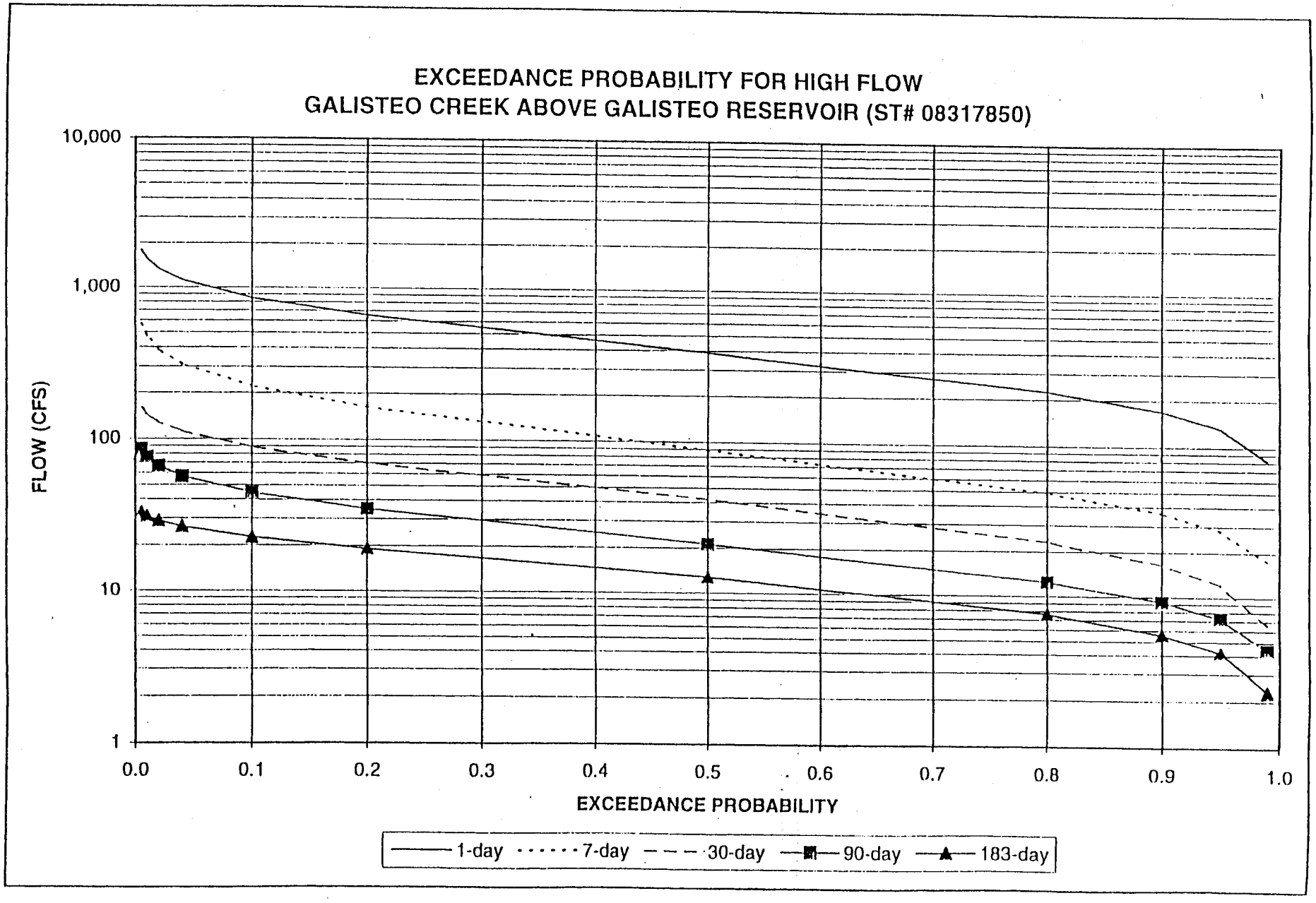

NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO GRANDE BELOW COCHITI DAM (ST# 08317400)
FLOW (CFS)
10,000.0
1,000.0
100.0
10.0
1.0
0.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day

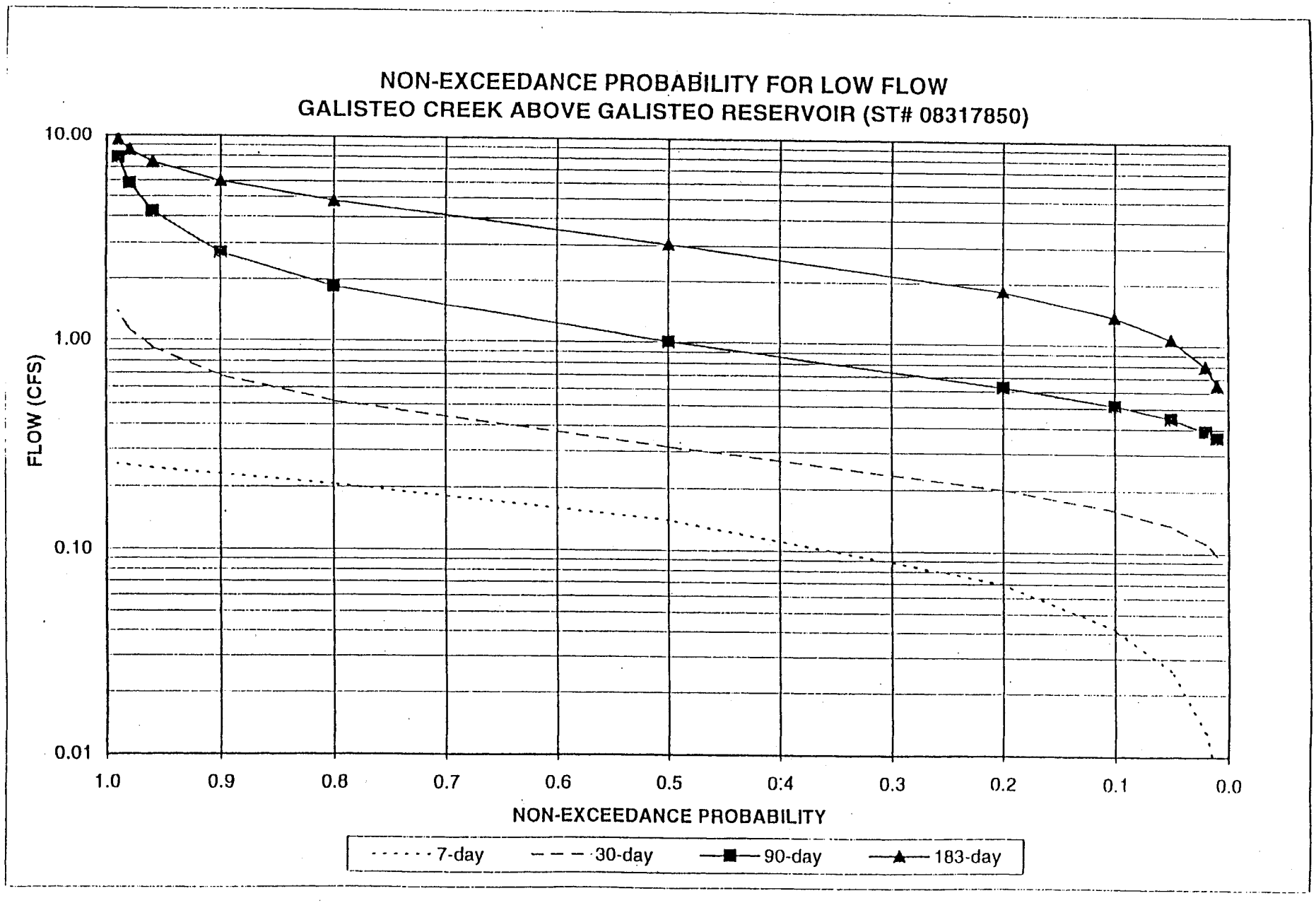

EXCEEDANCE PROBABILITY FOR HIGH FLOW
RIO GRANDE AT SAN FELIPE (ST# 08319000)
100,000
10,000
1,000
100
FLOW (CFS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day


NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
RIO GRANDE AT SAN FELIPE (ST# 08319000)
FLOW (CFS)
10,000
1,000
100
10
1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day


NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
GALISTEO CREEK AT DOMINGO (ST# 08318000)
FLOW (CFS)
100
10
1
0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day


EXCEEDANCE PROBABILITY FOR HIGH FLOW
GALISTEO CREEK AT DOMINGO (ST# 08318000)
FLOW (CFS)
10,000
1,000
100
10
1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day


EXCEEDANCE PROBABILITY FOR HIGH FLOW
GALISTEO CREEK ABOVE GALISTEO RESERVOIR (ST# 08317850)
FLOW (CFS)
10,000
1,000
100
10
1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
EXCEEDANCE PROBABILITY
1-day
7-day
30-day
90-day
183-day


NON-EXCEEDANCE PROBABILITY FOR LOW FLOW
GALISTEO CREEK ABOVE GALISTEO RESERVOIR (ST# 08317850)
FLOW (CFS)
10.00
1.00
0.10
0.01
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NON-EXCEEDANCE PROBABILITY
7-day
30-day
90-day
183-day

APPENDIX G

GLOSSARY OF TERMS USED IN DETERMINING AGRICULTURAL DEPLETIONS AND RETURN FLOWS

APPENDIX F

GLOSSARY OF TERMS USED IN DETERMINING AGRICULTURE DEPLETION AND RETURN FLOWS

Consumptive irrigation requirement(CIR). The quantity of irrigation water expressed as a depth or volume, exclusive of effective precipitation, that is consumptively used by plants or is evaporated from the soil surface in a specific period of time. It does not include incidental depletions (See definition of incidental depletions) nor does it include water requirements for leaching, frost protection, wind erosion protection or plant cooling. Such requirements are accounted for in the on-farm efficiency values. The consumptive irrigation requirements may be numerically determined by subtracting effective rainfall from consumptive use.

Consumptive use (U) or evapotranspiration (ET). The unit amount of water consumed on a given area in transpiration, building of plant tissue, and evaporated from adjacent soil, water surface, snow, or intercepted precipitation in a specific period of time. The term includes effective rainfall. Consumptive use may be expressed either in volume per unit area such as acre-inches or acre-feet per acre, or depth, such as in inches or feet. Note however, that consumptive use of water by a crop does not include incidental depletions. (See definition of incidental depletions.)

Depletion. That part of a withdrawal that has been evaporated, transpired, incorporated into crops or products, consumed by man or livestock, or otherwise removed from the water environment. It includes that portion of ground water recharge resulting form seepage or deep percolation (in connection with a water use) that is not economically recoverable in a reasonable number of years, or is not usable.

Farm delivery requirements (FDR). The quantity of water exclusive of effective rainfall, that is delivered to the farm headgate or is diverted from a source of water which originates on the farm itself, such as a well or spring, to satisfy the consumptive irrigation requirements of crops grown on a farm in specific period of time. The farm delivery requirement is computed by dividing the consumptive irrigation requirement, expressed as a depth or volume, by the on-farm irrigation efficiency, expressed as decimal.

Farm application efficiency. The ration of the low-quarter depth or volume of irrigation water added to the root zone to the depth or volume of water applied to the soil. The application efficiency does not account for the conveyance losses, which may occur between the farm headgate and the fields, which are irrigated. (See definition of on-farm irrigation efficiency.)

Incidental depletion, above-farm. Evaporation from canals and laterals that convey water from stream or reservoir to the farm headgate; transpiration by phreatophytes along canals and laterals; and evaporation of leakage from off-farm water supply pipelines.

Incidental depletions, on-farm. Evaporation from on-farm reservoirs used to store water for irrigation; evaporation from farm ditches and irrigated field during surface application; transpiration by phreatophytes along farm ditches, evaporation of leakage from irrigation water pipes; sprinkler spray evaporation and drift losses; and evaporation from wetted crop canopies (interception).

Incidental depletions, below farm. Evaporation of runoff and seepage from irrigated fields; evaporation from open drains and tail water recovery pits; and transpiration by phreatophytes along drains and below irrigation fields.

Off farm conveyance efficiency (Ec). The ratio, expresses as a percentage of the quantity of water delivered to the farm headgate by an open or closed conveyance system, to the quantity of water introduced into the conveyance system at the source or sources of supply.

On-farm distribution system. An on-farm distribution system may consist of a series of ditches or pipes, and related appurtenances, which convey the water delivered to the farm, to the appropriate field.

On-farm irrigation efficiency (Ef). The ratio, expressed as a percentage, of the average low-quarter depth or volume of irrigation water infiltrated and stored in the root zone to the depth or volume of water diverted from the farm headgate or a source of water originating on the farm itself, such as a well or spring. So that the reader may clearly understand what the low quarter means, let's assume that we have measured the change in soil moisture content in the root zone after an irrigation at 12 sampling sites on a field. The low quarter, would be the average of the three lowest values recorded. The on-farm efficiency reflects the efficiency of the on-farm distribution system and application system and includes deep percolation losses necessary as a beneficial use for the leaching excess salts from the root zone. In the design system and operation of an irrigation system and in the administration of water rights, it is the on-farm irrigation efficiency which is used in the determination of the farm delivery requirement.

Per capita use. the average quantity of water used per person or per head of livestock, per day.

Project or system irrigation efficiency (Ej). The combined efficiency of the entire irrigation system from the ultimate diversion point to the crop zone. In mathematical terms, it is the product expressed as a percentage of the on-farm efficiency (E_f) and the off-farm conveyance efficiency (E_c). When the irrigation water originates on the farm itself, such as from a well or spring, the off-farm conveyance efficiency does not apply and thus the project or system efficiency is the same as the on-farm irrigation efficiency.

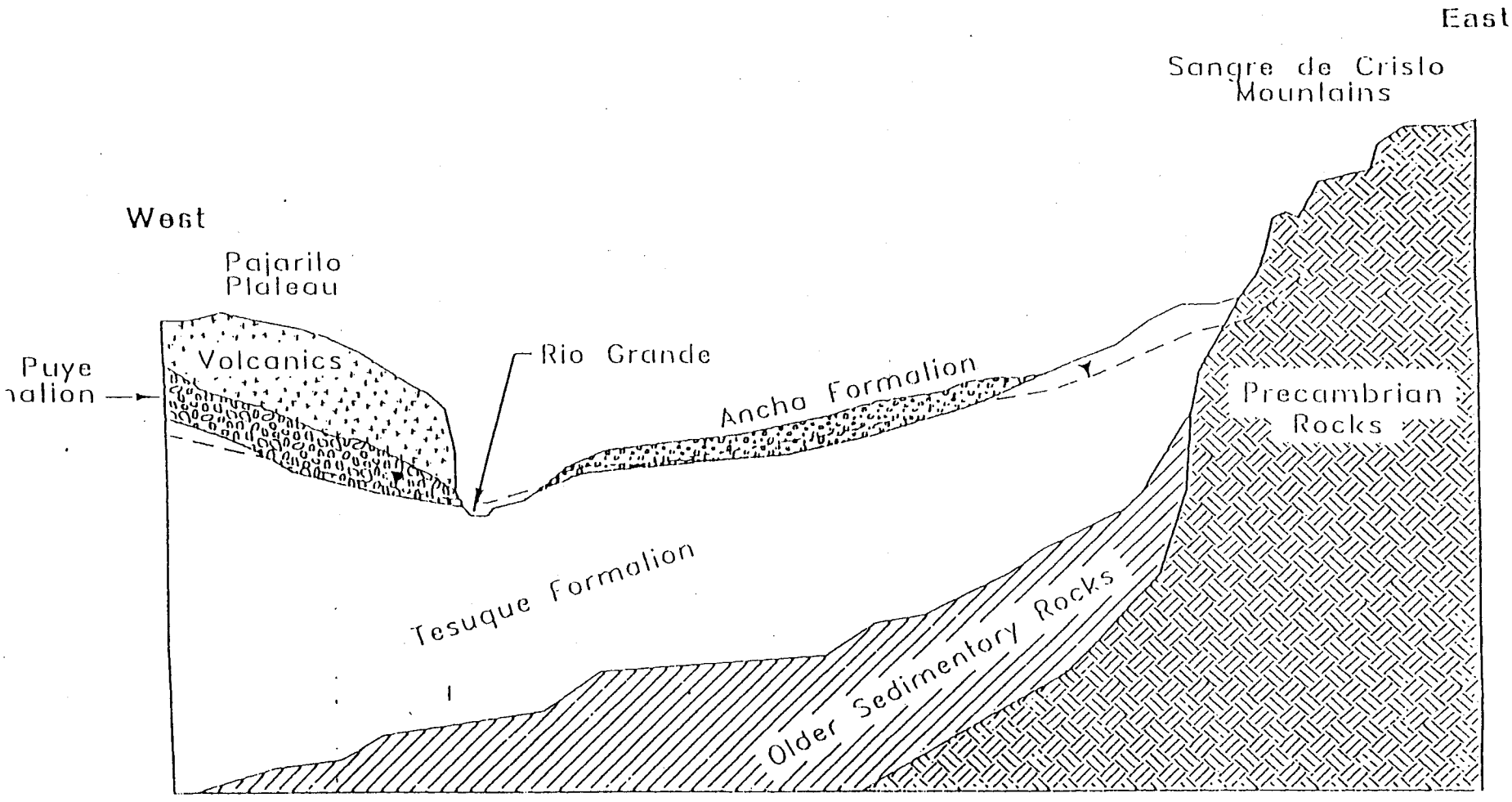
Self-supplied. Water users who withdraw water directly from a ground or surface water source.

APPENDIX H

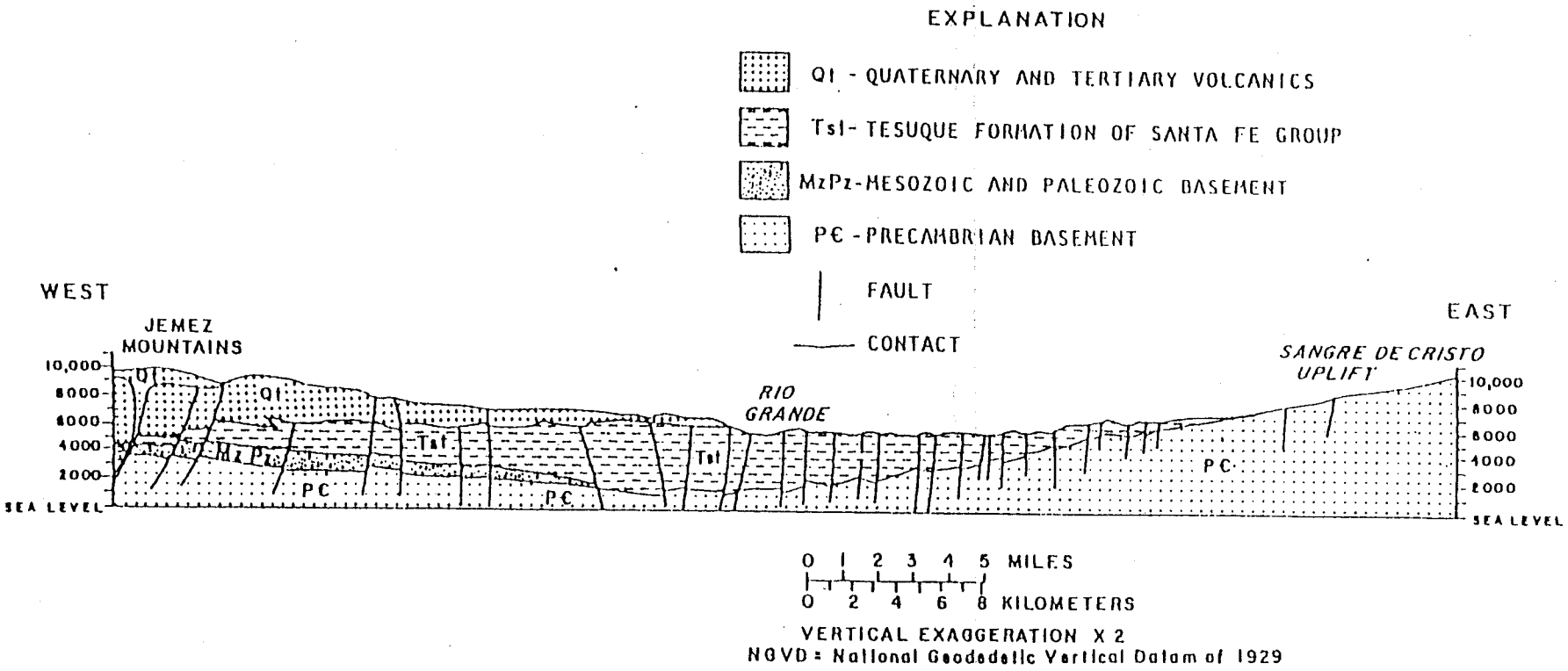
GEOLOGIC CROSS SECTIONS

Geologic Code Descriptions

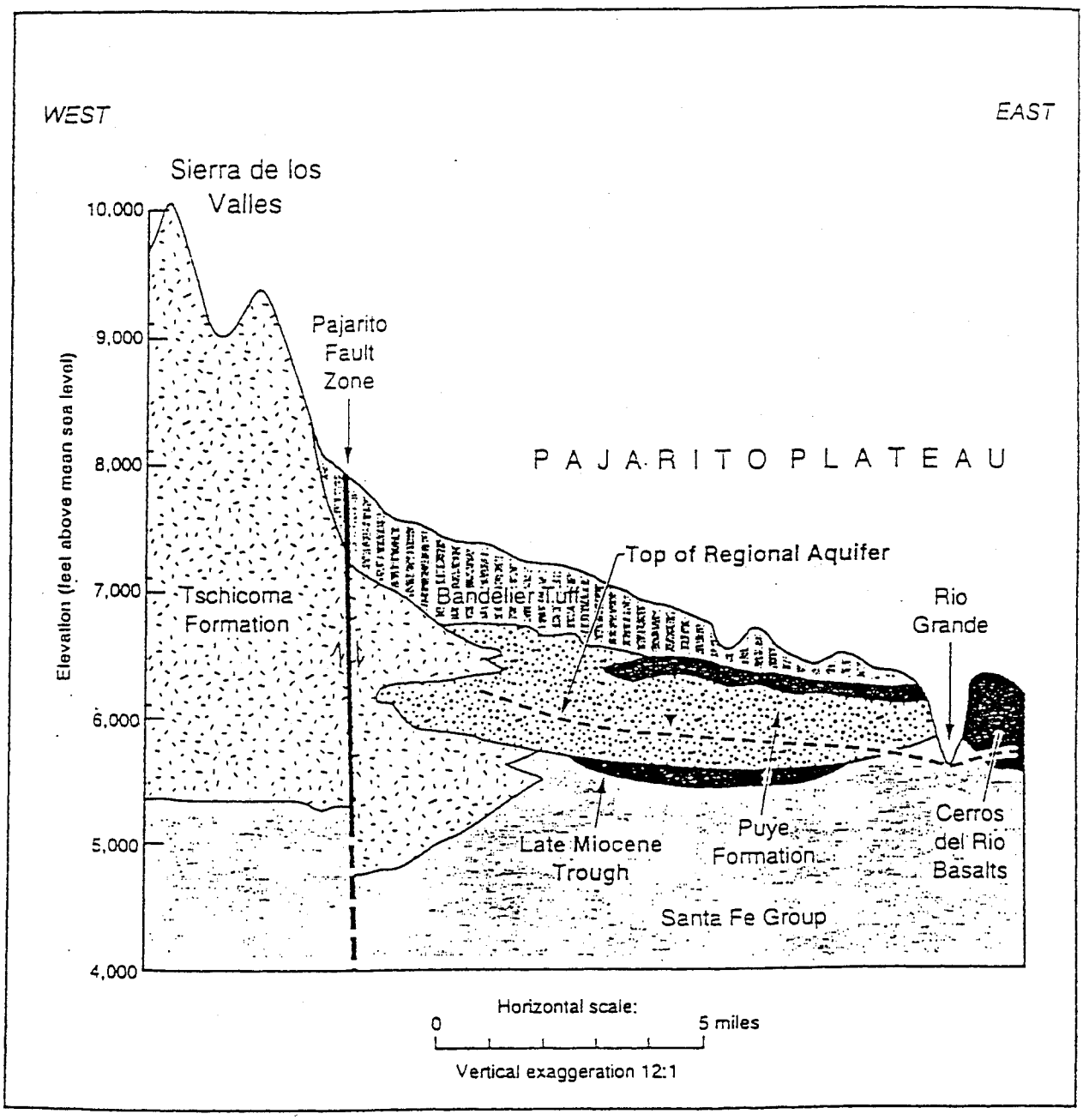
Qa	Alluvium; upper and middle Quaternary
Ql	Landslide deposits and colluvium
Qbt	Bandelier Tuff; Jemez Mountains area only
Qoa	Older alluvial deposits of upland plains and piedmont area, and calcic soils and eolian cover sediments of High Plains region
QTs	Upper Santa Fe Group
Qp	Piedmont alluvial deposits; upper and middle Tertiary
Tsf	Lower and Middle Santa Fe Group
Tnb	Basalt and andesite flows; Neogene. Includes flows interbedded with Santa Fe and Gila Groups
Tpb	Basalt and andesite flows; Pliocene
Tnr	Silicic to intermediate volcanic rocks; mainly quartz latite and rhyolite, Neogene.
Tps	Paleogene sedimentary units; includes Baca, Galisteo, El Rito and Blanco Basin Formations
Km	Mancos Shale; divided into Upper and Lower parts by Gallup Sandstone
TR	Chinle Group; Upper Triassic; includes Moenkopi Formation (Middle Triassic) at base in many areas
YXp	Middle and Lower Proterozoic plutonic rocks, undivided
Xm	Lower Proterozoic metamorphic rocks, dominantly felsic volcanic, volcanoclastic
Xp	Lower Proterozoic plutonic rocks (older than 1600 Ma)



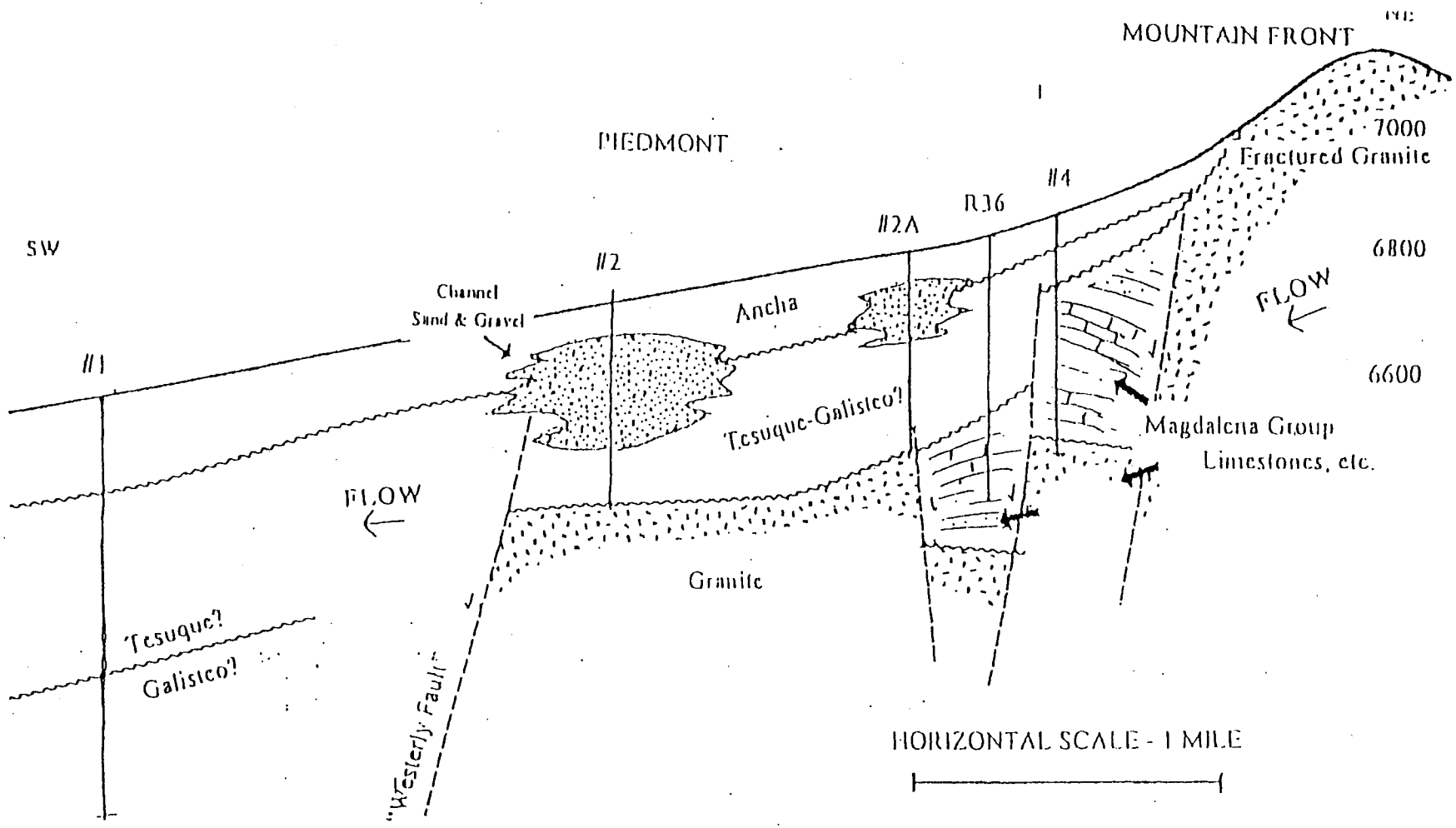
Schematic East-West Geologic Section of the Santa Fe Aquifer System
(After DBS&A, 1994)



Generalized East-West Geologic Cross Section Near Pojoaque River Basin
(After Hearne, 1985)



Geologic Cross Section Across the Pajarito Plateau
(After Los Alamos National Laboratory,
Hydrologic Workplan, May 1998)



WEST-EAST CROSS SECTION ALONG NORTH BOUNDARY OF ELDORADO

(After Frost & Associates, 1996)

APPENDIX I

SUMMARY OF REPORTED AQUIFER PARAMETERS

Summary of Reported Aquifer Parameters

Location	Reported Aquifer	Well Depth (ft)	Screen Thickness (ft)	Estimated Saturated Thickness (ft)	Transmissivity (gpd/ft)	Hydraulic Conductivity (gpd/ft2)	Specific Capacity (gpm/ft)	Storage	Reported Static DTW (ft)	Reference
T10N.R07E.7.242					11000			0.01		Jenkins, March 1980
T10N.R07E.4.112					114000			0.01	322	Geohydrology Ass., Jan. 1989
T10N.R07E.4.212					58000			0.00038	305	Geohydrology Ass., Jan. 1989
T10N.R07E.4.242		448			74000				306	Geohydrology Ass., Jan. 1989
T10N.R07E.14.343					640000			0.05		Geohydrology Ass., Jan. 1989
T10N.R07E.23.111		304			610000		165		176	Geohydrology Ass., Jan. 1989
T10N.R07E.23.113					61000			0.0038		Geohydrology Ass., Jan. 1989
T11N.R07E.20.114		360			1800				310	Geohydrology Ass., Jan. 1989
T11N.R07E.28.442		420			120				283	Geohydrology Ass., Jan. 1989
T11N.R07E.29.211		252			63000				239	Geohydrology Ass., Jan. 1989
T11N.R07E.29.242		630			4000		10.7		440	Geohydrology Ass., Jan. 1989
T11N.R07E.33.434		451			13500		36.4		317	Geohydrology Ass., Jan. 1989
T11N.R07E.33.442		501			130000		19.4	0.011	326	Geohydrology Ass., Jan. 1989
T12N.R07E.5.4	San Andres					428				AGW, March 1993
T12N.R07E.11.442	Triassic SS					0.4				AGW, March 1993
T12N.R08E.8.224	Morrison Fm					0.01				AGW, March 1993
T13N.R07E.21.222	Mancos Shale (?)					1.3				AGW, March 1993
T13N.R08E.	Gallisteo & Mesaverde Fm	360			2.7		0.0018		74	AGW, March 1993
T13N.R08E.	Lithic tuff					10				AGW, March 1993
T13N.R08E.	Mesaverde Fm					0.4				AGW, March 1993
T13N.R08E.	Mesaverde Fm					1.1				AGW, March 1993
T13N.R08E.	Mesaverde Fm					0.092				AGW, March 1993
T13N.R08E.	Mesaverde Fm and latite					40				AGW, March 1993
T13N.R08E.	Mesaverde Fm					0.09				AGW, March 1993
T13N.R08E.	Granodiorite					0.63				AGW, March 1993
T13N.R08E.	Mesaverde Fm					0.2				AGW, March 1993
T13N.R08E.	Mesaverde Fm					6.8				AGW, March 1993
T13N.R08E.11.133	Lithic tuff					0.18				AGW, March 1993
T13N.R08E.19	Breccia					45				AGW, March 1993
T13N.R08E.19	Mesaverde Fm					27				AGW, March 1993
T13N.R08E.19.134	Lithic tuff					0.18				AGW, March 1993
T13N.R08E.19.431	Mononite and baked shale					0.4				AGW, March 1993
T13N.R08E.30.424	Monzonite (?)					2				AGW, March 1993
T13N.R08E.32.332	Morrison Fm (?)					4.1				AGW, March 1993
T13N.R08E.32.332	Morrison Fm (?)					0.47				AGW, March 1993
T13N.R08E.11.433b	Mesaverde Fm					1				AGW, March 1993
T13N.R08E.19.323a	Ore body					40				AGW, March 1993
T13N.R08E.19.323c	Ore body					40				AGW, March 1993
T13N.R08E.31.322	Mancos					0.2				AGW, March 1993

Summary of Reported Aquifer Parameters

Location	Reported Aquifer	Well Depth (ft)	Screen Thickness (ft)	Estimated Saturated Thickness (ft)	Transmissivity (gpd/ft)	Hydraulic Conductivity (gpd/ft2)	Specific Capacity (gpm/ft)	Storage	Reported Static DTW (ft)	Reference
T14N.R08E.3	Ancha/alluvium				77					Tymkowych, undated
T14N.R08E.3	Ancha/alluvium				60					Tymkowych, undated
T14N.R08E.3	Ancha/alluvium				69					Tymkowych, undated
T14N.R08E.3	Ancha/alluvium				3					Tymkowych, undated
T14N.R09E.25				101				0.02		Hagerman, April 1987\
T14N.R10E.4.131	?	300			10300		13.33		45	VeneKlasen, 1987
T14N.R11E.9				85				0.015		Turner, Jan. 1985
T14N.R11E.9.4311		350			110					AGW, Jan. 1985
T15&16N.R08&09E.	Tesuque Fm				1120			0.000085		Coons, Feb. 1983
T15N.R08E.25	Ancha			200				0.05		Cooper, undated
T15N.R08E.26.2	Ancha				2200					Jenkins, July 1977
T15N.R08E.34.1321	Tertiary Intrusives	500			110				208.8	AGW, Nov. 1983
T15N.R08E.13&24				350	75					AGWC, Dec. 1985
T15N.R08E.2.21132		715		550	2800				135	Fleming, 1991
T15N.R08E.2.22213		795		527	4200				153	Fleming, 1991
T15N.R08E.26.224		-		80	2200				72	Fleming, 1991
T15N.R08E.34&35	Ancha & Espinosa			200	26					Lazarus, May 1988
T15N.R09E.1.3314		350	197.7		101000	510.9				VeneKlasen, 1987
T15N.R09E.3	Precambrian			448	10					Lazarus, Oct. 1989
T15N.R09E.25.331		345		60	37				58	Fleming, 1991
T15N.R09E.3.13		560		276	1130				234	Fleming, 1991
T15N.R10E.2	Precambrian			2.5						Hagerman, Sept. 1984
T15N.R10E.2.14314	Precambrian			180	900			0.02		VeneKlasen, & Ass., May 1986
T15N.R10E.3	Precambrian	240			74				88 07	Geohydrology Ass., Sept. 1993
T15N.R10E.3	Precambrian				1280					Geohydrology Ass., Sept. 1993
T15N.R10E.3	Precambrian	300			2500			0.00044	84.05	Geohydrology Ass., Sept. 1993
T15N.R10E.3	Precambrian	300			500			0.0013	90.54	Geohydrology Ass., Sept. 1993
T15N.R10E.5.341		374			500					VeneKlasen, 1987
T15N.R10E.5.343		324			90					VeneKlasen, 1987
T15N.R10E.8.122	Precambrian	239			13				120	VeneKlasen, 1987
T15N.R10E.8.123	Precambrian	280	161.6		50				120	VeneKlasen, 1987
T15N.R10E.8.124	Precambrian	250			16				120	VeneKlasen, 1987
T15N.R10E.8.211	Precambrian	244			1800				120	VeneKlasen, 1987
T15N.R10E.8.212		192			1300					VeneKlasen, 1987
T15N.R10E.10.4122	Precambrian				1				70	VeneKlasen, 1987
T15N.R10E.10.4122	Precambrian				550		0.86		70	VeneKlasen, 1987
T15N.R10E.11	Precambrian			200				0.01		Souder, Miller & Ass., Aug. 1993
T15N.R10E.11	Precambrian			40				0.1		Souder, Miller & Ass., Aug. 1993
T15N.R10E.12	Sangre De Cristo			126	190			0.05		Cooper, 1990

Summary of Reported Aquifer Parameters

Location	Reported Aquifer	Well Depth (ft)	Screen Thickness (ft)	Estimated Saturated Thickness (ft)	Transmissivity (gpd/ft)	Hydraulic Conductivity (gpd/ft2)	Specific Capacity (gpm/ft)	Storage	Reported Static DTW (ft)	Reference
T15N.R10E.16.42221	Precambrian	620			5.3 - 370				74	VeneKlasen, 1987
T15N.R10E.18	Ancha		40		16000				218	VeneKlasen, 1987
T15N.R10E.18		280		42	16000				218	Fleming, 1991
T15N.R10E.19		268		100	4200				168	Fleming, 1991
T15N.R10E.19	Ancha	250	44		4200				169	VeneKlasen, 1987
T15N.R10E.21.124	Gallisteo						0.18			VeneKlasen, 1987
T15N.R10E.33.434		102			12000		2.7		41.62	VeneKlasen, 1987
T15N.R10E.11&12&13	Sangre De Cristo			315	210			0.02		Cooper, July 1991
T15N.R10E.15&16					0.4 - 150					Jenkins, May 1983
T15N.R10E.2&3	Precambrian			336	170 - 1100			0.02		VeneKlasen, May 1986
T15N.R10E.8.122		239		100	13				125	Fleming, 1991
T15N.R10E.8.124		250		100	16				125	Fleming, 1991
T15N.R10E.8.213		280		100	46				130	Fleming, 1991
T15N.R11E.2,3,10,11	Sangre De Cristo			160?	195					Dawson, June 1993
T16N.R08E.	Santa Fe Group			450	400			0.018		Geohydrology Ass., May 1988
T16N.R08E.22.3423	Santa Fe Group	310		182	3500				128	Fleming, 1991
T16N.R08E.25	Santa Fe Group			215	1100					Lazarus, July 1985
T16N.R03E.27	Santa Fe Group				750 - 82000					Jenkins, 1979
T16N.R08E.28	Santa Fe Group				1200					AGWC, April 1986
T16N.R08E.26&27	Santa Fe Group		740	572	1900					Lazarus, Oct. 1987
T16N.R09E.1	Santa Fe Group			180	120					Lazarus, Aug. 1983
T16N.R09E.15	Santa Fe Group			369	1400					VeneKlasen & Ass., Feb. 1986
T16N.R09E.23	Santa Fe Group			50	1700					VeneKlasen & Ass., Dec. 1984
T16N.R09E.25.1	Santa Fe Group	280		143	300				137	Fleming, 1991
T16N.R09E.25.3	Santa Fe Group	250		108	300				142	Fleming, 1991
T16N.R09E.34.134	Santa Fe Group	760		218	1107				218	Fleming, 1991
T16N.R10E.	Santa Fe Group	250			1500			0.17	128.56	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	250			125			0.002778	78.05	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	250			300			0.00363	127.62	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	325			1500		0.47		152.94	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	250			2000			0.000322	84.24	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	250			300			0.00862	127.59	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	250			2000			0.000472	80.16	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	250			125			0.000498	91.17	Hydrotechnics, Feb. 1973
T16N.R10E.	Precambrian	300			10000		8.8		171.38	Hydrotechnics, Feb. 1973
T16N.R10E.	Precambrian	360			20		0.04		91.21	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	250			1500			0.0525	124.43	Hydrotechnics, Feb. 1973
T16N.R10E.	Precambrian	160			10000		5		114.11	Hydrotechnics, Feb. 1973
T16N.R10E.	Santa Fe Group	277			300		0.17		126.28	Hydrotechnics, Feb. 1973

Summary of Reported Aquifer Parameters

ll	Location	Reported Aquifer	Well Depth (ft)	Screen Thickness (ft)	Estimated Saturated Thickness (ft)	Transmissivity (gpd/ft)	Hydraulic Conductivity (gpd/ft2)	Specific Capacity (gpm/ft)	Storage	Reported Static DTW (ft)	Reference
3	T16N.R10E.	Santa Fe Group	250			2000			0.00267	79.86	Hydrotechnics, Feb. 1973
3	T16N.R10E.	Santa Fe Group	250			200			0.00398	94.37	Hydrotechnics, Feb. 1973
3	T16N.R10E.5	Precambrian			288	15 - 30					Lazarus and Drake, Dec. 1990
1	T16N.R10E.5.34	Precambrian				100 - 2800					Lazarus and Drake, Dec. 1991
2	T16N.R10E.7.211	Precambrian			100	300					AGWC, Oct. 1983
3	T16N.R10E.8.1	Precambrian				15					Jenkins, June 1980
1	T16N.R10E.18	Precambrian			196	53000					Lazarus, Jan. 1989
5	T16N.R10E.19	Tesuque Fm				100 - 24100					Hydrotechnics, Feb. 1973
5	T16N.R10E.20	Precambrian				3500					Cooper, Sept. 1993
7	T16N.R10E.20&29	Precambrian			200	700					VeneKlasen & Ass., Oct. 1981
3	T16N.R10E.25&26	Precambrian			157	110					Gloriela Geoscience, Aug. 1992
3	T16N.R11E.32.4	Sangre De Cristo				80					Cooper, March 1992
3	T16N.R11E.33	Sangre De Cristo			276	900					VeneKlasen & Ass., April 1993
1	T16N.R11E.8&17	Santa Fe Group			440	1120					VeneKlasen & Ass., Aug 1993
2	T16N.T08E.22					700					Fleming, 1991
3	T16N.T08E.25.144		420		213	1200				207	Fleming, 1991
1	T16N.R09E.23	Santa Fe Group			290	1400					Drake and Lazarus, March 1991
5	T17N.R09E.2	Tesuque				1100					Cooper, Sept. 1986
3	T17N.R09E.28	Tesuque		340		14000					Lazarus, Jan. 1989
7	T17N.R10E.6.334	Santa Fe Group			455	400					Lazarus, May 1991
3	T17N.R10E.9	Precambrian			408	30					Lazarus, May 1991
3	T17N.R10E.9	Precambrian							0.015		Updegraff, Aug. 1978
3	T17N.R10E.33	Precambrian			455	90					Lazarus, Aug. 1990, Souder revi
1	T18N.R09E.26	Santa Fe Group			288	5200 - 31000					Jenkins, April 1982
2	T18N.R09E.33				202				0.15		Cooper, July 1992
3	T18N.R09E.33				105				0.08		Cooper, July 1992
1	T18N.R09E.33.344	Santa Fe Group			381	2600					Drake and Lazarus, April 1992
5	T18N.R09E.18&19	Santa Fe Group				2400					Cooper, Jan. 1993
3	T18N.R09E.28,29,33	Tesuque Fm			166	100 - 150					Cooper, undated
7	T18N.R10E.7	Santa Fe Group			502.5	500					VeneKlasen & Ass., Aug. 1986
3	T18N.R10E.17.3242		743		427	30			0.01	316	LWA, Aug. 1988
3	T18N.R10E.18.214		500		353	110			0.01	147	LWA, Aug. 1988
3	T18N.R10E.18.321		649		465	110			0.01	184	LWA, Aug. 1988

APPENDIX J

SUMMARY OF GROUNDWATER LEVEL ELEVATION DATABASE

Summary of Water Level Elevation Database

Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
354438106093801	18N.07E.35.442	6636	1090	1090		1937	8	25	980	5656.0
353749106030201	16N.08E.12.31231	6423		384		1939	1	1	272	6151.0
354051105573601	17N.09E.23.334	6860		200	121TSUQ	1946	1	21	141	6719.1
350421105591701	10N.09E.21.431	6210	101	101		1946	5	15	27	6182.9
354113105561801	17N.09E.24.324	6985		255		1946	8	28	42	6943.5
353907105583701	16N.09E.03.1213	6750		60	110AVMB	1947	1	1	22	6728.0
354059105575501	17N.09E.22.444	6840			121TSUQ	1947	2	10	53	6787.0
354150105544001	17N.10E.17.333	7370	290			1947	4	1	75	7295.0
350312106025501	10N.08E.36.1112	6222	309	231	110AVMB	1947	9	15	35	6187.1
351947105435001	13N.11E.25.241	7050	700			1947	10	21	300	6750.0
350230106035401	10N.08E.35.33112	6250	188	188	110AVMB	1948	5	20	65	6184.9
350245106032701	10N.08E.35.4113	6247		270	110AVMB	1948	5	20	63	6184.1
350250106034401	10N.08E.35.312	6255			110AVMB	1948	5	20	65	6189.8
350252106035301	10N.08E.35.233	6250	270	270		1948	5	20	63	6187.1
350340106025501	10N.08E.25.3111	6261	238	238	110AVMB	1948	5	20	74	6187.4
350250106043101	10N.08E.34.4111	6267		500	110AVMB	1948	8	11	79	6188.4
350316106032801	10N.08E.35.122	6235		165	110AVMB	1948	8	11	52	6183.0
350737106004801	10N.09E.05.1113	6260	695	325	110BLSN	1948	8	11	120	6139.5
350438106093301	10N.07E.23.24313	6470		206	325MDER	1948	8	25	143	6326.9
350458106094001	10N.07E.23.21243	6470	200		325MDER	1948	8	25	138	6331.7
350515106062301	10N.08E.17.423	6330		150	110AVMB	1949	2	17	135	6194.5
350344106004601	10N.09E.29.1334	6244	200	140	110BLSN	1949	2	18	55	6188.9
353607106023401	16N.08E.24.4112	6390		296		1950	2	1	270	6120.0
350647106050301	10N.08E.03.3333	6358		180	110AVMB	1950	2	21	168	6190.3
350534106024801	10N.08E.13.1332	6274		513	110BLSN	1950	2	22	87	6187.3
350606106034401	10N.08E.11.332	6308		142	110AVMB	1950	2	22	121	6187.1
350407106084701	10N.07E.25.211	6459	324	324	325MDER	1950	4	25	122	6337.5
350414106084501	10N.07E.24.433	6450	140	140		1950	4	25	127	6323.0
350558106083601	10N.07E.12.434	6450	267			1950	4	27	228	6221.7
350645106102101	10N.07E.11.111	6530		154		1950	4	27	148	6381.6

Summary of Water Level Elevation Database

Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
350249105584001	10N.09E.34.311	6202				1950	7	3	24	6178.4
350230105542801	10N.10E.32.333	6336	158			1950	7	4	139	6196.5
350314105441501	10N.11E.35.214	6779				1950	7	5	10	6769.0
354051105575101	17N.09E.23.333	6840		108	110AVMB	1950	7	17	79	6761.3
350248106032601	10N.08E.35.233	6250	270	270		1950	8	30	63	6187.0
355457106070901	20N.08E.32.343	5538	40	40		1950	9	11	18	5519.7
355324106024801	19N.08E.12.411	5745		80		1950	9	12	18	5727.0
355331106025501	19N.08E.12.321	5730		51.7		1950	9	12	3	5726.8
355331106062001	19N.08E.09.311	5600		35		1950	9	12	28	5572.0
355358106010001	19N.09E.05.333	5860		50		1950	9	13	12	5847.9
355353105581701	19N.09E.10.211	6090		144		1950	9	14	47	6042.9
355400105584301	19N.09E.03.334	6080		31		1950	9	14	24	6055.8
355950105554501	20N.09E.01.224	6140		44		1950	9	15	37	6103.0
355350106051001	19N.08E.10.114	5640		32		1950	9	25	28	5612.0
354849105543101	18N.10E.05.330	6934	110	110		1950	9	26	60	6874.0
355913106002901	20N.09E.05.433	5790		16		1950	9	28	10	5779.9
355411106074001	19N.08E.06.4224	5523	40	40	110AVMB	1950	9	29	7	5516.1
355445106002701	19N.09E.05.211	5965		60		1950	9	29	30	5935.0
354445106032101	18N.08E.35.420	6480	900			1950	10	13	896	5584.0
354536106061801	18N.08E.28.310	6130	1500			1950	10	13	1494	4636.0
354627105560601	18N.09E.24.410	6718		132		1950	10	16	48	6670.4
355321106011301	19N.09E.07.423	5845		85		1950	10	17	16	5829.3
355339106055701	19N.08E.09.144	5600		60		1950	10	17	41	5558.7
355352106011201	19N.09E.07.2214	5830		54	110AVMB	1950	10	19	6	5823.7
355445105584201	19N.09E.03.112	6075		75		1950	10	19	26	6049.0
355353105583401	19N.09E.10.121	6065		117		1950	10	20	59	6006.2
353827106010601	16N.09E.06.4424	6558		327	121TSUQ	1950	11	30	222	6336.0
354133105571501	17N.09E.23.231	6910		165		1950	12	8	53	6857.1
355736106011101	20N.09E.18.4421	5801		200	121TSUQ	1950	12	28	49	5752.5
365444105484701	31N.11E.19.140	7634	365	365	000EXRV	1951	1	1	311	7323.0

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Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
354005106013501	17N.09E.30.43333	6575		440		1951	2	28	412	6163.0
354039105560301	17N.09E.25.232	7060		85		1951	4	1	40	7020.0
354135105561701	17N.09E.24.124	7020	100	100		1951	4	1	66	6954.0
355228105570501	19N.09E.14.414	6185		48		1951	4	20	39	6145.6
353449106041601	16N.08E.35.11111	6215				1951	7	4	86	6128.6
353719105580201	16N.09E.15.22321	6830		200		1951	7	6	188	6642.4
354019105550701	17N.10E.30.413	7310	238	238		1951	7	17	209	7101.2
354052105582101	17N.09E.27.211	6836	197	197	121TSUQ	1951	7	17	57	6779.0
354026105563401	17N.09E.25.312	7020		106		1951	7	18	40	6980.0
353941105555601	17N.09E.36.243	7090				1951	7	19	97	6992.6
353942105560401	17N.09E.36.234	7090		180		1951	7	19	101	6989.0
353742106024501	16N.08E.12.324	6430		300		1951	7	23	290	6139.8
353850106001801	16N.09E.05.23423	6630		154	112ANCH	1951	7	23	90	6540.5
353843106025001	16N.08E.01.321	6445	380	380		1951	7	24	179	6265.8
353855106061501	16N.08E.04.13214	6268		174		1951	7	24	135	6133.3
353922106045301	17N.08E.34.342	6350	310	185		1951	7	24	173	6177.0
354018105590701	17N.09E.28.423	6718	60	60	110AVMB	1951	7	24	6	6712.0
354019105590801	17N.09E.28.423 B	6718	60	58	110AVMB	1951	7	24	6	6712.0
354139105563501	17N.09E.24.114	6990		75		1951	7	27	70	6920.4
354034105585201	17N.09E.27.133	6750		38		1951	7	28	25	6725.2
354051105583901	17N.09E.22.343	6870		200	121TSUQ	1951	7	28	144	6725.6
354135105562401	17N.09E.24.123	7055	150	150		1951	7	28	82	6972.6
353544106030801	16N.08E.24.333	6322	225	225		1951	8	1	171	6150.7
354113105575701	17N.09E.22.424	6850		30		1951	8	3	28	6822.3
353108106042001	15N.08E.22.24221	6215		96	112ANCH	1951	8	7	85	6130.0
353218106073201	15N.08E.07.24122	6035		40		1951	8	7	36	5999.1
353220106070701	15N.08E.08.3414	6030		190		1951	8	7	29	6001.0
353257106042101	15N.08E.10.224	6195		55		1951	8	7	51	6143.5
353637106031701	16N.08E.14.444	6310		181	112ANCH	1951	8	8	158	6152.5
352924106050401	15N.08E.34.1233	6240				1951	8	9	243	5996.7

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Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
353536105595601	16N.09E.28.113	6560				1951	8	10	180	6380.1
353750106042201	16N.08E.10.424	6365	248	248		1951	8	13	208	6157.0
353803106031001	16N.08E.12.13114	6423		400	121TSUQ	1951	8	13	262	6160.5
353651106025401	16N.08E.13.323	6362		235		1951	8	14	212	6149.7
353703106022101	16N.08E.13.243	6405			121TSUQ	1951	8	14	252	6152.7
352936106013401	15N.09E.31.2112	6233				1951	8	15	60	6173.3
354041105581301	17N.09E.27.232	6810	740	740	121TSUQ	1951	8	22	46	6763.6
353840105565601	16N.09E.02.42141	6920		223	121TSUQ	1951	8	24	192	6727.7
354025105555501	17N.09E.25.421	7122		255		1951	8	24	70	7051.7
354038105580301	17N.09E.27.241	6845		140		1951	8	24	100	6744.8
354033105583701	17N.09E.27.143	6767		39	121TSUQ	1951	9	11	18	6749.0
354135105561702	17N.09E.24.124A	7020	180	180		1951	9	11	71	6949.2
354442105550001	18N.10E.31.414	6955	140	140		1951	10	3	31	6923.8
353947105590801	17N.09E.33.241	6730		40		1951	12	27	32	6698.1
354008105591701	17N.09E.28.434	6710				1951	12	27	8	6702.3
354013105580601	17N.09E.27.441	6845		989	121TSUQ	1951	12	27	102	6742.7
353204106062801	15N.08E.17.2232	6060		58		1952	1	2	9	6051.4
353840105580401	16N.09E.03.421	6780				1952	1	2	104	6676.4
353850105584301	16N.09E.03.134	6742	220	220		1952	1	2	180	6562.0
353922105570801	17N.09E.35.432	6945		230		1952	1	2	199	6746.1
353118106013101	15N.09E.19.211	6325				1952	1	6	125	6200.0
353137105591701	15N.09E.16.4143	6419		70		1952	1	6	54	6365.1
353205105574501	15N.09E.14.11413	6527		74	112ANCH	1952	1	6	58	6469.3
353148106010101	15N.09E.17.1333	6348		240		1952	1	11	157	6191.2
353302105590301	15N.09E.09.2223	6482		190		1952	1	12	113	6368.9
353328106025301	15N.08E.01.321	6280		200		1952	1	12	128	6151.6
353347106020101	15N.09E.06.1134	6385				1952	1	12	195	6189.6
353526106001101	16N.09E.29.241	6538				1952	1	12	208	6330.1
353736106030301	16N.08E.12.332	6415		340		1952	1	14	261	6154.2
353702105590801	16N.09E.16.2433	6655				1952	1	16	163	6492.3

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Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
353809106002101	16N.09E.08.21432	6580				1952	1	16	63	6517.4
354736105552801	18N.10E.18.132	6858	350		121TSUQ	1952	2	7	125	6732.6
354800105551601	18N.10E.07.342	6910		315	121TSUQ	1952	2	7	229	6681.3
353156106021001	15N.08E.13.2424	6320		190		1952	2	13	164	6156.4
354038105572101	17N.09E.26.142	6910	316	311		1952	7	18	155	6755.0
354046105570601	17N.09E.26.214	6938		250	110AVMB	1952	11	11	115	6822.6
353825106000601	16N.09E.05.44234	6615		159	112ANCH	1952	11	13	90	6525.0
354419106022601	17N.08E.01.2124	6540		1500		1952	11	20	395	6145.1
354427106060601	18N.08E.33.14312	6180		400		1952	11	20	339	5841.4
360950105404001	22N.12E.05.442	7700		140	112SNTF	1953	1	1	5	7695.0
354011105591102	17N.09E.28.423 A	6716			110AVMB	1953	1	15	5	6711.4
365644105363501	01S.74W.24.244	7628		270	110AVMB	1955	6	4	193	7435.0
364645105362501	29N.12E.03.244	7495	168	168	110AVMB	1955	7	7	35	7459.7
365458105342301	01S.73W.32.422	7636		505	110AVMB	1955	7	10	140	7496.4
365458105345501	01S.73W.32.322	7622		490	110AVMB	1955	7	10	131	7491.3
365524105342301	01S.73W.32.222	7651		525	110AVMB	1955	7	10	185	7465.7
365524105345601	01S.73W.32.122	7636		535	110AVMB	1955	7	10	166	7470.2
365535105374001	01S.74W.26.442	7585		256	110AVMB	1955	7	10	233	7352.1
365551105342301	01S.73W.29.422	7672		500	110AVMB	1955	7	10	210	7462.4
365551105345401	01S.73W.29.322	7652			110AVMB	1955	7	10	186	7465.6
365642105352801	01S.73W.19.422	7659		446	110AVMB	1955	7	11	201	7457.6
365644105363502	01S.74W.24.244	7628		475	110AVMB	1955	7	12	198	7430.1
365708105352801	01S.73W.19.222	7665		420	110AVMB	1955	7	12	203	7462.0
365142105364801	30N.12E.01.342	7515	146	146	110AVMB	1955	7	17	22	7493.2
365159105364801	30N.12E.01.144	7510	155			1955	7	17	18	7492.3
365305105380201	31N.12E.35.123	7544	334		110AVMB	1955	7	17	181	7362.9
365225105382501	31N.12E.34.444	7542			110AVMB	1955	7	18	116	7426.1
365408105334201	02S.73W.04.234	7645		149	110AVMB	1955	7	18	135	7510.1
365414105340401	02S.73W.04.141	7610			110AVMB	1955	7	18	100	7509.7
365710105320001	01S.73W.14.334	7818		160	110AVMB	1955	7	18	111	7706.9

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Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
364943105402201	30N.12E.21.111	7413.8	222	222	110AVMB	1955	7	25	91	7323.2
365029105393901	30N.12E.16.223	7436	127	127	112SNTF	1955	7	25	30	7406.3
365039105371001	30N.12E.12.334	7525		29	110AVMB	1955	7	26	14	7510.9
364653105345101	29N.13E.05.132	7861		148	110AVMB	1955	7	27	60	7801.4
364653105345501	29N.13E.05.131	7860	83	78	110AVMB	1955	7	27	65	7794.9
364942105375401	30N.12E.23.122	7511.7	267	251	110AVMB	1955	7	27	167	7344.6
364705105344601	29N.13E.05.121	7898			110AVMB	1955	7	28	45	7852.9
364706105372001	29N.12E.02.222	7535	42		110AVMB	1955	7	28	38	7497.3
364857105351101	30N.13E.19.444	7731	84		110AVMB	1955	7	28	30	7700.9
364520105361601	29N.12E.13.211	7596	126		110AVMB	1955	7	30	80	7516.2
364527105364801	29N.12E.12.344	7550		125		1955	7	30	82	7467.5
364639105374501	29N.12E.02.411	7510	40		110AVMB	1955	7	30	36	7474.0
364757105372801	30N.12E.35.221	7516	346	310	110AVMB	1955	8	1	32	7484.1
364443105581001	29N.09E.15.300	8520	40		120CRSN	1955	8	2	32	8488.0
364404105354301	29N.13E.19.322	7658		300	110AVMB	1955	8	23	157	7501.1
364427105354401	29N.13E.19.122	7667		170	110AVMB	1955	8	23	155	7511.8
364527105360001	29N.13E.07.443	7618	88		110AVMB	1955	8	23	80	7537.5
364519105353501	29N.13E.18.211	7670	195		110AVMB	1955	8	25	177	7493.2
364918105361301	30N.12E.24.422	7627	417	417	110AVMB	1955	8	30	71	7555.7
365339105373801	02S.74W.11.222	7559		435	110AVMB	1955	8	31	180	7379.2
364358105354702	29N.13E.19.320A	7651		300	110AVMB	1955	9	2	157	7494.3
350436106081901	10N.07E.24.224	6428	264	264	110AVMB	1955	9	15	135	6293.0
355324106053301	19N.08E.09.423	5660				1955	10	25	43	5617.4
355337106054801	19N.08E.09.233	5610		54		1955	10	26	18	5592.0
355337106063701	19N.08E.08.42121	5570		70	110AVMB	1955	10	26	17	5553.5
350308105593501	10N.09E.33.11213	6240	200	200	110BLSN	1955	11	4	64	6175.8
365250105350001	02S.73W.08.344	7555		80	110AVMB	1955	11	7	51	7504.1
365520105400501	01S.73W.33.212	7675		212	110AVMB	1955	11	7	170	7505.2
365340105363301	02S.74W.12.222	7546		250	110AVMB	1955	11	8	47	7498.8
364545105515101	29N.10E.10.311	7769		85	000EXRV	1956	1	9	76	7693.1

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Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
365705105374001	01S.74W.23.222	7596		430	110AVMB	1956	2	2	271	7324.8
364520105365501	29N.12E.13.121	7595		93	110AVMB	1956	2	20	87	7508.3
364400105355001	29N.13E.19.231	7660		180	110AVMB	1956	2	22	159	7501.1
365230105350001	02S.73W.17.142	7560			110AVMB	1956	2	22	61	7499.5
350556106113201	10N.07E.09.444	6583	340	291	325MDER	1956	9	12	263	6320.0
350454106082001	11N.07E.24.224	6465	180	180		1957			172	6293.0
353407106115001	16N.07E.33.442	6175	790			1956	12	6	527	5648.0
365359105382301	02S.74W.02.312	7542		476	110AVMB	1957	2	15	210	7332.4
353948106020201	17N.09E.31.131	6565				1957	4	23	55	6510.3
353827105574001	16N.09E.02.33241	6825		185	121TSUQ	1957	8	12	144	6681.4
353845105574101	16N.09E.02.31212	6835		393	121TSUQ	1957	8	13	140	6694.6
353908105573201	16N.09E.02.121	6890		291	121TSUQ	1957	8	14	179	6710.8
353735105581201	16N.09E.10.42114	6820		244	112ANCH	1957	8	16	193	6627.5
353933105585101	17N.09E.34.311	6765		61.3	112ANCH	1957	8	16	45	6719.6
353845105555901	16N.09E.01.2413	7042		290	121TSUQ	1957	8	17	36	7005.9
353923105591501	17N.09E.33.43212	6730		251	112ANCH	1957	8	17	198	6532.5
353353106034301	15N.08E.02.21132	6261		715		1957	8	29	157	6104.0
353933105575601	17N.09E.34.422	6865		820	110AVMB	1957	12	11	143	6722.5
355457106090101	20N.07E.36.400	5790	225			1958	4	1	132	5658.0
353445106043701	16N.08E.34.21234	6210		117		1958	5	1	75	6135.5
353905105591101	17N.09E.33.443	6710			112ANCH	1958	7	24	208	6502.0
353851106001601	16N.09E.05.23422	6630		213	112ANCH	1958	7	25	100	6529.7
353838105564301	16N.09E.01.31121	6945		290	121TSUQ	1958	8	26	155	6790.4
354220105580301	17N.09E.15.2432	7055			121TSUQ	1958	8	26	292	6763.2
355318106031001	19N.08E.12.331	5730		49		1958	9	13	18	5711.6
354404105582401	17N.09E.03.2331	7070		550		1959	1	1	360	6710.0
355235106002701	19N.09E.17.411	5930	87	87		1959	1	1	28	5902.0
353812105573601	16N.09E.11.112	6850		227	112ANCH	1959	3	2	187	6662.6
353924106004101	17N.09E.32.32322	6608		80	110AVMB	1959	3	3	26	6582.1
353924106010801	17N.09E.31.44221	6580		321	121TSUQ	1959	3	3	274	6305.8

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Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
353927106002902	17N.09E.32.41132	6625		350	110AVMB	1959	3	3	25	6599.5
353931106003701	17N.09E.32.14434	6603		69	110AVMB	1959	3	3	18	6584.6
353918105563101	17N.09E.36.323	7020		240	121TSUQ	1959	3	23	152	6867.6
353936105552701	17N.10E.31.134	7135		150	121TSUQ	1959	3	23	48	7087.3
354032105562001	17N.09E.25.144	7050		50		1959	3	23	25	7025.1
353842105584301	16N.09E.03.312	6700		230	121TSUQ	1959	3	24	217	6483.3
353752105593501	16N.09E.09.321	6657		165	112ANCH	1959	3	26	143	6513.6
353829105580401	16N.09E.03.441	6800		165	121TSUQ	1959	3	26	135	6664.7
353852105564001	16N.09E.01.11344	6945		234	121TSUQ	1959	3	26	149	6796.2
353829106024201	16N.08E.01.34223	6455		325	112ANCH	1959	3	27	292	6162.6
353838106002001	16N.09E.05.41212	6610		120	112ANCH	1959	3	27	75	6535.1
353855106022501	16N.08E.01.232	6480		270	112ANCH	1959	3	27	20	6459.8
353725106064401	16N.08E.17.2122	6218		244	112ANCH	1959	8	4	71	6147.4
353337106075001	15N.08E.06.23322	5910		198	112SNTF	1959	10	24	32	5878.0
353632106030201	16N.08E.24.112	6320			112ANCH	1961	2	8	194	6126.0
352846105593301	15N.09E.33.3443	6325	200		121TSUQ	1961	2	16	83	6241.8
352847105592301	15N.09E.33.433	6325		110		1961	2	16	83	6241.8
353022106030201	15N.08E.25.1141	6185		86	112ANCH	1961	2	16	66	6118.8
354555105564501	18N.09E.25.13111	6865		269	121TSUQ	1961	2	17	212	6653.4
350947106120301	11N.07E.21.144	6802	160	160	110BLSN	1962	7	2	108	6694.0
363210105401401	27N.12E.33.123	6780		18		1963	1	1	16	6764.0
355322106045301	19N.08E.10.32434	5700		150	121TSUQ	1964	1	7	60	5640.0
355203106001301	19N.09E.20.223	5970	135	135		1964	1	13	16	5954.2
355332105592701	19N.09E.09.1444	5940		75	110AVMB	1964	1	14	12	5928.5
355350106003001	19N.09E.08.2131	5870		78	110AVMB	1964	1	14	4	5865.5
355417106003001	19N.09E.05.4113	5905		150	121TSUQ	1964	1	14	46	5859.4
353636106021001	16N.08E.13.444	6395		337	121TSUQ	1964	2	19	255	6140.0
354057105594301	17N.09E.21.4344	6865		380		1967	1	1	320	6545.0
354117105592201	17N.09E.21.4114	6880	401	399		1967	7	20	367	6513.0
353853106021701	16N.08E.01.24142	6482		337		1967	8	15	308	6174.0

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Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
353718105592301	16N.09E.15.223	6800	253	253		1967	8	29	240	6560.0
354831105575201	18N.09E.10.22444	6425				1967	10	31	84	6340.7
354934105583601	18N.09E.03.121	6310	128	128	110AVMB	1967	10	31	75	6234.8
354423105560201	17N.09E.01.2122	7070		225		1967	11	1	185	6885.3
354646105550001	18N.10E.19.2321	7040				1967	11	1	105	6934.9
354655105563901	18N.09E.24.1114	6617		118		1967	11	1	53	6564.4
354738105553901	18N.10E.18.13112	6820		211	110AVMB	1967	11	1	94	6725.7
355437106010001	19N.09E.05.113	5915	370	216	110AVMB	1967	11	3	68	5846.7
355509106005501	20N.09E.32.31233	5980		212	121TSUQ	1967	11	3	150	5830.5
355204106003901	19N.09E.20.1241	5990		112	121TSUQ	1967	11	6	66	5924.5
355102105593901	19N.09E.28.1413	6105		78		1967	11	7	58	6046.5
355148106000601	19N.09E.20.2443	5995				1967	11	7	11	5983.9
355249106034701	19N.08E.14.1424	5780		180		1967	11	8	113	5666.7
355345105580001	19N.09E.10.22344	6110		300	121TSUQ	1967	11	8	77	6033.5
355420105585401	19N.09E.03.31113	6045		140		1967	11	8	45	6000.5
354928105552901	18N.10E.06.1142	6720		145		1967	11	9	42	6678.4
355331106002301	19N.09E.08.233	5950		115		1967	11	9	63	5887.1
355353105582601	19N.09E.10.122	6060		400		1967	11	9	35	6024.7
355407105583301	19N.09E.03.34123	6080		220		1967	11	9	56	6023.8
354933105552501	18N.10E.06.12113	6760		105		1967	11	10	51	6708.8
354910105544001	18N.10E.06.2444	6865		127		1967	11	13	39	6826.0
354917105545001	18N.10E.06.24312	6850		22	110AVMB	1967	11	13	10	6840.0
355452105562201	20N.09E.36.344	6494	244		110AVMB	1967	11	13	195	6298.8
354527105582101	18N.09E.27.431	6830		360		1967	11	14	206	6624.1
353757106022501	16N.08E.12.23422	6460		354		1968	5	11	299	6161.0
353735106013501	16N.09E.07.43131	6485		411		1968	5	18	335	6150.0
355649106010701	20N.09E.19.4244	5820	212			1968	8	27	97	5722.5
355755106014701	20N.09E.18.143	5730		90		1968	8	27	21	5709.0
355907105595801	20N.09E.09.111	5900		157		1968	8	27	38	5862.4
355952105592001	20N.09E.04.213	5845		75		1968	9	3	5	5840.1

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Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
355914106015601	20N.09E.06.334	5720		78		1968	9	4	37	5683.1
355930106005201	20N.09E.05.312	5800		54		1968	9	4	51	5749.3
355746106010901	20N.09E.18.422	5770		180		1968	9	11	46	5724.2
352430105555401	14N.09E.25.441	6142		254		1969	3	1	31	6110.7
354415105574601	17N.09E.02.11324	7125		509		1969	3	20	419	6706.0
354227105580001	17N.09E.15.2421	7060		360	121TSUQ	1969	5	6	300	6760.0
353456106060301	16N.08E.29.440	6140	105	105		1969	11	18	55	6085.0
355600105005901	20N.09E.29.31314	5910		185		1970	2	27	90	5820.0
355738106001801	20N.09E.17.400	5854				1970	2	27	1	5852.9
353258105575201	15N.09E.11.11311	6580		244		1970	4	6	116	6463.6
353303105590801	15N.09E.09.221	6482				1970	5	5	115	6367.2
353323106012401	15N.09E.06.414	6360				1970	5	5	68	6291.8
353327105564801	15N.09E.02.4224	6670		160		1970	5	5	146	6523.7
355844106003401	20N.09E.08.000	5815		153		1970	5	26	59	5755.7
355835105592101	20N.09E.09.41312	5875		24		1970	5	28	11	5864.1
353257105492801	15N.10E.12.222	6960	62	62		1970	7	13	32	6928.0
355218106005601	19N.09E.17.330	5925		109		1970	7	21	38	5886.6
354002105592101	17N.09E.33.2112	6710		290	110AVMB	1970	12	29	193	6516.8
354023105584701	17N.09E.27.3121	6755		64	121TSUQ	1970	12	29	44	6710.7
353315105565301	15N.09E.02.4423	6660		925		1971	1	1	240	6420.0
354400105593301	17N.09E.04.1443	6975		700		1971	1	1	620	6355.0
354021105585901	17N.09E.28.42223	6730		50	110AVMB	1971	1	5	21	6709.4
354018105584801	17N.09E.27.31344	6762		68	121TSUQ	1971	1	6	55	6706.7
354022105584701	17N.09E.27.31413	6760		809	121TSUQ	1971	1	11	73	6686.5
354013105590801	17N.09E.28.441	6725		85		1971	1	12	25	6700.3
353613106061301	16N.08E.21.134	6265	920		112SNTF	1971	2	15	10	6255.0
353918106003302	17N.09E.32.324 A	6610		80	110AVMB	1971	2	17	40	6570.2
355307106072901	19N.08E.18.2222	5522		93		1971	3	5	26	5496.4
354200105593301	17N.09E.16.342	6915				1971	4	30	494	6421.2
353752106014701	16N.09E.07.32121	6495		428		1971	8	12	331	6164.0

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						year	month	day		
354033105582901	17N.09E.27.144	6782		88		1971	8	18	28	6754.0
350324105435201	10N.11E.26.4444	6850		110	231DCKM	1971	9	27	70	6779.7
350921106125901	11N.07E.29.211	6807	252	252		1972			238	6568.9
355120105595201	19N.09E.21.34343	6060		100	112ANCH	1972	1	26	51	6008.7
354512105565801	18N.09E.35.2214	6975	308	308	121TSUQ	1972	1	27	260	6715.0
352805106035201	14N.08E.02.3243	6120		115	110AVMB	1972	2	9	86	6033.6
353810106021301	16N.08E.12.22432	6482		350		1972	2	29	313	6168.8
354844106080101	18N.08E.06.3444	5860		1200	121TSUQ	1972	5	8	75	5784.6
354002105555801	17N.09E.36.2211	7120		240		1972	5	16	71	7048.7
350831105471201	11N.11E.32.22221	6757			231DCKM	1972	5	18	54	6703.2
352344105564302	14N.09E.36.31343	6050		80	110AVMB	1972	5	18	21	6029.4
352349105513701	14N.10E.34.42241	6230	1650		231SNRS	1972	5	19	74	6155.5
350231106052801	10N.08E.33.431	6294			110AVMB	1972	6	22	160	6134.4
355028106080201	19N.08E.30.3444	5860		1910	121TSUQ	1972	7	20	72	5788.0
354822106050201	18N.08E.10.1433	6375		560		1972	7	25	524	5850.9
350407105564101	10N.09E.26.2223	6232			110BLSN	1972	7	27	75	6157.4
350501106051901	10N.08E.21.221	6318		270	110AVMB	1972	7	27	142	6176.3
350659106060701	10N.08E.04.3311	6378		270	110AVMB	1972	7	27	196	6182.0
350738106122801	11N.07E.32.4444	6670		440	325MDER	1972	7	27	359	6310.5
361935106020401	24N.09E.07.310	6300	54	50	110AVMB	1972	8	17	12	6288.0
353205105574502	15N.09E.14.11413	6527		300	112ANCH	1972	8	28	58	6469.4
352546106051201	14N.08E.22.130	5790		355	123GLST	1972	9	11	90	5700.0
364057105401701	28N.12E.09	7570		546		1972	9	29	487	7083.0
364422105403201	29N.12E.20.	7530		415		1972	9	29	344	7186.0
352301106101801	13N.07E.02.32112	6389		353	000IRSV	1972	11	8	86	6302.6
351255106031201	12N.08E.35.4433	6435		271	221MRSN	1972	11	9	244	6191.2
352718105554301	14N.10E.07.31312	6259	211	205	110AVMB	1972	11	10	33	6226.1
352620105523301	14N.10E.15.3133	6370		103		1972	11	14	73	6297.2
353313105563901	15N.09E.01.3314	6685		350	112ANCH	1972	11	14	151	6534.2
350451105584101	10N.09E.22.1311	6240		500	110BLSN	1973	2	23	79	6161.3

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						year	month	day		
351420106101701	12N.07E.26.131	7140	170	170		1973	3	7	80	7060.3
350459106045401	10N.08E.22.112	6288				1973	3	12	113	6174.8
350520106023901	10N.08E.13.3231	6262			110AVMB	1973	3	15	110	6152.4
352032106082001	13N.08E.19.130	7050		510		1973	3	19	20	7030.0
352058106071501	13N.08E.17.330	6635		410		1973	3	19	30	6605.0
352058106071502	13N.08E.17.330A	6635		41		1973	3	19	4	6631.0
350445106011301	10N.09E.19.232	6251				1973	3	22	91	6159.6
350433105530001	10N.10E.21.322	6454				1973	3	27	381	6073.3
350631105545101	10N.10E.07.2314	6361			313SADG	1973	3	28	214	6146.8
350737105581501	10N.10E.05.222	6402				1973	3	28	216	6186.1
350832105564401	11N.09E.35.2221	6338		306	110AVMB	1973	4	9	128	6209.7
351017105571201	11N.09E.14.34434	6403		430	231DCKM	1973	4	10	167	6236.0
351108106001501	11N.09E.08.433	6332				1973	4	10	123	6208.8
350858105551601	11N.10E.30.134	6390	182	182		1973	4	11	133	6257.1
351044105532401	11N.10E.16.311	6554				1973	4	16	288	6265.7
354916105544901	18N.10E.06.24314	6850		75	110AVMB	1973	4	16	22	6828.2
351134105471001	11N.11E.08.422	6818				1973	4	18	28	6790.3
350752105433601	11N.11E.36.3411	6875				1973	4	23	64	6810.8
350639105431501	10N.11E.12.114	6931				1973	4	25	121	6809.9
350642105445701	10N.11E.11.111	6884				1973	4	25	55	6829.4
350315105450701	10N.11E.34.222	6747				1973	4	26	60	6687.0
355854106023001	20N.08E.12.23412	5700	80	80		1973	4	26	32	5668.4
350823106021301	11N.08E.36.214	6279	120	120		1973	4	30	104	6175.4
350918106041901	11N.08E.27.2124	6332			110AVMB	1973	4	30	145	6186.7
351043106051401	11N.08E.16.2434	6410			110AVMB	1973	5	1	200	6210.0
350923106062401	11N.08E.29.221	6448	400			1973	5	2	290	6158.0
351358106025901	12N.08E.25.313	6496	372			1973	5	10	294	6202.2
351320105595801	12N.09E.32.243	6442	382	382		1973	5	15	97	6345.5
351534106004601	12N.09E.17.3332	6599	256		210MNCS	1973	5	15	110	6489.2
351316105563001	12N.09E.36.311	6536	350	191		1973	5	16	180	6356.4

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						year	month	day		
351427105571601	12N.09E.26.1232	6552	60			1973	5	16	52	6500.0
351708105563601	12N.09E.12.113	6310				1973	5	16	82	6228.1
351738105581401	12N.09E.03.411	6275				1973	5	16	20	6254.6
351332106102801	12N.07E.34.224	6980	602	600		1973	5	21	464	6515.6
352437105472701	14N.11E.29.4232	6798	470		313BRNL	1973	5	29	448	6349.7
352452105504501	14N.10E.26.134	6406	180			1973	5	29	52	6353.7
353529106064601	16N.08E.29.2144	6220		127		1973	5	29	104	6115.8
353541106074001	16N.08E.30.2211	6100				1973	5	29	2	6097.6
352056105475801	13N.11E.17.343	6760	464			1973	5	30	437	6322.9
352106105503901	13N.10E.14.4444	6312				1973	5	30	131	6181.0
353508106062101	16N.08E.28.31323	6160		75		1973	5	30	44	6115.6
353520106062501	16N.08E.28.13313	6200		107		1973	5	30	90	6110.5
353537106064701	16N.08E.29.2124	6215				1973	5	30	102	6113.2
353554106064301	16N.08E.20.43224	6210				1973	5	30	109	6101.5
353556106070701	16N.08E.20.3234	6135		100		1973	5	30	34	6101.4
351718105485801	12N.11E.06.343	6583	136			1973	5	31	58	6525.2
353422106063801	16N.08E.32.4211	6060				1973	5	31	4	6056.1
353447106081301	16N.08E.31.121	6010		20		1973	5	31	15	5995.1
353516106055201	16N.08E.28.2333	6118		10		1973	5	31	7	6111.4
353523106054001	16N.08E.28.2324	6125				1973	5	31	19	6106.5
353524106055501	16N.08E.28.14242	6140		80		1973	5	31	39	6100.7
351525105531601	12N.10E.21.1114	6384		200		1973	6	4	103	6281.0
353422106060901	16N.08E.33.3122	6110		31		1973	6	4	18	6091.9
351853105591001	13N.09E.33.241	6260		15		1973	6	5	7	6252.6
353442106060301	16N.08E.33.1232	6105		90		1973	6	5	19	6085.8
352320105541201	13N.10E.05.124	6082				1973	6	6	-6	6088.0
353628106021801	16N.08E.24.12411	6364		225		1973	6	6	213	6151.2
351849105574701	13N.09E.35.1314	6180				1973	6	11	30	6150.2
351852105574901	13N.09E.35.131	6175				1973	6	11	26	6149.1
351912105565001	13N.09E.26.44432	6105			210MNCS	1973	6	11	152	5953.2

Summary of Water Level Elevation Database

Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
353516106035801	16N.08E.26.32112	6285		395	110AVMB	1973	6	11	126	6159.4
353812106042001	16N.08E.10.22421	6347		500		1973	6	11	196	6151.4
351702106030201	12N.08E.11.224	6442				1973	6	12	18	6424.0
351823106003901	13N.09E.32.344	6398				1973	6	12	63	6334.9
351852105585101	13N.09E.34.131	6221				1973	6	12	14	6206.8
351905106024501	13N.08E.36.122	6220				1973	6	12	31	6188.8
351936106010101	13N.09E.29.133	6200				1973	6	12	13	6187.3
353404106053401	16N.08E.33.44312	6175		120		1973	6	12	56	6118.6
355608106010601	20N.09E.30.2444	5900		200		1973	6	12	91	5809.3
352248106022101	13N.08E.01.441	5956	40			1973	6	13	16	5940.5
352306105594801	13N.09E.04.134	5912	70	70		1973	6	13	23	5889.4
353448106043401	16N.08E.34.21241	6210		114		1973	6	13	81	6128.9
353424106043301	16N.08E.34.23441	6185		100	112ANCH	1973	6	18	63	6121.9
353442106043801	16N.08E.34.21414	6200		110		1973	6	18	67	6132.7
353444106042101	16N.08E.34.22234	6200		135		1973	6	18	69	6131.2
353426106045301	16N.08E.34.14432	6178		86		1973	6	19	50	6128.0
352356105435101	14N.11E.36.134	6742				1973	6	20	111	6631.4
352609105470301	14N.11E.16.334	6720				1973	6	20	26	6693.9
353853106021201	16N.08E.01.24232	6486		406		1973	6	20	313	6172.8
353911106020801	16N.08E.01.22222	6520		460		1973	6	20	366	6154.2
353837106023201	16N.08E.01.41324	6467		490		1973	6	21	288	6179.4
353823106015101	16N.09E.06.34311	6510				1973	6	28	356	6153.7
353822106010801	16N.09E.06.44414	6550		308	121TSUQ	1973	7	5	236	6314.5
351441106121201	12N.07E.21.343	7050	355	160		1973	7	10	157	6893.3
352445105563701	14N.09E.25.312	6110				1973	7	11	19	6091.1
355635106011901	20N.09E.19.44331	5875		250		1973	7	11	98	5777.2
355636106011401	20N.09E.19.44341	5860		220		1973	7	11	70	5790.4
351301106071801	12N.08E.31.441	6670	550			1973	7	12	518	6151.6
352443105565201	14N.09E.26.4224	6107				1973	7	12	38	6069.0
353817106010501	16N.09E.07.22222	6555				1973	7	13	245	6310.2

Summary of Water Level Elevation Database

Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
355843106002801	20N.09E.08.41112	5810		85	110AVMB	1973	7	13	38	5772.3
355843106005201	20N.09E.08.31221	5820		210		1973	7	13	51	5768.6
355904106000401	20N.09E.08.22243	5870				1973	7	13	52	5818.3
352357105573201	14N.09E.35.143	6121		282		1973	7	16	195	5926.4
352418105582301	14N.09E.34.2111	5988				1973	7	16	19	5969.3
352614106004601	14N.09E.17.343	6121				1973	7	16	4	6116.8
353733106013501	16N.09E.07.43133	6480		440	121TSUQ	1973	7	16	308	6171.7
353853106011501	16N.09E.06.24141	6555		328		1973	7	16	261	6294.3
353718106012901	16N.09E.18.2132	6450				1973	7	17	312	6138.0
353758106005801	16N.09E.08.1332	6500		206		1973	7	17	176	6324.1
353708105580001	16N.9E.15.240	6760	300	300		1973	7	20	230	6530.0
352505105585201	14N.09E.27.113	6110				1973	7	23	41	6069.4
352549106000701	14N.09E.20.242	6170				1973	7	23	55	6115.3
352615105570401	14N.09E.14.441	6126				1973	7	23	11	6115.2
352637105562301	14N.09E.13.144	6180				1973	7	23	15	6164.9
352728105562701	14N.09E.12.143	6280				1973	7	23	31	6248.5
352852105572101	15N.09E.35.3424	6522				1973	7	23	109	6413.1
353810106002701	16N.09E.08.21123	6544			112ANCH	1973	7	23	39	6504.9
353818106000501	16N.09E.08.22212	6605		195	112ANCH	1973	7	23	96	6508.8
352406106011501	14N.09E.31.241	5920				1973	7	24	65	5855.4
352456105592301	14N.09E.28.231	6180		150		1973	7	24	61	6118.5
352656106010701	14N.09E.18.222	6177				1973	7	24	36	6141.4
354117106054301	17N.08E.21.4123	6438		350		1973	7	24	311	6127.4
354153106060001	17N.08E.16.3441	6390				1973	7	24	461	5929.5
352718106031501	14N.08E.11.424	6140				1973	7	25	128	6011.8
352800106030701	14N.08E.01.331	6120		275		1973	7	25	77	6042.7
353802106001401	16N.09E.08.24132	6610		200		1973	7	25	101	6508.9
353805106001101	16N.09E.08.24121	6610		200		1973	7	25	88	6522.1
352537106040401	14N.08E.23.312	5840		231		1973	7	26	73	5767.2
353723106013001	16N.09E.18.21142	6445				1973	7	26	299	6145.9

Summary of Water Level Elevation Database

Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
353817106004701	16N.09E.08.12113	6563		254		1973	7	26	226	6336.8
352504106042801	14N.08E.27.223	5768	45			1973	7	30	17	5751.4
352505106051801	14N.08E.27.113	5765				1973	7	30	5	5760.3
352512106052201	14N.08E.28.222	5740				1973	7	30	1	5738.8
352748106040401	14N.08E.11.112	6040				1973	7	30	72	5968.0
352729106035001	14N.08E.11.144	6118	190	111		1973	7	31	95	6023.2
352827106052001	14N.08E.03.131	6047				1973	7	31	14	6033.1
353838106005201	16N.09E.05.31423	6585		334		1973	7	31	274	6311.0
353839106002801	16N.09E.05.41132	6610		117		1973	7	31	77	6533.0
353853106003901	16N.09E.05.14231	6610		90		1973	7	31	51	6559.1
352629106021401	14N.08E.13.422	6120		275		1973	8	1	85	6034.6
352647106024801	14N.08E.13.1241	6105		130		1973	8	2	65	6040.4
353831106003901	16N.09E.05.34211	6585		100		1973	8	6	81	6503.8
353833106003701	16N.09E.05.32434	6590		105		1973	8	6	88	6501.7
353847106001401	16N.09E.05.24332	6625				1973	8	6	109	6516.5
353847106001402	16N.09E.05.24332	6625				1973	8	6	105	6520.2
353833106001801	16N.09E.05.41443	6582		86		1973	8	7	39	6543.4
353911105594301	16N.09E.04.11222	6690		202	121TSUQ	1973	8	7	176	6514.1
353839105594101	16N.09E.04.3213	6640				1973	8	8	129	6510.8
353843105594401	16N.09E.04.3122	6640		146		1973	8	8	125	6514.7
353458106023101	16N.08E.25.4323	6300		200		1973	8	9	162	6138.4
353516106025101	16N.08E.25.32122	6335				1973	8	9	169	6166.3
353522106021401	16N.08E.25.2441	6370		280		1973	8	9	212	6157.9
353523106020801	16N.08E.25.2424	6378		290		1973	8	9	212	6165.9
353525106020101	16N.09E.30.1314	6385		316		1973	8	9	223	6161.6
353458106024801	16N.08E.25.34411	6282		210		1973	8	13	138	6144.3
353505106024401	16N.08E.25.3244	6295		250		1973	8	13	139	6156.5
353502106021401	16N.08E.25.4421	6340		306		1973	8	14	167	6172.8
353908105594301	16N.09E.04.11242	6685		186		1973	8	16	167	6518.0
353753105582701	16N.09E.10.14443	6780		340		1973	8	17	154	6625.7

Summary of Water Level Elevation Database

Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
353701105582401	16N.09E.15.1444	6715				1973	8	21	112	6603.4
353714105582301	16N.09E.15.12444	6740		145		1973	8	22	115	6625.1
365035105360501	30N.13E.18.1121	7597		500	110AVMB	1973	9	6	72	7525.5
353703105534801	16N.10E.17.243	7410	180			1973	9	11	54	7356.0
353810105550701	16N.10E.07.21321	7225			400PCMB	1973	9	14	45	7180.4
353824105542901	16N.10E.05.33234	7470		397	400PCMB	1973	9	14	112	7358.1
353846105550701	16N.10E.06.23341	7220		205		1973	9	15	70	7150.0
353623105555501	16N.09E.24.22321	6970		375	121TSUQ	1973	9	18	71	6899.0
353018106043201	15N.08E.27.2142	6182				1973	9	24	55	6127.1
353038106015701	15N.09E.19.332	6262				1973	9	25	124	6137.5
352937105580201	15N.09E.27.4434	6465				1973	9	27	47	6417.5
352847106030801	15N.08E.36.3332	6135				1973	10	1	74	6061.3
352921106035201	15N.08E.35.1421	6140		72		1973	10	1	72	6068.2
352944106034201	15N.08E.26.4313	6160		102		1973	10	1	84	6075.6
352953106030801	15N.08E.25.3134	6215		150		1973	10	1	120	6095.1
353202105531901	15N.10E.16.141	6964	86			1973	10	3	51	6912.8
353050105470601	15N.11E.21.312	7260	150			1973	10	9	23	7236.6
353238105522601	15N.10E.10.3112	7160		160	400PCMB	1973	10	15	89	7071.0
353352105443701	15N.11E.02.211	7200	185			1973	10	15	67	7133.4
353314105523501	15N.10E.03.3313	7170		180	400PCMB	1973	10	16	49	7120.8
353247105514801	15N.10E.10.232	7220	375			1973	10	17	69	7150.7
353840105570001	16N.09E.02.42132	6900				1973	10	26	217	6682.9
353833105572401	16N.09E.02.32434	6850		298		1973	10	27	182	6667.7
353911105570101	16N.09E.02.2211	6940		300		1973	10	27	226	6713.7
353343105520601	15N.10E.03.142	7300	134			1973	10	31	87	7212.7
353437105471401	16N.11E.33.113	7280	32			1973	10	31	17	7263.1
353517105472301	16N.11E.29.244	7520	90			1973	11	1	64	7455.5
353538105460501	16N.11E.27.1141	7460		313		1973	11	8	87	7372.9
353854105564901	16N.09E.02.24241	6920				1973	11	15	150	6769.5
353857105564701	16N.09E.02.24222	6925				1973	11	15	159	6766.1

Summary of Water Level Elevation Database

Site ID	Local ID	Land Surface Altitude (ft amsl)	Hole Depth (ft)	Well Depth (ft)	Aquifer Code	Water Level Date			DTW (ft)	W-Level (ft amsl)
						year	month	day		
353905105564801	16N.09E.02.22243	6960		278		1973	11	15	190	6769.7
353614106031101	16N.08E.24.13314	6295		312		1973	11	16	154	6141.1
353917105565701	17N.09E.35.44321	6960				1973	11	29	227	6733.0
354032106021701	17N.08E.25.144	6530	445			1973	12	13	367	6163.5
354009106012101	17N.09E.30.43424	6610			121TSUQ	1973	12	14	333	6276.7
354015106012401	17N.09E.30.43221	6655				1973	12	15	373	6281.8
354025106012601	17N.09E.30.41232	6640				1973	12	18	370	6270.2
354034106010901	17N.09E.30.24423	6690		450		1973	12	18	382	6308.0
354019106023901	17N.08E.25.41332	6540		486		1973	12	19	350	6189.6
354249106013501	17N.09E.07.43131	6710				1973	12	20	491	6219.1
354338105572101	17N.09E.02.3442	7250		620		1974	1	1	560	6690.0
354734105570901	18N.09E.14.232	6540	129	129		1974	1	29	56	6483.9
354740105565101	18N.09E.14.22432	6620		1000		1974	1	29	34	6585.6
362531105343201	25N.13E.08.212	6952		500		1974	2	8	9	6942.6
362731105362201	26N.12E.25.4122	7110		450		1974	2	8	21	7088.6
364759105360701	30N.13E.31.1112	7640				1974	2	8	86	7554.4
353918106013701	17N.09E.31.324	6590		600		1974	2	16	424	6165.5
354830105575801	18N.09E.10.24211	6410		164	121TSUQ	1974	2	16	73	6337.2
365148105364401	30N.12E.01.3244	7512			110AVMB	1974	2	20	12	7499.7
364813105350801	30N.13E.30.4422	7750			110AVMB	1974	2	21	35	7715.1
365245105354501	02S.73W.17.322	7537			110AVMB	1974	2	21	34	7502.8
365410105345601	02S.73W.05.244	7587			110AVMB	1974	2	21	81	7505.7
354005106003401	17N.09E.29.34444	6725		150		1974	3	7	140	6584.6
353857106011801	16N.09E.06.24111	6555				1974	3	8	265	6290.1
353933106004901	17N.09E.32.312442	6595		50	110AVMB	1974	3	12	20	6575.5
353939106002201	17N.09E.32.23434	6622		100		1974	3	14	49	6573.4
353946105595101	17N.09E.33.13231	6672		176		1974	3	14	162	6509.8
353948105595301	17N.09E.33.13123	6660				1974	3	14	159	6500.5
353604105463801	16N.11E.21.412	7685	495			1974	3	20	167	7518.3
354932105541701	18N.10E.05.121	7100		115	121TSUQ	1974	4	1	40	7060.0

APPENDIX K

SUMMARY OF GROUNDWATER RIGHTS DATABASE

OSE Code of Water Use

COM	Commercial
DOM	Domestic
EXP	Exploratory
IND	Industrial
IRR	Irrigation
MDW	Mutual Domestic Water
MIN	Mining
MOB	Mobil Home Park
MON	Monitoring Well
MUL	Multiple
MUN	Municipal
NOT	Not in Use
OBS	Observation
POL	Pollution Control Well
POU	Poultry and Egg Operation
PRO	Prospecting
PUB	Construction of Public Works
REC	Recreation
SAN	Commercial Sanitary
SCH	School
STK	Stock
SUB	Subdivision

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR VELARDE SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
COM	Commercial	6	45
DOM	Domestic	1467	4,401
EXP	Exploratory	1	0
IRR	Irrigation	34	1,458
MIN	Mining	1	70
MOB	Mobil Home Park	2	11
MUL	Multiple	37	84
MUN	Municipal	1	300
NOT	Not in Use	10	0
OBS	Observation	2	0
POL	Pollution Control Well	2	202
POU	Poultry and Egg Operation	1	5
PUB	Construction of Public Work	1	12
SAN	Commercial Sanitary	21	60
SCH	School	1	3
STK	Stock	10	30
Total:		1597	6,681

Summary			
Irrigation	IRR, AGR	34	1,458
Domestic	DOM, EXP, MOB, MUL, MUN, POL, POU, PUB, STK, SCH	1533	5,048
Commercial	COM, MIN, OBS, SAN, NOT	30	175

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR SANTA CRUZ SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
COM	Commercial	5	219
DOM	Domestic	1212	3,636
EXP	Exploratory	1	0
IRR	Irrigation	14	255
MDW	Mutual Domestic Water	3	127
MOB	Mobil Home Park	1	4
MUL	Multiple	37	111
NOT	Not in Use	2	0
PUB	Construction of Public Wo	1	0
SAN	Commercial Sanitary	21	63
SCH	School	1	1
STK	Stock	13	39
Total		1311	4,455

Summary			
Irrigation	IRR	14	255
Domestic	DOM, EXP, MOB, MUL, MUN, POL, POU, PUB, STK, SCH	1269	3918
Commercial	COM, MIN, OBS, SAN NOT	28	282

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR SANTA CLARA SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
COM	Commercial	1	8
DOM	Domestic	309	927
IRR	Irrigation	15	440
MUL	Multiple	9	27
NOT	Not in Use	3	0
PUB	Construction of Public Works	1	0
SAN	Commercial Sanitary	4	12
Total		342	1,414

Summary			
Irrigation	IRR	15	440
Domestic	DOM, MUL, PUB	319	954
Commercial	COM, SAN, NOT	8	20

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR LOS ALAMOS SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
DOM	Domestic	11	33
MUN	Municipal	18	5541
EXP	Exploratory	2	0
NOT	Not in Use	1	0
OBS	Observation	1	0
Total		33	5574

Summary			
Irrigation	IRR	0	0
Domestic	DOM, MUN, EXP	13	5,574
Commercial	OBS, NOT	2	0

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR NAMBE-POJOAQUE

CODE	USE	No. of Wells	Permitted Diversion (AFY)
COM	Commercial	2	3
DOM	Domestic	509	1527
EXP	Exploratory	2	0
IRR	Irrigation	14	142
MOB	Mobil Home Park	1	20
MUL	Multiple	11	21
NOT	Not in Use	3	0
SAN	Commercial Sanitary	14	42
SCH	School	3	29
STK	Stock	2	6
Total		561	1790

Summary			
Irrigation	IRR	14	142
Domestic	DOM, EXP, MOB, MUL, SCH, STK	528	1603
Commercial	COM, SAN, NOT	19	45

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR TESUQUE SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
COM	Commercial	1	76
DOM	Domestic	517	1,551
EXP	Exploratory	5	0
IRR	Irrigation	15	137
MUL	Multiple	40	90
NOT	Not in Use	5	0
OBS	Observation	3	0
PUB	Construction of Public Works	1	0
SAN	Commercial Sanitary	22	66
STK	Stock	5	15
Total		614	1935

Summary			
Irrigation	IRR	15	137
Domestic	DOM, EXP, MUL,PUB SCH, STK	568	1656
Commercial	COM, OBS, SAN, NOT	31	142

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR CAJA DEL RIO SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
DOM	Domestic	93	279
EXP	Exploratory	2	3
MUL	Multiple	7	18
MUN	Municipal	8	10000
NOT	Not in Use	4	0
OBS	Observation	4	0
PRO	Prospecting	1	0
SAN	Commercial Sanitary	3	9
STK	Stock	4	16
Total		126	10325

Summary			
Irrigation	IRR	0	0
Domestic	DOM, EXP, MUL, STK,MUN	106	10316
Commercial	NOT, OBS, PRO, SAN	12	9

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR SANTA FE RIVER SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
COM	Commercial	15	131
DOM	Domestic	2057	5,772
EXP	Exploratory	7	3
IND	Industrial	1	146
IRR	Irrigation	22	566
MDW	Mutual Domestic Water	2	100
MOB	Mobil Home Park	5	190
MUL	Multiple	166	459
MUN	Municipal	4	4,894
NOT	Not in Use	22	0
OBS	Observation	8	21
PRO	Prospecting	1	0
PUB	Construction of Public Works	2	0
REC	Recreation	1	3
SAN	Commercial Sanitary	110	291
SCH	School	2	12
STK	Stock	24	41
Total		2449	12,629

Summary			
Irrigation	IRR	22	566
Deomestic	DOM, EXP, MDW, MOB MON,MUL,MUN, PUB, REC, SCH, STK	2270	11,474
Commercial	COMM, IND, NOT, OBS, PRO, SAN	157	589

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR NORTH GALISTEO SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
COM	Commercial	3	43
DOM	Domestic	852	2,064
EXP	Exploratory	20	0
IRR	Irrigation	7	529
MDW	Mutual Domestic Water	39	3,561
MUL	Multiple	46	117
NOT	Not in Use	10	0
OBS	Observation	2	0
SAN	Commercial Sanitary	19	42
STK	Stock	8	18
Total		1006	6,374

Summary			
Irrigation	IRR	7	529
Domestic	DOM, EXP, MDW, MON MUL, STK	965	5760
Commercial	COM, NOT, OBS,SAN	34	85

SUMMARY OF THE OSE WATER RIGHTS DATABASE FOR SOUTH GALISTEO SUB-BASIN

CODE	USE	No. of Wells	Permitted Diversion (AFY)
COM	Commercial	6	64
DOM	Domestic	662	1,628
EXP	Exploratory	5	0
IRR	Irrigation	17	1,045
MDW	Mutual Domestic Water	20	1,031
MUL	Multiple	44	120
MUN	Municipal	5	154
NOT	Not in Use	9	0
PRO	Prospecting	3	0
PUB	Construction of Public Works	1	0
SAN	Commercial Sanitary	22	51
STK	Stock	24	69
SUB	Subdivision	2	38
Total		820	4,200

Summary			
Irrigation	IRR	17	1045
Domestic	DOM, EXP, MDW, MOB MON,MUL,MUN, PUB, REC, SCH, STK, SUB	763	3040
Commercial	COM, IND, NOT, OBS, PRO, SAN	40	115