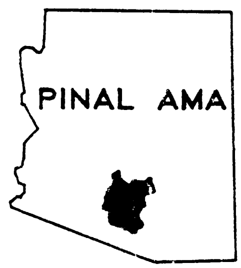
ARIZONA DEPARTMENT OF WATER RESOURCES

PINAL ACTIVE MANAGEMENT AREA REGIONAL GROUNDWATER FLOW MODEL PHASE ONE: HYDROGEOLOGIC FRAMEWORK, WATER BUDGET AND PHASE ONE RECOMMENDATIONS



BY

MATTHEW P. WICKHAM
EDWIN F. CORKHILL

HYDROLOGY DIVISION

MODELING REPORT NO. 1

ARIZONA
DEPARTMENT
OF WATER
RESOURCES

Phoenix, Arizona
June, 1989

PINAL AMA REGIONAL GROUNDWATER FLOW MODEL

P H A S E O N E

Hydrogeologic Framework, Water
Budget and Phase One
Recommendations

Final Report
June 1, 1989

by:
Matthew P. Wickham
Edwin F. Corkhill

HYDROLOGY DIVISION

ARIZONA DEPARTMENT OF WATER RESOURCES

PINAL AMA REGIONAL GROUND WATER FLOW MODEL

PHASE ONE

OUTLINE

F I N A L R E P O R T

Page

V. APPENDICES

A. Pinal AMA Hydrographs

B. Geological and Geophysical Well Logs within the Pinal AMA

C. Proposed Pinal AMA Groundwater Measurement Index Line - Revisions and Additions

D. Bibliography

E. Figures

FIGURES

TABLES

CHARTS

PHASE ONE REPORT:

DEVELOPMENT OF THE PINAL AMA REGIONAL GROUNDWATER FLOW MODEL

I. INTRODUCTION

A. INTRODUCTION

The Groundwater Management Act of 1980 established four geographic areas in Arizona, known as Active Management Areas (AMAs), in which intensive groundwater management is required to address severe impacts on groundwater supplies from extensive groundwater withdrawals. The Pinal Active Management Area is a 4000 square mile area located in the south-central portion of the state between Tucson and Phoenix and lies within Pinal and Pima counties. The Pinal AMA has a large multi-million dollar agricultural economy, with almost 164,000 acres currently farmed. Agriculture accounts for 91 percent of all current water demand and 95 percent of groundwater depletions in the Pinal AMA. Of available water supplies, 88 percent is contributed by groundwater (ADWR, 1985).

The primary management goal of the Pinal AMA is to allow the development of non-irrigation uses and to preserve the existing agricultural economy for as long as feasible without limiting future water supplies for non-irrigation uses. The First Management Plan covers the period of 1986 through 1989 and was developed to limit groundwater withdrawals and to manage groundwater resources up to the year 1990. In December, 1985 the Modeling Section of the Hydrology Division of the Arizona Department of Water Resources (ADWR) began the development of a digital groundwater flow model to aid in the analysis of management scenarios for the Pinal AMA. This report details the collection and analysis of the basic data necessary for the model development. This report also details problems associated with this effort, and offers suggestions for the solution of these problems.

The Pinal AMA covers 4,000 square miles of South-Central Arizona. A map of the Pinal AMA is provided in Figure 1. The study area encompasses approximately 1800 square miles and is the area within the AMA with the heaviest development, highest population density, and is where the majority of the water use occurs or will occur in the future. Figure 2 shows the model area which encompasses about 1100 square miles within the study area and was determined largely by data limitations. Figure 3 shows the distribution of wells with verified locations within the northern half of the Pinal AMA. This distribution of wells represents those areas of highest groundwater data resolution. The model area is bounded on most sides by non-water-bearing mountain fronts and by severe data voids within Indian reservation boundaries to the south, northeast and northwest.

This project is broken into two phases. Phase I consists of the hydrologic and geologic characterization of the study area. Also presented are the definition and quantification of groundwater recharge sources, pumpage, subsurface inflows and outflows, and recommendations to fill critical data deficiencies. Appendices of critical data are also included. Phase II will include the development, calibration and verification of the regional groundwater flow model, as well as recommendations for future modeling efforts. Phase II is currently underway.

B. OBJECTIVE, GOALS, AND SCOPE OF STUDY

The ultimate objective of the Pinal AMA groundwater modeling effort is to provide sound technical management tools with which to quantify the effects of various groundwater management and conservation scenarios on groundwater resources within the study area. At the onset of this study it was not known whether the objectives could be realized, due primarily to data limitations. These limitations and their solutions are discussed in section IV of this report. The reports generated under Phase I and Phase II of this modeling effort are the first step in an iterative process of model development and use. It is expected that a useful predictive management model for the Pinal AMA will be developed in the future, following the resolution of the data deficiencies identified in section IV of this report and in the Phase II study, now underway.

The goals of Phase I were three-fold: (1) to perform a comprehensive search and collection of all current and historic hydrologic, geologic and land use parameters (2) to analyze and interpret the assembled data,and (3) to define data deficiencies and provide data collection recommendations. The goal of Phase II (model development) is to develop a regional digital groundwater flow model to further understanding of the hydrogeology of the AMA and to better identify data needs and model code deficiencies. The scope of the Phase I effort was limited by the availability and reliability of current and historic data, the size of the study and model areas, and manpower restrictions. The Phase I report also presents recommendations for the remediation of data deficiencies. This report analyses data and derives hydrologic parameters and water budget components for the model area, but does not present data arrays for use in the groundwater flow model. This will be done in the Phase II report.

C. PURPOSE OF REPORT

The purpose of the Phase I report is to document the data collection activities and findings of the analysis of the hydrogeologic framework of the study area, and to document the procedures used in the determination of inflows and outflows, pumpage and recharge, and other model input parameters.

D. PREVIOUS AND ONGOING INVESTIGATIONS

Initiation of the current ADWR modeling effort began in December 1985. However, several previous investigations by various individuals and groups have been made. A bibliography of related reports, articles, investigations, and maps is presented in Appendix E.

Smith (1940) documented a groundwater supply study of the Eloy area in Pinal County. W. F. Hardt and R. E. Cattany (1965) prepared a report which provided detailed descriptions and analyses of the geohydrologic system in western Pinal County. Anderson (1968) developed a regional electric analog analysis of groundwater depletion in central Arizona. The US Bureau of Reclamation (USBR) released a regional geology and groundwater resources report for the Central Arizona Project for Maricopa and Pinal Counties (USBR, 1976).

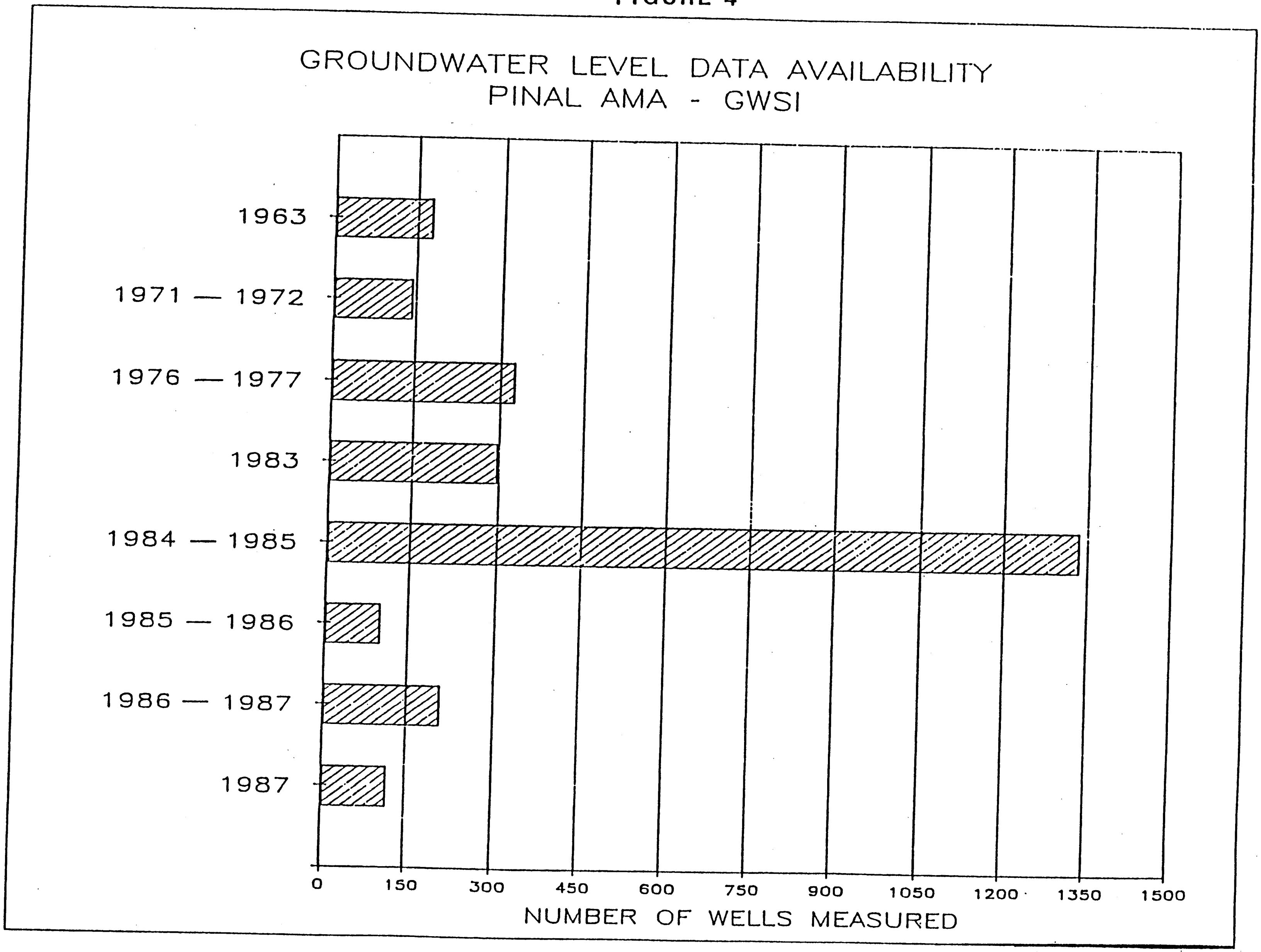
From 1982 to 1984 a modeling study was conducted by ADWR to investigate the Pinal AMA groundwater system. The study included collection of basic groundwater data, and an investigation of aquifer geometry and hydraulic parameters. A preliminary investigation was conducted and a two-dimensional groundwater flow model was developed and run at steady state. The model study was subsequently postponed due to lack of manpower and data. Presently, Leake and Pool of the US Geological Survey (USGS) are developing a three-dimensional flow model of the Eloy sub-basin for use in a land subsidence and compaction study (Leake and Prudic, 1988).

E. DATA SOURCES, DATA LIMITATIONS, AND MODEL CALIBRATION PERIOD

Hydrogeologic data have been collected in the study area for over 90 years. However, the collected data have never presented a complete picture of the hydrologic system within the AMA. Especially today the increasing complexity of the hydrology of the AMA, due to surface water and groundwater development, has exceeded the complexity of data collection efforts. In the 1890's when data collection began in earnest, wells were shallow and relatively few and the groundwater system was in a steady state condition. Surface water was diverted directly from the Gila River, which was perennial through the AMA. In 1928 Ashurst-Hayden Dam was completed on the Gila River. This provided a more reliable surface water supply to the San Carlos Irrigation Project, which occupies about 45,000 acres in the northern Eloy sub-basin of the AMA (see Figure 1). Completion of the dam also altered the surface water use patterns in the portions of the AMA near the Gila River. By the 1960's extensive groundwater development had lowered groundwater levels by 400 to 500 feet in some areas of the AMA, and the deepening of wells and new withdrawal patterns for the extensive agricultural base of the AMA had caused water level differences to develop between the aquifers. Groundwater data collection efforts by the USGS and ADWR have not changed with the developing complexity of the AMA's groundwater system, due primarily to budgetary constraints. Thus, although historic data may be abundant, they do not fully represent hydrologic conditions as they currently exist.

Static and pumping water levels, water quality analyses, and well construction information have been collected and compiled by both the USGS and ADWR and are currently accessible within ADWR's Groundwater Site Inventory (GWSI) and USGS's WATSTORE data-base management systems. Figure 4 lists the availability of water level measurement data between 1963 and 1987. Surface water flows for the Gila and Santa Cruz River systems have been measured since the early 1900's. Records have been maintained and are available from the USGS. The Bureau of Indian Affairs (BIA) San Carlos Irrigation Project (SCIP) has annually reported surface flow measurements for various periods of record dating back to 1930 for the San Carlos Reservoir, Ashurst-Hayden Diversion Dam, Picacho Reservoir and the San Carlos Irrigation Project diversion and canal distribution system.

FIGURE 4



GROUNDWATER LEVEL DATA AVAILABILITY
PINAL AMA - GWSI
1963
1971 — 1972
1976 — 1977
1983
1984 — 1985
1985 — 1986
1986 — 1987
1987
0
150
300
450
600
750
900
1050
1200
1350
1500
NUMBER OF WELLS MEASURED

The ADWR Registry of Groundwater Rights (ROGR) Annual Reports available for the calendar years 1984-1987 provided volumetric pumpage, water usage, Grandfathered Rights (GFR) irrigation acreage, and distribution of irrigation waters for each right holder. Also available were the Applications for Grandfathered Rights containing user-reported pumpage, irrigated acres, crops grown, and distribution of irrigation waters for 1975-1979 for each applicant. About four thousand geophysical, geologic, and drillers' logs are available for analysis for geologic data and for aquifer parameter data. Methods of analysis are individually addressed later in this report.

Although there appear to be an abundance of data, a large percentage was discounted for various reasons. For example, water levels were measured infrequently and usually at low spatial densities, and construction information for measured wells was not always available to correlate water levels to hydrogeologic units. Few surface water gages are located within the model area; reported canal losses by the San Carlos Irrigation Project (SCIP) are actually accounting losses and not measured losses, and therefore must be interpreted accordingly. Accurate pumpage figures are available from ROGR only for 1984 to the present. Most data available on a regional basis do not easily lend themselves to a more discrete areal distribution. Specific limitations are discussed in later sections.

Data and analyses are most complete and accurate for the period of 1985 to 1988. For this reason this period, although quite short, will be used to calibrate the Phase II groundwater flow model to the extent possible. In some sections of this report the period of analyses is extended to include previous years. This was done either to illustrate historical trends, to provide the reader with some insight into the variability of the data and the system, or to illustrate data availability and confidence.

II HYDROGEOLOGIC FRAMEWORK

A. GENERAL REGIONAL SETTING - Geography, Physiography and Climate

The Pinal AMA is located in south-central Arizona. It is divided into five sub-basins; Aguirre Valley, Eloy, Maricopa-Stanfield, Santa Rosa Valley, and Vekol Valley (Figure 1). The greatest percentages of agricultural and urban groundwater withdrawals are in the Eloy and Maricopa-Stanfield sub-basins. The urban centers, ranked by decreasing population size, and located within these two sub-basins are Casa Grande, Florence, Coolidge, Eloy, Maricopa and Stanfield. Indian lands in the Eloy and Maricopa-Stanfield sub-basins include the Tohono O'Odham Indian Reservation (formerly the Papago Indian Reservation) to the south, the Gila River Indian Reservation to the north, and the Ak-Chin Indian Reservation near Maricopa.

The Pinal AMA is located in the Basin and Range Physiographic Province in Arizona, which formed as a result of extensional tectonics approximately 15 million years ago. The main erosional agents of the present landscape are ephemeral streams, sheet runoff from high intensity rainstorms, and aeolian deflation (Hardt and Cattany, 1965). The physiography of the Pinal AMA consists of broad alluvial plains with isolated mountains that rise abruptly from the valley floor. Land surface elevations range from 1000 feet to 3000 feet above mean sea level (MSL). Two major ephemeral streams traverse the area: the Gila River to the north, which flows east to west; and the Santa Cruz River, which flows in a northwesterly direction. Their confluence is located in the northwest corner of the Pinal AMA.

The Pinal AMA is an arid region, with precipitation averaging about eight inches annually (ADWR, 1985). Rainfall generally occurs during two distinct periods of the year. Tropical air from the Gulf of Mexico causes occasional intense thundershowers during the summer months, particularly July and August. Slow-moving storms from the northwest bring precipitation during the winter months. Winter events are of lesser intensity, wider areal distribution and longer duration than summer storms. Lake evaporation rates in the AMA are estimated to be about 75 inches per year - about nine times the average annual precipitation (USDC, 1968). In general, rainfall events are infrequent, and of small depth, and most of the water is lost to evaporation. Therefore, rainfall is not considered to contribute directly to aquifer recharge. Summer daytime maximum temperatures average from 100°F to 110°F, with winter daytime maximum temperatures averaging 60°F to 70°F.

B. GEOLOGY OF THE PINAL AMA

Four major hydrogeologic units were recognized and delineated in this study; the Upper Alluvial Unit (UAU), the Middle Silt and Clay Unit (MSCU), the Lower Conglomerate Unit (LCU), and the Hydrologic Bedrock Unit (HBU). Their depositional history, characteristics and occurrence are discussed in the following sections.

Depositional History of the Alluvial Units

The formation of the Lower Santa Cruz River Basin began during the Miocene Epoch approximately 15-20 million years ago. Extensional tectonics resulted in the formation of grabens (basins) and horsts (mountains) which were separated by high-angle normal faults. Intermittent volcanic activity also occurred during this period. The basins slowly filled with alluvium from mass wasting of mountain highs and from nearby stream and sheet erosion. Coarse materials were deposited close to the basin edges while fine material settled out toward the centers as the capacity of the water to transport heavier sediments diminished (Hardt and Cattany, 1965). Subsequent material was deposited and the lower alluvial unit became consolidated and indurated from physical and chemical processes associated with diagenesis. This depositional period formed what is referred to as the Lower Conglomerate Unit.

Following the deposition of the LCU a period of renewed differential uplift accentuated the previously formed ridges, troughs, and ranges (Hardt and Cattany, 1965). The Casa Grande Ridge, a subsurface bedrock high, separated the region into two distinct sub-basins: the Maricopa-Stanfield sub-basin to the west and the Eloy sub-basin to the east. This buried ridge trends north to south from the Sacaton Mountains to the Silver Reef Mountains (approximately four miles west of Casa Grande) and played an important part in the depositional history of the Eloy and Maricopa-Stanfield sub-basins. The ancestral Santa Cruz River, entering into the Eloy sub-basin from the southwest, and possibly the Gila River entering from the northeast, were blocked and diverted by the newly formed Casa Grande Ridge. This event resulted in a low-energy lacustrine environment in the Eloy sub-basin characterized by the deposition of silts, clays and evaporites. Contemporaneous deposition of fines occurred in the western Maricopa-Stanfield sub-basin from Santa Rosa Valley and possibly from the Gila River. This depositional period formed what is referred to in this report as the Middle Silt and Clay Unit.

Several theories have been proposed to explain the depositional history of the Maricopa-Stanfield sub-basin. Hardt and Cattany (1965) suggest simultaneous sedimentation of the basins from separate sources: Eloy from the Santa Cruz River and Maricopa-Stanfield from the outflows of the Santa Rosa Wash.

Available information suggests that once the Eloy sub-basin was sufficiently silted up to allow the throughflow of the Santa Cruz River, substantial deposits of silts, clays, and evaporates began to form in the Maricopa-Stanfield sub-basin.

Commencement of the current depositional period, forming the Upper Alluvial Unit coincided with the through-flowing of the Santa Cruz River to its confluence with the Gila River near the Sierra Estrella Mountains. These unconsolidated materials occur in both basins and were deposited through fluvial depositional processes.

Definition of Hydrogeologic Units

The hydrogeologic units discussed above were defined for the Phase I study by using well logs from about 4000 wells in the study area and by using a limited quantity of pump tests.

The accurate identification and mapping of the alluvial deposits and impermeable units was one of the most crucial tasks in the development of the Pinal AMA groundwater flow model. A comprehensive well log file was assembled and a complete analysis of those logs undertaken. The file includes all well logs on file with ADWR and the accompanying site inventories from both the ADWR and USGS. Additional logs and analyses were obtained from the Arizona Oil and Gas Conservation Commission (AOGCC), US Bureau of Indian Affairs (USBIA), US Bureau of Reclamation (USBR), and others.

The analysis was accomplished using a variety of information and interpretive techniques. A combination of geophysical, geologist and drillers' logs, and particle-size analyses for about 4,000 wells were located and analyzed to map hydrogeologic units. Geophysical well logs provided the most reliable information. Although the interpretation of geophysical logs was primarily qualitative, certain generally accepted guidelines were followed. Table 1 summarizes common borehole measurement ranges for different types of surveys in various alluvial materials used in this study. The number of useful geophysical logs available in the Eloy sub-basin was substantially larger than for Maricopa-Stanfield. Geologist logs and particle-size analyses also provided a more reliable quality of information than did the drillers' logs. Geophysical and geologists logs were available from oil, gas, copper, and geothermal exploration, from site investigations for the USBR Central Arizona Project canal, and from large water production wells. Appendix B lists all known geophysical and geologists logs and their sources for the Pinal AMA.

Approximately 4,000 drillers' logs were assembled and reviewed for the study. These logs are tabulated in Table 2. A sufficient number of deep well logs greater than 1000 feet in depth were available to provide good definition of the stratigraphy, with numerous well logs greater than 2000 feet deep penetrating all major hydrogeologic units. Each log was reviewed and categorized, with stratigraphic breaks, trends, potential for perching, and anomalies noted. Although drillers' logs are relatively unreliable as an information source, their conjunctive use with more reliable data provided valuable results. In many areas drillers' logs were the sole data source and it was necessary to use these logs and interpret geologic conditions using information gained by comparing driller's logs and other types of logs in areas where better data were available.

TABLE 1

COMMON LOGGING PARAMETERS OF ALLUVIAL SANDS, GRAVELS, AND CLAYS

Parameter	Sands and Gravels	Clays
Electrical Resistivity	10 - 70 OHM • M	2 - 9 OHM • M
Gamma Radiation	30 - 80 APIU	40 - 90 APIU
Acoustic Delta T	80 - 133 Microseconds/ft	> 133 Microseconds/ft
Bulk Density	2.2 - 2.5 g/cc	2.05 - 2.3 g/cc
Neutron Porosity	21 - 36%	> 40%

(Source: Corkhill, 1980)

TABLE 2
Well Depths in the Pinal AMA

Depth Range (ft)	No. wells	Percentage	Cumulative Percentage
< 100	1400	34.6	34.6
100 to < 200	620	15.3	49.9
200 to < 400	399	9.9	59.8
400 to < 600	572	14.1	73.9
600 to < 800	328	8.1	82.0
800 to < 1000	280	6.9	88.9
1000 to < 1200	215	5.3	94.2
1200 to < 1400	113	2.8	97.0
1400 to < 1600	73	1.8	98.8
1600 to < 1800	16	.4	99.2
1800 to < 2000	11	.3	99.5
2000 to < 2500	7	.2	99.7
2500	12	.3	100.0

	4046		

An extensive search for pump test and aquifer test results was conducted. Water companies, well drilling and pump companies, consultants, and federal, state, county, and city governments were contacted. Data from thirty tests were collected and analyzed, but were of limited use for reasons including surging, short test duration, multiple aquifer completions, or data deficiencies.

Aquifer parameters were initially derived from the application of the DWR's Drillers' Log Program (DLP) (Long and Erb, 1980). The DLP was designed to analyze drillers' logs for approximate aquifer characteristics and can provide useful results when applied on a regional basis and tied to more reliable data. Results from the DLP were contoured using kriging interpolation and an inverse distance weighting method for regional contouring in order to define the areal character and magnitudes of specific yields and hydraulic conductivities. Table 3 details the initial estimates of hydraulic parameters derived from the DLP for use and in the conceptual water budget and in the model. These estimates may be modified during Phase II.

TABLE 3

Initial Hydraulic Aquifer Parameters from
Regional Application of the Drillers' Log Program

Unit	Wells Analyzed	Hydraulic Conductivity (gal/day/ft^2) Min	Max	Mean	Specific Yield (percent) Min	Max	Mean	Storage Coefficient (dimensionless)
UAU	913	100	1150	436	5	20	11	N/A
MSCU	614	1	<25	16	3	7	4	N/A
LCU	163	4	998	254	3	18	9	10^{-3}-10^{-5}*

* Driskol, 1986

Hydrogeologic Units

Upper Alluvial Unit

The UAU is at the land surface for almost the entire study area. The UAU consists mainly of unconsolidated to slightly consolidated interbedded sands and gravels with some finer grained materials existing as lenses. Drillers' log descriptions of this unit include sand, sandy clay, sandy gravel, sand and gravel, and sand with clay. The lower half to third of the UAU is a transitional zone, in which relatively coarse UAU material is interbedded with finer alluvial material typical of the underlying MSCU. The UAU thickness ranges from less than 50 feet near mountain fronts to 1200 feet at the basin centers. The UAU is a significant hydrogeologic unit throughout the model area, and is the uppermost aquifer. The UAU is an unconfined aquifer throughout most of the study area, however, confined aquifer conditions have been observed in some areas of the Eloy Sub-basin (Pool, 1988). Ground water is derived from two storage sources in the UAU: 1) the drainage of pore spaces as the water table declines; 2) the compression (both elastic and inelastic) of lenticular fine-grained sediments. The UAU is a highly productive unit, and can yield large quantities of water to wells. Well yields range upward to 3000 gpm (USBR, 1976) throughout the model area.

UAU structure and isopach contour maps have been generated (Figures 5, 6). Substantial dewatering of the UAU has taken place in the Maricopa-Stanfield Sub-basin and in the Casa Grande area. The 1984/1985 UAU Aquifer Thickness Map (Figure 7) shows the remaining saturated extent of this unit.

The initial hydraulic parameters for the UAU were generated by a DLP analysis of 913 wells penetrating the UAU. Estimates from wells with less than 200 feet of penetration tended to provide results for dewatered zones of the UAU, and were omitted as unrepresentative of the aquifer. Specific yields ranged from 5 to 20 percent with a mean of 11 percent. Hydraulic conductivities ranged from 100 to 1150 gpd/ft^2, with a mean of 436 gpd/ft^2.

Middle Silt and Clay Unit

The MSCU sediments are fine grained and consist predominantly of silt, clays and sands. Drillers' log descriptions of the MSCU include clay, sticky clay, silty clay, jointed clay, sandy clay, clayey silt and silt. The areal extent of the MSCU is dependent on the depositional history of each basin, which altered the occurrence and path of throughflowing streams. The MSCU varies in thickness from less then 50 feet to greater than 1600 feet in the Maricopa-Stanfield sub-basin and greater than 6500 feet in the Eloy sub-basin. The thickness increases toward the basin centers and decreases toward the edges of the Casa Grande Ridge. Concurrent and/or post depositional down-warping is indicated in all MSCU areas. Figure 5 indicates the areal extent and structure contours of the MSCU. A generalized isopach map of the MSCU is presented in Figure 8. The MSCU comprises a second regional aquifer. Confined and unconfined conditions exist in the MSCU, but confined conditions are predominate. Ground water is derived from two storage sources in the MSCU: 1) compression of fine grained sediments. Inelastic compression of the aquifer skeleton yields a one-time-only source of water and is closely associated with aquifer compaction and land subsidence (Leake and Prudec, 1988). 2) expansion of water caused by decreasing fluid pressures. The MSCU can be locally productive when wells penetrate sand or gravel stringers. On a regional basis, however, its productivity is much less than the UAU.

The MSCU may be divided into two sub-units. The uppermost sub-unit consists of 90% clays with the intermittent occurrence of gravel and sand lenses. In the deeper areas of the basins evaporite deposits consisting mainly of anhydrite (USBR, 1976), with minor clay and silt form the lower sub-unit. A formal subdivision of the MSCU went beyond the scope and desired resolution of this study, and therefore was not made.

The initial hydraulic parameters for the MSCU were generated from a DLP analysis of 614 wells. Specific yields ranged from 3 to 7 percent. Hydraulic conductivities normally were less than 25 gpd/ft^2. The highest values of both parameters were along the unit's periphery and within the upper MSCU subunit. The lowest values were found generally near the basin centers. A secondary storage factor or storage coefficient under confined conditions was assumed to be 10^{-3} to 10^{-5} (Driskol, 1986). Maps of aquifer parameters and the potentiometric surface were not prepared for the MSCU due to the discontinuous nature of the sand and gravel stringers in this unit. These stringers may be locally productive but do not interconnect hydraulically to such an extent that they form a unified regional aquifer.

Lower Conglomerate Unit

The LCU is the deepest alluvial deposit in the study area and occurs beneath each basin. The lithology is characterized by semi-consolidated to consolidated coarse sediments consisting of granite fragments, cobbles, boulders, sands and gravels. Although the lithology of the LCU varies by location within each basin, it is clearly discernable from the available logs. Drillers' log descriptions include conglomerate, cemented sands and gravels, hard sand, gravel, and sharp sand. The thickness of the unit ranges from less than 50 feet to over 1560 feet, with maximum thickness unknown. Depths from the land surface to the top of the LCU range from less than 50 feet to greater than 6700 feet near Eloy. A LCU structure contour map has been developed (Figure 9).

The LCU is the third and lowest aquifer in the study area and, in some extensively dewatered areas, is the most utilized. The LCU is a productive unit in many locations throughout the study area. Where the LCU aquifer is in direct contact with the UAU it is generally unconfined, and groundwater is derived from storage primarily from the drainage of pore space. Where the MSCU is present the LCU aquifer may be under confined or semi-confined conditions, and water is yielded from compression of fine grained materials and expansion of water caused by decreasing fluid pressures. Well yields from LCU wells can approach those associated with UAU wells.

Hardt and Cattany (1965) referred to a Local Gravel Unit (LGU) at the outflow of the Santa Rosa sub-basin where unconsolidated gravels dominate the lithology. The hydrogeologic analysis confirmed the presence of this sub-unit but insufficient data hindered definition of its exact structural character. The approximate extent of the LGU is shown on Figure 9. Water wells completed through this sub-unit generally have yields exceeding those of the UAU. For the purposes of this study, the sub-unit was considered part of the LCU.

The initial hydraulic parameters for the LCU were generated from a DLP analysis of 163 wells. Only those wells with greater than 200 feet of penetration of the LCU were analyzed. The specific yield ranged from 3 to 18 percent with a mean of 9 percent. The storage coefficient is estimated between 10^{-3} to 10^{-5} (Driskol, 1986). Hydraulic conductivities averaged 254 gpd/ft^2 and ranged from 4 gpd/ft^2 in extremely deep and compacted areas to 998 gpd/ft^2 in the Local Gravel Unit.

Hydrologic Bedrock Unit

The HBU consists predominantly of Precambrian granite, gneiss, and schist, the remainder consists of Mesozoic granite and related crystalline intrusive rocks, volcanic flows, and sedimentary and metamorphic rocks. The HBU forms an impermeable boundary which underlies and borders the model area. The HBU is described in driller's logs as bedrock, hardrock, granite, mountain formation, or rock. Further discrimination between different types of bedrock was unmerited since they do not yield appreciable quantities of water. The HBU is not considered an aquifer in this modeling study.

The HBU underlying much of the study area is at depths seldom reached by water wells, therefore efforts were concentrated near basin edges where most HBU values were observed in logs. Problems encountered during log analysis for the HBU were scarcity of geophysical logs, and the uncertainty of drillers' logs descriptions of bedrock. In the 1100 square mile model area, only 60 values for HBU were found with acceptable confidence. An unsuccessful attempt was made to statistically and graphically correlate observed HBU depths with residual Bouguer gravity anomaly maps using five best fit methods and regressions. Further attempts at cross-sectional gravity modeling were beyond the scope of this study. Previous reports were reviewed but most were found to have inadequate resolution. A depth to bedrock map, developed by Oppenheimer and Sumner (1980), was digitized and aided in the development of the final HBU map.

HBU depths below land surface range from ground level at the mountain fronts to 9880 feet at the Humble Well (D-8-8) 2DBC, near the center of the Eloy subbasin (AOGCC, 1987). The HBU is near the land surface underlying an extensive area near the City of Casa Grande. In this area the HBU forms a north-south trending ridge just west of the City of Casa Grande. This shallow sub-surface feature is commonly referred to as the Casa Grande Ridge. Figure 10 is the HBU structure map.

Geologic and Hydrogeologic Sections

Geologic sections were constructed for the Pinal AMA to aid in structural contouring. Six regional sections were constructed using one to two of the most representative wells per township for each of the transect lines (Figure 11.1). Figure 11.2 is a generalized east-west section which shows the basic hydrogeologic character of the model area. The detailed regional geologic sections are presented in Figures 11.3 - 11.8.

Land Subsidence and Earth Fissuring

Groundwater depletion and water level declines in the study area have caused compaction of silt and clay layers, which has resulted in large scale subsidence and earth fissuring. Benchmark releveling has indicated subsidence is occurring throughout the study area. More than 15 feet of land subsidence was measured as of 1985 in the Eloy sub-basin south of the City of Eloy. In the Maricopa-Stanfield sub-basin near Stanfield, land subsidence was measured at 11.8 feet by 1977, (Schumann and Genualdi, 1986).

Earth fissures in the Pinal AMA are common at basin edges or near the periphery of subsidence areas. They are caused primarily by differential land subsidence stretching the sediments and producing horizontal tensional stresses. These fissures eventually connect to form linear systems, the longest being about nine miles in length near Picacho Peak.

The compaction of compressible fine-grained sediments from water level declines is of considerable concern to groundwater flow modeling in the study area. Compaction of compressible sediments affects the water-bearing properties of an aquifer, resulting in diminished groundwater storage capacity and lower hydraulic conductivities. The USGS (Pool, 1988) estimates that up to one third of the ground water pumpage in the Eloy area may have been derived from compaction since the mid-1960's.

GENERALIZED HYDROGEOLOGIC SECTION — PINAL AMA

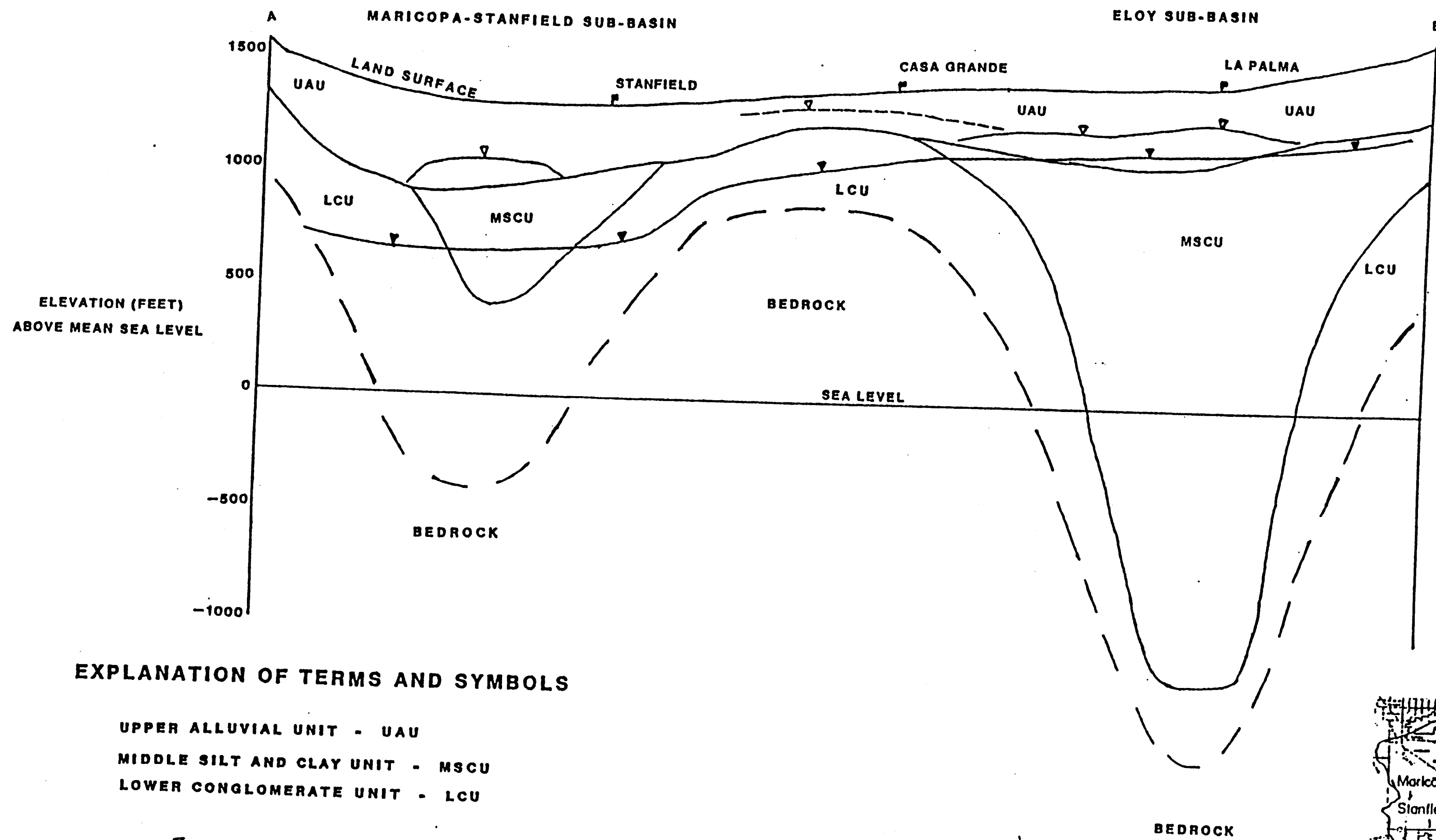


FIGURE 11.2

EXPLANATION OF TERMS AND SYMBOLS

UPPER ALLUVIAL UNIT - UAU

MIDDLE SILT AND CLAY UNIT - MSCU

LOWER CONGLOMERATE UNIT - LCU

REMNANT UAU WATERTABLE

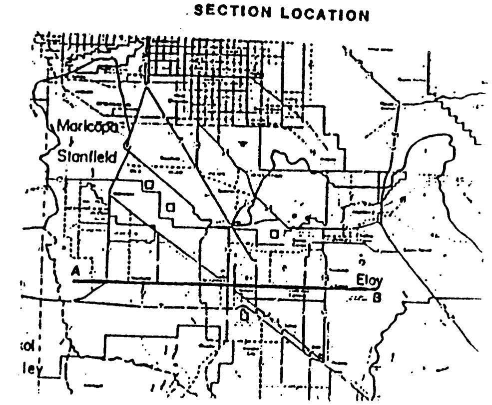
PERCHED WATERTABLE

LCU POTENTIOMETRIC SURFACE

GEOLOGIC CONTACT

INFERED GEOLOGIC CONTACT

SECTION LOCATION



C. GROUNDWATER HYDROLOGY

Methodology of Data Analysis

Measured water levels for over 4000 wells from 1900 to 1988, totaling some 8000 values within the Pinal AMA, were available from the GWSI. Values for desired years were then isolated, plotted, and contoured both manually and by computer. Water levels were assigned to the UAU, MSCU, and LCU according to available well perforation information and the maps of hydrogeologic structure. All final contouring was automated by the use of a computer-based program which allowed depth to water, elevation, saturated aquifer thickness, dewatered area, and water level decline maps to be generated from user-input water level elevation and hydrogeologic structure data. Maps were developed for the UAU and LCU aquifer systems. Maps were not developed for the MSCU because the water-transmitting sand and gravel stringers of this unit are not hydraulically continuous across the study area.

About 70 hydrographs were generated. Where several aquifer systems or perching systems exist, two or three hydrographs were overlain, data permitting. Appendix A is a partial compilation of selected hydrographs. Figure 12 indicates the location of these hydrographs.

Historical Development of the Groundwater System

1900 (predevelopment) to 1920

Prior to 1923, the hydrogeologic system in central Arizona was considered to be in equilibrium (Anderson, 1968). Thomsen and Baldys (1985) of the USGS released a report outlining pre-development water levels, circa 1900, in central Arizona. Most of the water levels presented were measured during the years 1897 and 1905. Depths to water ranged from 10 to 70 feet below land surface prior to groundwater withdrawals. Groundwater flow as inferred from water level contours, was to the northwest in a gently sloping UAU water table (Thompsen and Baldys, 1985). The LCU potentiometric surface probably was near the UAU groundwater table in many areas. However, Smith (1940) indicates that wells that were drilled to depths greater than 500 feet in the Eloy area during the mid-1930's encountered water levels significantly higher than those in shallower wells. The altitude of the water levels in these deeper wells is greater than the altitude of the water table shown on the map of Thompsen and Baldys (1985). These wells indicate that vertical head gradients existed in the Eloy area before development of the area. The greatest underflow into the Eloy sub-basin occurred along the Gila River near Twin Buttes. Underflow into the Eloy sub-basin also occurred south of Picacho Peak along the Santa Cruz River and from the Cactus Forest area north of the Picacho Mountains. Underflow occurred out of the AMA along the Gila River and on the north between Pima Butte and the Sierra Estrella Mountains.

1920 to 1963

Long-term pumpage for irrigation did little to disrupt the regional hydrogeologic system prior to the 1940's, but by the late 1940's impacts from increased pumping, the creation of new recharge sources and areas, and the diversion of natural surface runoff became apparent. As water levels fell, perched water bodies were left behind, wells were deepened to draw from multiple hydrogeologic units, and cones of depression formed near pumping centers. Differences between UAU and LCU water levels began to develop as the result of groundwater withdrawals.

A composite water level elevation map was prepared from the 156 measured water levels for 1963 (Figure 13). A composite water level map represents water levels from wells that are completed in multiple aquifers.

The UAU became dewatered in many parts of the Maricopa-Stanfield sub-basin. The remanent UAU aquifer thickness ranged from 0 feet to 400 feet in the Maricopa-Stanfield sub-basin. Depths to water were measured at approximately 100 feet to 515 feet. Flow patterns for 1963 were very different from those of the system in equilibrium. The direction of flow by 1963 was generally towards the northwest from Casa Grande, and south from the Gila River. A large cone of depression had formed beneath and immediately south of the Ak Chin Indian Reservation. Water table gradients indicated no underflow out of the Maricopa-Stanfield sub-basin.

Dewatering of the UAU was not as extensive in the Eloy sub-basin. UAU aquifer thickness ranged from 0 feet to 940 feet and depths to groundwater ranged from 32 feet for a perched system near Casa Grande to 300 feet near Picacho Peak. Groundwater flow directions were north-northwest from the Picacho Peak area and generally west-southwest from the Cactus Forest area. Water table gradients indicate some underflow out of the sub-basin along the Gila River to the northwest, and also underflow to the Maricopa-Stanfield sub-basin west of Casa Grande.

As the regional water table declined wells were deepened and pumpage from the LCU increased. An extensive perched system developed in the upper half of the UAU near Casa Grande. Although this system is believed to have originally occurred as a remnant water table, it is currently recharged and maintained by agricultural return flows, irrigation canal losses, and other sources. The western extent was marked by a sharp drop in water levels to the regional water table just west of the Casa Grande Ridge. The eastern boundary was not clearly pronounced and it appeared that the perched system gradually dropped to the regional water table. The vertical saturated thickness of the perched system is not known. A 1973 drilling report from a water well located at (D-6-5)13BAD reported water at a depth of 55 feet. The driller then cased off 140 feet of the well through the perched zone and again encountered water at 435 feet.

A thorough definition of the regional water levels beneath the perched zone was not possible for 1963. Since almost every well was completed in both the perched zone and the regional aquifer system the water levels measured in wells were composites which generally represented shallower perched water levels. The composite water level map (Figure 13) therefore represents this perched zone rather than the underlying regional system.

A map of the 1963 potentiometric surface of the LCU was not constructed. However, it may be loosely interpreted from the composite water level map, Figure 13. Where the UAU is dewatered and the MSCU does not overlie the LCU, the potentiometric surface shown in Figure 13 is that of the LCU. Where the MSCU exists, the potentiometric surface of the LCU is assumed roughly equal to or greater than that of the unconfined UAU aquifer water levels, except in the vicinity of the Casa Grande perched system. By 1963, in the basin centers where the LCU potentiometric head is the greatest, few wells had penetrated this unit, nor was there significant pumping of groundwater from the confined aquifer.

The water levels associated with the MSCU were not contoured for 1963. Again, this is because the MSCU is not hydraulically continuous throughout the study area.

1963 to 1977

Continued pumping and increased development from 1963 to 1977 further impacted the hydrogeology of the area. Groundwater level changes over this 14-year period ranged from 90 feet of rise in the Eloy sub-basin south of Casa Grande Mountain to 352 feet of drawdown west of the town of Maricopa, with measured depths to water ranging from 34 feet to 708 feet below land surface. Figure 14 shows contours of 1977 composite groundwater elevations. As with 1963 water levels, the LCU and MSCU potentiometric surface were not separately analyzed. There were 239 measured water levels for 1977.

Groundwater flow directions in the Maricopa-Stanfield sub-basin were generally directed toward the cones of depression near Maricopa and Stanfield and south from the Gila River. Inflow to the regional water table was also from the east from under the Casa Grande perched system. Figure 15, which shows water level changes from 1963 to 1977, was derived by using water levels from wells measured for both years. Large declines in water levels were observed throughout the entire Maricopa-Stanfield sub-basin. Expansion of the cones of depression under the eastern and western edges of the Maricopa Indian Reservation had occurred. Large drawdowns were also observed southwest of Stanfield. A second set of water levels are contoured on the 1977 composite water level map. These are water level contours of the remanent UAU aquifer in the Maricopa-Stanfield sub-basin. The composite groundwater map clearly illustrates the separation of the water levels in the UAU from the potentiometric surface of the LCU in the area of the Maricopa-Stanfield sub-basin.

The Eloy sub-basin experienced no significant changes in flow patterns. In the north, groundwater flow direction was south to southwest from the Gila

River and Cactus Forest areas, while the groundwater flow south of Picacho Peak was to the northwest. Flattened UAU groundwater gradients were common throughout the Eloy sub-basin. Figure 15 shows virtually no drawdown impact to the northern Eloy sub-basin between 1963 and 1977 emphasizing the stabilizing impacts of agricultural return flows and Gila River flows. However, large declines in water levels were observed in the southern Eloy sub-basin. The Casa Grande perched system experienced water level declines of as much as 50 feet over the 14 year period.

1977 to 1985

The analysis of groundwater levels for October 1984 through March 1985 was the most complete and comprehensive for all years studied. Individual water levels were classified by hydrogeologic unit using hydrogeologic unit elevation maps, (Figures 5 and 9), and well perforation information. For data-deficient and "problem" areas, additional groundwater levels were measured in 1986. Contours were then generated for the UAU and LCU using over 1300 measured water levels.

Figures 16 and 17 show 1985 UAU groundwater elevations and depths to water. Figure 16 also shows the groundwater elevations of the Casa Grande perched system. These maps differ from the composite water level maps for 1963 and 1977 in that separate UAU regional water levels are shown, and the Casa Grande perched system is contoured as a separate system.

UAU groundwater flow directions may be inferred using Figure 16. In both sub-basins the groundwater flow was directed toward the cones of depression. In the Maricopa-Stanfield sub-basin, the areal extent of UAU dewatering increased and decline rates continued to be significant near the Ak Chin Indian

Reservation, reflecting nearby groundwater withdrawals. Some recovery was observed to the north along the Gila River Indian Reservation. The Eloy sub-basin experienced no significant change in UAU flow patterns from 1977 conditions. In the early to mid 1970's, many production wells in the northern Eloy sub-basin were deepened to tap the LCU aquifer rather than the rapidly declining UAU aquifer. The effects of the reduced UAU pumping and relatively abundant surface water due to wet years are evidenced by a reduction in the water level decline rates and in some areas a water level rise. In the northern Eloy sub-basin the flow direction was south to southwest, while the groundwater inflow south of Picacho Peak was to the northwest.

A thorough analysis of the LCU water levels was performed to produce a LCU potentiometric surface map. Figure 18 shows the estimated potentiometric surface elevation contours for the study area including the regional LCU water table beneath the Casa Grande perched system. Figure 19 is the generalized depth to the LCU potentiometric surface for 1985, and represents the probable static depth to water in a well drilled and perforated in the LCU, which is a confined aquifer except near basin margins and in areas of the Maricopa-Stanfield sub-basin where the UAU has been de-watered and the MSCU is absent.

LCU groundwater flow in both sub-basins was directed toward cones of depression. In the Maricopa-Stanfield sub-basin the LCU groundwater flow was directed toward the basin center. In a large part of the Eloy sub-basin it was not possible to develop the potentiometric surface map due to data deficiencies and groundwater flow directions are not known in this part of the sub-basin. However, flow was directed toward a cone of depression south of the Casa Grande Mountains caused from extensive pumping from deep wells in that area.

The trend in composite groundwater level changes between 1977 and 1985 can be seen in Figure 20. Groundwater levels generally declined in the Maricopa-Stanfield sub-basin. The declines ranged from 5 to 224 feet. In the northern Eloy sub-basin the groundwater levels rose from 2 to 40 feet. In the southern Eloy sub-basin the groundwater levels declined. The declines ranged from 5 to 40 feet. Although the net trend for 1977 to 1985 was one of declining water levels, hydrographs show a decrease in the rates of annual decline over the eight year period in both sub-basins (See Appendix A).

1985 to 1988

Large groundwater level rises occurred primarily in the Eloy sub-basin, while declines continued in the Maricopa-Stanfield sub-basin between 1985 to 1988. Measured index wells provided sufficient groundwater elevation data to estimate 1988 regional water levels. Groundwater flow directions were similar to those in 1985. Groundwater level changes between 1985 and 1988 are shown in Figure 21.

Groundwater flow in the Maricopa-Stanfield sub-basin was directed toward cones of depression located south of the Gila River and west of the Casa Grande Ridge. The effects of continued pumping near the Maricopa Indian Reservation were evident. Some recovery of groundwater levels occurred west of Maricopa and north along the Gila River Indian Reservation due to reduced agricultural irrigation and recharge along the river channel from wet years.

The Eloy sub-basin experienced regional water level recoveries of as much as 46 feet between 1985 and 1988. The largest rises were centered in the basin near Eloy, the Pichacho Reservoir, and the San Carlos Irrigation Project area. Groundwater level recovery of as much as 20 feet was present near Casa

Grande. No water level measurements were available near the cone of depression west of the Picacho Mountains. Various factors have probably contributed to the recovery of water levels within the Eloy sub-basin. Possibly deep percolation of 1983 flood water in the Santa Cruz River channel and Gila River channel has had some effect. It is also possible that the reduction in pumping associated with the Payment in Kind (PIK) program contributed to the recovery.

Another factor contributing to the water level rises measured in the Eloy sub-basin is not fully recognized in historic groundwater level collection activities. Most of the recharge in the sub-basin has occurred to the UAU, while wells have been deepened and groundwater withdrawals have increased in the LCU. Historic groundwater level data tend to reflect data from index wells, many of which have records extending for many years but which are perforated in several aquifers. The measured water levels in these wells represent a "composite" of the mix of aquifers and no longer fully reflect the developing complexity of the groundwater system of the Pinal AMA. It is possible that data from only the LCU aquifer would not show a large rise, but instead a drop in overall groundwater levels. Unfortunately, availability of aquifer-specific water level measurements do not permit the confirmation of this explanation. The conceptual water budget developed for the Eloy sub-basin, discussed later in this report, lends some credence to this explanation however.

D. Surface Water Hydrology

Of the three main watercourses in the Pinal AMA, only the Santa Cruz and Gila Rivers significantly interact with the groundwater systems of the model area. Santa Rosa Wash, an ephemeral stream running north into the Maricopa-

Stanfield sub-basin near Vaiva Vo, was dammed by the US Army Corps of Engineers in 1974 for flood control purposes. Dam releases and spillage from the Tat Momolikot Dam are negligible and are not believed to impact the hydrogeology of the model area.

The Santa Cruz River flows ephemerally into the Pinal AMA between Picacho Peak and the Silverbell Mountains. It runs in a northwesterly direction to its confluence with the Gila River near the Sierra Estrella Mountains. Sporadic natural surface water runoff is augmented by sewage effluent and agricultural return flows from the Upper Santa Cruz and Avra Valley sub-basins. The majority of flow, when present, is diverted for agriculture shortly after entering the AMA. Only for extraordinary rainfall events do appreciable surface flows reach the Eloy sub-basin. Seasonal flow also occurs in the Santa Cruz River between Casa Grande and the Gila River, primarily from agricultural return flows, and effluent discharges.

Streamflow data for the Santa Cruz River within and near the model area is inadequate for determining streamflow or groundwater recharge. The closest upstream gage is Santa Cruz River at Marana (USGS gage 09486250), approximately 15 miles upstream of the Pinal AMA boundary. No information is available to identify diversions from flow. Santa Cruz River outflows are available from a streamflow gage on the Santa Cruz River near Laveen (USGS gage 09489000), near its confluence with the Gila River. The low flow at this gage is from irrigation return flows and from municipal effluent discharges. Effluent discharges were estimated to be less than 4000 acre-feet per year by the Pinal AMA staff. Larger flows are primarily runoff in response to precipitation events within the Pinal AMA. Groundwater recharge from the Santa Cruz River is considered negligible in this study, but a recommendation for field work to better quantify this factor has been made in Section IV of this report.

The Gila River system is the largest and most important source of surface water in the Pinal AMA. The river flows into the AMA northeast of Florence and continues west through the Gila River Indian Reservation just north of the Sacaton Mountains. In 1928 the BIA constructed the Coolidge Dam on the Gila River near Globe as part of the San Carlos Irrigation Project (SCIP) for the purpose of providing stored surface water to 100,000 acres of farmland. About 45,000 acres are currently supplied irrigation water by the SCIP. Water released from Coolidge Dam is diverted at the Ashurst-Hayden Diversion Dam for delivery to the San Carlos Irrigation Project. The project then distributes the water to its customers via a predominantly unlined canal system. Flow in the canals is augmented by groundwater from wells. The SCIP office in Florence compiles flow and loss data, together with reported canal diversions, and summarizes this data in an annual report. These reports have been used to calculate Gila River recharge and canal losses, however, these reports provide only a general picture of water diversions and use in the SCIP area as a whole. It was estimated that the average annual recharge from SCIP canal seepage to the UAU in the model area was 138,000 acre-feet for the period 1985-1988.

III GROUNDWATER BUDGET: INFLOWS AND OUTFLOWS

The inflows and outflows for the Pinal AMA conceptual water budget are presented by this section in four parts: A) subsurface inflows and outflows (underflow), B) pumpage, C) recharge, D) and a conceptual groundwater budget.

A. GROUNDWATER UNDERFLOW

The calculation of model area underflow is fundamental to the development of a conceptual water budget. Underflow (or groundwater flux) is defined as groundwater which flows in or out of the Eloy and Maricopa-Stanfield sub-basins through the subsurface in response to a hydraulic gradient. Figure 22 shows the areas where significant inflows and outflows exist.

Underflows were calculated using flow-net analysis. Fluxes were calculated separately for the UAU and LCU. The MSCU was not considered since the unit is absent near basin edges. Analysis of 1985 groundwater levels indicated significant hydraulic gradients exist at the model area boundaries. Water levels and hydraulic gradients were estimated for data deficient areas. Structure contour and groundwater level maps provided the information to determine aquifer cross-sectional area and saturated thickness for each flow net.

The UAU saturated thickness was derived from Figure 7. The LCU saturated thickness is equal to the difference between the LCU potentiometric surface elevation and the bottom elevation of the LCU. If the LCU potentionmetric surface elevation is greater than the top elevation of the LCU, the saturated thickness is equal to the difference between the LCU top and LCU bottom elevations. It is believed that little subsurface flow occurs in the LCU below a saturated thickness of 2000 feet. Therefore, the LCU saturated thickness was limited to a maximum of 2000 feet. Preliminary hydraulic conductivities derived during steady state model calibration were used.

The Darcy flow equation was used to calculate flux through each flowtube.

$$Q = K\ i\ A$$

where Q is volume of flow
K is hydraulic conductivity
i is hydraulic gradient
A is saturated cross-sectional area

The fluxes for each area did not vary significantly from 1985 through 1987. This is evidenced by the lack of change in water levels near basin edges during this period. Individual flows are summarized in Table 4, and totaled in the conceptual water budgets, shown in Part D of this section. These are preliminary estimates based on representative hydraulic conductivities. Since these aquifer parameters will be modified during the modeling process, these estimates are subject to change during Phase Two of this project.

TABLE 4

GROUNDWATER INFLOWS/OUTFLOWS 1985-1987
PINAL AMA MODEL AREA
(See Figure 22)

FLUX AREAS		(ACRE-FT/YR)*
INFLOWS		
Aguirre Inflow		4,100
Cactus Forest Inflow		2,800
North Maricopa - Stanfield Inflow		32,000
South Picacho Peak Inflow		35,300
Waterman Wash Inflow		600
	TOTAL INFLOW	74,800
OUTFLOWS		
Florence Outflow		4,200
Santan-Sacaton Mountains Outflow		4,800
	TOTAL OUTFLOW	9,000
	NET FLUX (INFLOW-OUTFLOW)	65,800

(Figures are preliminary estimates subject to revision)

Values used to calculate Table 4 Inflows/Outflows
Average UAU K 350 gpd/Ft^2 - 450 gpd/Ft^2
LCU K 35 gpd/Ft^2 - 45 gpd/Ft^2
Average Saturated Thicknesses Derived from Figures 9, 7, 18
Average Gradients Derived from Figures 16, 18

* Figures rounded to nearest 100 ACRE-FT/YR

B. PUMPAGE

Pumpage is addressed in this section for two time periods: 1) Historical, 1915 to 1983, and 2) 1984 to 1987. Annual pumpage volumes are presented for all years. Pumpage volumes distributed by section (square mile) for 1985 through 1987 are presented in Figure 23.

Historical (1915-1983)

The first use of groundwater for irrigation of agricultural land in the Lower Santa Cruz basin began in the 1890's. By 1910, annual groundwater withdrawals of about 80,000 acre-feet for irrigation of approximately 25,000 acres of farm lands (Hardt and Cattany, 1965). By 1948, groundwater withdrawals had risen to 1 million acre-feet annually (AFA) irrigating 280,000 acres.

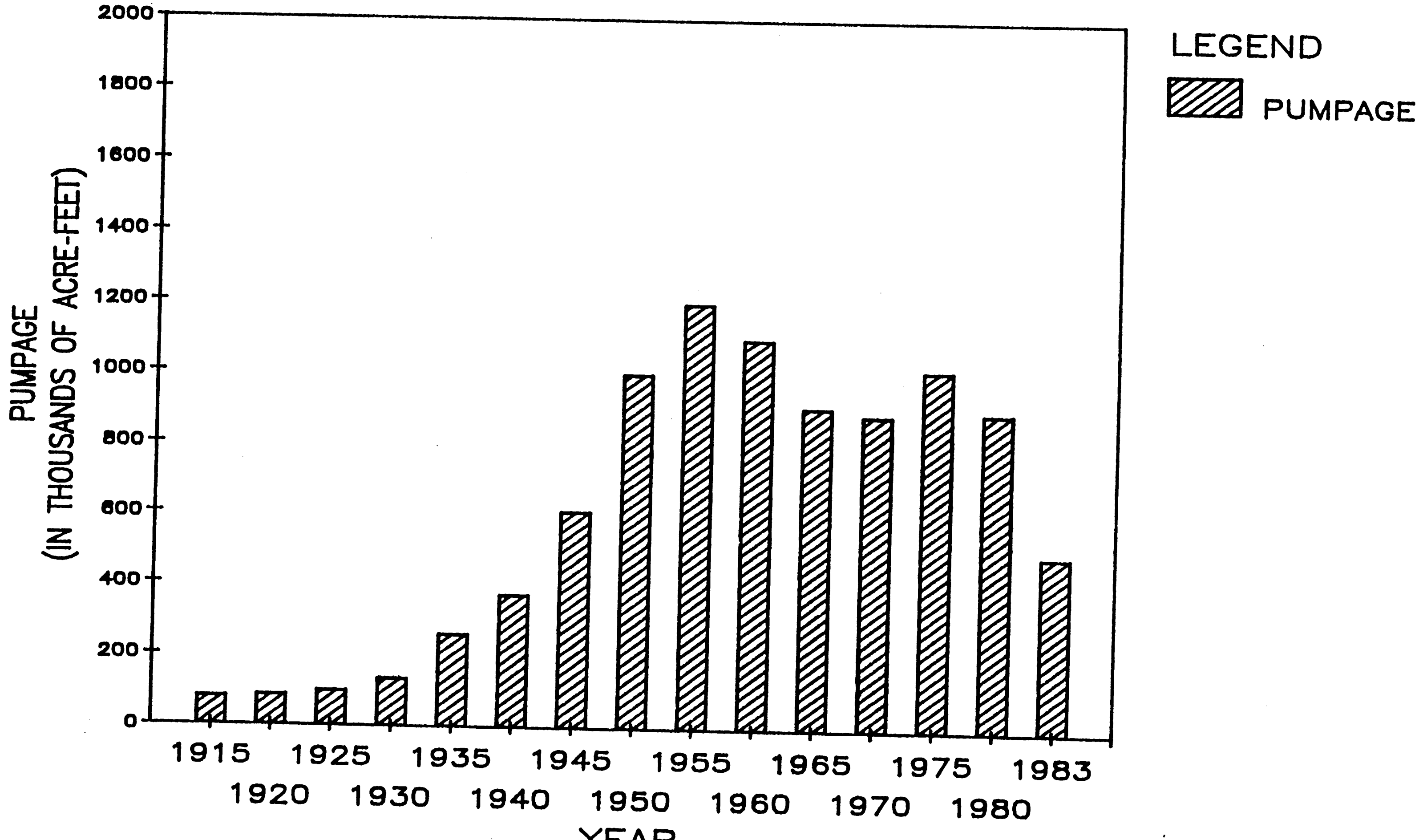
Groundwater withdrawals and the resulting groundwater level declines continued until the early 1980's and long term pumping continued to deplete groundwater supplies much faster than they were replenished. Chart 1 shows US Geological Survey estimates of groundwater withdrawals for the Lower Santa Cruz Basin, an area roughly equivalent to the area of the Pinal AMA. The majority of groundwater pumpage shown is for agriculture with only a small percentage for other uses.

Sources and methods for pumpage estimates prior to 1984 are varied. Hardt and Cattany (1965) estimated pumpage for irrigation use based on a blanket water duty per acre. Electric power consumption records have been used by the USGS to estimate regional pumpage for many years (USGS, 1985). The Groundwater Management Act of 1980 required all groundwater users who wished to secure a withdrawal right to submit to ADWR information regarding cropped acreages, crops grown, groundwater pumped, water received and delivered, and other information for the application period 1975-1979. This information was later verified by ADWR and is available for the Pinal AMA for these years. Since most values of pumpage for 1975-1979 are unmeasured estimates reported by applicants, the pumpage figures should be scrutinized.

CHART 1

ESTIMATED GROUNDWATER PUMPAGE IN THE LOWER SANTA CRUZ AREA

(Numbers rounded to the nearest 1000 acre-feet)



(Source: USGS, 1985)

1984 - 1987

Since 1984 all non-exempt groundwater right holders have been required to report their metered groundwater pumpage and inter-right water distributions. Domestic or exempt wells which pump a maximum of 10 AF/YR are not required to report pumpage. As of 1988, there were 1,016 exempt or domestic wells within the Pinal AMA. Therefore, the maximum exempt or domestic pumpage is estimated to be less than 10,000 AF/YR. The pumpage information for non-exempt groundwater withdrawal right holders is accessible from the Registry of Groundwater Rights (ROGR) data-base management system at the ADWR Operations Division. ROGR, SCIP annual reports, and reported Ak-Chin Farms pumpage provided total withdrawal volumes for the model area.

In order to assign groundwater withdrawals to the UAU or LAU, available well perforation intervals for all wells were summed by section (one square mile) Total pumpage was weighted by aquifer unit for each section based on available well perforation data and representative specific yields from the DLP analysis. A well-by-well analysis of pumpage for hydrogeologic assignment was not practical primarily due to the large volume of data. Additionally, reported wells in ROGR are not consistently linked to ADWR and USGS Groundwater Site Inventory (GWSI) well construction data.

The total Pinal AMA groundwater withdrawals for 1984-1987 from ROGR do not include withdrawals volumes by the Ak-Chin Farms on the Maricopa Indian Reservation, or the San Carlos Irrigation Project. Ak-Chin Farms pumpage volumes were reported to be 29,000-30,000 AF/YR. Measured well production capacities, provided by the Ak-Chin Farms, were used to weight pumpage volume by well for distribution into model area. San Carlos Irrigation Project pumpage by well is estimated by power consumption, and is reported in their annual reports. Table 5 presents total groundwater pumpage for 1984-1987 for the Pinal AMA. The pumpage information presented in Chart 1 shows that the total groundwater pumpage in the Pinal AMA decreased substantially in 1983. This decrease is attributed in part to the retirement of agricultural land due to the PIK program which reduced agricultural production. Figure 23 shows generalized composite pumpage distributions for the model area.

Table 5

Total Groundwater Pumpage in Model Area

1984 - 1987

(Acre-Feet)*

Year	Ak-Chin Farms**	San Carlos Irrigation Project	ROGR	Total
1984	~30,000	52,600	529,700	612,300
1985	~30,000	39,200	559,100	628,300
1986	~30,000	54,800	464,700	549,500
1987	~30,000	44,700	513,600	588,300

* Figures rounded to nearest 100 acre-feet

** Estimate provided by Ak-Chin Farms

C. Recharge

Groundwater recharge, or the addition of percolating waters to the aquifer was considered an important water budget component in this study. Recharge sources evaluated include the Gila River, San Carlos Irrigation Project canals and Picacho Reservoir, and agricultural irrigation. Effluent and mountain front recharge and recharge from the Santa Cruz River were also assessed, but the combined total recharge volume from these sources was estimated to be less than 12,000 Af/year, and they were not considered for the purposes of this study.

River Recharge

The only river recharge source considered for this report is the Gila River where it intersects the northern model boundary of the Eloy sub-basin. (See Figure 1). Comparatively small flows from the Santa Cruz River reach the Pinal AMA boundary, however these flows have not been measured and they were not currently considered in this report. Inflows to the study area from the Gila River were obtained from the SCIP Annual Reports, which provided monthly surface flow volumes sluiced or spilled at the Ashurst-Hayden Diversion Dam. Gila River outflows were available at USGS gage 09479500, Gila River near Laveen. The measured stream reach length within the model area was 24 miles, and the total reach length between the Ashurst-Hayden Diverson Dam and the USGS gage at Laveen was 64 miles. Additions to flow along the reach were accounted for, data permitting. These included discharge into the Gila River from the SRP Gila Storm Drain and from the City of Chandler Lone Butte Wastewater Treatment Plant. No information was available to estimate agricultural return flows to the river channel from within the Gila River Indian Reservation. City of Coolidge effluent discharges were estimated to be less than 900 acre-feet/year.

Chart 2 presents Gila River flows and calculated routing losses from 1972 through 1987. The Gila River routing losses were calculated for the model area by prorating the total routing loss according to the ratio of the reach length inside the model area to the total length of the stream reach. Although river recharge was derived using annual inflow and outflow volumes, monthly data exist and may be used during Phase Two to derive more precise estimates.

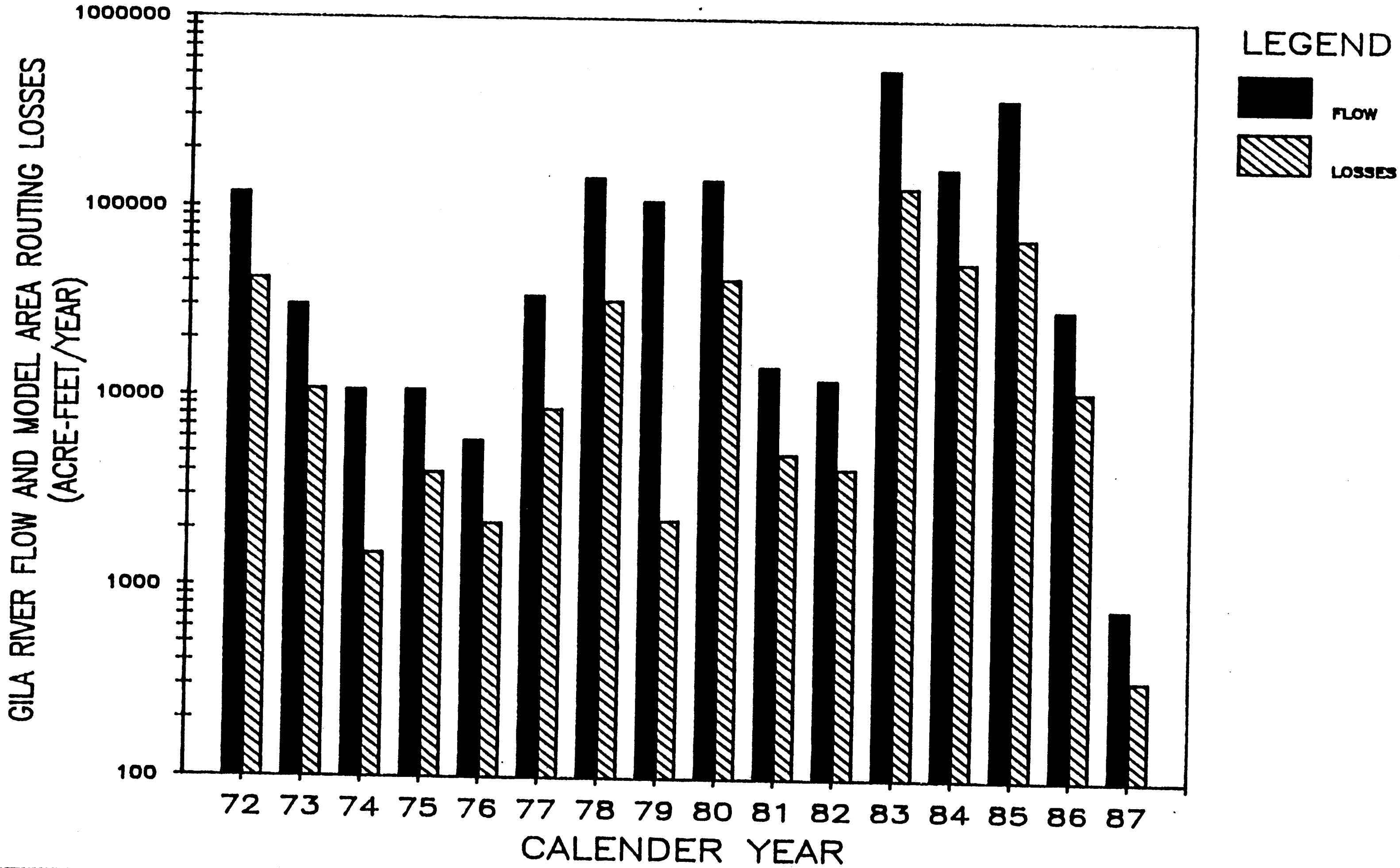
The following assumptions were made for this initial analysis:

- stream flow and recharge occur within the Gila River channel
- losses = reach inflow + additions to flow - reach outflow.
- losses = maximum potential recharge; no evapotranspiration losses
- no additional diversions of flow within reach
- loss rate is constant for any channel segment

These assumptions provide an estimate of the maximum potential recharge to groundwater from the Gila River since no evaporation or evapotranspiration has been accounted for. During Phase II it may be necessary to reconsider some of these assumptions, and therefore reduce these initial estimates.

CHART 2

GILA RIVER FLOWS AND CALCULATED MODEL AREA LOSSES
FROM ASHURST-HAYDEN DAM TO USGS GAGE 09479500 NEAR LAVEEN
(LOSSES=MAXIMUM POTENTIAL RECHARGE)



San Carlos Irrigation Project (SCIP) Canal and Reservoir Losses

Estimates for canal and reservoir losses in the unlined distribution system were derived from SCIP annual reports, which report accounting losses to their system. Figure 24 presents the generalized distribution of canal and reservoir losses in the Pinal AMA. Three potential sources of recharge were identified: the main canal system, the lateral canal system, and Picacho Reservoir.

Main canal losses in the study area occur along the Florence-Casa Grande Canal, the Northside Canal, and the unlined portion of the Pima-Lateral Canal. Losses for the main canal system were reported by SCIP. Losses for the lateral canal system and the Picacho Reservoir are not reported, and were calculated using a water budget analysis. Lateral canal loss distribution was accomplished by partitioning the entire irrigation district into 9 sub-areas based on the configuration of the distribution system (Figure 25). The total lateral surface area value for each sub-area was then used to weight the volume of losses to be distributed over each respective area.

The potential evaporation losses were calculated for the SCIP canal and reservoir system. Losses due to evaporation from canals and laterals were estimated to be less than 500 Af/yr. The evaporation losses for the Picacho Reservoir were estimated to be greater than 5,000 Af/yr. The evaporation losses for the canal system were disregarded for this study, but the reservoir evaporation losses were accounted for in the calculation of the maximum potential recharge.

Table 6 is an example of reported and calculated water distribution and losses for the San Carlos Irrigation Project for 1984. Table 7 is a summary of canal and reservoir losses for the San Carlos Irrigation Project from 1984 through 1986.

The following assumptions were made in order to estimate losses:

- All laterals carried flow for equal duration during distribution periods
- SCIP reported diversions for irrigation along laterals were accurate
- Infiltration occurred evenly for all channel surfaces

It should be noted that these initial assumptions provide an estimate of the maximum potential recharge to groundwater from the SCIP canals, laterals, and the Picacho Reservoir. During Phase II it may be necessary to re-evaluate some of these assumptions, and therefore reduce these initial estimates.

CALCULATED MAXIMUM POTENTIAL RECHARGE FOR MODEL AREA
SAN CARLOS IRRIGATION PROJECT - 1984

1.	66,002 AF	Reported main canal losses*
	-11,432 AF	Adjustment of 17.3% of main canal losses which occur outside model area
	54,570 AF	Adjusted Main Canal Losses
2.	196,738 AF	Total Water Diverted to District*
	- 125,511 AF	Total Water Delivered to Land*
	71,228 AF	Lateral Canal Losses
3.	46,738 AF	Total Water Delivered to Picacho Reservoir*
	- 26,609 AF	Reservoir Releases*
	- 5,649 AF	Evaporation Loss (at 7 FT/YR x 807 acres of reservoir surface area)
	14,577 AF	Picacho Reservoir Losses
4.	54,570 AF	Adjusted Main Canal Losses
	71,227 AF	Lateral Canal Losses
	14,577 AF	Pichacho Reservoir Losses
	140,454 AF	Model Area Maximum Potential Recharge

* Data from 1984 SCIP Annual Report.

TABLE 7

CANAL AND RESERVOIR LOSS SUMMARY FOR MODEL AREA
SAN CARLOS IRRIGATION PROJECT
(ACRE-FEET)

Year	Reported Main Canal Losses*	Adjusted Main Canal Losses**	Lateral Canal Losses	Picacho Reservoir Losses	Maximum Potential Recharge Pinal AMA	Maximum Potential Recharge Model Area
1984	66,002	54,570	71,227	14,577	151,806	140,454
1985	36,557	30,269	83,951	11,428	131,936	125,648
1986	57,133	47,306	83,729	17,045	157,907	148,080
3987	40,209	33,293	73,304	14,806	128,319	121,403

* Data from SCIP Annual Reports

** Adjustment of 17.3% for model area

Groundwater Recharge from Agricultural Irrigation

Groundwater recharge from agricultural irrigation is the most important source of recharge in the Pinal AMA. Agricultural recharge is defined in this report as the water applied to the ground surface for the purpose of producing crops or forage which does not go to consumptive use, and through deep percolation contributes to the aquifer. Both groundwater and surface water are used to irrigate crops in the Pinal AMA. Surface water use has historically been restricted to the Eloy sub-basin on San Carlos Irrigation Project lands, but Central Arizona Project (CAP) water will be delivered both to the Maricopa-Stanfield and Eloy sub-basins in the future and must be considered in later studies of the Pinal AMA. Groundwater users for irrigation purposes are required to have an Irrigation Grandfathered Right (IGFR). IGFR holders are required to report IGFR acreage and amount of groundwater withdrawn, and surface water and groundwater received and delivered. Use of this information permits the calculation of a groundwater application volume for each IGFR.

The areal distribution of agricultural irrigation was accomplished using IGFR reports which are filed annually with ADWR. Unfortunately, reporting of crop type is not required and farmers often irrigate less land than the maximum they are legally allowed. The reported IGFR averages are the maximum acreage legally irrigable. The amount of land actually irrigated is usually less. Therefore, an accurate annual application depth could not be calculated nor could IGFR-specific crop consumptive use factors be assigned.

Figure 26 is a map of 1986 Eligible Grandfathered Irrigation Areas within the study area, but does not indicate those areas actually irrigated. Non-Indian irrigated acreage for 1986 was calculated using reported groundwater and surface water application volumes, estimated irrigation efficiencies and a regional consumptive use factor. The representative consumptive use factor of 2.77 acre-feet/acre was provided by the Pinal AMA office. This factor is an approximation of the average consumptive use for the entire Pinal AMA. Irrigation efficiencies were provided by the Pinal AMA office and were derived from 1980 and 1986 field investigations of irrigation systems. The only Indian irrigated acreage considered was that reported by AK Chin Farms. Total non-Indian irrigated acreage for 1987 was obtained from digital processing of Landsat images. Only IGFR areas were analyzed because irrigation of non-IGFR areas is restricted, and exempt wells may not be used to irrigate areas larger than two acres.

The total Maximum Potential Agricultural Recharge (MPAR) was calculated using irrigated acreage, application volumes, and a representative consumptive use factor. Individually calculated IGFR application volumes were used to areally distribute the calculated MPAR. The total calculated application and MPAR volumes for the model area for 1984 through 1987 are listed in Table 8. Figure 27 presents generalized distributions of MPAR for 1985, 1986 and 1987. The MPAR volume is similar to other estimates of recharge in that it is the maximum volume available. During Phase II it may be necessary to reconsider various assumptions, and reduce these initial estimates.

Table 8
Agricultural Recharge

APPLICATION AND RECHARGE VOLUMES 1984-1987
PINAL AMA MODEL AREA

	IRRIGATION ACREAGE				APPLIED VOLUMES		MAXIMUM POTENTIAL RECHARGE VOLUMES
	A	B	C	D	E	F	G
YEAR	NON-INDIAN	INDIAN	TOTAL	Irrig. Eff.	ROGR (AF)	AK-CHIN (AF)	(AF/YR)
1984	163,510*	5,330***	168,840	67%	676,005	30,000	238,317
1985	173,946*	5,330***	179,276	68%	708,575	30,000	241,979
1986	145,320*	5,330	150,650	69%	583,388	30,000	196,086
1987	163,889**	5,630	169,519	70%	705,597	30,000	266,029

* Calculated value.
** Determined from Landsat image processing.
*** Estimated value from later year.

A = E / (2.77/D)
G = (E+F) - (2.77C)
Consumptive Use Factor = 2.77

Effluent Recharge

A complete file for effluent production, treatment and disposal in the Pinal AMA was assembled. Most disposal schemes involve the application of treated effluent to farmland and golf courses for irrigation, or to holding and evaporation ponds. At this time, effluent recharge is considered negligible because discharge volumes are relatively minor. The Pinal AMA estimates the approximate volume of effluent which is generated annually within the AMA to be 4000 acre-feet. This is less than 1% of the estimated maximum annual volume of water available for recharge and it was not felt worthwhile for this project to further analyze this budget component.

Mountain Front Recharge

Mountain front recharge is defined for the purpose of this report as that portion of runoff generated by precipitation on mountainous areas adjacent to an alluvial basin which contributes at the mountain base or front to groundwater storage. This form of recharge was investigated as an inflow source in order to determine its influence on the regional groundwater flow model.

The mountains surrounding the model area are generally small in areal extent and usually below 3000 feet above Mean Sea Level (MSL) with the exception of the Picacho Mountains (highest point 4508 feet above MSL) and the Table Top Mountains southwest of Stanfield (highest point 4373 feet above MSL). All mountainous areas in the Pinal AMA support only desert vegetation. Rarely is winter precipitation stored as snowpack. Watson et al. (1976) found that no recharge occurred in the Basin and Range Province when annual rainfall was less than 8 inches. In areas with 8 to 12 inches of annual rainfall, 3% is contributed to recharge. In areas receiving 12 to 15 inches annual rainfall, 7% is contributed to recharge. Basin precipitation for the study area averages about 8 inches per year. Mountain precipitation is usually greater than 8 inches but not likely to exceed 15.5 inches annually. As an example, the total mountainous contributing area for the Picacho Mountains from Picacho Peak to south Cactus Forest is 6429 acres, An 8 to 15 inch yearly precipitation would contribute between .24 to 1.05 inches, with a range for maximum potential recharge of 129 to 562 acre-feet per year for this mountain range. Most mountains in the study area are much lower than the Picacho Mountains and recharge along their fronts would be less.

This study concluded that mountain front recharge has a negligible impact on the overall groundwater budget of the study area. In addition, the work required to generate estimates is not proportional to their importance. However, if during Phase Two it appears necessary to include these recharge estimates, mountain front recharge will be further evaluated.

D. Conceptual Groundwater Budget

Conceptual groundwater budgets were developed for both the Maricopa-Stanfield sub-basin and the Eloy sub-basin. The budgets cover only the three year period of 1985 through 1987, since it was felt more complete and accurate data were available for this period. The budget components previously derived in this report have been divided by sub-basin to provide a clear picture of the hydrologic system in each sub-basin.

An additional budget component which has been calculated is the change in groundwater storage within the sub-basins. This calculation was made using changes in composite groundwater levels (Figure 21), representative specific yields, and area weighting. A comparison between the calculated change in storage, and the change in storage obtained from the water budget shows a large discrepancy for both sub-basins. As these two quantities should ideally be equal, some explanation is required.

The water budget for the Maricopa-Stanfield sub-basin shows that there was a net decrease in groundwater storage between 1985 and 1988 (see Table 9). Both the calculated change in storage from water level changes of -56,800 acre-feet and the sum of the budget inflows and the outflows of -290,500 acre-feet reflect a decrease in groundwater in storage.

The water budget for the Eloy sub-basin shows that there was a net decrease in storage over the three year period. The calculated change in storage from groundwater level changes was 621,000 acre-feet, and the sum of the budget inflows and the outflows was -70,800 acre-feet. It is likely that several factors discussed below contribute to the difference between these estimates.

TABLE 9

CONCEPTUAL GROUNDWATER BUDGET*
MARICOPA-STANFIELD SUB-BASIN MODEL AREA
PINAL AMA

	(ACRE-FEET)** 1985	1986	1987	3-YEAR TOTALS
I. INFLOWS				
A. Groundwater Underflow	32,600	32,600	32,600	97,800
B. Groundwater Recharge				
1. Agricultural Irrigation	84,200	61,900	83,200	229,300
		TOTAL INFLOW		327,100
II. OUTFLOWS				
A. Pumpage				
1. ROGR	210,000	155,600	162,300	
3. Ak-Chin	29,900	29,900	29,900	
	239,900	185,500	192,200	-617,600
		TOTAL OUTFLOW		-617,600
III. CHANGE IN STORAGE				
		TOTAL INFLOW		327,100
		TOTAL OUTFLOW		-617,600
		TOTAL INFLOW+TOTAL OUTFLOW		-290,500
		CALCULATED CHANGE IN STORAGE FROM WATER LEVELS		-56,800

* Values presented are for a composite groundwater system.

** (Figures Rounded to Nearest 100 Acre-Feet)

TABLE 10

CONCEPTUAL WATER BUDGET*
ELOY SUB-BASIN MODEL AREA
PINAL AMA

	(ACRE-FEET)**			
I. INFLOWS	1985	1986	1987	3-YEAR TOTALS
A. Groundwater Underflow	42,200	42,200	42,200	126,600
B. Groundwater Recharge				
1. Agricultural Irrigation	157,800	134,200	182,800	
2. SCIP Canals, Laterals, Reservoir	125,700	148,100	121,400	
3. Gila River	70,700	11,000	300	
	354,200	293,300	304,500	952,000
		TOTAL INFLOW		1,078,600
II. OUTFLOWS				
A. Groundwater Underflow	9,000	9,000	9,000	-27,000
B. Pumpage				
1. ROGR	349,000	309,300	351,500	
3. SCIP	31,800	45,900	34,900	
	380,800	355,200	386,400	-1,122,400
		TOTAL OUTFLOW		-1,149,400
III. CHANGE IN STORAGE				
		TOTAL INFLOW		1,078,600
		TOTAL OUTFLOW		-1,149,400
		TOTAL INFLOW+TOTAL OUTFLOW		- 70,800
		CALCULATED CHANGE IN STORAGE FROM WATER LEVELS		621,000

* Values presented are for a composite groundwater system.

** (Figures Rounded to Nearest 100 Acre-Feet)

In both sub-basins the magnitude of the calculated change in storage from groundwater level changes was greater than the change in storage obtained from the water budget. One explanation for this is that the various budget components of inflow and outflow are inaccurate estimates, and that inflow is underestimated compared to outflow. However, when the individual budget components are examined, and their methods of derivation considered, it seems unlikely that these numbers could be so inaccurate. In addition, the inflow components of the water budget (recharge and basin underflow) were purposely estimated as maximum potential quantities. A more likely explanation for the difference between the change in storage calculated from changes in water levels and the change in storage based on the water budget is that the change in storage based on water level changes is derived from composite groundwater levels which do not completely or accurately define the hydrologic system, and mis-estimated specific yields.

The change in storage calculated from changes in water levels may be inaccurate because the water levels in many wells exhibit semi-confined to confined responses to aquifer stress. The USGS has measured seasonal water level variations between 80 and 100 feet in a piezometer well, (D-7-8)31BBA, which is perforated only in the UAU aquifer (Pool, 1988). These large fluctuations are typical of a confined response to seasonal aquifer stresses, and indicate confined conditions can exist in the UAU. Since confined conditions can exist in the UAU, it is possible that the measured water level changes in wells are not representative of true water table changes, and the storage changes do not necessarily occur over the same depth intervals in the UAU in which the water levels fluctuate. The calculated change in storage from water level changes is based upon the assumption that changes in storage occur over the same depth intervals in which the water levels change. This assumption is reasonable in a totally unconfined aquifer, but it may not be appropriate for the UAU in the model area.

The change in storage calculation based on water level changes may also be inaccurate because of the inability to use these water levels to accurately estimate changes in storage within the LCU. Figure 21 is a composite water level change map. Most of the positive water level changes occurred in the UAU to which recharge accrues, while most of the negative changes occurred in the unconfined LCU from which substantial groundwater withdrawals occur. It was possible to make estimates of the percentage of groundwater pumped from each aquifer in each sub-basin. In the Maricopa-Stanfield sub-basin it is estimated that approximately 30% of the groundwater pumped between 1985 and 1987 was derived from the UAU aquifer. The remaining 70% was derived from the LCU and MSCU aquifers. In the Eloy sub-basin estimates place UAU pumpage at approximately 50%, and combined LCU and MSCU pumpage at 50%. Due to the fact that few LCU water levels were collected it was not possible to observe regional changes in the LCU potentiometric surface. It is likely that the LCU potentiometric surface dropped basin-wide, considering pumpage and recharge distributions, but it was not possible to verify or quantify this. As a result the calculated changes in storage may not show the full extent of the decrease in storage in the LCU, and could be erroneously estimated.

Another factor which may have contributed to the difference between the two estimates of the change in storage is the mis-estimation of the average specific yield of the UAU. Severe overdrafting of the groundwater system has caused land subsidence and aquifer compaction to occur. More than 15 feet of land subsidence has occurred in the Eloy sub-basin, and more than 12 feet has occurred in the Maricopa-Stanfield sub-basin (Schuman and Genualdi, 1986).

The lowering of the groundwater table or a decrease in artesian head results in the rearrangement and closer packing of the coarse incompressible aquifer grains and the compression and partial dewatering of compressible fine-grained materials (Davidson, 1973). It is possible that the original DLP estimates of specific yield may no longer be representative of post-compaction values. Also, the average UAU specific yield value may not be representative at the depths over which the storage changes occurred. The UAU tends to be fine grained at depth, and therefore decrease in specific yield with depth. It is possible the depths over which the water levels are fluctuating are finer grained than the average UAU (Pool, 1988).

It seems likely that the calculated changes in storage, based upon water level changes, are not accurate estimates. Better estimates of the change in storage within the Pinal AMA groundwater system are obtained from the water budgets. It would be desireable, given that two distinct regional aquifers exist in the study area, for separate water budgets for the UAU and LCU to be developed. This was unfortunately not possible given the lack of definition in groundwater level data. Section IV of the Phase I report gives recommendations that will make further definition of the groundwater system of the Pinal AMA possible for future updates of the Pinal AMA model.

IV. PHASE ONE: DATA DEFICIENCIES WITH RECOMMENDATIONS

One of the objectives of the Phase One study was to identify and define data deficiencies within the model area as they pertain to the development of a regional groundwater flow model, and to provide possible detailed remedies to be implemented to improve future data collection efforts. Four primary data deficiencies were recognized during Phase One: they are summarized below and later discussed in detail.

DATA DEFICIENCIES

A. Groundwater level measurements: The selection and the sampling density of wells on the current ADWR water level index line do not adequately represent the complexity of the groundwater system for modeling purposes. Many of these index line wells have a very long history of water level measurements, but may no longer reflect the groundwater system now present in the Pinal AMA. Recommended adjustments to the current index line are listed in Appendix C of the Phase I report.

B. Current well data: Well construction data, logs, and particle-size analyses for wells drilled or deepened within the study area are inadequate or unavailable. This causes severe problems in basic geologic definition of the aquifers of the Pinal AMA, and with determination of accurate groundwater levels, and flow directions, and drawdowns for the UAU and LCU. Recommendations for field work and requirements for more complete applications to drill a well are made.

C. Unit-specific aquifer parameters: Data for hydraulic conductivity and storage coefficient obtained from various field tests are not useful or are insufficient for accurate repesentation of the groundwater system. Accurate aquifer parameters are a basic requirement for almost all hydrogeologic analysis. Recommendations are made for field work and further analysis of ADWR file data.

D. Santa Cruz River flow measurements: Flow in the Santa Cruz River into the Pinal AMA is not currently measured and may be locally important as a recharge source. A recommendation is made for fieldwork to correct this lack of data.

The following section provides a detailed discussion of these data deficiencies, and recommendations are made which will reduce or eliminate these deficiencies.

A. GROUNDWATER LEVEL MEASUREMENTS

Water level measurements are essential to the modeling effort. Annually, the ADWR Basic Data Section measures groundwater levels in index wells in the Pinal AMA, collects water quality samples, and measures well discharges. The current Pinal AMA index line was examined during the Phase I effort. It was found that index well construction data were lacking or inadequate for many of the wells on the index line. It was also found that many of the wells were completed in multiple hydrogeologic units, and therefore hydrogeologic unit-specific water levels could not be obtained from these wells. The following modifications to the index line are recommended.

1) Revise the line to phase out wells that have non-useful well construction data, or are completed in multiple aquifers and replace these with others for which more complete well construction data are available.

2) Increase the number of wells measured to cover data deficient areas.

Recommended additions and deletions to the Pinal AMA index line are listed in Appendix C. Fieldwork must be done to assess the actual availability of suggested additional wells.

B. CURRENT WELL DATA

A fundamental part of any modeling effort is the definition of the areal and vertical extent of hydrogeologic units. In some areas it is not possible to adequately define these units because there are no well logs or sieve analyses available. The ADWR Operations division currently receives and processes applications for well drilling permits. The following recommendations are made to help provide the Department with new information which should help better define the hydrogeology of the Pinal AMA.

1. The Operations Division should be requested to notify Hydrology of current well drilling operations in the Pinal AMA.
2. Allocation of funds for the collection and particle-size analyses of cuttings from wells drilled in data-deficient areas should be made. If manpower and funding are limited, collect and store the cuttings until such a time when sieve analyses can be performed.
3. The Department should no longer accept applications which are partially blank; much valuable information is lost because of this practice.

C. UNIT-SPECIFIC AQUIFER PARAMETERS

The accurate estimation of unit-specific aquifer parameters is essential to the modeling process. These parameters were estimated during Phase One, but often with little data. These estimates should be calibrated to field data for accuracy. The following recommendations should produce field measurements for model calibration and verification.

1. Perform long-term aquifer tests. These tests should provide the best estimates of aquifer parameters.
2. Compile and analyze specific capacity data for wells. Well pump tests or completion tests may provide this type of information. Existing data examined for this study were of poor quality and it was not possible to associate specific capacity data with specific hydrogeologic units.

A list of potential aquifer test wells was compiled. However, these wells were field checked and determined to be unsuitable for a variety of reasons which included lack of access, destruction of wells, and small well diameters unsuitable for pumping. A new list should be compiled based on field studies.

D. SANTA CRUZ RIVER FLOW MEASUREMENTS

The Santa Cruz River periodically flows into the Pinal AMA. The Pinal AMA estimates the 1985 inflow to be 20,000 acre-feet (ADWR, 1988). Recharge from this flow may be locally significant and should be accounted for in future modeling efforts. It is recommended that some measurement of streamflow be made to provide inflow and recharge information. Field observations by the Basic Data section of ADWR indicate that there is no appropriate site for a permanent stream gage in the area where the Santa Cruz River flows into the Pinal AMA. However, it would be possible to make periodic measurements of the average wetted channel length, width, water depth, and water velocity. Measurements such as these could be made by the Hydrology Division, and they would provide a reasonable estimate of Santa Cruz River flow within the model area.

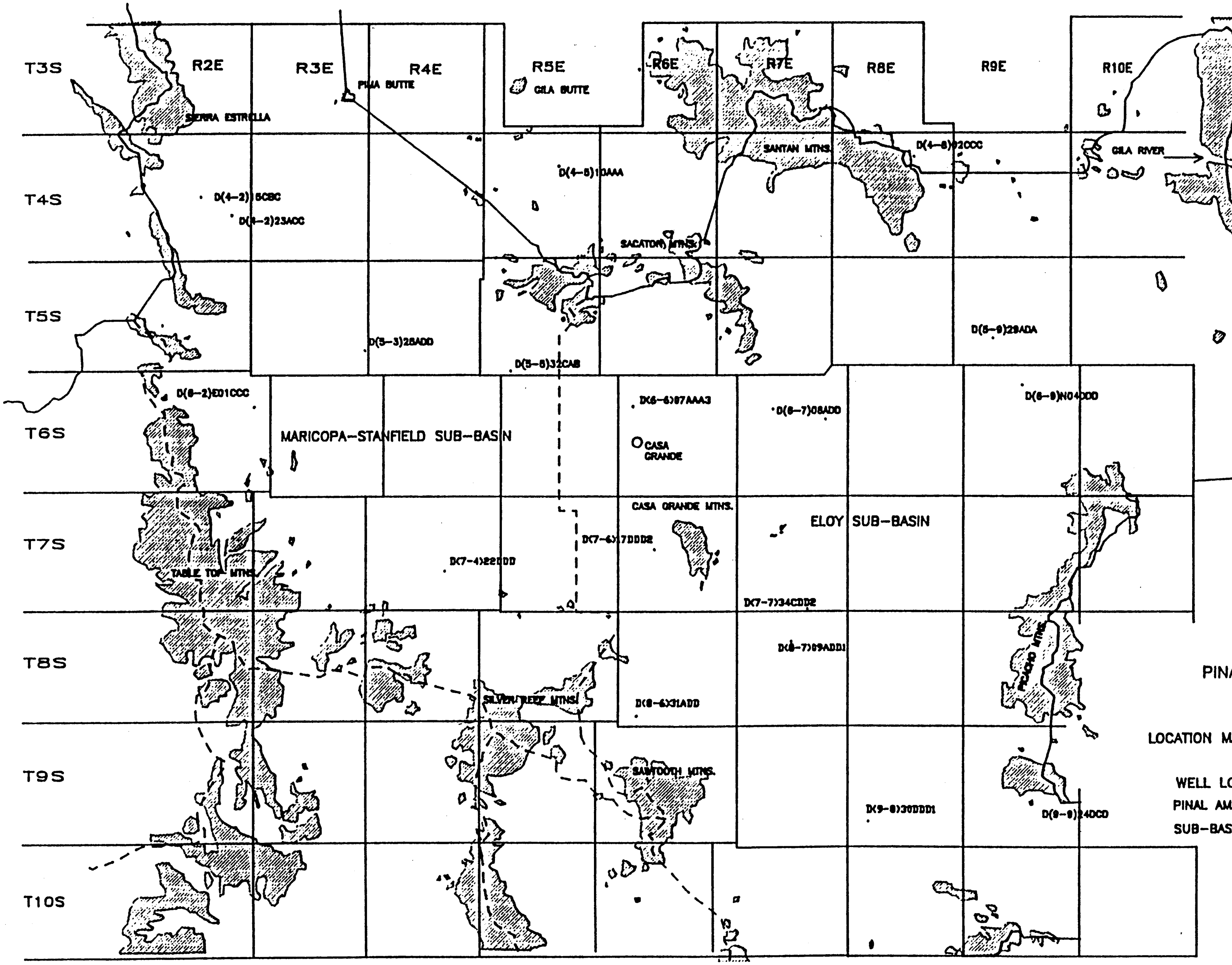
APPENDIX A

PINAL AMA HYDROGRAPHS

PINAL AMA HYDROGRAPHS
(REFER ALSO TO FIGURE 28) *

WELL LOCATION	YEAR COMPLETED	WELL DEPTH (FT)	CASING INTERVAL (FT)	PERFORATED INTERVAL (FT)
(D-4-2)15CBC	1950	372	0-372	125-365
(D-4-2)23ACC	1951	800	-	-
(D-4-5)10AAA	1934	376	0-376	100-362
(D-4-8)02CCC	1941	485	-	-
(D-5-3)25ADD	-	550	0-550	115-535
(D-5-5)32CAB	1952	500	-	150-
(D-5-9)29ADA	1935	616	0-614	134-226 336-342 352-355 378-384 412-420 432-440
(D-6-2)E01CCC	1949	-	0-551	150-551
(D-6-6)07AAA3	1959	620	0-680	155-610
(D-6-7)08ADD	-	-	-	-
(D-6-9)N04DDD	1943	600	0-600	200-580
(D-7-4)22DDD	1951	808	0-400	180-400
(D-7-6)17DDD2	1941	155	0-100	50-100
(D-7-7)34CDD2	1945	900	0-900	130-886
(D-8-6)31ADD	1941	282	0-220 220-282	75-208 232-282
(D-8-7)09ADD1	1939	418	0-418	110-418
(D-9-8)30DDD1	1940	600	0-600	180-580
(D9-9)24DCD	1952	420	0-420	200-416

*DATA FROM ADWR GWSI



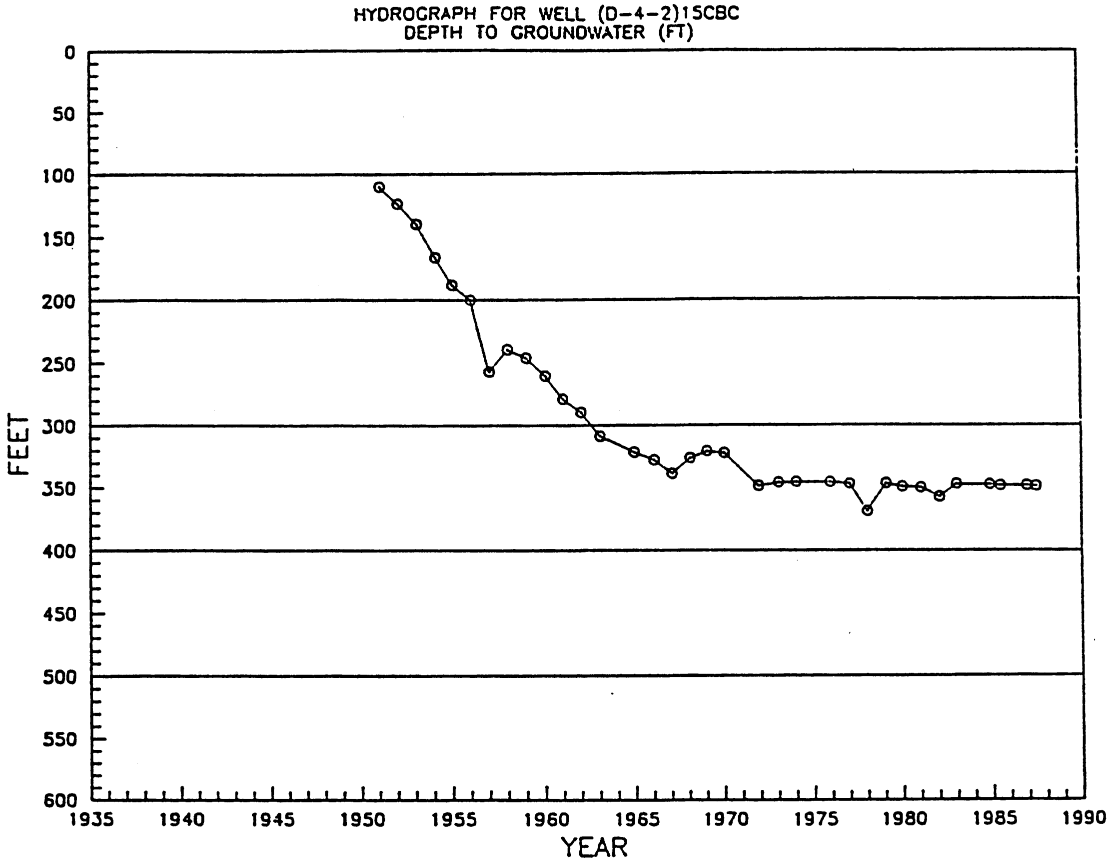
PINAL AMA MODEL AREA

FIGURE 12

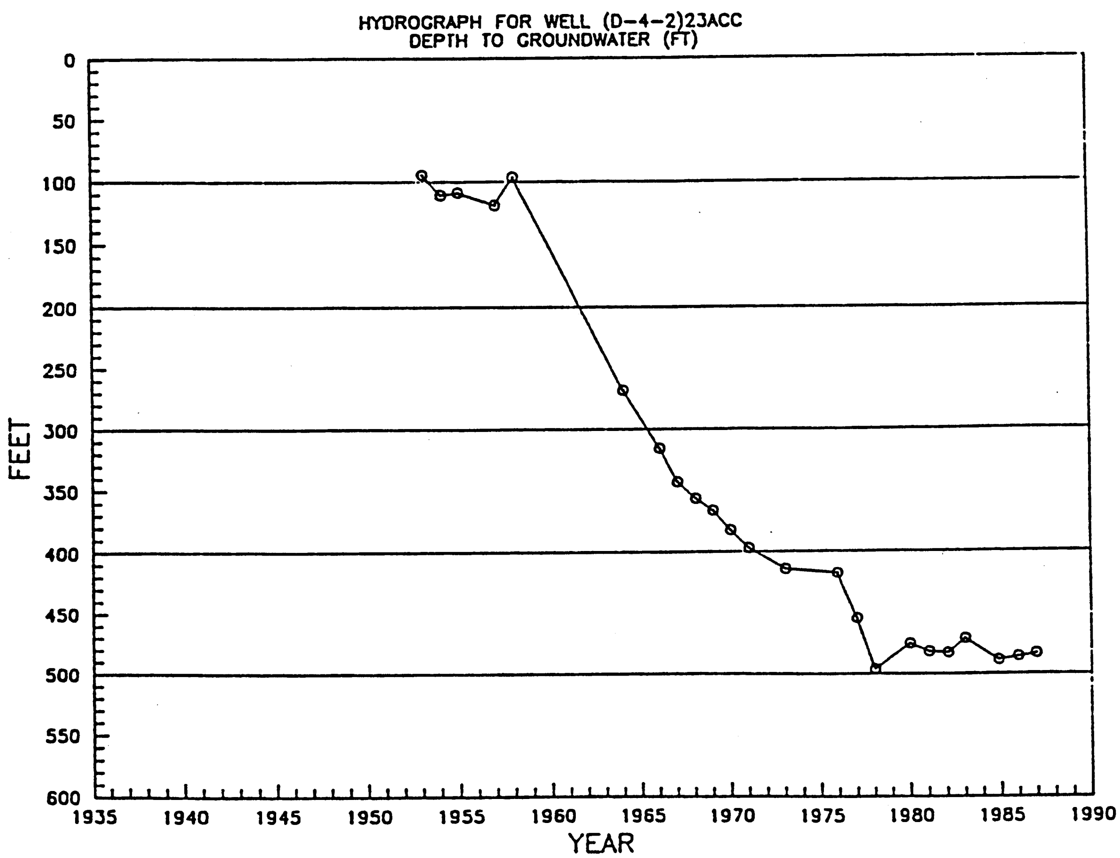
LOCATION MAP FOR WELLS WITH HYDROGRAPHS

WELL LOCATION ·
PINAL AMA BOUNDARY ———
SUB-BASIN BOUNDARY – – – –

0 2 4
SCALE IN MILES

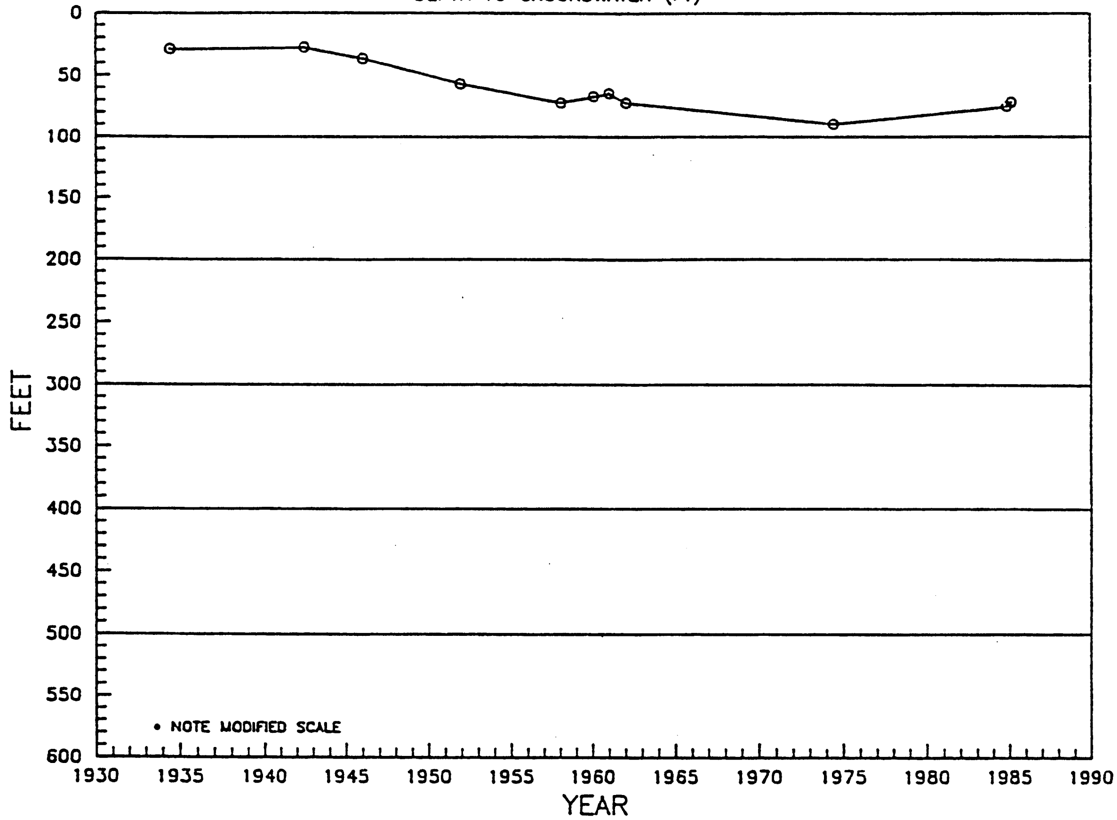


HYDROGRAPH FOR WELL (D-4-2)15CBC
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990

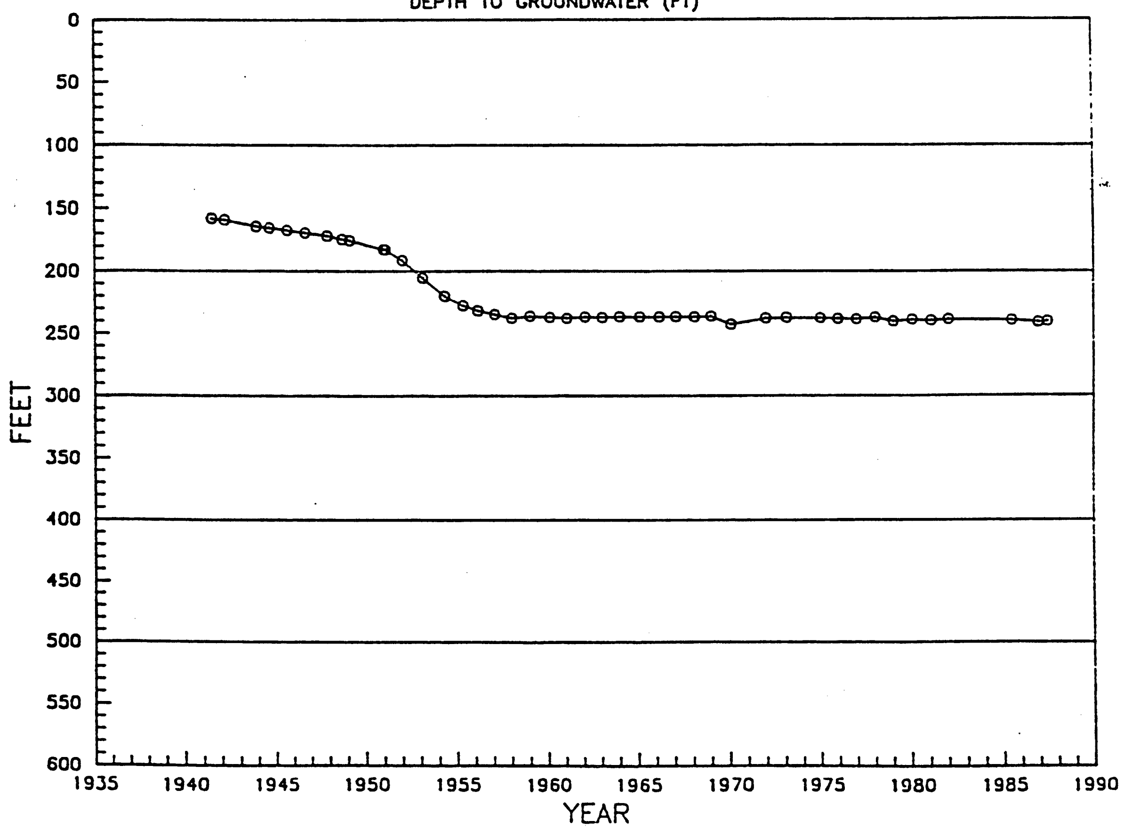


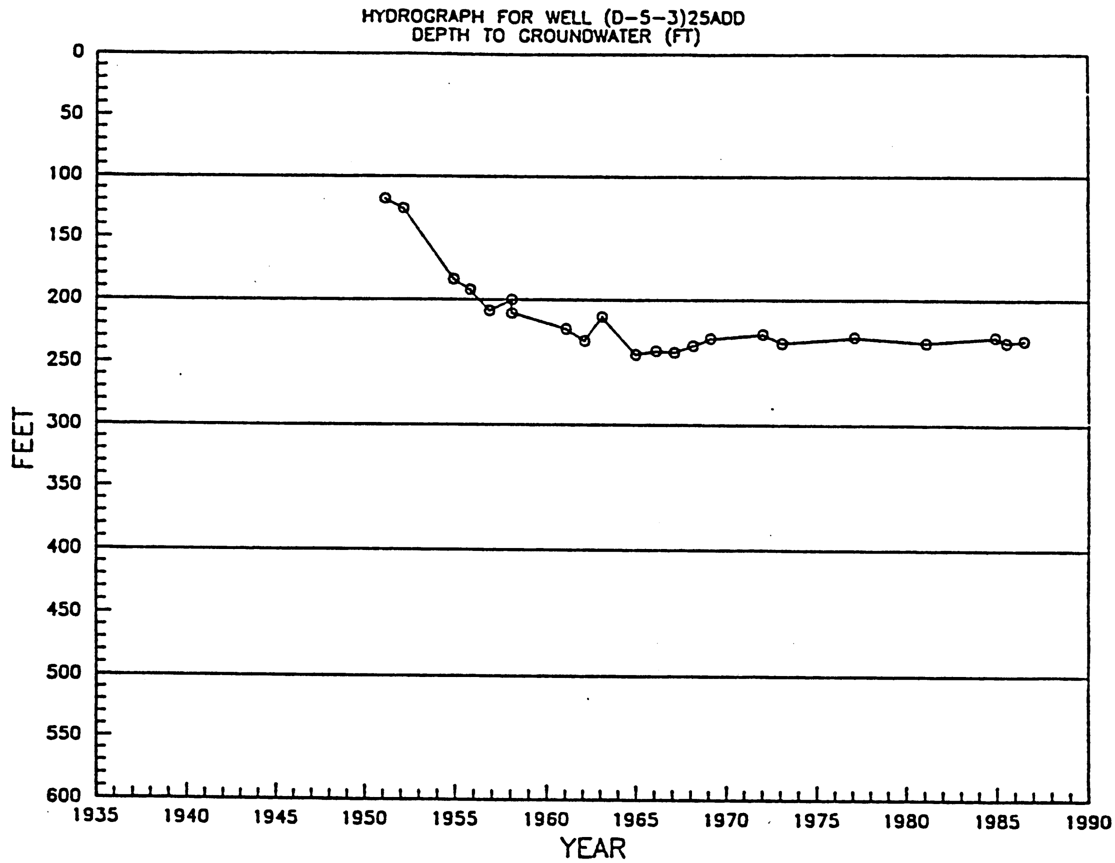
HYDROGRAPH FOR WELL (D-4-2)23ACC
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990

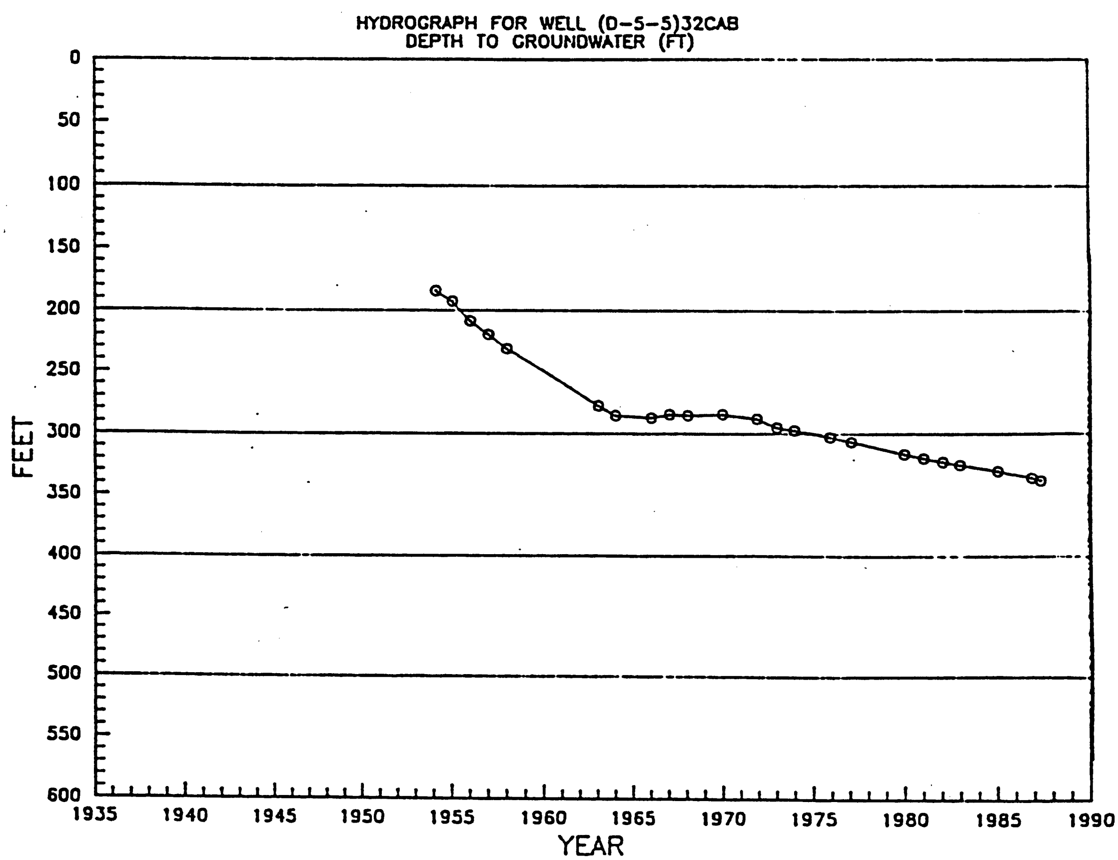
HYDROGRAPH FOR WELL (D-4-5)10AAA
DEPTH TO GROUNDWATER (FT)



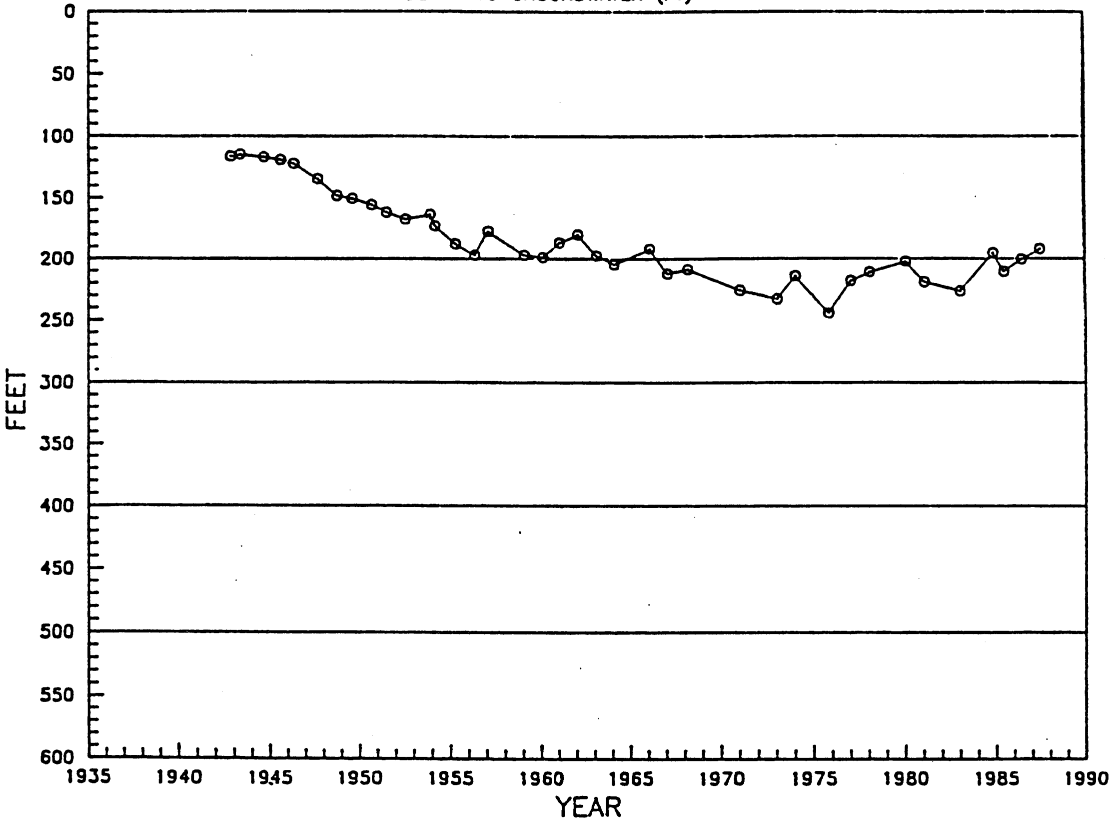
HYDROGRAPH FOR WELL (D-4-8)02CCC
DEPTH TO GROUNDWATER (FT)



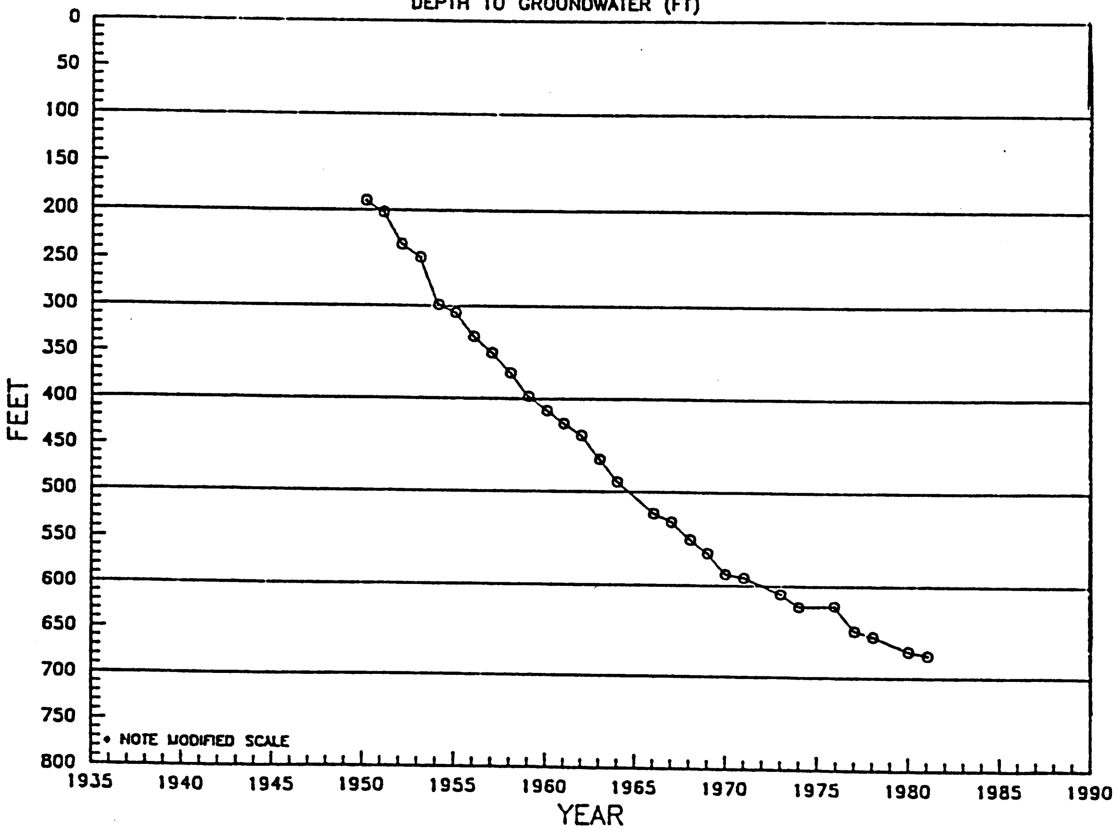

HYDROGRAPH FOR WELL (D-5-3)25ADD
DEPTH TO GROUNDWATER (FT)
FEET
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR

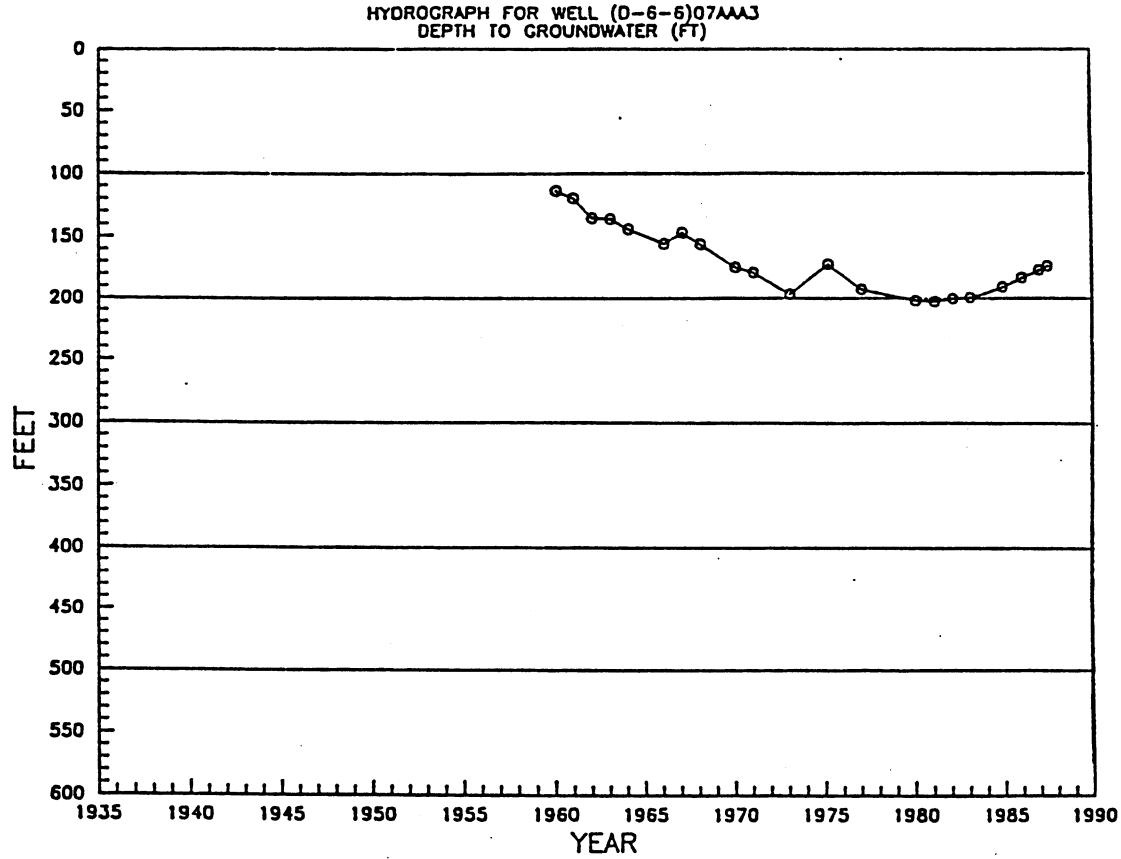

HYDROGRAPH FOR WELL (D-5-5)32CAB
DEPTH TO GROUNDWATER (FT)
FEET
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR

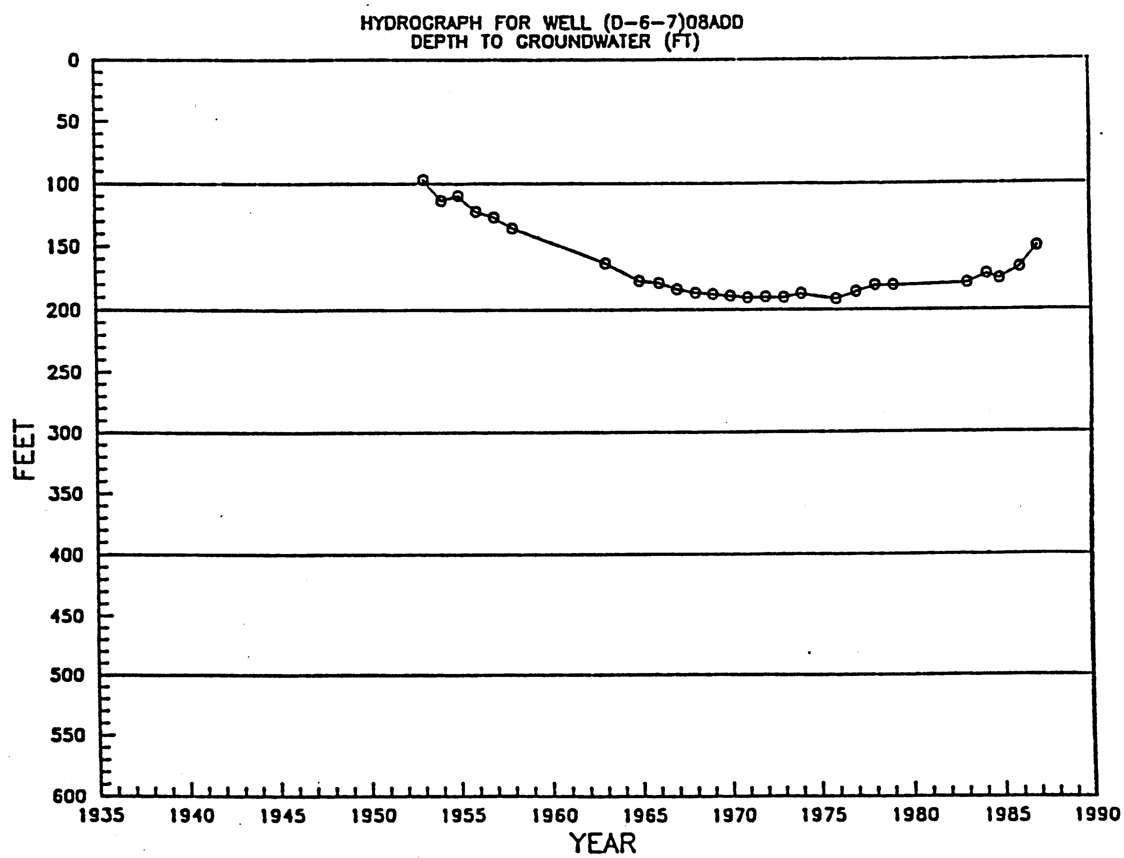
HYDROGRAPH FOR WELL (D-5-9)29ADA
DEPTH TO GROUNDWATER (FT)

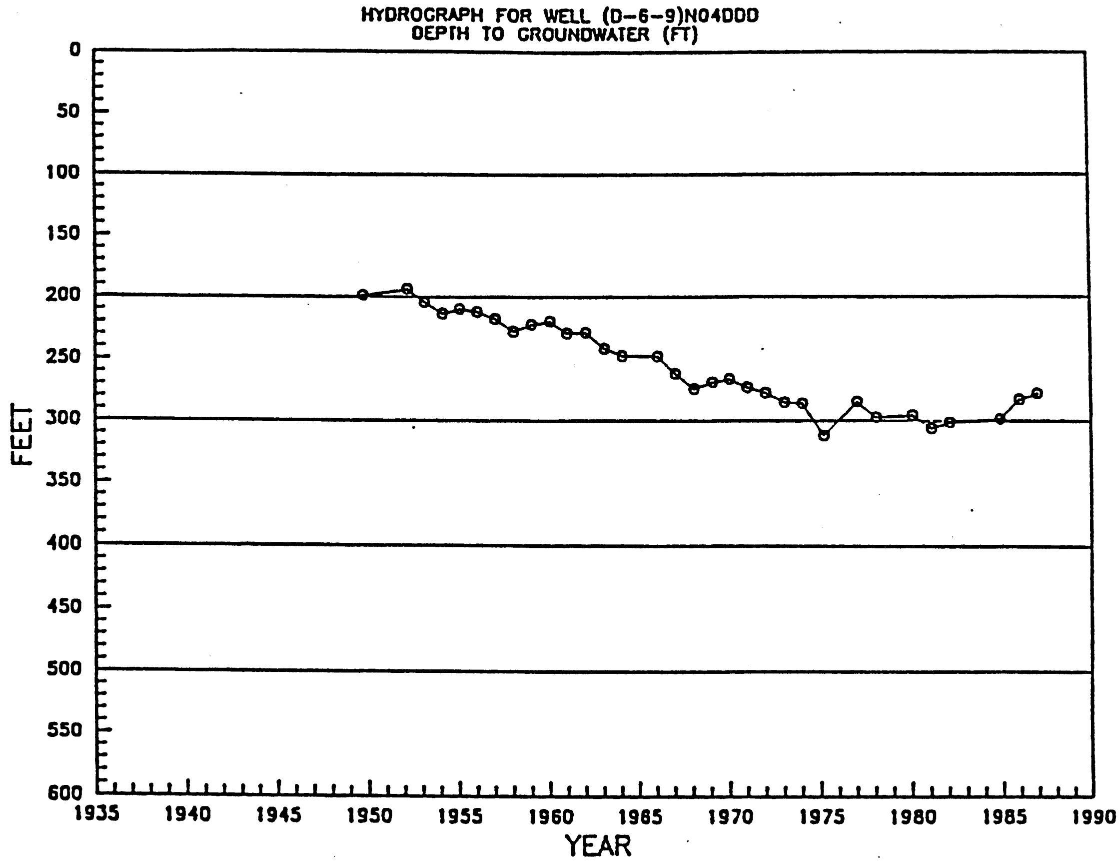


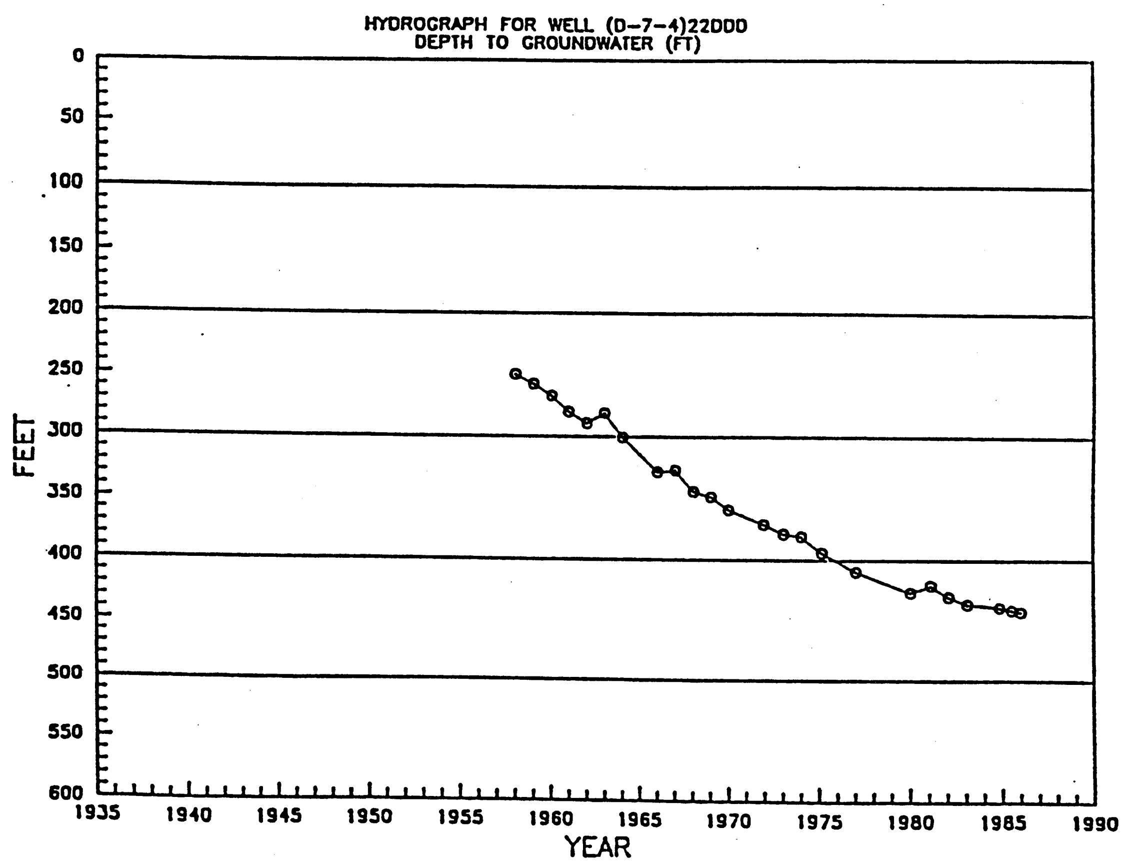
HYDROGRAPH FOR WELL (D-6-2)E01CCC
DEPTH TO GROUNDWATER (FT)

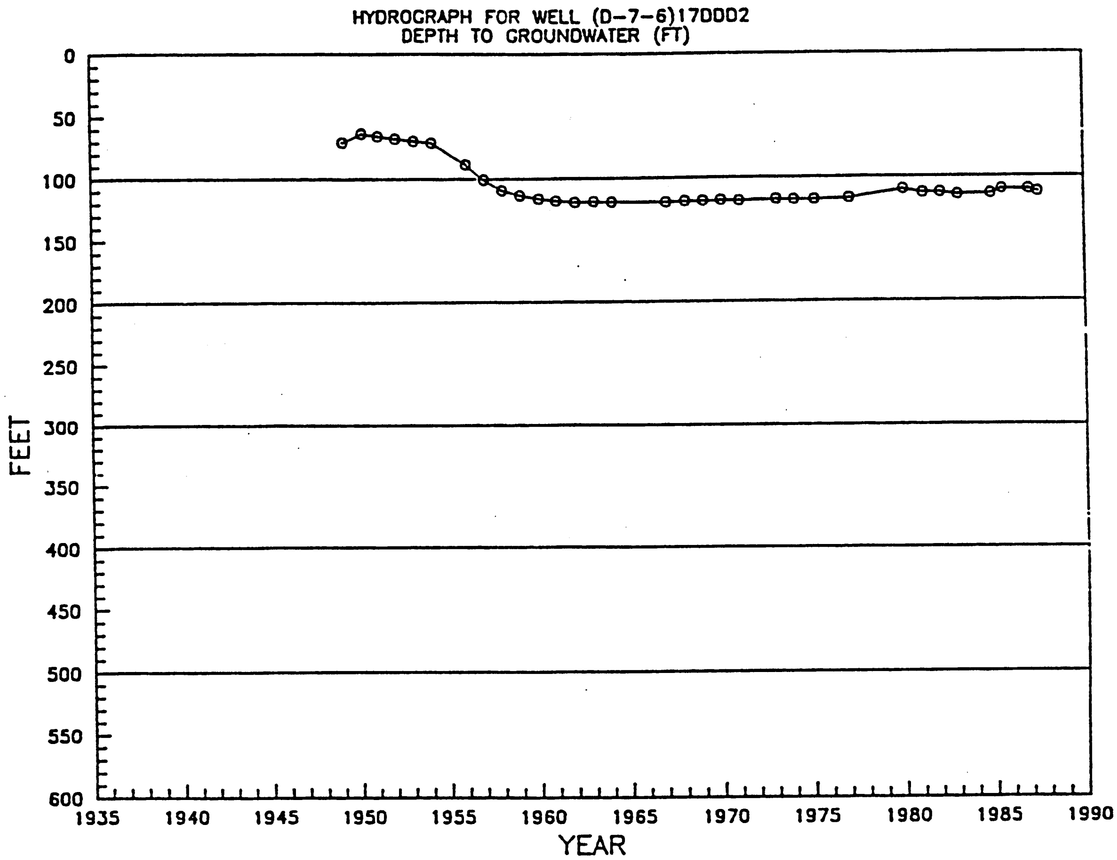


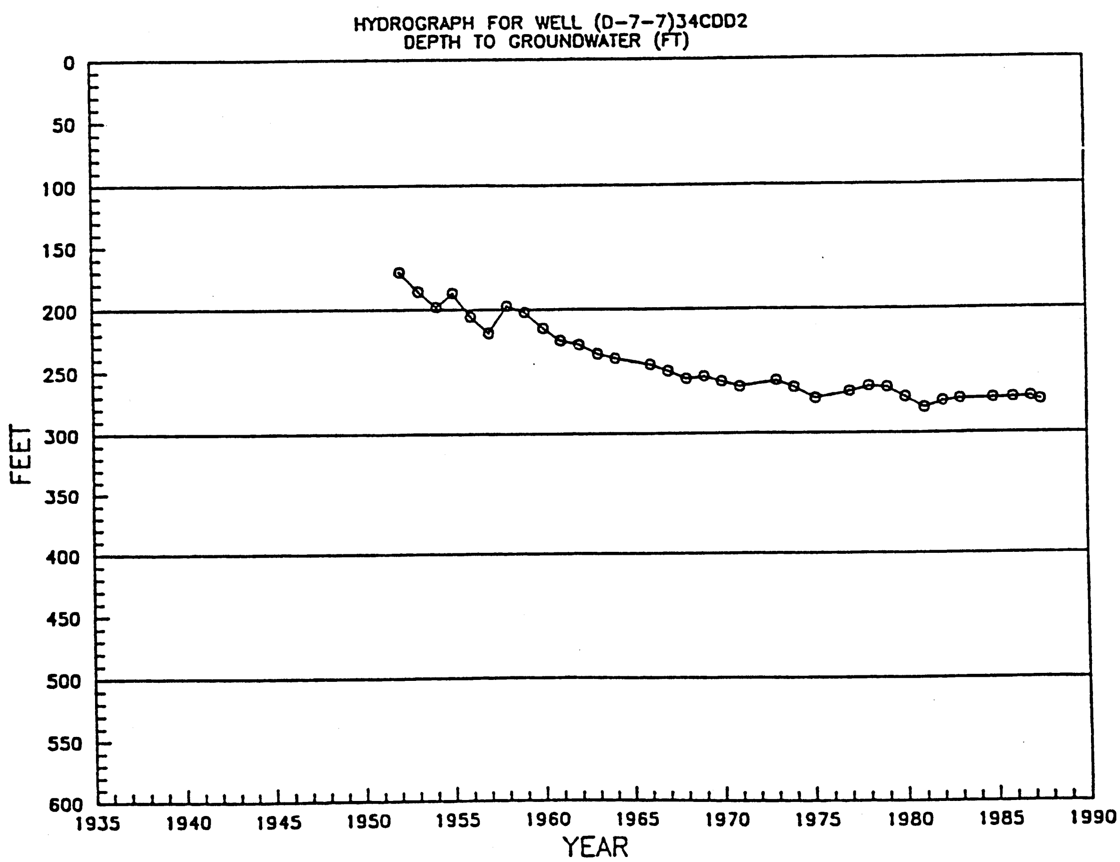

HYDROGRAPH FOR WELL (D-6-6)07AAA3
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990

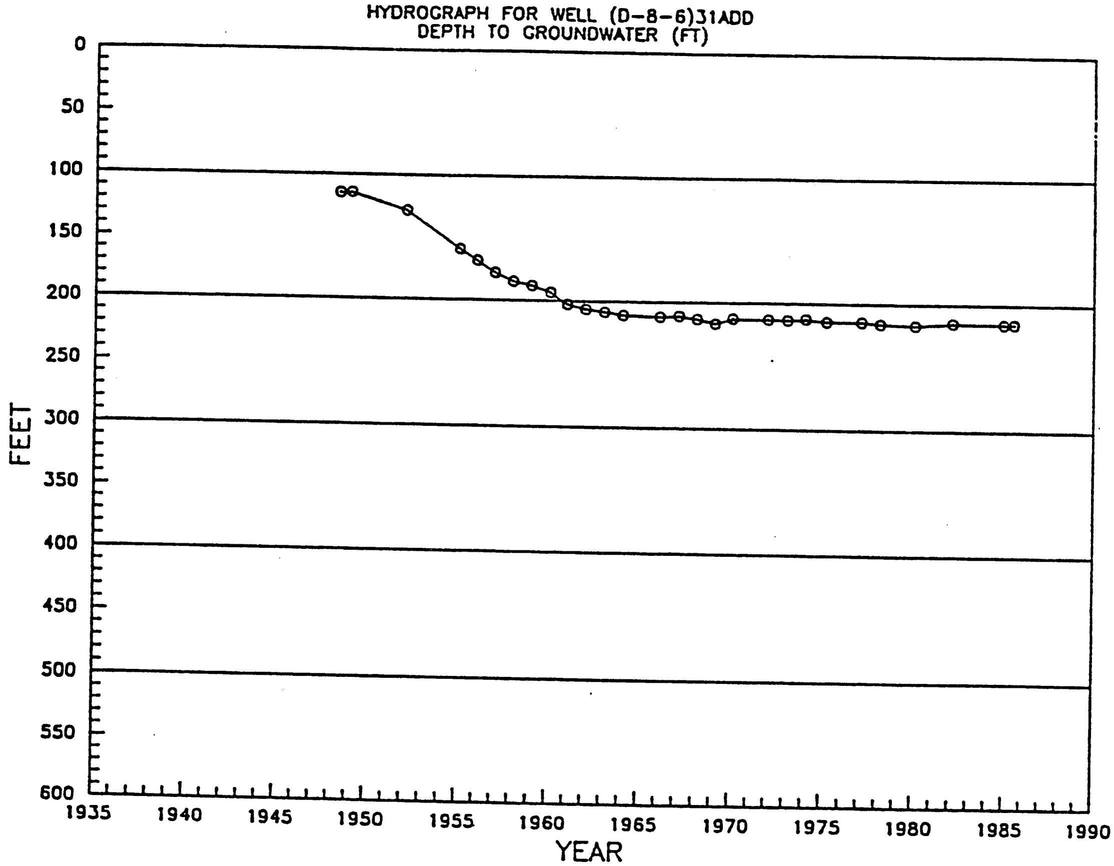

HYDROGRAPH FOR WELL (D-6-7)08ADD
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990

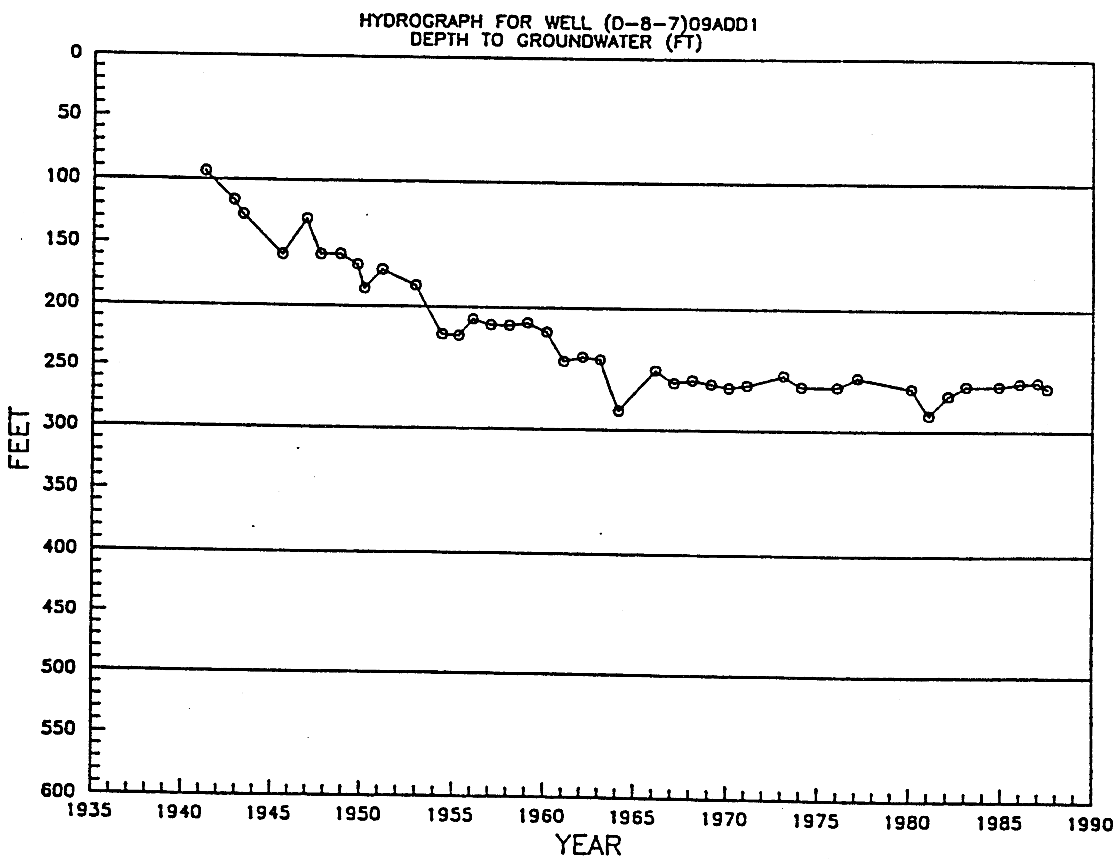

HYDROGRAPH FOR WELL (D-6-9)N04DDD
DEPTH TO GROUNDWATER (FT)
0
50
100
150
200
250
300
350
400
450
500
550
600
FEET
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR

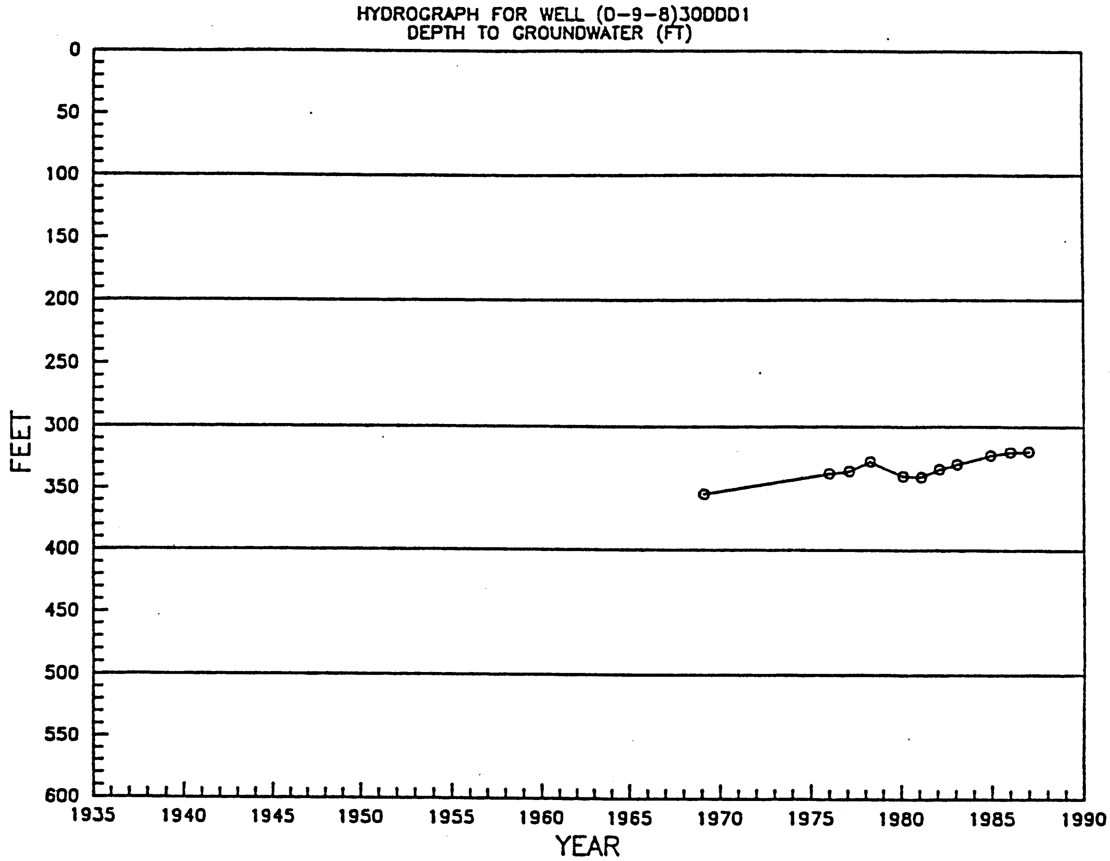

HYDROGRAPH FOR WELL (D-7-4)22DDD
DEPTH TO GROUNDWATER (FT)
0
50
100
150
200
250
300
350
400
450
500
550
600
FEET
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR

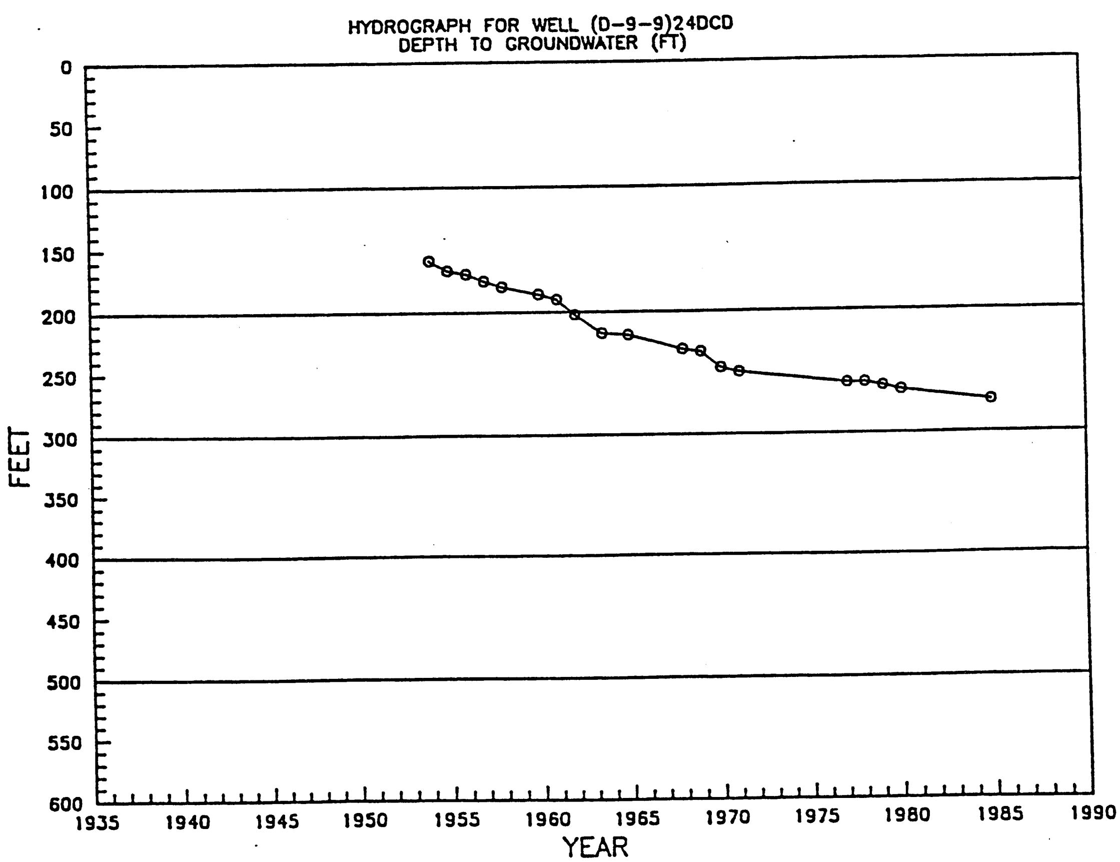

HYDROGRAPH FOR WELL (D-7-6)17DDD2
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990


HYDROGRAPH FOR WELL (D-7-7)34CDD2
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990


HYDROGRAPH FOR WELL (D-8-6)31ADD
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990


HYDROGRAPH FOR WELL (D-8-7)09ADD1
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990


HYDROGRAPH FOR WELL (D-9-8)30DDD1
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990


HYDROGRAPH FOR WELL (D-9-9)24DCD
DEPTH TO GROUNDWATER (FT)
FEET
YEAR
0
50
100
150
200
250
300
350
400
450
500
550
600
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990

APPENDIX B

GEOLOGICAL AND GEOPHYSICAL

WELL LOGS WITHIN THE PINAL AMA

WELLS WITH GEOPHYSICAL AND/OR GEOLOGIST'S LOGS WITHIN THE PINAL AMA

WELL LOCATION	TD (ft)	LOG TYPE	SOURCE	WELL OWNER
D-02-03 27BCA	472.0	D,G	ADWR	GILA RIVER FARMS
D-03-02 23DAA		J,T	SRP	SRP
D-03-02 23DBB		J,T	SRP	SRP
D-03-02 23DCA		J,T	SRP	SRP
D-03-02 25AAD	1838.0	C,D,J,T,V	SRP	SRP
D-04-02 15CBC	372.0	D,G	ADWR	DICK BOULAIS
D-04-03 09CA	1600.0	E,G	O&GCC	
D-04-03 09CDD	1777.0	E,G	O&GCC	USBR
D-04-04 34CBC	965.0	C,J,N,U	USGS	JOHN VANCE
D-04-04 34DDD		C,J,N,U	USGS	JOHN VANCE
D-04-07 18CCD	176.0	D,J	USGS	
D-04-07 19BDD	533.0	D,G	ADWR	
D-04-07 27BBB	459.0	D,G	USGS	
D-04-07W36CAD	835.0	D,G	ADWR	SAN CARLOS IRR PROJ
D-04-08 33DBB1	227.0	D,G	ADWR	PIMA COOLIDGE ECONOMIC DEV
D-04-08 33DBB2	131.0	D,G	ADWR	PIMA COOLIDGE DEV
D-04-08 33DDB	321.0	D,G	ADWR	PIMA COOLIDGE ECONOMIC DEV
D-04-09 15BAB2	613.0	C,E,J,N,U	USGS	USBR
D-04-09 28CAA	1662.0	D,G	USGS	CONOCO
D-04-10 18DCD	1560.0	C,D,E,G,J,N,U	USGS	USBR
D-05-02 27BAB	471.0	D,J	USGS	FRED ENKE/HELEN HAWKINS
D-05-02 34DCC	375.0	D,G,Z	ADWR	
D-05-02 36BAD	1061.0	D,E,G	USGS	ARIZONA STATE LAND
D-05-03 24CDC	1944.0	G	USGS	MARICOPA INDIAN TRIBE
D-05-03 32CCC	1245.0	D,E	USGS	
D-05-03 33DCB2	1230.0	D,G	ADWR	RICHARD ANGLIN
D-05-04 11BDB	994.0	D,G	ADWR	
D-05-05 30DCC	570.0	D,J	USGS	
D-05-05 31ACC	1000.0	D,G	ADWR	
D-05-07 01DDD	800.0	D,G	ADWR	
D-05-07 09ADB	415.0	D,G	ADWR	USBIA SAN CARLOS
D-05-07 22ADD2	745.0	D,G,Z	ADWR	SAN CARLOS IRRIG PROJ
D-05-07 22BAC	800.0	D,G	ADWR	SAN CARLOS IRRIG PROJ
D-05-07 22BDC	930.0	D,G	ADWR	SAN CARLOS IRRIG PROJ
D-05-07 34CCD	1295.0	D,G	ADWR	WAYNE WUERTZ
D-05-08 05BBA	634.0	D,G	ADWR	SAN CARLOS IRRIG PROJ
D-05-08 07BAA	645.0	D,G	ADWR	SAN CARLOS IRRIG PROJ
D-05-08 10CDD1	785.0	D,F,J,T	USGS	
D-05-08 15BDB	970.0	D,G	ADWR	ARIZONA WATER CO
D-05-08 17ADD	1110.0	D,G,J	USBR	SAN CARLOS IRRIG PROJ
D-05-08 17BBB2	820.0	D,G	ADWR	SAN CARLOS IRRIG PROJ
D-05-08 18BBB	935.0	D,G	ADWR	
D-05-08 35DBB	410.0	E	USGS	
D-05-08 36ADD2	1000.0	D,J	USGS	SAN CARLOS IRRIG PROJ
D-05-09 12BCB	535.0	D,G	ADWR	SAN CARLOS IRRIG PROJ
D-05-09 14CAC	1598.0	C,D,E,G,N,S,U	USGS	USBR
D-05-09 28BAB	950.0	D,G,Z	ADWR	SAN CARLOS IRRIG PROJ
D-05-09 30CBB	800.0	D,J	USGS	SAN CARLOS IRRIG PROJ
D-05-10 06ABC	1170.0	C,D,E,G,N,S	USGS	USBR
D-05-10 06ACB	1114.0	C,D,E,J,N,U	USGS	USBR

LOG CODES

A = Time
B = Coller
C = Caliper
D = Driller's
E = Electric and/or Self Potential
F = Fluid Conductivity
G = Geologist (litho)
H = Magnetic
I = Induction
J = Gamma Ray
K = Dipmeter
L = Lathering
M = Microlog
N = Neutron
O = Microlateral
P = Photographic
Q = Radioactive
S = Sonic
T = Temperature
U = Gamma-gamma
V = Fluid Velocity
X = Core
Z = Other

WELLS WITH GEOPHYSICAL AND/OR GEOLOGIST'S LOGS WITHIN THE PINAL AMA

WELL LOCATION	TD (ft)	LOG TYPE	SOURCE	WELL OWNER
D-05-10 31BBB	828.0	C,E,J,N,T,U,V,Z	USGS	USBR
D-05-10 31CC	5142.0	F,G	O&GCC	WESTERN OIL
D-06-02 03CCC	891.0	D,J	USGS	
D-06-02 13ACC2	544.0	J	USGS	
D-06-02E12AAA	1015.0	A,D	USGS	HIDDEN VALLEY FARMS
D-06-02W12BDD	550.0	D,J	USGS	BORG ARIZONA RANCHES
D-06-03 03DCC		J	USGS	
D-06-03 05BCC	650.0	D,G	ADWR	
D-06-03 15ADD	1103.0	A,D	USGS	RED RIVER LAND CO
D-06-03 17DCC	1205.0	A,D	USGS	
D-06-03 19BBA	1255.0	E	USGS	MILTON SMITH
D-06-03 21BBA	1803.0	E,G	USGS	USBR
D-06-03 28ABA	910.0	C,E,J,N,U,S	USGS	USBR
D-06-04 16ADD1	420.0	J	USGS	M ANDERSON
D-06-04 24AAA	1482.0	A	ADWR	CASA GRANDE CO
D-06-05 01ACC		G	USGS	HENRY KOCHMEIER
D-06-05 11AAA	495.0	G	USGS	
D-06-05 19DDA	1780.0	E,G	USGS	USBR
D-06-05 20CBB	925.0	D,G	ADWR	FRANCISCO G RESORT
D-06-05 21ADD2	400.0	D,G	ADWR	BERT CAMBELL
D-06-06 07BDD	680.0	D,E	USGS	A M WARD
D-06-06 17CCA	487.0	D,G	ADWR	ARIZONA WATER CO
D-06-06 18BCB	480.0	E,G,Z	ADWR	R DAVIS
D-06-06 28ADD2	675.0	D,G	ADWR	
D-06-06 28CBA2	535.0	D,G	ADWR	SAN CARLOS IRRIG DISTRICT
D-06-06 34CCB	480.0	D,G	USGS	SAN CARLOS IRRIG DISTRICT
D-06-06 34DAD	725.0	D,G	USGS	SAN CARLOS IRRIG DISTRICT
D-06-07 1DCD	3053.0	E	O&GCC	GALLIGHER
D-06-07 10CDD	1390.0	D,G	ADWR	JACK A ROBERTS
D-06-07 20BDC	795.0	D,G	ADWR	BILLIE PRUITT
D-06-07 25CDD2	810.0	D,F,G,J,N	USGS	SAN CARLOS IRRIG PROJ
D-06-07 25DDD	4742.0	D,E,J	O&GCC	CASA GRANDE OIL & DEVELOPMENT
D-06-07 27DDD2	1385.0	D,G	USGS	SAN CARLOS IRRIG DISTRICT
D-06-07 30BAA3	655.0	D,G,Z	ADWR	EPNG
D-06-07 32AAA	1000.0	D,G	USGS	SAN CARLOS IRRIG PROJ/DIST
D-06-07 35ADD	2580.0	E	USBR	
D-06-08 03AAA	2300.0	Z	ADWR	
D-06-08 06DCA	2725.0	D,E,G	USBR	
D-06-08 11DDA	2255.0	E	USBR	
D-06-08 17CDD	1572.0	E	USGS	T D'AMBROSIO
D-06-08 18CDD	3243.0	E,I	O&GCC	CROUCH DRILLER'S & ASSOC.
D-06-08 28DBB		J	USGS	
D-06-08N03DDA	2305.0	D,G	USGS	G E PETERSON
D-06-08N06DDD2	2567.0	D,G	ADWR	CLAY V HANNAH
D-06-08S06DCA	2578.0	D,G	ADWR	T D'AMBROSIO
D-06-09 17BAB	1065.0	C,E,J,N,U	USGS	SAN CARLOS IRRIG PROJ
D-06-09 29BBA1	1806.0	C,E,G,J,N	USGS	USBR
D-06-09 29BBA4	1520.0	C,E,G,J,N,U	USGS	USBR
D-06-09S06DCD	1050.0	D,G,Z	ADWR	SAN CARLOS IRRIG PROJ
D-07-04 05CCC	823.0	D,G,Z	ADWR	EL DORADO RANCHES

LOG CODES

A = Time
B = Coller
C = Caliper
D = Driller's
E = Electric and/or Self Potential
F = Fluid Conductivity
G = Geologist (litho)
H = Magnetic
I = Induction
J = Gamma Ray
K = Dipmeter
L = Lathering
M = Microlog
N = Neutron
O = Microlateral
P = Photographic
Q = Radioactive
S = Sonic
T = Temperature
U = Gamma-gamma
V = Fluid Velocity
X = Core
Z = Other

WELLS WITH GEOPHYSICAL AND/OR GEOLOGIST'S LOGS WITHIN THE PINAL AMA

WELL LOCATION	TD (ft)	LOG TYPE	SOURCE	WELL OWNER
D-07-04 16BCC	990.0	C,E,J,N,S,U	USGS	USBR
D-07-05 29DDA	575.0	D,G	ADWR	PAPAGO
D-07-05 30DBC	350.0	D,G	ADWR	PAPAGO
D-07-06 01CCC	630.0	D,G	ADWR	SAN CARLOS IRRIG PROJ
D-07-06 01DDB	893.0	D,G	ADWR	SAN CARLOS IRRIG PROJ
D-07-06 02CCA	457.0	G	ADWR	
D-07-06 05DDD	230.0	D,G	ADWR	W C PATE
D-07-06 20CDC2	1405.0	G	ADWR	
D-07-07 05ABD	1184.0	E	USGS	
D-07-07 10CBB	860.0	D,G	ADWR	
D-07-07 18CCC	480.0	D,G	ADWR	TREJO INVESTMENTS
D-07-07 19BBB	482.0	D,G	ADWR	MOBIL OIL CORP
D-07-08 08DD	8024.0	C,G,I,N,S,T,Z	O&GCC	GEOTHERMAL KINEMATICS
D-07-08 25CCC	1944.0	E,G,J,S	O&GCC	STATE OF ARIZONA
D-07-08 26CDD3	1203.0	D,G	ADWR	WEDDLE FARMS
D-07-08 31BBA	828.0	E,G	O&GCC	USBR
D-07-09 08DDD	1500.0	C,E,J,N,U	USGS	USBR
D-07-09 09AAA	1710.0	E,G,J,U	USGS	USBR
D-07-09 15BDD	1225.0	S,Z	USGS	USBR
D-07-09 15DCD	1067.0	C,E,S,U	USGS	USBR
D-07-09 16ACA	1630.0	J,N,S,Z	USGS	USBR
D-07-10 02DAA1	700.0	D,G	ADWR	ANSCHUTZ CORP
D-08-06 02DAA	1080.0	G	ADWR	ARIZONA CITY DEVELOPMENT
D-08-06 05ADD	348.0	D,G	ADWR	PAPAGO
D-08-06 05BDD	375.0	D,G	ADWR	PAPAGO
D-08-06 08ADD	790.0	D,G	ADWR	PAPAGO
D-08-06 12CBD	1300.0	G,Z	ADWR	
D-08-06 17AAA	495.0	G	ADWR	PAPAGO INDIAN TRIBE
D-08-06 17ADD	665.0	D,G	ADWR	PAPAGO INDIAN TRIBE
D-08-06 17DCB	305.0	D,G	ADWR	
D-08-06 17DCC	504.0	D,G	ADWR	PAPAGO INDIAN TRIBE
D-08-06 17DDD	610.0	D,G	ADWR	PAPAGO INDIAN TRIBE
D-08-06 33BCD	1780.0	G	ADWR	CHUICHU RANCH
D-08-06 35AAD	1180.0	Z	ADWR	
D-08-06 35BAA	1100.0	G	ADWR	
D-08-07 01DDD2	1090.0	G	ADWR	
D-08-07 06CDA	1139.0	D,E,Z	USGS	ARIZONA CITY CLUB INC
D-08-07 12BDD	2700.0	D,E	O&GCC	CREED 1 CHERRY
D-08-07 21DDD	1697.0	D,E	USGS	HAMILTON FARMS
D-08-07 30ADA	1336.0	D,G,Z	ADWR	
D-08-08 02DBC	10177.0	D,E,G,I,J,N	O&GCC	EXXON OIL CO
D-08-09 05ACD	1193.0	C,D,G,N,S,U	USGS	USBR
D-08-09 05BCB	1790.0	C,D,G,J,N,S,U,V	USGS	USBR
D-08-09 07ADD	1381.0	D,G,Z	ADWR	NEWMAN PEAK RANCH
D-09-07 03DDD	1645.0	E	USBR	
D-09-07 17DBB	1700.0	E	USGS	SCHRAMM RANCH
D-09-07 34DD	2007.0	E,G,J,N,S,Z	O&GCC	USBR
D-09-08 05DDC	1200.0	D,G	ADWR	
D-09-08 08DCC	888.0	J	USGS	
D-09-08 17CDD	600.0	J	USGS	

LOG CODES

A = Time
B = Coller
C = Caliper
D = Driller's
E = Electric and/or Self Potential
F = Fluid Conductivity
G = Geologist (litho)
H = Magnetic
I = Induction
J = Gamma Ray
K = Dipmeter
L = Lathering
M = Microlog
N = Neutron
O = Microlateral
P = Photographic
Q = Radioactive
S = Sonic
T = Temperature
U = Gamma-gamma
V = Fluid Velocity
X = Core
Z = Other

WELLS WITH GEOPHYSICAL AND/OR GEOLOGIST'S LOGS WITHIN THE PINAL AMA

WELL LOCATION	TD (ft)	LOG TYPE	SOURCE	WELL OWNER
D-09-08 19DDA	1430.0	G	ADWR	WEST COAST LAND & CATTLE
D-09-08 35DDD1	1124.0	J	USGS	
D-09-08 36AAC	1300.0	G	ADWR	
D-09-08 36ACB	1398.0	D, G	ADWR	
D-09-09 14BAD	600.0	D, G	ADWR	
D-09-10 28ADC	1500.0	C, E, N, U, V, Z	USGS	USBR
D-10-08 04ADA	984.0	D, E	USGS	
D-10-09 10BB	450.0	G	ADWR	

• Not all the logs indicated for SOURCE = USGS were located at the USGS but are believed to be in their possession.

APPENDIX C

PROPOSED

PINAL AMA GROUNDWATER MEASUREMENT INDEX LINE

REVISIONS AND ADDITIONS

CURRENT PINAL AMA INDEX LINE AND RECOMMENDATIONS
GROUNDWATER MEASUREMENT WELLS
(REVISED MAY 1989)

CURRENT INDEX WELLS	RECOMMENDED REPLACEMENT WELLS	FIRST OPENING (ft)	LAST D.T.W. (ft)	LAST DATE MEASURED	RECOMMENDATION
D(2-3) 11BAB	-	NR	-	-	MAINTAIN
D(2-3) 22DDD	-	100	-	-	MAINTAIN
D(4-2) 15CBC	-	125	-	-	MAINTAIN
D(4-2) 23ACC2	-	NR	-	-	REPLACE
	D(4-2) 23CDD	85	214	11/84	
	D(4-2) 23DDD2	450	490	11/84	
D(4-3) 09CDD1	-	1200	-	-	MAINTAIN
D(4-3) 09CDD2	-	NR	-	-	MAINTAIN
D(4-3) 13DDD	-	65	-	-	MAINTAIN
D(4-3) 15DCC	-	60	-	-	MAINTAIN
D(4-3) 16CBB	-	NR	-	-	DELETE
D(4-3) 20DCD	-	NR	-	-	DELETE
D(4-3) 35DDD	-	70	-	-	MAINTAIN
D(4-4) 16CDD	-	65	-	-	MAINTAIN
D(4-4) 20CDD	-	180	-	-	MAINTAIN
D(4-7) 19BBC	-	NR	-	-	REPLACE
	D(4-7) 18CCB	30	106	1/81	
D(4-10) 30BDD	-	100	-	-	MAINTAIN
D(4-11) 07DBB	-	NR	-	-	REPLACE
	D(4-11) 07ADA	30	21	11/84	
D(5-2) 02DCD	-	450	-	-	MAINTAIN
D(5-2) 22DAD	-	388	-	-	MAINTAIN
D(5-2) 36BAD	-	398	-	-	MAINTAIN
D(5-3) 01CDD	-	155	-	-	MAINTAIN
D(5-3) 02DDD	-	250	-	-	MAINTAIN
D(5-3) 03CCC	-	150	-	-	MAINTAIN
D(5-3) 12CDD1	-	110	-	-	MAINTAIN
D(5-3) 25ADD	-	115	-	-	MAINTAIN
D(5-3) 29BCC1	-	300	-	-	MAINTAIN
D(5-3) 33DBC2	-	810	-	-	MAINTAIN
D(5-5) 32CAB	-	150	-	-	MAINTAIN

* LOCATIONS AS FOUND IN ADWR GWSI.

CURRENT PINAL AMA INDEX LINE AND RECOMMENDATIONS
GROUNDWATER MEASUREMENT WELLS
(REVISED MAY 1989)

CURRENT INDEX WELLS	RECOMMENDED REPLACEMENT WELLS	FIRST OPENING (ft)	LAST D.T.W. (ft)	LAST DATE MEASURED	RECOMMENDATION
D(5-6) 28CAA	-	NR	-	-	REPLACE
	D(5-6) 28DAA	180	370	11/84	
D(5-7) W13CAD	-	95	-	-	MAINTAIN
D(5-7) 28DCC2	-	NR	-	-	REPLACE
	D(5-7) 28CBD	134	298	02/84	
D(5-7) 33DDD	-	NR	-	-	REPLACE
	D(5-7) 34BDC	600	286	10/84	
D(5-7) 34DDD	-	92	-	-	MAINTAIN
D(5-8) 02AAA	-	30	-	-	MAINTAIN
D(5-8) 12AAD	-	38	-	-	MAINTAIN
D(5-8) 17BBB2	-	135	-	-	MAINTAIN
D(5-8) 25BBC	-	98	-	-	MAINTAIN
D(5-8) 31DCC2	-	NR	-	-	REPLACE
	D(5-8) 31DCB	100	155	10/84	
D(5-8) 31DDD	-	126	-	-	MAINTAIN
D(5-9) 03DAC	-	NR	-	-	REPLACE
	D(5-9)14CACP1	1354	272	03/79	
	D(5-9)14CACP2	1092	271	03/79	
	D(5-9)14CACP3	698	276	03/79	
D(5-9) 14CBB	-	200	-	-	MAINTAIN
D(5-9) 18BDD1	-	80	-	-	MAINTAIN
D(5-9) 18BDD2	-	490	-	-	MAINTAIN
D(5-9) 22CBA	-	155	-	-	MAINTAIN
D(5-9) 29ADA	-	134	-	-	MAINTAIN
D(5-9) 31ADD	-	155	-	-	MAINTAIN
D(6-2) E01CDD2	-	NR	-	-	MAINTAIN
D(6-3) 02DDD2	-	285	-	-	MAINTAIN
D(6-3) 11CDD1	-	70	-	-	MAINTAIN
D(6-3) 15BDC	-	400	-	-	MAINTAIN
D(6-3) 27CCC	-	550	-	-	MAINTAIN
D(6-4) 02CDD	-	450	-	-	MAINTAIN
D(6-4) S04DDD2	-	450	-	-	MAINTAIN
D(6-4) S04DDD3	-	NR	-	-	REPLACE
	D(6-4)S04DDD1	300	252	11/84	

CURRENT PINAL AMA INDEX LINE AND RECOMMENDATIONS
GROUNDWATER MEASUREMENT WELLS
(REVISED MAY 1989)

CURRENT INDEX WELLS	RECOMMENDED REPLACEMENT WELLS	FIRST OPENING (ft)	LAST D.T.W. (ft)	LAST DATE MEASURED	RECOMMENDATION
D(6-4) S06DDD	-	200	-	-	MAINTAIN
D(6-4) 07CCC	-	103	-	-	MAINTAIN
D(6-4) 11CDD	-	NR	-	-	REPLACE
	D(6-4) 12BCC2	160	555	11/84	
	D(6-4) 12BCC3	740	559	11/84	
D(6-4) 22CDD	-	NR	-	-	REPLACE
	D(6-4) 22CAA	250	607	01/83	
D(6-4) 36DDD	-	106	-	-	MAINTAIN
D(6-5) 09ADD	-	NR	-	-	MAINTAIN
D(6-5) 16DAD1	-	NR	-	-	MAINTAIN
D(6-5) 16DAD2	-	NR	-	-	MAINTAIN
D(6-5) 19DDA1	-	1162	-	-	MAINTAIN
D(6-5) 19DDA2	-	535	-	-	MAINTAIN
D(6-5) 25BBB	-	30	-	-	MAINTAIN
D(6-5) 34BDD	-	NR	-	-	MAINTAIN
D(6-6) 07AAA3	-	155	-	-	MAINTAIN
D(6-6) 09DAD	-	280	-	-	MAINTAIN
D(6-6) 12BDB	-	90	-	-	MAINTAIN
D(6-6) 16ADD	-	690	-	-	MAINTAIN
D(6-6) 16CDD	-	60	-	-	MAINTAIN
D(6-6) 22CCD	-	1	-	-	MAINTAIN
D(6-6) 36DDA	-	112	-	-	MAINTAIN
D(6-7) 08ADD	-	NR	-	-	REPLACE
	D(6-7) 08DDD2	480	427	08/86	
	D(6-7) 09DDD2	135	150	11/84	
D(6-7) 11DD 2	-	NR	-	-	
D(6-7) 34BBC	-	225	-	-	MAINTAIN
D(6-7) 35DDD	-	60	-	-	MAINTAIN
D(6-8) S02DAD	-	119	-	-	MAINTAIN
D(6-8) S04ADD1	-	73	-	-	MAINTAIN
D(6-8) 11ADA1	-	110	-	-	MAINTAIN
D(6-8) 14CCC	-	55	-	-	MAINTAIN
D(6-8) 27BDD2	-	214	-	-	MAINTAIN
D(6-8) 31CDD	-	130	-	-	MAINTAIN
D(6-9) N04DDD	-	200	-	-	MAINTAIN

CURRENT PINAL AMA INDEX LINE AND RECOMMENDATIONS
GROUNDWATER MEASUREMENT WELLS
(REVISED MAY 1989)

CURRENT INDEX WELLS	RECOMMENDED REPLACEMENT WELLS	FIRST OPENING (ft)	LAST D.T.W. (ft)	LAST DATE MEASURED	RECOMMENDATION
D(6-9) N06DAA	-	128	-	-	MAINTAIN
D(6-9) 19BBD	-	NR	-	-	REPLACE
	D(6-9) 18BDC	250	250	11/84	
D(7-4) 22DDD	-	180	-	-	MAINTAIN
D(7-4) 23DDD	-	125	-	-	MAINTAIN
D(7-4) W36BAC	-	NR	-	-	MAINTAIN
D(7-6) 17DDD2	-	50	-	-	MAINTAIN
D(7-6) 26DDD	-	100	-	-	MAINTAIN
D(7-6) 28DDD	-	150	-	-	MAINTAIN
D(7-7) 02ACC	-	NR	-	-	MAINTAIN
D(7-7) 08BAA	-	205	-	-	MAINTAIN
D(7-7) 11CDD	-	100	-	-	MAINTAIN
D(7-7) 23ADD	-	190	-	-	MAINTAIN
D(7-7) 24DDD	-	120	-	-	MAINTAIN
D(7-7) 30CDD	-	200	-	-	MAINTAIN
D(7-7) 34CDD2	-	130	-	-	MAINTAIN
D(7-8) 05DCC	-	120	-	-	MAINTAIN
D(7-8) 09DDD	-	100	-	-	MAINTAIN
D(7-8) 17CDD	-	150	-	-	MAINTAIN
D(7-8) 30CDD	-	NR	-	-	MAINTAIN
D(7-8) 31BBA	-	560	-	-	MAINTAIN
D(7-8) 33DDD	-	490	-	-	MAINTAIN
D(8-6) 22DDD	-	309	-	-	MAINTAIN
D(8-6) 31ADD	-	75	-	-	MAINTAIN
D(8-6) 35DDD2	-	NR	-	-	MAINTAIN
D(8-7) 09ADD1	-	110	-	-	MAINTAIN
D(8-7) 14DDA	-	644	-	-	MAINTAIN
D(8-7) 19DDD	-	NR	-	-	MAINTAIN
D(8-8) 01DDD	-	220	-	-	MAINTAIN
D(8-8) 07DDD1	-	NR	-	-	MAINTAIN
D(8-8) 07DDD2	-	250	-	-	MAINTAIN
D(8-8) 10CDD	-	380	-	-	MAINTAIN
D(8-8) 14DDD	-	170	-	-	REPLACE
D(8-8) 18CDD1	-	NR	-	-	MAINTAIN
D(8-8) 18CDD2	-	450	-	-	MAINTAIN

CURRENT PINAL AMA INDEX LINE AND RECOMMENDATIONS
GROUNDWATER MEASUREMENT WELLS
(REVISED MAY 1989)

CURRENT INDEX WELLS	RECOMMENDED REPLACEMENT WELLS	FIRST OPENING (ft)	LAST D.T.W. (ft)	LAST DATE MEASURED	RECOMMENDATION
D(8-8) 29BCC	-	1100	-	-	MAINTAIN
D(8-8) 29BCD	-	150	-	-	MAINTAIN
D(8-9) 07ADD	-	550	-	-	MAINTAIN
D(9-7) 04ADD	-	190	-	-	MAINTAIN
D(9-7) 22DAA	-	490	-	-	MAINTAIN
D(9-7) 25CDD	-	400	-	-	MAINTAIN
D(9-7) 25DDA1	-	164	-	-	MAINTAIN
D(9-7) 25DDA2	-	580	-	-	MAINTAIN
D(9-7) 27DDD1	-	NR	-	-	MAINTAIN
D(9-8) 06DDD	-	NR	-	-	REPLACE
	D(9-8) 06ADD	125	403	11/84	
D(9-8) 17CDD	-	NR	-	-	MAINTAIN
D(9-8) 20ADD1	-	NR	-	-	MAINTAIN
D(9-8) 20ADD2	-	NR	-	-	MAINTAIN
D(9-8) 29BCC	-	440	-	-	MAINTAIN
D(9-8) 30DDD1	-	180	-	-	MAINTAIN
D(9-8) 31DAA	-	600	-	-	MAINTAIN
D(9-8) 35ADD2	-	NR	-	-	REPLACE
	D(9-8) 36BAA	585	531	11/84	
D(10-6) 11DDD2	-	152	-	-	MAINTAIN
D(10-7) 08AAA	-	198	-	-	MAINTAIN
D(10-8) 12CAA	-	NR	-	-	MAINTAIN
D(10-9) 18ACC	-	NR	-	-	MAINTAIN

NR - No records available.

RECOMMENDED ADDITIONS TO THE PINAL AMA
GROUNDWATER MEASUREMENT INDEX LINE

WELL LOCATION (QUAD D)	DATE LAST MEASURED	LAST D.T.W. (ft)	WELL DEPTH (ft)	FIRST OPENING (ft)
	LCU GROUNDWATER LEVELS			
(5-7)34BDC	10/84	286	1020	600
(5-8)15BDB	11/84	117	970	250
(5-8)34DAD	10/84	231	2185	1600
(6-7)15DDD	11/84	330	1838	1200
(6-7)35ADD4	11/84	390	2538	1999
(8-6)12CBD	10/85	546	1300	720
(8-6)14CDD	11/84	399	800	340
(8-6)26DBA	11/84	511	1360	697
(8-7)06CDA	11/84	208	1139	879
(9-7)17DDC	11/84	524	1580	965
(9-7)27DDD3	11/84	517	1400	1160
	UAU & MSCU GROUNDWATER LEVELS			
(4-4)07cdd	01/83	240	NR	NR
(4-4)22ddd1	11/84	368	415	109
(4-4)29cdc	11/84	281	440	110
(4-4)31ddd	11/84	192	606	200
(4-4)33cdc	11/84	446	885	400
(5-3)12caa	11/84	217	501	222
(5-3)16ccc1	06/86	213	501	105
(5-3)18bcc	11/84	623	1360	660
(5-3)27ddd	11/84	219	600	130
(5-3)35daa	11/84	225	560	110
(5-4)03add	11/84	368	750	252
(5-4)08ddd	11/84	528	1000	80
(5-4)07dda	11/84	228	985	250
(5-4)11caa	11/84	541	434	170
(5-4)15add	11/84	539	592	160
(5-4)19dd	11/84	218	NR	NR
(5-4)23bdd2	11/84	597	1100	NR
(5-4)28dda	11/84	617	1005	400
(5-4)31aaa	11/84	223	303	105
(5-4)33dda	11/84	606	550	135
(5-4)35ddd	11/84	316	850	NR
(5-5)31add	11/84	507	NR	NR
(5-6)17ada	11/84	322	450	250
(5-7)26dcd2	06/87	162	1610	146
(5-8)07baa	01/83	218	645	42
(5-8)10add	02/83	129	200	40
(5-8)14cad2	11/84	146	730	140
(5-8)29cac2	06/85	233	606	150
(5-8)35dad1	11/84	145	400	119
(6-7)11cdc	11/84	194	425	200
(6-7)21cbc	11/84	151	530	149

RECOMMENDED ADDITIONS TO THE PINAL AMA
GROUNDWATER MEASUREMENT INDEX LINE

WELL LOCATION (QUAD D)	DATE LAST MEASURED	LAST D.T.W. (ft)	WELL DEPTH (ft)	FIRST OPENING (ft)
(6-7)25cdd2	11/84	213	810	162
(6-7)31cdd	11/84	134	NR	NR
(6-8)07bdd	03/85	256	508	100
(6-8)20bdd	11/84	140	285	115
(7-3)21bdc	11/84	71	NR	NR
(7-4)03ddd	11/84	653	2660	NR
(7-4)06cbc2	10/84	731	1170	500
(7-4)14cdc	11/84	554	1285	400
(7-4)17cdd	10/84	723	1490	500
(7-4)36Wbac	01/82	368	900	NR
(7-5)01ada	11/84	34	NR	NR
(7-5)07ddd	11/84	451	857	168
(7-5)16aaa	11/84	335	650	137
(7-6)04dcc	11/84	76	NR	NR
(7-6)31aaa	11/84	155	220	80
(7-7)18ccc	11/84	206	480	172
(7-7)22bdd3	11/84	247	NR	200
(8-6)03add	11/84	254	800	200
(8-6)29ddd	11/84	338	750	78
(8-6)12aaa	11/84	191	NR	171
(8-6)17dda	01/83	203	NR	NR
(8-8)06dca1	11/84	343	1000	350
(9-8)23ddd	11/84	502	500	80
(9-8)08daa	11/84	428	1000	300
(9-8)10ddd2	11/84	461	1000	235
(8-8)11bdd	11/84	396	1075	175
(8-8)31daa	11/84	366	1010	320
(8-8)27ddd2	11/84	497	1400	475

NR - No record available.

APPENDIX D

BIBLIOGRAPHY

BIBLIOGRAPHY

Anderson, T.W., 1968. Electric-analog Analysis of Groundwater Depletion in Central Arizona. USGS WSP 1860.

Arizona Bureau of Mines, University of Arizona. 1959. Geologic Map of Pinal County, Arizona.

Arizona Crop & Livestock Reporting Service. 1970-1985. Cropland Atlas of Arizona, 1974.

ADWR 1985. Management Plan, First Management Period: 1980-1990, Pinal Active Management Area.

ADWR 1988. Draft Management Plan, Second Management Period: 1990-2000, Pinal Active Management Area.

Arizona Oil and Gas Conservation Commission. 1987. Well Location Map Four.

Arizona Water Commission. 1973. Annual Report on Groundwater in Arizona Spring 1971-1972. 1978 Projected Water Uses, Supplies and Groundwater Conditions in Selected Basins in Arizona.

Babcock, H.M., and Cushing, E.M. 1941. Recharge to Groundwater From Floods in a Typical Desert Wash, Pinal County, Arizona.

Babcock, H.M. 1970, August. Groundwater Conditions in Gila River Indian Reservation, Pinal and Maricopa Counties, Arizona Open File Report.

Banks, and Docktor. 1976. Map, MF-793, Reconnaisance Geologic Map of the Vaca Hills Quad, Arizona.

Beck, R.W. and Associates. 1963, June. The Statement and Economic Survey, Maricopa-Stanfield Irrigation and Drainage District, Arizona.

Beck, R.W. and Associates. 1971, 1977. Central Arizona Project; Engineering and Planning Study. Update. Central Arizona Irrigation and Drainage District Preliminary Draft, 1977.

Berqurst, Banks and Blacet. Map, MF990, Eloy Quad, Arizona.

Berqurst, et al. Map, MP-935, Geology of the Santa Rosa Mountains Quad.

Blacet, et al. Map, MF-934, Geology of the Silver Reef Mountains.

Bradbury, K.R., and Rothschild, E.R. 1986, January. TGUESS. IGWMC-BAS19. VERSION IBM PC 1.0. A BASIC Program to Correct Specific Capacity Data for Partial Penetration and Well Losses, and Estimates Transmissivity and Hydraulic Conductivity. International Groundwater Modeling Center. Butler University.

Bryan, Kirk. 1925. The Papago Country, Arizona; A Geographic, Geologic and Hydrologic Reconnaissance with a Guide to Desert Watering Places. USGS WSP 499. 436 p.

Burdak. 1969. Effect of Falling Water Table in Pinal County, Arizona. Deptartment of Agriculture, University of Arizona unpublished master's thesis.

Central Arizona Association of Governments Project. 1977. Point Source Inventory and Main Report for Pinal County. Tasks 533, 534 and 535.

Corkhill, E.F. 1980. Geophysical Methods Utilized in the Water Well Industry. Salt River Project and National Waterwell Association - Groundwater and Wells Symposium Notebook.

Cotts, H.V. 1915. Papago Nomadic Survey: United States Indian Service unpublished folio.

Cushman, R.L. and Babcock, H.M. 1947. Pumpage and Groundwater Levels in Arizona in 1947; Graham, Greenlee, Pima, Pinal, Santa Cruz and Yuma Counties.

Cushman, R.L. 1952. Groundwater in the Gila River Basin and Adjacent Areas, Arizona. USGS Open File Report 115-135 pp.

Davidson, E.S. 1973. Geohydrology and Water Resources of the Tucson Basin, Arizona: USGS WSP 1939-E. 81p.

Decook, J.K. 1978. Water Service Organizations in Arizona; compiled by the Water Resources Research Center, University of Arizona.

Docktor, and Reith. Map, MF-931, Vekol Mountains.

Driscoll, F.G., 1986. "Groundwater & Wells" 2nd Edition: A Comprehensive Study of Groundwater and the Technologies Used to Locate, Extract, Treat and Protect this Resource.

Dunlap and Associates, Inc. 1969, June. Impact of Declining Water Levels on the Economy of Pinal County, Arizona. A report to the Arizona Interstate Stream Commission. 9 p.

Filleman, T. 1986. Engineering Bulletin Number Two. Arizona Department of Water Resources. Aquifer Studies - Distance From Pumped Well. Pg. 5-7.

Frenzel, S.A. 1984. Methods For Estimating Ground-Water Pumpage For Irrigation. USGS WRI Report 83-4277. 11 p.

Gilkey, M.M. and Beckman, R.T. 1963. Water Requirements and Uses in Arizona Mineral Industries. Arizona Bureau of Mines Information Circular 8162.

Hardt, W.F., Cattany, R.E, and Kister, LR. 1964. Basic Groundwater Data for Western Pinal County. Arizona State Land Department, Water Resources Report 18.

Hardt, W.F., and Cattany, R.E. 1965. Description and Analysis of the Geohydrologic System in Western Pinal County, Arizona. USGS Open File Report. 92 p.

Heindl, L.A. 1960. Cenozoic Geology of the Papago Indian Reservation: Pima, Maricopa and Pinal, Arizona. Arizona Geological Digest Volume 3. 31-34 pp.

Heindl, L.A., and Armstrong, C.A. 1963. Geology and Groundwater in the Gila Bend 2nd Reservation. Geology and Groundwater of the Gila River Indian Reservation, Maricopa County, Arizona.

Heindl, L.A. 1961. Cenozoic Geology in the Mammoth Area, Pinal County, Arizona. United States Geological Survey Open File Report. Update in 1963 USGS Bulletin 1141-E. 97 p.

Heindl, L.A., and Cosner, O.J. 1961. Hydrologic Data and Driller's Logs, Papago Indian Reservation, Arizona. Arizona State Land Department. Water-Resources Report 9. 116 p.

Holland and Rabin Associates. Pinal County 1985 Development Plan Part I, Eastern Pinal County.

Hurr, T.R. 1966. A New Approach for Estimating Transmissibility from Specific Capacity. Water Resources Research, Volume 2, Number 4. 657-663 pp.

Jennings, Mark. 1977. Geophysical Investigations near Subsidence Fissures in Northern Pinal and Southern Maricopa Counties, Arizona. Master's thesis, Arizona State University. 95 p. appendices.

Kisser, K.G., and Haimson, J.S. 1981. Estimates of Aquifer Characteristics Using Driller's Logs: Hydrology and Water Resources of the Southwest, Arizona-Nevada Academy of Science. Volume 11. 113-116 pp.

Kister, L.R., and Hardt, W.F. 1966. Salinity of Ground Water in Western Pinal County, Arizona. USGS WSP 1819-E. 21 p.

Kister, L.R. and Hardt, W.F. 1961. Correlation of Groundwater Quality with Different Sediment Types, Lower Santa Cruz Basin, Arizona. Arizona Geologic Society Digest Volume 4. 79-85 pp.

Koester, E.A., and J.N. Conley. 1972. Wells Drilled for Hydrocarbons, Helium and Geothermal Resources, Stratigraphic Information and Selected Wells Drilled for Water in Pinal County, Arizona. Arizona Oil and Gas Conservation Commission.

Konieczki, A.D., and English C.S. 1977. Maps Showing Groundwater Conditions in the Lower Santa Cruz Area, Pinal, Pima and Maricopa Counties, Arizona. Water Resources Investigations Draft. 56-79 pp.

Laney, et al. 1978. Maps showing water level declines, land subsidence, and earth-fissures in South-Central Arizona. USGS WRI 78-83.

Leake, S.A., Prudic, D.E. 1988. Documentation of a Computer Program to Simulate Aquifer-System Compaction using the Modular Finite-Difference Ground-Water Flow Model. USGS OFR 88-482. 80 p.

Long, L. and Erb, S. 1980. Computerized Depth Interval Determination of Groundwater Characteristics from Well Driller Logs. Hydrology and Water Resources in Arizona and the Southwest. Arizona-Nevada Academy of Science. Volume 10. 203-206 pp.

Lysonski, Sumner, Aiken, C. Schmidt, J. Schmidt. Residual Bouguer Gravity Anomaly Map of Arizona (IGSN 71).

Matlock, W.G., Schwalen, H.C., and Shaw, R.I. 1965. Progress report on Study of Water in the Santa Cruz Valley, Arizona. Department of Agricultural Engineering. 28 p., maps, charts, tables.

McDonald, M.G., and Harbaugh, A.W. 1988. Techniques of Water Resources Investigations of the USGS. A Modular Three-Dimensional Finite-Difference Groundwater Flow Model. USGS Book 6 Chapter A-1. 528 p.

Meinzer, O.E. and Wenzel, L.K. 1944. Water Levels and Artesian Pressure in Observation Wells in the U.S. in 1942; Part 6, Southwestern US and Territory of Hawaii. USGS WSP 949. 344 p. Tables.

Oppenheimer, and Sumner. 1980. Depth to Bedrock Map, Basin and Range Province. Pinal Laboratory of Geophysics, University of Arizona.

Pashley, E.F. 1961. Subsidence Cracks in Alluvium Near Casa Grande, Arizona Geologic Society Digest Volume 4. 95-101 pp.

Peterson, D.E. 1962. Earth Fissuring in the Picacho Area, Pinal County, Arizona. Unpublished University of Arizona masters thesis.

Peterson, D.L. 1968. Bouguer Gravity Map of parts of Maricopa, Pima, Pinal and Yuma Counties, Arizona.

Pool, D.R. 1988. Personal Communication.

Regional Recharge Research for Southwest Alluvial Basins, Final Report. 1980. Mountain Front Recharge. The University of Arizona. Chapter 4.

Remick, W.H. 1987. State of Arizona, Department of Water Resources, Open-File Report Number 4, Bibliography of Selected Reports on Groundwater in Arizona.

Schmidt, K.D. and Scott, R.C. 1977. Hydrogeologic Conditions and Waste Disposal at the Hassayampa, Casa Grande and Sommerton Landfills, Ariz.

Schumann, H.H., and Genualdi, R.B. 1986. Map 23 - Land Subsidence, Earth Fissures, and Water-Level Change in Southern Arizona. Arizona Geological Survey, Bureau of Geology and Mineral Technology - University of Arizona.

Schwalen, H.C. and Shaw, R.J. 1959. Water in the Santa Cruz Valley, Bulletin Number 288, University of Arizona Agriculture Experiment Station.

Schwalen, H.C. and Shaw, R.J. 1961. Progress Report on the Study of Water in the Santa Cruz Valley. Arizona Report Number 205. University of Arizona Agricultural Experiment Station. 20 p. Plates.

Schwennesen, A.T. 1921. Geology and Water Resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation, Arizona. USGS WSP 450-A. 27 p., 11 pls., 5 figs.

Small, G.G. 1973-1974. Coolidge Regional Park Project Progress Report.

Smith, G.E.P. 1938. Physiography of Arizona Valleys and Occurrence of Groundwater. Technical Bulletin Number 77. University of Arizona Agricultural Experiment Station.

Smith, G.E.P., 1940. The Groundwater Supply for the Eloy District in Pinal County, Arizona University of Arizona Agricultural Technical Bulletin 87. 1-42 pp.

State Land Department, State of Arizona. 1968. Annual Report on Groundwater in Arizona, Spring 1967- Spring 1968.

Tenney, J.B., 1934. Economic Geological Reconnaissance of Casa Grande Mining District, Pinal County, Arizona, Casa Grande Chamber of Commerce.

Theis, Brown, Meyer. 1963. Estimating the Transmissibility of Aquifers from the Specific Capacity of Wells. USGS WSP 1536-Methods of determining permeability, transmissibility, and drawdown. Compiled by Ray Bentall.

Thomsen, B.W., Baldys, S. 1985. Ground-Water Conditions in the Gila Indian Reservation, South Central Arizona. USGS WRI 85-4073.

Turner, S.F., et al. 1945. Groundwater Pumpage in Southern Arizona in 1945. USGS.

Turner, S.F., et al. 1943. Groundwater resources of the Santa Cruz Basin, AZ, USGS 84 p., Maps, Graphs.

Turner, S.F., et al. 1947. Further Investigation of the Groundwater Resources of the Santa Cruz Basin, Arizona. USGS. 45 p., Maps, Surveys.

USBIA. 1978. Final EIS Vekol Hills Project.

USBIA. 1980. AK-Chin Indian Community

1) Environmental Assessment
2) Engineering Report
3) Addendum to Engineering Report

USBIA 1981. Ak-Chin Water Supply Project: Draft Environmental Impact Statement.

USBR, Lower Colorado Region, Volume 1. 1976. Central Arizona Project - Geology and Groundwater Resources Report - Maricopa and Pinal Counties, Arizona.

USDC. 1968. United States Department of Commerce - Climatic Atlas of the US.

USGS. 1919. Contribution to the Hydrology of the United States WSP 450.

USGS. 1985. Annual Summary of Ground-Water Conditions in Arizona, Spring 1983 to Spring 1984 Open-File Report 85-410.

USSCIP. 1980-1987. Annual Reports.

USSCS. 1977. Directory of Arizona Agencies and Organizations.

USSCS. 1977. Santa Cruz-San Pedro River Basin, Arizona: Main Report and Draft Report.

USSCS, and ERS. 1972. Plan of Work Type IV Survey, Santa Cruz-San Pedro River Basin, Arizona.

University of Arizona, College of Agriculture, Agricultural Extension Service. 1931. An Economic Survey of Pinal County Agriculture. 39 p. Tables.

Van Cleve Associates. 1963. Pinal Profiles Volume 2.

Watson, P., et al. 1976. Quantitative Evaluation of a Method for Estimating Recharge to the Desert Basins of Nevada: Journal of Hydrology, V. 31, No. 3/4, pp. 335-337.

White, K. Co. 1969. Comprehensive Water and Sewer Plan for Pinal County, Arizona. 7 parts.

White, N.D., Stulik, R.S., et al. 1964. Effects of Groundwater Withdrawals in part of Central Arizona Projected to 1969. Arizona State Land Department, Water-Resources Report 16.

Wilson, R.P. 1979. Availability of Groundwater on Federal Land Near Ak-Chin Indian Reservation, Arizona: A Reconnaissance Study. USGS. 62 p.

Winikka, Carl C. 1964. Subsidence in the Eloy-Picacho Area. Eleventh Annual Land Surveyors Conference-University of Arizona.

Yost Jr., C.B. 1953. Geophysical and Geological Reconnaissance to Determine Groundwater Resources of Chiu Chuischu Area, Papago Indian Reservation, Arizona. USGS. 19 p. Graphs, Maps.

rb

FIGURES 5,9,10,11.1,11.3–11.8,13,14,16,18,26

ARE CONTAINED IN THE ACCOMPANYING MAP ENVELOPE

APPENDIX E

FIGURES

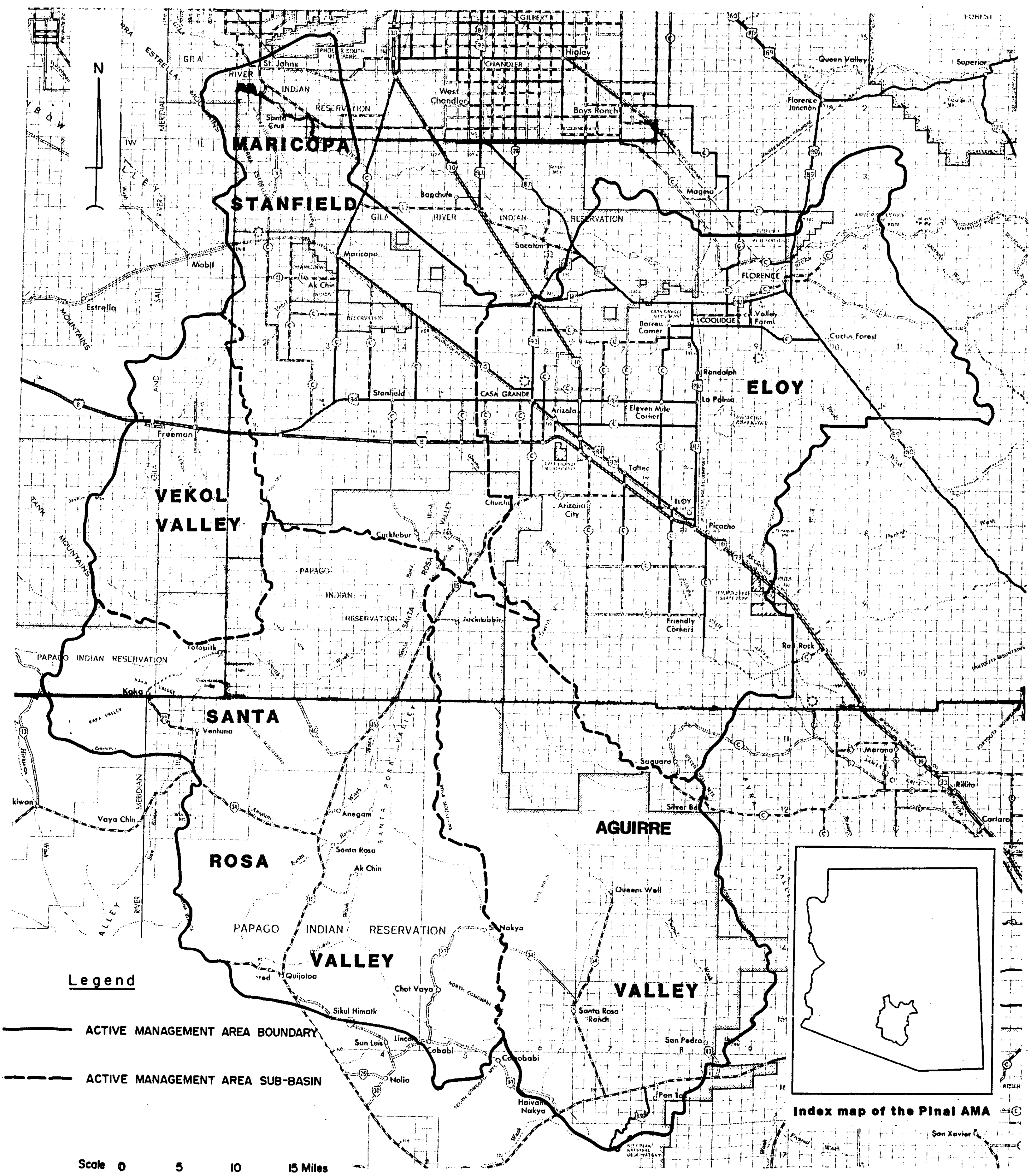
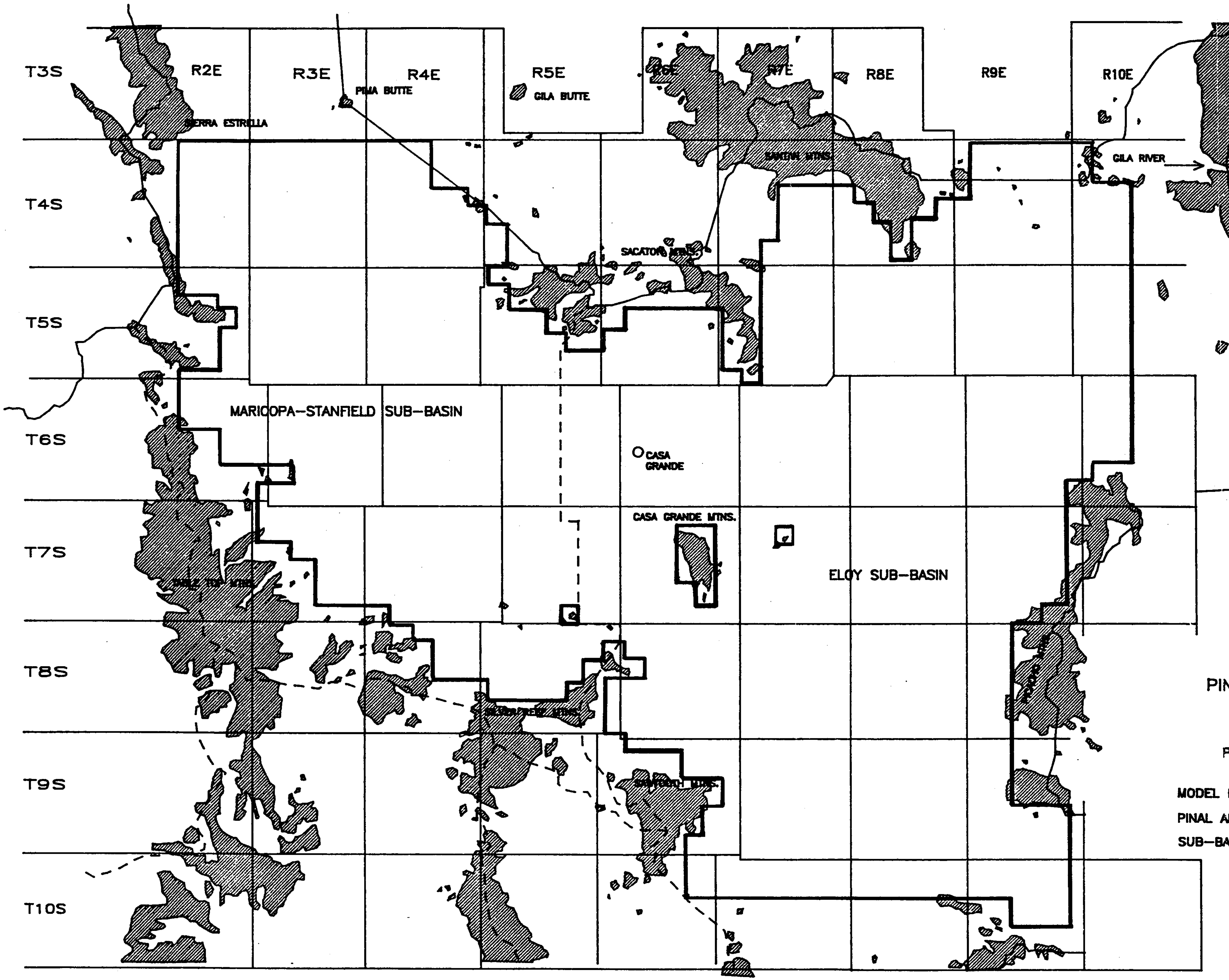

N
MARICOPA
STANFIELD
VEKOL
VALLEY
ELOY
SANTA
ROSA
VALLEY
AGUIRRE
VALLEY
PAPAGO INDIAN RESERVATION
GILA RIVER INDIAN RESERVATION
CASA GRANDE
FLORENCE
COOLIDGE
ELOY
CHANDLER
GILBERT
Maricopa
Stanfield
Florence Junction
Queen Valley
Superior
Picacho
Red Rock
Marana
Arizona City
Sacaton
Santa Rosa
Sells
Legend
ACTIVE MANAGEMENT AREA BOUNDARY
ACTIVE MANAGEMENT AREA SUB-BASIN
Scale 0 5 10 15 Miles
Index map of the Pinal AMA

FIGURE 1



NORTH

PINAL AMA MODEL AREA

FIGURE 2

PINAL AMA MODEL AREA

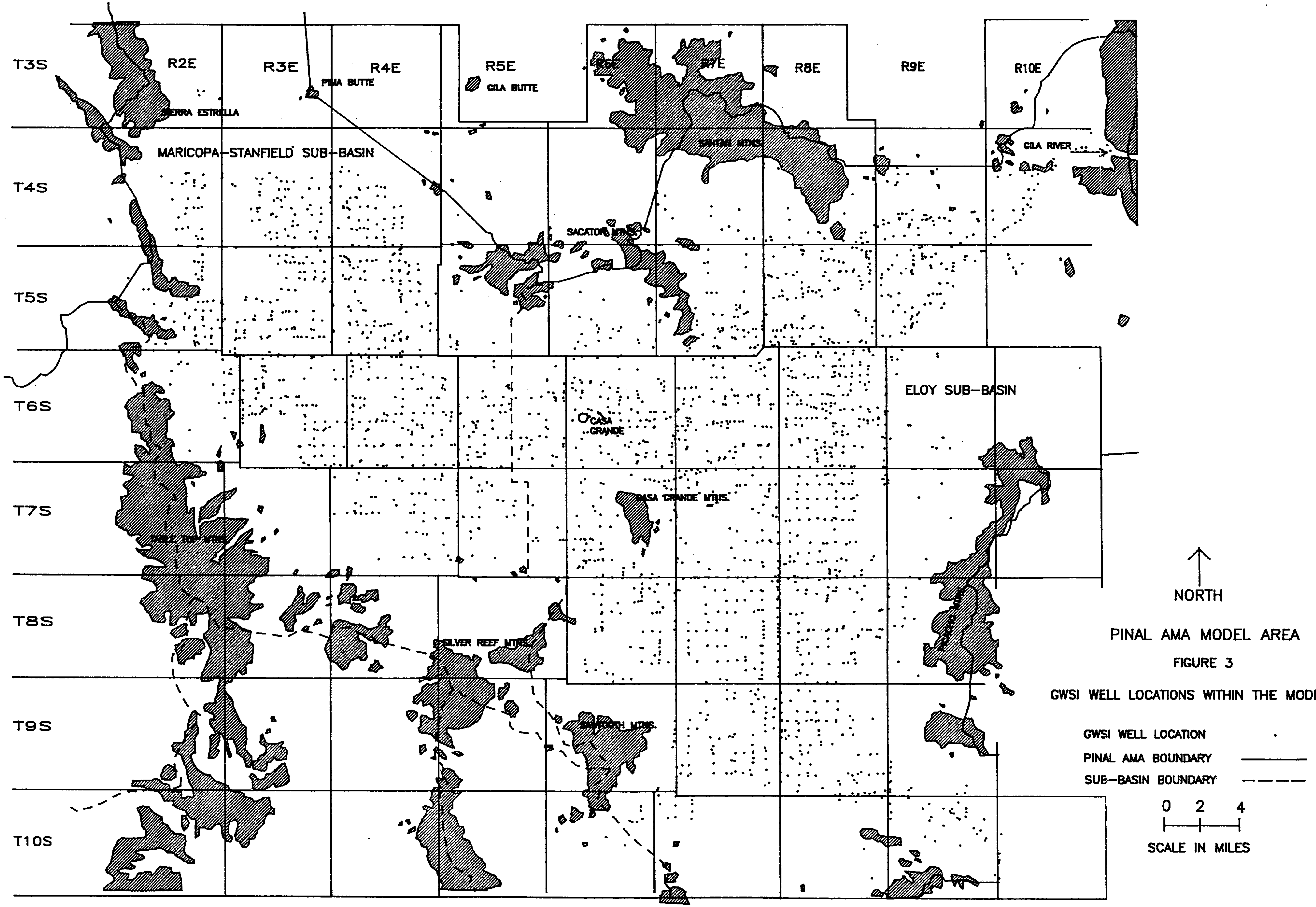
MODEL BOUNDARY

PINAL AMA BOUNDARY

SUB-BASIN BOUNDARY

0 2 4

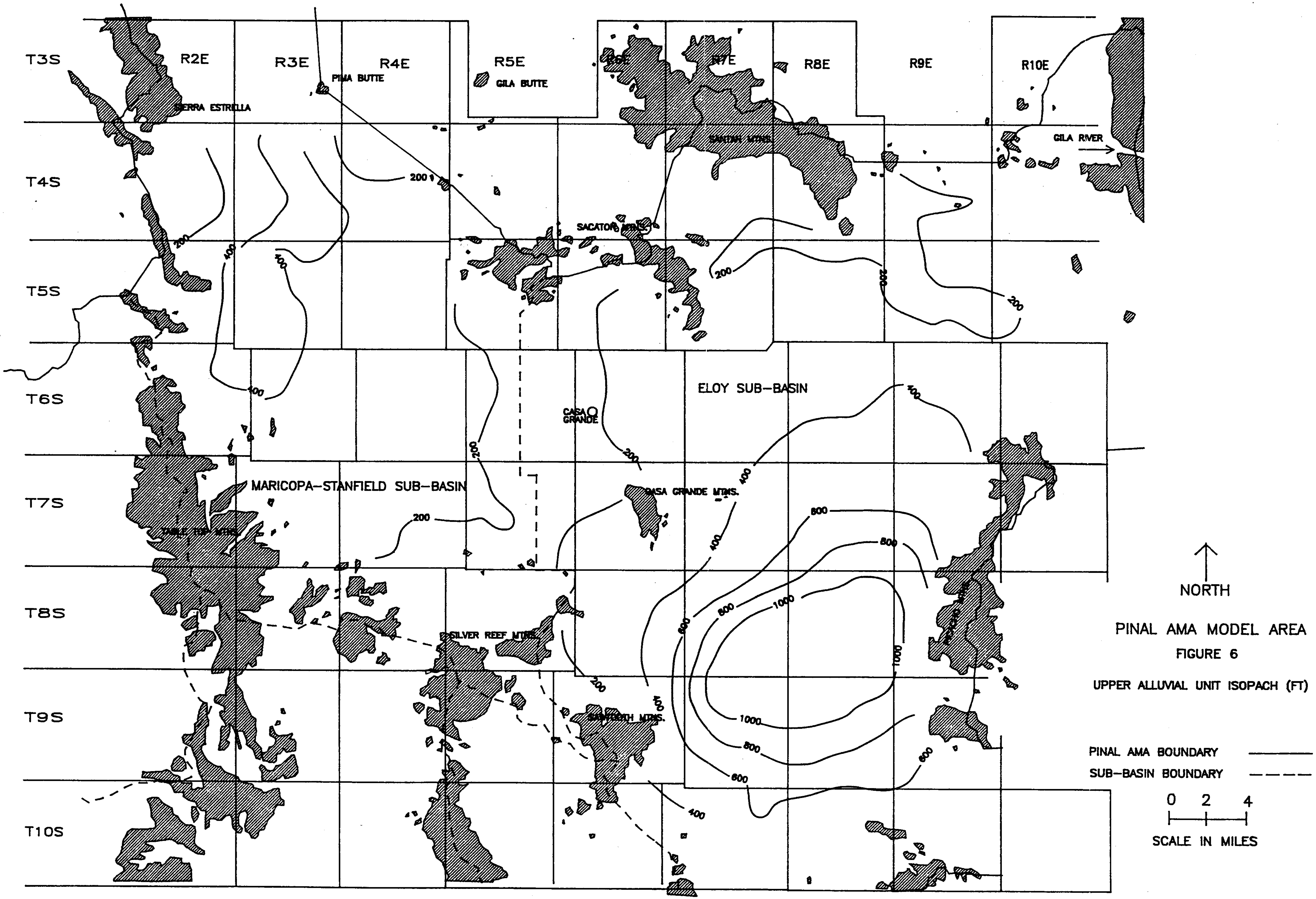
SCALE IN MILES



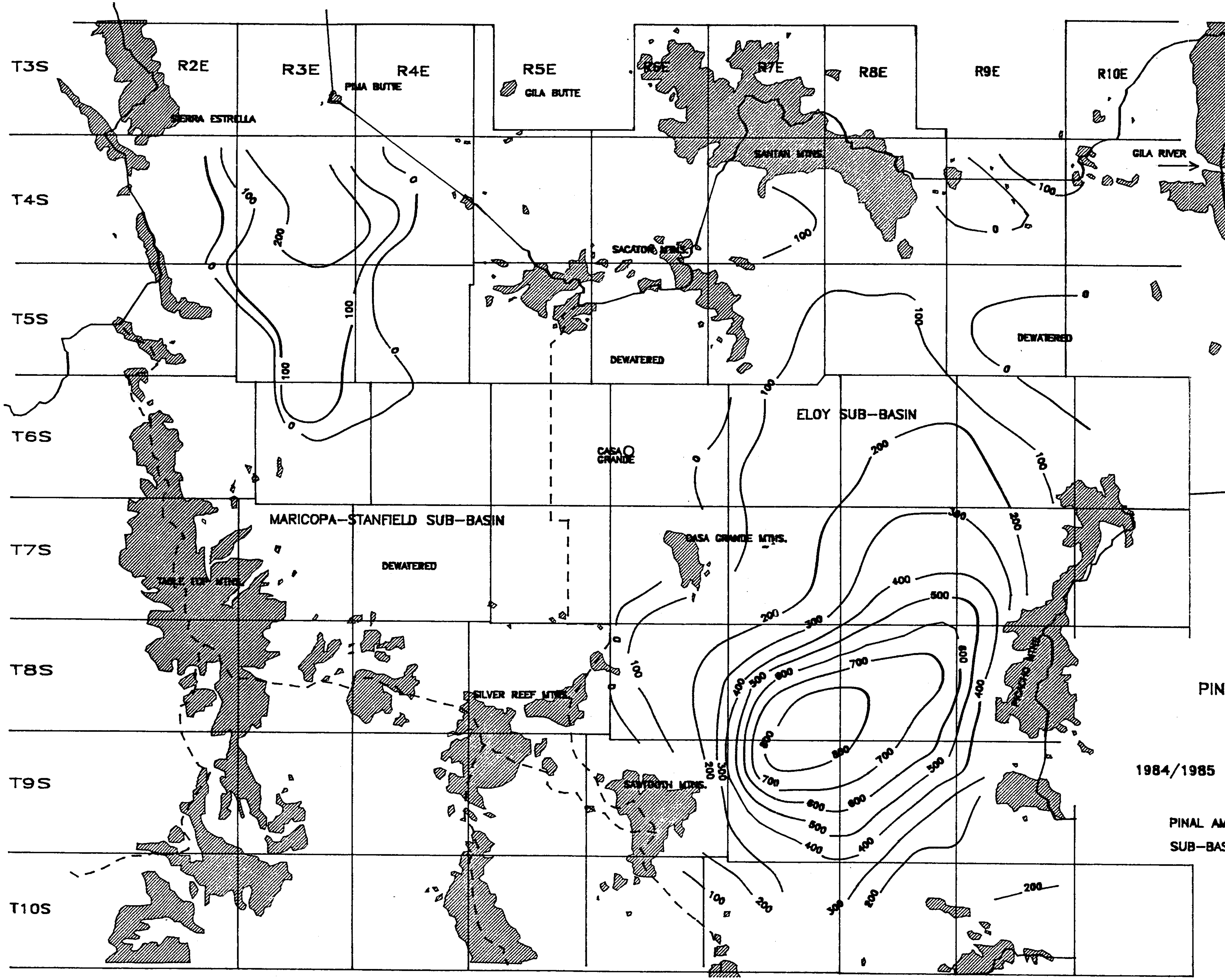
PINAL AMA MODEL AREA

FIGURE 3

GWSI WELL LOCATIONS WITHIN THE MODEL AREA



PINAL AMA MODEL AREA
FIGURE 6
UPPER ALLUVIAL UNIT ISOPACH (FT)



NORTH

PINAL AMA MODEL AREA

FIGURE 7

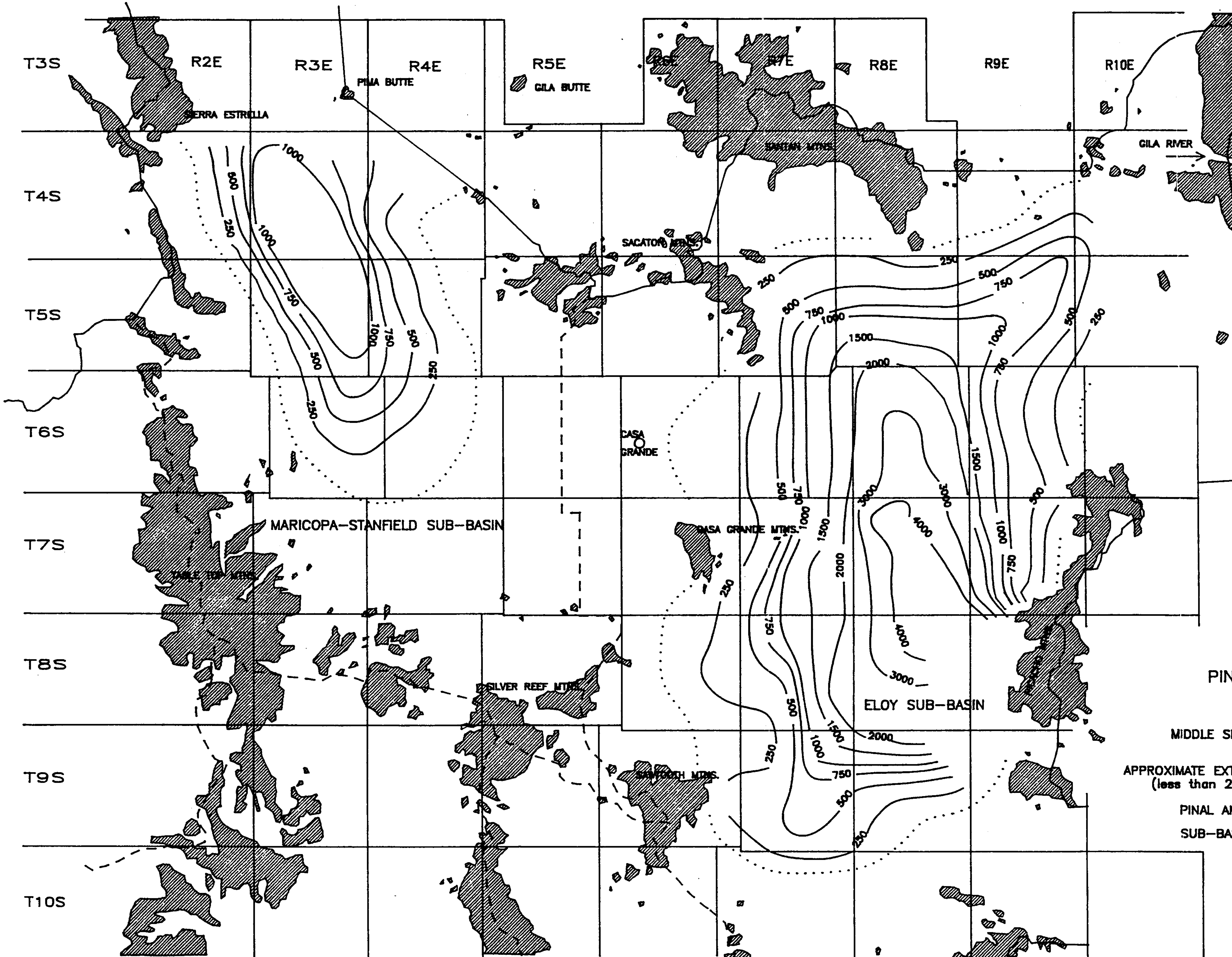
1984/1985 UAU SATURATED THICKNESS (FT)

PINAL AMA BOUNDARY

SUB-BASIN BOUNDARY

0 2 4

SCALE IN MILES

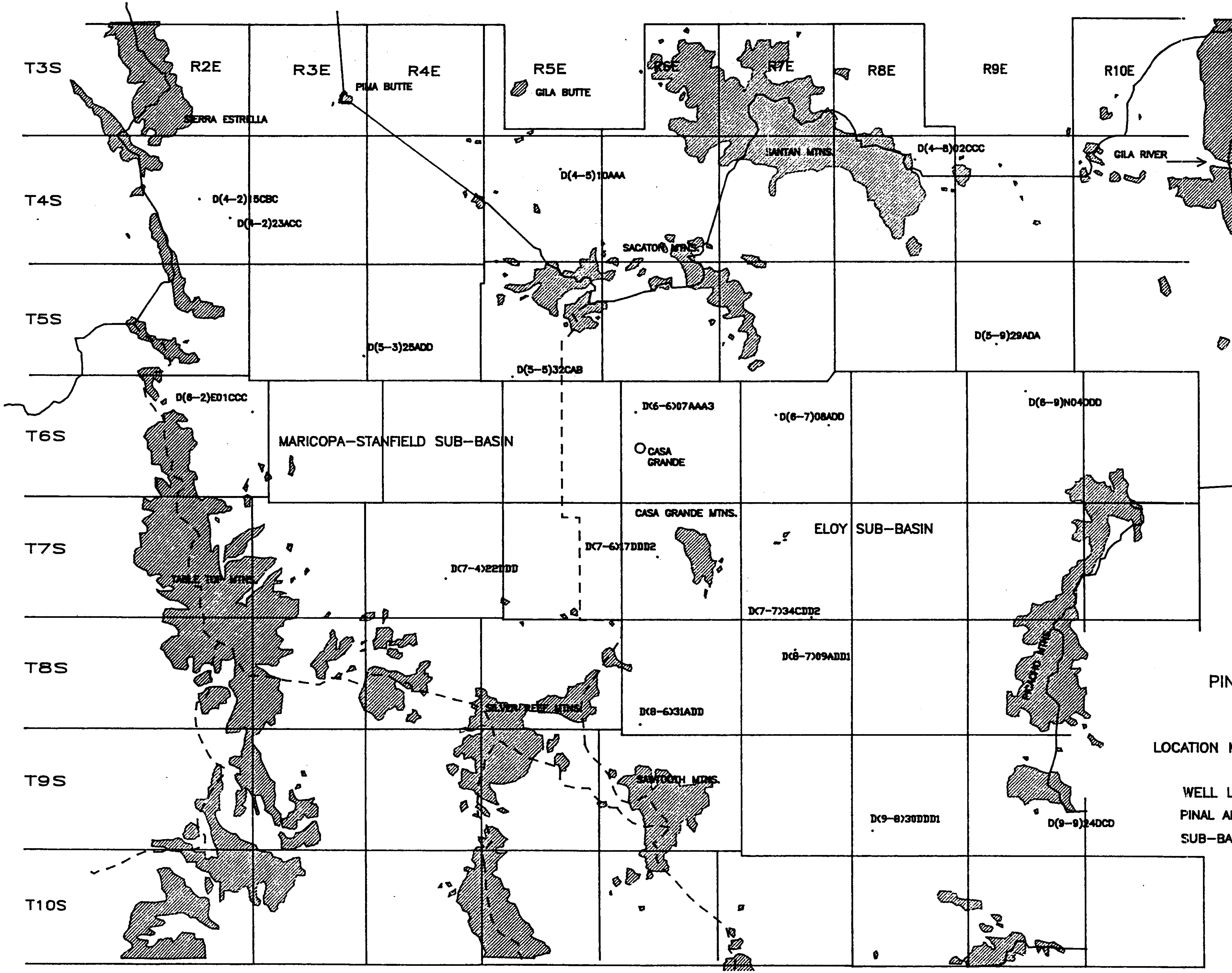


NORTH

PINAL AMA MODEL AREA
FIGURE 8
MIDDLE SILT AND CLAY UNIT ISOPACH (FT)

APPROXIMATE EXTENT OF UNIT (less than 20 feet)
PINAL AMA BOUNDARY
SUB-BASIN BOUNDARY

0 2 4
SCALE IN MILES



PINAL AMA MODEL AREA

FIGURE 12

LOCATION MAP FOR WELLS WITH HYDROGRAPHS

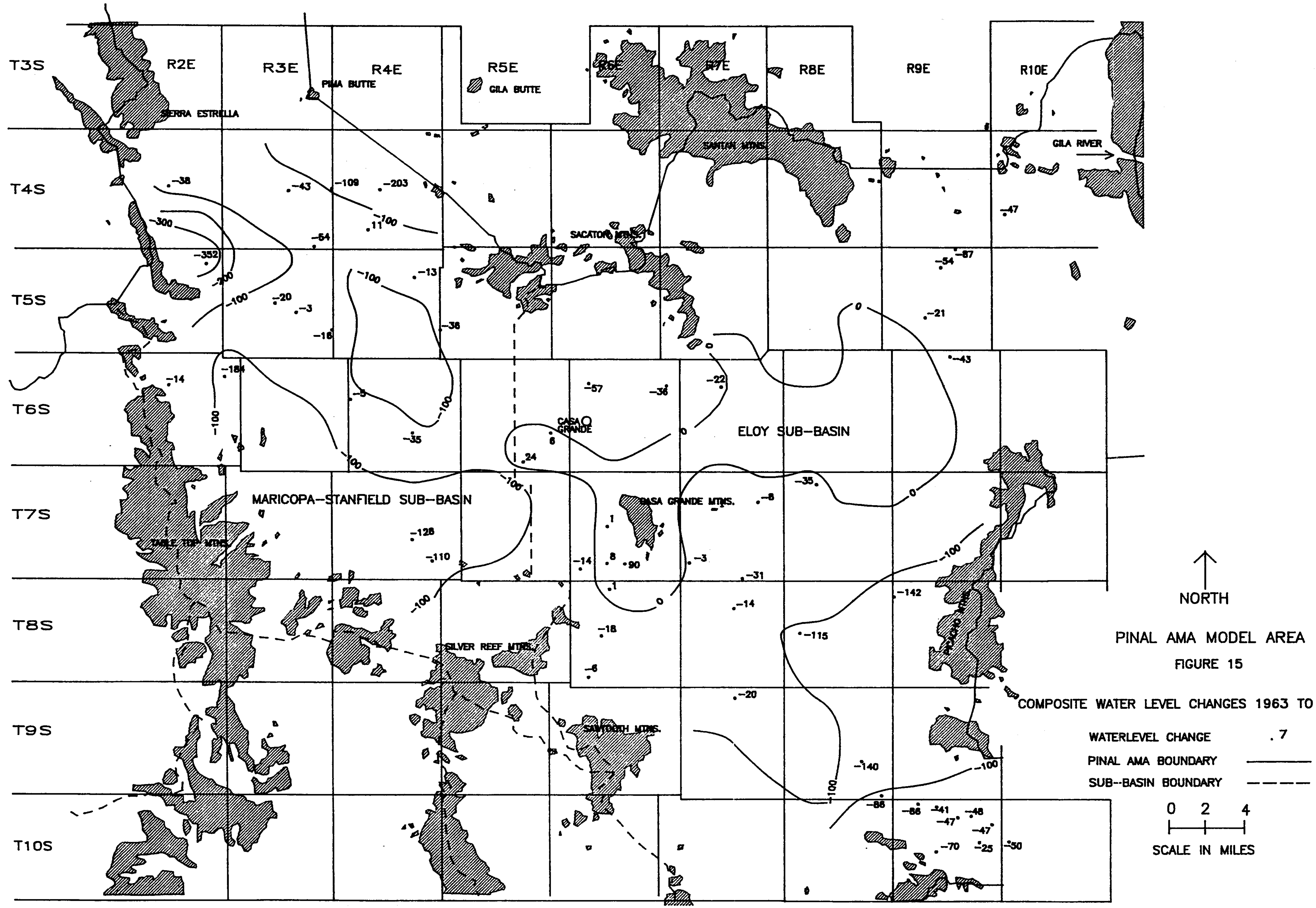
WELL LOCATION ·

PINAL AMA BOUNDARY ———

SUB-BASIN BOUNDARY – – – –

0 2 4

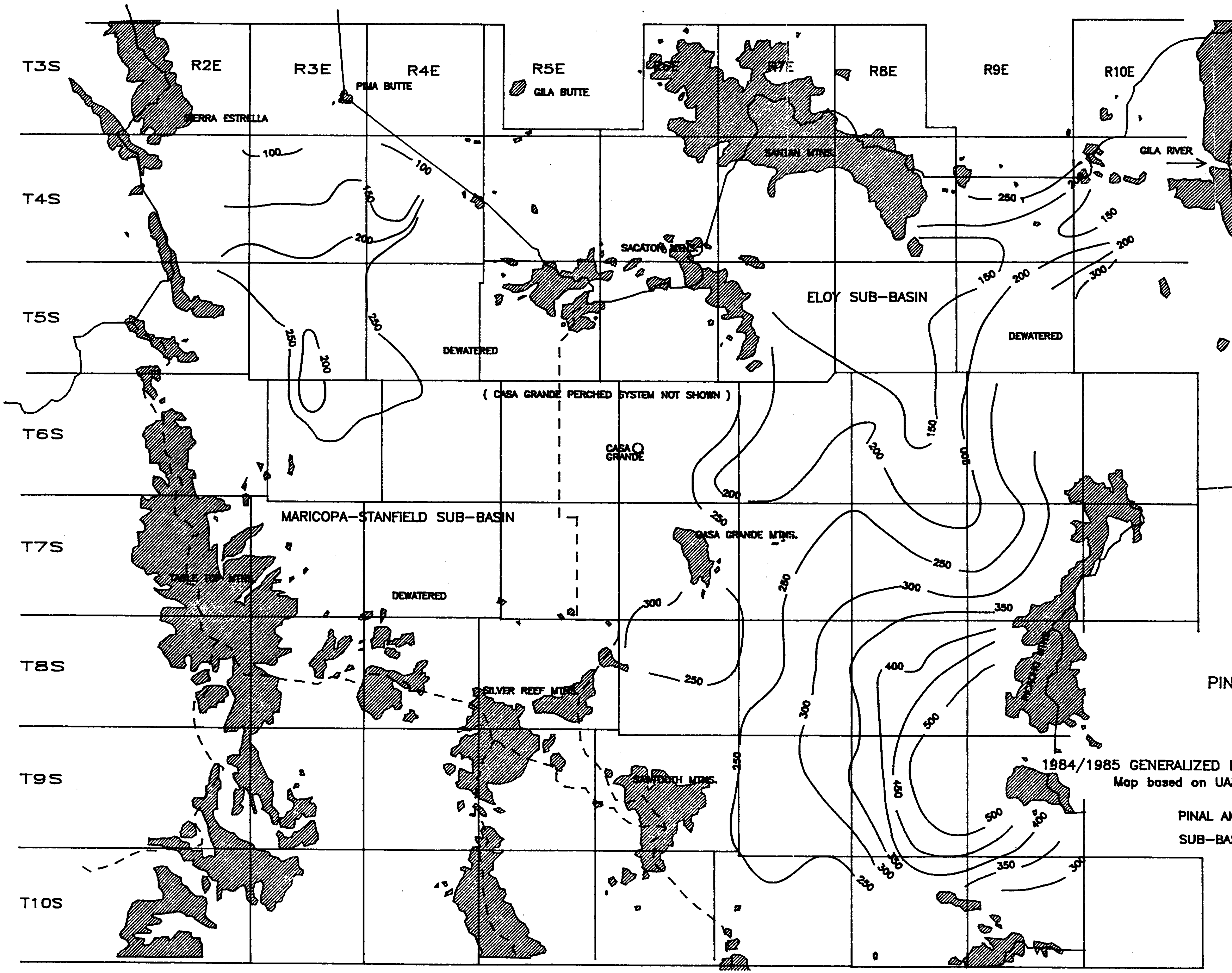
SCALE IN MILES



PINAL AMA MODEL AREA

FIGURE 15

COMPOSITE WATER LEVEL CHANGES 1963 TO 1977 (FT)



NORTH

PINAL AMA MODEL AREA

FIGURE 17

1984/1985 GENERALIZED DEPTH TO GROUNDWATER (FT) – UAU AQUIFER

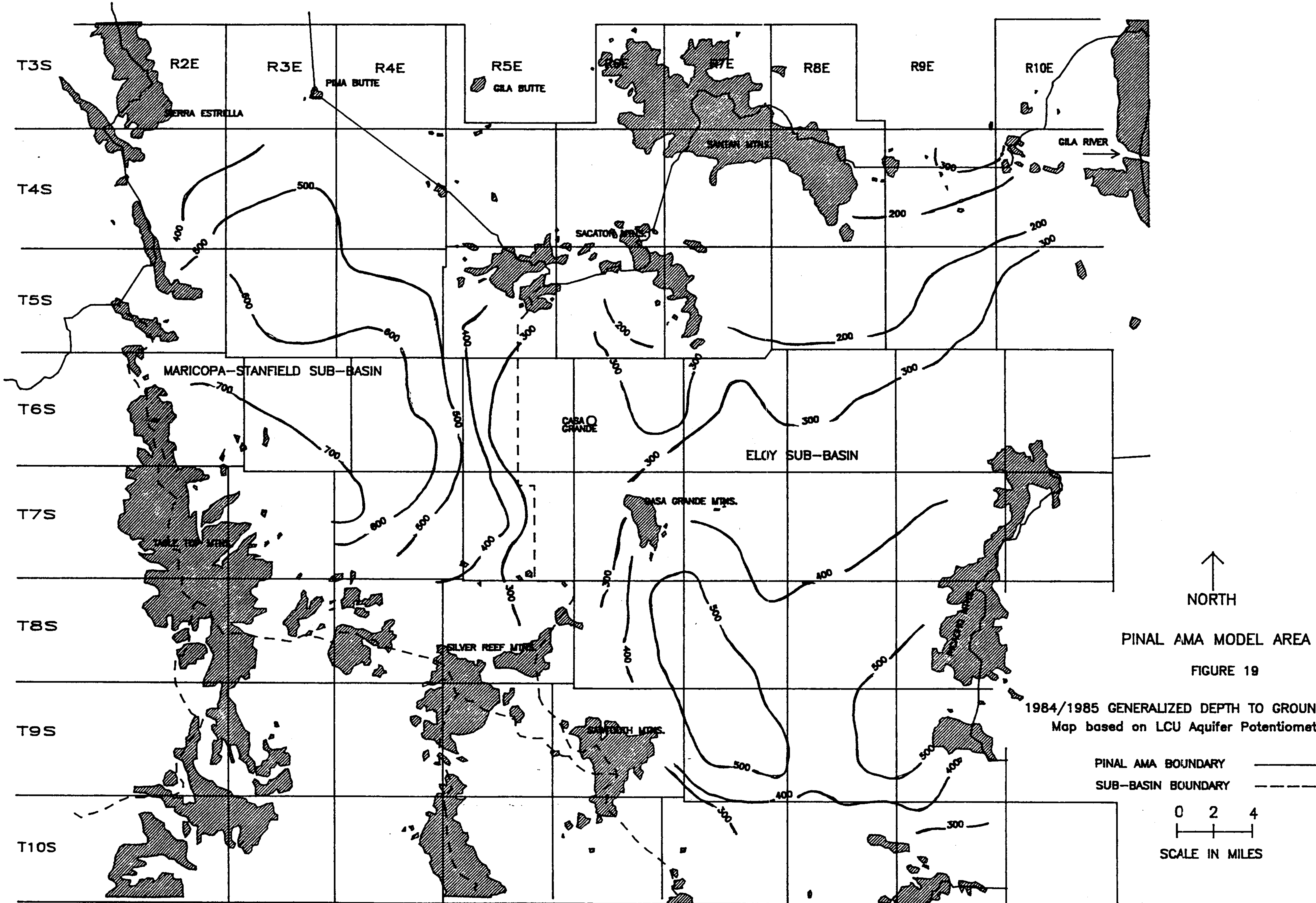
Map based on UAU Groundwater Elevation Contours

PINAL AMA BOUNDARY

SUB-BASIN BOUNDARY

0 2 4

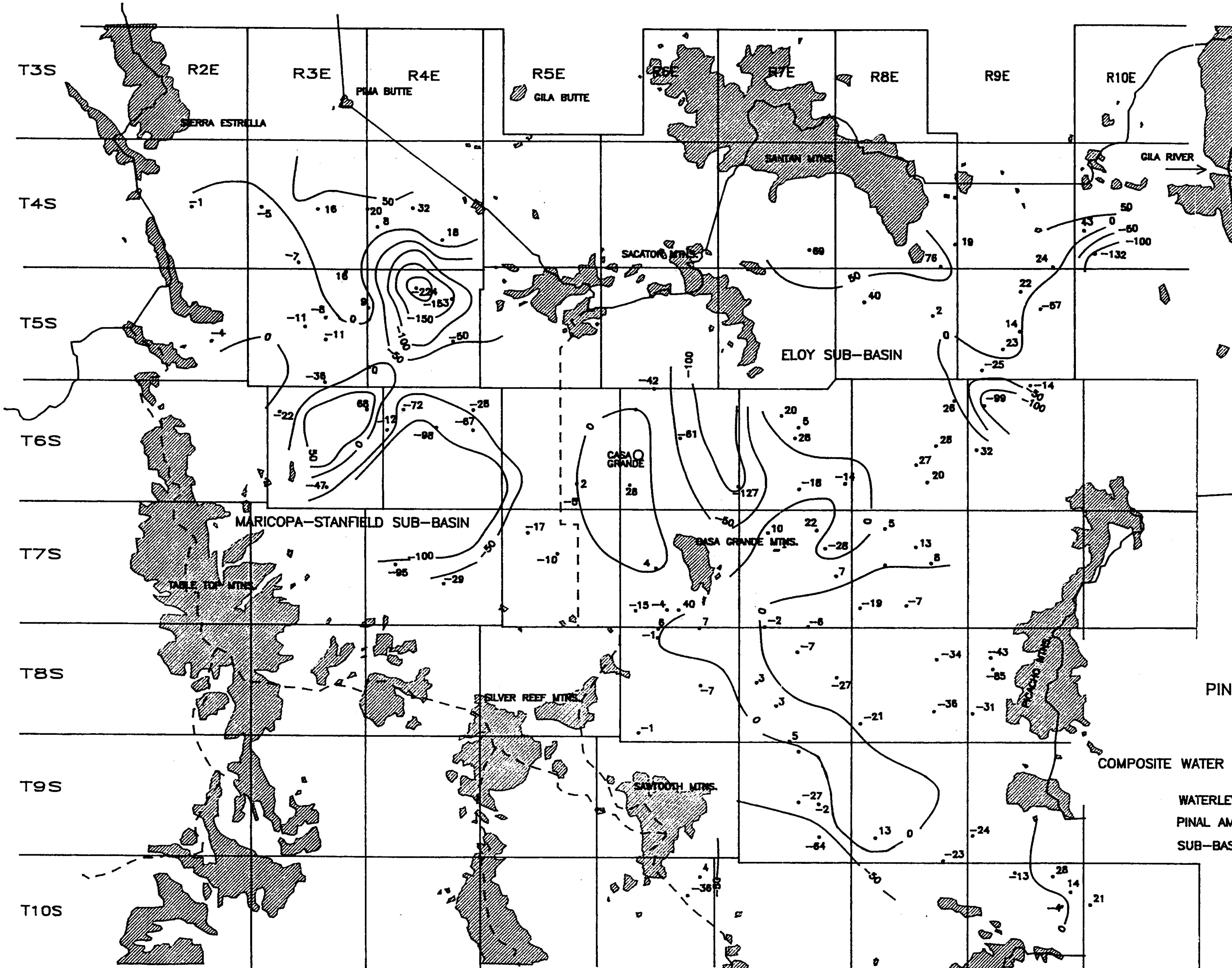
SCALE IN MILES



PINAL AMA MODEL AREA

FIGURE 19

1984/1985 GENERALIZED DEPTH TO GROUNDWATER (FT) – LCU AQUIFER
Map based on LCU Aquifer Potentiometric Surface Contours



PINAL AMA MODEL AREA

FIGURE 20

COMPOSITE WATER LEVEL CHANGES 1977 TO 1985 (FT)

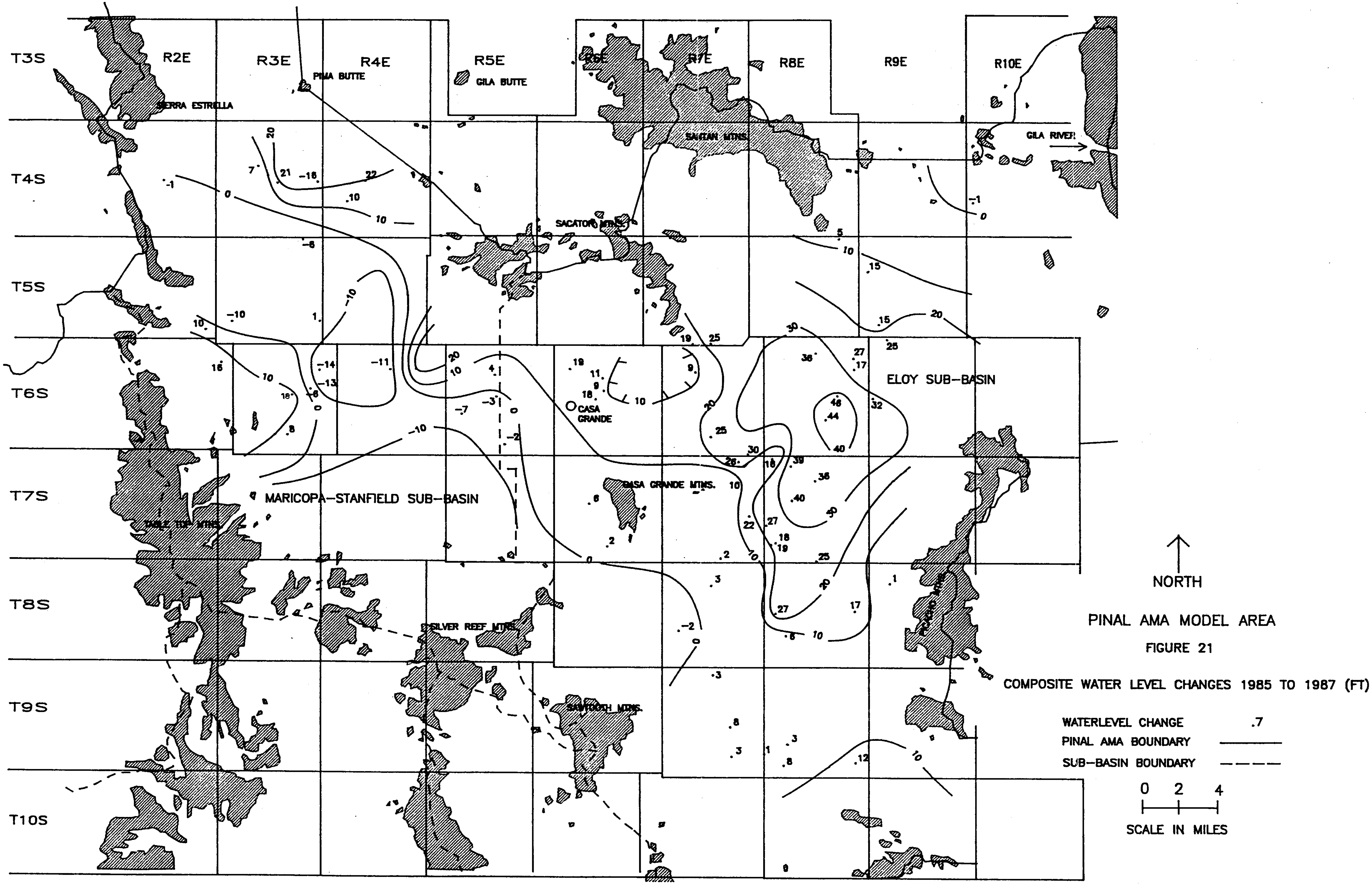
WATERLEVEL CHANGE .7

PINAL AMA BOUNDARY

SUB-BASIN BOUNDARY

0 2 4

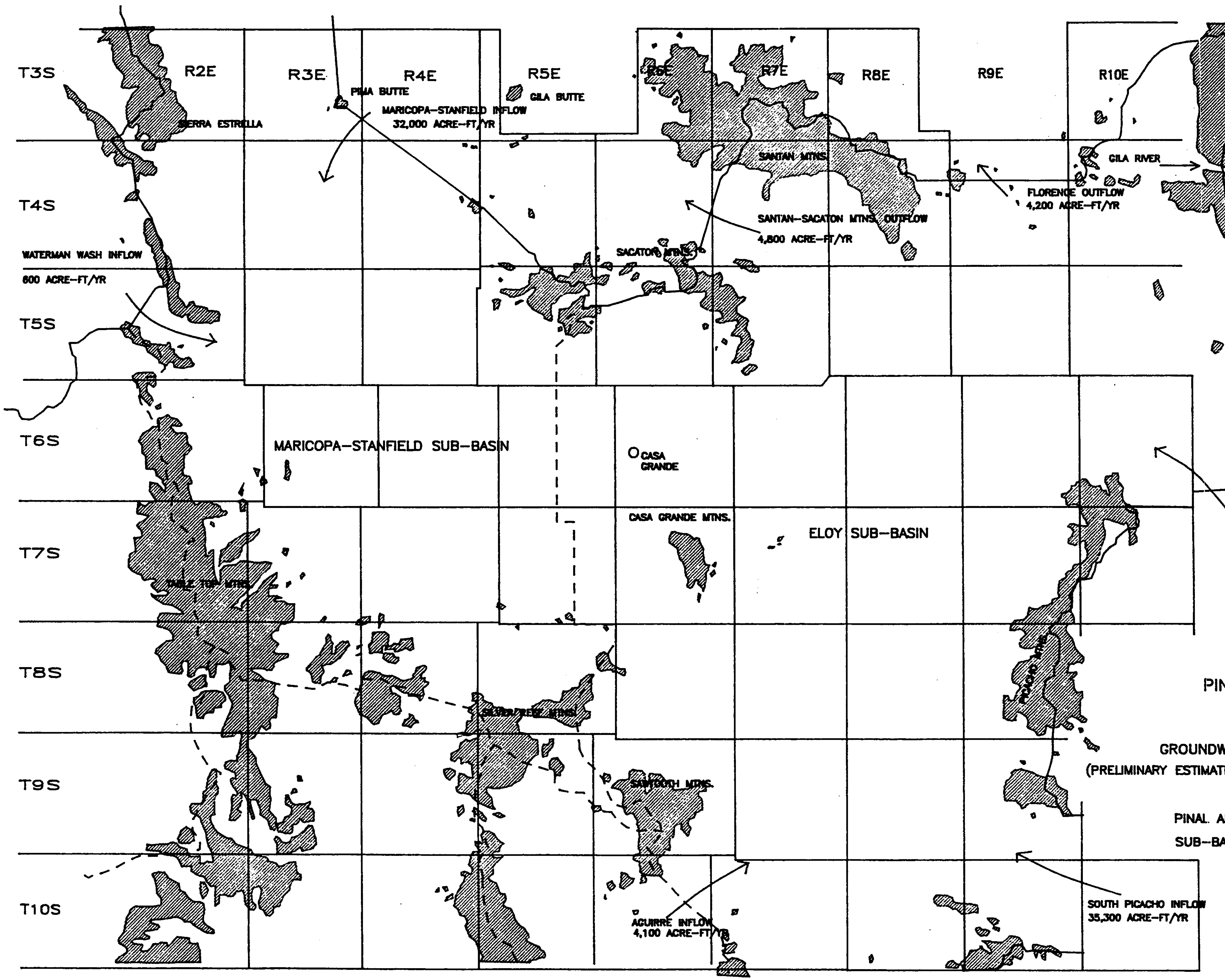
SCALE IN MILES



PINAL AMA MODEL AREA

FIGURE 21

COMPOSITE WATER LEVEL CHANGES 1985 TO 1987 (FT)



NORTH

PINAL AMA MODEL AREA

FIGURE 22

GROUNDWATER INFLOWS AND OUTFLOWS

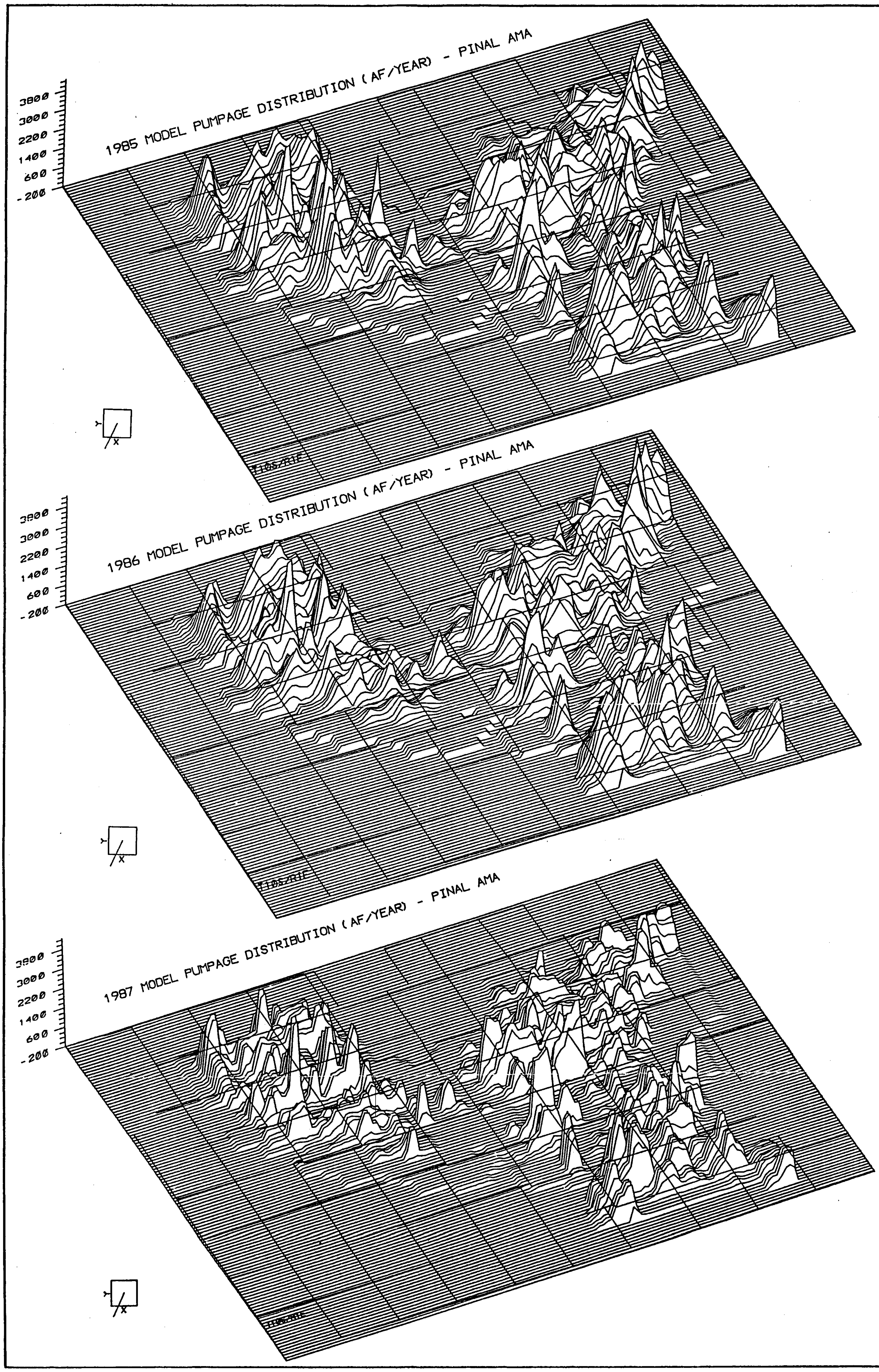
(PRELIMINARY ESTIMATES WHICH ARE SUBJECT TO CHANGE IN PHASE II)

PINAL AMA BOUNDARY

SUB-BASIN BOUNDARY

0 2 4

SCALE IN MILES



1985 MODEL PUMPAGE DISTRIBUTION (AF/YEAR) - PINAL AMA
3800
3000
2200
1400
600
-200
Y
X
1986 MODEL PUMPAGE DISTRIBUTION (AF/YEAR) - PINAL AMA
3800
3000
2200
1400
600
-200
Y
X
1987 MODEL PUMPAGE DISTRIBUTION (AF/YEAR) - PINAL AMA
3800
3000
2200
1400
600
-200
Y
X

FIGURE 23

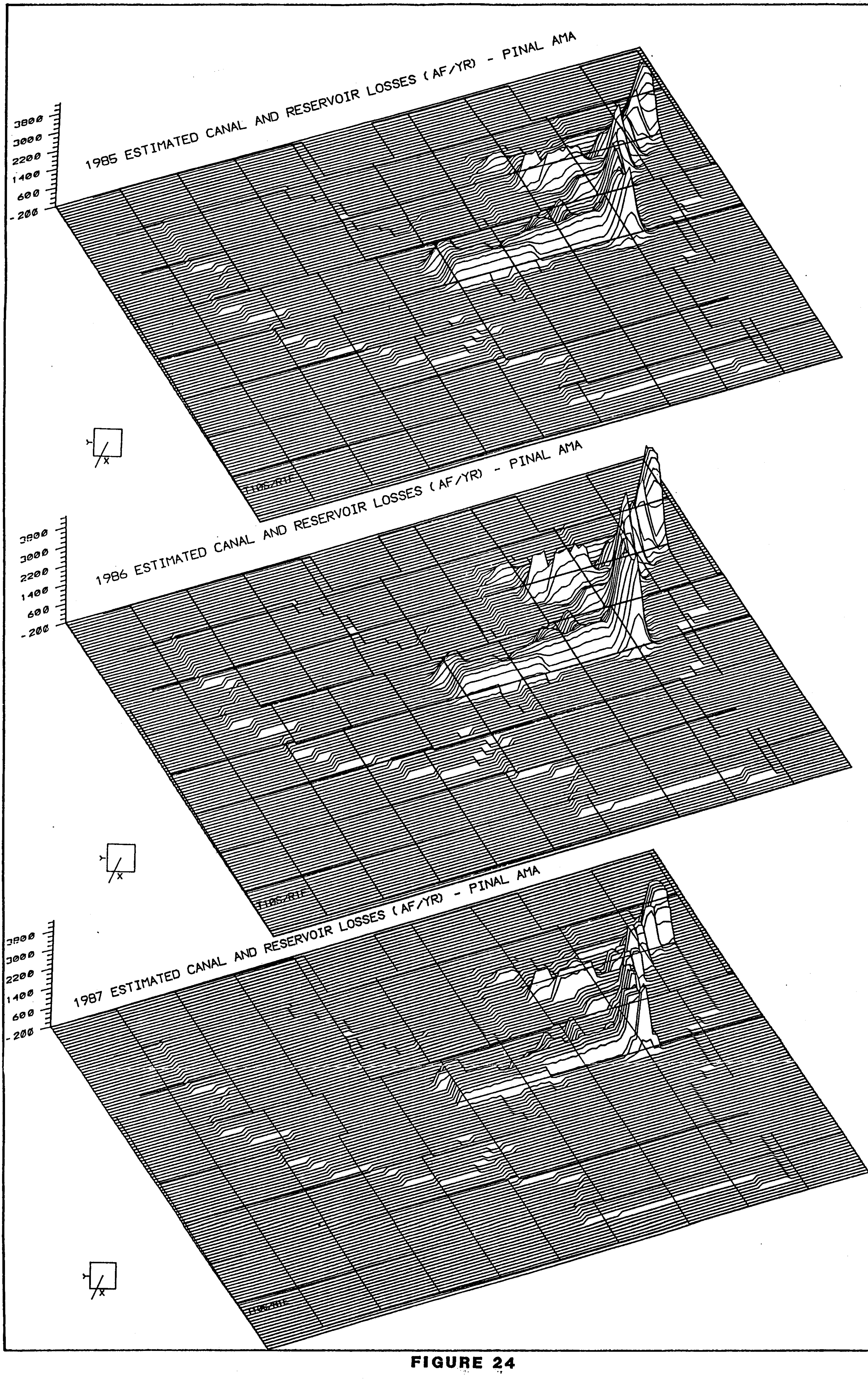
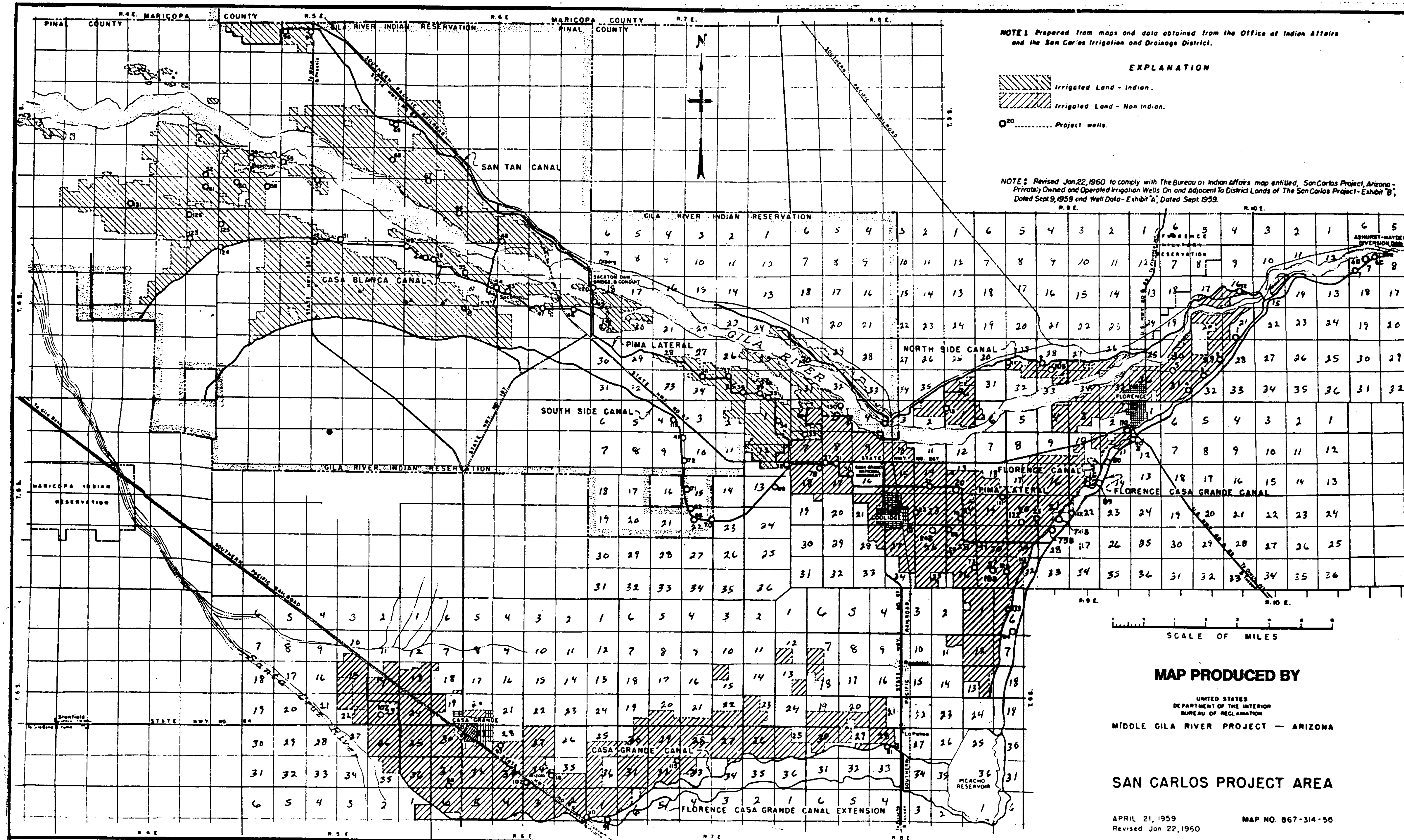

1985 ESTIMATED CANAL AND RESERVOIR LOSSES (AF/YR) - PINAL AMA
3800
3000
2200
1400
600
-200
Y
X
1986 ESTIMATED CANAL AND RESERVOIR LOSSES (AF/YR) - PINAL AMA
3800
3000
2200
1400
600
-200
Y
X
1987 ESTIMATED CANAL AND RESERVOIR LOSSES (AF/YR) - PINAL AMA
3800
3000
2200
1400
600
-200
Y
X

FIGURE 24



MAP PRODUCED BY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MIDDLE GILA RIVER PROJECT — ARIZONA

SAN CARLOS PROJECT AREA

APRIL 21, 1959
Revised Jan 22, 1960

MAP NO. 867-314-56

FIGURE 25

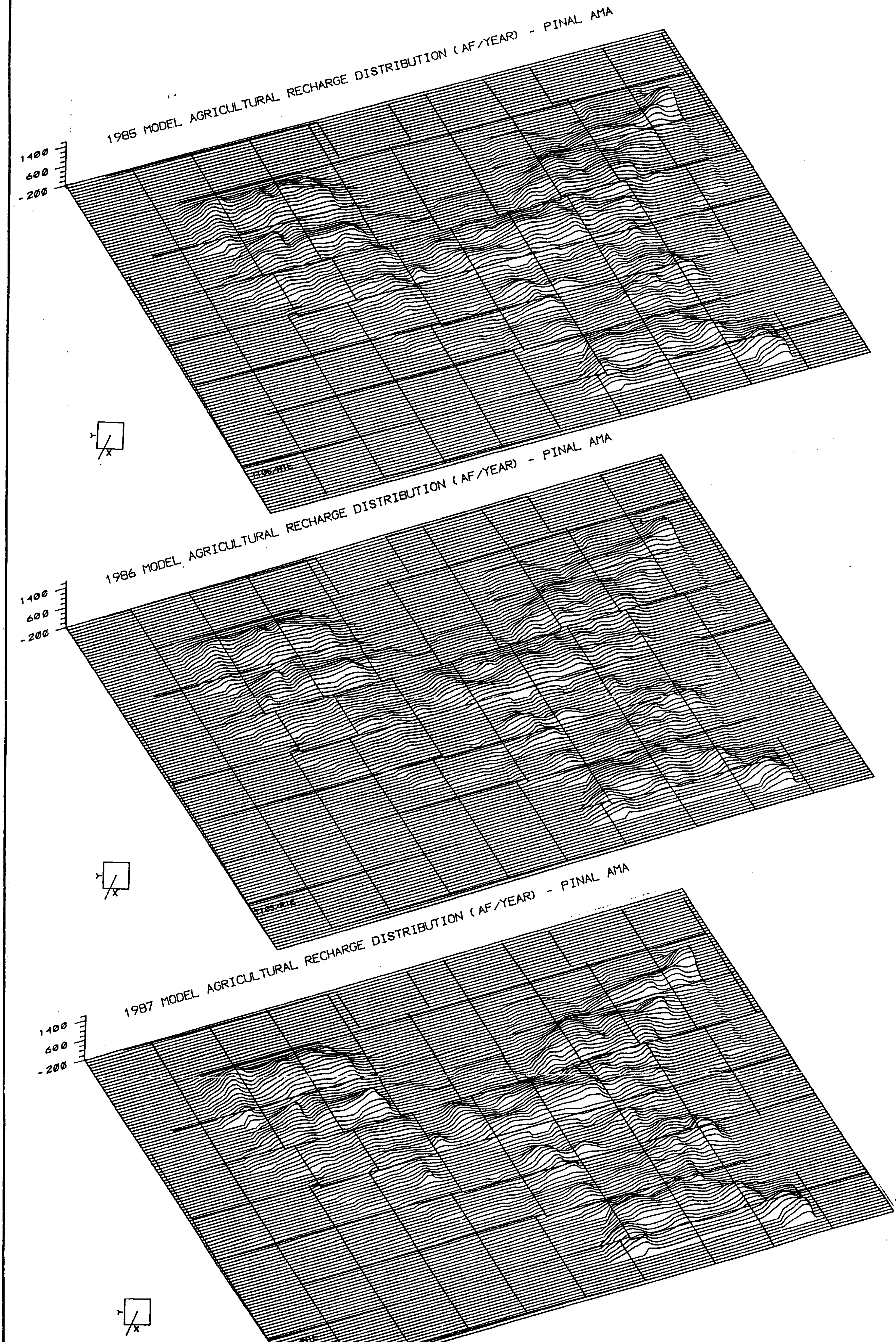

1985 MODEL AGRICULTURAL RECHARGE DISTRIBUTION (AF/YEAR) - PINAL AMA
1400
600
-200
Y
X
1986 MODEL AGRICULTURAL RECHARGE DISTRIBUTION (AF/YEAR) - PINAL AMA
1400
600
-200
Y
X
1987 MODEL AGRICULTURAL RECHARGE DISTRIBUTION (AF/YEAR) - PINAL AMA
1400
600
-200
Y
X

FIGURE 27